BULKY DOCUMENTS

(Exceeds 100 pages)

Filed: 09-09-12

Title: Petition For Cancellation

Part 2 of 6 - Binder B

1811481

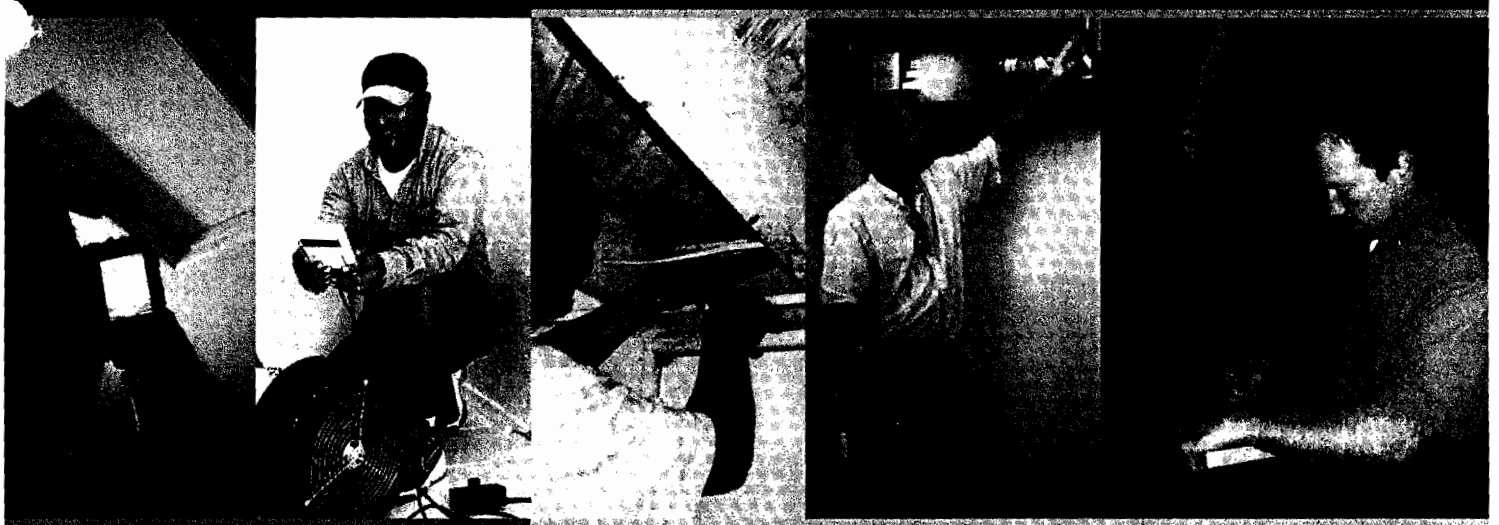
Binder B Contents

Category: Federal Agency

1. Building America Best Practices Series Air Sealing
2. Building America Best Practices Series HVAC
3. Building America Builder System performance package
4. Building America Case Study Green Home Solutions by Group
5. Building America Hathaway Solar Patriot House
6. Building America High Performance Builder Pulte Phoenix
7. Building America Measure-Guideline Interior Ducts
8. Building America Residential System Research Results
9. Building America Summer hill Villa Savona from marine
10. Department of Energy Advanced Diagnostics
11. Department of Energy Basic Energy Auditing and House Assessment
12. Department of Energy Building technologies program Spotlight Albuquerque
13. Department of Energy Multi County Weatherization Program Pomo Indians
14. Department of Energy Strategy Guideline Transitioning HVAC Companies
15. Department of Energy Weatherization Conference - Ducts How the system works
16. ENERGY STAR - Clark Howard does his Homework
17. ENERGY STAR - Efficient Solutions for Existing Homes
18. ENERGY STAR - Existing Homes Efficiency
19. ENERGY STAR - Independent Inspection and Testing
20. ENERGY STAR- Financing Guidebook
21. National renewable Energy Laboratory - Building America System
22. National renewable Energy Laboratory - Field Evaluating of a Near Zero Energy home
23. National renewable Energy Laboratory - Financing an Energy Efficient Home
24. U.S. Department of Housing and Urban Development - Air Distribution System
25. Weatherization Assistance Program - Poverty Conference 2006
26. Weatherization Assistance Program - Training & Technical Assistance Plan

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

BUILDING TECHNOLOGIES PROGRAM



VOLUME 10.

BUILDING AMERICA BEST PRACTICES SERIES

Retrofit Techniques & Technologies:

Air Sealing

A Guide for Contractors to Share with Homeowners

PREPARED BY

Pacific Northwest National Laboratory
& Oak Ridge National Laboratory

April 12, 2010

Building America
U.S. Department of Energy
Research Toward Zero Energy Homes

April 12, 2010 • PNNL-19284

BUILDING AMERICA BEST PRACTICES SERIES

Retrofit Techniques and Technologies:

Air Sealing

A Guide for Contractors to Share with Homeowners

PREPARED BY

Pacific Northwest National Laboratory

Michael C. Baechler

Theresa Gilbride, Marye Hefty, Pam Cole, and Jennifer Williamson

and

Oak Ridge National Laboratory

Pat M. Love

April 12, 2010

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RLO 1830

PNNL-19284

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor Battelle Memorial Institute, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or Battelle Memorial Institute. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Building AMERICA
U.S. Department of Energy
Research Toward Zero Energy Homes

You can learn more about Building America and download additional copies of this document, other best practices, research reports, and case studies at

www.buildingamerica.gov

Preface

The U.S. Department of Energy recognizes the enormous potential that exists for improving the energy efficiency, safety, and comfort of existing American homes. This series of Retrofit Techniques and Technologies describes approaches for homeowners and builders working on existing homes. This guide will help homeowners identify ways to make their homes more comfortable, more energy efficient, and healthier to live in. It also identifies the steps to take, with the help of a qualified home performance contractor, to seal unwanted air leaks while ensuring healthy levels of ventilation and avoiding sources of indoor air pollution. Contractors can use this document to explain the value of these air sealing measures to their customers. The references in this document provide further explanation of air sealing techniques and technologies.

Studies show that the measures described in this guide can typically achieve whole-house energy savings of 10% to 20% over pre-retrofit energy usage. In older homes or homes with greater levels of air leaks, savings may be much higher.

These practices are based on the results of research and demonstration projects conducted by the U.S. Department of Energy's Building America and Home Performance with ENERGY STAR sponsored by the U.S. Environmental Protection Agency and DOE. Home Performance with ENERGY STAR offers a comprehensive, whole-house approach to improving the energy efficiency and comfort of existing homes and requires a test-in/test-out to test combustion products (www.energystar.gov/homeperformance).

DOE's Building America has worked with some of the nation's leading building scientists and more than 300 production builders on over 41,000 new homes. Building America's research applies building science to the goal of achieving efficient, comfortable, healthy, and durable homes.

Please submit your comments via e-mail to:
George James (George.James@ee.doe.gov)

Contents

Preface i

Introduction 1

Finding a Contractor 3

Test In/Test Out 4

- Step 1. The Audit 4
- Step 2. Installing Air Sealing Measures 5
- Step 3. Testing Out 5

Diagnostic Tools Used During Test-In Test-Out 6

Safety and Health Issues 7

Ventilate it Right 8

New Code Air Sealing Requirements 9

An Air Sealing Checklist 10

1. Air Barrier and Thermal Barrier Alignment 12
2. Attic Air Sealing 13
3. Attic Kneewalls 14
4. Duct Shaft/Piping Shaft and Penetrations 15
5. Dropped Ceiling/Soffit 16
6. Staircase Framing at Exterior Wall/Attic 17
7. Porch Roof 18
8. Flue or Chimney Shaft 19
9. Attic Access/Pull-Down Stair 20
10. Recessed Lighting 21
11. Ducts 22
12. Whole-House Fan Penetration at Attic 24
13. Exterior Walls 25
14. Fireplace Wall 26
15. Garage/Living Space Walls 27
16. Cantilevered Floor 29
17. Rim Joists, Sill Plate, Foundation, and Floor 30
18. Windows and Doors 32
19. Common Walls Between Attached Dwelling Units 33

Introduction

Imagine opening a window in your house and leaving it that way 24 hours a day, all year long. On balmy spring days, the breeze wouldn't be so bad. But, in the freezing cold of winter and the sticky heat of summer, with the furnace or air conditioner on, smart homeowners would recognize they might as well be throwing buckets of quarters out the window to pay for the escaping heated or cooled air.

Air leaks in most existing homes add up to an open window in your home. Air sealing is one of the least expensive and most cost-effective measures you can take to improve your home's comfort and energy efficiency. By sealing uncontrolled air leaks, you can expect to see savings of 10% to 20% on your heating and cooling bills, and even more if you have an older or especially leaky house. But, before you grab your caulk gun, there are some things you should consider.

Many older homes lack proper ventilation, so they depend on those cracks and leaks to let in air, especially when fuel-burning appliances are operating inside the home. Without ventilation, carbon monoxide and air pollutants from cleaning chemicals, combustion appliances, and off-gassing household products can build up, creating an unhealthy and even dangerous environment in the home. Opening windows is one way to ventilate, but there are times when opening the windows is not practical (e.g., it is too cold or too hot outside). Fortunately there are other options for bringing fresh air into your home. A *certified* contractor can help you get all the energy savings and comfort possible from a well sealed home, along with the safety of proper ventilation.

Your house is a system and every component in it works together. Adding insulation and sealing air leaks can improve the energy efficiency of your home and improve your home's comfort and durability. However, every change you make to the building's envelope (walls, floors, and ceiling) and components will affect how the home works to keep out the elements and keep your family safe and comfortable. Tightening the building envelope without providing appropriate ventilation can cause pressure imbalances or negative pressure in the house. This negative pressure can set up the conditions for backdrafting of fireplaces or fuel-burning (combustion) appliances and may draw pollutants into the home. A trained contractor understands how systems work together to keep your house operating as it should.

This guide gives homeowners tips on where to find a good contractor, how to get your home tested for airtightness, where the biggest air leaks usually are and how to fix them, what the potential health and durability concerns are, and how your contractor can handle these concerns—in short, what you need to know to proceed with confidence to a more comfortable, energy-efficient, and healthy home for your family.

If you are a contractor, share this guide with your customers so that they can understand the process you will follow to make their home more comfortable, durable, and energy efficient. See the references in this guide for detailed explanations of air sealing techniques.

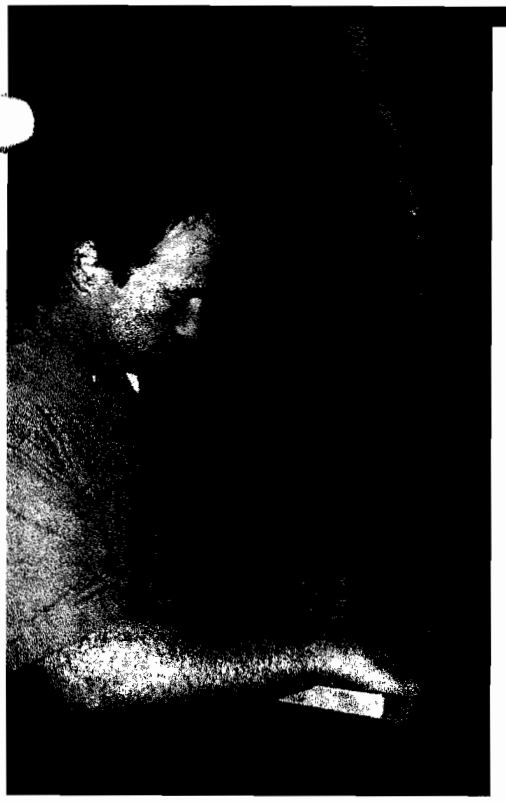
Air Sealing versus Insulation:

Why do I need to air seal? I thought all I needed to do was add more insulation.

Insulation is like a fuzzy wool sweater on a winter day. It will certainly keep you warm if the air is calm. But, if the wind picks up, you are going to need a windbreaker to keep the breeze from carrying away the heat. Air sealing is like adding the windbreaker. It keeps the conditioned air where it belongs.

Keys to indoor air quality:

- Remove pollutant sources, if possible.
- Avoid combustion (fuel-burning) appliances that do not directly vent to the outdoors.
- Never use non-vented combustion (e.g., kerosene) heaters inside the house.
- Fix water leaks and moisture management problems.
- Test for radon and carbon monoxide levels.
- Provide adequate ventilation.



Certified contractors are trained in building science principles to know the safest and most effective ways to improve your home's energy efficiency.

CERTIFIED PROFESSIONAL

Finding a Contractor

There are two nationally recognized energy certifications for home energy auditors and contractors: the Building Performance Institute (BPI) Building Analyst certification and the Residential Energy Services Network (RESNET) HERS Rater certification. Historically, BPI certification has focused on understanding the building science of retrofitting *existing* homes and RESNET has focused on building science in *new* home construction.

BPI is a nonprofit organization that accredits auditors, contractors, and other building professionals. Auditors or building analysts specialize in evaluating building systems and potential energy savings in homes. The certified BPI Building Analyst energy auditor has passed both written and field exams, and must recertify every three years. Contractors learn about building systems and are trained to install energy-efficiency measures. For more information see www.BPI.org

A certified RESNET energy auditor is called a HERS Rater. HERS (the Home Energy Rating System) provides a miles-per-gallon type rating for expected energy consumption in homes based on computer models. Each home receives a score that can be compared with other new or existing homes—the lower the score, the more efficient the home. More information about HERS can be found at www.natresnet.org.

An easy way to find a certified contractor is through a national or regional retrofit program. One such program is Home Performance with ENERGY STAR, a national program from the U.S. Environmental Protection Agency and the U.S. Department of Energy that promotes a comprehensive, whole-house approach to energy-efficiency improvements. To find a Home Performance with ENERGY STAR contractor for your area, go to www.energystar.gov and click on the link for Home Performance with ENERGY STAR. Next, click on the "locations" link for certified contractors in your state. For cities and states without Home Performance with ENERGY STAR contractors, you can find lists of contractors in your area who understand the building science whole-house approach through the BPI and RESNET websites: www.bpi.org or www.natresnet.org

Many local, state, and federal entities offer grants and tax credits for energy-efficient home improvements. Check with your local utility or city, or check the DOE-sponsored Database of State Incentives for Renewables and Efficiency (DSIRE) at www.dsireusa.org. This site is frequently updated and is a wealth of information, organized by state, on state, local, utility, and federal incentives, tax credits, and policies that promote renewable energy and energy efficiency.

Test-In/Test-Out

If you are participating in a home performance or weatherization program, one of the first steps may be an energy audit. Depending on the program, this audit may be conducted by an independent auditor or by a weatherization contractor. Details will vary by location and program, but here is what you can typically expect.

Step 1 - The Audit

First, the contractor or auditor should inspect, evaluate, and analyze your home. This step is commonly called an audit, but that term has been around for a long time and can mean many things. Perhaps the most important part of the audit is the conversation between the occupants and the auditor. Be prepared to talk about comfort issues and energy bills.

Here is what your audit should include:

- SIZING THINGS UP – The auditor may measure your house and identify square footage, window area, door area, and the condition of insulation, mechanical equipment, and air leaks.

- TESTING IN – The auditor will use diagnostic equipment to measure how your house performs in ways that cannot be seen by eyes alone. These tests may include a blower door test, duct pressurization testing, infrared cameras and smoke sticks, combustion safety testing, and carbon monoxide sampling. A heating and cooling contractor may evaluate your furnace and air conditioning system supply and return air balance. More information on these tests is included in the next section.

- COST-BENEFIT ANALYSIS AND ESTIMATES – The auditor will estimate the costs of installing the measures and use a computer program to estimate the expected energy savings. The cost of the measures divided by the annual savings will tell you the "simple pay back" or how many years the measures will take to pay for themselves. Often investments in energy efficiency provide a better return than stocks, bonds, or savings accounts, while improving comfort.

- GETTING THE GREEN LIGHT – Expert visual inspections and tests can identify safety and operational problems that may require attention before any other work on the house proceeds. Combustion safety issues must be addressed before air sealing begins. Auditors should also point out any obvious sources of indoor air pollution. Dry rot and moisture problems must be repaired.

Your contractor may test duct leakage as part of the home's energy audit.

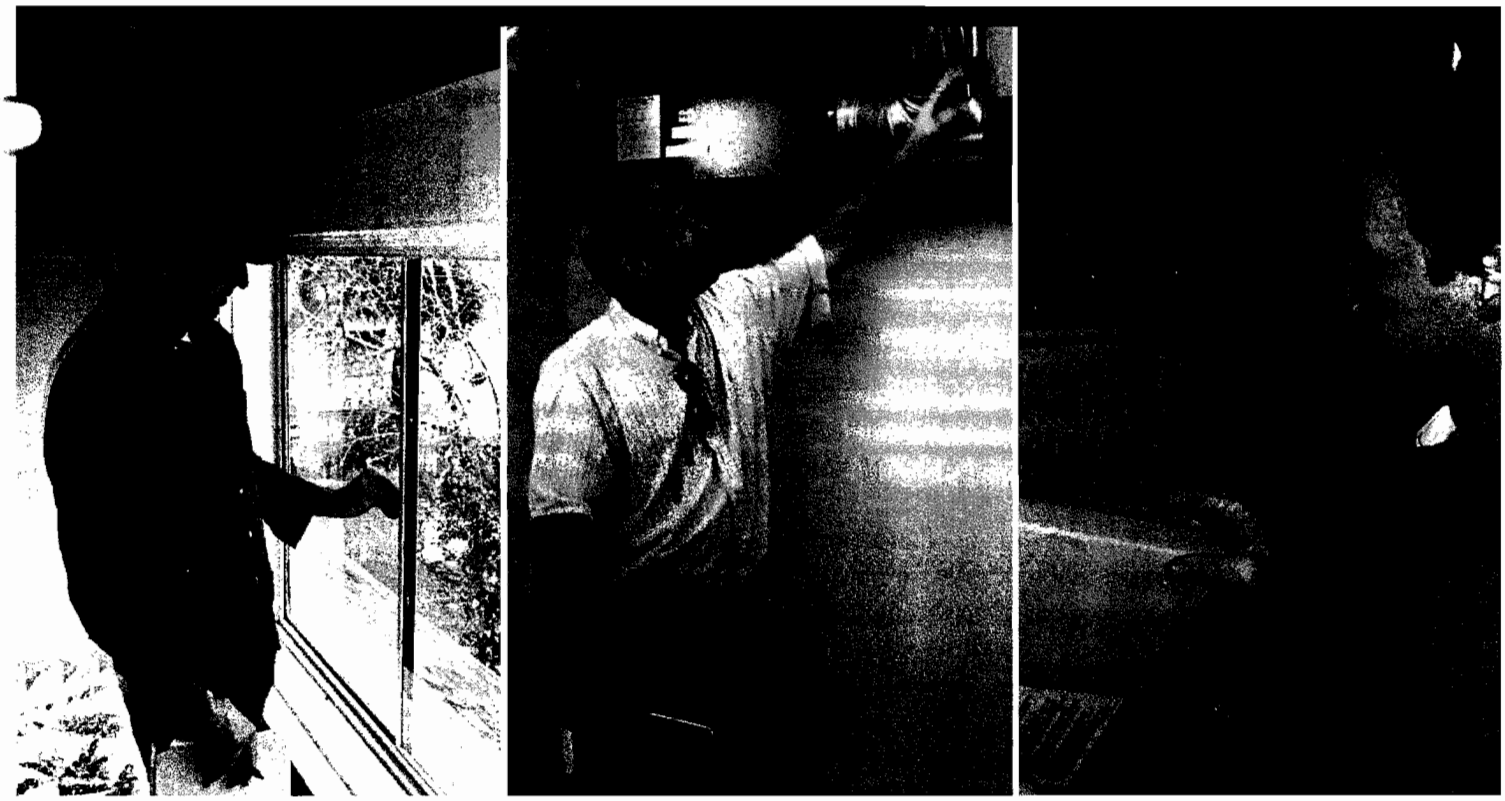
Test-In/Test-Out Steps

1. Audit
2. Installing Air Sealing Measures
3. Testing Out

Do not proceed with retrofit work if

- **The house has active knob and tube wiring** - Rewire the house first.
- **The house has vermiculite insulation** - Vermiculite insulation may contain asbestos. Contact your state department of health.
- **Bathroom fans are vented into the attic** - Vent fans to outside.
- **The house has a leaking roof** - Repair the roof leak before air sealing and insulating

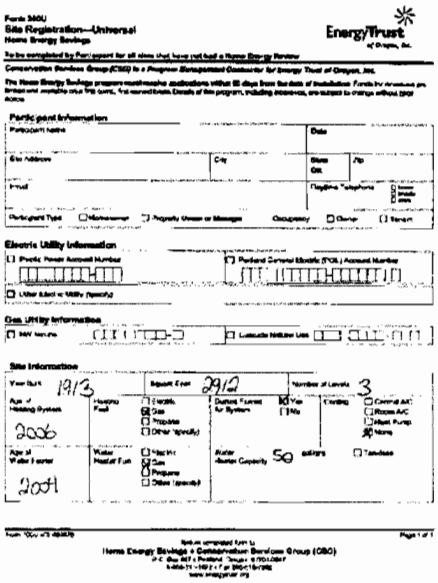
(Lstiburek 2010)



(left) Auditors will check for dry rot and moisture problems as well as air leakage.

(middle) Your contractor will visually inspect the home and test for safety concerns before air sealing begins.

(right) Once safety and health issues have been addressed, your contractor will proceed with air sealing measures.



Form 3400
Site Registration—Universal
Home Energy Savings

EnergyTrust of Oregon, Inc.

Participant Information

Participant Name | Date
Site Address | City | State OR | Zip
Email | Daytime Telephone | Best Time to Call
Participant Type ☐ Homeowner ☐ Property Owner or Manager | Occupancy ☐ Owner ☐ Tenant

Electric Utility Information

☐ Pacific Power Account Number | ☐ Portland General Electric (PGE) Account Number
☐ Other Electric Utility (Specify)

Gas Utility Information

☐ NW Natural | ☐ Cascade Natural Gas ☐

Site Information

Year Built 1913 | Square Feet 2912 | Number of Levels 3

Age of Heating System 2006 | Heating Fuel ☐ Electric ☒ Gas ☐ Propane ☐ Other (specify) | Ducted Forced Air System ☒ Yes ☐ No | Cooling ☐ Central A/C ☐ Room A/C ☐ Heat Pump ☒ None

Age of Water Heater 2001 | Water Heater Fuel ☐ Electric ☒ Gas ☐ Propane ☐ Other (specify) | Water Heater Capacity 50 gallons | ☐ Tankless

Form 3400 (Rev. 4/1/2009) Page 1 of 1

Home Energy Savings a Conservation Services Group (CSG) Program
P.O. Box 867 • Portland, Oregon • 97207-0867
1-866-11-ENERGY or 1-866-113-7435
www.energytrust.org

Auditors use forms like this one from Energy Trust of Oregon for test-in and test-out.

Step 2. Installing Air Sealing Measures

Within a week or so, your home performance contractor should analyze the test results and provide you with a detailed proposal including a prioritized list of energy-efficiency measures, packaged options, and cost estimates. Critical safety or health issues should be dealt with before work proceeds on the agreed-upon energy-efficiency improvements. Your contractor understands state and local building codes and will work with code officials when necessary to ensure that the improvements meet building code requirements. Your contractor may bring in specialized subcontractors if needed.

Step 3. Testing Out

Testing out means repeating some of the tests used at the beginning of the audit process now that the installation is complete. Final testing verifies that renovations have improved the home's performance and that safety standards have been met. Some contractors offer a guaranteed level of energy savings on their retrofit projects. Homeowners receive a report summarizing the improvements completed, test results, and estimated energy savings. In addition to testing out, in Home Performance with ENERGY STAR, at least 1 in 20 homes is spot-checked by independent third-party building professionals to ensure program compliance.

Diagnostic Tools for Test-In and Test-Out

A trained contractor may run these and other diagnostic tests on your home as part of the test-in and test-out process.

Combustion Safety

High-efficiency combustion appliances are usually sealed combustion, meaning that they draw in oxygen from outside the home through a dedicated vent and send exhaust fumes outside through a separate, dedicated vent pipe. These exhaust flues are sealed to prevent backdrafting, where exhaust fumes come back down the flue into the living space.

Older and less efficient combustion appliances are sometimes atmospheric vented, meaning they draw combustion air from the room in which they are located, often through an opening at the base of the exhaust pipe. Auditors or contractors will check combustion appliances such as stoves, furnaces, water heaters, and fireplaces for carbon monoxide levels, backdrafting, and other safety hazards, such as gas leaks and cracked heat exchangers. If problems are identified, no air sealing occurs until the problem is fixed. These may be serious safety problems; in rare instances, occupants may need to leave the house until problems are repaired.

Blower Door

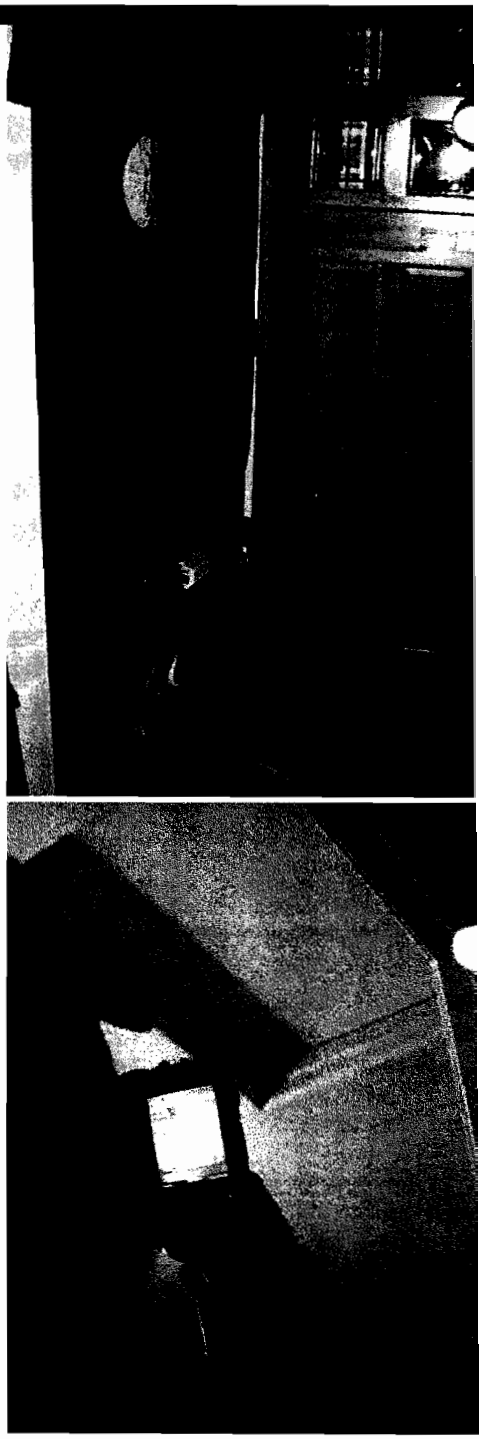
A blower door uses a calibrated fan to measure how much air a home leaks. The blower door mounts into an exterior door frame. The fan pulls air out of the house, lowering the air pressure inside. Outside air then flows into the house through all unsealed cracks and openings. The amount of fan pressure required by the fan to maintain the test pressure tells the auditor how much leakage the house has. Some contractors will seal simple air leaks as they are identified while the blower door is operating.

Infrared Camera

An infrared camera produces images called thermographs that show variations in temperature not visible to the human eye. Infrared cameras can be used during blower door tests to capture images of temperature differences that can indicate air leakage or other conditions such as gaps in insulation and overheating circuits.

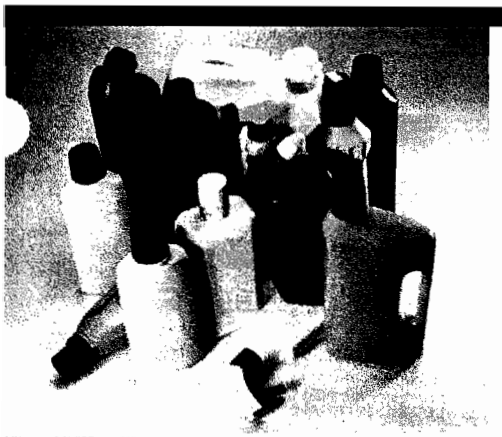
Duct Blaster

Leaky ducts in attics or crawlspaces can account for 20% or more of a home's heating and cooling energy losses. A Duct Blaster (duct pressurization test) uses a calibrated fan to test the air leakage rate in air ducts. Another approach uses a blower door and a shallow pan (a pressure pan) to cover each register and grill to measure and prioritize duct leaks.



(top) Your contractor can use a blower door to measure overall house air leakage.

(bottom) The infrared cameras can show air leaks not visible to the naked eye.



(top) Studies show homes and garages may contain over 150 household products that may be harmful to humans.

(bottom) Lack of ventilation, poor moisture management, installation issues, and pressure imbalances combine leading to mold problems inside walls.

Be Safe:
All combustion appliances should be tested for backdrafting. Replace natural draft combustion appliances with sealed combustion, induced draft, or power-vented appliances, if possible. Homes with combustion appliances should have carbon monoxide detectors that meet UL 2034.

Safety and Health Issues

Inspection and testing can identify health and safety issues that should be fixed before any air sealing or other efficiency improvements are made. Taking care of these issues is important to your family's health, and these issues should be fixed before doing any home improvements. If the problems are severe, fix them before returning home. Here are some problems to watch for.

BACKDRAFTING - Air pressure imbalances between the outside and inside or between rooms of the house can cause fireplaces, furnaces, and other appliances that burn fuel (such as wood and natural gas) to pull exhaust gases back into the house instead of letting them vent up the flue. This situation is known as backdrafting. Carbon monoxide (CO), a toxic gas without odor and color, can backdraft into homes causing illness and death.

ROLL-OUT - Combustion appliances may have a pilot light flame. Backdrafting, air pressure imbalances, and mechanical problems can cause the pilot to blow out, or worse, the flame can "roll out" of the appliance, causing a house fire.

MOISTURE PROBLEMS - If the home is not properly ventilated, water vapor from showering, cooking, breathing, and burning fuels can concentrate in the home increasing humidity levels. This can lead to mold and mildew, dust mites, wood rot, material damage, and subsequent health and structural problems.

POLLUTANTS - Many homes contain hazardous substances (such as cigarette smoke, volatile organic compounds and other offgases from carpets, paints, finishes, and home electronics; cleaning chemicals; and pesticides) as well as allergens (such as pet dander and dust mites). It is important to avoid or exhaust pollutants at their source. Also, air pressure imbalances between the outside and inside of the house can draw in pollutants from outside. These can include solvents and car exhausts from attached garages or radon emanating from the soil.

RADON - Radon is a naturally occurring radioactive gas. Radon gas is colorless, odorless, and tasteless and cannot be detected by human senses. In some geographic areas with high concentrations of radon in the soil, it can accumulate in the home and may adversely affect human health.

Ventilate it Right

Studies show the average American spends up to 90% of their time indoors. About 23 million people including 6.8 million children in the United States now suffer from asthma. Some see a correlation and point to indoor air pollutants—chemicals, gases, mold, dust, etc.—as a culprit. To provide fresh air in your older home, your contractor may recommend adding mechanical ventilation.

An old adage for building scientists is "build tight, ventilate right." When air leaks in the home are sealed up, mechanical ventilation may need to be added.

There are several options for mechanical ventilation systems. Spot ventilation, using exhaust-only fans in the kitchen and bathroom, removes water vapor and pollutants from specific locations in the home, but does not distribute fresh air. Balanced ventilation systems, like air-to-air exchangers, heat-recovery ventilators, and energy-recovery ventilators, both supply and exhaust air. Your contractor can help you determine which one is most appropriate for your specific climate, house design, and budget.

Pros and Cons of Various Mechanical Ventilation Systems

		Cons
Exhaust Only (air is exhausted from the house with a fan)	Easy to install Simple method for spot ventilation Inexpensive	• Negative pressure may cause backdrafting • Makeup air is from random sources • Removes heated or cooled air
Supply Only (air is supplied into the house with a fan)	Does not interfere with combustion appliances Positive pressures inhibit pollutants from entering Delivers to important locations	• Does not remove indoor air pollutants at their source • Brings in hot or cold air or moisture from outside • Air circulation can feel drafty • Furnace fan runs more often unless fan has an ECM (variable-speed motor)
Balanced Air Exchange System (heat and energy recovery ventilators)	No combustion impact No induced infiltration/exfiltration Can be regulated to optimize performance Provides equal supply and exhaust air Recovers up to 80% of the energy in air exchanged	• More complicated design considerations • Over ventilation unless the building is tight • Cost

Heat and Energy Recovery Ventilation Systems

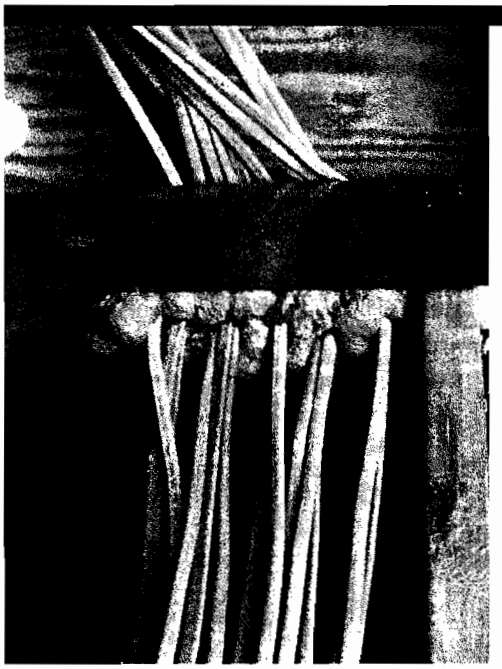
Heat-recovery ventilators (HRVs) and energy-recovery (or enthalpy-recovery) ventilators (ERVs) both provide a controlled way of ventilating a home while minimizing energy loss by using conditioned exhaust air to warm or cool fresh incoming air. There are some small wall- or window-mounted models, but the majority are central, whole-house ventilation systems that share the furnace duct system or have their own duct system.

The main difference between an HRV and an ERV is the way the heat exchanger works. With an ERV, the heat exchanger transfers water vapor along with heat energy, while an HRV only transfers heat. The ERV helps keep indoor humidity more constant. However, in very humid conditions, the ERV should be turned off when the air conditioner is not running. Air-to-air heat exchangers or heat recovery ventilators (HRV's) are recommended for cold climates and dry climates. Energy recovery ventilators (ERV's) are recommended for humid climates.

Most energy recovery ventilation systems can recover about 70%–80% of the energy in the exiting air. They are most cost effective in climates with extreme winters or summers, and where fuel costs are high. Energy recovery ventilation systems operated in cold climates must have devices to help prevent freezing and frost formation.

Ventilation – too little, too much, just right

Too little ventilation can lead to indoor air quality problems, too much can waste energy and cause comfort issues. Your contractor will use ASHRAE Standard 62.2 and other industry guidelines to determine how much passive and mechanical ventilation is right for your home.



The holes in the sill plate were properly air sealed during construction of this house.

New Code Air Sealing Requirements

The 2009 International Energy Conservation Code (IECC) and the 2009 International Residential Code (IRC) have several new mandatory requirements for air sealing in new construction and additions. These codes apply to new construction where adopted by local jurisdictions. In general, these requirements do not apply to retrofit projects unless the project adds living space to the building or changes the building's energy load. The existing, unaltered portions of the structure are not required to comply with all of the requirements of the 2009 IECC or IRC. However, Building America recommends implementing these requirements in existing portions of your home wherever they are applicable and your budget allows or health and safety concerns make them necessary.

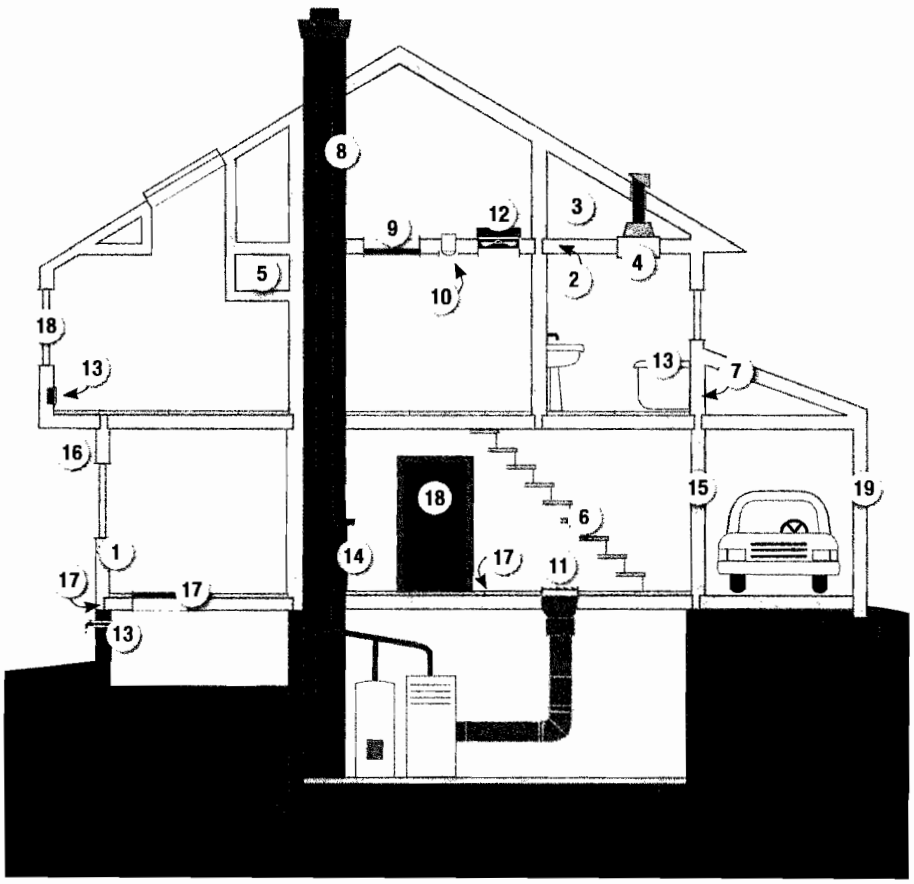
The requirements regarding new buildings can be summarized in this section excerpted from IECC, Chapter 4, Section 402.4, Air Leakage (mandatory) (quoted verbatim). Builders can see IECC 2009, Chapter 4 "Residential," and IRC 2009, Chapter 11 "Energy Efficiency," for more details:

> "The building thermal envelope shall be durably sealed to limit infiltration. The sealing methods between dissimilar materials shall allow for differential expansion and contraction. The following shall be caulked, gasketed, weather stripped or otherwise sealed with an air barrier material, suitable film, or solid material:
>
> 1. all joints, seams and penetrations,
> 2. site-built windows, doors, and skylights,
> 3. openings between window and door assemblies and their respective jambs and framing,
> 4. utility penetrations,
> 5. dropped ceilings or chases adjacent to the thermal envelope,
> 6. knee walls,
> 7. walls and ceilings separating a garage from conditioned spaces,
> 8. behind tubs and showers on exterior walls,
> 9. common walls between dwelling units,
> 10. attic access openings,
> 11. rim joists junction,
> 12. other sources of infiltration."

An Air Sealing Checklist

This section provides descriptions of the areas of the home most likely to have air leakage, when to address those problems, durability and health concerns related to the problems, and references for more information. Additional information on how to identify and fix these problems and other building science information can be found in the Building America Best Practices guides produced by DOE and available for free download at www.buildingamerica.gov. Work with your contractor to determine which of these measures are most needed and most cost-effective.

Common air sealing trouble spots are shown on the graphic below and listed on the following page. Each of these trouble spots is described further in the pages that follow.



Building America research identifies 19 key areas where air sealing can improve a home's energy efficiency, comfort, and building durability. The information in this guide can help you find a certified home performance contractor and work with your contractor to identify problem areas, prioritize projects with safety in mind, and start sealing the air leaks in your home for cost-effective energy savings.

Get the Details

Contractors, see the references in the sections below for detailed descriptions of air sealing techniques and technologies.

Air Sealing Trouble Spots

1. Air Barrier and Thermal Barrier Alignment
2. Attic Air Sealing
3. Attic Kneewalls
4. Shaft for Piping or Ducts
5. Dropped Ceiling/Soffit
6. Staircase Framing at Exterior Wall
7. Porch Roof
8. Flue or Chimney Shaft
9. Attic Access
10. Recessed Lighting
11. Ducts
12. Whole-House Fan
13. Exterior Wall Penetrations
14. Fireplace Wall
15. Garage/Living Space Walls
16. Cantilevered Floor
17. Rim Joists, Sill Plate, Foundation, Floor
18. Windows & Doors
19. Common Walls Between Attached Dwelling Units

Air Sealing List

Each of these items is addressed on the following pages.

Air Barrier	Completion Guidelines
1. Air Barrier and Thermal Barrier Alignment	Air barrier is in alignment with the thermal barrier (insulation).
2. Attic Air Sealing	Top plates and wall-to-ceiling connections are sealed.
3. Attic Kneewalls	Air barrier is installed at the insulated boundary (kneewall transition or roof, as appropriate).
4. Duct Shaft/Piping Shaft and Penetrations	Openings from attic to conditioned space are sealed.
5. Dropped Ceiling/Soffit	Air barrier is fully aligned with insulation; all gaps are fully sealed.
6. Staircase Framing at Exterior Wall/Attic	Air barrier is fully aligned with insulation; all gaps are fully sealed.
7. Porch Roof	Air barrier is installed at the intersection of the porch roof and exterior wall.
8. Flue or Chimney Shaft	Opening around flue is closed with flashing, and any remaining gaps are sealed with fire-rated caulk or sealant.
9. Attic Access/Pull-Down Stair	Attic access panel or drop-down stair is fully gasketed for an air-tight fit.
10. Recessed Lighting	Fixtures are provided with air-tight assembly or covering.
11. Ducts	All ducts should be sealed, especially in attics, vented crawlspaces, and rim areas.
12. Whole-House Fan Penetration at Attic	An insulated cover is provided that is gasketed or sealed to the opening from either the attic side or ceiling side of the fan.
13. Exterior Walls	Service penetrations are sealed and air sealing is in place behind or around shower/tub enclosures, electrical boxes, switches, and outlets on exterior walls.
14. Fireplace Wall	Air sealing is completed in framed shaft behind the fireplace or at fireplace surround.
15. Garage/Living Space Walls	Air sealing is completed between garage and living space. Pass-through door is weather stripped.
16. Cantilevered Floor	Cantilevered floors are air sealed and insulated at perimeter or joist transition.
17. Rim Joists, Sill Plate, Foundation, and Floor	Rim joists are insulated and include an air barrier. Junction of foundation and sill plate is sealed. Penetrations through the bottom plate are sealed. All leaks at foundations, floor joists, and floor penetrations are sealed. Exposed earth in crawlspace is covered with Class I vapor retarder overlapped and taped at seams.
18. Windows and Doors	Space between window/door jambs and framing is sealed.
19. Common Walls Between Attached Dwelling Units	The gap between a gypsum shaft wall (i.e., common wall) and the structural framing between units is sealed.

1. Air Barrier and Thermal Barrier Alignment

The air barrier is in alignment with (touching) the thermal barrier (insulation).

Convective loops can form in wall cavities if there are gaps between the insulation and the air barrier. Convective loops (air movement within the wall cavities caused by temperature differences) will get cold air falling and hot air rising. This air movement reduces the effectiveness of the insulation and can pull in outside air and cause moisture problems. Arches, soffits, chases, and other design features create an uneven air barrier (drywall plane) that is difficult to insulate thoroughly. Expect the contractor to inspect these areas visually or with an infrared camera to make sure batts or blown insulation completely fill wall cavities.

Thermal and air barrier alignment is not an issue with insulation materials like spray foam or rigid foam that form an air barrier as well as thermal barrier, as long as they form a continuous air barrier from top to bottom and side to side. Spray foams should be sprayed to a consistent minimum depth across the area to be sealed and insulated. Rigid foam board that is serving as the air and thermal barrier should be taped at the seams with housewrap tape and glued with caulk at the edges to the wall framing, sill plate, or top plate. Blown cellulose and blown or batt fiberglass insulation will not stop air flow.

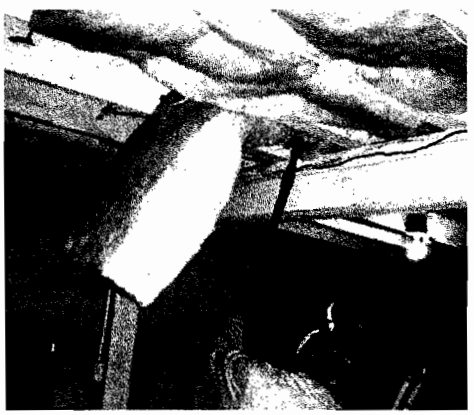


Figure 1.1. *(left)* Cut fiberglass batt insulation to fit around electrical boxes and wiring or pipes that run through the walls. Compressions like these ruin the batt's thermal alignment with walls and lessen its effectiveness.

Figure 1.2. *(right)* Install batts to fit smoothly and to completely fill wall and ceiling cavities. Here fiberglass batts completely fill joists of basement ceiling.

When To Do This

When replacing dry wall, replacing siding, adding an addition, adding insulation to attic or crawlspace or any time access is available.

Durability & Health

Convective loops in walls can pull in pollen, dust, and moisture. Walls that are not well insulated can provide a cold surface in wall cavities where warm indoor air can condense in winter and warm outdoor air can condense in the summer, encouraging mold growth in walls.

2009 IECC/2009 IRC Code

Requirement for New Construction and Additions

- Exterior thermal envelope insulation for framed walls is installed in substantial contact and continuous alignment with building envelope air barrier.
- Breaks or joints in the air barrier are filled or repaired.
- Air-permeable insulation is not used as a sealing material.
- Air-permeable insulation is inside of an air barrier.

More Information

- Building America Best Practices
- U.S. Department of Energy 2009b
- U.S. Environmental Protection Agency 2008b

2. Attic Air Sealing

Top plates and wall-to-ceiling connections are sealed.

When To Do This

When replacing dry wall, replacing siding, adding an addition, adding insulation to attic, anytime you see cracks at the inside seam of the wall and ceiling. In vaulted ceilings, the ceiling-to-wall intersection can be accessed and sealed from the inside or from the outside when reroofing occurs.

Durability & Health

Heat moves from high-temperature regions to low-temperature regions. The warmer the air, the more water vapor it can carry with it. If warm, moist air gets into a cold attic through leaks in the home's thermal envelope, it can condense on rafters and other solid surfaces, which may lead to water damage and mold growth.

2009 IECC/2009 IRC Code

Requirement for New Construction and Additions

Ceiling/attic

Air barrier in any dropped ceiling/soffit is substantially aligned with insulation and any gaps are sealed.

More Information

- Building America Best Practices
- Lstiburek 2010
- U.S. Environmental Protection Agency 2008a
- U.S. Environmental Protection Agency 2008c

Good air-sealing and a continuous air barrier between the attic and the home's conditioned (living) space are important not only to save energy and reduce fuel bills, but also to prevent moisture problems in the attic. Sealing holes in the attic makes chimneys and flues work better because a leaky attic ceiling acts like a chimney and will compete with the real chimney for air. Air sealing the leaky attic ceiling also reduces the house's "suction" (or stack effect) so less contaminants are drawn up into the house from the ground such as radon and other soil gases (Lstiburek 2010).

On the inside of the home, the ceiling drywall can serve as an air barrier. Visible cracks at the seam of the wall and ceiling can be taped, mudded, and painted or filled with paintable caulk, such as silicon latex. Your contractor can determine where leaks are with an infrared camera, by feeling for air flow, or by inspecting the attic insulation. Dirty insulation is an indication that air is flowing through the insulation and pulling dust with it.

Your contractor may pull back or scoop out the insulation to apply caulk, spray foam, or other sealant where the walls meet the attic floor. Other places in the attic that often are big sources of air leaks are soffits (dropped-ceiling areas, duct chases, plumbing chase), behind or under attic kneewalls, around recessed can lights, around flue pipes, around ducts, and at attic hatches (see strategy #3, #4, #5, #8, #9, #10, and #11).

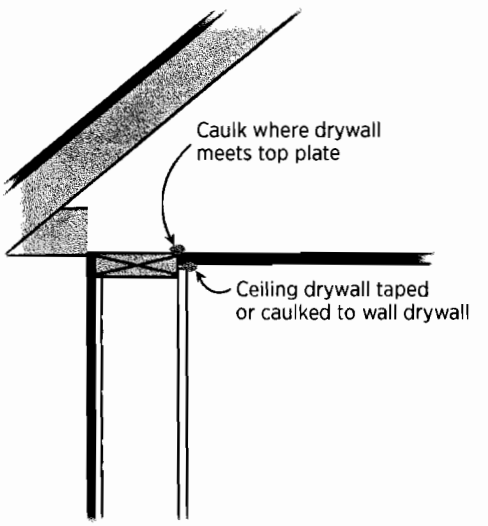


Figure 2.1. Seal the wall drywall to the top plate and ceiling drywall.

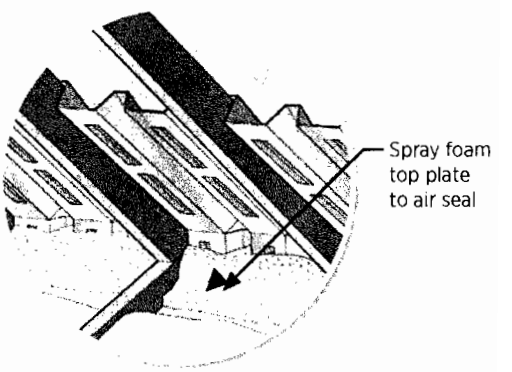


Figure 2.2. Pull back insulation to seal drywall to top plate with spray foam, caulk, or other sealer (Lstiburek 2010).

3. Attic Kneewalls

Air barrier is installed at the insulated boundary (kneewall transition or roof, as appropriate).

Kneewalls, the sidewalls of finished rooms in attics, are often leaky and uninsulated. Your contractor can insulate and air seal these walls in one step by covering them from the attic side with sealed rigid foam insulation. Your contractor can plug the open cavities between joists beneath the kneewall with plastic bags filled with insulation or with pieces of rigid foam. Another option is to apply rigid foam to the underside of the rafters along the sloped roof line and air seal at the top of the kneewall and the top of the sidewall, which provides the benefit of both insulating the kneewall and providing insulated attic storage space.

Doors cut into kneewalls should also be insulated and airsealed by attaching rigid foam to the attic side of the door, and using a latch that pulls the door tightly to a weather-stripped frame.

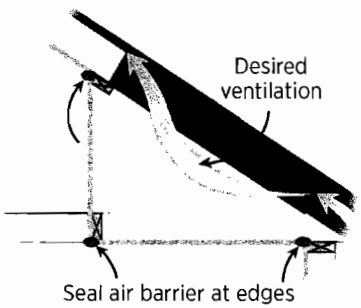


Figure 3.1. Insulate and air seal the kneewall itself, as shown, or along the roof line (Source: DOE 2000a).

Figure 3.2. Air seal floor joist cavities under kneewalls by filling cavities with fiberglass batts that are rolled and stuffed in plastic bags (as shown here) or use rigid foam, OSB, or other air barrier board cut to fit and sealed at edges with caulk.

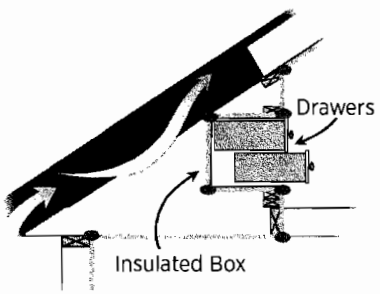


Figure 3.3. Build an airtight, insulated box around any drawers or closets built into attic knee walls that extend into uninsulated attic space. Insulate along air barrier (shown in yellow on drawing) or along roof line with rigid foam (Source: Iowa Energy Center 2008).

When To Do This

Any time you have access to kneewalls.

Durability & Health

If warm moist air gets into a cold attic through leaks in the home's thermal envelope, it can condense on rafters and other solid surfaces, which may lead to water damage and mold growth.

2009 IECC/2009 IRC Code

Requirement for New Construction and Additions

Ceiling/attic

Attic access (except unvented attic), kneewall door, or drop down stair is sealed.

More Information

- Building America Best Practices
- Iowa Energy Center 2008
- Lstiburek 2010
- U.S. Department of Energy 2000a
- U.S. Environmental Protection Agency 2008a
- U.S. Environmental Protection Agency 2008b
- U.S. Environmental Protection Agency 2008c

4. Duct Shaft/Piping Shaft and Penetrations

Openings from attic to conditioned space are sealed.

Any chases, shafts, or building cavities that contain piping or wiring can serve as links between conditioned and unconditioned space. Your contractor can inspect these areas and close the gaps with caulk, spray foam, and blocking material (pieces of rigid foam, plywood, or oriented strand board cut to fit and sealed in place with spray foam). Furnace flues require high-temperature-rated sealing materials.

When To Do This

Any time you have access.

Durability & Health

HVAC, plumbing, and wiring chases can bring conditioned air into attics, leading to condensation and mold problems. They can also connect crawlspaces and living spaces bringing soil gases into the home.

2009 IECC/2009 IRC Code

Requirement for New Construction and Additions

Shafts, penetrations

Duct shafts, utility penetrations, knee walls and flue shafts opening to exterior or unconditioned space are sealed.

More Information

- Building America Best Practices
- Iowa Energy Center 2008
- U.S. Environmental Protection Agency 2008a
- U.S. Environmental Protection Agency 2008c
- House Energy 2009

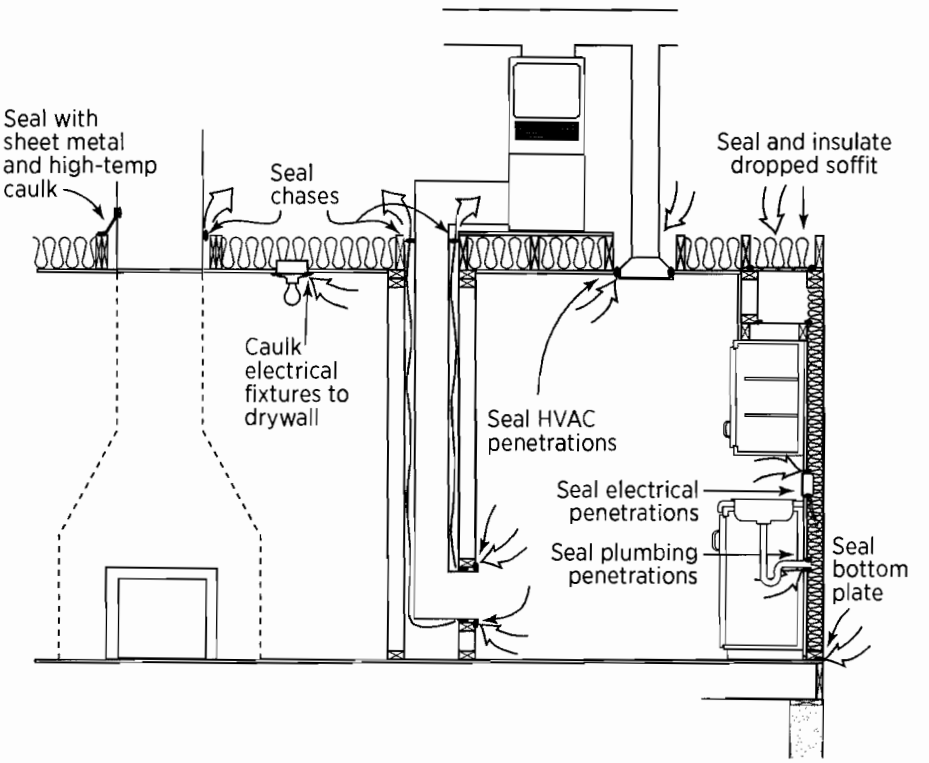


Figure 4.1. Seal attic and wall penetrations associated with mechanical ventilation systems, electrical chase openings, and dropped soffits (Source: DOE 2000a).

5. Dropped Ceiling/Soffit

Air barrier is fully aligned with insulation; all gaps are fully sealed.

Soffits (dropped ceilings) found over kitchen cabinets or sometimes running along hallways or room ceilings as duct or piping chases are often culprits for air leakage. Your contractor will push aside the attic insulation to see if an air barrier is in place over the dropped area. If none exists, the contractor will cover the area with a piece of rigid foam board, sheet goods, or reflective foil insulation that is glued in place and sealed along all edges with caulk or spray foam, then covered with attic insulation. If the soffit is on an exterior wall, sheet goods or rigid foam board should be sealed along the exterior wall as well. If the soffit contains recessed can lights, they should be rated for insulation contact and airtight (ICAT) or a dam should be built around them to prevent insulation contact.

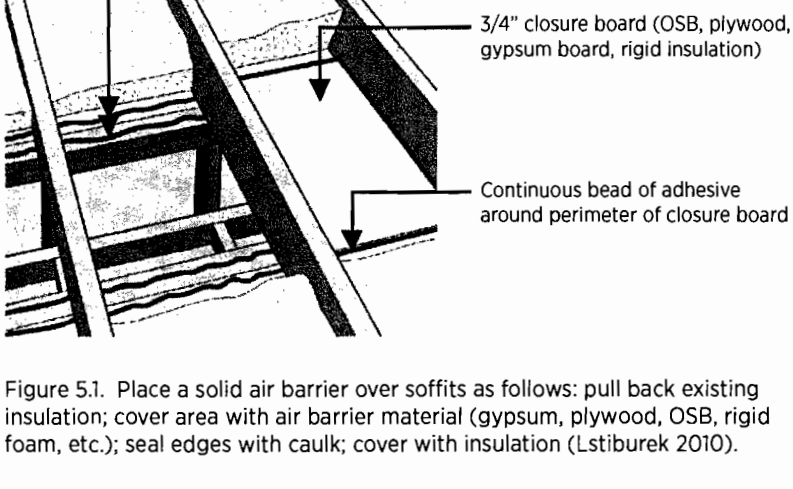


Figure 5.1. Place a solid air barrier over soffits as follows: pull back existing insulation; cover area with air barrier material (gypsum, plywood, OSB, rigid foam, etc.); seal edges with caulk; cover with insulation (Lstiburek 2010).

When To Do This

Any time, if attic construction allows access to area above soffits.

Durability & Health

If warm moist air gets into a cold attic through leaks in the home's thermal envelope, it can condense on solid surfaces, which may lead to water damage and mold growth.

2009 IECC/2009 IRC Code

Requirement for New Construction and Additions

Air barrier in any dropped ceiling/soffit is substantially aligned with insulation and any gaps are sealed.

More Information

- Building America Best Practices
- Iowa Energy Center 2008
- Lstiburek 2010
- U.S. Environmental Protection Agency 2008a
- U.S. Environmental Protection Agency 2008b
- U.S. Environmental Protection Agency 2008c

6. Staircase Framing at Exterior Wall/Attic

Air barrier is fully aligned with insulation; all gaps are fully sealed.

When To Do This

Any time.

Durability & Health

Uninsulated exterior walls with no air barriers present a cold surface where condensation and mold can form.

2009 IECC/2009 IRC Code

Requirement for New Construction and Additions

Air barrier and thermal barrier

- Exterior thermal envelope insulation for framed walls is installed in substantial contact and continuous alignment with building envelope air barrier.
- Air-permeable insulation is inside of an air barrier.

More Information

- Building America Best Practices
- U.S. Environmental Protection Agency 2008c
- House Energy 2009

If the area under the stairs is accessible, look to see if the inside wall is finished. If not, have your contractor insulate it, if needed, and cover it with a solid sheet product like drywall, plywood, oriented strand board, or rigid foam insulation. Then, your contractor can caulk the edges and tape the seams to form an air-tight barrier. Stairs should be caulked where they meet the wall.

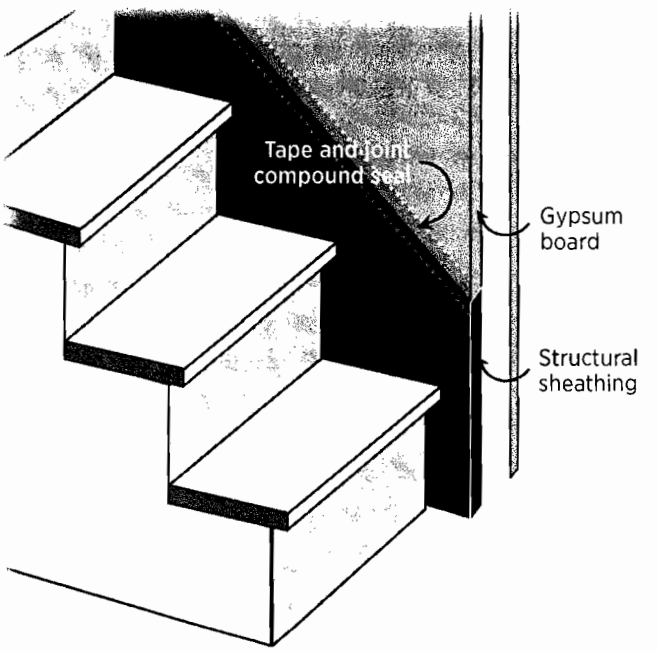


Figure 6.1. Install an air barrier and air sealing on exterior walls behind stairs. If the area behind the stairs is inaccessible, caulk stairs where they meet the wall. Use caulk if the area is already painted; use tape and joint compound if area will be painted.

7. Porch Roof

Air barrier is installed at the intersection of the porch roof and exterior wall.

If a test-in inspection identifies air leakage at the wall separating the porch from the living space, the contractor will investigate to see if the wall board is missing or unsealed. If this is the case, the contractor will install some type of wall sheathing (oriented strand board, plywood, rigid foam board) cut to fit and sealed at the edges with spray foam. Your contractor will also make sure this wall separating the attic from the porch is fully insulated.

Studies Show

Steven Winter Associates, a Building America research team lead, used a blower door test and infrared cameras to investigate high-energy bill complaints at a 360-unit affordable housing development and found nearly twice the expected air leakage. Infrared scanning revealed an air leakage path on an exterior second-story wall above a front porch. Steven Winter Associates found that, while the wall between the porch and the attic had been insulated with unfaced fiberglass batts, wall board had never been installed. The insulation was dirty from years of windwashing as wind carried dust up through the perforated porch ceiling, through the insulation, into the attic and into the wall above. Crews used rigid foam cut to fit and glued in place with expandable spray foam to seal each area. Blower door tests showed the change reduced overall envelope leakage by 200 CFM_{50}. At a cost of $267 per unit, this fix resulted in savings of $200 per year per unit, for a payback of less than two years.

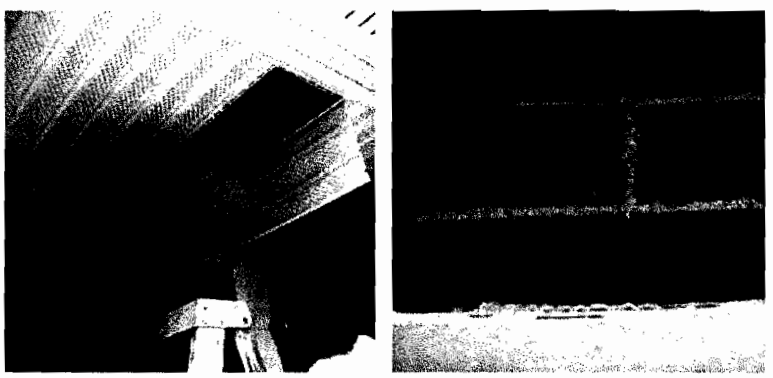


Figure 7.1. When researchers pulled back the porch ceiling, they found the wall board was missing so nothing was covering the insulation on this exterior wall. An air barrier of rigid foam board was put in place with spray foam (Source: Moriarta 2008).

When To Do This

Any time, if porch wall is accessible, either from the attic or from the porch.

Durability & Health

Cold surfaces in the exterior wall encourage condensation and mold. If the air barrier is missing, wind can carry dust and pollen into the living space.

2009 IECC/2009 IRC Code

Requirement for New Construction and Additions

- Exterior thermal envelope insulation for framed walls is installed in substantial contact and continuous alignment with building envelope air barrier.
- Breaks or joints in the air barrier are filled or repaired.
- Air-permeable insulation is inside of an air barrier.

More Information

- Building America Best Practices
- Moriarta 2008
- U.S. Environmental Protection Agency 2008b

8. Flue or Chimney Shaft

Opening around flue is closed with flashing, and any remaining gaps are sealed with fire-rated caulk or sealant.

When To Do This

Any time the flue pipe is accessible in the attic.

Durability & Health

Use the right sealing products and techniques to keep flammable materials from touching hot flues.

2009 IECC/2009 IRC Code

Requirement for New Construction and Additions

Duct shafts, utility penetrations, knee walls and flue shafts opening to exterior or unconditioned space are sealed.

More Information

- Building America Best Practices
- U.S. Environmental Protection Agency 2008a
- U.S. Environmental Protection Agency 2008c

There are often gaps around chimneys, furnaces, and water heater flues that allow conditioned air to flow up into the attic. Your contractor can seal this gap with lightweight aluminum flashing (sheet metal) and special high-temperature (heat-resistant) caulk. A metal dam should be used to keep insulation away from the flue. The same technique is used for masonry chimneys.

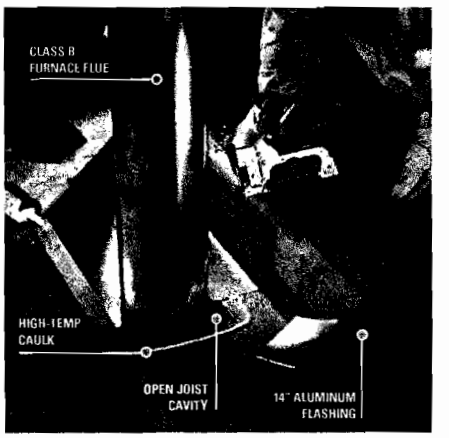


Figure 8.1.

Step 1: Cut aluminum flashing to fit around flue.

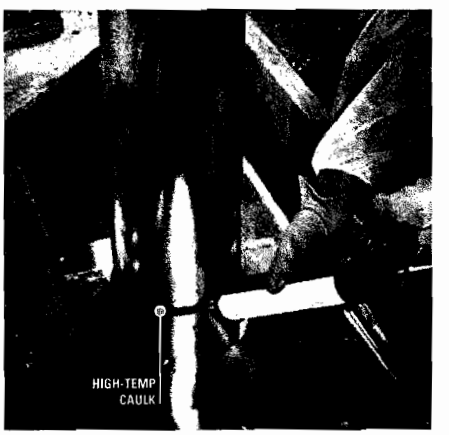


Figure 8.2.

Step 2: Seal flashing to pipe with high-temperature caulk.

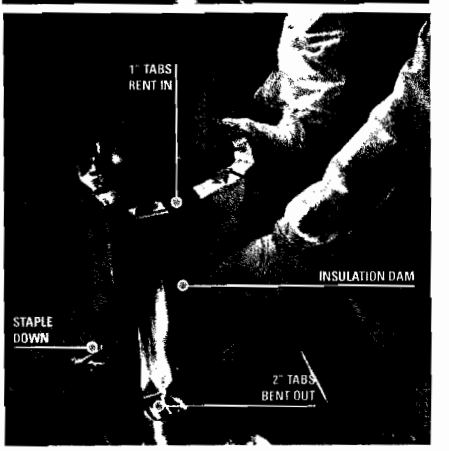


Figure 8.3.

Step 3: Form an insulation dam to keep the insulation from coming into contact with the flue pipe.

(Source: EPA 2008a)

9. Attic Access/Pull-Down Stair

Attic access panel or drop-down stair is fully gasketed for an air-tight fit.

A home's attic access, which could be an attic hatch, pull-down stairs, or a kneewall door, can leak a lot of heated or cooled air into the attic if it is not sealed properly.

Your contractor can add weather stripping either to the frame or panel of the attic access and may install latch bolts to ensure a tighter seal. The hatch lid, stairs, or door should be insulated too.

If you are planning to add an attic access, consider the location. An access hatch or pull-down stairs that is located in an unconditioned part of the house, such as a garage, covered patio, or porch, does not necessarily need to be air sealed or insulated. If your hatch connects conditioned space like a bedroom, hallway, or closet to an unconditioned attic, your contractor will check for air leakage.

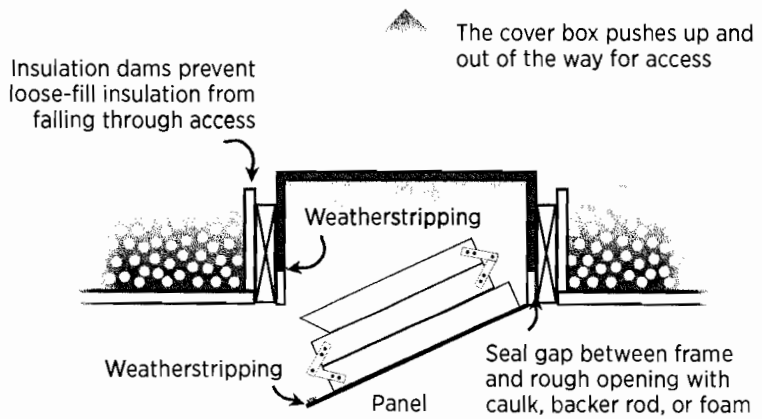


Figure 9.1. Insulate and air seal the attic access hatch cover.

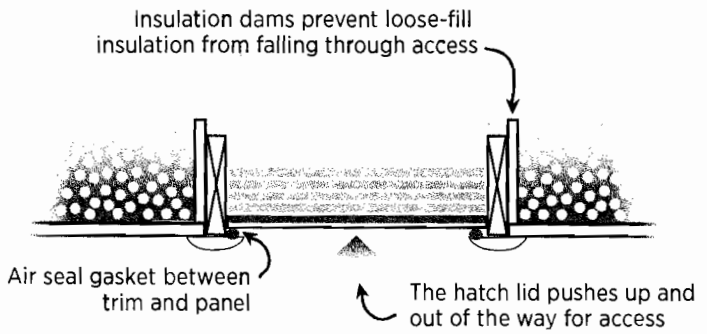


Figure 9.2. Insulate and air seal the pull-down attic stair.

When To Do This

Any time.

Durability & Health

Air sealing the attic access will minimize the amount of moisture-laden air that escapes into the attic reducing the risk of mold in the attic.

2009 IECC/2009 IRC Code

Requirement for New Construction and Additions

Ceiling/attic

Attic access (except unvented attic), knee wall door, or drop down stair is sealed.

More Information

- Building America Best Practices
- U.S. Department of Energy 2000b
- U.S. Department of Energy 2009a
- U.S. Environmental Protection Agency 2008a

10. Recessed Lighting

Fixtures are provided with air-tight assembly or covering.

When To Do This

Replace old uninsulated can fixtures when changing lighting fixtures; can caulk any time.

Durability & Health

Non-airtight recessed can fixtures can allow heated air to escape to attic during winter, carrying moisture that can condense in a cool attic. They can also draw hot attic air into the home in summer, pulling dust and insulation particles into the home.

2009 IECC/2009 IRC Code

Requirement for New Construction and Additions

Recessed lighting

Recessed light fixtures are airtight, IC rated, and sealed to drywall. Exception: fixtures in conditioned space.

More Information

- Building America Best Practices
- ASTM 1991
- McCullough and Gordon 2002

Recessed downlights are the most popular home lighting fixture in the United States. Older model recessed can fixtures are energy intensive in three ways—they are not approved for insulation contact so insulation has to be kept at least 3 inches away all the way around, leaving about 1 square foot of uninsulated ceiling space. Most are using incandescent bulbs that use 3 to 5 times the power of fluorescents and add to air-conditioning loads. Third, the cans are not airtight, so they allow conditioned air to escape from the living area into unconditioned spaces such as attics.

If your home has non-airtight fixtures, you can have a contractor replace the whole fixture with insulation contact-rated, air-tight (ICAT) fixtures, or caulk around the fixture, under the trim ring if caulking from inside the home. Other alternatives are to install the recessed cans in an air-sealed dropped soffit or to use surface-mounted fixtures instead. After air sealing, replace any incandescent lights in the recessed lighting fixture with low-wattage CFL or LED lamps.

Studies Show

Old, leaky recessed cans are like a hole in the ceiling, only worse. Old recessed cans with incandescent bulbs can pull 3 to 5 times as much air as a hole the same size, thanks to the "stack effect"—the heat inside the can pulls air from the house up into the attic. Replacing a leaky can with an ICAT (insulation contact-rated, air-tight) recessed downlight would save a Phoenix, AZ, homeowner $1.56 per year in cooling costs or a Minneapolis, MN, homeowner $3.57 per year in heating costs (these savings don't even include the possible energy savings of CFL bulbs over incandescent bulbs) (McCullough and Gordon 2002).

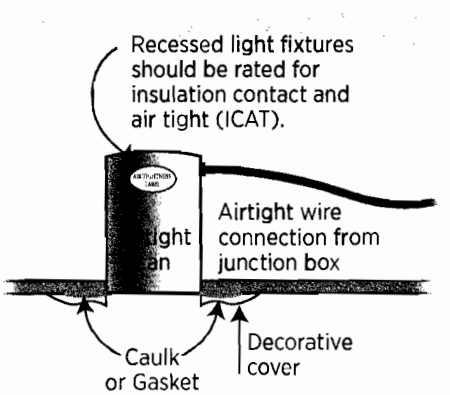


Figure 10.1. *(left)* Replace old, leaky can fixtures with insulated, airtight recessed light fixtures and caulk them where the housing meets the drywall.

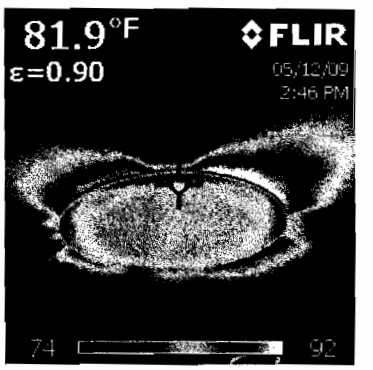


Figure 10.2. *(right)* Seal cans to prevent heated and cooled air from leaking into attics as shown in this infrared camera image.

11. Ducts

All ducts should be sealed, especially in attics, vented crawlspaces, and rim areas.

Repairing leaking ducts can yield big energy improvements. Duct sealing contractors often find more than just a few leaks: duct tape dries and falls away; ducts may have been torn or crumpled by other trades during installation; and poorly hung ducts can have bends and kinks that prevent air from flowing through them. It is not uncommon to find one or more ducts completely disconnected from their register.

If return ducts in the heating and air-conditioning system have holes, they can draw in hot attic air or cold outside air. As a result, the system must work harder and use more energy to heat and cool the inside of the house. In older homes, wall cavities and floor joist cavities are sometimes used as return "ducts" to bring air from the return registers back to the air handler unit, but these building cavities are rarely air sealed.

A heating and cooling equipment contractor may

- Inspect the duct system, including the attic and crawlspace.
- Evaluate the system's supply and return air flow.
- Repair damaged and disconnected ducts.
- Seal all leaks and connections with mastic (a thick sealant painted on duct joints).
- Seal all registers and grills to the ducts.
- Insulate ducts in unconditioned areas (like attics, crawlspaces, and garages) with duct insulation that has an R-value of 6 or higher.
- Replace the filter as part of any duct system improvement.
- Retest air flow after repairs are completed.
- Ensure there is no backdrafting of gas or oil-burning appliances, and conduct a combustion safety test after ducts are sealed.

When To Do This

Whenever and wherever ducts are accessible.

Durability & Health

Unsealed ducts can draw in dust, moisture, and contamination from unconditioned spaces in the home. Broken ducts can be a pathway for pests.

2009 IECC/2009 IRC Code

Requirement for New Construction and Additions

HVAC register boots

HVAC register boots that penetrate building envelope are sealed to subfloor or drywall.

More Information

- Building America Best Practices
- Building Science Corporation 2006
- Building Science Corporation 2009d
- Cummings et al. 1990
- Granade et al. 2009
- Jump and Modera 1994
- Karins et al. 1997
- ORNL
- Sherman et al. 2000
- U.S. Environmental Protection Agency 2008a
- U.S. Environmental Protection Agency 2009a

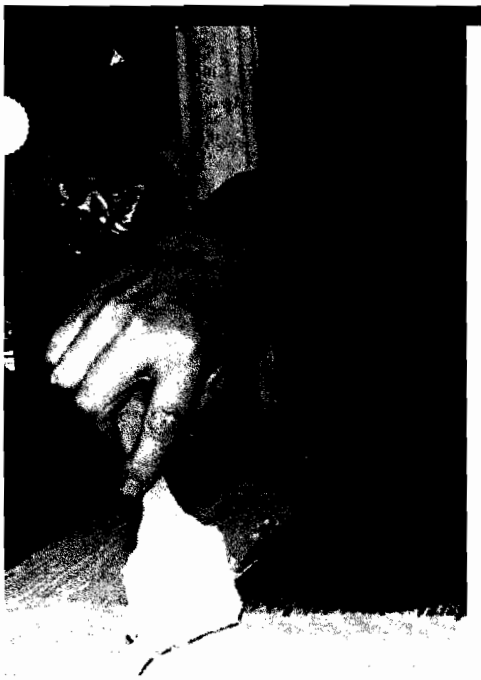


Figure 11.1. Paint mastic (a thick, gooey substance) on to the duct seams and joints. (Photo source: Habitat for Humanity Lakeland FL).

Studies Show

In a study of energy-efficient measures, DOE's Energy Information Administration reported that sealing the ducts yielded by far the greatest energy savings of the 12 measures studied, at the lowest cost (Granade et al. 2009). In a DOE study of 100 homes in Phoenix, Arizona, sealing ducts cut leakage by 30%, saving homeowners $80 per year. A study of 24 Florida homes found air-conditioning energy use was reduced by 18% after duct repairs were made (Cummings et al. 1990). A study of a retrofit project involving 25 apartments in New York found that sealing the HVAC ducts cut airflow leakage by 92 CFM for supply ducts and 223 CFM for return ducts with a simple payback of 3 to 4 years (Karins et al. 1997). Research on six homes in the southwest indicated that 30% to 40% of the thermal energy delivered to the ducts passing through unconditioned spaces is lost through air leakage and conduction through the duct walls. Sealing and insulating the ducts cut overall duct leakage approximately 64% (Jump and Modera 1994).

DOE studies show duct tape fails within months (Sherman et al. 2000).

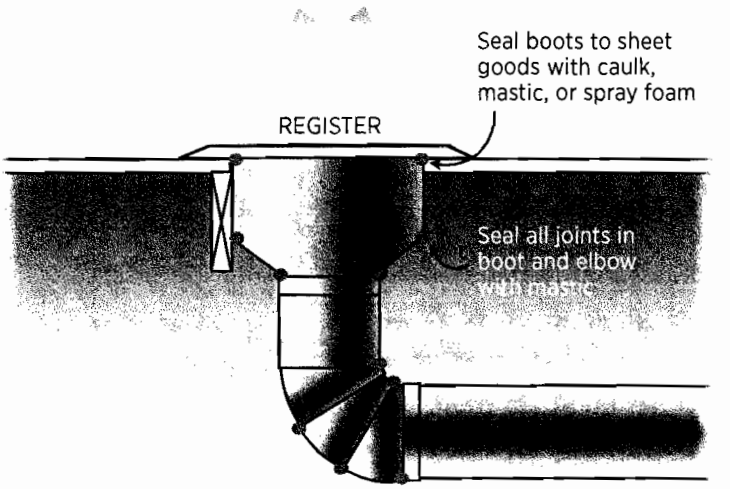


Figure 11.2. Mastic seal all supply and return air ducts.

12. Whole-House Fan Penetration at Attic

An insulated cover is provided that is gasketed or sealed to the opening from either the attic side or ceiling side of the fan.

A whole house fan is a fan installed in the ceiling to help quickly cool the house by drawing air into the house through open windows on summer mornings and evenings when the outside temperature is lower than the indoor temperature. Ideally, the air should be ducted to exhaust outside, not into the attic space. During the winter months (and in summer when the air conditioner is running), the whole house fan is not used. At those times, it represents a potential energy loss because it is essentially a large, uninsulated hole in the ceiling. Since standard fan louvers do not insulate or seal tightly, a cover should be constructed or purchased to air seal and insulate this hole from the attic side, the house side, or in case of very hot or cold weather, both sides. Homeowners must remember to remove cover(s) before operating the fan and to replace cover(s) during seasons when the fan is not in use.

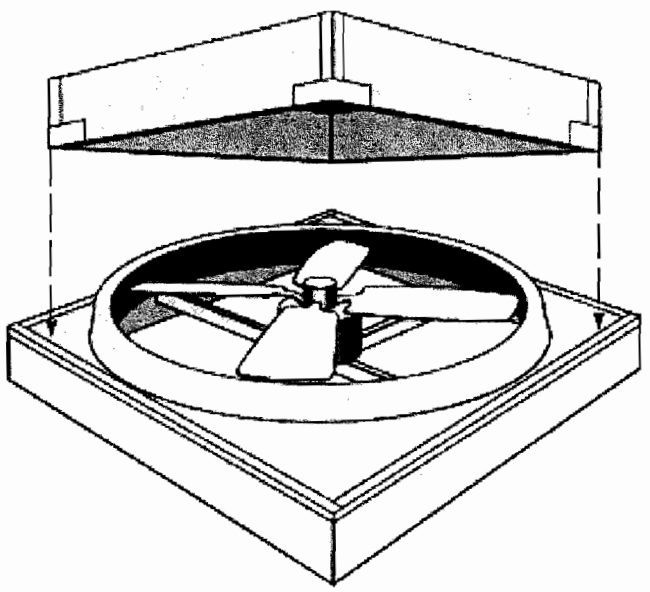


Figure 12.2. Install a removable, insulating, air-sealing cover over your whole house fan (Source: Southface Energy Institute 1999).

When To Do This

When a whole house fan is installed.

Durability & Health

A whole house fan can pull large quantities of air from the home and, if windows are not open, it can easily backdraft a fireplace or combustion appliance located in the home or attic. Some localities will not permit a whole house fan to be installed if a furnace is located in the attic or if there is a combustion appliance in the home that derives its combustion air from either the attic or the inside of the home unless the homeowner 1) encloses the combustion appliance so that it obtains combustion air from outside the home; 2) ducts the whole house fan directly to the exterior; or 3) provides a switching device that allows only one of the appliances (fan or furnace) to be on at a time (Davis 2001). The whole house fan should be ducted to the outside or adequate ventilation must be provided in the attic to prevent the attic from being overpressurized and pushing attic dust into the house.

2009 IECC/2009 IRC Code

Requirement for New Construction and Additions

Shafts, penetrations

Duct shafts, utility penetrations, knee walls and flue shafts opening to exterior or unconditioned space are sealed.

More Information

- Building America Best Practices
- Davis 2001
- DOE 1999
- Southface Energy Institute 1999

13. Exterior Walls

Service penetrations are sealed.

Your exterior walls may have a surprising number of holes in them—for plumbing pipes and vents, electrical wires and conduits, electrical fixtures, clothes dryer ducts, and exhaust fans. Holes may also have been drilled through the top and bottom plates; ideally, these were caulked and sealed during construction as these areas are nearly impossible to get to later, unless drywall or exterior sheathing is being replaced. Your contractor will caulk penetrations through walls from the exterior and interior. An ideal time to seal the drywall to the subfloor is when walls are being painted and baseplate trim is removed (just pull back the carpet) or when floor covering is being replaced.

When To Do This

Seal wall penetrations whenever accessible. Sill- and top-plate penetrations may only be accessible during construction of new walls or additions or when exterior or interior wall sheathing is being replaced. Electrical switches and outlets can be accessed any time.

Durability & Health

Unsealed penetrations can be a pathway for dust and pests to enter the home. Penetrations through the top plate must be sealed if the top plate is in the plane of an intended air, smoke, or fire separation (BSC 2009).

2009 IECC/2009 IRC Code

Requirement for New Construction and Additions

Shafts, penetrations

Duct shafts, utility penetrations, knee walls and flue shafts opening to exterior or unconditioned space are sealed.

Shower/tub on exterior wall

Showers and tubs on exterior walls have insulation and an air barrier separating them from the exterior wall.

Electrical/phone box on exterior walls

Air barrier extends behind boxes or air sealed-type boxes are installed.

More Information

- Building America Best Practices
- Building Science Corporation 2006
- Building Science Corporation 2009e
- U.S. Environmental Protection Agency 2008a

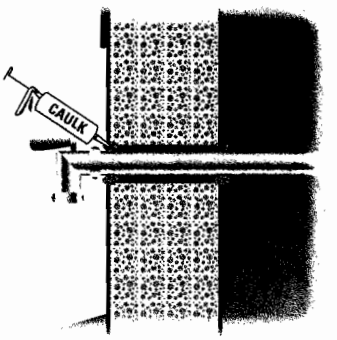


Figure 13.1. Caulk all plumbing penetrations through exterior walls.

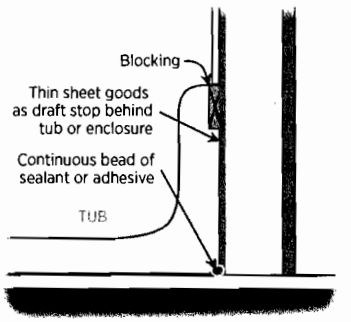


Figure 13.2. If you are remodeling a bathroom make sure you seal and insulate behind the tub or shower, especially if it is on an exterior wall.

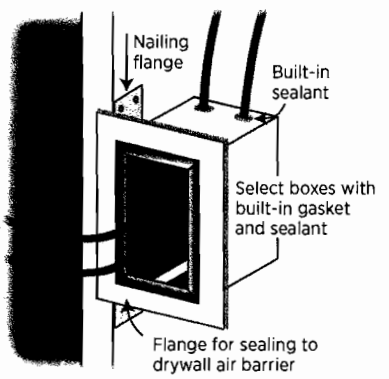
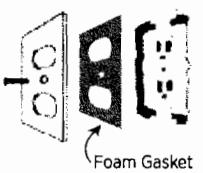


Figure 13.3. Seal all electric outlets and switches with foam sealant, or select boxes with built-in sealant or gaskets. Install foam gaskets between electrical outlets or switches and their coverplates, and insert plastic "child-safety" plugs into the outlets to further block airflow.



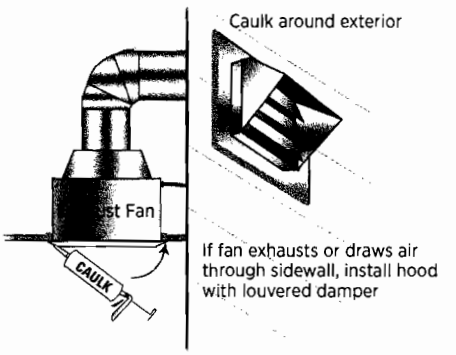


Figure 13.4. Caulk around exhaust fans at the ceiling and exterior wall. Also caulk around exterior outlets and light fixtures.

14. Fireplace Wall

Air sealing is completed in framed shaft behind the fireplace or at fireplace surround.

Fireplaces have many potential areas of air leakage. Air sealing and insulation are often missing from the enclosure that forms a prefabricated fireplace. There are often unsealed air gaps around the flue and the surround. Flue dampers are not airtight, allowing air to escape up the chimney even when no fire is burning in the fireplace (BSC 2009). A fireplace can actually waste more heat than it creates (Iowa Energy Center 2008).

Even if you close the fireplace damper and it leaks just a little, a lot of warm air from your home will be drawn up the chimney and be replaced by cold air leaking into the house. If you use the fireplace, follow these air sealing tips: (Iowa Energy Center 2008)

- Every year, have the fireplace and chimney inspected and cleaned by a certified chimney sweep.
- Check the seal of the flue damper with an incense stick or piece of burning paper. Seal around the damper assembly with refractory cement, but don't seal the damper closed. Replace warped or missing dampers.
- Use a removable plug like a chimney balloon that you insert in the chimney above the damper and inflate to plug air leaks when you're not using the fireplace. If you forget to remove it before starting a fire, it will react to the heat and quickly deflate.
- Install tight-fitting glass doors.
- Make a tight-fitting air barrier to cover the fireplace opening when not in use from rigid board insulation and plywood edged with pipe insulation (Iowa Energy Center 2008).
- Consider installing a sealed, natural gas or propane fireplace insert. These inserts are sealed combustion and do away with door and flue leaks.

Studies Show

Studies have shown that fireplace dampers are often left open. One study showed found 80% of fireplace dampers were inadvertently left open (Tyrol and Pate 2007). In a DOE-funded study of 56 new homes in Arkansas with gas or wood fireplaces, the fireplaces accounted for 5.3% of total house air leakage (Brown 1999).

When To Do This

At any time.

Durability & Health

An open, unsealed fireplace carries risks of backdrafting carbon monoxide, smoke, and ash into the home. A sealed fireplace with its own combustion air intake is preferred. Homes that use gas or wood fireplaces should have carbon monoxide detectors.

2009 IECC/2009 IRC Code

Requirement for New Construction and Additions

Fireplace

Fireplace walls include an air barrier.

More Information

- Building America Best Practices
- Brown 1999
- Building Science Corporation 2009a
- Dalicieux and Nicolas 1990
- Iowa Energy Center 2008
- Tyrol and Pate 2007
- U.S. Environmental Protection Agency 2008a

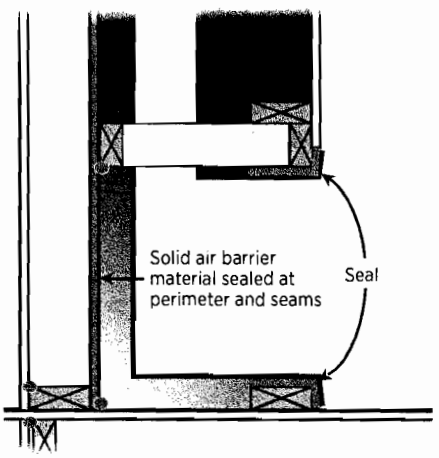


Figure 14.1. Air seal the enclosure surround and flue.

15. Garage/Living Space Walls

Air sealing is completed between garage and living space. Pass-through door is weather stripped.

When To Do This

At any time.

Durability & Health

Garages often contain harmful chemicals and gases that must be kept out of the living space by thorough air sealing of any common walls and ceilings.

2009 IECC/2009 IRC Code

Requirement for New Construction and Additions

Air sealing is provided between the garage and conditioned spaces.

More Information

- Building America Best Practices
- Aspen Publishers 2000
- Iowa Energy Center 2008
- University of Illinois Extension Office
- U.S. Environmental Protection Agency 2010

For occupant health and safety, the garage should be completely air sealed from the living areas of the house. When the garage is beneath a second-story living space, the gaps created by the floor joists spanning both the living space and the garage must be blocked off and sealed. If the air handler for a central furnace must be located in the garage, it should be in an air-sealed closet with its own air intake, so that it is not drawing garage air to circulate through the house.

If you have an attached garage, expect your contractor to visually inspect for cracks or improper sealing of the walls separating the garage from the home, to test the seal tightness of doors linking the garage with the rest of the home, to test carbon monoxide levels in the house, to measure interface leakage between the garage and house, and to determine what size garage exhaust fan, if any, is advisable.

Steps to a Healthier Garage – *eliminate, isolate, ventilate.*

Keep in mind the following:

1. Your very best option is to build a detached garage.
2. If that is not possible, try removing or isolating pollutants. Park cars, mowers, etc., outside. Do not let cars or mowers idle in the garage (and of course never start them with the garage door closed). Start gas-powered mowers, leaf blowers, etc., outside. Store paints, solvents, and other chemicals in tight containers.

Your contractor can assist you with the following recommendations:

3. Seal all penetrations through the common wall and ceiling. Use gaskets, airtight drywall technique, etc., to make the common wall and ceiling airtight.
4. Seal ducts located in the garage. (Avoid locating supply or return registers in the garage when remodeling.)
5. Install a self-closing, insulated, metal, fire-rated door with a good weather seal between the living space and the garage.
6. Install a passive roof vent to keep the garage at a negative pressure in relationship to the house. If needed, install a timed exhaust fan that vents to the outside.

Studies Show

In a field study of 12 homes in Anchorage, Alaska, researchers found that carbon monoxide (CO) from car starts in the garages entered all but 1 of the 12 houses. Four of the homes came close to the EPA CO exposure limit and, in one case, exceeded it (Aspen Publishers 2000). Noted the author: "In all but one case, the house was operating under negative pressure relative to the garage due to the stack effect. In other words, the house was sucking CO and other airborne contaminants through the common walls and ceilings." The researchers found high CO in homes where furnace ductwork was located in the garage and where the garage was located under occupied space above. A study by Health Canada identified 150 different pollutants commonly found in garages. Preliminary results from 25 houses tested in that study found that an average of 13% of all infiltration into the houses was through the common wall between the garage and house. A Minnegasco study measured typical leakage at an even higher 25% (Aspen 2000).

15.2. Seal rim joists of the wall separating the house's living space from the garage with pieces of wall board and spray foam.

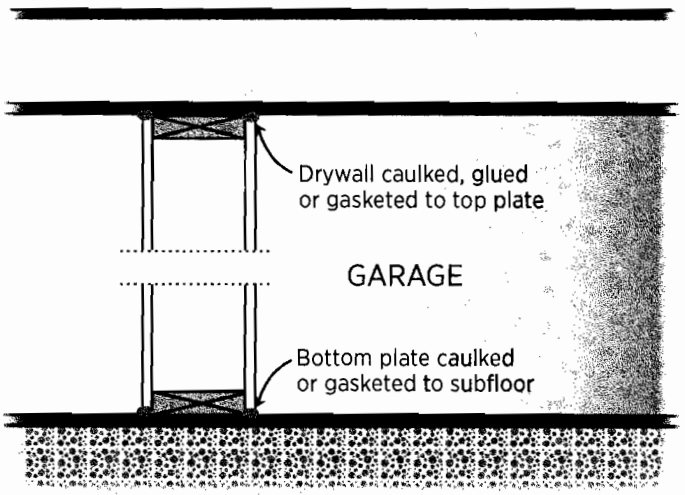


Figure 15.1. Finish the walls that separate the garage from the rest of the home with drywall that is sealed to the top and bottom plate with a bead of caulk.

16. Cantilevered Floor

Cantilevered floors are air sealed and insulated at perimeter or joist transitions.

Cantilevered floors, second-story bump-outs, and bay windows are another area in the home that is often lacking proper air sealing. The floor cavity must be filled with insulation with good alignment (i.e., that is completely touching) the underside of the floor. The interior and exterior sheathing needs to be sealed at the framing edges. Blocking between floor joists should form a consistent air barrier between the cantilever and the rest of the house. Continuous sheathing, such as insulating foam sheathing, should cover the underside of the cantilever, and be air sealed at the edges with caulk.

When To Do This

When comfort complaints or high utility bills warrant it; if an infrared camera inspection reveals the cantilever floor to be a source of high leakage.

Durability & Health

If a cantilever isn't properly air sealed and insulated, moist air from the home can pass into the cantilever floor cavity and condense on the coldest surface it finds—the backside of the sheathing or band joist—causing mold to grow there.

2009 IECC/2009 IRC Code

Requirement for New Construction and Additions

Floors (including above-garage and cantilevered floors)

Insulation is installed to maintain permanent contact with underside of subfloor decking. Air barrier is installed at any exposed edge of insulation.

More Information

- Building America Best Practices
- Lugano 1998
- U.S. Environmental Protection Agency 2008b

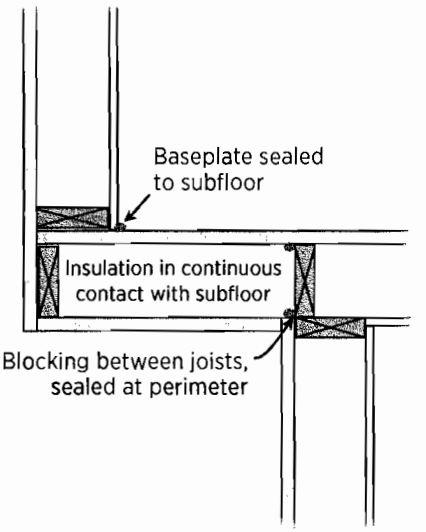


Figure 16.1. Block and air seal both the floor-to-upper wall junction and the floor-to-lower wall junction.

17. Rim Joists, Sill Plate, Foundation, and Floor

Rim joists are insulated and include an air barrier. Junction of foundation and sill plate is sealed. Penetrations through the bottom plate are sealed. All leaks at foundations, floor joists, and floor penetrations are sealed. Exposed earth in crawlspace is covered with Class I vapor retarder overlapped and taped at seams.

The rim joist (also called a band joist) is the horizontal beam that rests on top of the foundation wall or between floors. The floor joists are attached to or run parallel with it. Rim joists are a particularly troublesome area for air leakage. Several framing components (foundation wall and sill plate or top plate, rim joist, and subfloor above) need to be connected and sealed to form a continuous air barrier. Your contractor will inspect this area and, if needed, air seal and insulate along the joints where the floor joists meet the rim joist and the rim joist meets the subfloor. The rim joist can be air sealed and insulated with caulk and batt insulation, or rigid foam cut to fill the space between each floor joist and sealed in place with spray foam. Another option is to spray high- or low-density urethane foam at each joist bay to cover the foundation wall-top plate-rim joist-subfloor connections.

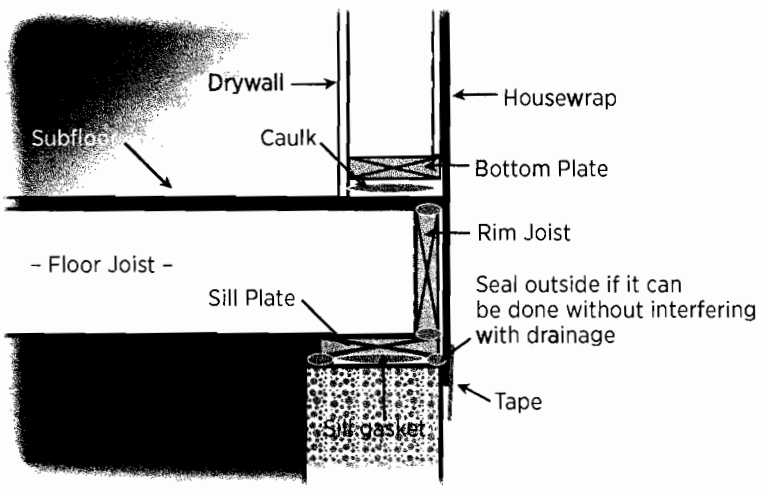


Figure 17.1. Use caulk or spray foam to air seal where the foundation wall meets the sill plate, where the sill plate meets the rim joist, and where the rim joist meets the subfloor.

When To Do This

Air sealing rim joists below the first floor can be done in conjunction with finishing the basement, when insulating the basement walls, or whenever an unsealed rim joist is accessible from inside. Plywood subfloor seams can be sealed when replacing flooring or replacing or installing insulation beneath the floor.

Durability & Health

The interior side of the rim joist is a cold surface in wintertime; condensation can form there if it is not properly insulated. A dirt crawlspace floor should be covered with a Class 1 vapor retarder (e.g., 6-mil polyethylene). If the home has an unvented crawlspace, the underside of the floor should be air sealed and a vent stack can be installed to minimize entry of soil gases into living space.

2009 IECC/2009 IRC Code

Requirement for New Construction and Additions

Walls

Junction of foundation and sill plate is sealed.

Corners and headers are insulated.

Rim joists

Rim joists are insulated and include an air barrier.

Crawlspace walls

Exposed earth in unvented crawlspaces is covered with Class I vapor retarder with overlapping joints taped.

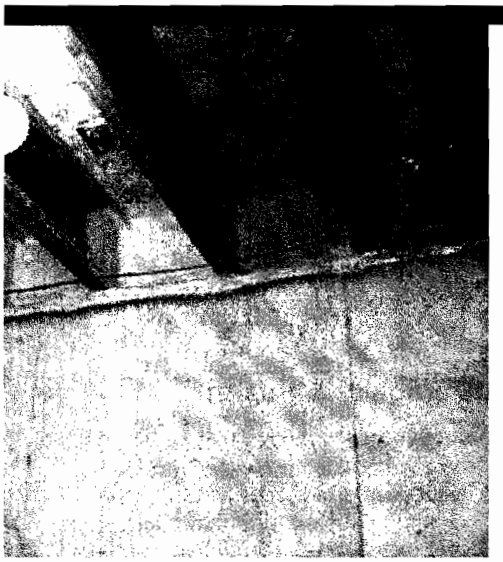


Figure 17.2. Spray foam along the basement rim joist to provide a complete air barrier connecting the foundation wall, sill plate, rim joist, and subfloor (Source: BSC 2009C).

Your contractor will seal the seams of the subfloor plywood panels if they are accessible. The contractor will also seal all holes that go through the basement ceiling to the floor above, such as holes for plumbing, HVAC ducts, and furnace vent pipes if the furnace is located in the basement.

If your house's foundation is a slab, your contractor can check for and seal air leaks where the sill plate meets the foundation. If your home has an unvented crawlspace your contractor will check the foundation for cracks and holes that may need sealing. The crawlspace access hatch should be weather stripped or gasketed. If the crawlspace floor has exposed earth, this should be covered with Class I vapor retarder with overlapping joints that are taped.

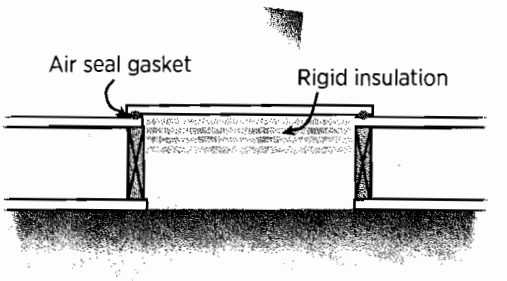


Figure 17.3. Air seal the crawlspace access hatch by installing a gasket or weather stripping around the hatch edges.

More Information

- Building America Best Practices
- Building Science Corporation 2009c
- Conbere and Fried 2006
- Braun 1995
- Building Science Corporation 2009e
- Lstiburek 2004a, b; 2006; 2008
- U.S. Department of Energy 2000a
- U.S. Environmental Protection Agency 2008b
- U.S. Environmental Protection Agency 2009b
- U.S. Environmental Protection Agency 2009c

Studies Show

One homeowner in Illinois had spent thousands of dollars re-siding his house with rigid foam insulation, adding insulation, upgrading his furnace, and replacing windows but his house was still drafty and his utility bills were still high. He called in a BPI-certified contractor who conducted several assessments including a blower door test of the whole house and individual rooms to determine where air was leaking. The blower door showed the home's air leakage was three times higher than preferred. The contractor recommended plugging leaks in the crawlspace and rim joists; adding joist insulation; air-sealing all plumbing, electrical, service, and duct penetrations; and insulating and air sealing the crawlspace access and attic hatch cover. The upgrades cost $2,500 and saved the homeowner $700 a year in energy costs (Conbere and Fried 2006).

18. Windows and Doors

Space between window/door jambs and framing is sealed.

When windows are installed in a new house, the rough opening (the space left for the window) is typically 1.5 to 2 inches larger than the window frame to give the installer room to install, plumb, and square the window. The same is true of doors. Your contractor can properly seal around the existing windows by removing the interior trim and filling the rough opening with non-expanding foam or backer rod and caulk. A simpler but more visible alternative is to leave the interior trim in place and seal around it with a clear silicone caulk or paintable latex caulk with silicone. Replace any cracked or loose panes. Consider replacing older, single-pane windows that show signs of leakage, water damage, or condensation with new double-pane windows installed with proper air sealing and flashing.

Windows and doors should be weather stripped. See the DOE Energy Savers website for a comprehensive description of different types of caulking and weather stripping material www.energysavers.gov/your_home/insulation_airsealing/index.cfm/mytopic=11260.

Older homes often have double-hung windows with chases hidden in the wall for counter weights. Access these chases by removing the side trim or by going through access ports along the sides of the window. If the window is replaced, the weight should be removed and the chases filled with insulation and sealed. If you have old windows with working pulleys, the pulley holes can be air sealed but kept usable with plastic caps called pulley seals. Doors should be self-closing and have a tight fitting sill.

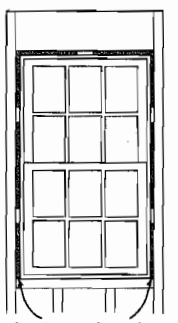


Figure 18.1. Use backer rod, caulk, or nonexpanding foam approved for windows and doors to fill the rough-in gap around doors and windows (DOE 2000).

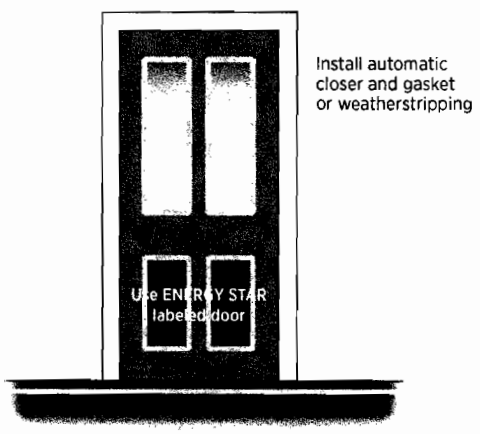


Figure 18.2. Install automatic closer and gasket or weather stripping around doors. Caulk around trim.

When To Do This

Any time.

Durability & Health

More efficient windows may be less prone to condensation and related mold growth. Painted window sashes and frames in homes built before 1978 may contain lead-based paint; use a contractor experienced in lead removal.

2009 IECC/2009 IRC Code

Requirement for New Construction and Additions

Windows and doors

Space between window/door jambs and framing is sealed.

More Information

- Building America Best Practices
- Building Science Corporation 2009b
- Stovall et al. 2007
- U.S. Department of Energy 2000a
  U.S. Department of Energy 2009c
- U.S. Environmental Protection Agency 2008b

Studies Show

A study conducted at Oak Ridge National Laboratory's Buildings Technology Center on window air sealing showed that windows with ¾-inch rough-in gaps had an equivalent leakage area of 28.2 cm^2/m^2. When the gap was caulked from the interior side of the wall, the equivalent leakage area was cut to 0.5 cm^2/m^2 *(Stovall et al. 2007)*.

19. Common Walls Between Attached Dwelling Units

The gap between a gypsum shaft wall (i.e., common wall) and the structural framing between units is sealed.

When To Do This

Whenever common wall is accessible.

Durability & Health

Common walls between units are fire-rated and should be air sealed and properly blocked to minimize fire spread and entry of air, moisture, and pests.

2009 IECC/2009 IRC Code

Requirement for New Construction and Additions

Air barrier is installed in common wall between dwelling units.

More Information

- Braun and Woods 1995
- Building Science Corporation 2009e
- U.S. Environmental Protection Agency 2008b

Common walls between units in multi-family housing (e.g., townhouses, duplexes, and apartments) should be constructed as airtight assemblies for sound, smoke, fire, and air quality control. However, experience has shown that these common walls can often be significant sources of air and heat loss if gaps or cracks exist in the connections between each unit's walls. Your contractor can determine whether this is a significant source of air leakage in your home.

To reduce air leakage, this assembly should be air sealed at all boundaries. Your contractor will seal wood frame walls with fireproof spray foam (EPA 2008). Masonry block party walls, which form "chimneys" because of their porosity and open cores, can be air sealed with two-component urethane foam, which also reduces sound, odor transfer, and dust, insects, and moisture entry (Braun et al. 1995).

Because these walls are fire-rated assemblies for each unit, acceptable materials for air-sealing common walls can vary significantly around the country. Your contractor will confirm with local code officials which material is preferred for fire safety reasons, prior to retrofitting. The contractor will seal all plumbing penetrations through the drywall surface of common walls with fire-rated sealant materials (BSC 2009).

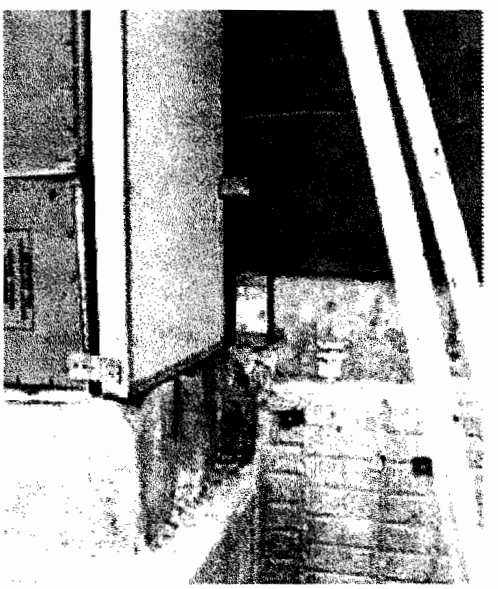


Figure 19.1. Seal air gaps between two framed common walls *(Source: Energy Services Group, from EPA 2008)*

References

Aspen Publishers 2000. "How Attached Garages Poison Our Indoor Air, And What Builders Can Do About It." in *Energy Design Update*, Volume 20, No. 12; December 2000 http://arkansasenergy.org/business_development/energy/files/Clearinghouse/How%20Attached%20Garages%20Poison%20Our%20Indoor%20Air.pdf

ASTM 1991. "Standard Test Method for Determining the Rate of Air Leakage through Exterior Windows, Curtain Walls, and Doors under Specified Pressure Differences across the Specimen." ASTM E283-91, West Conshohocken, Pennsylvania.

Building America Best Practices, *Volumes 1-9.* These Best Practices Guides from the U.S. Department of Energy provide building science guidance for builders of energy efficient homes in every U.S. climate zone. Available for free download at http://www1.eere.energy.gov/buildings/building_america/publications.html

Braun, B. J. Hansen, and T. Woods 1995. "Urethane foams and air leakage control" *Home Energy* Vol. 12 (4), published Jul-Aug 1995.

Brown, Evan 1999. *Energy Performance Evaluation of New Homes in Arkansas*, Evan Brown, consultant to the Arkansas Energy Office, December 1999, www.energycodes.gov/implement/pdfs/Arkansas_rpt.pdf

Building Science Corporation 2006. *Read This Before You Design, Build, or Renovate* www.buildingscience.com/documents/primers/plonearticlemultipage.2006-12-05.5229931729/section-2-recommendations

Building Science Corporation 2009a. "Air Barriers—Tub, Shower and Fireplace Enclosures," Information Sheet 407 for All Climates 5/20/2009, prepared by BSC for DOE's Building America program, www.buildingscience.com/documents/information-sheets/4-air-barriers/air-barriers2014tub-shower-and-fireplace-enclosures/?searchterm=building%20america

Building Science Corporation 2009b. "Air Sealing Windows," Information Sheet 406 for All Climates 5/20/2009, prepared by BSC for DOE's Building America program, www.buildingscience.com/documents/information-sheets/4-air-barriers/sealing-air-barrier-penetrations/?searchterm=building%20america

Building Science Corporation 2009c. "Critical Seal (Spray Foam at Rim Joist)" Information Sheet 408 for All Climates 09/18/2009, prepared by BSC for DOE's Building America program, www.buildingscience.com/documents/information-sheets/4-air-barriers/info-408-critical-seal-spray-foam-at-rim-joist/?searchterm=building%20america

Building Science Corporation 2009d. *Duct Sealing*, Information Sheet 603, prepared by BSC for DOE's Building America program. www.buildingscience.com/documents/information-sheets/hvac-plumbing-and-electrical/information-sheet-duct-sealing/?searchterm=building%20america

Building Science Corporation 2009e. "Sealing Air Barrier Penetrations," Information Sheet 405 for All Climates 5/20/2009, prepared by BSC for DOE's Building America program, www.buildingscience.com/documents/information-sheets/4-air-barriers/sealing-air-barrier-penetrations/?searchterm=building%20america

Conbere, Susan and Kate Fried 2006. "A Doctor in the House; Building performance testing has given one Illinois remodeler an edge in his market - and on the books," *Professional Remodeler*, June 1, 2006.

Consumer Product Safety Commission 2010. "What You Should Know About Combustion Appliances and Indoor Air Pollution." CPSC Document #452, accessed 3/12/2010, www.cpsc.gov/cpscpub/pubs/452.html

Cummings, J.B., J.J. Tooley, N. Moyer, and R. Dunsmore, "Impacts of duct leakage on infiltration rates, space conditioning energy use, and peak electrical demand in Florida homes," in *Proceedings of the 1990 ACEEE Summer Study on Energy Efficiency in Buildings*, Asilomar, CA, (1990), pp. 69-76.

Dalicieux P and C Nicolas 1990. "Ventilation Perturbations Due to an Open Fireplace in a House." *Energy and Buildings* 14(3):211-214

Davis 2001. *Whole House Fan Installation*, Building Department, City of Davis, California, July 23, 2001. www.city.davis.ca.us/cdd/pdfs/Whole_House_Fan.pdf

Granade, HC, J Creyts, A Derkach, P Farese, S Nyquist, and K Ostrowski 2009. *Unlocking Energy Efficiency in the US Economy.* McKinsey and Company. www.mckinsey.com/clientservice/electricpowernaturalgas/US_energy_efficiency/

House Energy 2009. "Ventilation and Electrical Penetrations," webpage, www.house-energy.com/AirLeaking/HvacAL.html

Iowa Energy Center 2008. *Home Tightening, Insulation, and Ventilation*, Home Series 1, Iowa Energy Center, Ames, Iowa. www.energy.iastate.edu/homeseries/downloads/HomeSeries1.pdf

2009 International Residential Code For One- and Two-Family Dwellings. www.iccsafe.org

Jump, D. and M. Modera 1994. *Energy Impacts of Attic Duct Retrofits in Sacramento Houses*, LBL-35375, prepared by Lawrence Berkeley National Laboratory, for the U.S. Department of Energy, Washington, DC.

Karins, N.H., A. Tuluca, and M. Modera 1997. *Effectiveness of Duct Sealing and Duct Insulation in Multi-Family Buildings.* Prepared by Steven Winter Associates and Lawrence Berkeley National Laboratory for the New York State Energy Research and Development Authority and the U.S. Department of Energy.

Lstiburek, Joseph 2004a. *Builders Guides.* Guides to mixed humid, hot-dry, mixed-dry, and cold climates, for purchase at www.eeba.org/bookstore.

Lstiburek, Joseph W. 2004b. *Conditioned Crawl Space Construction, Performance and Codes*, Research Report - 0401, Building Science Corporation, www.building science.com

Lstiburek, Joseph 2006. *EEBA Water Management Guide*, available for purchase at www.eeba.org/bookstore/prod-Water_Management_Guide-9.aspx

Lstiburek, Joseph 2008. *Concrete Floor Problems*, BSI-003, Building Science.com. www.buildingscience.com/documents/insights/bsi-003-concrete-floor-problems

Lstiburek, Joseph 2010. *Guide to Attic Air Sealing*. Prepared for U.S. Department of Energy by Building Science Corporation. www.buildingscience.com/documents/primers/guide-to-attic-air-sealing-with-details/?searchterm=air%20sealing

Lugano, Fred 1998. "First Step in Cellulose Sealing: Spot the Style," *Home Energy Magazine Online* May/June 1998, www.homeenergy.org/archive/hem.dis.anl.gov/eehem/98/980508.html

McCullough, Jeff J. and Kelly L. Gordon 2002. "High Hats, Swiss Cheese, and Fluorescent Lighting?" *Proceedings of the 2002 ACEEE Summer Study*, prepared by PNNL. www.aceee.org/conf/bldindex.htm

Moriarta, Courtney 2008. "Fixing Air Leakage in Connecticut Town Houses," *Home Energy Magazine* July/Aug 2008, p 28-30, www.swinter.com/news/documents/FixingAirLeakage.pdf&amp

ORNL. "Sealing Duct Leaks Saves Energy and Money," Oak Ridge National Laboratory, www.ornl.gov/info/ornlreview/rev28_2/text/duct.htm.

Sherman, M. H., I. S. Walker, and D.J. Dicerkhoff 2000. "Stopping Duct Quacks: Longevity of Residential Duct Sealants," in *Proceedings of the 2000 ACEEE Summer Study on Energy Efficiency in Buildings*, prepared by Lawrence Berkeley National Laboratory. www.osti.gov/bridge/product.biblio.jsp?query_id=1&page=3&osti_id=776574

Southface Energy Institute 1999. "Whole House Fan: Installing and using a whole house fan" Energy Technical Bulletin 10, Southface Energy Institute, Atlanta Georgia, www.southface.org/web/resources&services/publications/factsheets/housefan.pdf

Stovall, T. K., T. Petrie, J. Kosny, P.W. Childs, J.A. Atchley, and K. D. Hulvey 2007. "An Exploration of Wall Retrofit Best Practices," *Proceedings of the Thermal Performance of the Exterior Envelopes of Whole Buildings X Conference*, Clearwater Beach, FL, USA, Dec 02-07, 2007.

Tyrol, Mark D and Joe Pate 2007. Seal Fireplace Dampers with Weather Stripping to Conserve Energy, in *Proceedings of the 3rd International Conference on Environmental Science and Technology 2007*, August 5-9, 2007, Houston, Texas, prepared by Tyrol Engineering, LLC. http://hearth.com/econtent/index.php/wiki/Seal_Fireplace_Damper/

U.S. Department of Energy 1999. *Whole House Fan: How to Install and Use a Whole House Fan*, DOE/GO-10099-745, prepared by Southface Energy Institute and Oak Ridge National Laboratory for the U.S. Department of Energy. http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/26291.pdf

U.S. Department of Energy 2000a. *Air Sealing Fact Sheet*, Prepared by Southface Energy Institute and Oak Ridge National Laboratory. http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/26446.pdf

U.S. Department of Energy 2000b. *Attic Access Technology Fact Sheet*. Prepared by Southface Energy Institute and Oak Ridge National Laboratory. www.ornl.gov/sci/roofs+walls/insulation/fact%20sheets/attic%20access.pdf

U.S. Department of Energy 2009a. *Attic Access Insulation and Air Sealing*. www.energysavers.gov/your_home/insulation_airsealing/index.cfm/mytopic=11400

U.S. Department of Energy 2009b. "Energy Savers: Sealing Air Leaks," www1.eere.energy.gov/consumer/tips/air_leaks.html

U.S. Department of Energy 2009c. "Energy Savers: Your Home - Weather Stripping." DOE www.energysavers.gov/your_home/insulation_airsealing/index.cfm/mytopic=11280

U.S. Environmental Protection Agency 2008a. *A Do-It-Yourself Guide to Sealing and Insulating with ENERGY STAR*. EPA, May 2008, www.energystar.gov/index.cfm?c=diy.diy_index

U.S. Environmental Protection Agency 2008b. *ENERGY STAR Qualified Homes Thermal Bypass Checklist Guide*. www.energystar.gov/ia/partners/bldrs_lenders_raters/downloads/TBC_Guide_062507.pdf

U.S. Environmental Protection Agency 2008c. "Indoor Air Quality and Attics." www.epa.gov/iaq/homes/hip-attic.html

U.S. Environmental Protection Agency 2009a. *Duct Sealing*. EPA, Feb 2009, www.energystar.gov/ia/products/heat_cool/ducts/DuctSealingBrochure04.pdf

U.S. Environmental Protection Agency 2009b. *Model Standards and Techniques for Control of Radon in New Residential Buildings*. Cited 6/18/09. www.epa.gov/radon/pubs/newconst.html#Principles

U.S. Environmental Protection Agency 2009c. *Sealing Air Leaks: Basement* www.energystar.gov/index.cfm?c=diy.diy_sealing_basement

U.S. Environmental Protection Agency 2010. "Indoor airPLUS Building Professionals." www.epa.gov/indoorairplus/building_professionals.html

U.S. Environmental Protection Agency and U.S. Department of Energy 2010. *What to Expect from Home Performance with ENERGY STAR*, accessed 3/12/2010. www.energystar.gov/homeperformance

University of Illinois Extension Office "Five Steps to a Healthier Garage." http://web.extension.uiuc.edu/will/factsheets/family116.html

Visit our Web sites at:

www.buildingamerica.gov

www.pathnet.org

www.energystar.gov

Research and Development of Buildings

Our nation's buildings consume more energy than any other sector of the U.S. economy, including transportation and industry. Fortunately, the opportunities to reduce building energy use—and the associated environmental impacts—are significant.

DOE's Building Technologies Program works to improve the energy efficiency of our nation's buildings through innovative new technologies and better building practices. The program focuses on two key areas:

- Emerging Technologies
  Research and development of the next generation of energy-efficient components, materials, and equipment
- Technology Integration of new technologies with innovative building methods to optimize building performance and savings

Building America Program

George S. James • New Construction • 202-586-9472 • fax: 202-586-8134 • e-mail: George.James@ee.doe.gov

Lew Pratsch • Existing Homes • 202-586-1512 • fax: 202-586-8185 • e-mail: Lew.Pratsch@ee.doe.gov

Building America Program • Office of Building Technologies, EE-2J • U.S. Department of Energy • 1000 Independence Avenue, S.W. • Washington, D.C. 20585-0121 • www.buildingamerica.gov

Building Industry Research Alliance (BIRA)

Robert Hammon • ConSol • 7407 Tam O'Shanter Drive #200 • Stockton, CA 95210-3370 • 209-473-5000 • fax: 209-474-0817 • e-mail: Rob@consol.ws • www.bira.ws

Building Science Consortium (BSC)

Betsy Pettit • Building Science Consortium (BSC) • 70 Main Street • Westford, MA 01886 • 978-589-5100 • fax: 978-589-5103 • e-mail: Betsy@buildingscience.com • www.buildingscience.com

Consortium for Advanced Residential Buildings (CARB)

Steven Winter • Steven Winter Associates, Inc. • 50 Washington Street • Norwalk, CT 06854 • 203-857-0200 • fax: 203-852-0741 • e-mail: swinter@swinter.com • www.carb-swa.com

Davis Energy Group

David Springer • Davis Energy Group • 123 C Street • Davis, CA 95616 • 530-753-1100 • fax: 530-753-4125 • e-mail: springer@davisenergy.com • deg@davisenergy.com • www.davisenergy.com/index.html

IBACOS Consortium

Brad Oberg • IBACOS Consortium • 2214 Liberty Avenue • Pittsburgh, PA 15222 • 412-765-3664 • fax: 412-765-3738 • e-mail: boberg@ibacos.com • www.ibacos.com

Industrialized Housing Partnership (IHP)

Philip Fairey • Florida Solar Energy Center • 1679 Clearlake Road • Cocoa, FL 32922 • 321-638-1005 • fax: 321-638-1439 • e-mail: pfairey@fsec.ucf.edu • www.baihp.org

National Association of Home Builders (NAHB) Research Center

Tom Kenney • National Association of Home Builders (NAHB) Research Center • 400 Prince George's Boulevard • Upper Marlboro, MD 20774 • 301-430-6246 • fax: 301-430-6180 • toll-free: 800-638-8556 • www.nahbrc.org

National Renewable Energy Laboratory

Ren Anderson • 1617 Cole Boulevard, MS-2722 • Golden, CO 80401 • 303-384-7433 • fax: 303-384-7540 • e-mail: ren_anderson@nrel.gov • www.nrel.gov

Tim Merrigan • 1617 Cole Boulevard, MS-2722 • Golden, CO 80401 • 303-384-7349 • fax: 303-384-7540 • e-mail: tim_merrigan@nrel.gov • www.nrel.gov

Oak Ridge National Laboratory

Pat M. Love • P.O. Box 2008 • One Bethel Valley Road • Oak Ridge, TN 37831 • 865-574-4346 • fax: 865-574-9331 • e-mail: lovepm@ornl.gov • www.ornl.gov

Pacific Northwest National Laboratory

Michael Baechler • 620 SW 5th, Suite 810 • Portland, OR 97204 • 503-417-7553 • fax: 503-417-2175 • e-mail: michael.baechler@pnl.gov • www.pnl.gov

Produced for the U.S. Department of Energy (DOE) by Pacific Northwest National Laboratory, Contract DE-AC05-76RLO 1830.

Printed with a renewable-source ink on paper containing at least 50% wastepaper, including 20% postconsumer waste.

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

BUILDING TECHNOLOGIES PROGRAM

VOLUME 14.

BUILDING AMERICA BEST PRACTICES SERIES

Energy Renovations

HVAC

A Guide for Contractors to Share with Homeowners

PREPARED BY

Pacific Northwest National Laboratory
& Oak Ridge National Laboratory

August 2011

Building America
U.S. Department of Energy

August 2011 • PNNL-20421

BUILDING AMERICA BEST PRACTICES SERIES

Energy Renovations

Volume 14: HVAC

A Guide for Contractors to Share with Homeowners

Prepared by

Pacific Northwest National Laboratory

Program Manager: Michael C. Baechler

Theresa L. Gilbride, Michael C. Baechler, Marye G. Hefty, and James R. Hand

and

Oak Ridge National Laboratory

Pat M. Love

August 2011

Prepared for the
U.S. Department of Energy Building America Program

PNNL-20421
Pacific Northwest National Laboratory
Richland, Washington 99352
Contract DE-AC05-76RLO 1830

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor Battelle Memorial Institute, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or Battelle Memorial Institute. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Preface

Research conducted by the U.S. Department of Energy (DOE) has shown that Americans can significantly improve the energy efficiency, safety, and comfort of their homes while reducing emissions and utility bills. Studies show that upgrading a home's heating and cooling equipment can reduce energy use by up to 20% or more, depending on the condition of the existing systems. Similar savings may be realized by improving the distribution efficiency of the heating and cooling systems.

This guide, which is part of a series of Best Practices guides produced by DOE's Building America program, describes ways homeowners can reduce their energy costs and improve the comfort, health, and safety of their homes by upgrading their heating, ventilation, and air conditioning (HVAC) equipment. A variety of types of heating and cooling equipment are described. The references throughout this document provide additional information about important aspects of residential HVAC.

The recommendations provided here are primarily based on the results of research and demonstration projects conducted by DOE's Building America research teams. Building America collaborates with building scientists, researchers, and more than 300 home builders across the country with the goal of constructing homes that are safer and more energy-efficient, comfortable, and durable, with low or no additional cost.

Much of the information in the ventilation chapter was drawn from work prepared by Armin Rudd of Building Science Corporation, one of the Building America research teams. All photographs and figures in this report were prepared by Pacific Northwest National Laboratory (PNNL) unless otherwise noted.

You can learn more about Building America and download additional copies of this document, other best practices, research reports, and case studies at www.buildingamerica.gov

Go to http://www1.eere.energy.gov/buildings/building_america/research_teams.html to view the current list of Building America teams.

Contents

Preface i

1.0 Introduction 1

1.1 Building America's Whole-House Approach 1

1.2 The Home Performance Energy Assessment 2

1.3 Space Heating and Cooling 3

1.4 Building Permits and Codes 3

2.0 Heating Systems 5

2.1 Furnaces 8

2.1.1 Furnace Efficiency 8

2.1.2 Repair or Replace? 10

2.1.3 Ducts 12

2.2 Electric Heaters 15

2.2.1 Electric Central Furnaces 15

2.2.2 Room Heaters 15

2.2.3 Zoning 16

2.3 Heat Pumps 17

2.3.1 Central Air-Source Heat Pumps 18

2.3.2 Ductless Heat Pumps 19

2.3.3 Ground-Source Heat Pumps 20

2.4 Boilers and Hydronic Heating 23

2.4.1 Steam and Hot Water Radiators 23

2.4.2 Radiant Floor Heating 24

2.4.3 Repair or Replace 24

2.5 Wood and Pellet Heating 25

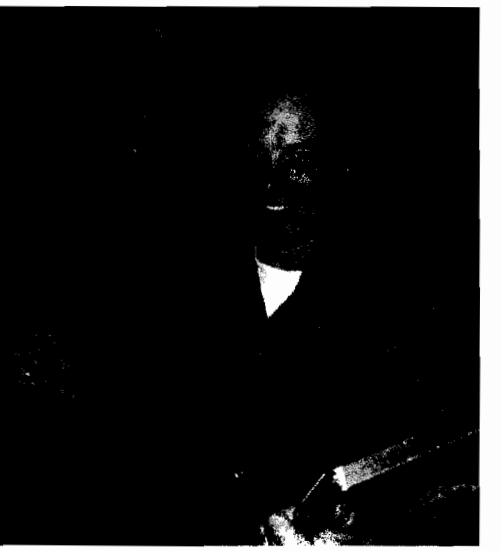
2.6 Solar Heating 26

2.6.1 Passive Solar Heating 27

2.6.2 Active Solar Heating 28

3.0 Cooling Systems 29
3.1 Central Air Conditioning 33
3.1.1 Repair or Replace? 34
3.2. Room Air Conditioning 36
3.3 Heat Pumps 36
3.3.1 Central- and Ground-Source Heat Pumps 36
3.3.2 Ductless Heat Pumps 36
3.3.3 Absorption Heat Pumps 37
3.4 Evaporative Coolers 38
3.5 Radiant Cooling 39
3.6 Dehumidifiers 40
3.7 Natural Cooling Strategies 41
3.7.1 Fans and Ventilation for Cooling 41
3.7.2 Passive Cooling 44
4.0 Ventilation 47
4.1 Exhaust-Only Ventilation 49
4.2 Supply-Only Ventilation 50
4.3 Balanced Systems 51
4.4 "Semi-Balanced" System 51
5.0 The Home Performance Energy Assessment 53
5.1 Certified Energy Contractors 53
5.2 The Energy Assessment Process 54
5.2.1 Step 1. The Energy Performance Assessment 54
5.2.2 Step 2. Making Energy-Efficiency Upgrades 55
5.2.3 Step 3. Testing Out 55
References 56
Definitions 58
Building America Teams 59

1.0 Introduction



For the average American homeowner, heating and cooling accounts for 40% of annual energy usage (DOE Building Energy Data Book 2009). Picking the right heating and cooling equipment can reduce this significant portion of your utility bill.

This guide provides information about energy-efficient heating, ventilation, and cooling (HVAC) equipment options to help homeowners cut their energy use, reduce their carbon footprint, and increase their homes' comfort, health, and safety. This guide will help you make informed decisions about purchasing new HVAC equipment or improving existing equipment for more efficient operation.

If you are a homeowner, use this guide to learn more about energy-efficient options in HVAC equipment. If you are a contractor, share this guide with your customers.

1.1 Building America's Whole-House Approach

HVAC energy upgrades can improve the energy efficiency, air quality, and comfort of your home, and can save money in the long term. However, it is important to recognize that each component of the HVAC system interacts with the rest of the house. Changing one component—for example upgrading heating or cooling equipment, adding ventilation, increasing insulation or air sealing—without taking into account these system interactions could result in safety issues.

To ensure health and safety, your HVAC options should be considered within a whole-house, systems-based approach advocated by the U.S. Department of Energy Building America program and

Building America® U.S. Department of Energy

The best practices and recommendations in this guide are based on years of building science research by the U.S. Department of Energy's (DOE) Building America and its 15 teams of building science researchers. These Building America teams collaborate with building scientists, industry partners, and researchers, and more than 300 home builders across the country with the goal of constructing and renovating more energy-efficient, comfortable, and durable homes. Building America's work has directly influenced the performance of more than 42,000 new and retrofitted homes to date.

An energy contractor can help you evaluate the best options for replacing or upgrading your home's heating and cooling equipment.

How to find a certified energy contractor

An easy way to find a certified energy contractor is through a national or regional retrofit program. One such program is Home Performance with ENERGY STAR, a national program from the U.S. Environmental Protection Agency and the U.S. Department of Energy that is applied at the state level. Go to www.energystar.gov and click on the link for Home Performance with ENERGY STAR. Next, click on the "locations" link for certified contractors in your state. You can also find local contractors who understand the whole-house approach through the Building Performance Institute, www.bpi.org, and the Residential Energy Services Network, www.resnet.us. The Air Conditioning Contractors of America website has a list of members at www.acca.org. ACCA produced a checklist homeowners can use to evaluate HVAC contractors' bid proposals (ACCA 2011a). North American Technician Excellence (NATE) also certifies HVAC contractors (www.hvacadvice.com).

HOME PERFORMANCE WITH ENERGY STAR

building scientists across the country. This whole-house approach, which is based on years of research in thousands of real homes, takes into account how one change in a home's HVAC system can affect the energy efficiency, comfort, durability, health, and safety of the whole house.

To implement this whole-house approach and and to confirm real energy-use improvements, Building America recommends that HVAC home energy upgrades start with a home performance energy assessment.

1.2 The Home Performance Energy Assessment

The home energy assessment is conducted within the context of a whole-house system-based approach to home performance to ensure homeowner health and safety as well as energy performance. The home energy assessment should be conducted by a contractor who is trained in building science principles, such as those described in the DOE *Guidelines for Home Energy Upgrade Professionals* and the U.S. Environmental Protection Agency's *Healthy Indoor Environment Protocols for Home Energy Upgrades*, as well as those recommended by Home Performance with ENERGY STAR, the Building Performance Institute (BPI) standards, state weatherization programs, or accredited college program recommendations.

The assessment (also known as an audit) consists of three steps: testing in, conducting the work, and testing out. In the test-in step, the contractor interviews homeowners about any concerns they have about their HVAC system, such as comfort complaints or high utility bills; conducts safety tests and tests for air leakage in the ducts and whole house; and visually inspects for insulation levels and signs of mold or moisture problems. The contractor uses energy software to analyze the results and gives this report to the homeowner, along with a prioritized list of recommendations. The homeowner works with the energy performance contractor or HVAC contractor to determine a scope of work and have the work completed. In the test-out step, the completed work is evaluated with safety tests and visual inspections.

For more information on what you can learn from a home performance energy assessment and why it is a good idea to have one, see Chapter 5 of this report.

1.3 Space Heating and Cooling

Replacing or upgrading your HVAC system offers excellent opportunities for cutting your utility bills and improving your home's indoor air quality, comfort, and durability. Your certified energy contractor or HVAC contractor can help you determine which heating and cooling options are right for you. Talk to your contractor about fuel types and prices in your region. Your contractor can help you determine whether it is safe and cost-effective to repair and improve the HVAC equipment you already have or to replace or supplement it with new, more efficient equipment.

The contractor can also provide advice about other ways to improve the energy efficiency of your home, such as by sealing air leaks and adding insulation. These efficiency improvements are often the most cost-effective means of saving energy in the long run.

If you decide to replace an existing heating or cooling system, one option is to replace the existing equipment with an updated model of the same type, especially if the distribution system (ducts or radiators) is still good. However, this may not be the most efficient heating and cooling option for your money.

See the following chapters for information and recommendations on the many heating, cooling, and ventilation options available today.

1.4 Building Permits and Codes

Your contractor will check with your local building department to determine what building codes apply and to obtain any needed permits. Depending on the extent of your project, you may need a building permit and plumbing, electrical, or mechanical permits. State or local building codes, including health, safety, and energy codes, may apply to building alterations and additions.

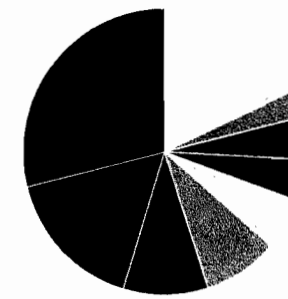
Your local utilities are a good resource for equipment incentives, rebates, and low-interest loan programs, as well as listings of local licensed contractors and details on any utility requirements that might affect your project. Underwriters Laboratory is responsible for third-party testing of HVAC equipment, so look for the Underwriters Laboratory seal when purchasing equipment (ANSI 2011).

Federal, State, and Utility Incentive Programs

Many local, state, and federal entities offer grants and tax credits for energy-efficient home improvements. Check with your local utility or city, or check the DOE-sponsored Database of State Incentives for Renewables and Efficiency (DSIRE) at www.dsireusa.org.

This site is frequently updated and is a wealth of information, organized by state, regarding state, local, utility, and federal incentives, tax credits, and rebates for renewable energy and energy-efficiency upgrades.

HOW THE TYPICAL U.S. HOMEOWNER'S ENERGY BILL GETS DIVIDED (Source: DOE Building Energy Data Book 2009)



- Space heating 30%
- Water heating 17%
- Space cooling 10%
- Lighting 9%
- Refrigeration 6%
- Clothes washers, dryers and dishwashers 5%
- Electronics 5%
- Cooking 3%
- Computer 1%
- Other 18% (includes small electronics, heating elements, motors, swimming pool and hot tub heaters, outdoor grills)

2.0 Heating Systems

A variety of technologies are available for heating your house; each of these is described in more detail in this chapter; they are listed here, in the sections below, from most to least common (EIA 2005).

FURNACES – Furnaces are the most common way to heat a home; 65% of single-family homes in the United States have a central forced-air furnace that distributes heated air throughout the house via ducts. More than two-thirds of these are fueled by natural gas; other heat sources are electricity, oil, and propane.

ELECTRIC HEATING – Not including heat pumps, 14% of single-family homes are heated with electric resistance heat; most are central forced-air electric furnaces, but many homes use electric space heating, either wall-mounted or baseboard, as their main heat source.

HEAT PUMPS – 10% of U.S. homes use heat pumps. These systems can be air-source or ground-source, and are ducted or ductless.

BOILERS – Boilers are used for heating in 8% of U.S. homes. Boilers use natural gas, oil, electricity, or propane to heat water for steam or hot water that is distributed via pipes to upright radiators, baseboard convectors, or radiant floor tubing. Combination units can provide space and water heating.

WOOD AND PELLET-FUEL STOVES – These provide a way to heat your home using biomass or waste sources and are a primary heat source for 3.5% of single-family homes.

SOLAR – Active solar heating uses the sun to heat air that is then ducted or blown into living space. Less than 0.4% of homes have active solar heating. Solar water heaters can preheat water for radiators or radiant floor heat.

$ How Much Does it Cost?

The National Renewable Energy Laboratory has created a database of purchase and installation costs for heating and cooling equipment and energy-efficiency upgrades (http://www.nrel.gov/ap/retrofits/group_listing.cfm.)

HOME PERFORMANCE WITH ENERGY STAR

Look for the ENERGY STAR label when you shop for HVAC equipment and other home appliances to find products that meet high energy-efficiency and performance criteria.

Heating Fuel Costs

Costs for heating oil and natural gas have varied greatly in recent years. For an apples-to-apples comparison of heating types by cost and percent efficiency, see the Heating Fuel Comparison Calculator developed by the U.S. DOE Energy Information Administration (EIA). Fuel costs are tied to databases that update weekly or daily (www.eia.doe.gov/neic/experts/heatcalc.xls).

These heating types are described in the next sections. Decisions about repair or replacement are influenced by many factors that your contractor can help you evaluate in the context of whole-house performance.

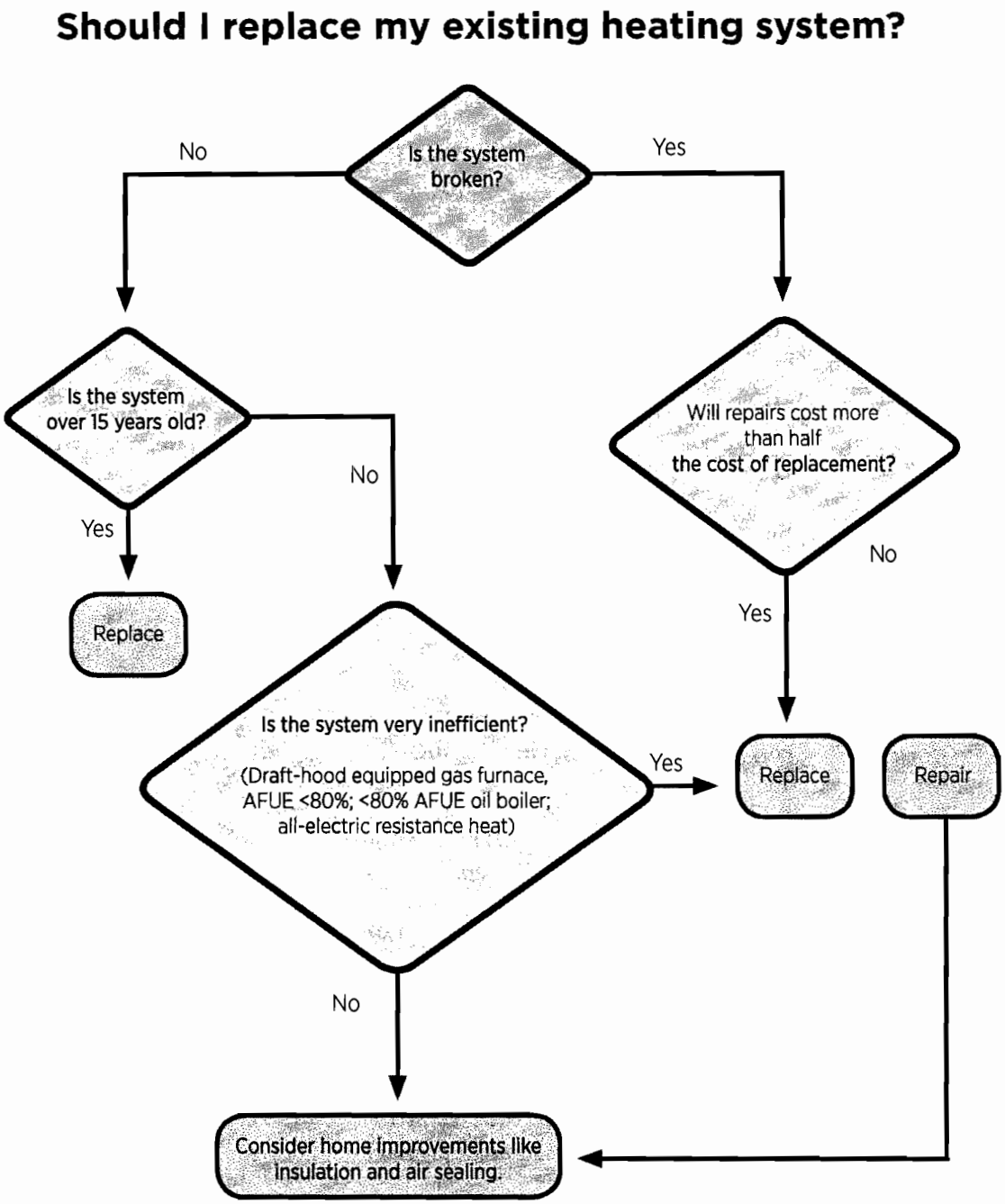


Figure 2.1. Basic Decisions for Replacing your Heating System

Table 2.1. Common Heating System Options

	Fuel Type	Installed Cost*	Ducts or No Ducts	Central or Room Heating	Best Climates	Minimum Federal Efficiency Requirement	Expected Efficiency of High-Performing Models	ENERGY STAR Version 3.0 Minimum Efficiency**	CEE Minimum Efficiency
Furnace	Natural Gas, Fuel Oil, Propane	Medium-High	Ducts	Central	Moderate-Cold	78% AFUE	90% - 98% AFUE	Gas: 80% AFUE CZ 1-3; 90% AFUE CZ 4-8 Oil: 80% AFUE CZ 1-3; 85% AFUE CZ 4-8	Tier 1: 90% AFUE Tier 2: 92% AFUE Tier 3: 94% AFUE
Electric Resistance	Electricity	Low	Either	Either	Warm-Hot	--	100%	NA	
Air-Source Heat Pump	Electricity	Medium-High	Ducts	Central	Moderate-Warm	7.7 HSPF	10-12 HSPF, 200+%	8.2 HSPF CZ 1-3; 8.5 HSPF CZ 4; 9.25 HSPF CZ 5; 9.5 HSPF CZ 6***	Tier 1: 8.5 HSPF Tier 2: ≥ 8.5 HSPF
Ground-Source Heat Pump	Electricity	Very High	Ducts	Central	All	7.7 HSPF	2.3-5 COP, 300+%	ENERGY STAR Qualified Models	Closed-loop 3.3 COP; Open-loop 3.6 COP; Direct Expansion 3.5 COP; With Desuperheater
Ductless Mini-split Heat Pump	Electricity	Medium-High	No Ducts	Room Heating	All	7.7 HSPF	10-12 HSPF	8.2 HSPF CZ 1-3; 8.5 HSPF CZ 4; 9.25 HSPF CZ 5; 9.5 HSPF CZ 6***	Tier 1: 8.5 HSPF Tier 2: 9.0 HSPF
Boiler	Natural Gas, Fuel Oil, Propane	High	No Ducts	Central	Cold	75% AFUE steam, 80% AFUE hot water	90%-95% AFUE	80% AFUE CZ 1-3; 85% AFUE CZ 4-8	Tier 1: 85% AFUE
Wood, Pellet	Wood, Pellet	Low-High	No ducts	Room Heating	All	Varies	72% to 90%	75%	--

*Estimated typical installed cost ranges for retrofits. These estimates do not include adding or repairing distribution systems. Low: $2,000 or less, Medium: $2,000 – $4,500, High: $4,500 – $10,000, Very High: $10,000 or more (www.energysavers.gov).

**ENERGY STAR Version 3.0 criteria, which became effective 4/1/2011, are climate specific and are based on the U.S. climate zones (CZ) identified in the International Energy Conservation Code (IECC) 2009 as defined by the U.S. DOE Building Energy Codes Program (www.energycodes.gov).

***An 8.2 HSPF air-source heat pump will qualify for ENERGY STAR in Climate Zones 4 – 8 if it is combined with an ENERGY STAR-qualified dual-fuel backup furnace.

CEE = the Consortium for Energy Efficiency, www.cee1.org

Annual Fuel Utilization Efficiency (AFUE): AFUE is the amount of fuel converted to space heat in proportion to the amount of fuel entering the boiler or furnace; expressed as a percentage. It does not include the electricity consumption of the fan and controls.

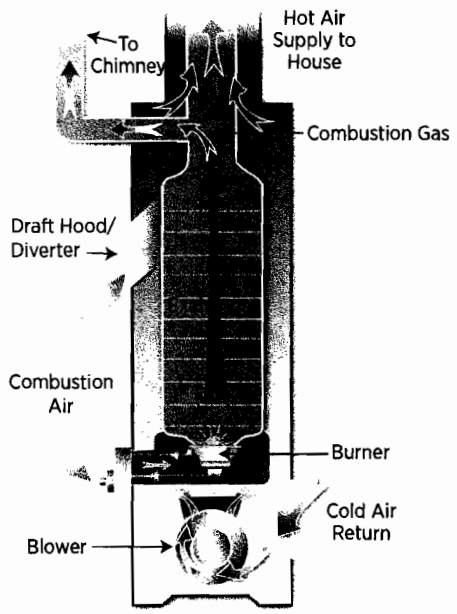
Coefficient of Performance (COP): COP is a measure of efficiency for heat pumps in the heating mode that represents the ratio of total heating capacity to electrical energy input. For example, if a heat pump has a COP of 3, it will deliver three units of energy for every one unit of electricity consumed.

Heating Seasonal Performance Factor (HSPF): HSPF is a measure of a heat pump's energy efficiency over one heating season. It represents the total heating output of a heat pump (including supplementary electric heat) during the normal heating season (in Btus) as compared to the total electricity consumed (in watt-hours) during the same period.

Furnace and Boiler Equipment Efficiency

AFUE (annual fuel utilization efficiency) is the amount of fuel converted to space heat in proportion to the amount of fuel entering the boiler or furnace; it is expressed as a percentage. It does not include the electricity consumption of the fan and controls.

In 1987 the federal minimum efficiency standard was set at 78% AFUE for gas and oil furnaces, 75% for steam boilers, and 80% for hot water boilers, effective 1992, per the National Appliance Energy Conservation Act of 1987 (NAECA). In 2007 new efficiency minimums were set at 80% AFUE for gas furnaces, 82% for oil furnaces, 82% for gas-fired hot-water boilers, and 83% for oil-fired hot-water boilers, effective 2015 (LBNL 2011). The furnace efficiency standard is scheduled to be revised in 2011, with new requirements becoming effective in 2016.



Conventional Gas Furnace

Older low-efficiency (<72%) gas furnaces relied on natural draft to bring in combustion air and exhaust pollutants. The burn was less efficient and a lot of heat was lost up the chimney.

2.1 Furnaces

More than 65% of U.S. homes are heated with central forced-air furnaces. Most furnaces heat air by burning gas, oil, or propane. Some use electricity to heat an element. The furnace burner is located in the air handler box along with a fan. The fan blows the heated air into supply ducts, for distribution to registers located throughout the house. Air from individual rooms or common areas is drawn into return registers and brought back through return ducts to the furnace air handler where it is reheated and redistributed.

2.1.1 Furnace Efficiency

The efficiency of a furnace or boiler is measured by annual fuel utilization efficiency (AFUE). AFUE is the ratio of heat output of the furnace or boiler to the total amount of fuel consumed by a furnace or boiler. An AFUE of 90% means that 90% of the energy in the fuel becomes heat for the home and the other 10% escapes out the vent pipe and through the furnace jacket. AFUE doesn't include the power consumption of the fan and controls. Nor does it include heat losses of the duct system, which can be up to 30% or more when ducts are leaky, poorly insulated, and located in an uninsulated attic or crawlspace. If not properly maintained, the actual efficiency of the furnace can be significantly lower than the rated efficiency.

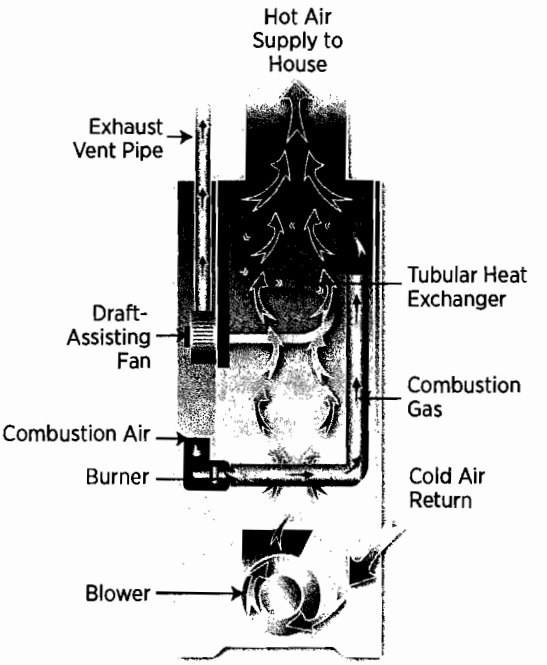
2.1.1.1 Low-Efficiency Furnaces (Less than 78%)

While nearly all furnaces sold today have an AFUE of at least 80%, many older, less efficient furnaces in the 56% to 72% range are still in operation, including even old coal burners that have been switched over to oil or gas. If a furnace has a pilot light, it was probably installed prior to 1992 and likely has an efficiency of less than 72%. Old gas furnaces may lack a vent damper (which saves energy by limiting the flow of heated air up the chimney when the heating system is off).

Older style furnaces can be called draft-hood furnaces because they draw combustion and dilution air from the room in which they are located; the dilution air enters through a draft hood (also called a draft diverter). Oil furnaces use a barometric damper instead of a draft diverter for dilution air in the chimney or vent system to decouple the burner from the chimney, thus avoiding poor combustion.

Older style furnaces also rely on natural draft to carry exhaust gases out of the home. The combustion gases exit the home

through the chimney using only their buoyancy, combined with the stack effect of the chimney's height. Naturally drafting chimneys can have problems exhausting the combustion gases because of chimney blockage, wind, or depressurization of the home, which can overcome the buoyancy of the gases. Depressurization is a situation that can occur if more air is being pulled out of the home than is being drawn into the home through air leaks or intentional ventilation. Certain changes in the home can lead to depressurization, for example, if a new kitchen range is installed with a high-powered exhaust fan or if a significant amount of air sealing is done. These changes could possibly increase the risk of backdrafting, where exhaust products spill back into the house rather than going up the flue. A certified energy contractor will conduct combustion safety testing as part of any combustion appliance repair or replacement or air sealing project. The testing will ensure that the furnace and combustion appliances have adequate combustion air and are venting properly.



Mid-Efficiency Gas Furnace

Mid-efficiency furnaces (80% to 82%) use fan-assisted combustion systems to pull flue gases through the heat exchanger. No dilution air is required for the vent system, which is still buoyancy-driven.

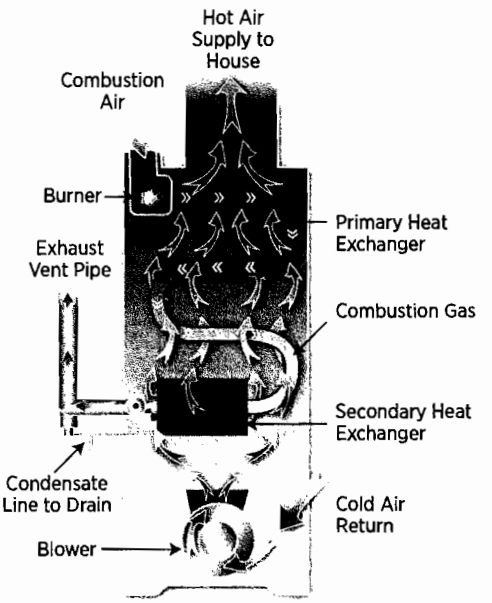
2.1.1.2 Mid-Efficiency Furnaces (80% to 82%)

Mid-efficiency (80% to 82%) furnaces have no draft hood. Instead, they use fan-assisted draft with a fan located at the outlet (draft inducer) of the heat exchanger to create a regulated flow of combustion air. This design change increased efficiency from 65% AFUE in atmospheric draft furnaces to over 80% in fan-assisted furnaces. Fan-assisted draft minimizes the risk of backdrafting.

For furnaces with an oil burner, one way to determine the age and efficiency is to look at the nameplate. If the oil furnace has a nameplate motor speed of 1,725 rpm, it is most likely an older model with a less efficient burner. Models with a nameplate motor speed of 3,450 are newer than 20 years old and have a flame retention burner that wastes less heat; they have a steady-state efficiency of 80% or more.

2.1.1.3 High-Efficiency Furnaces (90% to 98%)

The most efficient furnaces available today are sealed-combustion (direct-vent) condensing furnaces, which have efficiencies of 90% to 98%. About 12% of the heat from the combustion process is captured in water vapor as latent heat. A condensing furnace condenses this water vapor through a secondary heat exchanger to capture the heat rather than letting it escape up the flue. This technological advance enabled gas furnaces to jump from 82% AFUE to 90% AFUE or higher (ACEEE 2011). There are no gas furnaces with AFUE ratings between 83% and 89% because of problems arising from condensation in the heat exchangers that occur within this range.



High-Efficiency Gas Furnace

High-efficiency (90% to 98%) furnaces add a second heat exchanger to pull more heat out of exhaust vapor, then vent emissions directly outside, eliminating the risk of back-drafting flue gases into the home.

Bigger isn't Always Better

Many older furnaces and central air conditioning systems are oversized. An energy performance contractor can run energy analysis software to help you determine your heating and cooling needs after air sealing and insulation improvements are made.

In the past, many HVAC contractors used "rules of thumb" to determine HVAC sizing and, as a result, many installed oversized systems. Today's trained HVAC contractor should determine your heating and cooling loads, and the right size for your HVAC equipment, based on calculations developed by the Air Conditioning Contractors of America (ACCA 2005; 1995; 2009).

The ACCA published its guidelines in Manuals J, S, and D. Manual J outlines the procedures necessary to estimate the heat loss and heat gain of residential structures. Manual S provides guidance for equipment selection based on load calculations. Manual D describes proper duct sizing and design.

It should be noted that, in a cold climate, if the homeowner chooses to install an air-source central heat pump for heating and cooling, the contractor may opt for a larger size heat pump than indicated by Manual S to minimize the need for back up heat. This is a tradeoff—as the heat pump may then be oversized for the cooling load. Also, with the variable-speed motors and variable refrigerant flow compressors now available in some of the newest models of furnaces and heat pumps, oversizing is less of an issue because the equipment can modulate to operate at lower, more energy-efficient speeds when the demand is lower.

High-efficiency condensing furnaces avoid back-drafting issues by having sealed combustion. These furnaces are designed to vent exhaust gases (combustion products) directly to the outside through a dedicated vent pipe. They should also be installed with a second vent pipe to bring outside air directly into the combustion chamber.

Although a condensing unit costs more than a non-condensing unit, the condensing unit will save money in fuel costs over its 15- to 20-year life and is a particularly wise investment in cold climates.

Both mid- and high–efficiency furnaces are available with two-stage gas valves, two-speed draft fans, and variable-speed blower fans, which reduce their electricity usage by better matching air flow rate to the heating needs of the home.

Nearly all combustion furnaces sold today meet or exceed 80% AFUE. About one-third of current sales on a national basis are 90% AFUE or better. In just the past 10 years alone, about 7.5 million condensing furnaces went into replacement installations in the United States (ACEEE 2011).

The AFUE rating for an all-electric resistance furnace or boiler is between 95% and 100%; because there is no combustion, no heat loss occurs up the flue, but there may be some heat loss through the furnace housing. However in some parts of the country, electricity is expensive to purchase and it can be expensive to produce from an environmental standpoint as well, making electric heat a less cost-effective option.

2.1.2 Repair or Replace?

Although older combustion furnaces have efficiencies in the range of 56% to 70%, modern conventional heating systems can achieve efficiencies as high as 98%, converting nearly all the fuel to useful heat for your home. Energy-efficiency upgrades like sealing ducts and air leaks and adding insulation, together with a new high-efficiency heating system, can often cut your fuel bills and your furnace's pollution output in half. Upgrading your furnace or boiler from 60% to 90% efficiency in an average cold-climate house will save 1.5 tons of carbon dioxide emissions each year if you heat with gas, or 2.5 tons of emissions if you heat with oil (ENERGY STAR calculator, www.energystar.gov).

A contractor can help you determine whether your furnace or boiler is too old, worn out, inefficient, or oversized. If it is, the simplest solution is to replace it with a modern high-efficiency model. A newer furnace may be more efficient but is still likely to be oversized.

If you plan to make energy-efficiency improvements to your home at the same time that you replace your furnace, talk to your contractor about how they will affect your furnace system. With a better building envelope, the new furnace or boiler can sometimes be a smaller size than the original, which can save you money. Whenever you make energy efficiency upgrades, your contractor should test to make sure that any new and existing combustion appliances (such as a furnace, water heater, or clothes dryer) still operate safely.

When shopping for high-efficiency furnaces and boilers, look for the ENERGY STAR® label. The Consortium for Energy Efficiency also provides efficiency ratings and HVAC information at www.cee1.org. Invest in the highest efficiency system you can afford, especially if you live in a cold climate. You can estimate the annual savings from heating system replacements by using Table 2.2, which shows how much you'll save for every $100 you spend in fuel when you replace your old furnace with a more efficient furnace. For example, if you currently spend $1,000 per year on cooling costs and you switch from an AFUE 65% furnace to an AFUE 95% furnace, you could save about $320 per year in heating costs. The table assumes that both furnaces have the same heat output. However, most older systems are oversized, and will be particularly oversized if you significantly improve the energy efficiency of your home. Because of this additional benefit, your actual savings in upgrading to a new, smaller system or one with a variable speed motor could be higher than indicated in the table.

Table 2.2. How much you'll save when you increase your heating equipment efficiency:*

Annual Estimated Savings for Every $100 You Spend on Fuel
(Source: www.energysavers.gov)

Existing System AFUE	New/Upgraded System AFUE				
	75%	80%	85%	90%	95%
50%	$33	$38	$41	$44	$47
55%	$27	$31	$35	$39	$42
60%	$20	$25	$29	$33	$38
65%	$13	$19	$24	$28	$32
70%	$7	$13	$18	$22	$26
75%	----	$7	$12	$17	$21
80%	----	----	$6	$11	$16
85%	----	----	----	$6	$11
90%	----	----	----	----	$5

*Assuming the same heat output

A Furnace Tune-Up

Have an HVAC technician tune-up your furnace to improve its efficiency and check for problems that may justify a replacement. (See www.energysavers.gov "Furnaces and Boilers" for more details.)

- Test for flue gas spillage and fix.
- Check the condition of the vent connector and chimney.
- Check heat exchanger for cracks or leaks.
- Adjust temperature controls for efficiency and comfort.
- Adjust blower control and supply-air temperature.
- Clean and oil the blower motor. If this is an old, <75% efficient furnace; most mid- and high-efficiency blower motors are permanently lubricated.
- Remove dirt, soot, and corrosion from the furnace or boiler.
- Check fuel input and flame characteristics, and adjust if necessary.
- Air seal connections between the furnace and main ducts.

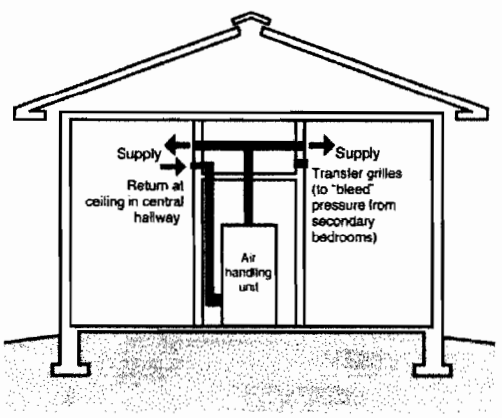
ANSI/ACCA HVAC Standards

The Air Conditioning Contractors of America has produced several American National Standards Institute (ANSI) approved standards on HVAC equipment installation and maintenance including

- ANSI/ACCA Standard #4 Maintenance of Residential HVAC Systems (ACCA 2010a)
- ANSI/ACCA Standard #5 HVAC Quality Installation Specification (ACCA 2010b)
- ANSI/ACCA Standard #6 Restoring the Cleanliness of HVAC Systems (ACCA 2010c)
- ANSI/ACCA Standard #9 Quality Installation Verification (ACCA 2010d).

Your contractor will test the leakiness of the ducts with a duct blaster test (Source: NREL).

Mastic is a thick sealant that is painted on to rigid ducts to seal seams and joints (Source: FSEC).



If you are adding ducts, you will save energy by placing them inside the living space in compact duct runs, such as in a dropped hallway chase (Source: BSC).

If your furnace is less than 15 to 20 years old and you decide to keep it, talk to your contractor about options for improving its efficiency. Repairing the furnace and its distribution system to increase efficiency may be an option. The costs of repairs should be weighed against the cost of a new furnace, taking into consideration the age and condition of the system. If the cost of repairs is more than half the cost of replacement, it is better to replace with a new system than to invest in repairing an old one (Krigger and Dorsi 2009). See the Furnace Tune-Up checklist (in sidebar) for maintenance activities that an HVAC technician can perform to improve your existing system's efficiency.

One way to improve furnace efficiency may be to replace a single-speed blower fan motor with an electrically commutated (ECM) variable-speed fan motor. Your HVAC contractor should take into account the size and condition of your current ducts when considering this option to determine if any energy savings can be gained. (If the ducts are poorly installed or in bad condition, an ECM motor will work harder to push air through, negating any energy savings compared to a standard split-capacitor fan motor.) Other ways to improve HVAC energy efficiency include installing programmable thermostats, and pressure testing, air sealing, and insulating ducts. For more suggestions on improving furnace efficiency, see www.energysavers.gov, "Furnaces and Boilers." See Section 2.1.3 of this guide for more information on ways to save energy with duct design, installation, and air sealing.

2.1.3 Ducts

Heated air from the furnace is distributed throughout your home via ducts located in the attic, basement, crawlspace, in ceiling soffits, or between floors. Supply ducts supply conditioned air from the furnace to the rooms of your house. Return air is air that comes from the rooms back to the furnace for filtering and reconditioning, either through individual ducted returns in each room or through a return register located in a central place like a hallway ceiling. The age and condition of these ducts is a factor in deciding whether to keep or replace a heating system. For example, the cost of replacing a poorly installed, leaky duct system may justify the switch to ductless heat pumps.

As part of a home performance assessment, the energy contractor will inspect your ducts for proper installation and insulation and test them for duct air tightness and air flow at each register. Heating and cooling comfort complaints can often be addressed by fixing blocked registers, stuck dampers, or disconnected or damaged ducts, or by replacing register grilles that don't direct the air adequately.

2.1.3.1 Existing Ducts

If you decide to replace your HVAC equipment but keep the existing ducts, your energy contractor can assess the ducts for proper sizing, balanced pressures, and adequate air flow to each register, and adequate return air to the furnace.

Your contractor will test the leakiness of the ducts with a Duct Blaster test. For some comparison of what is considered leaky, the International Energy Conservation Code (IECC) 2009 requires that duct leakage be tested in new construction if the ducts are located in unconditioned space, like an attic or crawlspace. According to the IECC 2009, total duct leakage in a finished house should not exceed 12 cubic feet per minute (cfm) per 100 ft^2 of conditioned floor area at 25 Pascals of pressure if the ducts are located in unconditioned space. (Duct leakage must be less than or equal to 6 cfm/100 ft^2 CFA at 25 Pa if the ducts are tested at rough in, per IECC 2009 403.2.2.) For the IECC 2012, these requirements will go to 4 cfm total leakage/100 ft^2 CFA at 25 Pa, whether tested at rough in or finished construction.

If the duct system is shown to be leaky, steps can be taken to seal the ducts, joints, and air handler cabinet. Ducts and air handler connections should be sealed with mastic, which is painted on all seams and joints. Flex duct connections should be reinforced with approved metal tape and compression bands (clamps). Cloth-backed duct tape should not be used; DOE studies have shown that it can dry out and fail within months (Sherman et al. 2000). As noted in Chapter 1, testing out should be done by a certified energy contractor after duct sealing to make sure no combustion safety problems are introduced (Cummings et al. 2011).

If your ducts are located in conditioned space (inside the living area of the house, for example in a dropped soffit or between floors), an attempt should still be made to seal the ducts wherever accessible, at least at the registers, boots, and connection to the air handler.

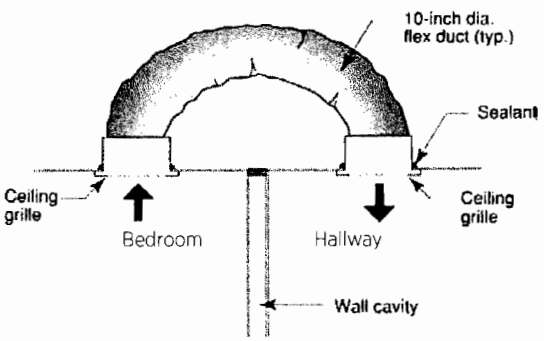
Ducts not located in conditioned space should be insulated to R-8 for supply ducts and R-6 for return ducts (IECC 2009 403.2). Ducts within the house should be insulated if possible to ensure heated and cooled air gets where it is needed—and to reduce the possibility of condensation and mold on or inside the ducts.

One common problem with existing duct systems is lack of adequate return air flow, which can hamper furnace performance. Return air is air that comes from the rooms back to the furnace either through individual ducted returns in each room or through a central return

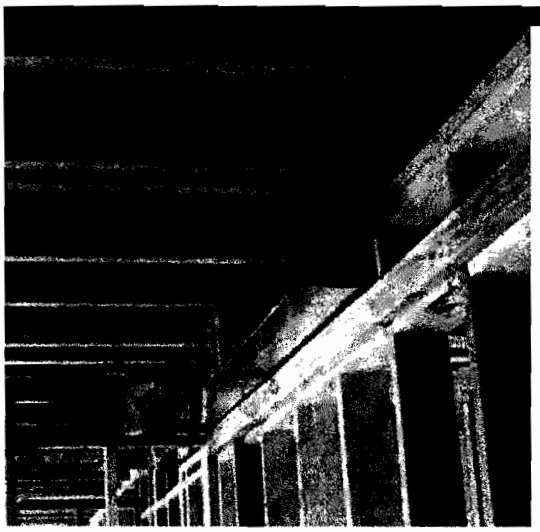
A Word about Chimneys

If you are upgrading to a 90% or higher condensing furnace or boiler, it will have its own dedicated exhaust and may no longer use the chimney. If no other appliances exhaust through the chimney, it can be closed up or removed, reducing chimney maintenance costs and possibly adding living space to the home. If another appliance, such as an atmospheric vented gas water heater, still uses the chimney, the chimney may now be oversized, which could lead to a situation where the chimney provides inadequate draft allowing combustion exhaust gases to spill back into the home. The chimney will need to be relined and sized to the water heater alone, or it may be less expensive, and more safe, to replace the old water heater with a higher efficiency sealed combustion water heater. If you are replacing an old furnace with a mid-efficiency 80% to 82% furnace or boiler (90%+ is recommended), the chimney may need to be relined and sized to handle the lower volume, lower temperature exhaust gases. The cost of relining the chimney may justify upgrading to a 90%+ furnace.

Jump Duct



If duct pressure testing shows that your existing duct system has pressure imbalances or inadequate return air, there are several possible fixes to allow air to flow back to the central return air grille, including installing jump ducts or transfer grilles between closed rooms and common spaces (Source: BSC).



This Building America builder puts ducts inside the home instead of above the insulation where they would be exposed to cold and hot attic conditions.

register located in an open area like a hallway. Central return ducts are often undersized in existing duct systems; installing a large central return duct can improve system performance and reduce noise. There are several options that allow air to return from rooms that are often closed. Individual return air ducts can be installed in these rooms; transfer grilles can be installed in the doors or walls; jump ducts can be installed in the ceilings to connect the rooms to open areas. Some contractors use door undercuts, but these may not provide adequate air flow.

2.1.3.2 New Ducts

If your contractor recommends installing a new duct system in the house, there are several things that can be done to ensure the new duct system is as efficient as possible. It should be sized according to the ACCA Manual D or equivalent.

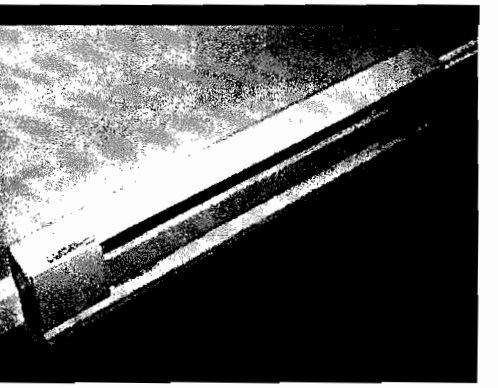
Work with your HVAC contractor to see if it is possible to install the ducts and furnace in conditioned space inside your home. Building America has shown this can be a source of significant energy savings and can also improve indoor air quality because leaking ducts aren't heating, cooling, or drawing air from unintended places and furnace and air-conditioning equipment isn't having to overcome the effects of cold crawlspaces or hot attics. Putting the ducts inside can be accomplished in several ways. The ducts can be installed in a dropped ceiling chase in the main hallway of a one-story house or between floors in a two-story house that uses open-web floor trusses (Beal et al. 2011). Another option is ducts can be installed in an insulated basement or an insulated attic (i.e., where the insulation is installed along the underside of the roof deck instead of on the ceiling deck.) The ducts could also be installed in an insulated, air-sealed crawlspace (i.e., where insulation is on the walls of the crawlspace, not the underside of the floor). The air handler can be located in a utility closet inside the house or in an air-sealed closet in the garage.

Duct design and installation is also important. In homes that are well insulated, the ducts can be laid out in a compact duct design with shorter runs and registers mounted on inside walls for adequate heating with less distribution losses. Your HVAC contractor should select supply registers for adequate throw, drop, and spread of conditioned air.

For adequate air flow, ducts should be laid straight with adequate support and no sharp turns. If flex duct is used, it should be fully stretched and supported at least every 4 feet with strapping at least 1.5 inches wide to prevent sagging. Care should be taken to avoid tearing, compressing, or kinking the flex duct during installations (CEC 2009).

2.2 Electric Heaters

Currently, 14% of U.S. single-family homes use electric resistance heat to heat their homes: almost 11% have an electric central forced-air furnace, and more than 3% use some form of electric space heating. An additional 10% use heat pumps, which will be described in the next section.



Although not cost-effective as your main heating source, in a home with average insulation, baseboard electric heaters are an inexpensive way to provide supplemental room heating.

2.2.1 Electric Central Furnaces

Electric forced-air furnaces distribute heat with an air handler and ducts, just like gas furnaces (see Section 2.1 for more on furnaces and ducts). The AFUE rating for an all-electric furnace is 95% to 100%. This is because electric furnaces provide heat through resistance, not combustion, so there are no heat losses up the chimney. All of the electricity is converted to heat, minus a small amount of heat loss through the air handler cabinet. This AFUE rating does not include any heat losses through leaky or uninsulated ducts. However, although it varies based on local utility rates, electricity is still one of the most expensive heating fuels.

If you have an electric furnace and your duct system is good, consider switching to a high-performance air-source heat pump. Electricity savings can be 30% or more when compared with electric resistance heating.

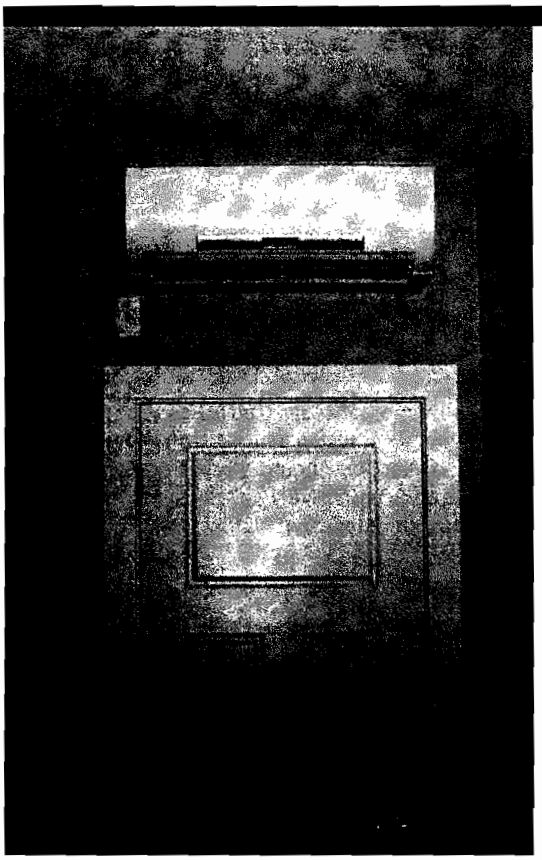
2.2.2 Room Heaters

Room heating here refers to heating systems that heat one room or area of a home, unlike central systems, which distribute heat throughout the entire house via ducts or piping. Electricity is the most common fuel type for room heaters, but there are other fuel types as well.

Unvented combustion space heaters, which can release dangerous combustion gases into the home, are illegal in some states and should not be used. The use of portable space heaters is also not recommended because of their inefficiency and potential burn and tripping hazards.

In an average- or large-sized home with minimal or average insulation, electric resistance room heaters (baseboard or wall-mounted) are not typically a cost-effective method for heating the whole house over the long term. In a very well-insulated and air sealed home that requires little heating, they can be a cost-effective choice. They can also be a cost-effective choice for heating infrequently used rooms when the main living areas are heated with ductless heat pumps or radiant floor heat.

Building America's Consortium for Advanced Residential Buildings (CARB) worked with Rural Development, Inc. to design a community of townhouses in western Massachusetts that were so well insulated that a two-stage sealed-combustion gas space heater met the design load. The heaters had a capacity of 10,200 Btu/hr on low fire and 16,000 Btu/hr on high fire with an AFUE of 83% (Source: Rural Development, Inc.).



Ductless heat pumps can provide efficient zoned heating and cooling.

2.2.3 Zoning

Many homeowners who have forced-air systems will shut vents and close a door in a room they aren't using, thinking that this saves energy. This is not recommended because it can reduce airflow through the air handler, causing pressure imbalances, putting stress on the duct connections, and affecting air quality if you are using your air handler for ventilation. Zoning can be accomplished with central forced-air systems, using damper controls installed in the ducts by an HVAC professional, but the dampers will affect system efficiency and balance. In large homes, zoning of central heating and forced-air systems is more commonly (and more effectively) accomplished by installing multiple systems, with one unit per floor.

Hydronic heating systems can be configured, with piping and valves, to provide zone heating. Zone control works best in homes where the different zones can be isolated from each other with closable doors. Never shut off the heat entirely in an unused part of your home because condensation could form on cold inside wall surfaces leading to mold. Keep all rooms at a minimum of 50°F in the winter to prevent water pipes from freezing.

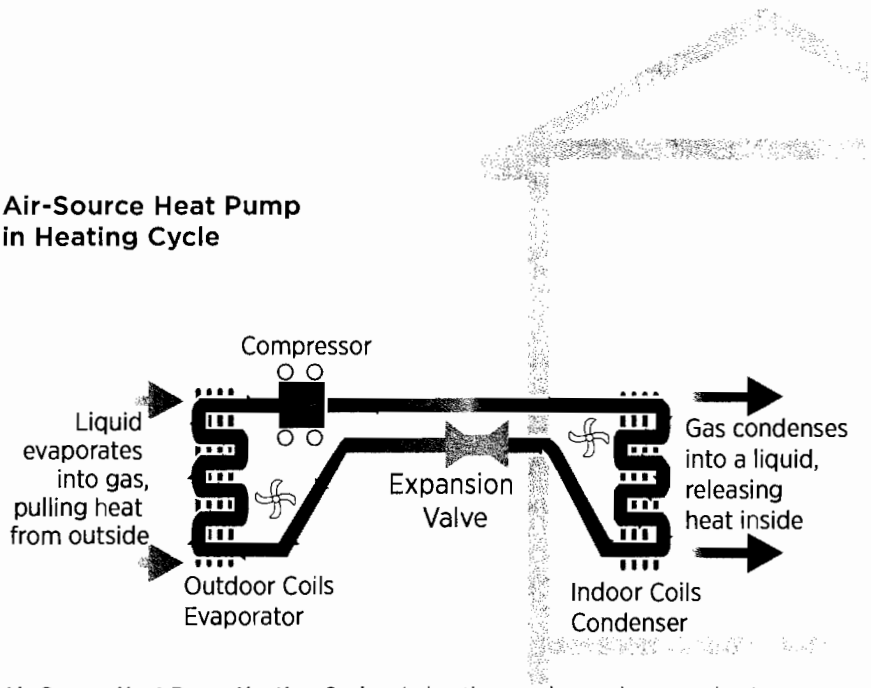
Room heaters can be used as an inexpensive way to provide zone heating when a central forced-air system is the main heating system for the home. Other forms of room heating that might be considered for supplemental heating or for additions include ductless heat pumps (described in Section 2.3.2), electric radiant wall and ceiling panels, active solar space heating (described in Section 2.6), sealed-combustion gas room heaters, and high-efficiency wood or pellet stoves (see Section 2.5).

2.3 Heat Pumps

A heat pump uses the same refrigeration cycle technology as your home's refrigerator or air conditioner pooling heat from one environment and dumping it in another. Because a heat pump is equipped with a reversing valve, it can both heat and cool your home. During the heating season, heat pumps move heat from the outdoor air to warm your house; during the cooling season, the cycle is reversed.

About 85% of the installed residential heat pumps are air-source heat pumps, which transfer heat between the house and the outside air. These can be either large central units that distribute heat and cooling through ducts (see Section 2.3.1) or smaller ductless units that are installed in one or more areas of the home for zoned heating and cooling (see Section 2.3.2). Ground-source and water-source heat pumps are other options (described in Section 2.3.3). More information on these and other types of heat pumps, including absorption or gas-fired heat pumps and reverse-cycle chiller heat pumps, can be found at www.energysavers.gov.

Air-Source Heat Pump in Heating Cycle

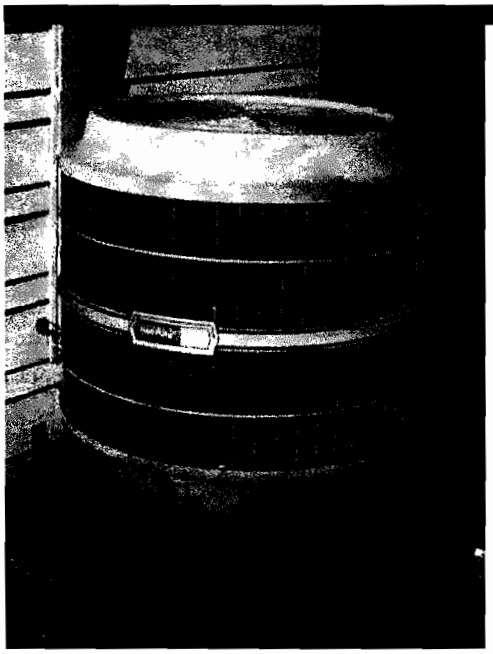


Air-Source Heat Pump Heating Cycle – In heating mode, an air-source heat pump evaporates a refrigerant in the outdoor coil. As the liquid evaporates, it pulls heat from the outside air. The hot gas is compressed and pressurized as it passes through the compressor to the indoor coil (or condenser). Here it condenses to a high-pressure liquid, releasing heat to the inside of the house as it cools. The liquid then passes outside and through a pressure-lowering expansion valve and enters another heat exchanger, the evaporator, where the fluid absorbs heat and boils. The pressure changes caused by the compressor and the expansion valve allow the gas to evaporate at a low temperature outside and condense at a higher temperature indoors. In cooling mode, the reverse happens.

Heat Pump Heating Efficiency

Heating Season Performance Factor (HSPF) is a measure of a heat pump's energy efficiency over one heating season. It represents the total heating output of a heat pump (including supplementary electric heat) during the normal heating season (in Btus) as compared to the total electricity consumed (in watt-hours) during the same period. Heat pumps and furnaces must have an HSPF of 7.7 or higher (per federal requirements that went into effect in 2006).

Ground-source heat pump efficiency is also measured by Coefficient of Performance (COP). The COP is a measure of efficiency in the heating mode that represents the ratio of total heating capacity to electrical energy input. For example, if a heating system has a COP of 3, it will deliver three units of energy for every one unit of electricity consumed. Heating COPs for heat pumps range from 1.5 to 4 depending on climate, design, and installation.



Old air-source heat pumps should be serviced as recommended below. New heat pumps may be significantly more efficient and can operate at wider temperature ranges.

A Central Air-Source Heat Pump Checklist

Here is a checklist of maintenance activities that you or your HVAC contractor can do to maintain your heat pump's efficiency and performance. (See www.energysavers.gov "Air-Source Heat Pumps" for more details.)

- Inspect and clean filters monthly or per manufacturers' instructions.
- Vacuum or brush coils.
- Clean the fan; oil the fan motor only if the manufacturer instructions specify this, newer models are sealed.
- Check the fan for incorrect pulley settings, loose fan belts, or incorrect motor speeds.
- Inspect ductwork; make sure air flow is not restricted by loose insulation, abnormal buildup of dust, or any other obstacles that occasionally find their way through the grills.
- Be sure that vents and registers are not blocked by furniture, carpets, or other items that can stop airflow.
- Confirm that the drain pan is draining correctly.

2.3.1 Central Air-Source Heat Pumps

Most heat pumps installed in U.S. homes are central air-source heat pumps that distribute heated and cooled air through ducts, just like a central forced-air furnace. Most of these air-source heat pumps are split systems meaning that the air handler (which houses the blower fan) is indoors and the compressor is outdoors. The air handler contains the blower and the inside coil for the heat pump.

Current federal law requires that air-source heat pumps have a minimum heating efficiency, or Heating Season Performance Factor (HSPF), of 7.7 and a minimum cooling efficiency of Seasonal Energy Efficiency Ratio (SEER) of 13. Higher efficiency central air-source heat pump models are available with up to 9.6 HSPF and SEER 23.

Because the heating efficiency of standard, central air-source heat pumps drops when outside temperatures drop below about 35°F, a backup heat source is often needed, especially in cold climates. Air-source heat pumps can be all-electric or dual-fuel systems. All-electric air-source heat pumps come equipped with electric-resistance strip heaters for supplementary heat if needed. Dual-fuel systems combine the air-source heat pump with another source of supplementary heat, such as a gas furnace. Another type of central air-source heat pump developed in Canada for cold climates is the bivalent heat pump; it uses a gas- or propane-fired burner to increase the temperature of the air entering the outdoor coil, allowing the unit to operate at lower outdoor temperatures with less frost buildup on the outside coil (NRCan 2009).

If you heat with electricity, a heat pump can trim the amount of electricity used for heating by as much as 30% to 40% compared to electric resistance heat. The efficiency of today's air-source heat pumps is one to two times greater than those available 30 years ago due to technical advances such as thermostatic expansion valves, variable-speed blowers, improved coil design, two-speed compressors (instead of single-speed compressors), and improved motor designs (www.energysavers.gov). Variable-speed compressor designs that better match refrigerant flow to load are in development and will make heat pumps more effective at lower outside temperatures. Variable-refrigerant-flow, ductless "mini-split" heat pumps are already available that can heat at 100% capacity at outdoor temperatures as low as 5°F.

If you plan to install a heat pump, ask your HVAC installer to confirm that the existing ducts are appropriately sized for the heat pump. Ducts may need to be larger for a heat pump than for a gas

or oil furnace because furnaces generally deliver air to the living space at between 130°F and 140°F. Heat pumps provide air at about 80°F to 115°F so more air needs to be delivered to provide the same amount of warmth (NRCan 2009). Your HVAC contractor should confirm that the supply air registers achieve a "throw" appropriate for a heat pump. Choosing the right register design can be important for minimizing comfort complaints because heat pumps blow more air at cooler temperatures than gas- or oil-fired furnaces.

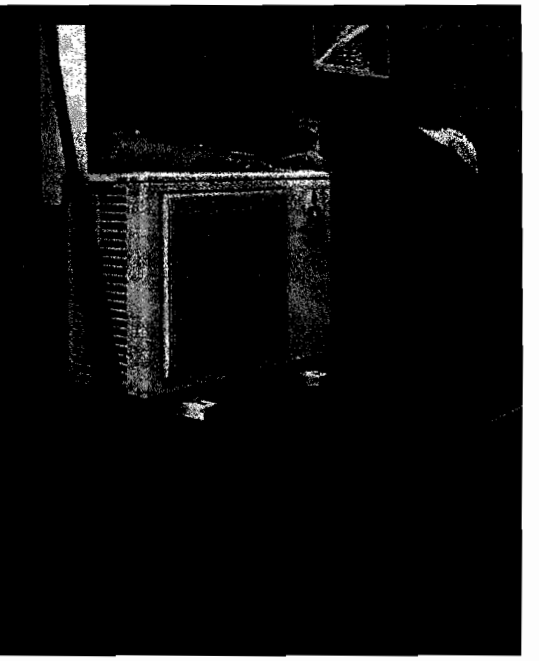
Some researchers suggest central-air-source heat pumps may need to be slightly oversized, to enable the system to provide enough warmth without turning on the backup heat.

2.3.2 Ductless Heat Pumps

High-performance ductless heat pumps are an efficient alternative to central ducted heat pump systems. Ductless heat pumps are sometimes referred to as mini-split heat pumps because they consist of a single outside compressor/condenser unit connected to one or more wall- or ceiling-mounted indoor air handler units. They can provide zone heating and cooling without ducts. The outdoor units are mounted on the wall or on a concrete or stone pad outside the house; refrigerant tubing connects the inside and outside units through a small hole in the wall.

Ductless heat pumps have been used in Asia and Europe since the 1970s and they comprise 80% to 90% of the residential HVAC market there. They have been used in U.S. commercial buildings since the 1980s, but they still comprise less than 3% of the U.S. residential market (Karr 2011). They are 25% to 50% more efficient than electric baseboard or wall heaters (NEEA 2009). Ductless heat pumps provide increased energy savings over standard heat pumps in several ways. Because they are ductless and mounted inside conditioned space, they avoid the distribution losses of a central furnace that has leaky ducts installed in an unheated attic or crawlspace. Ductless heat pumps provide zoned heating because units can be turned off or not installed in rooms that aren't being used. They use a much smaller blower than central units; however, more than one inside unit is typically needed to serve the whole house. Up to eight inside units can be connected to one outside unit.

Advances in technology in recent years have increased performance to the point that units are now available with heating efficiencies as high as 12 HSPF and cooling efficiencies as high as SEER 26. The most efficient ductless heat pumps use a variable-speed compressor that can vary the refrigerant flow. They also have linear expansion



Ductless heat pumps are sometimes referred to as mini-splits because they have a single outdoor unit and one or more small, wall-mounted indoor air handler units. The outdoor unit can be located on a concrete pad or mounted on an exterior wall (Source: Northwest Energy Works).

Ductless Demo Hits 10,000

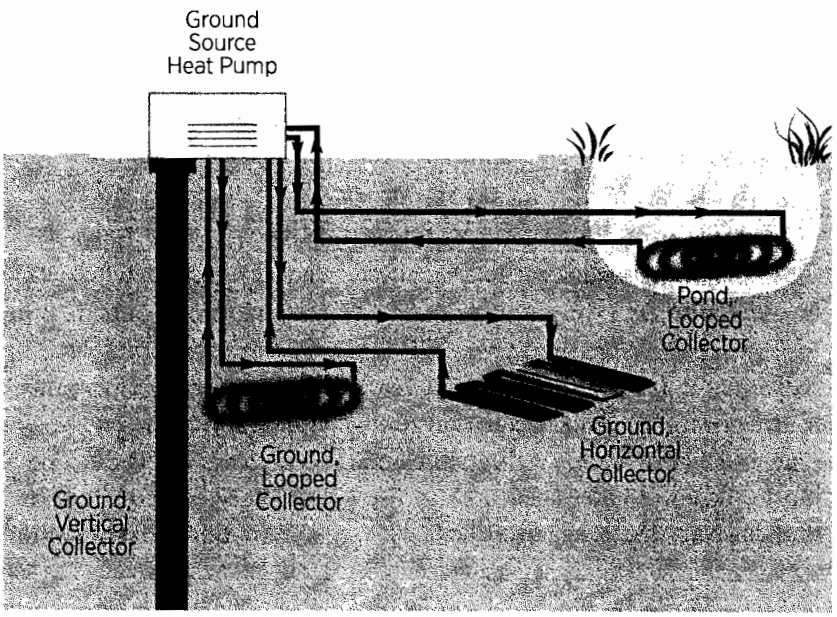
The Northwest Ductless Heat Pump Project is a large-scale ductless heat pump demonstration project conducted by the Bonneville Power Administration and the Northwest Energy Efficiency Alliance that has installed more than 10,000 ductless heat pumps since 2009. See their site (www.nwductless.com) for more information on ductless heat pumps, including installation tips, product recommendations, and performance details.

valves rather than open/close valves, and multi-speed rather than single-speed fans to continuously match the heating or cooling load. Unlike conventional air-conditioning and heating systems that stop and start repetitively, the inverter technology adjusts the motor speed, allowing the system to adapt more smoothly to shifts in demand with less temperature variation and much lower energy use. When maximum capacity is not needed, compressor revolution and power decreases, increasing energy efficiency. For example, one model reports a capacity range of 3,100-24,000 Btus in heating mode and 3,800-14,500 Btus in cooling mode.

The best performing ductless heat pump models perform at a much wider temperature range than standard heat pumps. Some models can operate at an outdoor temperature range of -5°F to 75°F for heating and 14°F to 115°F for cooling, eliminating the need for backup heat sources in most locations.

2.3.3 Ground-Source Heat Pumps

A ground-source heat pump is an electric heat pump that exchanges heat with the ground or ground water, instead of air. The temperature of the earth below the surface remains fairly constant at a U.S. average of 55°F throughout the year (cooler in the north, warmer in the south) with less than 20 degrees variation over the year at 5 feet below the surface.



Collector Configuration Options for Closed-Loop Ground-Source Heat Pumps

Unlike air-source heat pumps, which draw heat from the air, ground-source heat pumps use the moderate temperature below ground to achieve high efficiencies of 300%+ year round. In a closed-loop system, piping loops can be laid horizontally, vertically, or looped in the ground or in ponds. These collector options are shown in heating mode with fluid circulating to collect heat (red) from the ground, release it to the indoor heat pump through a heat exchanger, and return cooled fluid (blue) to collect more heat.

Because heat is exchanged with the ground rather than the outside air, which has more erratic temperatures, ground-source heat pumps remain a very efficient source of heating and cooling all year. Additional efficiency is gained by using water rather than air as the heat-exchange fluid (Karr 2011). (The ground-source systems we are describing here do not include the geothermal systems that use high below-ground temperatures associated with volcanic activity for heat and power production.)

Ground-source heat pumps may be closed-loop or open-loop systems. A "closed-loop" ground-source heat pump circulates water (or a mixture of water and anti-freeze) from the heat pumps to horizontal or vertical pipes that are buried in the ground in contact with the earth, which serves as a heat source in winter and heat sink in summer. After exchanging heat with the ground, the water is circulated back to the heat pumps in a closed loop. Closed-loop configurations include piping laid in horizontal rows or loops in trenches 5 to 10 feet deep, or vertical loops inserted in boreholes that are 75 to 500 feet deep and filled in with bentonite or other grout materials to aid heat transfer to the soil. Closed loops can also be laid in a private pond to exchange heat with the pond water. Another much less common type of closed-loop system is the direct exchange heat pump, which circulates refrigerant rather than water or antifreeze directly through the ground in a single closed loop of copper tubing. This system uses more refrigerant and copper tubing, which are expensive but are more efficient at heat transfer so less tubing length and thus less digging is required.

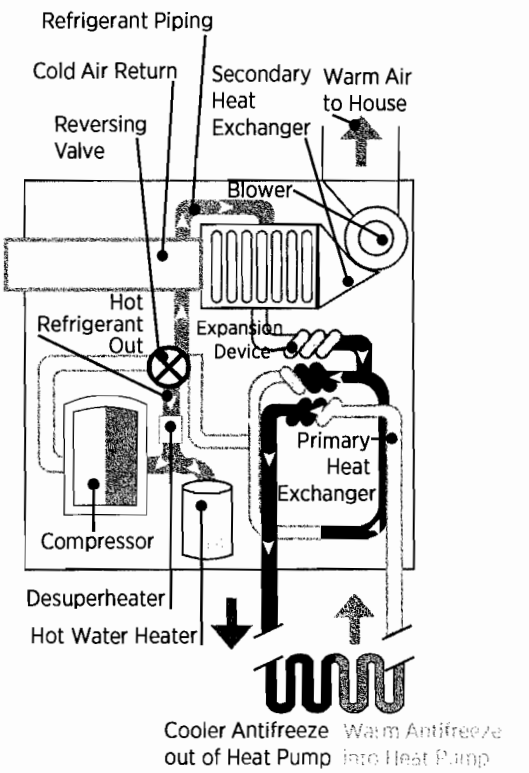
An "open-loop" ground-source heat pump uses groundwater from a well as the heat source and heat sink. The water circulates through the heat pump(s) once and is returned to the ground through a separate injection well or through surface discharge (EIA 2010).

In heating mode, the heat is transferred from the ground loop to the refrigerant loop in the heat pump, then distributed to the home via a second heat exchanger, by warming either air, which is blown over the heat exchanger and through ducts just like a central furnace, or fluid, which flows through tubing installed in the floors to provide radiant heat to the rooms.

Because the compressor for the ground-source heat pump is located inside the home, it is subject to much less wear and tear than the outdoor compressor fans of air-source heat pumps, and as a result, ground-source heat pump equipment lasts longer and maintains its efficiency better than air-source heat pumps. Two-speed compressors that more effectively match demand and scroll compressors with fewer moving parts have dramatically increased efficiency since the 1990s.

Ground-Source Heat Pump in Heating Mode

In heating mode, the heat is transferred from the ground loop to the refrigerant loop in the heat pump and then distributed to the home via a second heat exchanger, by warming air, which is blown over the heat exchanger and through ducts just like a central furnace. The heat can also be distributed via heated fluid, which flows through tubing installed in the floors to provide radiant heat to the rooms. In cooling mode, a desuperheater can use some of the heat pulled from the home's interior to heat domestic hot water.



Most ground-source heat pumps are equipped with a desuperheater, which is an auxiliary heat-recovery system that can be connected to the home's water heater tank to provide up to 25% to 50% of the home's domestic hot water (Smith and Arco 1996). Because they use extra heat from the cooling process they are more effective in hot climates where the heat pump is in cooling mode most of the time.

Ground-source heat pumps can have high installation costs because they require drilling or trenching (CEC 2011). If there is a pond on the property, the loops can be laid on the pond bed, a less costly installation than digging trenches, as long as the tubing is covered by 8 feet of water year-round.

Ground-source heat pumps have risen in popularity in the United States from 35,600 units shipped in 2000 to 115,400 ground-source heat pumps shipped in 2009. The ground-source closed-loop units shipped in 2009 had an averaged rated heating efficiency of 4.1 Energy Efficiency Ratio (EER) Btus/hr/W and an average rated cooling efficiency of 20.4 EER Btus/hr/W (EIA 2010).

Ground-source heat pump efficiencies of 300% to 600% have been reported, compared to 175% to 250% for central ducted air-source heat pumps (www.energysavers.gov). Pump power consumption is not usually included in the rated efficiency of the system and should be taken into account when considering a ground-source heat pump installation (Sherwin et al. 2010). Good thermal connectivity between the loop and ground is essential for high efficiency and soil irregularities can affect performance. System life is estimated at 25 years for the inside components and 50+ years for the ground loop (www.energysavers.gov).

While ground-source heat pumps can save more energy than central ducted air-source-heat pump systems, studies are still being done to determine whether their additional costs justify their installation over variable refrigerant flow ductless heat pumps. One option that has been proposed for increasing ground-source heat pump efficiency is combining the ground-source heat pump with the variable refrigerant flow technology of ductless heat pumps. In a modeling study of multifamily housing (using energy savings data that were confirmed by field studies), ground-source heat pumps combined with variable refrigerant flow technology cut energy use by 36% compared to an air-source central heat pump system, while ductless heat pumps cut energy use by 32% and a regular ground-source heat pump alone cut energy use by 28% (Karr 2011).

2.4 Boilers and Hydronic Heating

Hydronic heating systems use steam or hot water that is heated by a boiler and distributed via pipes to radiators or baseboard convectors, or to tubes for radiant floor heating. The hot water can also be used to heat air via a coil and blower. The boiler may burn oil, gas, propane, or wood or use electricity to heat the water. The water may be preheated using a solar thermal system or ground-source heat pump. Steam is distributed via pipes to steam radiators. Hot water can be distributed via baseboard radiators, wall radiators, or radiant floor systems; or, the hot water can be used to heat air via a coil and blower. Steam boilers operate at a higher temperature than hot water boilers and are inherently less efficient, but high-efficiency versions of both types of boilers (up to 95%) are currently available.

The minimum federal rating for a fossil-fueled boiler is 80%. For more on boiler efficiency and considerations on replacing your existing boiler, see Section 2.1 above. Also see "Furnaces and Boilers" at www.energysavers.gov.

Hydronic heating systems can provide energy and cost savings by being zoned to only provide heating to areas of the house that are in use. Zoning can be done by installing separate circulating lines, using zone valves controlled by separate thermostats, or using a central electronic controller and emitters with controls on them.

2.4.1 Steam and Hot Water Radiators

Steam heating is one of the oldest heating technologies. Steam moves itself through piping without the use of pumps. Older, high-mass boilers are less efficient and there is also a significant lag time from when the boiler turns on to when the heat arrives in the radiators.

Hot-water systems pipe the hot water to the different rooms of the house where heat is distributed through baseboard convectors or upright wall radiators (similar in design to steam radiators) or through radiant floor heating loops.

Building America partner Building Science Corporation worked with Shaw Construction to design a hydronic heating system that uses baseboard radiators that deliver water heated by roof-mounted solar water heating panels. A gas-fired boiler provides back-up heat for these townhouses in Aspen, Colorado.

A Boiler Tune-Up

Proper maintenance and inspection by an HVAC technician can improve system performance for greater efficiency and may identify problems that justify replacing the boiler. (See energysavers.gov, "Furnaces and Boilers," for more details.)

For Both Hot Water and Steam Systems:

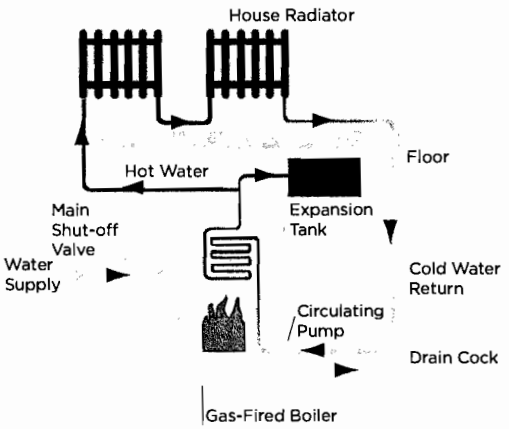
- Test for carbon monoxide spillage and remedy if found.
- Check the condition of the vent connection pipe and chimney.
- Check the heat exchanger for cracks or leaks.
- Adjust temperature controls for efficiency and comfort.

For Hot Water Systems:

- At the start of each heating season, bleed air from each radiator.
- Test pressure-relief valve.
- Test high-limit control.
- Confirm that pressure tank is filled with air, not water.
- Clean the heat exchanger.

For Steam Systems:

- Drain some water from the boiler to remove sediments.
- Test low-water cutoff safety control and high-limit safety control.
- Drain the float chamber to remove sediments.
- Analyze boiler water and add chemicals as needed to control deposits and corrosion.
- Check and replace clogged air vents.
- Check that radiator is level and drains fully when cool.
- Check and replace sticking steam traps.
- Clean the heat exchanger.
- Install reflectors behind wall radiators.



Typical elements of a hydronic water heating system include a gas- or oil-fired burner, a circulating pump, and a distribution system, and either wall radiators, baseboard radiators, or radiant floor loops.

2.4.2 Radiant Floor Heating

Hydronic radiant floor systems pump heated water through tubing, which is laid in a pattern underneath the floor. The cost of installing a hydronic radiant floor system varies by location and also depends on the size of the home, the type of installation, the floor covering, and the cost of labor. Because radiant floor heating requires lower temperature water than radiator heating, the water for hydronic floor heating can be heated or preheated with a solar thermal heating system or a ground-source heat pump.

When the heat source is a ground-source heat pump, the cycling can be reversed in the summer to provide cooling. Radiant floor cooling works best in dry climates; it is not recommended in humid climates because of the potential for condensation to form on the floor surface.

The tubing can be installed in traditional concrete slabs, a thin layer of concrete, or pre-grooved wood panels. The slab under the radiant tubing must be insulated. Some flooring types such as thick carpet can diminish the heat transfer ability of radiant flooring.

Radiant heat wall and ceiling panels that distribute hot water through tubing installed in wall- or ceiling-mounted panels are also available.

2.4.3 Repair or Replace

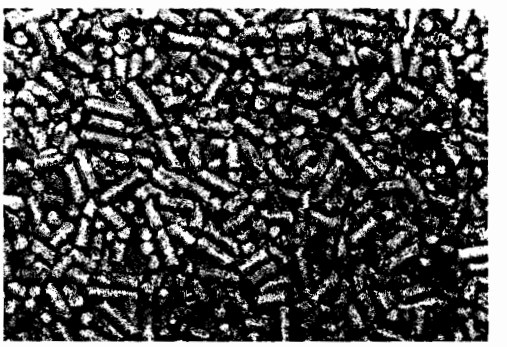
If you have an existing hydronic system that you are not ready to replace, talk to your contractor about what can be done to improve its efficiency. Hydronic systems can have problems with corrosion that clogs components. Some annual maintenance is required by homeowners and HVAC technicians. See the sidebar on this page for tune-up recommendations.

2.5 Wood and Pellet Heating

New wood stoves reach efficiencies of 80%. Masonry heaters and pellet stoves are other higher efficiency options.

About 2.9 million households use wood as their primary heating source, and 8.9 million homes use it as a secondary heating source (EIA 2005). Newer wood- and pellet-burning appliances include models that are cleaner burning, more efficient, and powerful enough to heat many average-sized, modern homes.

Traditional open masonry fireplaces should not be considered heating devices. Traditional fireplaces draw in as much as 300 cubic feet per minute of heated room air for combustion, and then send it straight up the chimney. Fireplaces also produce significant air pollution. When burning a fire in a traditional fireplace, you should turn your heat down or off and open a window near the fireplace. Close the flue when the fireplace is not in use. Consider installing an inflatable flue stopper in rarely used fireplaces or during summer months to stop air leaks.



These pellets, for burning and pellet stoves, are made from recycled products.

Pellet stoves, which burn small pellets made from compacted sawdust, wood chips, bark, recycled paper, or agricultural crop waste, are among the cleanest wood-burning options. They have combustion efficiencies of 78%–85%, heating capacities of 8,000 to 90,000 Btu per hour. They can be direct-vented to the outside and do not need a chimney. They require electricity to run the fans, controls, and pellet feeders.

Masonry heaters, also known as "Russian," "Siberian," and "Finnish" fireplaces, produce more heat and less pollution than any other wood- or pellet-burning appliance. They commonly reach a combustion efficiency of 90%. Masonry heaters include a firebox, a large masonry mass (such as bricks), and long twisting smoke channels that run through the masonry mass. A small hot fire built once or twice a day releases heated gases into the long masonry heat tunnels. The masonry absorbs the heat and then slowly releases it into the house over a period of 12–20 hours.

New high-efficiency wood stoves with catalytic combustors have advertised efficiencies of 70%–80%.

Modern fireplaces (which have vents under the firebox for drawing in room air, a heat exchanger, vents at the top of the fireplace for routing heated air, and a dedicated supply of outside air for combustion) provide benefits at efficiencies near those of woodstoves.

Before investing in a new wood-burning appliance, check with your local building codes department or state environmental agency about wood-burning restrictions.

If you have an older wood-burning appliance, consider upgrading to one of the newer >75% efficient appliances certified by the U.S. Environmental Protection Agency (EPA). More information on wood-burning appliances and tax credits can be found on the EPA website, www.epa.gov/burnwise/appliances.html#woodstoves.

2.6 Solar Heating

Solar energy is a hot topic in buildings today. When you mention solar, many people think of photovoltaic (PV) panels mounted on the roof to produce electricity. This electricity can certainly be used by homeowners to offset the cost of heating and cooling, especially with electric equipment like heat pumps.

However, solar energy can also be used to directly heat homes, using either passive or active methods. See www.energysavers.gov/your-home/space_heating_cooling for more information about using the sun to heat and cool your home.

Both photovoltaic and solar thermal water heating panels are mounted on the roof of this duplex in the Wisdom Way Solar Village, an affordable housing project in western Massachusetts built by Rural Development, Inc. with design assistance from the Consortium for Advanced Residential Buildings (CARB), a Building America research team (Photo source: Steven Winter Associates).

2.6.1 Passive Solar Heating

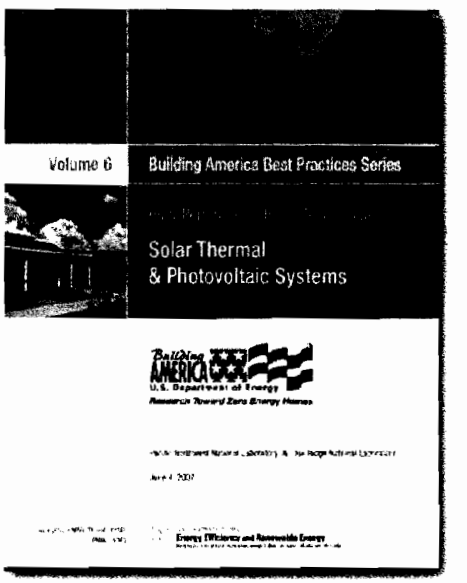
Passive solar heating uses a home's design elements to take advantage of sunlight that reaches into the living spaces of the home. Passive solar design features like thermal mass walls and floors, sun rooms, and south-facing building orientation are most easily incorporated when designing a new home. However, existing buildings can be adapted or "retrofitted" to passively collect and use solar heat. The energy savings from passive solar heating are very dependent on climate. It may not be cost-effective to add passive heating features in a cold climate location with few sunny winter days. In hot climates the extra cooling load may offset any winter heat gains. Regardless of the climate, when considering passive solar heating options, know that you'll have to take steps to minimize unwanted heat gain during the summer. This might include planting shade trees, adding awnings, or increasing roof overhangs.

THERMAL MASS WALLS OR FLOORS – A thermal mass wall or thermal mass floors can be incorporated into a remodeling project. A thermal mass floor or wall is made of a material that will absorb and retain a large amount of heat, for example, a brick wall or concrete slab floor. The thermal mass is located where it will absorb sun through a large window for several hours of the day, then, because heat moves from hot to cold, the mass will release that heat gradually during the evening hours. In the morning, when the wall or floor has cooled, it will be ready to absorb more heat.

SUN ROOM – A sun room or sun porch can be added that has large south, and possibly east- and west-facing windows. The sun room should be separated from the rest of the house by an insulated wall with openable doors and shaded windows so that heat can be let in during the winter and kept out to avoid overheating the house during the summer.

SOUTH-FACING WINDOWS – If you are already planning to add or replace windows as part of a remodel and if you live in a cold or mixed climate that gets adequate sun during the winter, you may want to consider adding larger, south-facing windows that can let in winter sun but are protected by overhangs, awnings, plants, or shades to keep out summer sun. The windows should be high-performance ENERGY STAR-rated windows to minimize heat loss.

If you live in a cold climate and are replacing windows as part of a remodel, consider that windows placed on the south side can provide beneficial solar heat gain in the winter, provided they are shaded from excessive heat gain in the summer. To be effective they should have a solar heat gain coefficient of >0.6 to maximize winter heat gain, a U-factor of <0.3 to reduce conductive heat transfer, and a high visible transmittance (www.energysavers.gov "Passive Solar Window Design").

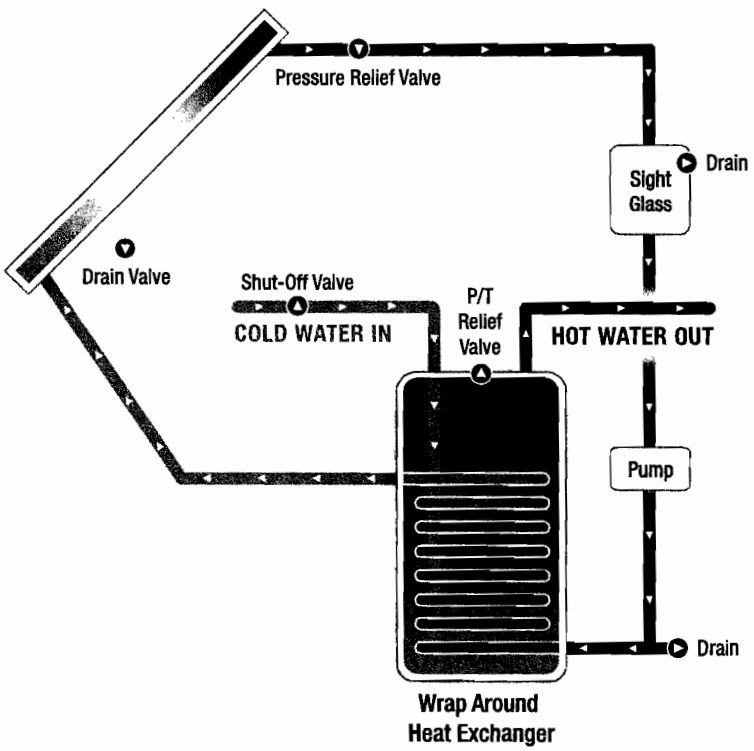


Building America has produced a solar guide that can help homeowners and contractors understand their options in solar water heating and photovoltaics. The guide "Building America Best Practices Series, Volume 6: High-Performance Home Technologies: Solar Thermal & Photovoltaic Systems" (DOE 2007) is available at www.buildingamerica.gov.

2.6.2 Active Solar Heating

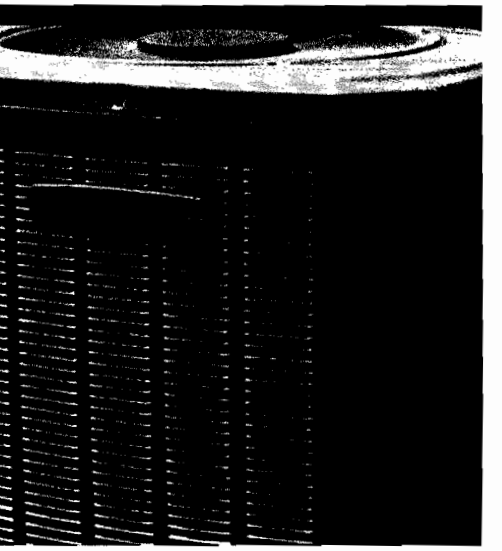
Active solar heating uses solar collectors that heat water or air. The most common are solar thermal water heaters. These are typically used for heating domestic hot water. If you are planning to install a solar thermal water heater and have or are considering installing a hydronic heating system, you can check with your installation contractor on the feasibility and cost-effectiveness of connecting the solar water heating system with the hydronic heating system to heat or preheat the water.

Another form of active solar heating equipment is a room air heater which uses an exterior wall- or roof-mounted flat plate collector to heat air that is drawn from the room, passes through the collector, and is redistributed to the room. Combination systems are also becoming available that draw heated air from underneath roof-mounted photovoltaic panels to heat air and/or water via heat exchangers located in the attic. More information on active solar heating is available at www.energysavers.gov/your-home/space_heating_cooling. Costs vary depending on system type, size, and components. Rebates are available: see www.dsireusa.org.



Solar thermal panels on the roof heat a water-antifreeze solution that is piped through a heat exchanger inside a water tank to heat or preheat water that can be used for room heating and household hot water.

3.0 Cooling Systems



Air conditioning and other manufactured cooling systems are used throughout most of the country. This chapter describes typical cooling technologies, including air conditioning, heat pumps, evaporative cooling, radiant floor cooling, and dehumidifiers. However, with home improvements such as air sealing and insulating, in some climates home cooling needs can be met naturally, without the use of air conditioners, so fans, ventilation and passive cooling strategies are also described.

In moderate climates in a well-insulated home, passive cooling strategies like shading, low-solar heat gain windows, and radiant barriers can be combined with ceiling fans, ventilation, and dehumidification to eliminate or limit the need for air conditioning. These techniques should be considered before installing a new air conditioning system. See Section 3.7 for more information about natural cooling strategies, including the use of fans, night cooling, and passive cooling design techniques.

Many types of air conditioning systems are available, including central ducted air conditioners, room air conditioners, and heat pumps (both ducted and ductless). Evaporative coolers and radiant cooling are options in dry climates.

Over the past few decades, cooling systems have become much more efficient. In 2006, the federal government raised the minimum efficiency level for residential cooling equipment from SEER 10 to SEER 13. Heat pumps are more efficient than standard electric air conditioning and new models of ductless heat pumps offer SEER ratings as high as 26 at a wide outdoor temperature range.

In the United States, 61% of households have a central cooling system (EIA 2011). Nearly all new homes are built with central air conditioning. Energy-efficient alternatives are available.

Cooling Efficiency

The cooling efficiency of air conditioners and heat pumps is referred to as the Seasonal Energy Efficiency Ratio (SEER). SEER is a measure of equipment energy efficiency over the cooling season. It represents the total cooling of a central air-conditioner or heat pump (in Btus) during the normal cooling season as compared to the total electric energy input (in watt-hours) consumed during the same period.

Cooling efficiency can also be measured by the Energy Efficiency Ratio (EER). The EER is a measure of the instantaneous energy efficiency of cooling equipment. EER is the steady-state rate of heat energy removal (e.g., cooling capacity) by the equipment in Btu per hour divided by the steady-state rate of energy input to the equipment in watts. This ratio is expressed in Btu per hour per watt (Btu/hr/watt). EER is used for room units, while SEER is used for centralized units.

The current minimum standard for air conditioner and heat pump cooling efficiency is SEER 13; this went into effect January 23, 2006. Prior to that, the minimum efficiency mandated by the federal government was SEER 10 which took effect in 1992. The standard is scheduled to be revised by DOE in 2011, with new requirements becoming effective in 2016.

The following sections describe the advantages and disadvantages of typical mechanical cooling systems and recommendations for maximizing the efficiency of your new system while reducing upfront costs. A contractor can help you determine which system is best for your home.

Your choice will likely be influenced by the age and condition of your current system, the climate zone, cost, other remodeling activities, and energy-efficiency goals. Here are some things to consider.

- If you have a central air conditioning system, existing ductwork might be reused but have the duct system inspected before assuming it is usable. The ducts may have been installed poorly, gotten damaged over time, or be incorrectly sized for a new system. For more information about ducts, see Section 2.1.3.
- If you have a furnace but don't have central air conditioning, it may be possible to incorporate it with your existing ductwork, depending on cooling load and sizing.
- If you do not have ductwork, installing ducts in an existing home may not be worth the cost (unless you are also installing a central furnace). Ductless mini-split heat pumps may be a good alternative.
- If you only plan on cooling sections or additions to your home, ductless heat pumps work well for zone cooling. Alternatively, window unit air conditioners can be used to cool individual rooms. Look for energy-efficient models.
- If you live in a moderate climate, see Section 3.7 for passive cooling strategies.

The decision tree in Figure 3.1 and the cooling systems characteristics listed in Table 3.1 may also help you in your decision-making process. Table 3.1 presents details on the most common of the cooling systems discussed in this chapter, including an indication of cost. It also gives the Federal minimum efficiency rating (if established), the minimum ENERGY STAR efficiency criteria, and a range of efficiency levels for high-performing models you should look for if you are purchasing a new system.

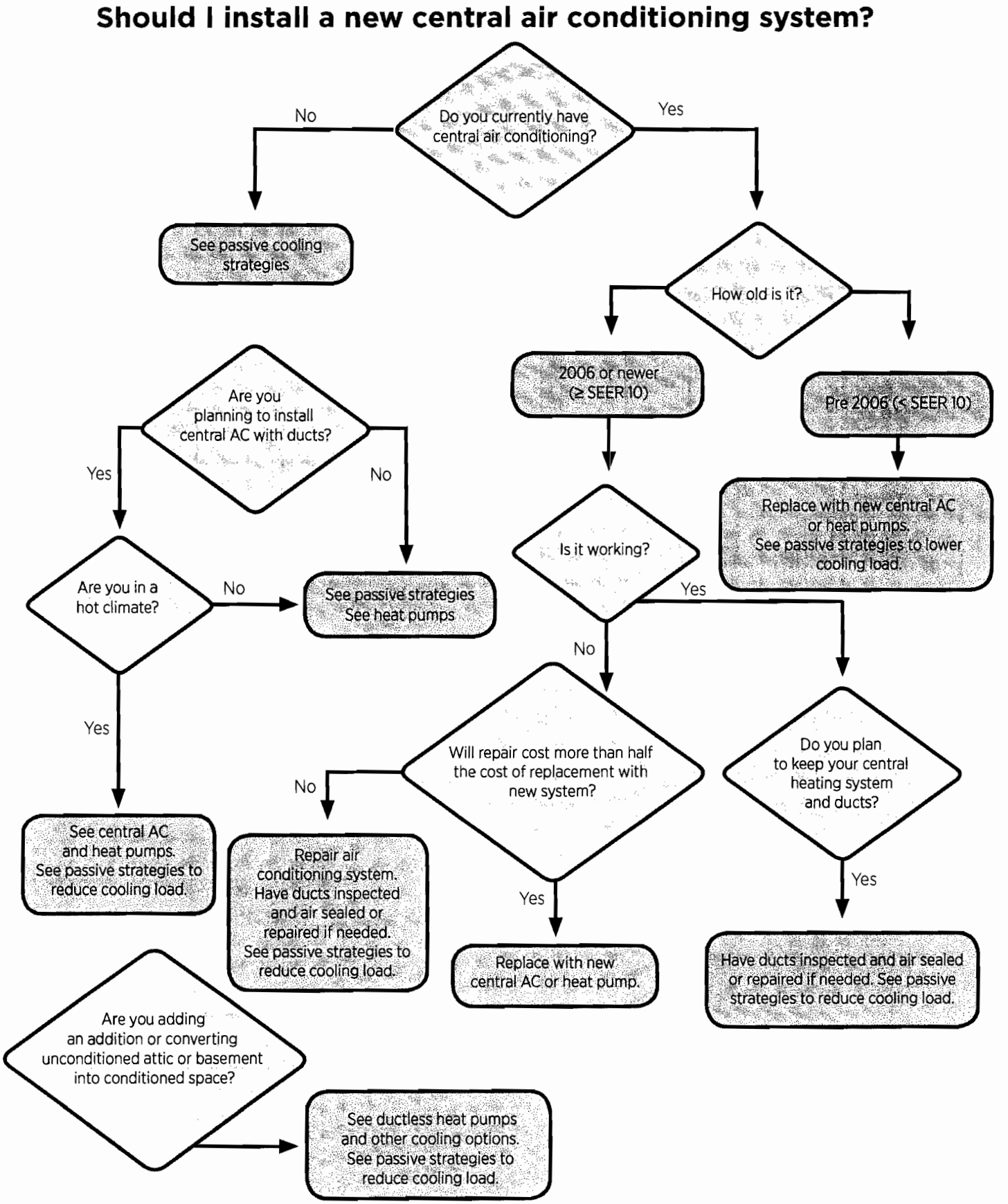


Figure 3.1. Basic Decisions for Replacing Your Cooling System

Table 3.1. Common Cooling Systems Options

	Fuel Type	Cost*	Ducts or No Ducts?	Central or Room Cooling	Operates as Heater in Winter	Federal Minimum Efficiency Req	Efficiency Range for high-performing models	Energy Star Minimum Efficiency	CEE Minimum Efficiency†
Ducted Central AC (Split)*	Electricity	Medium	Ducts	Central	No	SEER 13	SEER 14.5-20, EER 9-15	SEER 14.5, EER 12	Tier 1: 14.5 SEER, 12 EER; Tier 2: 15 SEER, 12.5 EER; Tier 3: 16 SEER, 13 EER
Room Air Conditioning	Electricity	Low	No Ducts	Room	No	EER 9.8	EER 10.7-12	10.7 EER***	9.8-11.8 EER ††
Air-Source Heat Pump	Electricity	Medium-High	Ducts	Central for Air-Source HP	Yes	SEER 13	SEER 14.5-22, EER 9-14	SEER 14.5, EER 12	Tier 1: 14.5 SEER, 12 EER; Tier 2: 14.5 SEER, 12 EER; Tier 3: 15 SEER, 12.5 EER
Ground-Source Heat Pump	Electricity	Very High	Ducts	Central	Yes	--	EER 8.7-23**	EER 14.1	Closed-loop 14.1 EER; Open-loop 16.2 EER; Direct Expans. 15 EER; With Desuperheater
Ductless Heat Pump	Electricity	High	No Ducts	Room for Ductless	Yes	SEER 13	SEER 14.5-26	SEER 14.5, EER 12	Tier 1: 14.5 SEER, 12 EER; Tier 2: 14.5 SEER, 12 EER; Tier 3: 15 SEER, 12.5 EER

*Estimated typical installed costs; does not include adding or repairing ducts. Low: $1,500 or less; Medium: $1,500-$4,500; High: $4,500-$10,000: Very High: $10,000 or more (www.energysavers.gov).

**This is the ENERGY STAR level for closed-loop water-to-air systems. Find minimum EERs for other configurations at EnergyStar.gov.

***This is the ENERGY STAR level for window units with louvered sides and capacities between 14,000-19,999 Btu/Hr. Find minimum EERs for other configurations at EnergyStar.gov.

†CEE is the Consortium for Energy Efficiency, www.cee1.org

††Depends on air conditioner size:
>8,000 Btu/hr: Tier 1–11.2 EER, Tier 2–11.6 EER
8,000–13,999 Btu/hr: Tier 1–11.3 EER, Tier 2–11.8 EER
14,000-19,999 Btu/hr: Tier 1–11.2 EER, Tier 2–11.6 EER
>20,000 Btu/hr: Tier 1–9.8 EER, Tier 2–10.2 EER

Seasonal Energy Efficiency Ratio (SEER): SEER is a measure of equipment energy efficiency over the cooling season. It represents the total cooling of a central air conditioner or heat pump (in Btu) during the normal cooling season as compared to the total electric energy input (in watt-hours) consumed during the same period.

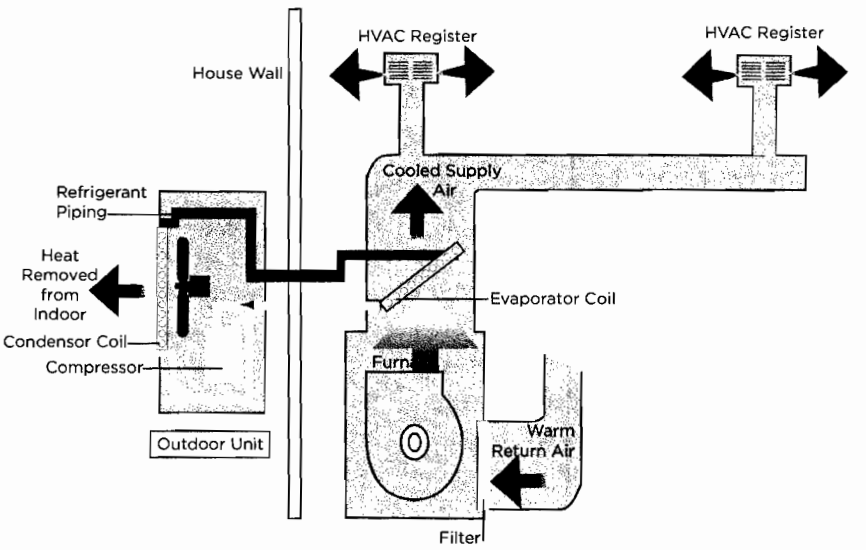
Energy Efficiency Ratio (EER): EER is an efficiency rating for room air conditioners based on how many Btus of heat per hour the unit can remove for each watt of power it draws. This ratio is expressed in Btu per hour per watt (Btu/hr/watt).

3.1 Central Air Conditioning

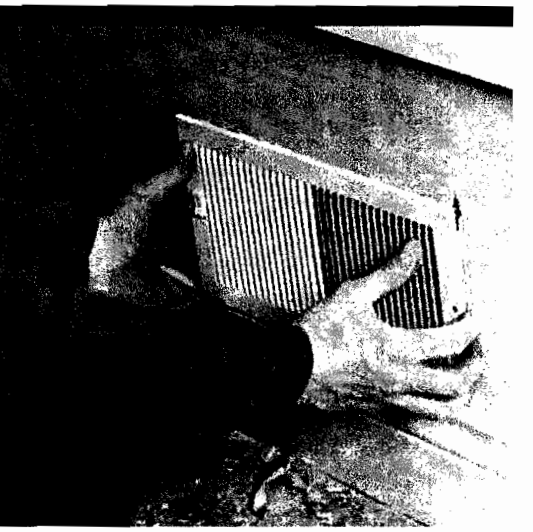
Central air conditioning provides cooled air throughout your house. Central air conditioners are typically installed with central furnaces and use the same ducts and blower. Refrigerant is piped to the evaporator coil in the air handler unit where it cools the distribution air. Central air conditioners are generally more efficient than room air conditioners, so if you plan on cooling the majority of your house, a central air conditioner can save energy and money.

Air conditioners have become much more efficient over the past few decades. Technology improvements include variable-speed motors that allow more control over air distribution, which can lower energy consumption and increase comfort. The majority of systems rated SEER 15 or higher incorporate variable-speed motors to achieve this efficiency. Advanced compressors and micro-channel heat exchangers are other advancements that have improved efficiency.

If your existing air conditioner is a pre-2006 model, a new unit could reduce your cooling costs by 20% to 40% (DOE 2010). Central air conditioning systems are rated according to their seasonal energy efficiency ratio (SEER). Look for units with high SEER ratings to maximize your energy savings over the course of the cooling season. Since 2006 the federal government has required new air conditioners sold in the United States to have a SEER rating of 13 or higher. However, many older systems have much lower SEER ratings. Split system air conditioners (the most common in homes) can use the ENERGY STAR label if their SEER is 14.5 or greater. The best available air conditioning units can have SEER ratings of over 20.



Central air conditioning equipment shares the air handler cabinet and duct distribution system with the furnace.



Register design can have a big impact on the comfort of central heating and cooling systems.

Sizing up old Air Conditioners

Air conditioners are sized by their capacity in terms of tons. One ton equals 12,000 Btu of cooling capacity. Not sure of the current size of your air conditioner? Look at the name plate on the outdoor condensing unit and locate the model number (not the serial number). You are looking for two digits in the model number that match the numbers below to indicate tons or Btus.

18 = 1.5 Ton	(18,000 Btu/hr)
24 = 2 Ton	(24,000 Btu/hr)
30 = 2.5 Ton	(30,000 Btu/hr)
36 = 3 Ton	(36,000 Btu/hr)
42 = 3.5 Ton	(42,000 Btu/hr)
48 = 4 Ton	(48,000 Btu/hr)
60 = 5 Ton	(60,000 Btu/hr)

For example, a model SSX160241 is a 2-ton (24,000 Btu) air conditioner.

Bigger is not always Better

Your old air conditioner may be oversized. An overly large system will blast on quickly, bringing the air temperature below the set point and shutting off before it has had time to remove moisture from the air, which can be a problem where summers are humid. Contractors sometimes oversize central air conditioners because they use rules of thumb rather than performing load calculations. The contractor should use ACCA Manual J to calculate your cooling load and ACCA Manual S to correctly size your new central air conditioning system (ACCA 2005; 1995). This is especially important if you have done significant air sealing and insulating, which will reduce your heating and cooling load. (The ACCA has produced two 2-page brochures for contractors on using Manual J and Manual S. See ACCA 2011 b, c) Note that central air-to-air heat pumps may require some oversizing to perform adequately because they typically do not supply as much cooling per air volume as a standard air conditioner. Also oversizing is less of an issue with some of the latest heating and cooling equipment that has variable speed motors and compressors, which can operate at lower speeds and capacities that better match low demand times, while having the ability to increase capacity when demand spikes.

Table 3.2 lists the potential energy cost savings from switching to a high-efficiency unit per $100 spent on cooling costs. For example, if you currently spend $400 per year on cooling costs (what the typical family spends annually on cooling in warm climates [EIA 2008]) and you switch from a SEER 10 unit to a SEER 15 unit, you will save about $132 per year. Studies indicate that if you upgrade from a SEER 9 unit to a new SEER 15 unit you can save 35% in cooling costs; if your air conditioner is a SEER 6 and you upgrade to a SEER 15, savings could be as high as 51%. Savings will be higher if you are in a hot climate. Annual savings will increase over time if utility rates rise.

Table 3.2: How Much You'll Save When You Increase Your Cooling Equipment Efficiency

Annual Estimated Savings for Every $100 of Costs.
(Source: www.energysavers.gov)

Existing System SEER	New/Upgraded System SEER							
	13	14	15	16	17	18	19	20
10	$23	$29	$33	$38	$41	$44	$47	$50
11	$15	$21	$27	$31	$35	$39	$42	$45
12	$8	$14	$20	$25	$29	$33	$37	$40
13	-	$7	$13	$19	$24	$28	$32	$35
14	-	-	$7	$13	$18	$22	$26	$30
15	-	-	-	$6	$19	$17	$21	$25
16	-	-	-	-	$6	$11	$16	$20

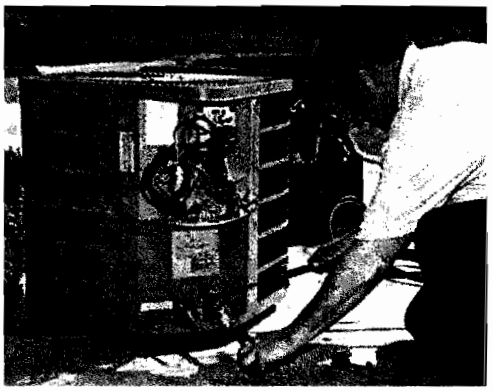
3.1.1 Repair or Replace?

High-efficiency units can cost more than units with the minimum required SEER (ConsumerSearch Inc. 2008) but should pay for themselves over time (see "air conditioning" at www.energystar.gov for a payback calculator). Talk to your contractor about costs and savings in comparison to heat pumps.

Your contractor can give you recommendations for getting the most out of a new or existing central air conditioning system:

- SIZING – Your air conditioner should be properly sized using ACCA's Manual S. If you have improved the efficiency of your house, it may be possible to select a smaller size when replacing your unit or to replace two central units with one central unit, recouping part of your investment in energy efficiency. Oversized air conditioners will cycle on and off frequently, decreasing efficiency and increasing maintenance costs. Frequent cycling means that oversized units do not dehumidify as well as properly sized units (an important consideration for humid climates).

- AIR CONDITIONER SETTINGS – The time-delay relay on many newer air conditioning units is set to keep the fan running for about two minutes after the compressor shuts off. The relay can help boost efficiency in dry climates, but allows some of the moisture on the evaporator coil to evaporate back into the air stream, contributing to indoor humidity in humid climates. The time-delay relay is typically jumper selectable and should be set to 30 seconds or less in humid climates. Also, the fan on central air conditioning systems should always be set to "Auto" rather than "On" for the most efficient operation. Set the compressor to start before the blower. Make sure the drain pans are correctly installed.
- ZONING – Your contractor may recommend two or more air conditioners to provide zoning of separate floors of a multi-story house. Dampered zoning has some performance issues, including noise and difficulty maintaining flow over the coil.
- ECONOMIZERS – In dry climates, take advantage of night-time cooling with economizers that draw in outside air during evening and early morning hours (McWilliams and Walker 2005).
- FILTERS – Building America recommends using filters that are rated MERV 8 or higher in new furnaces that are built to accommodate 2-inch to 4-inch thick filters. In older air handlers that have 1-inch filter slots, high-MERV 1-inch filters may block air flow; it may be preferable to use lower MERV filters that are replaced more often, even monthly, when the air handler is running often.
- REFRIGERANT CHARGE – The level of refrigerant may be too low (undercharged) because of leaks or too high (overcharged) because the installer added too much. One study found that in a system that was undercharged by 20%, the efficiency dropped by about 21%. Likewise, in a system that was overcharged by 20%, the efficiency dropped by about 12% (Farzad and O'Neal 1998). The EPA reports that 75% of installed air conditioners had the wrong amount of refrigerant when tested. Incorrect refrigerant levels can lower efficiency by 5% to 20% and can cause premature component failure, resulting in costly repairs (see EPA Heating and Cooling Refrigerant Charging guidelines at www.epa.gov).
- TEST AIR FLOW AND DUCT LEAKAGE – Improper air flow and leaking ducts can significantly affect the performance and efficiency of your system. The only way to know if you have a blocked or disconnected duct, big air leaks, or inadequate air flow is to test your ducts with duct leakage and air flow tests.

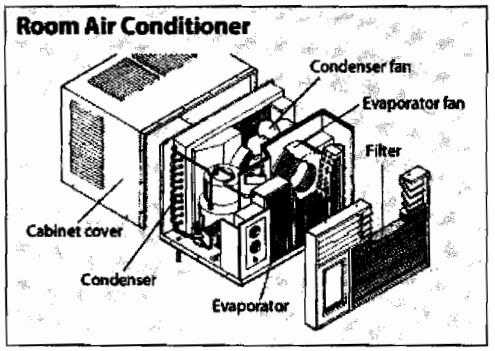


Have your refrigerant charge checked by a certified HVAC technician. Under- and over-charged systems can affect the system's efficiency and cause premature component failures.

ANSI/ACCA HVAC Standards

The Air Conditioning Contractors of America has produced several American National Standards Institute (ANSI) approved standards on HVAC equipment installation and maintenance including

- ANSI/ACCA Standard #4 Maintenance of Residential HVAC Systems (ACCA 2010a)
- ANSI/ACCA Standard #5 HVAC Quality Installation Specification (ACCA 2010b)
- ANSI/ACCA Standard #6 Restoring the Cleanliness of HVAC Systems (ACCA 2010c)
- ANSI/ACCA Standard #9 Quality Installation Verification (ACCA 2010d).



Components of a room air conditioner. (DOE 2010)

3.2. Room Air Conditioning

Window and through-the-wall air conditioners are used to cool single rooms or small zones within a house. They typically have a lower efficiency than central AC systems. Window units often lack insulation and air sealing around them because they are usually temporary installations; therefore, using them is not considered an energy-efficient best practice. However, room air conditioners will cost less to purchase and install than a central AC system, and there may be some energy savings if you only plan to cool a small part of your house.

If you choose to install a room air conditioner for zone cooling, find a unit with an EER of 10 or more. Properly size the unit to the space because oversized units will cycle on and off frequently, affecting their ability to reduce humidity levels. Direct sunshine on the outdoor components can reduce efficiency by as much as 10%, so ideally window units should be installed in a shady area on the north or east side of the house (DOE 2010). Room air conditioners may be an effective solution if air conditioning is rarely called for. However, if air conditioning is desired on a daily basis for most of the cooling season, consider investing in a ductless heat pump.

Room Air Conditioner Efficiency Ratings

The efficiency of window units is measured by their energy efficiency ratio (EER, the ratio of cooling capacity in Btu/hour to power input in watts). Minimum Federal standards were first established in 1987 and became effective in 1990. The requirement varies by unit size and type, but for the most common type (an 8,000–13,999 Btu/hour unit with side vents) the 1987 law required an efficiency of 9.0 EER. This was revised by the Federal government to 9.8 EER effective October 2000. DOE is required to publish a new standard by June 2011, to be effective in 2014, and an EER of 11.0 is being considered. ENERGY STAR specifications were last updated in 2001 and specify a 10.8 EER for the most common units. Specifications for ENERGY STAR Version 3.0 were due in May 2011 and will be effective in February 2012 (ACEEE www.standardsasap.org/products/room_ac.html).

3.3 Heat Pumps

Standard air-source heat pumps, ground-source heat pumps, and ductless mini-split heat pumps all provide cooling as well as heating. Heat pumps also dehumidify like air conditioners.

3.3.1 Central- and Ground-Source Heat Pumps

Central air-source heat pumps and ground-source heat pumps are described in Section 3.0. Efficient centralized heat pumps have a SEER of 15 or more; very efficient heat pumps can have a SEER of 18 to 21. Ground-source heat pumps can achieve efficiencies of 300%.

3.3.2 Ductless Heat Pumps

Ductless heat pump technology was described in Chapter 2. Ductless heat pumps save energy and money because they can be used for zone cooling (only cooling parts of the house) and because they avoid the large fan energy and duct losses typically associated with central ductwork. The advanced inverter technology incorporated into these units has also increased their efficiency at a wider

temperature range so that backup heating is unnecessary. Ductless heat pump models are available with SEER ratings as high as 26.

Ductless mini-splits generally cost about 30% more than central heat pumps, not including the cost of ductwork for central systems (DOE 2010). However, if you would need to install ducts to add a central AC system to your home, the ductless mini-split heat pumps may be a less expensive option up front. Ductless heat pumps are a good option for additions.

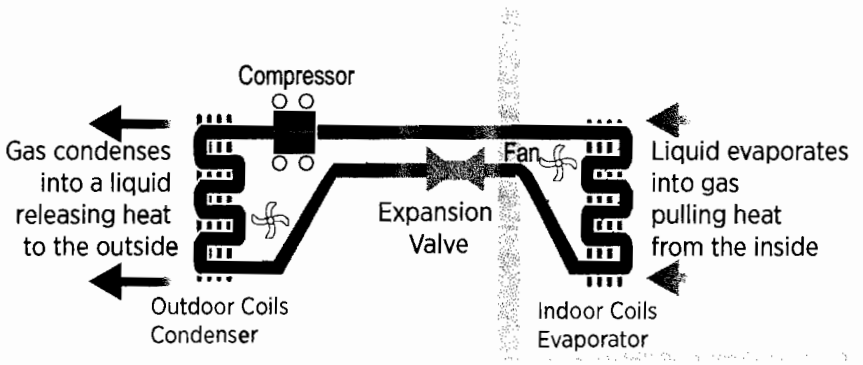
Ductless mini-split air conditioning systems, which provide cooling but not heating, are also available. Mini-split AC systems could be an option in houses that use a non-ducted heating system that you aren't ready to replace.

3.3.3 Absorption Heat Pumps

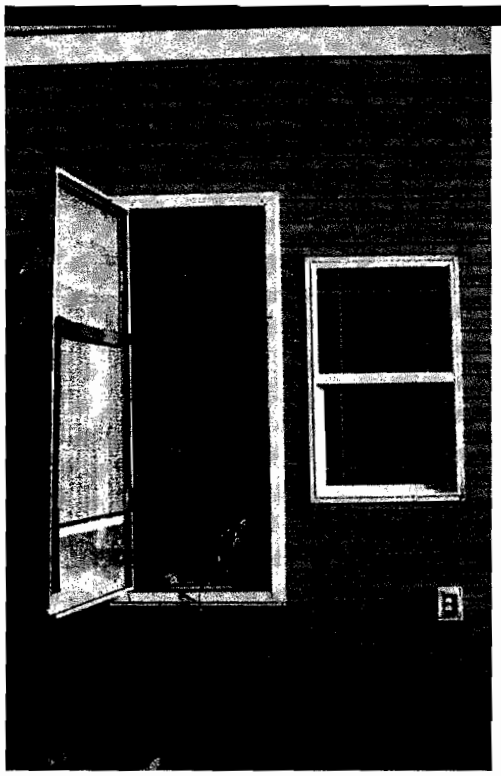
Absorption heat pumps, sometimes called gas-fired heat pumps, are essentially air-source heat pumps driven not by electricity, but by a heat source such as natural gas, propane, solar-heated water, or geothermal-heated water. The cooling version is called an absorption cooler or gas-fired cooler. It works on the same heat pump principle but is not reversible and cannot serve as a heat source as well.

Although mainly used in industrial or commercial settings, absorption coolers are now available for large homes (4,000 ft^2 or more). Absorption heat pumps for smaller homes are being developed. Absorption coolers and heat pumps have lower efficiencies than other heat pumps (1.2+ COP for heating; 0.7+ COP for cooling), but they can make use of solar energy, geothermal hot water, or other heat sources and may be cost-effective where electricity rates are very high.

Air-Source Heat Pump in Cooling Cycle



Air-Source Heat Pump Cooling Cycle - In cooling mode, an air-source heat pump evaporates a refrigerant in the indoor coil. As the liquid evaporates, it pulls heat from the air in the house. After the gas is compressed, it passes into the outdoor coil and condenses, releasing heat to the outside air. The pressure changes caused by the compressor and the expansion valve allow the gas to condense at a high temperature outside and evaporate at a lower temperature indoors.



This evaporative cooler mounts on an exterior wall of a home built by Community Development Corporation of Utah with design assistance from Building America's Consortium for Advanced Residential Buildings (CARB) research team (Source: Steven Winter Associates).

3.4 Evaporative Coolers

Evaporative coolers can be an effective and less expensive alternative to compressor-based air conditioners for cooling your home if you live in a dry climate. Evaporative coolers (known in the past as swamp coolers) use evaporation and blowing air to cool. They can use about one-quarter as much energy as central air conditioners and cost half the price. Evaporative coolers require regular maintenance to keep the water reservoir clean.

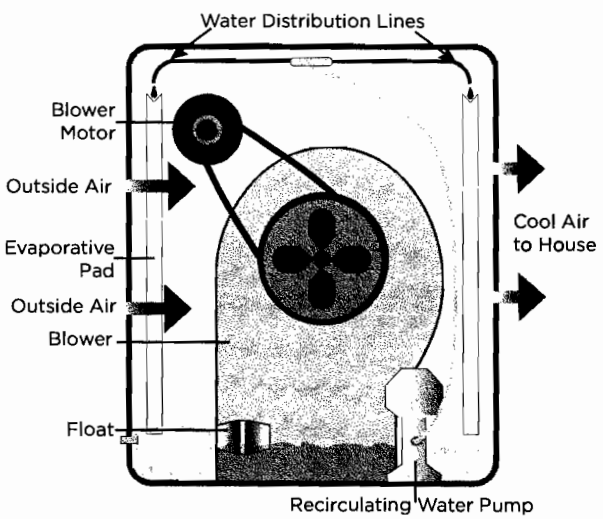
Today's evaporative coolers come in one of three general designs: direct, indirect, and indirect/direct.

Direct, single-stage evaporative coolers work by drawing outside air through water-saturated pads. The flowing air evaporates some of the water, giving up heat in the process, which can reduce the air temperature by 15°F to 40°F. The cooled, humidified air is then blown into the home. The air is not recirculated inside the house but is blown through the house and an exit must be provided for it; thus, a window or vent must be opened to allow air to leave the house. Lower air flow helps the cooler to work more efficiently. An evaporative cooler should have at least two speeds and a vent-only option. The vent-only operation allows the unit to be used as a house fan during mild weather.

Indirect coolers use an air-to-air heat exchanger so they don't add humidity to the cool air. The main fan supplies outside air that is cooled by passing through the heat exchanger into the home. A second fan draws exhaust air from the home and/or outside air through the wet pads, which are in contact with the heat exchanger and cool it without raising the humidity of the air that flows into the home.

Evaporative Coolers

Direct evaporative coolers consist of a fan surrounded by thick pads that are continually soaked with sprayed water. As the fan pulls outside air through the pads, the water absorbs heat from the air and evaporates, which lowers the dry bulb temperature of the incoming airstream. The cooled air is blown into the house through a short duct to direct the cold air to the home's main living area. Two advanced forms of evaporative coolers are now available. Indirect coolers use an air-to-air heat exchanger so they don't add humidity to the cool air. Indirect/direct coolers use a heat exchanger to precool the air then pass it through the direct cooling stage which further cools and humidifies the air.



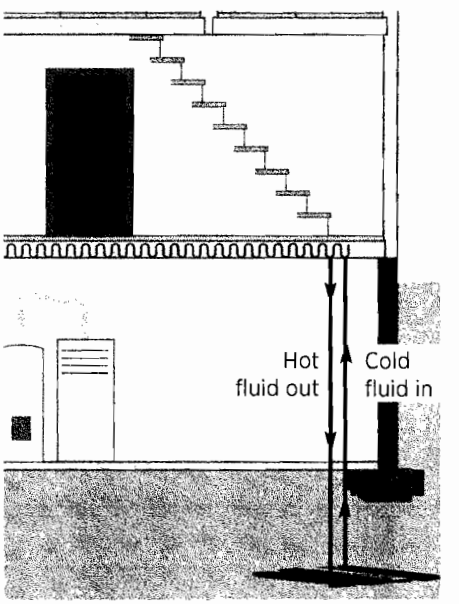
Indirect/direct coolers cool in two stages. In the first stage, the air passes through an indirect cooler, which lowers the temperature without adding humidity. The air then enters the second, direct cooling stage where it flows through the wet pads to be further cooled and humidified before flowing into the home. One model, developed by Building America partner Davis Energy, reportedly provides up to 5 tons of cooling while using less than 1600 watts. The model is eligible for utility rebates up to $1,100 in several south-western states. The installed cost for an efficient indirect/direct evaporative cooler is similar to or less than that of a new central air conditioning system (Eastment et al. 2005). Evaporative coolers do use water and water costs should be included when considering installing an evaporative cooler.

Another innovative evaporative technology is the water-cooled evaporative condenser, which is a scaled-down residential version of the 250-ton chillers used on commercial buildings. Inside the housing, a mist of water is continually sprayed on the condenser coils to remove heat from the refrigerant and at the same time reduce the work of the compressor. Unlike traditional air conditioners, which use 10% more power for each 10° F increase in temperature above 95° F, an evaporative-cooled condenser draws about the same power over a wide range of outdoor temperatures. It uses about half the energy costs of conventional "air-cooled" condensing units. One model has an EER of 17 at 95°F.

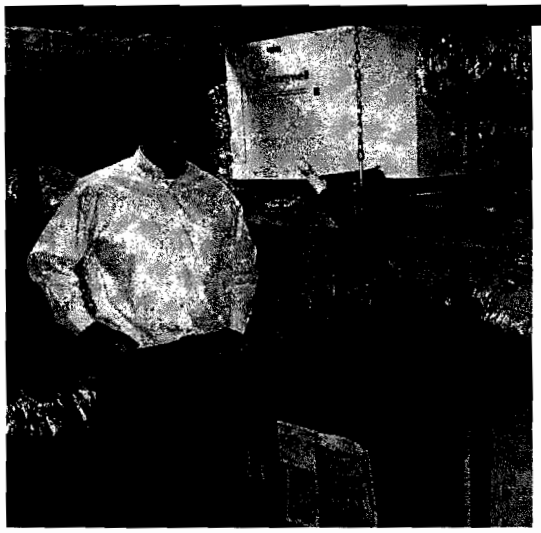
There are now evaporative coolers on the market that use photovoltaic (PV) panels to create the electricity used to run the blower and the water pump. For hot, desert areas, the combination of evaporative cooling and solar power is a perfect match: the afternoon, when the most solar energy is available, is also the hottest part of the day, when cooling is most needed. And, because evaporative coolers use a fraction of the energy of air conditioners, PV cells can provide enough electricity to run the system effectively (CEC 2011).

3.5 Radiant Cooling

Ground-source heat pumps can be used to provide radiant cooling as well as heating. Closed-loop systems circulate cool water through tubes in the floor, ceiling, or wall panels, cooling living spaces as they absorb heat, which is transported and released through loops in the ground or in cooling ponds. While radiant heating has been well received, radiant cooling is problematic due to comfort issues (bare feet on cold floors) and condensation issues in rugs and carpets. Because of the moisture issues, radiant cooling is only recommended in dry climates. For more on this technology, see Section 2.4.2.



Ground-source heat pumps can provide cool water for radiant floor cooling in hot dry climates.



Dehumidifiers can be ducted to a furnace or heat pump central air handler. Dehumidifiers, air handlers, and ducts perform best when installed in conditioned spaces. This dehumidifier and air handler were installed in the insulated attic of a a high-performance home built by KB Home in Orlando, Florida (Source: FSEC).

3.6 Dehumidifiers

In hot, humid climates, there are times of the year, especially in the spring and fall, when the temperature is not high enough to call for air conditioning, but the humidity level is high enough to make conditions inside the home uncomfortable. At times like these, a dehumidifier can bring the humidity down to a comfortable level, without the need for air conditioning.

One study done by Building America partner Building Science Corporation in Houston, Texas (Rudd et al. 2005) indicated that separate dehumidification is even more necessary in energy-efficient homes because efficiency measures like better insulation, air sealing, and energy-efficient windows reduce the home's temperature but don't reduce humidity. Also, in an energy-efficient home, a central air conditioning system does not have to operate as much to bring the indoor temperature down. Therefore, the air conditioner may not operate long enough to reduce the humidity, especially in the spring and fall when outdoor temperatures are not much higher than indoor temperatures. The study also compared dehumidifier technologies and found that stand-alone dehumidifiers were a cost-effective option compared to more expensive, integrated systems.

Before installing a dehumidifier, your contractor will rule out other sources of moisture in the home that need to be repaired. This could include a dirt basement or crawlspace floor that is not covered with a plastic vapor barrier, open sump pumps, improper site grading that allows water to pool around the foundation, inadequate exhaust ventilation, or exhaust fans that vent to the attic (Cummings et al. 2011).

3.7 Natural Cooling Strategies

In a well-insulated home in a moderate climate, summer heat may be adequately controlled by ventilation and dehumidification, combined with passive cooling strategies, such as low-solar heat gain windows, shading, cool roofs, and radiant barriers to minimize summer solar heat gain. Through the energy assessment, your contractor can help you determine whether your home needs additional air sealing and insulation. Once these things are done, and before installing a central air conditioning system, consider the following strategies.

3.7.1 Fans and Ventilation for Cooling

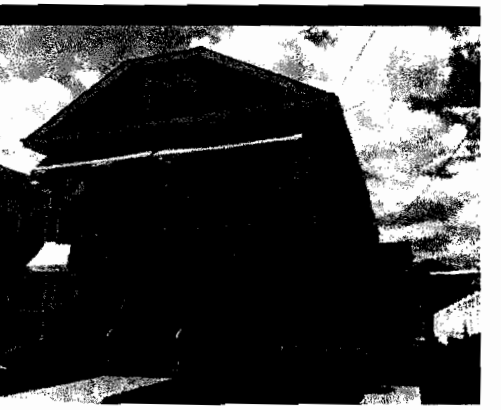
Natural and fan ventilation strategies can be the least expensive and most energy-efficient way to cool buildings. Fans works best in moderate to cool climates, in climates where temperatures drop at night, and in climates that are not excessively humid. In hot, humid climates where temperatures stay warm through the night and outdoor air remains humid through most of the summer, ventilation alone may not be enough to control the heat and you may want to consider air conditioning. However, even in hot, humid climates, ventilation and supplemental dehumidification, combined with the heat-avoiding passive cooling strategies discussed below, will reduce your air conditioning needs.

3.7.1.1 Central Fan-Integrated Night Cooling

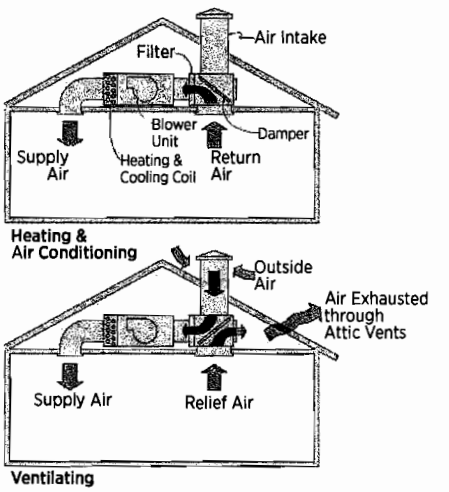
Fan-integrated night cooling uses your central furnace fan and a fresh air intake to draw in cool outside air at night, mix it with returning house air, and distribute it through the house. Dampers on the fresh air intake can be controlled by temperature sensors to open when outside evening or early morning temperatures drop below inside temperatures. Humidistat sensors can close the dampers if humidity levels outside are too high. The system is most cost-effective in dry climates.

This fan-integrated night cooling provides several advantages over just opening windows: the incoming outside air can be drawn through a filter, it is evenly distributed throughout the home, and there is security in not having to leave windows open at night. It is best implemented with a variable-speed fan motor that allows lower air flow rates and energy savings. This system is further described in Chapter 4.0, "Ventilation."

If you don't have a central furnace fan, you can still use this concept to take advantage of night cooling by having an outside air duct with a mechanical damper installed that connects to a centrally located exhaust fan installed in reverse to draw air in rather than pull air out. Both the fan and the damper can be wired to a temperature sensor.



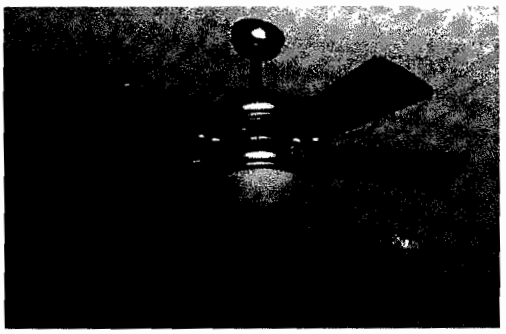
Porches, awnings, and windows that open to provide cross ventilation can all help homeowners take advantage of natural cooling strategies to reduce cooling energy bills.



Source: Davis Energy Group

Night Breeze—

Building America Partner Davis Energy Group developed the NightBreeze system, an "intelligent" sensor-controlled system that integrates ventilation cooling and fresh air ventilation with regular ducted central heating and air conditioning systems. Studies for the California Energy Commission have shown that NightBreeze can reduce cooling energy costs by about 25%-40% in California central valley climates and can eliminate the need for air conditioning in coastal climates while improving indoor air quality and comfort. Unlike whole house fans, it filters outdoor air and does not require windows to be opened. (Source: Davis Energy Group)



Turn on the ceiling fan and you can raise that thermostat 4 degrees with no complaints. Ceiling fans work best when the blades are 7 to 9 feet above the floor and 10 to 12 inches below the ceiling. Fan blades should be at least 8 inches from the ceiling and 18 inches from the walls. Multiple fans work best in rooms longer than 18 feet.

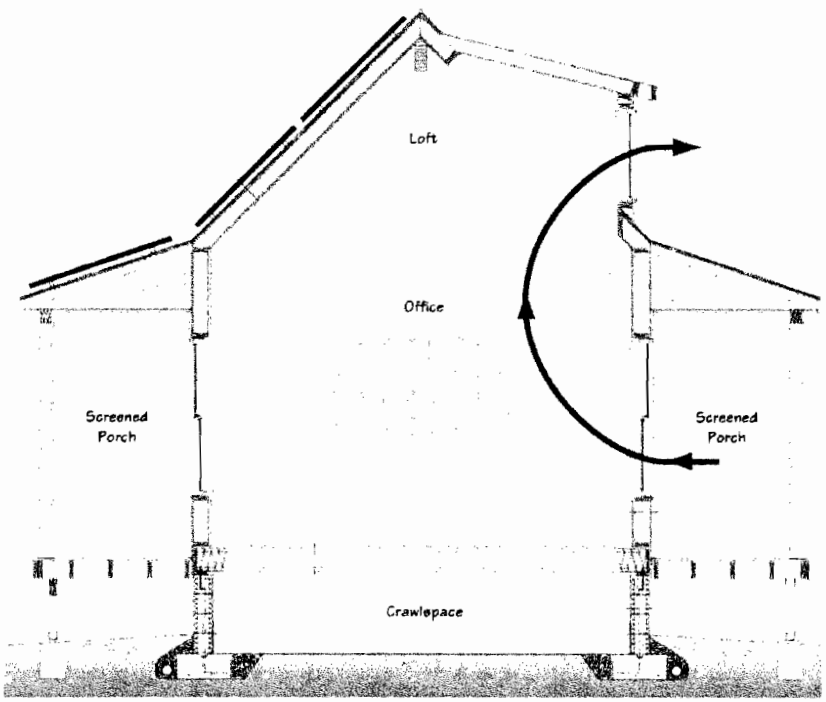
3.7.1.2 Natural Draft

Depending on the location and design of the home, natural convection and cool breezes can help cool the home without requiring even the aid of mechanical fans. If you are replacing windows, determine if picture windows can be replaced with windows that open, if they face favorable prevailing breezes.

If you have a two-story house, you can take advantage of the "stack effect." (You can see this at work in a chimney when air rises through the column and out the opening at the top due to air pressure differences inside and outside of the chimney.) Windows can be opened downstairs at the same time as windows upstairs, or at the tops of stairwells, or at openable skylights to draw hot air up and out of the house.

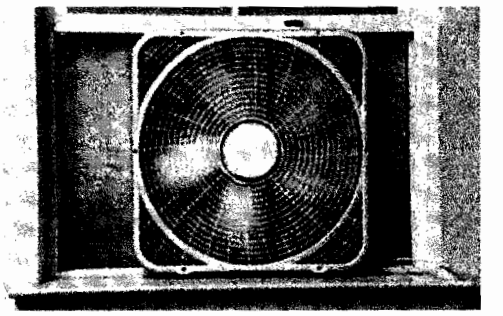
3.7.1.3 Circulating Fans

Circulating fans include ceiling fans, table fans, and floor fans. These fans create a wind chill effect that will make you more comfortable in your home, even if it is also cooled by air conditioning. In temperate climates, or during warm weather, fans may allow you to avoid using your air conditioner altogether. However, be sure to turn off ceiling fans when you leave a room; fans cool people, not rooms. If you use air conditioning, a ceiling fan will allow you to raise the thermostat setting about 4°F with no reduction in comfort. A larger blade will also provide comparable cooling at a lower velocity than a smaller blade. Check the noise ratings, and, if possible, listen to your fan in operation before you buy it.



Building America's research team lead Building Science Corporation used convection to help cool this structural insulated panel (SIP) cottage in Georgia. Cool air from the screened porches is drawn into the building's interior where it heats up and is pulled up and out by the "stack effect" (in the same way that air is drawn up a chimney by differences in the air pressure inside the chimney and outside the chimney). The air flows out the second-story windows, drawing more air in through the shaded first-story windows.

3.7.1.4 Window Fans



Window fans pull hot air out of the home.

Window fans use relatively little electricity and can provide sufficient cooling for homes in many parts of the country. Window fans are best used in windows facing away from the prevailing wind; the fan is installed facing in to pull air out of the house, not push air into the house. The window fan will work best if you close windows near the fan and open windows at the opposite end of the house. If your house is multilevel, put the fan in an upstairs window and open windows downstairs at the other end of the house. Windows on shaded parts of the house provide the best intake air for cooling. When buying window fans, look for ENERGY STAR® rated fans, which are 20% more efficient than standard models.

3.7.1.5 Attic Vents

Ventilating your attic can reduce the amount of accumulated heat that would otherwise warm your house and make air conditioning equipment installed in the attic work harder. Properly sized and placed roof vents help prevent overheating in your attic. Ventilated attics are about 30°F cooler than poorly ventilated attics (www.energysavers.gov). Electric and solar-powered attic fans that mount in gable vents are available, but they are not necessarily recommended. They have not been shown to reduce air conditioning bills. They can pull air-conditioned air out of your home and into your attic if the ceiling of your home is not well air sealed.

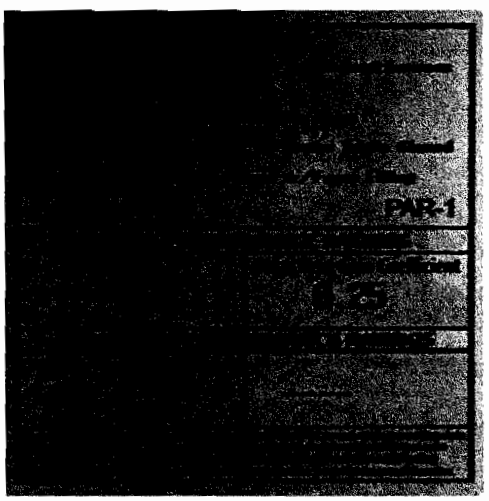
3.7.1.6 Whole House Fans

If you live in a dry, moderate climate with a large day-to-night temperature difference, a whole house fan might be worth considering for home cooling. Whole house fans are located in the ceiling of a centrally located area on the upper floor of your home. (Install in the second-story if you have a two-story home.) The fan is operated with lower-floor windows open. Your attic must be well ventilated with ridge and/or gable vents. Whole house fans draw air through the house and push it out through your attic. Whole house fans can quickly cool your house at night, once the outside temperature has dropped.

The fans are large and can be loud, especially if they are poorly designed. Also, be cautious and avoid running the fan while combustion equipment (like a natural-draft water heater) is running. Combustion equipment may backdraft when the fan turns on, if not enough windows are open. Whole-house fans are not recommended in humid climates, because they pull in humid air and add humidity to the attic. They may not be appropriate in areas where opening first-floor windows at night would cause security concerns. When not in use the fan should be covered from the attic side with a tight-fitting, gasketed, insulated cover.

Window Ratings

- **Solar Heat Gain Coefficient** measures the fraction of solar energy transmitted and tells you how well the product blocks heat caused by sunlight. SHGC is measured on a scale of 0 to 1; values typically range from 0.25 to 0.80. The lower the SHGC, the less solar heat the window transmits.
- The **Shading Coefficient (SC)** describes how much solar energy is transmitted through a window compared to a clear single glass, which has an SC of 1.0. The lower the number, the less solar heat will enter your home and the lower your cooling bills will be. For example, a window treatment with a shading coefficient of 0.40 will prevent about 60% of the solar heat gain while a shading coefficient of 0.3 will block out about 70%.
- **U-Factor (U-value)** measures the rate of heat transfer and tells you how well the window insulates. U-factor values generally range from 0.25 to 1.25 and are measured in Btu/hr·ft^2·°F. The lower the U-factor, the better the window insulates.
- **Visible Transmittance (VT)** measures the amount of light the window lets through. VT is measured on a scale of 0 to 1; values generally range from 0.20 to 0.80. The higher the VT, the more light you see.



When window shopping, check the label for energy efficiency or look for ENERGY STAR-rated windows.

3.7.2 Passive Cooling

Passive cooling refers to use of the home's design to keep the home's interior cool. While the best time to incorporate passive design is in the home's initial construction, many passive strategies can be incorporated in common remodeling projects. These include upgrading windows, adding shading, replacing roofing with cool roof materials, and installing radiant barriers.

3.7.2.1 Windows

NEW WINDOWS – While energy-savings alone won't necessarily justify the purchase of high-performance windows, if you are already planning to replace your windows, invest in energy-efficient windows that meet the ENERGY STAR criteria. A contractor can help you determine which windows are best for your climate zone, using window ratings such as the solar heat gain coefficient (SHGC) and the U-factor.

SHGC is a measure of how well the window blocks heat caused by sunlight. Look for windows with a lower SHGC if you live in a warm climate. U-factor is a measure of how well the window performs at stopping heat flow. Look for windows with a lower U-factor (the lower the U-factor, the better).

Your contractor will likely recommend ENERGY STAR-certified windows. ENERGY STAR ratings for windows vary based on the climate you live in. The current minimum specification for ENERGY STAR windows in southern climates is less than or equal to 0.27 SHGC and less than or equal to ≤ 0.60 U-factor. In northern climates, the current minimum specification for ENERGY STAR windows is a U-factor of less than or equal to 0.30; the SHGC is not specified because solar heat gain is desirable for much of the year in cold climates.

In warm climates, look for windows manufactured with spectrally selective low-emissivity coatings. These super-thin, virtually invisible metal coatings block heat gain but allow most visible light to come through.

For more information about windows, see the DOE-sponsored Efficient Windows Collaborative website at www.efficientwindows.org.

EXISTING WINDOWS – If you are keeping your existing windows, there are some steps you can take to reduce how much heat they let in. On south- and west-facing windows, you can install sun screens that have small aluminum louvers, fiberglass mesh, or tough metalized polyester film laminated to vinyl. Such removable shade screens can be taken down to allow you to take advantage of the sun's heat during the winter.

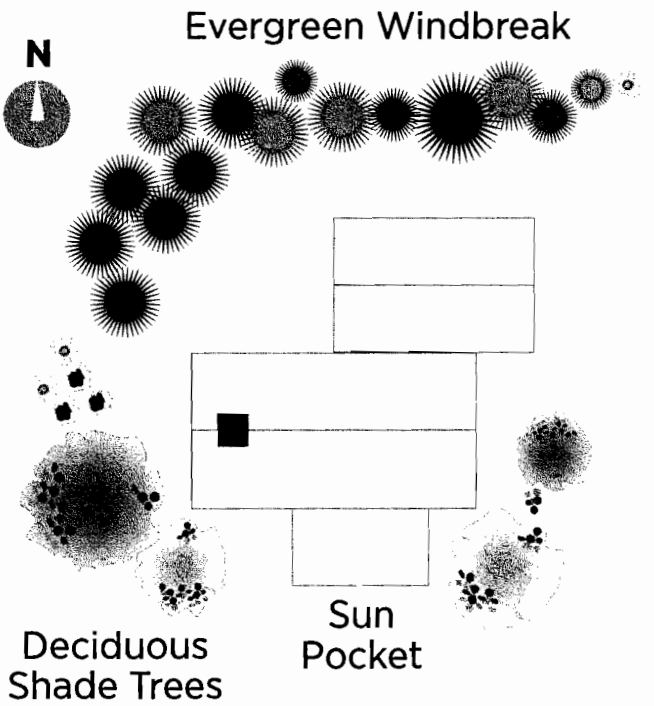
You can also reduce heat from the sun by applying window-tinting films. One problem with these films is that they can reduce the clarity of the glass; they may also need to be reapplied. However, such treatments and shades are much less expensive than new windows.

3.7.2.2 Shading

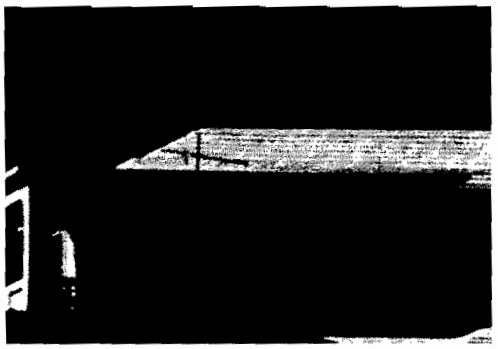
According to the U.S. Department of Housing and Urban Development, stopping the sun's heat *before* it penetrates windows and sliding glass doors is up to seven times more effective than using interior blinds or curtains (APS 2009).

Exterior shading options include trees, porches, awnings, pergolas, trellises, working shutters. If your remodeling project includes changing the roofline, include overhangs in your design, especially on south-facing walls. Overhangs protect windows and walls from heat gain and ultraviolet radiation, as well as rain, hail, and snow. Optimal overhang dimensions for blocking summer sun while allowing winter sun to come in can be calculated at www.susdesign.com/overhang/index.php.

Mature, well-placed trees can reduce cooling costs by 5% to 10%.



Careful landscaping can preserve rooftop solar exposure for solar panels and provide shading to help control solar heat gain through windows. Large deciduous shade trees on the southwest corner of the home provide welcome relief from summer afternoon sun while allowing desirable winter sun to warm the house (Walker and Newman 2009).



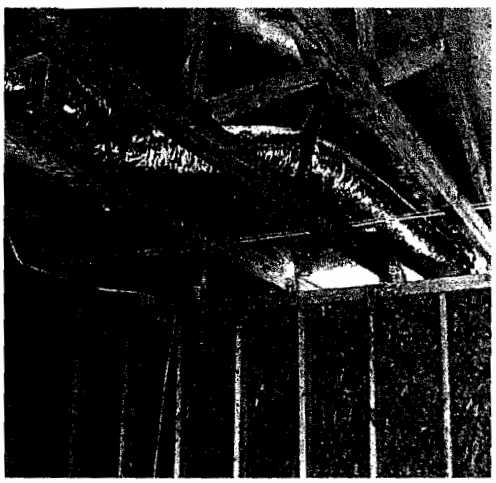
Light-colored roofing can help minimize heat gain from solar radiation. Reflective roofs help keep homes (and surrounding neighborhoods) cool and help offset carbon emissions.

Trees reduce cooling requirements, particularly when located on the south and west side of the home, by blocking the peak solar-gain of low-angle, late-afternoon sun. Deciduous trees are ideal for summer shading in cold climates because their lack of leaves in the winter will not block desirable sunshine during the heating season. Studies have shown a mature tree canopy can reduce peak July afternoon temperatures around a home by 1°F to 3°F, and the total effect of shading—lower summer air temperature and reduced wind speed—can reduce cooling costs by 5% to 10% (McPherson et al. 1994).

3.7.2.3 Cool Roofs

If you are replacing your roof and you live in a hot climate, consider replacing it with a cool roof. Cool roofs are white or light-colored roofs or roofs made with coatings that have high solar reflectance. These roofs reflect back most of the solar energy received, and they have high thermal emittance so they are able to radiate back absorbed solar heat (Parker and Sherwin 2008). Studies show that cooling cost savings of 7% to 15% are possible (www.coolroofs.org). Savings will be greater if your heating and cooling ducts are installed in the attic.

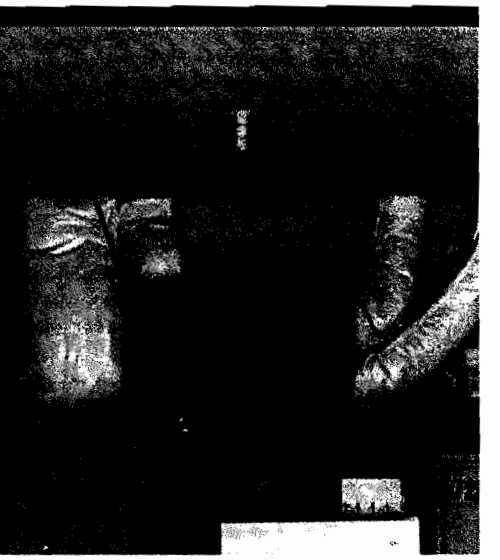
3.7.2.4 Radiant Barriers



Radiant barriers can significantly reduce solar heat gain through the roof in warm climates.

Radiant barriers can be installed in attics to reduce solar heat gain. These work well in hot climates where you want to keep heat out of the attic but are not recommended in cold climates where heat gain is desirable. Sometimes called reflective insulation, radiant barriers can come in sheets that consist of a layer of aluminum foil with a backing of kraft paper, plastic film, polyethylene bubbles, or cardboard. The sheets are stapled to the underside of the attic rafters to shield the attic from solar heat gain. The barrier is stapled shiny side down with an air gap of at least 3/4 inch between the shiny side and the attic insulation below so the radiant barrier can work properly. Also available are radiant barriers that come factory-adhered to OSB roof sheathing. Research by the Florida Solar Energy Center (a Building America team) showed radiant barriers can provide cooling energy savings of about 8% to 12%. (See the FSEC Radiant Barrier Primer for more information, including installation recommendations, http://www.fsec.ucf.edu/en/publications/html/FSEC-EN-15/).

4.0 Ventilation



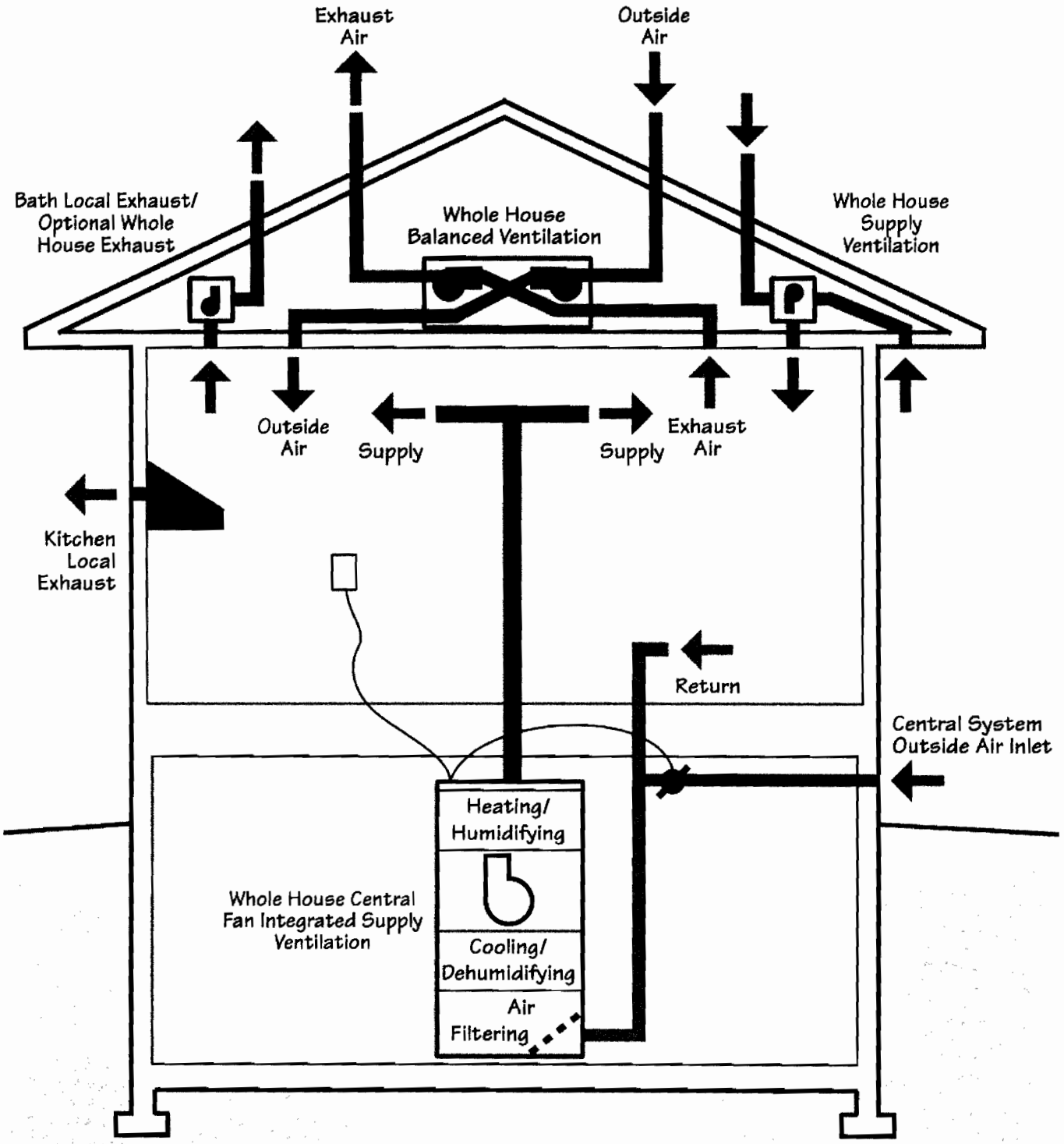
Ventilation is needed for good air quality inside your home. Ventilation brings in fresh air and removes stale air, including indoor contaminants like house cleaning chemicals and off-gassing paints and plastics, excess moisture from showering and cooking, and pollutants like carbon monoxide and other combustion byproducts. Air may be brought in and removed incidentally through air leaks or naturally through open windows. Or, it can be brought in and removed intentionally through mechanical means. Most home heating and cooling equipment, including forced-air heating equipment, is not manufactured to bring fresh air into the house and expel stale air. To accomplish this, either the heating and cooling equipment must be combined with a ventilation system or a separate ventilation system must be installed.

Ventilation equipment can be thought of in three categories: exhaust-only, which removes stale air from the house; supply-only, which provides fresh air to the house; and balanced systems, which do both. These ventilation strategies are described below and are described in depth with numerous examples of configuration options in the report, *Local Exhaust and Whole House Ventilation Strategies*, prepared by Building Science Corporation for Building America (Rudd 2011). Advantages and disadvantages of each strategy are summarized in Table 4.1 at the end of this chapter. The best strategy for your home depends on several factors, including the climate you live in, the air tightness of your home, and what type of heating and cooling equipment you have.

How much ventilation do we need? The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) provides recommended indoor ventilation requirements for new homes in a standard known as ASHRAE 62.2 (2010 is the most recent version). States and jurisdictions can adopt this standard by referencing it in their state or local building codes. Many utility weatherization programs require it and it is

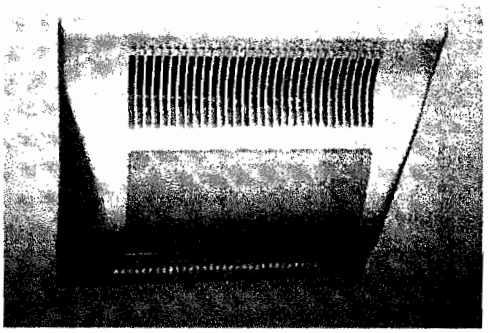
How Much Ventilation?

In ASHRAE Standard 62.2, the the American Society of Heating, Refrigerating and Air-Conditioning Engineers recommends a continuous ventilation rate of 1 cubic foot per minute (cfm) per 100 ft^2 of building area plus 7.5 cfm x (# bedrooms +1). An intermittent fan (an exhaust fan on a timer) can meet this requirement if the airflow rate is adjusted upward based on specific ventilation effectiveness requirements published in the standard.



Homes might use exhaust-only, supply-only, ERV/HRV, or some combination of all three types (Rudd 2011).

recommended by BPI and HERS raters. Most states that adopt the family of international building codes automatically adopt the International Mechanical Code, which includes less detailed requirements for mechanical ventilation. If you are remodeling an existing home, check with your building department to determine what ventilation requirements may apply. Even if not required by code, additional mechanical ventilation may be needed if you increase the air tightness of your home. Your energy performance contractor can advise you on how much ventilation is needed.



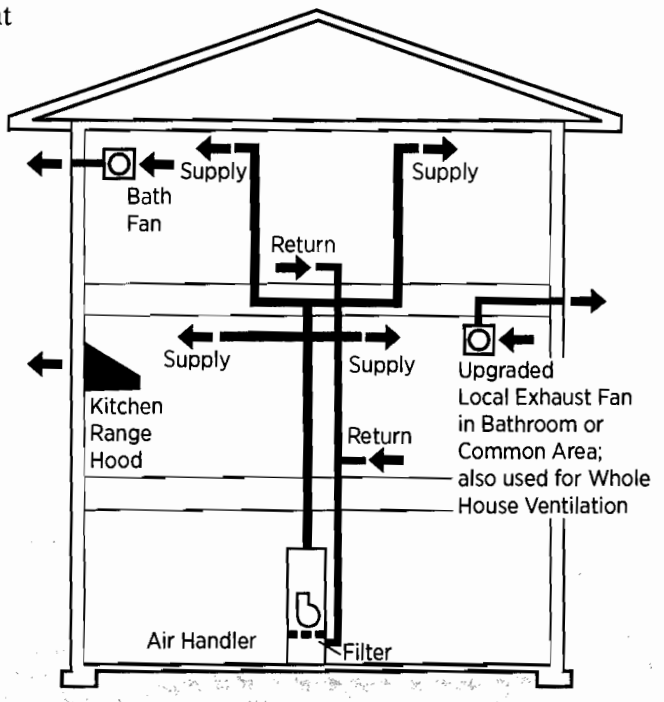
ENERGY STAR exhaust fans are available with sone ratings of 1.5 or less, indicating very quiet operation.

4.1 Exhaust-Only Ventilation

For mechanical ventilation, the strategy most people are familiar with is exhaust-only, using exhaust fans located in bathrooms and over the kitchen range. Continuously operating an exhaust fan located in a bathroom or central area of the house provides low-cost ventilation that meets the requirement of ASHRAE 62.2, although this may not be the best option in humid climates where it can pull in humidity. High-quality, quiet, efficient fans that have lower and higher speeds for ventilation and exhaust are typically used for this application. Exhaust fans help to improve indoor air quality by removing air contaminants near their source, such as moisture from a shower. Exhaust fans, even ENERGY STAR-rated models, are a relatively inexpensive way to ventilate a home. It is important that each exhaust fan be ducted to the outside of the house and not into the attic. Another solution is to have several exhaust ducts that are connected and routed through a single, continuously operating, high-efficiency fan that is vented to the outside.

If exhaust fans are used and incoming air is not intentionally provided to the home, the home will depressurize (like sucking the air out of a straw), forcing outside air to be pulled in. Often it comes from somewhere undesirable, for example, from the crawlspace through cracks or holes in the subfloor or sill plates or from the garage through air leaks in adjoining walls and ceilings.

In a high-performance home, those air leaks have been sealed up, so a fresh air intake must be added to the home to supply fresh air. Failing to provide an outside air intake can cause the home to become negatively pressurized (i.e., depressurized). This can increase the risk of backdrafting any atmospheric-vented, combustion (fuel-burning) appliances or fireplaces that may be in the home.



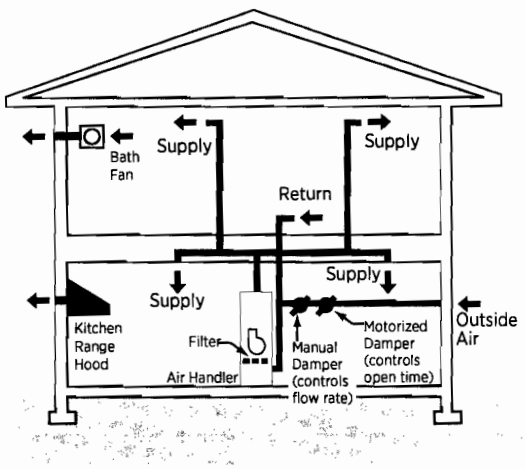
Exhaust fans provide simple, inexpensive ventilation but may depressurize the house, pulling air in from crawl spaces and through cracks in walls. (Rudd 2011).

4.2 Supply-Only Ventilation

Supply whole-house ventilation systems draw in fresh outside air from a known location (as opposed to through leaks in the building shell) and deliver it to the interior living space. The outside air can be brought in through a duct from a fresh air intake located for example in a porch ceiling or under a roof eave. The air can be brought through a filter on the air intake register and it should be conditioned by mixing it with recirculated indoor air before blowing it into living spaces (Rudd 2011).

Supply ventilation will tend to pressurize an interior space relative to the outdoors, causing inside air to be forced out through leaks in the building shell. In warm, humid climates, this strategy minimizes moisture entry into the building enclosure from outdoors. In cold climates, it may be advisable to balance the air intake with exhaust to minimize the risk of condensation inside walls (Rudd 2011).

Central fan integrated supply (CFIS) ventilation systems provide ventilation air through a duct that extends from outdoors to the return air side of a central heating and cooling system air handling unit (AHU). By using the existing central system air ducts, CFIS ventilation systems achieve full distribution of ventilation air. However, CFIS ventilation systems only provide ventilation air when the AHU fan is operating, therefore, an automatic timer must be used to ensure ventilation air is periodically supplied during periods of heating and cooling inactivity. A motorized outside air damper and associated control should also be added to limit outside air introduction to a maximum regardless of how long the fan operates. Continuous operation of the air handler fan is not recommended as it would consume too much electricity and is detrimental to humidity control in warm, humid climates (Rudd 2011).



Supply-only ventilation brings in fresh outside air through a dedicated duct (Rudd 2011).

Central fan integrated supply ventilation can be used with a central air handler equipped with an electronically commutated motor (ECM) rather than a permanent split capacitor (PSC) motor and some fan energy consumption savings may be possible (Rudd 2011). The key is that the ducts have been properly designed and installed according to manufacturers' specifications to eliminate excessive airflow resistance. However, there are still concerns that at the high speed required to draw enough air in through the CFIS system the ECM is likely to have no savings relative to a PSC blower and at the lower air flows where the ECM performs better, the air flow through the exterior duct will not meet desired ventilation rates (Walker 2011).

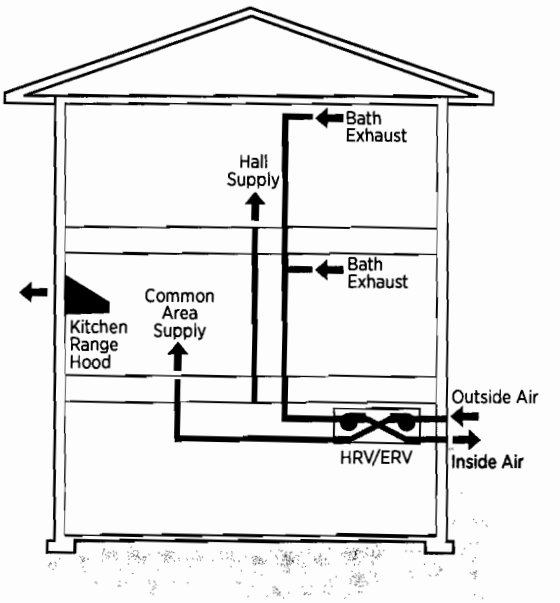
Because the operational time of the air handler fan is increased with central fan integrated ventilation, the importance of sealing and

insulating the ducts is increased. Of course, for every central space conditioning system, the best practice is always to locate the entire air distribution system inside conditioned space (Rudd 2011).

For homes that don't have a central heating and cooling system, a fan, like an exhaust fan, can be used to draw in outside air. This outside air should be mixed with indoor air to temper it before it is delivered into the home (Rudd 2011).

4.3 Balanced Systems

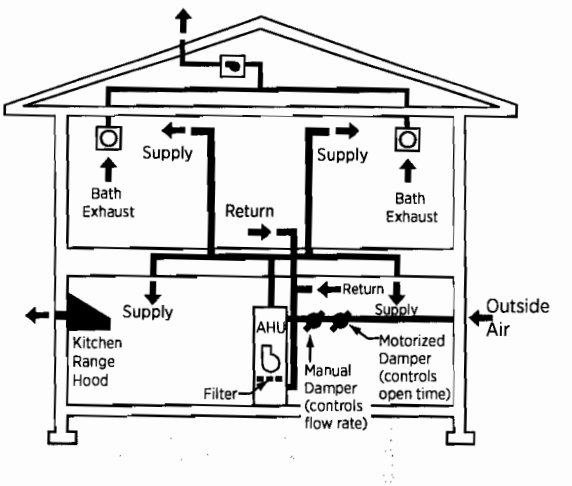
Balanced systems intentionally provide both supply and exhaust. The best means for providing this balanced ventilation is with a heat recovery ventilator (HRV) or an energy recovery ventilator (ERV). Both provide a controlled way of ventilating a home while minimizing energy loss because they incorporate a heat exchanger that uses the heat or cooling from the outgoing exhaust air to warm or cool the fresh incoming air. The incoming and outgoing air volumes are balanced and air is evenly distributed throughout the house. These ventilators are whole-house systems; they can share a central furnace air handler and duct system or have their own duct system. The main difference between an HRV and an ERV is the way the heat exchanger works. With an ERV (also called an enthalpy-recovery ventilator), the heat exchanger transfers water vapor along with heat energy, while an HRV only transfers heat. See the manufacturers' specifications for determining which model is best in which climate and install it according to their directions for best performance, especially in regard to ERVs in humid climates. Most ERVs can recover about 70% to 80% of the sensible energy in the exiting air (Rudd 2011).



Heat and energy recovery ventilators bring in fresh air, exhaust stale air, and save energy by transferring heat to incoming air through a heat exchanger (Rudd 2011).

4.4 "Semi-Balanced" System

Balanced whole-house ventilation systems both exhaust and supply in roughly equal amounts. Inside air is exhausted to the outdoors and outside air is supplied indoors. Balanced ventilation, by definition, should not affect the pressure of the interior space relative to outdoors. HRVs and ERVs are balanced systems. A balanced system can also be made up of any combination of the exhaust and supply ventilation systems described above (Rudd 2011). In reality the balance may never be perfect due to fluctuations in wind and stack pressures. Balanced ventilation can be used effectively in any climate. Rudd 2011 shows several examples of configurations of balanced systems.



Semi-balanced ventilation systems provide fresh air and exhaust stale air but flow rates may not be balanced (Rudd 2011).

Table 4.1. Summary of whole-house ventilation system types and cost and performance trade-offs (adapted from Rudd, A. 2011. "Local Exhaust and Whole House Ventilation Strategies," prepared by BSC for DOE Building America)

Balanced Systems	Exhaust Systems	Supply Systems
ERVs/HRVs and semi-balanced exhaust/ supply		
• Exhaust fan and fresh air supply fan running simultaneously. • Can be integrated with heat/cool system ducts and air handler. • Use timers or other controls to empower continuous and intermittent use. • Install heat recovery ventilator or energy recovery ventilator with independent system of smaller sized ducts to supply filtered outdoor air to each room or zone and return stale air from each room or zone passing thru heat exchanger enroute to exhaust vent to temper incoming air. ERVs transfer some moisture as well.	• Use continuous operation or use timers or other controls to empower intermittent use.	• Use a fresh air duct into central air handler return duct, or use a separate supply fan with recirculation air for tempering. • Use a fan timer and damper control. • Combined with low airflow resistance, ECM air handlers help save energy.
Advantages: • Most effective regardless of house airtightness. • Applicable in all climate zones. • Known source of ventilation air. • Less likely to affect combustion appliance venting. • HRV or ERV technology can recover up to 70% of heat. • Have opportunity to filter and temper fresh air.	**Advantages:** • Simple and inexpensive. • Good for removal of pollutants at their source. • Good, quiet local exhaust can double for whole-house ventilation. • Negative pressure can help keep walls drier in cold climates.	**Advantages:** • Simple, inexpensive, uses existing central duct system. • Known source of ventilation air. • Ensures good fresh air distribution. • Gives opportunity to filter and condition fresh air. • Positive pressure minimizes combustion spillage potential, and can help keep walls drier in warm, humid climates. • Tempers fresh air and filters it if filter is located at the air handler after the air inlet not at return grilles.
Design/Installation Issues: • Requires interlock with central air. handler fan if integrated with central ducts. • ERVs/HRVs more expensive first cost. • ERVs/HRVs require pre-planning for unit, vents, and duct locations.	**Design/Installation Issues:** • Unknown source and entry path of outdoor air. • Test to see if make-up air is needed to avoid combustion spillage and soil gas entry. • No opportunity to filter, temper, or condition incoming air. • May lack fresh air distribution.	**Design/Installation Issues:** • Need proper duct design and installation to ensure adequate air flow. • Need proper register grille design to avoid uncomfortable drafts. • Still need bathroom local exhaust. • May need to operate blower continuously to get enough air flow.

5.0 The Home Performance Energy Assessment

The U.S. Department of Energy Office of Renewable Energy and Energy Efficiency (DOE-EERE) and the U.S. Environmental Protection Agency are committed to a whole-house approach to energy upgrading a home to ensure homeowner health and safety as well as cost-effective energy savings. This approach is based on an understanding that every system in the home interacts with the other systems in the home. Thus, changes to the home's heating, ventilating, and cooling equipment can have health and safety consequences that must be taken into account. A home energy performance assessment, conducted by trained contractors, following recognized guidelines such as DOE's *Workforce Guidelines for Home Energy Upgrades,* will take into account these interactions and help homeowners identify and implement safe, effective energy improvements.

Homeowners should have a home energy performance assessment done when adding or replacing HVAC equipment, when they want to improve their home's efficiency by air sealing or adding new insulation, or when they are planning a major remodelling project.

CERTIFIED PROFESSIONAL

Building Performance Institute -The BPI is a nonprofit organization that accredits auditors, contractors, and other building professionals. Auditors or building analysts specialize in evaluating building systems and potential energy savings in homes. The certified BPI Building Analyst energy auditor has passed both written and field exams, and must recertify every three years. Contractors learn about building systems and are trained to perform energy efficiency assessments and conduct combustion safety testing. For more information see www.BPI.org

5.1 Certified Energy Contractors

A Building America-approved home energy assessment is conducted by a contractor who is trained and certified in building science principles and follows a prescribed approach to ensure the safest and most efficient ways to improve your home's energy efficiency.

There are two nationally recognized energy certifications for home performance energy contractors: the Building Performance Institute (BPI) Building Analyst certification and the Residential Energy Services Network (RESNET) HERS Rater certification. Historically,

A certified Residential Energy Services Network (RESNET) energy auditor is called a HERS rater. HERS raters are certified to provide homes with a HERS (the Home Energy Rating System) score, which provides a miles-per-gallon type rating of expected energy consumption that makes it easy to compare the energy performance of one home to another. More information about HERS can be found at www.resnet.us.

The home's building envelope contains the insulation in the attic, walls, and floor. This insulation should be in contact with a continuous air barrier that could include the taped drywall of the walls and ceiling and caulked subfloor plus weather-stripped doors and windows. Any holes in this air barrier (for wiring, plumbing, flue pipes, etc.) should be caulked to keep air from leaking in or out.

BPI certification has focused on understanding the building science of retrofitting existing homes and RESNET has focused on building science in new home construction. Also, states have adapted BPI and RESNET standards in state-specific training programs offered through weatherization programs and Home Performance with ENERGY STAR, a national program from EPA and DOE that promotes a comprehensive, whole-house approach to energy-efficiency improvements.

5.2 The Energy Assessment Process

Details of a home energy assessment will vary by program, but here is what you can typically expect.

5.2.1 Step 1. The Energy Performance Assessment

First, the energy contractor will evaluate the homeowner's energy upgrade needs, comfort issues, past home energy performance, home health and safety, and cost considerations. Here is what your assessment should include:

As part of an energy performance assessment, your certified energy contractor will do a thorough visual inspection of your home and conduct combustion safety and air leakage testing.

- SIZING THINGS UP – The contractor will interview you to understand your concerns about any comfort, heating, cooling, or safety issues related to your home. The contractor will ask for printouts of the last 12 months of utility bills, which you can access by contacting your utility companies. The utility data will show if your house is using too much energy for heating or cooling and areas to focus on for improvement. The contractor will take measurements of your home's total square footage, window area, and door area, and document specific features of the living space, such as if a basement is heated or cooled through furnace ducts. While taking these measurements, the contractor will also visually check for moisture problems outside and inside the home, including site drainage issues, gutter problems, and any evidence of water staining, dry rot, or mold.
- TESTING – With this preliminary information collected, the energy contractor begins conducting safety tests. These include checking all natural gas lines and gas appliances for gas leaks, performing a worst-case depressurization test and worst-case spillage test for combustion (fuel-burning) appliances that are naturally drafting (lack an enclosed flue pipe), and checking carbon monoxide levels around combustion furnaces and appliances. Exhaust fan operation is checked. Insulation levels

in walls, attics, and basements are visually checked. Ducts are visually inspected. Furnace filters are checked. After all safety tests reveal that the whole house operates safely, only then will the contractor conduct tests to determine energy performance. These tests include a blower door test to measure whole-house air leakage and a duct blaster test to measure duct leakage. Tools like a pressure pan, infrared camera, or smoke stick also might be used to identify air leaks.

- SAFETY FIRST – Visual inspections and health and safety tests can identify problems that need immediate attention, such as a hole in a roof or excessive mold in a wall structure. Addressing these problems is a priority, and the energy upgrade process will continue after such issues are resolved.
- COST-BENEFIT ANALYSIS AND ESTIMATES – The contractor will estimate the costs of installing specific energy-improvement measures and use a computer program to estimate the expected energy savings. The cost of the measures divided by the annual savings will tell you the "simple payback" or how many years the measures will take to pay for themselves. Often investments in energy efficiency provide a better return than stocks, bonds, or savings accounts, while improving comfort.

After energy-efficiency improvements are done, the house is tested out with a blower door, duct leakage, and other tests to make sure the home's energy performance has been improved and that safety standards are met.

5.2.2 Step 2. Making Energy-Efficiency Upgrades

Within a week or so, the contractor will review the test results and provide you with a detailed proposal, including a prioritized list of energy-efficiency measures, packaged options, and price estimates. Together you agree on an energy-upgrade approach, costs, and timelines. Sometimes the certified analyst is an HVAC contractor who can perform the work. Other times, the energy contractor brings in qualified contractors and subcontractors as needed. An energy contractor understands state and local building codes and will work with code officials when necessary to ensure that the improvements meet building code requirements.

5.2.3 Step 3. Testing Out

After the energy upgrades are completed, your contractor will conduct another round of testing to make sure the renovations have improved the home's performance and that safety standards have been met. This "testing out" step usually includes visual inspections, combustion safety (if open-combustion equipment is in the home), and duct blaster and blower door tests. Homeowners should receive a report summarizing the work completed, test results, and estimated energy savings.

References

ACCA. 1995. *Manual S: Residential Heating and Cooling Equipment Selection*, Air Conditioning Contractors of America, Arlington, VA. www.acca.org

ACCA. 2005. *Manual J: Residential Load Calculation, Eighth Edition*. Air Conditioning Contractors of America, Arlington, VA. www.acca.org

ACCA. 2009. *Manual D: Residential Duct Systems*. Air Conditioning Contractors of America, Arlington, VA. www.acca.org

ACCA. 2010a. *ANSI/ACCA Standard #4 Maintenance of Residential HVAC Systems*, Air Conditioning Contractors of America, Arlington, Virginia, https://www.acca.org/industry/quality/quality-maintenance

ACCA. 2010b. *ANSI/ACCA Standard #5 HVAC Quality installation Specification*, Air Conditioning Contractors of America, Arlington, Virginia, https://www.acca.org/industry/quality/quality-installation

ACCA. 2010c. *ANSI/ACCA Standard #6 Restoring the Cleanliness of HVAC Systems*, Air Conditioning Contractors of America, Arlington, Virginia, https://www.acca.org/industry/quality/quality-restoration

ACCA. 2010d. *ANSI/ACCA Standard #9 Quality Installation Verification*. Air Conditioning Contractors of America, Arlington, Virginia, www.acca.org https://www.acca.org/industry/quality/quality-verification

ACCA. 2011a. *Residential Quality HVAC Installation*, Air Conditioning Contractors of America, accessed 6-21-11, www.acca.org/Files/?id=186

ACCA. 2011b. *Verifying ACCA Manual J Procedures*. Air Conditioning Contractors of America, accessed 6-20-2011, https://www.acca.org/Files/?id=68

ACCA. 2011c. *Verifying ACCA Manual S Procedures*. Air Conditioning Contractors of America, accessed 6-20-2011, https://www.acca.org/Files/?id=67

ACEEE. 2011. "Appliance Standards Awareness Project," American Council for an Energy-Efficient Economy, http://www.standardsasap.org/

AHRI. 2003. *Unitary Air Conditioning and Air-Source Heat Pump Equipment*. Standard 210/240, Air-Conditioning & Refrigeration Institute. Arlington, Virginia, http://www.ahrinet.org/App_Content/ahri/files/standards%20pdfs/Superseded%20Standards/AHRI%20(ARI)%20Standard%20210.240-2003.pdf

ANSI. 2011. "Resources: Conformity Assessment Bodies in the U.S.," American National Standards Institute, www.standardsportal.org/usa_en/resources/cab.aspx

APS. 2009. "Shade Treatments and Window Treatments." Arizona Public Service Company, MM-5K-0699-AS, http://www.aps.com/aps_services/residential/waystosave/ResWaystoSave_9.html

ASHRAE. 2007. Standard 52.2-2007, "Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size," American Society of Heating, Refrigerating and Air Conditioning Engineers, www.ashrae.org

Beal, D. J. McIlvaine, K. Fonorow, and E. Martin. 2011. *Summary of Interior Ducts in New Construction, Including an Efficient, Affordable Method to Install Fur-Down Interior Ducts*, prepared by BA-PIRC/Florida Solar Energy Center for the U.S. Department of Energy Building America program, www.buildingamerica.gov

CEC. 2009. "Procedures for HVAC System Design and Installation," California Energy Commission. www.energy.ca.gov/efficiency/qualityhomes/procedures.html

California Energy Commission. 2011. "Geothermal Ground Source Heat Pumps." http://www.consumerenergycenter.org/home/heating_cooling/geothermal.html

ConsumerSearch, Inc. 2008. "Central Air Conditioners: Reviews." The New York Times Company. http://www.consumersearch.com/central-air-conditioners

Cummings, J., C. Withers, E. Martin, and N. Moyer. 2011. *Managing the Drivers of Air Flow and Water Vapor Transport in Existing Single Family Homes*, prepared by BA-PIRC/Florida Solar Energy Center for the U.S. Department of Energy Building America program, www.buildingamerica.gov

DOE. 2007. *Building America Best Practices Series, Volume 6: High-Performance Home Technologies: Solar Thermal & Photovoltaic Systems*. NREL/TP-550-41085; PNNL-16362, Prepared by Pacific Northwest National Laboratory for the U.S. Department of Energy, Richland, WA. www.pnl.gov/main/publications/external/technical_reports/PNNL-16362.pdf

DOE. 2009. "Table 2.1.6 2010 Residential Energy End-Use Splits, by Fuel Type." U.S. Department of Energy Building Energy Data Book. http://buildingsdatabook.eren.doe.gov/TableView.aspx?table=2.1.6

DOE. 2010. "Energy Savers: Space Heating and Cooling." U.S. Department of Energy. http://www.energysavers.gov/your_home/space_heating_cooling/

DOE. 2011. *Building America Best Practices Series Volume 12: Builders Challenge Guide to 40% Whole-House Energy Savings in the Cold and Very Cold Climates*, PNNL-20139, Prepared by the Pacific Northwest National Laboratory for the U.S. Department of Energy, www.buildingamerica.gov

Eastment, M., E. Hancock, and C. Kutscher. 2005. *Projected Costs and Benefits of New Residential Evaporative Cooling Systems*, Golden, CO: National Renewable Energy Laboratory. www.nrel.gov/docs/fy07osti/39342.pdf

EIA. 2005. "Residential Energy Consumption Survey: Preliminary Housing Characteristics Tables," U.S. Energy Information Administration, http://www.eia.doe.gov/emeu/recs/

EIA. 2010. "Geothermal Heat Pump," U.S. Energy Information Administration. http://www.eia.gov/cneaf/solar.renewables/page/heatpumps/heatpumps.html

EIA. 2008. "Average Expenditures for Air-Conditioning by Equipment Type, 2005," U.S. Energy Information Administration. http://www.eia.doe.gov/emeu/recs/recs2005/c&e/airconditioning/excel/tableac7.xls

Farzad, M. and D.L. O'Neal. 1998. *An Evaluation of Improper Refrigerant Charge on the Performance of a Split System Air Conditioner with Capillary Tube Expansion*, Prepared for the Energy Systems Laboratory Research Consortium, Texas A&M University. ESLTR-88/07-01. http://repository.tamu.edu/bitstream/handle/1969.1/2041/ESL-TR-88-07-01.pdf?sequence=1

Henkenius, Merle. 1998. "Geothermal Heating," *Popular Mechanics*, Oct 1, 1998, http://www.popularmechanics.com/home/improvement/energy-efficient/1274631

IECC. 2009. *International Energy Conservation Code*, International Code Council (ICC), Washington, D.C. www.iccsafe.org/Store/Pages

Karr, M. 2011. "Ground-Source Variable Refrigerant Flow Heat Pumps," Washington State University Extension Energy Program, www.energy.wsu.edu/Documents/EEFactsheet-GSHP-Feb2011.pdf

Krigger, John and Chris Dorsi. 2009. *Residential Energy: Cost Savings and Comfort for Existing Buildings, 5th Edition*, Saturn Resource Management, http://srmi.biz/Bookstore.Professionals.Residential_Energy.htm

LBNL. 2011. "Energy Efficiency Standards," Lawrence Berkeley National Laboratory, accessed 2011. http://ees.ead.lbl.gov/taxonomy/term/1

McPherson, G.E., D.J. Nowak, and R.A. Rowntree (eds). 1994. *Chicago's Urban Forest Ecosystem: Results of the Chicago Urban Forest Climate Project*. U.S. Department of Agriculture, Forest Service, Northeastern Research Station.

McWilliams, J.A., I.S. Walker 2005. *Renovating Residential HVAC Systems*, Lawrence Berkeley National Laboratory. LBNL 57406. http://epb.lbl.gov/publications/lbnl-57406.pdf

Northwest Energy Efficiency Alliance. 2009. "Ductless Heat Pump Project," NEEA, http://www.nwductless.com/

NRCan. 2009. "Personal: Residential Air-Source Heat Pumps," Natural Resources Canada, http://oee.nrcan.gc.ca/publications/infosource/pub/home/heating-heat-pump/asheatpumps.cfm

Parker, D., J. Sherwin. 2008. *Experimental Evaluation of the NightCool Nocturnal Radiation Cooling Concept: Annual Performance Assessment in Scale Test Buildings*, Florida Solar Energy Center, http://securedb.fsec.ucf.edu/pub/pub_show_detail?v_pub_id=4389

Rudd, Armin, Joseph Lstiburek, and Kohta Ueno. 2005. *Residential Dehumidification Systems Research for Hot-Humid Climates*, Building Science Corporation Research Report 0505, http://www.buildingscience.com/documents/reports/rr-0505-residentialdehumidificationsystems-research-for-hot-humid-climates

Rudd, Armin. 2011. *Local Exhaust and Whole House Ventilation Strategies*, Prepared by Building Science Corporation for the U.S. Department of Energy, www.buildingamerica.gov

Russell, Marion, Max Sherman, and Armin Rudd, 2005. *Review of Residential Ventilation Technologies*. LBNL Report 57730, Ernest Orlando Lawrence Berkeley National Laboratory. http://www.buildingscience.com/documents/guides-and-manuals/gm-reviewresidentialventilation-technologies/at_download/file

Sherman, M.H., I.S. Walker, and D.J. Dicerkhoff. 2000. "Stopping Duct Quacks: Longevity of Residential Duct Sealants," in *Proceedings of the 2000 ACEEE Summer Study on Energy Efficiency in Buildings*, prepared by Lawrence Berkeley National Laboratory. www.osti.gov/bridge/product.biblio.jsp?query_id=1&page=3&osti_id=776574

Sherwin, J., C. Colon, D. Parker, and E. Martin. 2010. "Performance of Four Near Zero Energy Homes: Lessons Learned," *In Proceedings of the ASHRAE Thermal Performance of the Exterior Envelopes of Whole Buildings XI International Conference*, December 5-9, 2010, in Clearwater Beach, FL, FSEC-PF-452-10, Florida Solar Energy Center, www.baihp.org/pubs/pdf/4zehs_B11.pdf

Smith, B.R. and J. Arco. 1996. "Do You Dig Ground Source Heat Pumps?" *Home Energy Magazine*, www.homeenergy.org/archive/hem. dis.anl.../961112.html

Walker, Ian, Lawrence Berkeley Laboratory, Personal Communication 06-06-2011.

Walker, L. and S. Newman. 2009. *Landscaping for Energy Conservation*. No 7.225, www.treesearch.fs.fed.us/pubs/4285

Definitions

AIR HANDLER: Air handlers blow air through the ductwork for heating, cooling, or ventilation purposes.

ANNUAL FUEL UTILIZATION EFFICIENCY (AFUE): The AFUE measures the amount of fuel converted to space heat in proportion to the amount of fuel entering the boiler or furnace. This is commonly expressed as a percentage. Test procedures have been developed by the Department of Energy to test AFUE.

BRITISH THERMAL UNIT (BTU): A Btu is a unit of energy that is commonly used when describing heating systems.

CONDITIONED SPACE: Conditioned space includes the sections of your house that are intentionally heated and/or cooled. Conditioned space is surrounded by a continuous thermal envelope, which includes an air barrier and thermal barrier. Attics, for example, are unconditioned space if they are vented and have insulation on the attic floor. If you have an unvented attic with insulation along the attic slopes, it is part of the conditioned space.

COEFFICIENT OF PERFORMANCE (COP): COP is a measure of efficiency in the heating mode that represents the ratio of total heating capacity to electrical energy input. For example, if a heating system has a COP of 3, it will deliver 3 units of energy for every one unit of electricity consumed.

ENERGY EFFICIENCY RATIO (EER): EER is a measure of the instantaneous energy efficiency of cooling equipment. EER is the steady-state rate of heat energy removal (e.g., cooling capacity) by the equipment in Btu/h divided by the steady-state rate of energy input to the equipment in watts. This ratio is expressed in Btu/h per watt (Btu/h/watt). EER is based on tests performed in accordance with AHRI 210/240 (AHRI 2003).

HEATING SEASONAL PERFORMANCE FACTOR (HSPF): The HSPF is a measure of a heat pump's energy efficiency over one heating season. It represents the total heating output of a heat pump (including supplementary electric heat) during the normal heating season (in Btu) as compared to the total electricity consumed (in watt-hours) during the same period. HSPF is based on tests performed in accordance with AHRI 210/240 (AHRI 2003).

INTERNATIONAL ENERGY CONSERVATION CODE (IECC): The IECC 2009 was published in January 2009. The IECC 2012 will be published in June 2011.

SEASONAL ENERGY EFFICIENCY RATIO (SEER): SEER is a measure of equipment energy efficiency over the cooling season. It represents the total cooling of a central air conditioner or heat pump (in Btu) during the normal cooling season as compared to the total electric energy input (in watt-hours) consumed during the same period. SEER is based on tests performed in accordance with AHRI 210/240 (AHRI 2003).

Building America Teams

Advanced Residential Integrated Energy Solutions (ARIES)
Lead: The Levy Partnership, Inc.
Members: CDH Energy, Southern Energy Management, Syracuse University Center of Excellence, NTA, Inc., Corporation for Enterprise Development, Ford Foundation, Fannie Mae, Habitat for Humanity International, Manufactured Housing Institute, NeighborWorks America, New York State Energy Research & Development Authority, Systems Building Research Alliance.

Alliance for Residential Building Innovation (ARBI)
Lead: Davis Energy Group
Members: Rocky Mountain Institute, the UC Davis Western Cooling Efficiency and Lighting Technology Centers, Polaris, Heschong Mahone Group, Recurve, Green Home Solutions, Bevilacqua-Knight, Renewable Funding.

Building America Retrofit Alliance (BARA)
Lead: Building Media, Inc,
a subsidiary of E. I. du Pont de Nemours and Co
Members: New Jersey Institute of Technology Center for Building Knowledge, Steve Easley and Associates, and Confluence Communications.

Building America Partnership for Improved Residential Construction (BA-PIRC)
Lead: Florida Solar Energy Center (FSEC)
Members: Newport Partners, Washington State University, Northwest Energy Works, Residential Energy Services Network, Gas Technology Institute, WellHome, Florida Home Energy and Resources Organization, Calcs-Plus and TexEnergy Solutions.

Building Energy Efficient Homes for America (BEEHA)
Leads: University of Nebraska-Lincoln, Lincoln, NE, and the University of Florida, Gainesville, FL
Members: HearthStone Homes, Rezac Construction, City of Omaha, Home Builders Association of Lincoln, Lincoln Remodelers Council, HolyName Housing Cooperation, Excite Builders, City of Lincoln, Barry Rutenberg and Associates, G.W. Robinson Homes, Tommy Williams, Stephan O. Nellis, Omaha Public Power District and Johnson Controls.

Building Industry Research Alliance (BIRA)
Lead: Consol
Members: Washington State University, Arizona State University, UC Davis, University of Utah, General Electric, PVT, MASCO, Ennovationz, Tendril, Sacramento Municipal Utilities District, San Diego Gas & Electric, Arizona Public Service, Salt River Project, Bank of America.

Building Science Corporation (BSC)
Lead: BSC
Members: Affordable Comfort, ARES Consulting, Camroden Associates, Community and Economic Development Association of Cook County, DEAP Energy Group, Greencoast Enterprises, Transformations, Inc., National Grid, and Michael Blasnick & Associates.

Consortium for Advanced Residential Buildings (CARB)
Lead: Steven Winter Associates, Inc.,
Members: MaGrann Associates, Green Builder Media, Alliance to Save Energy's Building Codes Assistance Project, Pratt Center for Community Development, Masco Home Services/WellHome, Fraunhofer Center for Sustainable Energy Systems, Jay Hall & Associates, Inc., Johnson Research and Polaris Consulting Engineers.

Fraunhofer Center for Sustainable Energy Systems (CSE)
Lead: Fraunhofer Center for Sustainable Energy Systems
Members: Owens Corning, Fraunhofer Institute for Solar Energy Systems (ISE), Fraunhofer Institute for Building Physics (IBP), Architect Research Partners, Next Phase Studios Architects, Barley & Pfeiffer Architects, WBRC, Conservation Services Group, Byggmeister, Cambridge Design and Development, and Massachusetts Institute of Technology.

Habitat Cost Effective Energy Retrofit Program
Lead: Dow Chemical Company
Members: Michigan State University, Ferris State University, and Habitat for Humanity, with technical contributions from Duke Energy, DTE, and Exelon.

IBACOS
Lead: IBACOS
Members: building scientists and trainersproduction homebuilders, whole house retrofit companies.

NAHB Research Center Industry Partnership for High Performing Homes (NAHBRC Partnership)
Lead: NAHB Research Center
Members: Southface Energy Institute, ARES Consulting, Jeannie Leggett Sikora, USDA Forest Products Laboratory, Business Excellence Consulting, Brick by Brick, Residential Building Industry Consulting Services, Utilivate Technologies.

National Energy Leadership Corps (N.E.L.C.)
Lead: Pennsylvania State University
Members: SmartDwell, Sequentric Energy Systems, Envinity, ONTILITY, Solar Strategies, Eaton Corporation, Pittsburgh Green Innovators, Partnership for Achieving Construction Excellence (PACE), Conservation Consultants, East Liberty Development, and the Green Building Alliance.

NorthernSTAR Building America Partnership
Lead: University of Minnesota
Members: Center for Energy and Environment, Energy Center of Wisconsin, Building Knowledge, Building Green, Conservation Technologies, Hunt Utilities Group, Verified Green, Wisconsin Energy Conservation Corporation, McGregor Pearce, Minnesota Pollution Control Agency, the University of Wisconsin, and Wagner Zaun Architecture.

Partnership for Advanced Residential Retrofit (PARR)
Lead: Gas Technology Institute
Members: CNT Energy, the Midwest Energy Efficiency Alliance, the Building Research Council at the University of Illinois, and Future Energy Enterprises.

Visit our Websites at:

www.buildingamerica.gov

www.energystar.gov

Building America Program

Building America Program • 1-877-EERE-INFO (1-877-337-3463)
Office of Building Technologies, EE-2J • U.S. Department of Energy •
1000 Independence Avenue, S.W. • Washington, D.C. 20585-0121 •
www.buildingamerica.gov

National Renewable Energy Laboratory
www.nrel.gov

Oak Ridge National Laboratory
www.ornl.gov

Pacific Northwest National Laboratory
www.pnnl.gov

Research and Development of Buildings

Our nation's buildings consume more energy than any other sector of the U.S. economy, including transportation and industry. Fortunately, the opportunities to reduce building energy use—and the associated environmental impacts—are significant.

DOE's Building Technologies Program works to improve the energy efficiency of our nation's buildings through innovative new technologies and better building practices. The program focuses on two key areas:

- Emerging Technologies
  Research and development of the next generation of energy-efficient components, materials, and equipment
- Technology Integration of new technologies with innovative building methods to optimize building performance and savings

Produced for the U.S. Department of Energy (DOE) by Pacific Northwest National Laboratory,
Under Contract DE-AC05-76RLO 1830.

U.S. DEPARTMENT OF
ENERGY
Energy Efficiency &
Renewable Energy

EERE Information Center
1-877-EERE-INFO (1-877-337-3463)
www.eere.energy.gov/informationcenter

August 2011 - PNNL-20421

For information on **Building America** visit **www.buildingamerica.gov**. The website contains expanded case studies, technical reports, and best practices guides.

NOTICE

This report was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or any agency thereof.

Available electronically at http://www.osti.gov/bridge

Available for a processing fee to U.S. Department of Energy
and its contractors, in paper, from:

U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
phone: 865.576.8401
fax: 865.576.5728
email: mailto:reports@adonis.osti.gov

Available for sale to the public, in paper, from:

U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
phone: 800.553.6847
fax: 703.605.6900
email: orders@ntis.fedworld.gov
online ordering: http://www.ntis.gov/ordering.htm

Printed on paper containing at least 50% wastepaper, including 20% postconsumer waste

Table of Contents

Part I. Best Practices for Achieving 30% Space Conditioning Energy Savings in Single-Family Detached Homes Cold-Climate Homes 1

Background and Introduction 1
Primary Recommendations 1
Secondary Recommendations 2
Primary Recommendations for the Envelope 2
Primary Recommendations for the Equipment 24
Secondary Recommendations 28
Case Study #1: Don Simon Homes 31
Introduction 31
Background 32
Standard Practice Home 33
Prototype Home 33
CARB Recommendations 34
Prototype Testing 42
ENERGY STAR Compliance 45
Case Study #2: Wausau Homes 46
Introduction 46
Background 46
Standard Practice Home 46
Prototype Home 49
CARB Recommendations 50
Furnace-Sizing Methods 56
Prototype Home Testing 56
Mechanical Drawings 58

Table of Contents (continued)

Part II: Best Practices for Achieving 30% - 40% Space Conditioning Energy Savings in Single-Family Detached Homes in Hot-Humid Climates 61

Background and Introduction 61
- Primary Recommendations 62
- Secondary Recommendations 63
- Primary Recommendations for the Envelope 63
- Primary Recommendations for the Equipment 70
- Secondary Recommendations 77

First Prototype Case Study: Four Generations of CARB / Mercedes Homes Concrete-Wall Prototypes 79
- Background 79
- Alternate Wall Systems 81
- Revised Base Case 82
- Final Building Specifications 83
- Building Design and Engineering 85
- Construction Process and Analysis 87
- Code Compliance 90
- Sales and Marketing 90

Second Prototype Case Study: Michele II 91
- Product and System Research 91
- Construction Process Analysis 94
- Code Compliance 95
- Cost and Performance 95
- Sales and Marketing 96
- Testing of the Second Prototype 96

Third Prototype Case Study 97
- Pre-Production Houses Concepts and Development 97
- Construction Process Analysis 101
- Cost and Performance 104
- Community-Scale Implementation 104

Table of Contents (continued)

Fourth Prototype Case Study 108
Summary 108
Design Objectives 109
Summary of Innovation System Design Strategies 109
Definition of Reference House 111
Comparison of Final Performance and Cost Tradeoffs with Current Builder Practice 112
Cost Comparison 115
Recommendations for Future Improvements in Design Details, Construction Practices, and Quality-Control Practices 116

Part III: Best Practices for Achieving 30% - 40% Space Conditioning Energy Savings in Single-Family Detached Hot-Dry Climate Homes 117

Background and Introduction 117
Primary Recommendations 117
Secondary Recommendations 119
Primary Recommendations for the Envelope 119
Primary Recommendations for the Equipment 129
Secondary Recommendations 134
Case Study #1: Beazer, Southern California 136
Introduction 136
Systems Engineering and Building Specifications 136
Additional Changes of Interest to the Builder 136
Blower-Door Testing 140
On-Going and Future Work with Beazer Southern California 141
Case Study #2: Beazer Homes, Sacramento, California 142
Background 142
Standard Specifications 142
Base Case 143

Table of Contents (continued)

Prototype Alternatives 143
Prototype Final Specifications 146
Modeled Prototype Performance 146
Test Objectives 147
Case Study #3: Second (PV) Prototype 148
Background 148
Initial Standard Specifications 148
First Prototype Specifications 148
Delayed Implementation 149
Initial Specifications Changes 149
The SMUD "Power Roof" Program 150
Beazer "Power House" 150
Photovoltaic Power Generation 151
Current Implementation 153

List of Terms Used

ABS	acrylonitrile butadiene styrene plastic (an easily machined, tough, low-cost rigid thermoplastic material with high impact strength)
AC	air conditioning
ACCA	Air-Conditioning Contractors of America
ACH	air changes per hour
AFUE	annual fuel utilization efficiency
B-vent	double-walled combustion gas ventilation piping for gas- or oil-burning appliances
CARB	Consortium for Advanced Residential Buildings
C.E.C.	California Energy Commission
CFC	chloro-fluoro carbon
CFM	cubic feet per minute
CMU	concrete masonry unit
CO	carbon monoxide
DSH	Don Simon Homes
DX cooling coil	direct expansion cooling coil
EF	energy factor
EIFS	Exterior Insulation Finish System
ELA	effective leakage area
EPS	expanded polystyrene
FSEC	Florida Solar Energy Center
HERS	Home Energy Rating Score
HSPF	heating seasonal performance factor
HUD	Housing and Urban Development
HVAC	heating, ventilating, and air-conditioning
ICF	insulated concrete form
IRC	International Residential Code
low-e	low-emissivity
MEC	Model Energy Code
MMBtu	million Btu
NFRC	National Fenestration Rating Council

OC	on center
OSB	oriented strand board
OVE	optimal value engineered
pa	pascals
PV	photovoltaic
PVC	poly-vinyl chloride
R&D	research and development
REM/Design	software for determining residential energy usage
SEER	Seasonal Energy Efficiency Ratio
SHGC	solar heat gain coefficient
SHR	sensible heating ratio
SMUD	Sacramento Municipal Utility District
SWA	Steven Winters Associates, Inc.
TJI	manufacturer of truss joists
VT	visible transmittance
UL	Underwriter's Lab
WECC	Wisconsin Energy Conservation Commission
WESH	Wisconsin ENERGY STAR Homes
WISCheck	software based on Wisconsin's version of the MEC
XPS	extruded polystyrene

I. Best Practices for Achieving 30% Space Conditioning Energy Savings in Single-Family Detached Cold-Climate Homes

Figure I-1. A CARB cold-climate house

Background and Introduction

The Consortium for Advanced Residential Building (CARB), one of the Building America teams, has worked with several cold-climate builders on home designs (Figure I-1) that achieve at least a 30% savings relative to the Model Energy Code (MEC). This report describes the recommended best practices to achieve these savings without compromising health or safety.

A list of Primary Recommendations and one of Secondary Recommendations is included, followed by a discussion of each item on the list. Case studies drawn from CARB's Building America experiences are presented as examples.

Primary Recommendations

Envelope

- Insulated low-E windows
- Exterior wall framing: 2 x 6 studs at 24 in. on-center
- Lumber-saving framing details (open three-stud corners, ladder bracing at interior partitions, right-sized headers)

- Unfaced cavity insulation with air sealing and vapor retarder, achieving blower door tightness criterion of 1/4 cubic feet per minute (CFM) @ 50 Pascals per square foot of building envelope area
- Full Oriented Strand Board (OSB) sheathing; or semi-permeable insulating sheathing with OSB corner bracing
- Well designed and executed building envelope water-management system
- Exterior insulation at band joists
- Interior foundation insulation or insulation within the foundation wall

Equipment

- Manual J / Manual D HVAC sizing
- Condensing furnace (91% AFUE+)
- Power-vented water heater
- Ducts mastic sealed (leakage to outside less than 5% of fan-flow)
- No ducts in outside walls, floor cantilevers, or attics
- No panned returns
- Central air-return with transfer grills at secondary spaces (balanced air-flows)
- Source point humidity control ventilation with low-sone bath fans on automated control
- No unvented gas appliances (except a gas range with a range hood exhausting to the outside)
- Exhaust-only fresh-air ventilation

Secondary Recommendations

- In-line framing
- Energy-efficient lighting
- ENERGY STAR™ appliances
- Compact duct distribution system

Primary Recommendations for the Envelope

Insulated Low-E Windows

Discussion

- Low-E coated double-glazed windows are universally applicable to cold-climate homes. A low-E coating reduces heat loss in cold weather and heat gain in hot weather (i.e., it has a high total-unit R-value).

This glass has the following characteristics, which can be found on the label attached to all glass (Figure I-2). Look for the National Fenestration Rating Council (NFRC ratings, which are slightly different from conventional ratings).

Desirable Low-E Glazing Characteristics for Cold Climates

- Total unit R-value should be more than 3.0.
- If possible, buy glass with the low-E coating on the #3 surface (this is the third of four surfaces on the two sheets of glass, counting in from the outside) to reduce heat loss to the outside. It is very likely that low-E glass with a high visible transmittance (VT) or high solar heat gain coefficient (SHGC); for enhanced passive solar gain, will have the coating on the #3 surface because it will be intended for use in cold climates, where passive gain is important.

Benefits Demonstrated in CARB/Building America Projects

- The cost-effectiveness of low-E glazing has been demonstrated in every CARB cold-climate project.
- The low-E coating provides the equivalent of another layer of glazing at a much lower cost.
- Low-E glazing feels warmer, making it possible to dispense with registers located directly below windows, and thus reducing the cost of air distribution.
- The risk of condensation is reduced because of the high R-value.

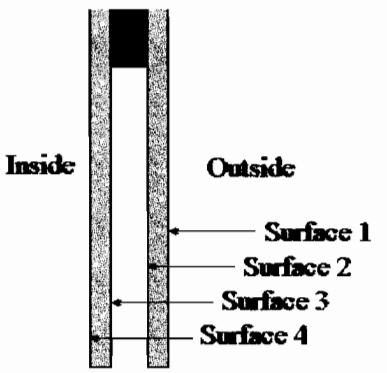


Figure I-2. Low-E glazing for cold climates

Exterior Wall Framing: 2x6 Studs at 24 in. On-Center

Discussion

The 2 x 6 studs at 24 in. on-center use less lumber than 2 x 4 studs at 16 in. on-center (assuming in both cases that measures are taken to reduce unnecessary studs – see next item). Less lumber means less thermal loss through the studs.

There is no need for concern about the longer span of the top plate. If a joist or rafter rests dead-center between the studs, at least one of the plates will span and support the load when using double top plates. See the "Secondary Recommendations" section for a discussion of in-line framing and single top plates. The primary concern with the use of 24 in. on-center studs is the capability of the exterior and interior finishes to span the extra distance between studs.

In practice, the lower strength of ½-in. board does not pose a problem for most home-buyers. Interior partitions using studs at 24 in. on-center and covered with ½-in. gypsum board are in wide use. But for custom or luxury levels of construction, it is recommended that 5/8-in. gypsum board be used with 24 in. on-center studs.

Some exterior finishes cannot span 24 in. With vinyl siding, it may be necessary to buy a heavier gauge material; check with the manufacturer's specifications for the maximum allowable span. Stucco applied over 1 in. of Expanded Polystyrene (EPS) foam also cannot span 24 in. Wall sheathing panels of all kinds are span-rated, so check the rating before choosing sheathing or exterior finish panels.

Application in CARB/Building America Case Studies

- CARB has used studs at 24 in. on-center in several projects.
- In most cases, in-line framing was used (see Secondary Recommendations).
- Where vinyl siding was used, CARB switched to all-OSB sheathing.
- Because the walls were fully sheathed, no changes were necessary in the thickness of vinyl siding.
- No problems arose with regard to interior finish.

Lumber-Saving Framing Details

Discussion

Many lumber saving details are possible that not only reduce cost, but save energy, along with saving timber.

Open Three-Stud Corners

As shown in Figure I-3, the three studs normally used at an outside corner can be rearranged to create an open cavity that can be insulated later (in the conventional box arrangement, the cavity must be insulated by the framers; typically this is not done). The stud that provides nailing for wallboard can be replaced by a 1 x 6, or by drywall clips.

Ladder Bracing at Interior Partitions

As shown in Figure I-4, the conventional method of framing at a T-intersection creates an uninsulated cavity. It also uses more material than necessary. Replacing the two studs normally used with three to five pieces of blocking saves lumber, provides a use for cut-off lumber pieces, and allows insulation to continue through the T-intersection. The blocking can be replaced by a 1x 6 (as shown), or by drywall clips.

For production convenience, builders commonly use the same (maximum) header size for all openings. This is wasteful of expensive large-dimension framing and increases heat loss because headers conduct more heat than does an insulated cavity. Simply using two (or three) header sizes for different width openings resolves this problem with a minimum of extra measuring.

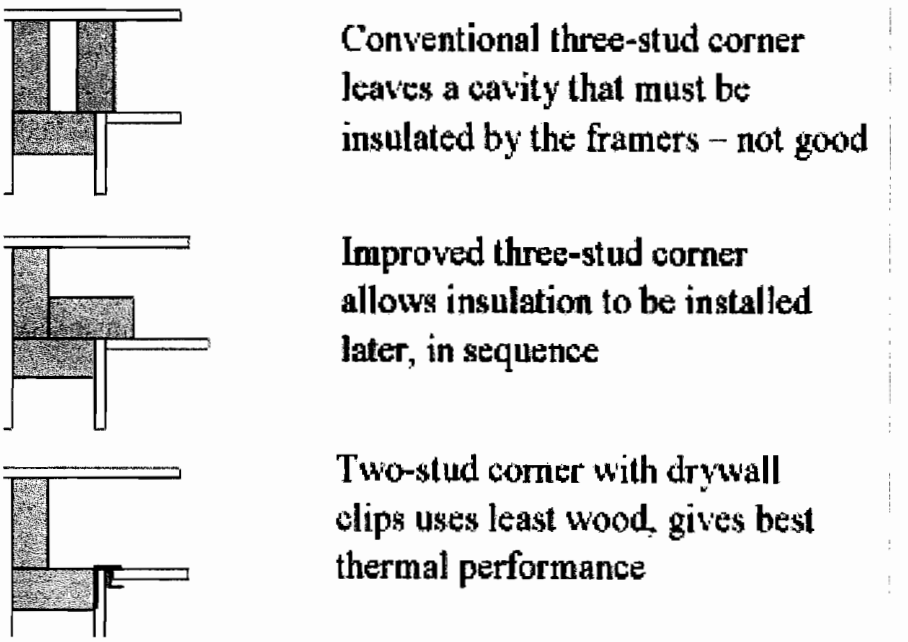


Figure 1-3. Three-stud corners

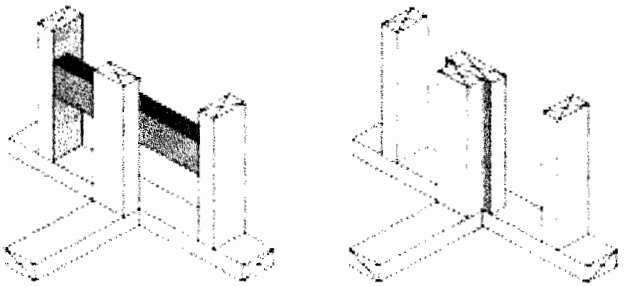


Figure I-4. Ladder bracing at T-intersections

Benefits Demonstrated in CARB/Building America Case Studies

- As part of its "value engineering" work for several builders, CARB has demonstrated the cost and energy savings of lumber-saving framing details.
- On a typical 2,000-ft^2 two-story home (see the Don Simon Case Study), these measures can save 750 board feet of lumber.

Air Sealing

Discussion

Moisture can penetrate through solid materials by "osmosis," a problem discussed later in the section about "Vapor Retarder." In all but the coldest climates most moisture problems stem not from osmosis, but from humid inside air leaking into the wall cavities and condensing on the cold sheathing or from cold outside air reaching inside surfaces, causing condensation and mold.

There are three solutions to this problem:

- Reduce the inside humidity
- Make the cavity warmer by using insulating sheathing (this only works for inside air leaking out)
- Prevent inside or outside air from circulating within the cavity.

Reducing Interior Relative Humidity

Very high inside relative humidity is not healthy for people or the building and should be prevented. The goal is not to dry the home out, but to keep inside relative humidity at healthy levels (35% to 50%). The occasions where inside humidity might exceed 50%, along with recommended cures, are as follows:

- A small home with many occupants (provide adequate ventilation – see later discussion)
- An unventilated shower (provide adequate ventilation)
- A dryer exhaust terminates within the living space (terminate outside)
- Use of a humidifier (never install one except where necessary to protect flooring in dry climates)
- Use of an unvented gas heater (strongly discourage their use – see below).

Heat-recovery ventilators are not recommended. They are expensive, require maintenance, and often are irritating to occupants because they tend to run all the time, delivering substantial flows of air that is colder than room air.

Using Insulating Sheathing

While insulating sheathing can help reduce condensation in walls, it is not the solution of choice for reasons discussed in detail below.

Air Sealing

Air sealing is the primary defense against condensation within cavities or on cold inside surfaces.

Because vapor retarders seldom if ever seal around penetrations or at edges, vapor retarders should not be thought of as an air-sealing measure. Leakage occurs at edges, corners, joints, and penetrations. If these areas are sealed, the gypsum board by itself seals the broad expanses of wall and ceiling, without the help of the vapor retarder.

Air-Sealing Techniques

Care must be taken to seal off all the passages by which interior air can migrate within the walls and into the attic or into cathedral ceiling cavities. The following areas should be sealed:

- Between electrical boxes and gypsum board (typically using low-expansion foam)
- Openings in the back of electrical boxes or installing boxes in an air-sealing shell made for the purpose
- Holes for electrical or plumbing in the top and bottom plates of exterior walls and in the top plates of interior partitions where wiring runs into the attic or a cathedral ceiling (figures I-5 and I-6)
- All penetrations into the attic or a cathedral ceiling, including the following:
    - Bathroom fan housings
    - Recessed light fixtures
    - Skylights and light tubes
    - Air diffusers
    - Smoke alarm outlet boxes.

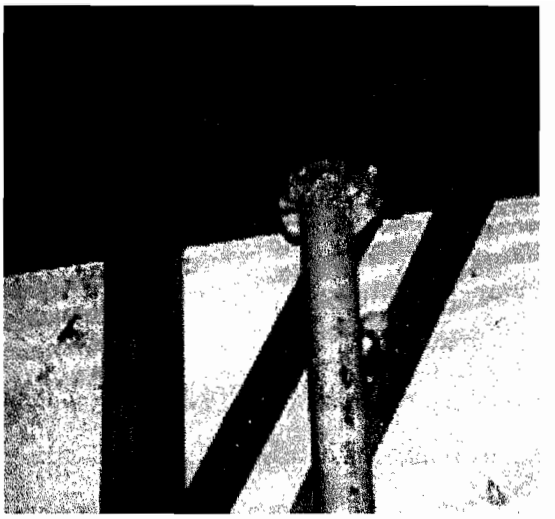


Figure I-5. Sealing techniques

It is also important to seal cracks and holes in the outside of walls.

Why? Air leaks to the outside can suck inside air into the walls. They contribute to heat loss in this way, as well as causing condensation.

Figure I-6. Sealing techniques around wiring

There are many sealing products available, each suited for a particular job:

- Foam guns (Figure I-7)
  - o This foam is the all-purpose sealing tool for nearly any gap
  - o Low-expansion foam is available in cans that attach to inexpensive application guns
  - o These guns feature a screw-plunger that closes off the nozzle and keeps the gun clean between uses
  - o There is also a can of cleaner that can be attached to the gun
  - o For large gaps, high-expansion foam is available.
- Sill sealer
  - o The gap under the mud sill can be foamed with low-expansion foam
  - o Protecto Wrap, called the "Triple Guard." (Figure I-8), is an alternative recommended product
- Other gaps in the wall
  - o Another product by Protecto-Wrap, "Energy Plate Liner" seals the gap between the subfloor and wall plate (Figure I-9)
  - o The easiest and best way to seal the horizontal gaps above and below top and bottom wall plates is to extend OSB or plywood sheathing down or up to cover the gaps.
- Sealing around windows
  - o If windows with flanges are used and they are properly flashed, air leakage between the window frame and the wall framing is unimportant
  - o However, filling these gaps with fiberglass or low-expansion foam will keep inside air from circulating and reduce condensation
  - o If ordinary wood windows are used without frames, it is very important to foam the gap between the window and the framing with low-expansion foam

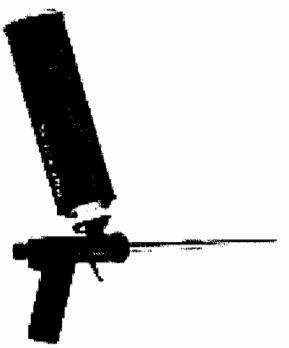


Figure I-7. Foam gun

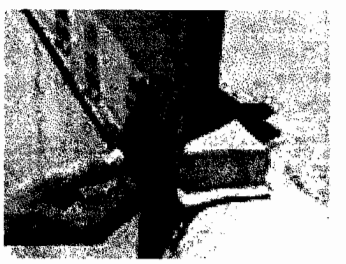


Figure I-8. Sill sealer

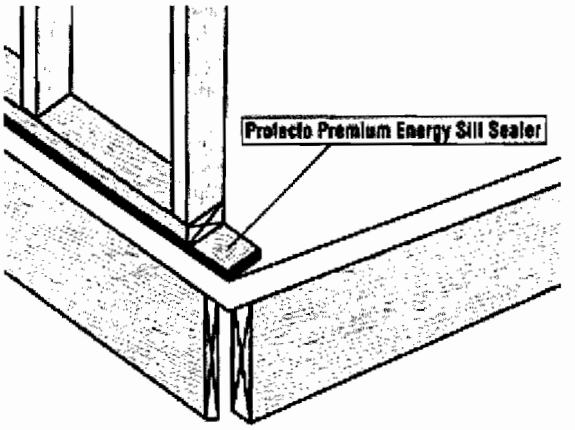


Figure I-9. Energy plate liner

Air-Sealing Criterion

CARB recommends that building envelope tightness measures, including air sealing, result in no more than 1/4 CFM per square foot of envelope area leakage when measured at 50 Pascals in a blower door test.

Application in CARB/Building America Case Studies

Gap sealing has proved to be a crucial aspect of high-performance home construction and is used on most CARB homes. CARB homes consistently achieve the targeted air leakage rates.

Un-faced Cavity Insulation and Vapor Retarder

Discussion

There are many types of insulation available, but none are as cost-effective as fiberglass batts. Fiberglass comes with and without facings. A kraft-paper facing adds cost, but if properly installed it provides a good vapor retarder for all but the coldest climates. CARB has found that it is rare for insulating sub-contractors to install faced batts properly. An acceptable job of insulating is more likely if unfaced batts with a separate vapor retarder are specified. Also, the vapor retarder can be "tuned" to the climate if it is separate from the insulation.

Unfaced Batt Installation

Unfaced batts should be installed as follows:

- Cut batts the proper width to fit narrow stud spaces
- Fit batts around wiring and piping. Split batts front to back so they fit on both sides of wiring.

- Fit batts to completely fill all the cavities, with a minimum of gaps and voids, to prevent any air that leaks into the cavity from circulating.

The R-value of a given thickness of fiberglass insulation increases as more fiberglass is added (density increases). For a modest increase in material cost, the R-value of 3-1/2 in. of insulation can increase from R-11 to R-13 or R-15. These denser insulations are readily available.

Vapor Retarder

Once the walls and ceilings are sealed to inhibit air movement, a vapor retarder can be chosen to suit a specific climate. The vapor retarder should be just enough of a barrier to control osmosis in the coldest weather, and no more. As the number of continuous cold days without a warming period decreases, the effectiveness of the vapor retarder should also decrease.

> *Why: A vapor retarder inhibits the desirable ability of the wall to dry toward the inside in the event that it gets wet for any reason.*

Specific recommendations include the following:

- In regions with more than 8,000 degree-days a continuous 6-mil polyethylene membrane or foil-backed gypsum wallboard are preferred solutions. Foil-backed gypsum board should not be used with tile or any other wall covering that creates a vapor retarder, such as vinyl wall fabric, because the gypsum board will then be trapped between two vapor retarders, enhancing the possibility of moisture damage.
- For less severe cold climates, 6-mil poly is acceptable, but vapor retarder paint is the recommended solution. Vapor retarder paint is a "good enough" vapor retarder with the advantage that it allows any moisture in the walls to dry to the interior.
- Kraft or foil facings on fiberglass batts are not recommended unless they are carefully installed:
    - Facings should be "face stapled, not "inset stapled," to avoid the puckers between the studs and insulation that occur with inset stapling (see figure I-10).
    - Face staples must be set flush with the studs to allow proper installation of drywall.

Application in CARB/Building America Case Studies:

CARB homes in cold climates typically have 6-mil poly vapor retarders over unfaced fiberglass batts. While the poly is not ideal in less than severely cold climates, it has performed satisfactorily.

Full OSB Sheathing or 1-in. Extruded Polystyrene (XPS) Insulating Sheathing

Discussion

Insulating sheathing has the following advantages and disadvantages relative to OSB or plywood sheathing:

Advantages

- It helps reduce condensation, especially in mild weather.
- It provides useful additional wall insulation, including insulation over the studs, plates and headers, which are otherwise a partial thermal short-circuit over 20% of the exterior wall.
- It provides outside insulation over band joists and headers.

Disadvantages

- Insulated sheathing adds cost.
- Insulated sheathing only applies to walls, and not the attic, which has an area comparable to the walls. Therefore, careful gap sealing is crucial regardless of the type of sheathing. An investment in gap sealing is much more important than investing in extra insulation.
- The IRC does not allow 1x 4 let-in bracing or metal bracing to be part of the wind-bracing system. At 7/16-in. OSB or plywood wind bracing, only ½ in. of insulation can be applied, providing only R-2 or R-2.5 insulating value over the approximately 30% of the wall that typically has wind bracing.
- Insulation does not support exterior finishes as well as wood panels and cannot be used under (for example) wood shingles. If the advantages of 24 in. stud spacing are to be realized, OSB sheathing will be required under many finishes.
- Insulating sheathing is least helpful in preventing condensation in the coldest weather because the R-value of the sheathing is not high enough to increase the interior sheathing surface temperature above the dew point during very cold conditions and condensation results
- Even with insulated sheathing, air sealing is crucial. Once the cavity is well-sealed, the insulating sheathing loses its importance in controlling condensation.

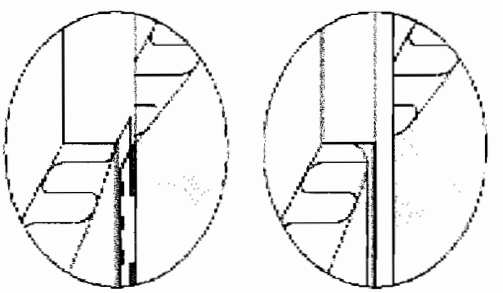


Figure I-10. The difference between face stapled (left) and inset stapled (right) Kraft or foil-faced fiberglass batts

These pros and cons balance each other. CARB recommends either full OSB or plywood sheathing, or 1-in. extruded polystyrene (XPS) foam sheathing or, ½-in. XPS foam over OSB or plywood wind bracing panels.

In cold climates, NEVER use the type of insulated sheathing that has vapor-retarding skins (typically some form of polyethylene sheet). This practice traps any moisture that gets into the walls.

CARB also does not recommend the use of highly vapor-permeable sheathing material (gypsum-based products).

> *Why? The combination of a water-absorbing exterior cladding, such as brick; a strong interior vapor retarder, such as 6-mil poly; and a vapor-permeable sheathing, such as gypsum sheathing together can create serious condensation and rot if the home is air conditioned.*

Application in CARB/Building America Case Studies

For both William Ryan Homes and Don Simon Homes, CARB substituted full OSB sheathing for both permeable sheathing and for highly impermeable foam sheathing. The energy cost was small, the added condensation risk was not important. Other CARB cold-climate builders have routinely used OSB sheathing without problems.

Well-Designed and Executed Building Envelope Water Management System

Discussion

Preventing water intrusion through the envelope is very important and typically neglected. The areas of greatest concern (beginning at the top of the house) are listed below, with numbers referring to Figure I-11.

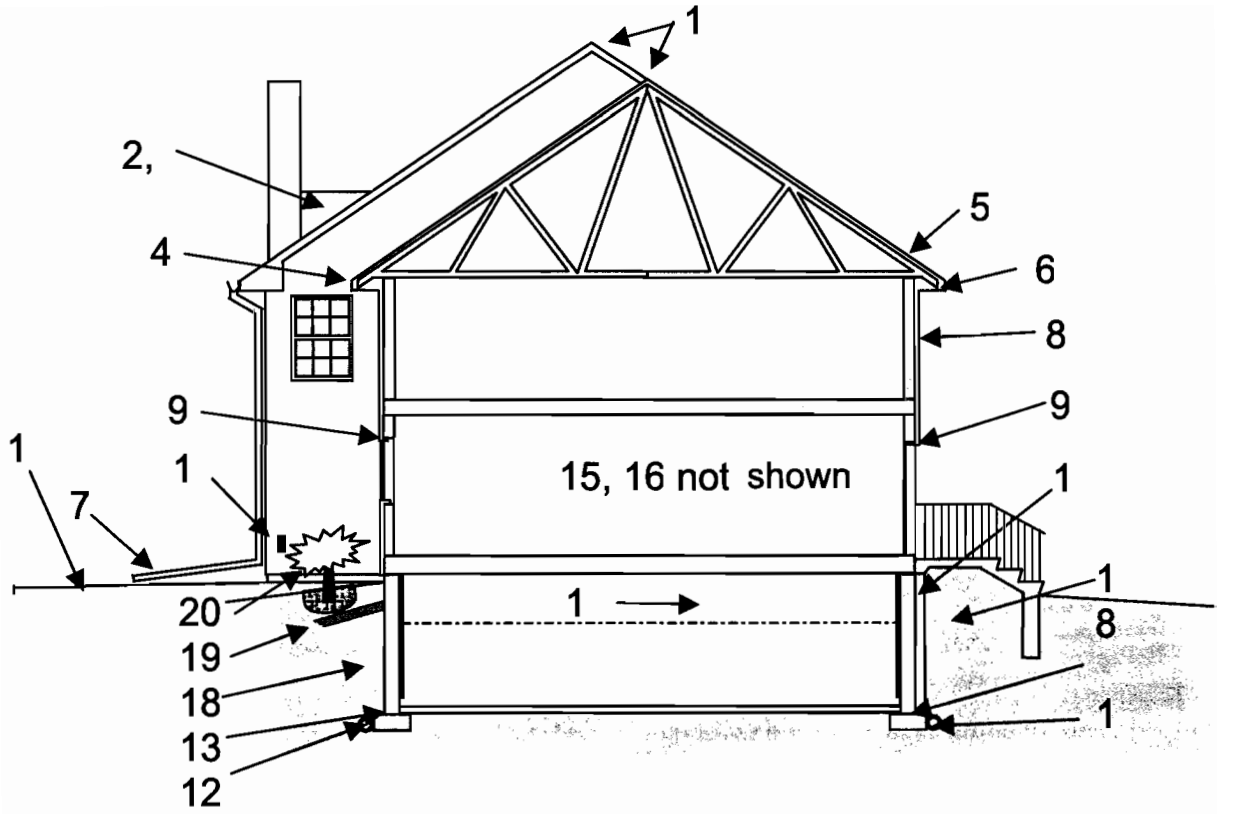


Figure I-11. Preventing water intrusion

Explanation of Figure I-11: Preventing Water Intrusion

Roof

1. Prevent Rain and Snow Leakage into Ridge Vents

The usefulness of roof cavity venting is controversial, but the practice is currently required by code. Minimizing rain and snow entry through the ridge vents is more important than ensuring a lavish flow of air. Choose a product on the basis primarily of how well it blocks water entry and secondarily on how well it ventilates.

2. Provide Adequate "Crickets" Behind Chimneys and Other Projections through the Roof

There must be a way of sending water around the objects like chimneys and skylights that block the flow of water down the roof. Behind tall objects like chimneys, install the largest and steepest "cricket" (small gabled roof) that will fit. This will also help prevent the buildup of snow.

3. Place Chimneys, Dormers, etc., away from Valleys and Adequately Separated from Each Other

Water collects and runs down valleys. Running valleys together (for example, between closely spaced dormers) or placing a chimney or other obstruction in a valley almost guarantees water leakage. During winter, snow will collect in these tight spaces and cause ice dams.

4. Use "Kick-Out" Flashing At The Joint Between An Eave And A Sidewall

Where a roof runs into a sidewall, "step flashing" is required at the joint. If the roof stops before the wall does, the water that collects against the step flashing will run in behind the siding unless it is directed back out onto the roof by "kick-out" flashing.

5. Use An Impervious Layer At Valleys And Eaves

At eaves and valleys, an impervious layer of peel-and-stick modified bituminous flashing material should be installed under the roofing.

> *Why? When it is about 20 degrees outside, snow on the roof is likely to melt, run down to the eaves, and freeze there, creating an ice dam. Further melting will run back up the roof behind the dam and leak through the shingles. The impervious layer keeps most of this water from entering the building.*

In snowy climates, a 3-ft band is recommended in both places. In very snowy climates, the entire roof might be better covered with metal roofing to encourage snow to slide off.

6. Size Gutters Properly and Provide More Than the Minimum Number of Downspouts

In snowy climates, the lip of gutters should be just below the plane of the roof shingles to minimize damage during snow slide-off. Larger gutters with frequent downspouts are more able to handle downpours.

7. Discharge Downspouts At Least 10 Ft Away From The Sidewall

Simply spilling a downspout onto a splash block will not keep this concentrated flow of water from flowing against the foundations.

- Extend downspouts at least 10 ft away from the house
- If a solid extension piece is used, it can be placed within a projecting planting bed to avoid interfering with mowing
- Collapsible extensions are available that can be mowed over.

Sidewalls

8. Use "Rain-Screen" Sidewall Construction

All siding materials leak. If the siding is designed as the only surface that sheds water, the smallest imperfection will let water in. Once in, the water cannot get out, and it will cause rot in the framing. Exterior Insulation Finish System (EIFS) is a prime example of this kind of construction. The only siding that actually sheds water is triple-layer wood shingles, where water that leaks in is kicked back out by the shingle beneath.

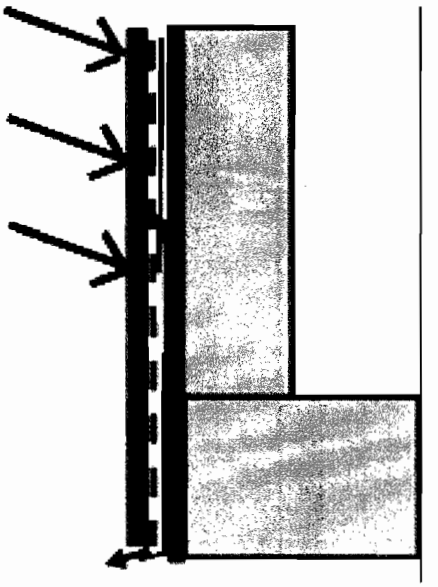


Figure I-12. Rain-screen sidewall construction

The proper way to build an exterior wall (Figure I-12) is as follows:

- Treat the cladding as a screen that stops the wind and most of the rain, but lets some water in
- Behind the cladding, protected from the wind, is the water-repellant membrane
- Because there is no wind pressure behind the cladding, water that penetrates will simply fall down the wall by gravity
- Because water will be running down the membrane, all flashing around windows, doors and other penetrations must be shingled top over bottom (see next item)
- Because water will be running down the membrane, wood or wood composite siding should not be placed hard against the membrane; use wood spacers or special sheet material made for the purpose.

The water-repellant membrane should be made as follows:

- Exposed OSB sheathing, exposed foam sheathing, or housewrap with vertical joints taped with red sheathing tape and horizontal joints protected with "Z" flashing (upper leg behind the upper sheet, lower leg over the lower sheet) made of metal or peel-and-stick flashing membrane
- Do not rely on surface-applied peel-and-stick flashing strips over the outside of horizontal joints; use the Z-flashing method in all cases.

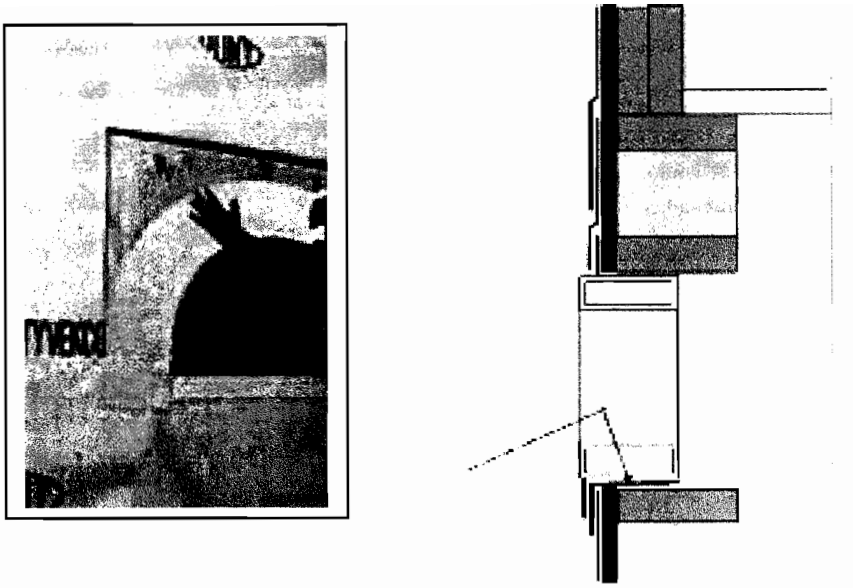


Figure I-13. Peel-and-stick flashing membranes used around windows and doors

9. Properly Flash Around Windows And Doors

The manufacturers of peel-and-stick flashing membranes, such as DuPont's FlexWrap, publish detailed instructions on the use of these products around windows and doors (Figure I-13). The typical requirements are as follows:

- If using housewrap, cut a flap over the top flange of the window and tape it up out of the way
- Apply tape over the side flanges
- Apply tape over the top flange and over the top of the side tapes
- Fold the flap down over the top flange and secure with tape
- Do not tape the bottom flange, which should lap over the housewrap; leave open for water to get out.

10. Use Flashing instead of Caulking around Wall Penetrations such As Bracket Lights, Hose Bibbs, and Exterior Receptacles

- At penetrations for outlet boxes, use prefabricated blocks (with vinyl siding) or create a mounting block that is shingle-flashed to the water-repellant membrane behind the cladding
- Seal between the cladding and penetrations where convenient, but don't rely on this sealant to stop the water.

Foundations

11. Cover Crawl Space Floors with an Impervious and Durable Material

Building scientists have shown that an essential means of preventing wet crawl spaces is to cover the floor with concrete or a plastic membrane. Fiberglass reinforced polyethylene is the membrane material of choice.

12. Provide Adequate Drainage of Ground Water through Footing Drains

- Measures taken to prevent surface water from reaching the foundations in most cases will solve water problems
- In some cases, high groundwater will keep the footings wet
- Water from wet footings can rise by capillary action into the foundations
- A good protection is to install drainage at the bottom of the footings
- These drains should be perforated PVC, not corrugated ABS
- They must drain to the surface by gravity
- If that is not possible, they must run to a dry well or to a sump pump that discharges the water well away from the foundations.

13. Provide a Membrane between Footings and Foundation Walls

In cases where ground water persists near or at the level of the footings, it is highly advisable to add a layer of plastic membrane on top of the footings. This membrane keeps water from rising into the foundations by capillary action ("rising damp"). Occasional penetrations for dowels are not a problem.

Porches and Terraces

14. Support Terraces, Porches and Decks at the Sidewall to Maintain a Slope away from the Sidewalls

All structures that abut the home need to be supported on solid supports:

> *Why? Even well-compacted backfill will slowly settle over time. If the terrace or porch is supported only on fill, it is likely sooner or later to slope the wrong way. Once this happens, the problem escalates, because more water flows toward the home, increasing settlement.*

Also, supporting a porch on fill places fill against the band joist framing, which is very bad practice.

15. Drain Subgrade under Terraces to Prevent Backflow toward Foundations

- Terraces are often set over a recessed, gravel-filled bed
- This bed acts like a swimming pool, holding water that flows through the cracks between the stones

- If this "pool" is not drained away, water can collect and drain back against the foundations.

Grading and Planting

16. Use Loose Stones or Other Means to Prevent Splashback from Eaves without Gutters

Water falling off un-guttered eaves, especially for two or more stories, will splash back onto the siding, causing unsightly stains, damaging the siding and removing the finish. A layer of loose stones set in a bed will help to break up the water and minimize splashing.

17. Grade away from the Sidewalls around all Sides of the Home (Figure I-14)

- Typical requirements are to grade away 6 in. in the first 10 ft
- This is sometimes impractical; for narrow spaces, grade more steeply
- At uphill conditions, create a swale (crosswise drainage ditch) between the slope and the foundations, making sure the swale drains to one or both sides.

18. Compact Backfill Against The Foundation To Prevent Settlement

- Builders often backfill quickly to provide access to the floor deck
- This backfill will settle, so that surface water flows back toward the foundations, creating serious water problems
- Instead, compact the backfill as it goes in to 90% compaction, in 6-in. layers
- Make sure the foundation is properly braced before backfilling.

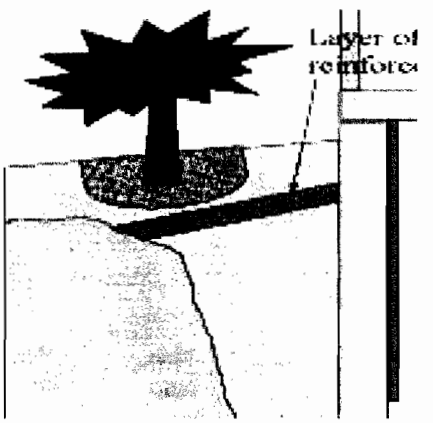


Figure I-14. Grading and planting

19. Provide a "Ground Roof" Spanning from the Foundations over Porous Backfill to Non-Porous Subsoil

A "Ground Roof" is an idea invented by building scientist William Rose. It provides very effective protection for foundations against water intrusion from surface run-off. In combination with positive surface drainage away from the foundation, the ground-roof provides additional protection from water intrusion when the surface becomes saturated or otherwise losses its ability to effectively drain surface water.

20. If there is no Ground Roof, do not plant near the Home

So-called "foundation planting" is destructive to the home in many ways

- It encourages mildew by inhibiting air flow
- It restricts proper maintenance of the home's outside skin
- Most important, watering the foundation planting automatically waters the backfill and, therefore, the foundations
- The ground roof prevents water from flowing down, so planting can occur above it
- In all other cases, keep shrubs and trees at least 5 ft from the foundations.

Application in CARB/Building America Case Studies

Working with its builder team-members, CARB encourages the use of most or all of the above measures. Some measures, such as the prohibition against foundation planting, are widely ignored, because the builder does not install the planting or try to educate the homeowner. Increasingly, these measures are becoming more of an issue with builders, because of concerns about litigation for mold.

The above measures are all good practice, and taken together will go a very long way toward preventing moisture-related problems throughout the building envelope.

Exterior Insulation at Band Joists

Discussion

No one has developed a simple, cost-effective method for insulating the band joist area, which typically accounts for 10% of the exterior wall. The most common solution, fiberglass insulation stuffed inside the band joists, is not the preferred solution. Inside basement air, which may be humid, can circulate behind the fiberglass (which is typically not installed carefully), condense on the band joist, and cause mold, or sometimes rot (this is less likely to occur at the second floor band).

XPS insulating sheathing warms up the band joist and inhibits condensation. However, approximately 30% of the band joist that is located at wind bracing will only be insulated with ½-in. foam insulation yielding R-2.5, which is not adequate. Thus, inside fiberglass will still be required, and condensation can occur behind the fiberglass.

One alternative that is often recommended, but seldom practiced, is to set the band joist in by 1-1/2 in. (assuming 2 x 6 wall construction) and to fill this gap with foam insulation

placed before sheathing. This system requires training framers in an unfamiliar practice and requires the framers to place the insulation. If they don't have the insulation at hand, it will be omitted, and no one will see the error.

Any system for insulating more carefully inside the band joist requires that the insulation be tightly fit between joists for that portion of the band where the framing is perpendicular to the outside wall, typically more than half its length. Many schemes have been proposed to accomplish this, but none have proved practical.

Balancing these issues, CARB recommends this solution:

- Include as part of the gap sealing the installation of urethane foam sealant at the perimeter of the fiberglass batt inserts placed inside the band joists. This has the advantage of simply extending gap sealing work that is needed elsewhere on the job.

Application in CARB/Building America Case Studies

CARB's builders have not seen this as an important issue (current practices does not lead to call-backs). They have therefore typically added fiberglass batt insulation inside the band joists. Given a rise in concern about mold, CARB expects that its builders may agree to the recommended added gap sealing.

Interior Foundation Insulation or Insulation Within the Foundation Wall

Discussion

Insulating basements is increasing for two reasons:

- More people are finishing their basements
- It is not possible to achieve a 30% reduction in space conditioning without insulating the basement, including the portion above grade.

Unfortunately, improperly installed basement insulation can cause major mold problems.

> *Why? Basements are at the bottom of the house. Any water overflowing within the living space or entering the roof or walls will tend to end up in the basement. Basement walls are vulnerable to surface and underground water entry. Finally, basement walls are often cold enough to cause the humidity in the basement air to condense. Insulation may cover up water problems, or keep walls cold during humid weather, both leading to mold growth.*

There are four ways to insulate a basement wall:

- Insulate the outside surface: CARB does not recommend this approach for two reasons:
    - It is very difficult to prevent the insulation from becoming a hidden route for termite access to the framing
    - No method has been invented to finish the insulation above grade (which is the most important insulation on the wall) with a material that will stand up to weed-whackers, mowers, and other mechanical damage and that looks acceptable.

- Insulate on both sides: Insulated Concrete Form (ICF) foundations are growing in popularity. But because they have exterior foam insulation, they have the same problems as exterior insulated walls.
- Insulate the inside surface: This is one of the two ways recommended by CARB, providing the insulation is installed as recommended or another example of insulation on the inside surface of the basement wall is the proprietary precast foundation, "Superior Wall."
- Insulate within a concrete wall: This configuration (for example as the in the "T-Mass" system by Dow) is also recommended.

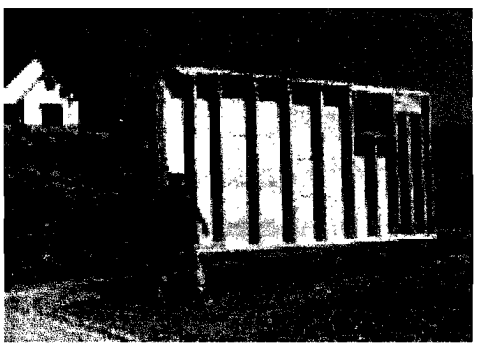


Figure I-15. Precast foundation system

Figure I-16. The T-Mass system

Insulating on the Inside Surface

Tests performed by CARB and others show that condensation forms between batt insulation and the basement wall if any air is allowed to circulate in the gap. CARB has had success with foam insulation adhesive-applied to the inside of the wall, effectively eliminating air circulation and, therefore, eliminating mold potential. This approach is incorporated into the proprietary Superior Wall precast foundation system (Figure I-15), which has a layer of XPS foam cast into the inside face

Insulating within a Concrete Wall

The T-Mass system suspends a layer (typically 2 in. thick) of Dow XPS foam ("Styrofoam") between the wall forms, creating a 10-in.-thick wall with two 4-in.-thick wythes of concrete sandwiching the foam (Figure I-16). In this system, the inner wythe will stay close to the temperature of the basement, avoiding condensation under nearly all conditions.

Application in CARB/Building America Case Studies

CARB has used Superior Wall foundations on several of its homes. Preliminary results from extensive tests performed for Cambridge Homes in Chicago show that adhesive-applied foam yields excellent results.

Primary Recommendations for the Equipment

Manual J / Manual D: Heating and Air-Conditioning System Sizing

Discussion

Increasingly in northern climates, builders are installing forced-air heating, which (unlike hydronic systems) can be fitted with air conditioning (AC). Such systems are typically designed by rules of thumb. This results in wastefully oversized systems and improperly sized distribution has long published a simple, but effective, method of determining loads ("Manual J"), sizing equipment ("Manual S"), and sizing ductwork ("Manual D"). These design tools are available in extremely user-friendly computerized form.

Applications in CARB/Building America Case Studies

All CARB projects have been designed using Manual J / Manual D computerized calculation, except those special cases where a more sophisticated program has been used. CARB often finds that systems are dramatically oversized, as one safety factor is piled on another. It is important that the designer have sufficient information to account properly for all envelope efficiency measures, which often result in a downsizing of equipment and ductwork sizes.

Condensing Furnace

Discussion

A wide variety of reliable furnaces are available with seasonal efficiencies of 90% or more. Highly efficient furnaces create an exhaust of such a low-temperature that there is insufficient stack effect to exhaust the gases; and acid condenses out of the gases during discharge. These furnaces therefore require plastic or stainless steel flues with power-driven exhaust. These flues, along with air intakes feeding sealed combustion chambers, typically discharge through the side wall, and have limits on length of run and number of elbows. Avoiding the difficulty of threading a B-vent through the plans is replaced by a limitation on where the furnace can be placed, in order to stay within the maximum allowable horizontal length of run of the vent. The units are somewhat more costly than conventional furnaces.

Benefits Demonstrated in CARB/Building America Projects

CARB always recommends furnaces with a seasonal efficiency of 90% or greater in its cold climate homes. Compared with atmospheric furnaces, which typically have 80% seasonal efficiency, these furnaces save about 12% of the heating energy.

Power-Vented Water Heater

Discussion

Along with a sealed combustion furnace, a power-vented water heater is a must in a well-sealed home as a safety measure to prevent backdrafting. Backdrafting can occur if all the exhaust systems are running together: ventilation fans, dryer, kitchen range hood, and bath fans. It is more cost-effective to install power-vented heating appliances than a

complicated balanced-flow ventilation system (which might not be operating when needed).

Applications in CARB/Building America Case Sudies

CARB recommends power-vented water heaters in all its homes.

Ducts Mastic Sealed (Leakage Less Than 5% Of Fan-Flow)

Discussion

Properly sealed ducts make sure air gets to the spaces intended, rather than leaking into a plenum space. It also minimizes the chances of creating pressure differentials from space to space that would induce airflow through the envelope. The process of sealing each joint reduces the chances of unconnected ductwork, a surprisingly common mistake.

Tape is not recommended as an alternative to mastic. Various tapes are tested to UL 181 standards, which supposedly makes them reliable for use on metal or plastic ductwork. However, it has been found that some duct tape (which is not suitable for taping ducts) passes UL 181. Mastic provides the most reliable duct sealing method.

All ductwork, including the air handler compartment (which typically has many leaky joints) should be mastic sealed. A common goal for duct leakage, measured using a "duct blaster" test, is 5 to 6% leakage to the outside.

Benefits Demonstrated in CARB/Building America Projects

Mastic duct sealing recommended for use in all CARB homes. Energy savings can be relatively modest, or substantial, depending upon how well-constructed the ductwork system is to begin with. Well-sealed ducts perform better (they send the air where it is designed to go), and they minimize the infiltration of air from garages and attics.

Another advantage is that having to go seal all the ducts makes it much more likely that all duct joints will be connected; unconnected ducts are surprisingly common. To be sure the sealing has worked, it is advisable to perform a duct-blaster test.

No Ducts In Outside Walls, Floor Cantilevers, or Attics

Discussion

Ducts belong within the conditioned envelope.

> *Why? Ducts in unconditioned spaces, or in outside wall cavities, place the hottest (or coldest) element in the house closest to outside air temperatures.*

Applications in CARB/Building America Case Studies

An important technical goal in all CARB designs has been to centralize the ductwork and to the greatest extent possible keep all the ductwork within the conditioned envelope. This maximizes the efficiency of the entire HVAC system.

No Panned Returns.

Discussion

"Panning" is commonly used to create a return air plenum between two floor joists. In some cases, this practice is justified. But all too often, the panning extends to the outside wall. In this case, the reduced pressure in the return system actively draws outside air into the ductwork through cracks under and above the mudsill. Also, panned returns are hard to seal, which tends to draw air into the system in unwanted places, unbalancing the system and reducing overall system efficiency.

Applications in CARB/Building America

Return air ductwork in CARB homes are not panned, reducing the potential for duct leakage (see next item).

Central Air-Return with Transfer Grills at Secondary Spaces (Balanced Air-Flows)

Discussion

There is nothing wrong with adding a ducted return from each room, as long as the returns are not panned and as long as they remain within the conditioned envelope of the home. However, ducted returns are an unnecessary expense in most housing and are a definite liability if they run in the attic.

A more reliable and cost-effective approach is to provide a central return and make sure that there are transfer grilles or transfer ducts, of adequate size, that allow air to return from individual closed rooms to the central space. A common requirement is that the difference in static pressure between any two rooms remain below 2.5 Pascals. This is a low, but achievable, number.

The worst possible conditions occur when there is neither a ducted return nor a transfer grille (Figure I-17).

Why? If one space is pressurized, some other space will be de-pressurized. In both cases, air is forced through cracks into or out of walls and attics, increasing energy losses. Moist inside air is also drawn into the walls and ceiling, creating the potential for condensation.

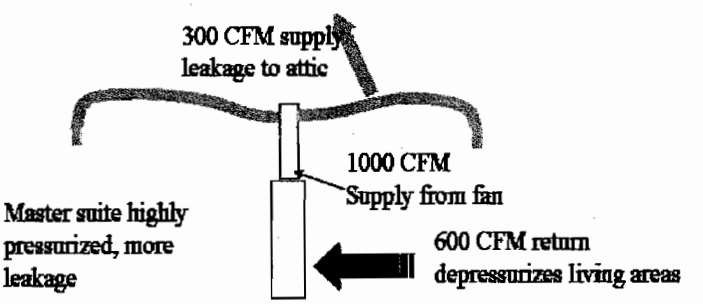


Figure I-17. Unequal pressurization in a home

Applications in CARB/Building America Projects

CARB has used several different, cost-effective methods of transferring return air without compromising acoustic or visual privacy. The most workable is a high grille on one side of an interior wall cavity and a low grille on the other. Sometimes rooms do not have any common wall with the main space (for example, a door at the end of a corridor). In these cases, grilles can often be put into and out of a closet, or grilles can be located opposite each other over the door.

Source Point Humidity Control Ventilation with Low-Sone Bath Fans on Automated Control

Discussion

A workable and cost-effective ventilation system is important, especially as small homes are built with tight envelopes. Elaborate systems, while workable, are typically not cost-effective and require continuing maintenance (that might be discontinued). The best solution is to ventilate where the greatest humidity loads (in bathrooms) or toxic gases (at gas ranges) are located. The bathroom vents, if properly designed, can be arranged to run for extended periods, to help ventilate the entire home.

Applications in CARB/Building America Projects

CARB's "standard" cold-climate bath exhaust system consists of a high-efficiency (quiet, low-sone) bathroom fan properly ducted to the outside, coupled with a controller. The controller can be a simple one with an on-off switch and an adjustable (by removing the cover) extended-run control. In a typical case, the fan will continue running for 20 minutes every time it is turned on. It is essential to have a quiet and efficient fan so that the extended running time is not annoying or wasteful of energy.

No Unvented Gas Appliances (Except Gas Range with Range Hood Exhausting to the Outside

Discussion

Unvented gas appliances, such as fireplaces or heaters, may or may not be a health hazard (this is controversial). What is not controversial is that they are potentially highly destructive to the framing of the building. These devices create vast quantities of water if they are run for extended periods, because the main products of complete combustion are water vapor and carbon dioxide. This water vapor raises the interior relative humidity to unreasonably high levels. Not only does this create mold within the home (typically behind clothes in closets), but any inside air that enters the wall cavities or attic carries with it large amounts of moisture, which then condenses and causes rot.

Application in CARB/Building America Case Studies

CARB recommends against the use of these devices and insists that all gas ranges be equipped with a range hood that ventilates to the outside. These are basic safety and indoor air quality measures that should always be observed.

Secondary Recommendations

In-Line Framing

Discussion

To obtain full benefit from 24-in. on-center wall studs (Figure I-18) it pays to adjust the plan to a 2-ft module, then align the floor joists and rafters on the 2-ft grid, so that all horizontal framing lands over a stud. This in principle eliminates the need for a double top plate, for additional savings.

Floor framing members may need to be increased in weight to handle the increased load without adding to the bounce of the floor. Also, the floor deck needs to be increased in thickness to prevent it from flexing between joists under point loads.

Application in CARB/Building America Case Studies

With Don Simon Homes, Beazer Homes in Houston, NVR/Ryan Homes, and William Ryan Homes, CARB has been successful in simplifying the plans and aligning the framing. However, in none of these cases did we use a single top plate: the advantages of overlapping and interlocking at corners and intersections outweighed the savings in lumber.

Energy-Efficient Lighting

Discussion

One of the most important ways in which energy is wasted is the use of incandescent lamps. Until recently, however, most fluorescent lamps had disadvantages that limited their use to some bathroom and kitchen lights (with high-end homes dispensing with them altogether). These disadvantages are rapidly being eliminated by successive generations of compact fluorescent lamps. While some still exhibit a time delay before they are fully bright, their color can be quite authentic, especially when reflected from a recessed can, or diffused through the shade of a lamp. Lights that are seldom used can remain incandescent with little loss in energy. Also, fluorescent lamps typically do not work as well outdoors as incandescent lamps.

Fig. I-18. In-line framing

Application in CARB/Building America Case Studies

Because of the past history of ineffective fluorescent lighting, CARB's builders have steered clear of fluorescent lighting, responding to market resistance to their use. As market acceptance grows, CARB will continue to suggest the increased use of fluorescent lamps in built-in fixtures.

ENERGY STAR Appliances

Discussion

Two of the most important appliances from a water-use and energy efficiency point of view are the washer and dryer, which are seldom supplied by the builder. However, the builder should include a gas line to make it possible for the homeowner to install a gas dryer. In most cases, gas energy is less costly than electricity. The two main appliances supplied by the builder where efficiency is important are the refrigerator and the dishwasher. There are now hundreds of models of refrigerators that are ENERGY STAR rated, and their use should be routine. There are also many energy-efficient dishwashers available.

Application in CARB/Building America Projects

CARB has had mixed success in encouraging builders to install ENERGY STAR appliances. Typically, as with McStain in Boulder, Colorado, ENERGY STAR appliances are requested by buyers in certain markets where energy performance is a major issue. In other cases, aesthetics or quiet operation govern, and the ENERGY STAR rating is not considered an important issue. This is gradually changing as ENERGY STAR becomes better known.

Compact Duct-Distribution System

Discussion

If low-E glazing is used and the home's envelope is relatively tight, it is possible to discharge conditioned air from inside walls in most cases without compromising comfort. By providing a central duct shaft with short branches to inside walls (Figure I-19), ductwork runs can be dramatically reduced.

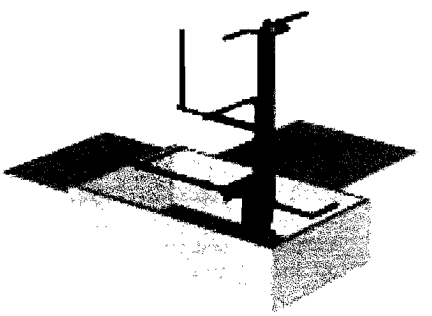


Figure I-19. Ductwork with short branches to inside walls

Application in CARB/Building America Case Studies

Compact duct distribution systems have played a central role in many CARB projects. This often requires minor adjustments to the plan, which seldom interfere with the design or plan efficiency.

Exhaust-Only or Exhaust/Supply Fresh-Air Ventilation

Discussion

For more continuous ventilation than the extended run of spot ventilation fans, all bathroom exhausts can be collected together and routed through an "in-line" high-efficiency fan located in the attic (Figure I-20). This fan can be controlled by an adjustable controller such as Tamarack Industries' "Airetrak" controller or the Grasslin pin timer. As this system de-pressurizes the home, it tends to prevent inside air from entering the wall and attic cavities, helping to control condensation. It is important that there be no atmospheric combustion appliances using the house air for combustion. Both the furnace and water heater need to be power vented. In very tight homes, it is also advisable to install a 6-in. or 8-in. diameter air intake from the outside to the return air plenum of the furnace, to provide a certain source of outside air. This duct should be equipped with a manual damper to control the flow, which occurs whenever the furnace fan is operating

Applications in CARB/Building America Case Studies

CARB used this system in its project with NVR/Ryan homes in Rochester, New York.

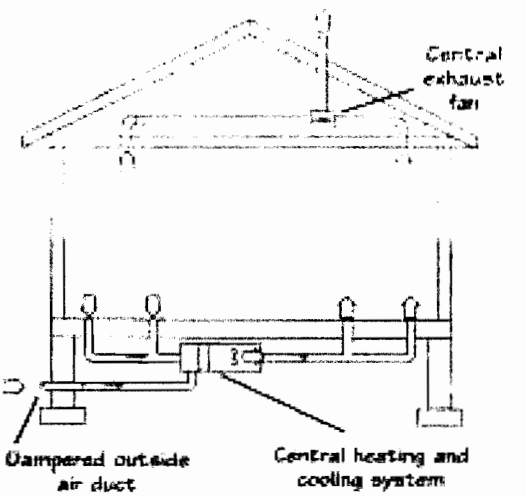


Figure I-20. "In-line" high-efficiency fan located in the attic

Case Study #1: Don Simon Homes

Introduction

In the past year, Steven Winter Associates, Inc., (SWA) has partnered with two new production builders in Wisconsin. Both Wausau Homes and Don Simon Homes are affiliated with the Wisconsin ENERGY STAR Homes Program. Wisconsin ENERGY STAR Homes (WESH) is sponsored by Wisconsin's Focus on Energy Program, a public-private partnership offering energy information and services to energy utility customers throughout Wisconsin. The goals of this program are to encourage energy efficiency and the use of renewable energy, enhance the environment, and ensure the future supply of energy for Wisconsin. This partnership has been made possible, in part, through a Building America grant from the U.S. Department of Energy to the State of Wisconsin.

This case study summarizes CARB's involvement in the design, construction, and testing of a prototype home for Don Simon Homes (DSH) in Madison, Wisconsin (Figure I-21). The intent of this program was to bring the Building America "Lessons Learned" to the Wisconsin state initiative.

Figure I-21. Newly completed Don Simon Prototype Home

Background

Founded in 1956, DSH is the largest builder of single-family homes in Dane County, Wisconsin. Family-owned and operated, the company has 50 full-time employees. In addition, DSH builds and certifies 100% of their homes as Green Built Homes. Green Built Home™ is a green building initiative that reviews and certifies compliance with sustainable building and energy standards. It is a voluntary program under the Wisconsin Environmental Initiative and is sponsored by participating homebuilder associations, leading utility companies, organizations promoting green building and energy efficiency, and the State of Wisconsin.

With an integrated systematic approach to home building, Don Simon Homes purchases the land, develops the site, and sells the lot and home as a single package. This neighborhood development strategy creates added value for communities and customers with economies of scale in land development and construction. The company's two primary target markets are first-time homebuyers and affordable move-ups. Ranking among the top 10 builders in Dane County for luxury homes, more than 70% of DSH are customized and built to the homeowners' specifications.

CARB became involved with DSH through the WESH. As one of the two building groups selected to participate in the WESH program, DSH agreed to use one of their most popular homes as a test case for improvements to their standard practice. The Huntington III model (Figure I-22) was selected for the prototype.

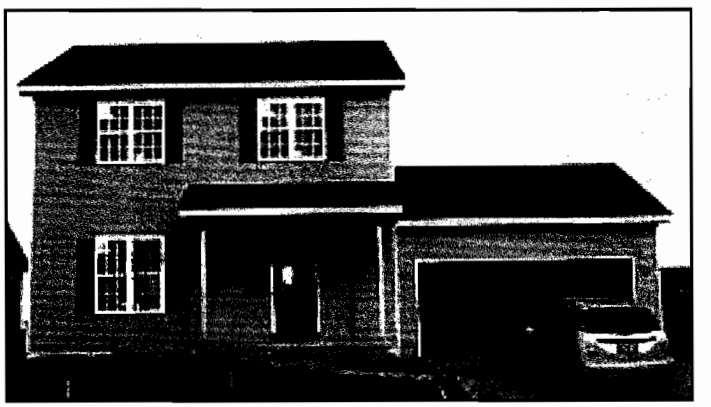


Figure I-22. Don Simon Homes
Huntington III Model

Standard Practice Home

The first step was a review of DSH standard building specifications. The base specifications are summarized below.

Wall Construction:	Exterior Walls 2 x 6 Studs at 16 in. On-Center with R-19 Cavity Insulation and 5/8-in. Celotex Structural Insulated Sheathing on the Exterior (R-5)
	Interior Walls 2 x 4 Studs at 24 in. On-Center
Roof Construction:	Wood Trusses with R-40 Insulation
Foundation Walls:	R-5 Insulation Required by Wisconsin Code
Windows:	Double Pane, Vinyl (Visions 2000, Single Slider Series)
Mechanical Equipment:	Janitrol 92% Annual Fuel Utilization Efficiency (AFUE) Furnace with Air Conditioning
	Honeywell T8112C, D Electronic Programmable Thermostat
	A.O. Smith 40 Gallon FPSH40 Power-Vented Water Heater, EF = 0.62 (A Power-Vented Water Heater is a WESH Program Requirement)
	Conventional, manually switched bath fans

A site visit to a standard Huntington III provided insight into the standard HVAC installation practices (Figure I-23). As shown in figures I-24 through I-26, it typically includes:

- High and low return grilles in each bedroom
- Panned returns
- Supply and return ducts in outside walls
- Floor supplies under windows.

Prototype Home

The Huntington III is a 1,456-ft^2, two-story home with an attached garage. It includes three bedrooms, two and a half baths, a kitchen, dining room, and living room. This home is set on a full foundation.

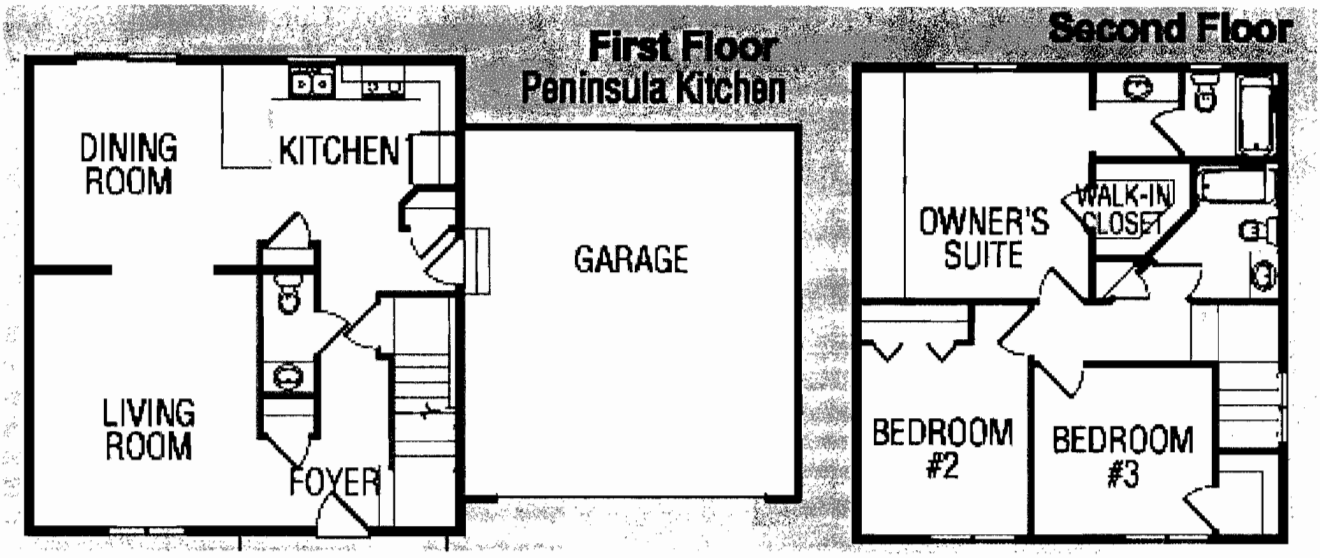


Figure I-23. Floor plan for Don Simon home

CARB Recommendations

After the review of DSH's standard building specifications, CARB recommended a list of improvements for a "whole building systems" approach to design. During a design meeting held June 25, 2002, each of these recommendations was presented to DSH and evaluated by their staff:

- Architectural Redesign
- Optimal Value Engineered Framing
- Exterior Foundation Insulation up to Sill
- Low-E, Argon Windows
- Mechanical Ventilation
- Redesigned HVAC System.

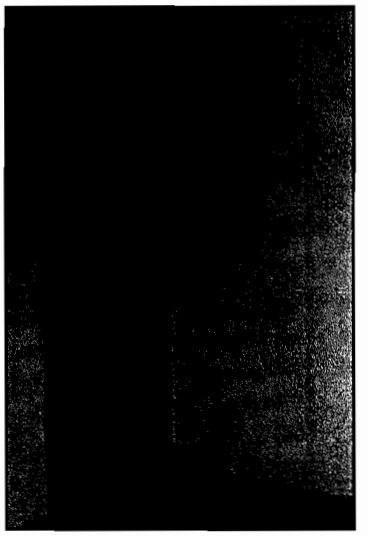


Figure I-24. High and low returns in exterior walls

Figure I-25. Supply ducts in exterior walls

Figure I-26. Panned returns

Architectural Redesign

An architectural review of the Huntington III was performed to rationalize the floor plan and maximize the use of the space. As part of the value engineering, adjustments were made in wall and window locations. Access from the garage was provided with a single step up into the stair landing of the house. By shifting the entrance location, additional space was gained for kitchen storage. Space previously designated as a pantry was utilized for mechanical chases. Minimal changes were made to the second floor plan. The second floor linen closet was reduced to accommodate the second floor return duct (Figure I-27).

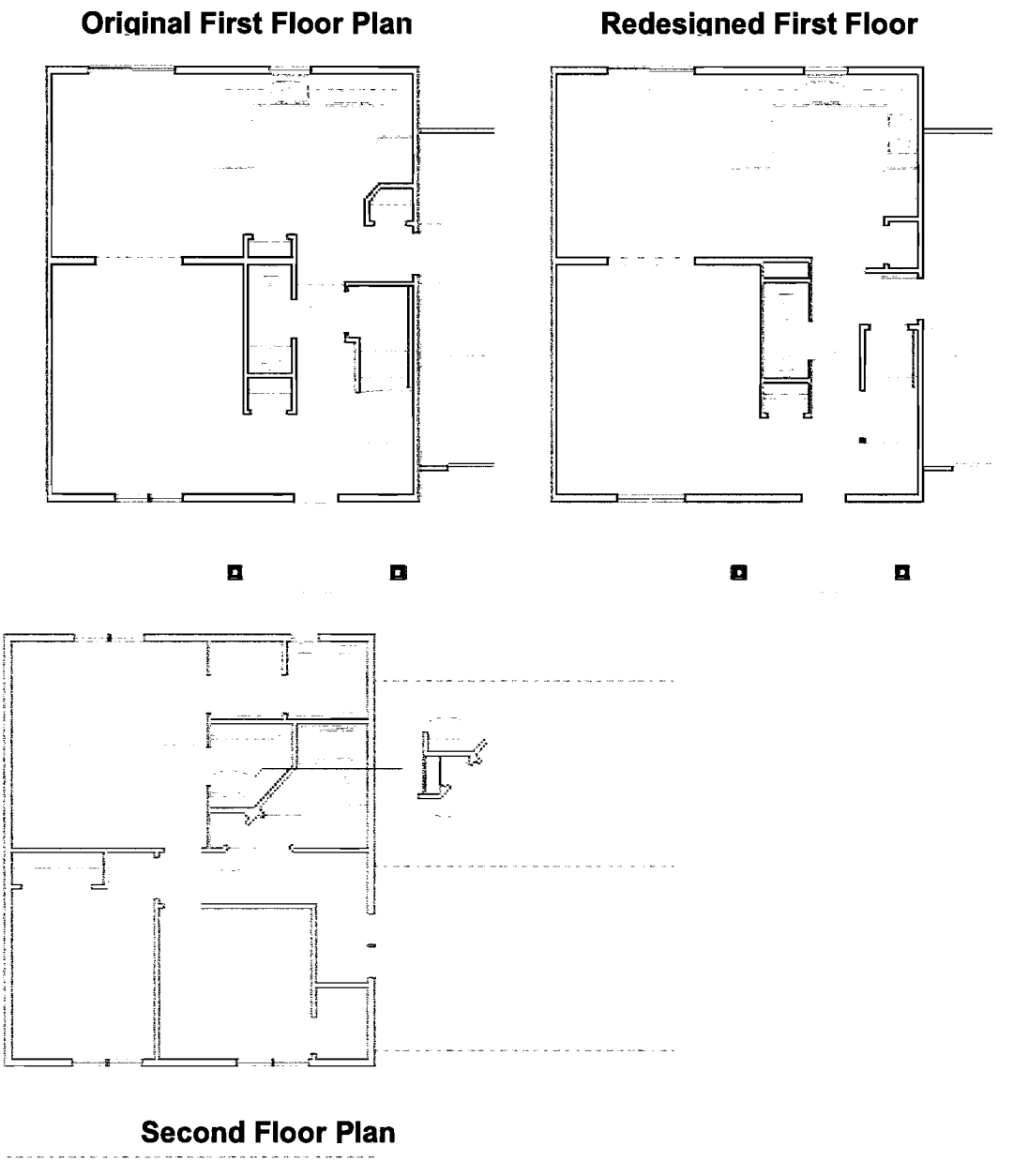


Figure I-27. Floor plans showing maximized use of space

Optimal Value Engineered Framing

Standard construction for the exterior walls includes the following: 2 x 6 studs at 16 in. on-center, R-19 Cavity Insulation, 5/8-in. Celotex Structural Insulated Sheathing on the exterior, an interior vapor barrier, and taped joints. Although the Celotex provides additional insulating value, it has a polyethylene coating on both sides. When combined with the interior vapor barrier and sealed joints, it effectively creates a double vapor barrier. With no way for moisture to escape, this could lead to mold and mildew problems.

For the prototype, CARB recommended optimal value engineered (OVE) framing (Figure I-28). This includes inline 2 x 6 studs at 24 in. on-center, Oriented Strand Board (OSB) sheathing on the exterior, and two stud corners with drywall clips (or three-stud corners, Figure I-29). The OSB replaced the insulated sheathing and bracing, eliminated the double vapor barrier, and reduced the concern for moisture problems in the wall cavity.

These advanced framing techniques have been in use for more than 20 years and have a proven track record of cost savings. CARB provided a complete set of framing drawings for the prototype, met with the framer in advance to discuss the procedures, and was present during the framing process.

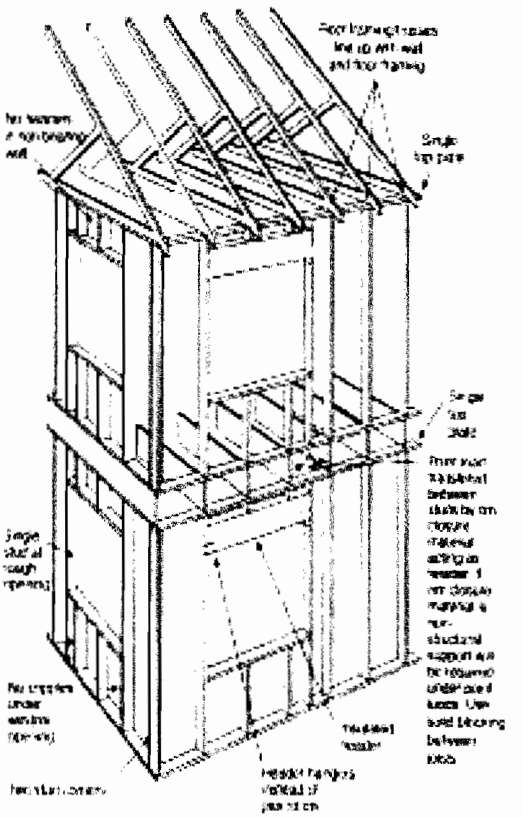


Figure I-28. Optimal value-engineering framing techniques

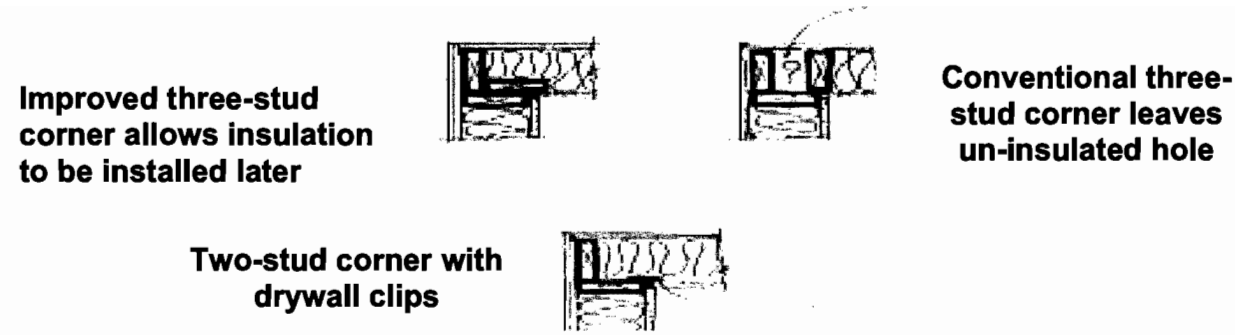


Figure I-29. Corner framing options

Exterior Foundation Insulation up to Sill

Wisconsin code requires a minimum insulation level of R-5 for the foundation. Typically, DSH installs Warm N' Dri, a 1-in. insulation and drainage board, to grade level. This leaves the above-grade portion of the foundation uninsulated. To provide greater energy savings, CARB suggested the insulation be brought up to the sill level despite aesthetic concerns and the possibility for mechanical damage to the exposed insulation. The builder opted to include this suggestion in the design of this prototype. Figure I-30 shows the foundation of the prototype home with full insulation.

Figure I-30. Prototype foundation insulation detail

Low-E Windows

To improve performance and meet the ENERGY STAR requirements, Low-E windows were recommended. As discussed in the standard specifications, double-pane, vinyl-frame windows are typically installed. However, DSH offers a window upgrade option. For the prototype home, DSH installed Visions 2000, vinyl-frame, double-pane, Low-E, argon-filled windows. The NFRC rated performance values for these windows are U = 0.33 and SHGC = 0.30.

Mechanical Ventilation

As part of the WESH program, a mechanical ventilation system must be provided for the home that is capable of delivering a continuous airflow equal to 20 cubic feet per minute (CFM) for the master bedroom and 10 CFM for each additional bedroom. There are no specific control or sound requirements. A standard bath fan with an airflow of 40 CFM, as measured by a balometer, satisfies the WESH program requirements for a three-bedroom home. CARB recommended that DSH go a step further to assure that the fan be relatively quiet, provide higher airflow and operates for greater periods of time.

DSH installed a Broan Solitaire Ultra Silent Series fan in the master bathroom and a similar model in both the powder room and second floor bath. Model S80U has a rated flow of 80 CFM, with a sound rating of 1.0 Sone. Each of the second floor bath fans is controlled by an EFI fan/light control with off delay. This control integrates the operation of the bathroom exhaust fan and the light. After the light is turned off, the fan will continue to operate for a preset time interval ranging from 1 to 60 minutes. This assures that the bathroom fan operates frequently enough to adequately remove moisture (Figure I-31)

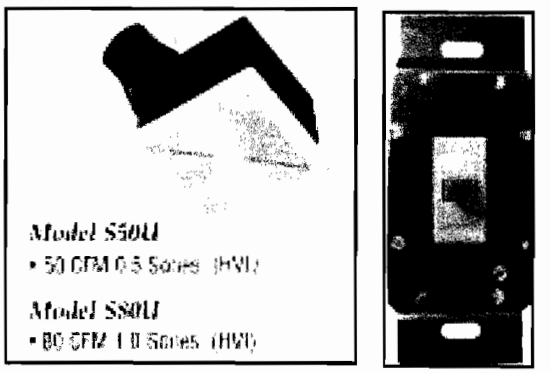


Figure I-31. Prototype home bath fan and control

Redesigned HVAC System

A key part of the prototype was the design of the HVAC system. To improve the design and ensure consistent HVAC system distribution performance, CARB developed an HVAC layout and provided it to DSH and the mechanical contractor. As previously discussed, the framing layout impacts the location of mechanical chases. Therefore, a coordination meeting with the framer and on-site assistance during the framing of the prototype were necessary to verify proper installation. An additional site visit was made during the installation of the mechanical system.

Heating and cooling loads were calculated using Wrightsoft software, which is based on the ACCA Manual J methods. Energy code compliance was verified using WISCheck software, which is based on Wisconsin's version of the Model Energy Code. Modeling with Rem/Rate, Residential Energy Analysis Software (version 10.3), was done by WESH to determine ENERGY STAR compliance.

Manual J heating and cooling loads were used to determine the required equipment size for the prototype. Equipment for a typical Huntington III includes a Janitrol GMNT series, 92.6% AFUE high-efficiency gas furnace, with a rated input of 60,000 BTUH and a 2-ton, SEER 10 condensing unit. The furnace and the air-conditioning system were downsized for the prototype. A smaller Janitrol GMNT series furnace, with a rated input of 40,000 BTUH and a 1.5-ton condensing unit were installed. Table I-1 summarizes the design loads and required CFMs for each room. Using these airflows, a duct layout was developed for the prototype. Figures I-53 and I-54 provide the mechanical plans.

Table I-1. Design Loads and Required CFMs

	Design Loads (Btu/h)		Flow (CFM)		
Room Name	Heating	Cooling (facing East)	Heating	Cooling	Design CFM
Dining Room	3663	1846	143	143	145
Kitchen	2170	1963	85	152	95
Living Room	3850	1549	150	120	135
Owner's Suite	2648	1443	103	112	105
Master Bath	1179	432	46	33	45
Bath #2	427	112	17	9	15
Bedroom #2	2689	1089	105	84	105
Bedroom #3	2622	1257	102	97	105
Basement	0	0	0	0	0
TOTAL:	19,248	9,691	751	750	

Total Flow:	750 CFM
AC Capacity (0.7 SHR):	1.5 tons
ACCA Furnace capacity (25% oversize):	25,000 Btu/h

As previously discussed, return grilles are normally installed for each bedroom. The CARB layout replaced those returns with high/low or over the door transfer grilles in each of the secondary bedrooms. A high central return was installed in the second floor hallway to pick up the return the air from the bedrooms. To provide more privacy and reduce noise transmission, a separate return was provided for the master suite. Where the two returns meet, a portion of the existing linen closet was used as a chase for the duct down to the first floor.

On the first floor, a low central return was built in the space previously used as a pantry. The new design eliminated the need for panned return branches. On the supply side, changes included fewer elbows and appropriately sized supply ducts. Most importantly, no supply ducts were run in the exterior walls. Supply ducts for the second floor were run vertically in the interior first floor wall cavities and horizontally out to floor registers. The supply for the kitchen was run vertically in the central chase and horizontally between floor joists to serve a ceiling diffuser (figures I-32 through I-36).

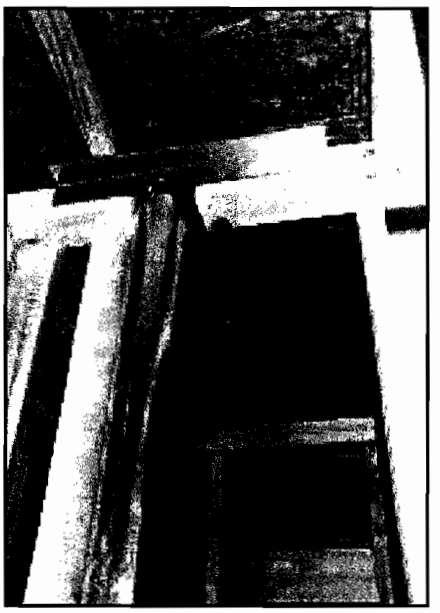


Figure I-32. Supply duct in wall cavity up to second floor

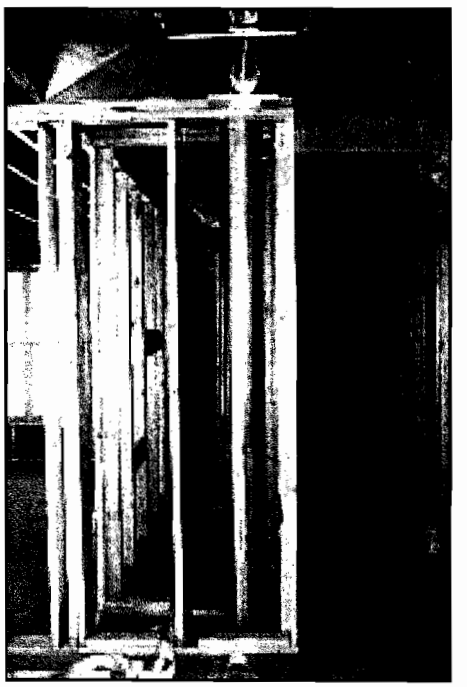


Figure I-33. Kitchen supply duct in central chase

Figure I-34. High/low transfer grille

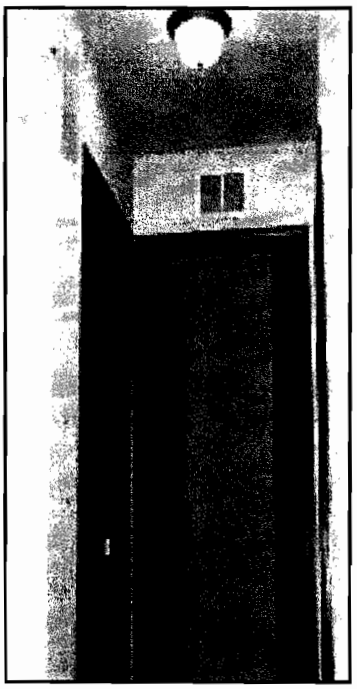


Figure I-35. Second-floor high central return and over-door transfer grille

Figure I-36. First-floor low central return

Prototype Testing

The final step was the side-by-side testing of the prototype house against a standard Huntington III. CARB tested both the houses on January 27-28, 2003, with assistance from Dave Kinyon of WESH and Hans Hoffman of Hoffman Energy Consultants, Inc. The tests included:

- Envelope Leakage (Blower Door test)
- Duct Leakage (Duct Blaster)
- Airflow measurements at the registers (LoFlo Balometer)
- Transfer Grille Performance
- Bath fan airflow measurements.

Blower-door tests were performed to compare the leakage of the two homes. As summarized in Table I-2, the envelopes of both homes are tight. Even with the changes in framing (2 x 6 at 24 in. on-center [OC] versus 2 x 6 at 16 in. OC) and sheathing (OSB versus structural insulated sheathing), the leakage of the two homes is equivalent.

Table I-2. Blower Door Test Results

Blower Door Test Results	CFM_{50}	ACH_n	ELA @ 4 Pa
Prototype	784	0.13	28.5
Control	755	0.13	27.5

Figure I-37 shows a comparison of the duct leakage for the two homes tested using a Duct Blaster. Both the total duct leakage and the duct leakage to the outside are shown. The leakage is further broken down into supply and return leakage for each of these categories.

Using an Alnor LoFlow Balometer, the supply and return airflows were measured at each register. A comparison of the supply and return airflows for each floor is shown in the Figure I-38. The floor-to-floor and supply-to-return airflows are better balanced in the prototype.

The supply airflows for both the Prototype and Control houses are summarized in Table I-3. Again, the airflows are better balanced in the prototype, particularly for the bedrooms.

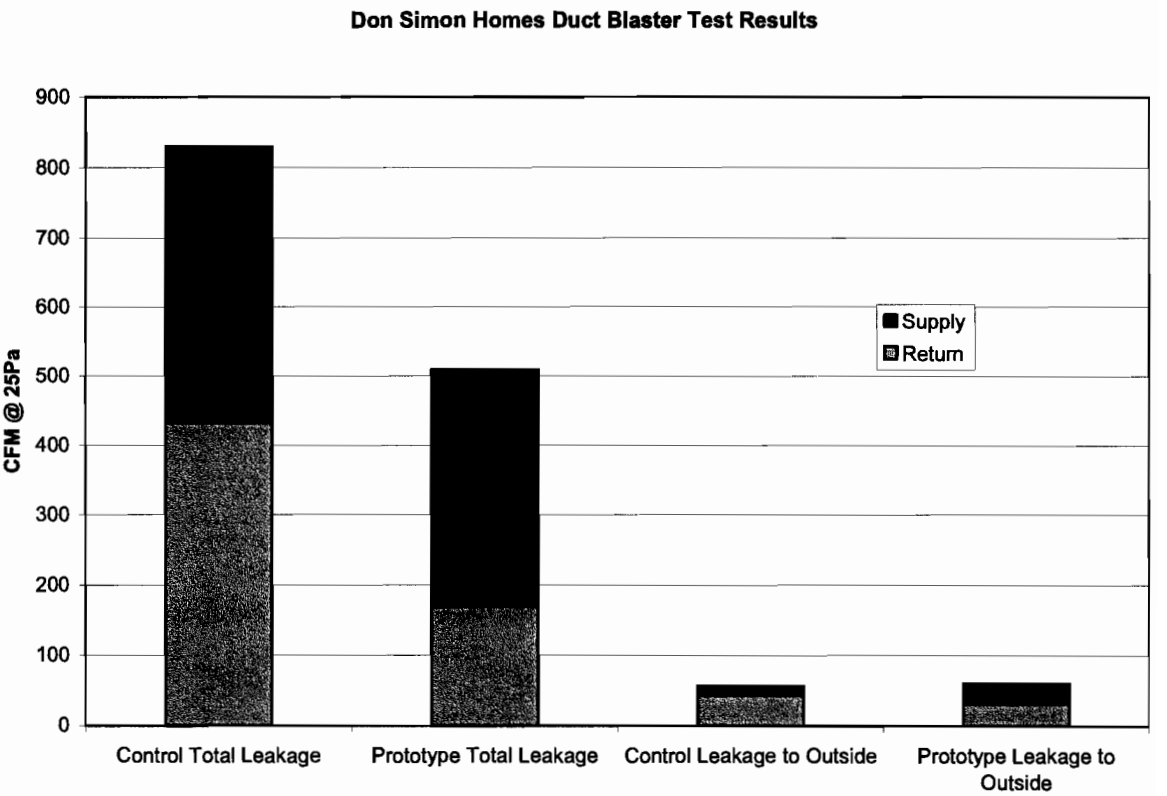


Figure I-37. Comparison of duct leakage in the two homes

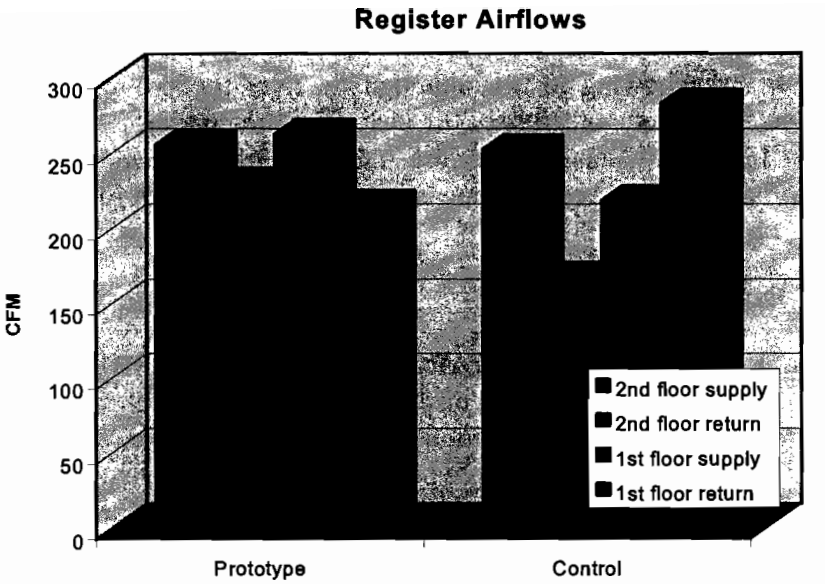


Figure I-38. A comparison of supply and return airflows

Return air paths for this home were provided by both transfer grilles and door undercuts. The transfer grilles for Bedroom #2 were installed in a stud bay, with one register high on the inside of the room and the other low in the hallway. For Bedroom #3, the transfer grille was installed over the door. Both the supply and transfer grille airflows were measured with the balometer. Pressure measurements were taken with the transfer grilles open and closed. A ¾-in. door undercut can deliver approximately 40 cfm of air with less than a 3-pa pressure drop. As shown in Table I-3, the combination of door undercuts and transfer grilles provides adequate air and pressure balancing.

Table I-3. Transfer Grille Performance

Transfer Grille Performance	Supply (cfm)	Transfer (cfm)	ΔP Open (Pa)	ΔP Closed (Pa)
Bedroom #2 (hi/lo)	69	30	1.1	2.8
Bedroom #3 (over door)	76	35	0.9	2.9

As previously discussed, a Broan Solitaire Ultra Silent Series fans with an EFI fan/light control was installed in the master bathroom. Measurements taken with the balometer indicated the fan was drawing 50 cfm, although it is rated for 80 cfm. The published fan ratings are based on a static pressure of 0.1 inch. The pressure drop for 4-in. flex duct is 0.6 inches per 100 feet of length. Therefore, a duct run of 20 ft will have a pressure drop of 0.12 in., without turns or a termination cap. This could account for the reduced airflow.

ENERGY STAR Compliance

As part of the Wisconsin ENERGY STAR Homes Program (WESH), three site visits are made to each home. During the initial inspection, the framing is checked before the insulation is installed. Next, the insulation is inspected before the walls are covered with sheet rock. Finally, a number of tests are performed on the completed house, including a blower door test to determine envelope leakage. These test results are then incorporated into the REM model to determine the final Home Energy Rating Score (HERS) of each home.

Using REM models provided by Hans Hoffman, the test results for infiltration and duct leakage were added to determine the final HERS score for both homes. With a minimum score of 86.0 required to meet ENERGY STAR, the prototype home achieved a HERS score of 89.2. The standard Huntington III received a HERS score of 88.0. Don Simon Homes' cooperation with both WESH and CARB has had a positive impact on the performance of these homes.

Case Study #2: Wausau Homes

Introduction

This case study summarizes CARB's involvement in the design, construction, and testing of a modular prototype home for Wausau Homes in Wausau, Wisconsin (Figure I-39). The intent of this program was to bring the Building America "Lessons Learned" to the Wisconsin state initiative.

Background

Since 1960, Wausau Homes has been producing technologically advanced housing and housing components. The Wausau Homes Group includes eight manufacturing facilities, supporting over 700 builders. Wausau is one of the leading producers of system-built homes in Wisconsin and throughout central and southeastern United States. Wausau has developed a system of finished components that are easily transported to and constructed at the jobsite. In addition, Wausau manufactures a modular home product. With a total production of approximately 4,000 homes per year, the modular homes account for about 20% or 800 homes annually.

In an agreement with Wisconsin Energy Star Homes (WESH), Wausau Homes committed to building modular and panelized homes with increased energy efficiency standards. CARB embarked on a pilot program, in cooperation with WESH and the Wisconsin Energy Conservation Commission (WECC). The intent of this program is to bring the Building America "Lessons Learned" to the Wisconsin state initiative. Wausau was one of two building groups selected to participate and agreed to use one of their most popular modular homes as a test case for improvements to their standard practice.

CARB visited the manufacturing plant, located in Wausau, Wisconsin, to evaluate the production of building components and advise on manufacturing steps to ensure that the final products are Wisconsin ENERGY STAR compliant. WESH certification is awarded after multiple on-site visits during construction and a final performance test. CARB and WESH worked with Wausau Homes to incorporate changes in the design phase, practices used on the factory floor, and the selection of components for the system-built homes. The result is a prototype home (Figure I-40), which incorporates the CARB recommendations discussed in this report.

Standard Practice Home

The first step was a review of Wausau's standard building specifications, an on-site evaluation of the manufacturing practices at the plant, and an observation of the set and finishing of a home in the field. The base specifications are summarized below.

Figure I-39. Newly completed Wausau Prototype Home

Figure I-40. Wausau/CARB prototype home

Wall Construction:	Exterior walls 2 x 6 studs at 16 in. on-center with R-19 cavity insulation
	Interior walls 2 x 4 studs at 16 in. on-center
Roof Construction:	*Wood trusses with R-40 insulation*
Foundation Walls:	*R-5 insulation required by Wisconsin code*
Windows:	*Clear, Double-pane, vinyl frame*
Mechanical Equipment:	*90% AFUE furnace*
	Air-conditioning optional Conventional, manually switched bath fans No HVAC duct design provided

A site visit to a Wausau home similar to the Monfort II provided insight into the standard HVAC installation practices. Although the standard practice varies with each contractor, it typically includes the following:

- Floor supplies with baseboard-style registers, provided by the plant
- Unbalanced airflows
- No duct layout provided to the contractor, leading to inconsistent results
- Return grilles from each bedroom, installed at the plant
- Panned returns in the basement, installed in the field.

Before designing the prototype HVAC system, Wausau took field measurements in an existing modular home. The tests indicated that the supply and return airflows varied considerably in each room. In addition, the standard floor registers installed at the plant are all the same size (18 in. long), regardless of airflow. The standard register (Figure I-41) is oversized for this application. For the average room design airflow, this register only has throw and spread distances of 4.5 ft.

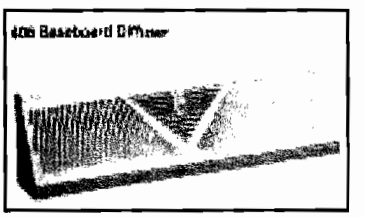
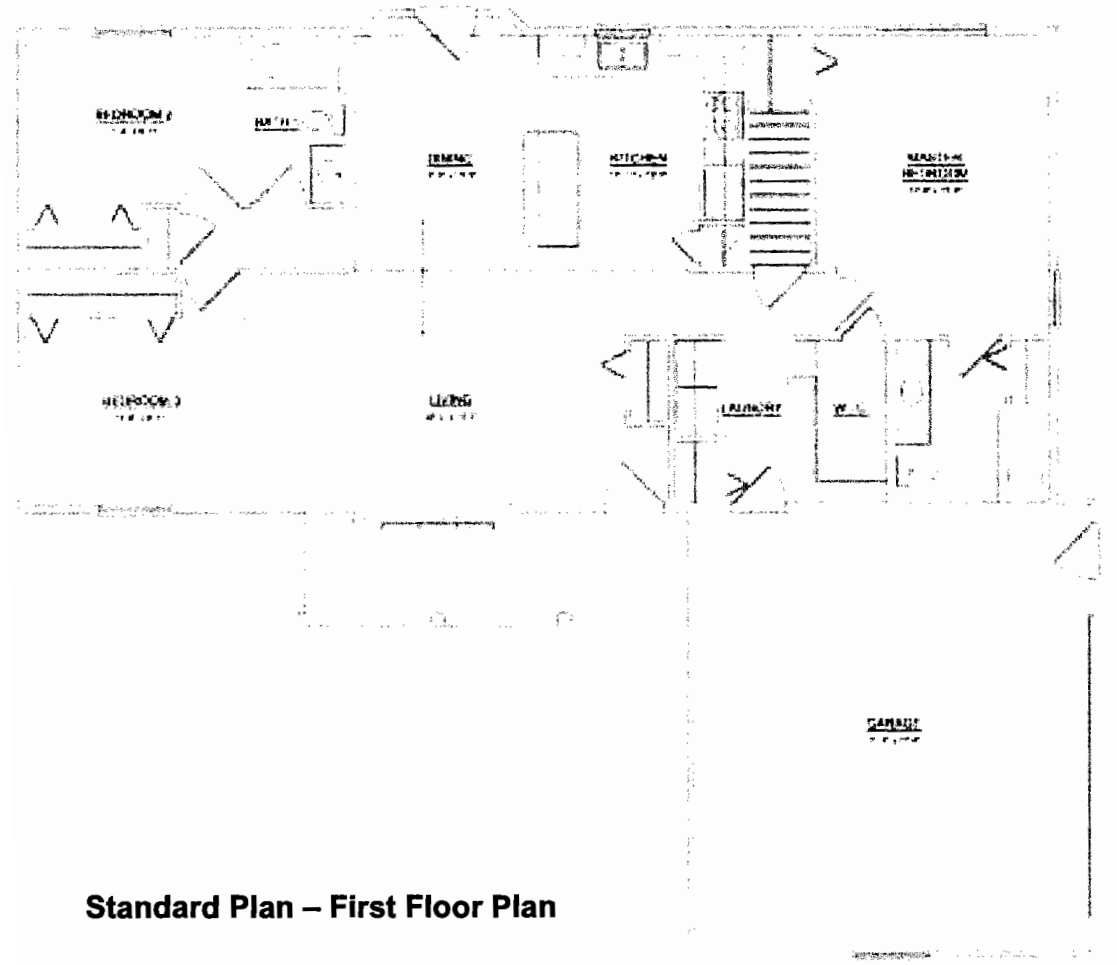


Figure I-41. Standard register

Prototype Home

As part of their commitment to the program, Wausau agreed to use one of their most popular modular homes as a test case for improvements to their standard practice. The Monfort II (Figure I-42) is a 1,335-ft^2 ranch-style home. It includes three bedrooms, two baths, a kitchen/dining room, and a laundry room. This home is set on a full foundation. It is shipped in two pieces, which are aligned and joined at the site.



Standard Plan – First Floor Plan

Figure I-42. Wausaw prototype home, the Monfort II

CARB Recommendations

After the review of Wausau's standard building specifications and manufacturing practices, CARB recommended a list of improvements for a "whole building systems" approach to design. During a design meeting held June 26, 2002, each of these recommendations was presented to Wausau and evaluated by their staff.

- Architectural Redesign
- Advanced Air-Sealing Techniques
- Improved Flashing Details
- Low-E Windows
- Mechanical Ventilation
- Redesigned HVAC System.

Architectural Redesign

An architectural review of the Monfort II was performed to rationalize the floor plan and maximize the use of the space. To improve traffic patterns throughout the home, changes in the direction of some door swings were recommended. Other suggestions included increased closet storage in the master bedroom and a workstation off of the kitchen. Although these recommendations were well received by the Wausau design team, a customer had already purchased the home selected for the prototype. Therefore, the architectural changes could not be incorporated in this prototype.

Advanced Air-Sealing Techniques

CARB team members visited the manufacturing plant to evaluate the construction techniques, which included insulation and air sealing. They were also on-site to observe the delivery and set up of a modular unit similar to the Monfort II. Close attention was paid to the joining of the two halves at the marriage wall.

Typically, Wausau attaches batt insulation at the plant to both halves of the unit along the marriage wall, as shown in figures I-43 and I-44. Once at the site, the two units are joined and this insulation is intended to fill the space between the modules. The modular design requires a ¾-in. gap between the two units for proper alignment.

Theoretically, air movement between the two modules is prevented by the batt insulation attached to each half. However, it was observed during the set process that much of the insulation was torn off during alignment. Once the first unit is placed on the foundation, the second one must slide past it to get into place. If the insulation is torn off during this step, the air barrier is ineffective.

Figure I-43. Batt insulation for sealing marriage wall

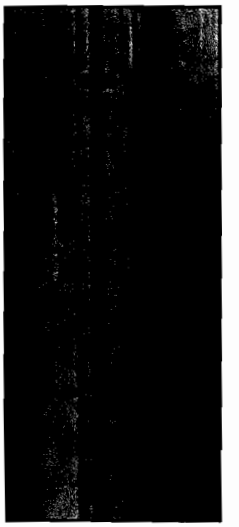


Figure I-44. Gasket seal at marriage wall

As a result of these observations, CARB recommended that either a Sof-Seal gasket material or expandable spray foam be used to seal around the marriage wall. Because spray foam does not fully expand during cold weather, Wausau agreed to use it only during summer installations, as shown in Figure I-45. For winter installations, the gasket material will be installed.

Improved Flashing Details

Window installation and flashing are completed at the manufacturing plant. The homes are covered with Tyvek Home Wrap, which is cut to accommodate the windows. Previously, a bituminous, self-sealing tape was used to seal between the bottom of the window and the Tyvek (Figure I-46). However, CARB saw opportunities for improving this detail.

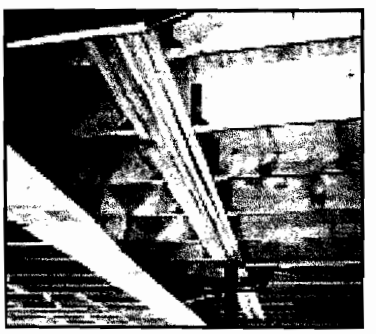


Figure I-45. Expandable spray foam at marriage wall

Figure I-46. Self-sealing tape at base of window

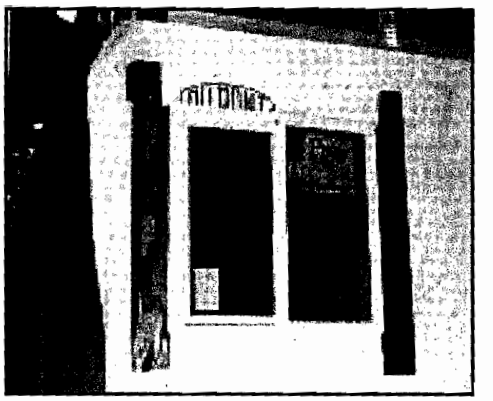


Figure I-47. Manufacturer's recommended window flashing detail

CARB suggested that Wausau incorporate the manufacturer's recommended window flashing practices. First, the Tyvek is folded over the framed window opening on the bottom and both vertical sides, to prevent any moisture from entering. The window is then inserted, and the vertical sides are sealed with a tape designed specifically for this application. After the window is in place, the Tyvek above the window is folded down to the frame and sealed on either side with the Tyvek tape (Figure I-47).

Low-E Windows

To meet the ENERGY STAR requirements, Low-E windows were recommended. As discussed in the standard specifications, double-pane, vinyl-frame windows are typically installed. However, Wausau offers a window upgrade option. For the prototype home, Wausau installed Vetter ProV, HiPro 4, vinyl-frame, double-pane, Low-E windows. The NFRC-rated performance values for these windows are U = 0.35 and SHGC = 0.34.

Mechanical Ventilation

As part of the WESH program, a mechanical ventilation system must be provided for the home that is capable of delivering a continuous airflow equal to 20 cubic feet per minute (CFM) for the master bedroom and 10 CFM for each additional bedroom. There are no specific control or sound requirements. A standard bath fan with an airflow of 40 CFM, as measured by a balometer, satisfies the WESH program requirements for a three-bedroom home. CARB recommended that Wausau go a step further to assure that the fan be relatively quiet, provide higher airflow and operates for greater periods of time.

Wausau installed a Broan Solitaire Ultra Silent Series fan in each of the two bathrooms (Figure I-48). Model S80U has a rated flow of 80 CFM, with a sound rating of 1.0 Sone. Each of these fans is controlled by an EFI fan/light control with off delay. This control integrates the operation of the bathroom exhaust fan and the light. After the light is turned off, the fan will continue to operate for a preset time interval ranging from 1 to 60 minutes. This assures that the bathroom fan operates frequently enough to adequately remove moisture.

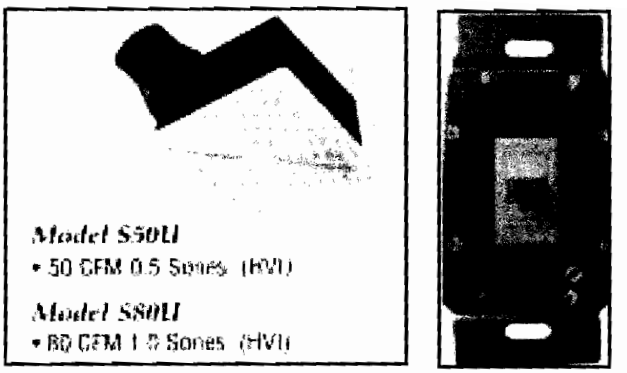


Figure I-48. Prototype home bath fan and control

Redesigned HVAC System

A key part of the prototype was the design of the HVAC system. As the manufacturer, Wausau has limited control over the design and installation of the mechanical system. With the exception of floor penetrations and register selection, the mechanical work is done on site by a separate contractor. To improve the design and ensure consistent HVAC system distribution performance, CARB developed an HVAC layout and provided it to the homebuilder and the mechanical contractor.

Heating and cooling loads were calculated using Wrightsoft software, which is based on the ACCA Manual J methods. Energy code compliance was verified using WISCheck software, which is based on Wisconsin's version of the Model Energy Code. Modeling with Rem/Rate, Residential Energy Analysis Software (version 10.3) was done by WESH to determine ENERGY STAR compliance.

The required equipment size for the Monfort II was selected based on the Manual J heating and cooling loads. Table I-4 summarizes the design loads and required CFMs for each room.

Using these airflows, a duct layout was developed for the prototype (Figure I-49). See figures I-54 and I-54 for the mechanical plans. Although the supply layout did not change significantly from the standard installation, the new design had a major impact on the return layout.

As previously discussed, return grilles are normally installed at the plant for each bedroom. The CARB layout replaced those returns with transfer grilles and a door undercut for each of the secondary bedrooms. A low central return was built into a closet at the plant, as shown in Figure I-50. A separate return was provided for the master suite to meet the greater airflow requirements, provide privacy, and reduce noise transmission. The new design eliminated the need for panned return branches. On the supply side, changes included a decreased number of takeoffs, fewer elbows, and register selection.

Table I-4. Design Loads and Required CFMs

Room Name	Design Loads (Btu/h)		Flow (CFM)		
	Heating	Cooling (East)	Heating	Cooling (East)	Design CFM
Master Bedroom	4053	1695	75	106	110
Master Bath	728	205	15	13	15
Living Room	7767	2694	137	168	150
Kitchen	1470	2007	27	127	50
Dining Room	2683	848	48	53	50
Bath	412	126	8	8	10
Bedroom #2	2502	1023	46	64	50
Bedroom #3	2502	1023	46	64	50
Basement (uncond.)	0	0	198	0	115
TOTAL:	22,117	9,621			

Total Flow:	600 CFM
AC Capacity (0.7 SHR):	1.5 tons
ACCA Furnace capacity (25% oversize):	28,000 Btu/h

Appropriately sized floor registers were provided by the plant, as shown in Figure I-51. For the average room design airflow, a 2-$^{1}/_{4}$-in. x 12-in. register has a throw of 6 ft with a spread of 8 ft.

After the mechanical system was installed, testing was done by CARB and WESH to determine the performance of the system. The layout in Figure I-52 shows the supply and return airflows found during testing. The central return, shown in the hall off the kitchen, was returning 400 CFM back to the unit. This return serves the kitchen, dining room, living room, bath 1, bedroom 2, and bedroom 3. The sum of those supply airflows is 402 CFM. The return in the master suite, which serves the master bedroom and bath 2, had a measured airflow of 161 CFM. The sum of those supply airflows is 155 CFM. The supply and return airflows for this home were well balanced.

Similar tests were performed to determine the airflows of the transfer grilles and the bathroom exhaust fans. The combined area of the transfer grilles and the door undercuts provided adequate return airflows from the secondary bedrooms. Although each bathroom exhaust fan is rated for 80 CFM, the master bath fan was only exhausting 36 CFM and the common bath was tested at 45 CFM. The published fan ratings are based on a static pressure of 0.1 in. The type of duct material used, length of the duct run, and the number of turns all impact the pressure drop and the resulting fan performance. Additional follow-up work is underway to improve the bath fan performance.

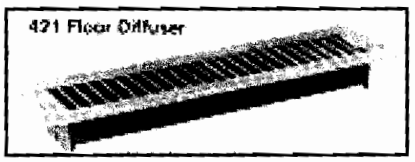


Figure I-49. Floor Diffuser used in Prototype

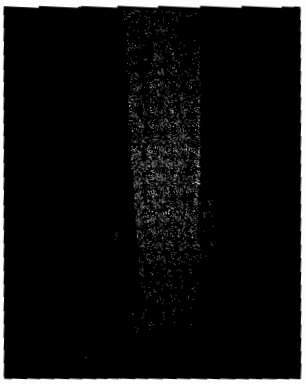


Figure I-50. Central Return in Hall

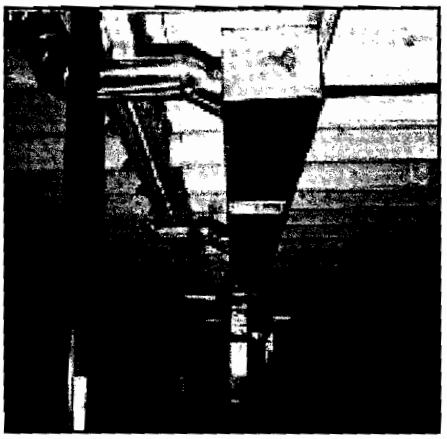


Figure I-51. Prototype

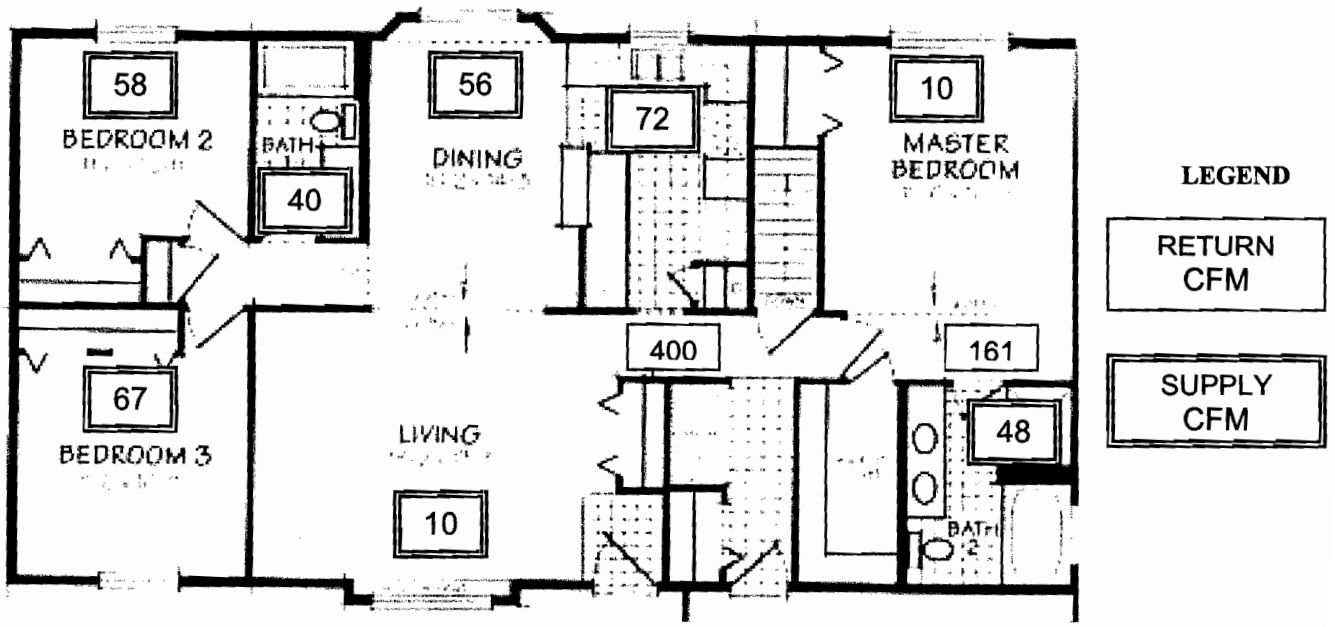


Figure I-52. Layout of supply and return airflows

Furnace-Sizing Methods

Initially, there was some confusion regarding the appropriate furnace size. The CARB Manual J calculations were based on a winter design temperature of -11°F and 0.35 ACH_n. Wausau provided the contractor with a WIS Check calculation based on -20°F, 0.5 ACH_n, and 15% oversize. WESH also provided the contractor with a WIS Check calculation based on -20°F, 0.19ACH_n, and 15% oversize.

The air change rate of 0.5 ACHn used by Wausau is the maximum allowable input, but not necessarily the recommended value. Similarly, 15% is the maximum oversize allowed by the WIS Check program. Wausau was being conservative by using both of these maximum allowed input values. Also, the Wisconsin Administrative Code specifies the winter design temperature to be used depending upon which of four climate zones the home is located in. The required winter design temperature was -20°F, 9 degrees lower than the ASHRAE design temperature. Using this extreme design temperature adds approximately 10% oversizing to the furnace, making the additional 15% oversizing unnecessary.

The standard MEC Check program, upon which WIS Check is based, does not include equipment sizing. Further, WIS Check is a design tool, but was not intended for equipment sizing. Now that the inputs into WIS Check have been revised, the disparity between sizing calculations can be avoided in the future. Unfortunately, this confusion was not resolved before furnace selection. The unit installed was larger than the one originally specified. However, the contractor agreed to set it on the lowest fan speed. With minor modifications, the problem was resolved, and the system was balanced.

Prototype Home Testing

The final step was the testing of the prototype house after construction was completed. The testing was performed by WESH, with assistance by CARB. Those present for the demonstration included: participants from Wausau Homes, the mechanical contractor, and representatives from Carrier Corporation.

In addition to the airflow measurements shown in the Redesigned HVAC System section of this report, Blower Door tests were performed on the Prototype Home. The home is tight, as indicated by Blower Door measurements of: $CFM_{50} = 1073$, $ACH_n = 0.15$, and an ELA of 48.08 $in.^2$ at 4 Pascals.

Significant leakage was found around the attic scuttle (165 CFM) and around both bath fan housings (33/41 CFM). These test results were put into Rem/Rate to obtain a final Home Energy Rating Score (HERS). With a minimum score of 86.0 required to meet Energy Star, this home achieved a HERS score of 87.8.

Based on the test results and feedback from those involved, future work with Wausau would include the following refinements:

- Increased transfer grille sizes to reduce dependence on door undercuts
- Extending supply plenum to locate registers under windows

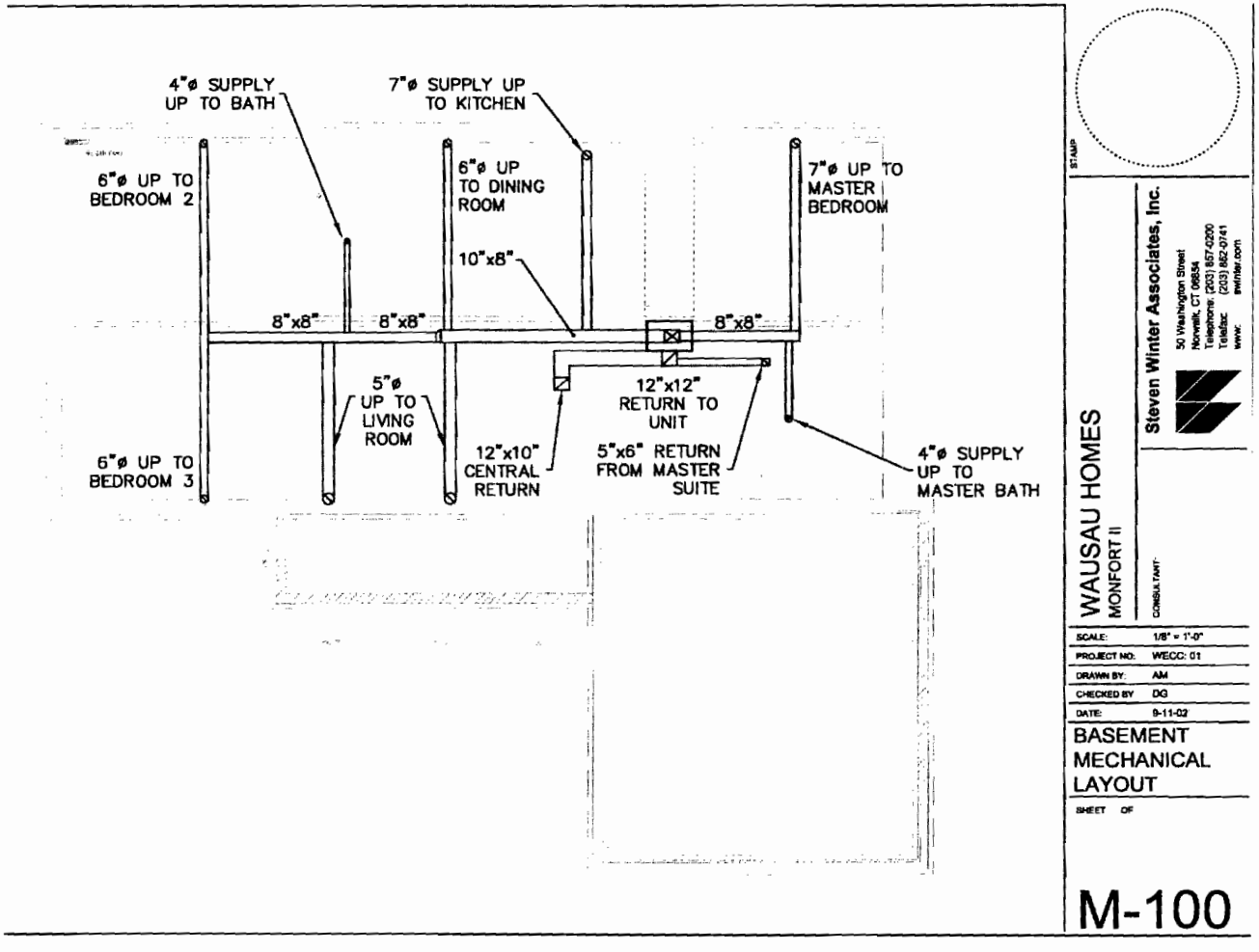
- Downsized duct to kitchen supply in the kickspace
- Properly sized take-offs and register boots

Return air paths for this home were provided by transfer grilles and door undercuts. Because door undercut performance varies with the type of flooring, larger transfer grilles sized for the total return airflow were recommended. This would ensure adequate return airflows, regardless of the door undercut.

In the standard supply duct layout, the bedroom supply registers are located beneath the windows. The supply run was shortened for this house. In the future, the registers will remain under the windows. The kitchen supply duct was sized for cooling and provided excessive airflow. Dampers were used to balance the system during the testing. A smaller duct would be specified for future installations.

For the prototype home, 4-in.-diameter supply ducts were specified for each bathroom. The contractor only had 6-in.-diameter take-offs readily available. Also, the supply boots provided by the plant were 6 in. diameter. To conform to the design layout, the 6-in. take-off was transitioned down to a 4-in. duct and then transitioned back up to fit the 6-in. supply boot. Obviously, this does not simplify the duct layout. In the future, efforts will be made to determine the availability of 4-in. boots and take-offs and comply with standard-size fittings.

Mechanical Drawings



STAMP

Steven Winter Associates, Inc.
50 Washington Street
Norwalk, CT 06854
Telephone: (203) 857-0200
Telefax: (203) 852-0741
www.swinter.com

CONSULTANT:

WAUSAU HOMES
MONFORT II

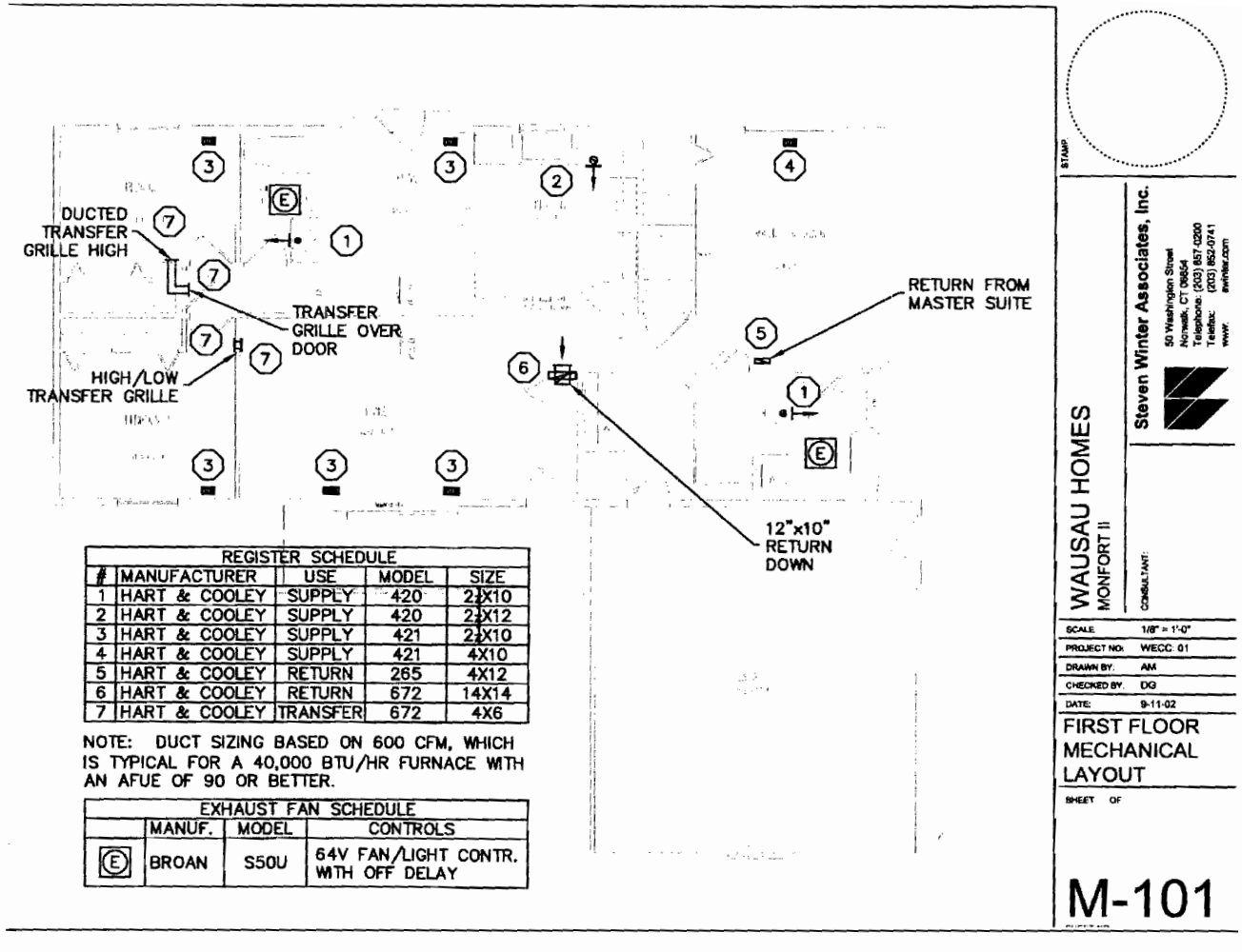
SCALE:	1/8" = 1'-0"
PROJECT NO:	WECC: 01
DRAWN BY:	AM
CHECKED BY	DG
DATE:	9-11-02

BASEMENT MECHANICAL LAYOUT

SHEET OF

M-100

Figure I-53. Mechanical drawing



REGISTER SCHEDULE				
#	MANUFACTURER	USE	MODEL	SIZE
1	HART & COOLEY	SUPPLY	420	2½X10
2	HART & COOLEY	SUPPLY	420	2½X12
3	HART & COOLEY	SUPPLY	421	2½X10
4	HART & COOLEY	SUPPLY	421	4X10
5	HART & COOLEY	RETURN	265	4X12
6	HART & COOLEY	RETURN	672	14X14
7	HART & COOLEY	TRANSFER	672	4X6

NOTE: DUCT SIZING BASED ON 600 CFM, WHICH IS TYPICAL FOR A 40,000 BTU/HR FURNACE WITH AN AFUE OF 90 OR BETTER.

EXHAUST FAN SCHEDULE			
	MANUF.	MODEL	CONTROLS
(E)	BROAN	S50U	64V FAN/LIGHT CONTR. WITH OFF DELAY

STAMP

Steven Winter Associates, Inc.
50 Washington Street
Norwalk, CT 06854
Telephone: (203) 857-0200
Telefax: (203) 852-0741
www.swinter.com

CONSULTANT:

WAUSAU HOMES
MONFORT II

SCALE	1/8" = 1'-0"
PROJECT NO:	WECC: 01
DRAWN BY:	AM
CHECKED BY:	DG
DATE:	9-11-02

FIRST FLOOR MECHANICAL LAYOUT

SHEET OF

M-101

Figure I-54. Mechanical drawing

Part II: Best Practices for Achieving 30% - 40% Space Conditioning Energy Savings in Single-Family Detached Home in a Hot-Humid Climate

Figure II-1. A CARB home built in a hot-humid climate

Background and Introduction

The Consortium for Advanced Residential Building (CARB), one of the Building America teams, has worked with several hot-humid climate builders on home designs (Figure II-1) that achieve at least a 30% savings relative to the Model Energy Code (MEC). This section of the report describes the recommended best practices to achieve these savings without compromising health or safety.

A list of Primary Recommendations and one of Secondary Recommendations is included, followed by a discussion of each item on the list. Case studies drawn from CARB's Building America experiences are presented as examples. CARB has experience with both one- and two-story frame homes in hot-humid climates. However, to supplement the "best practices" recommendations of other Building America teams, concrete wall technology is presented here in lieu of wood framing as the best practice for one-story homes.

Concrete (or concrete masonry) wall slab-on-grade construction has the significant advantage of being termite resistant when coupled with metal interior studs. In addition, concrete provides the superior hurricane-wind resistance required in many hot-humid locations. CARB has extensive experience with concrete-wall homes in Florida, where concrete masonry homes are common. Poured in place concrete walls have proven to be more cost-effective than conventional concrete masonry units for builders constructing enough homes to justify the cost of prefabricated aluminum forms. For other builders, poured-in-place concrete in conventional forms, or concrete masonry units can be substituted without changing the best practice recommendations.

Primary Recommendations

Envelope

- Double-glazed low emissivity (low-E) windows (Figure II-2) with shading coefficient of 0.4 or less
- 6-in. poured-in-place concrete with ¾-in. foil-faced poly-isocyanurate foam, 1 x 2 strapping and gypsum board; or
- 8-in. concrete block with 1-1/2-in. EPS, 1 x 2 strapping and gypsum board
- Exterior stucco finish
- Steel interior studs at 24 in. on-center
- Fire barrier air sealing at attic
- Conventional wood-truss roof with OSB sheathing
- Reflective roofing material

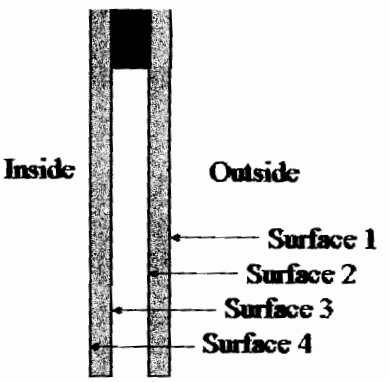


Figure II-2. Double-glazed, low-E window

Equipment

- Manual J / Manual D HVAC sizing
- Seasonal Energy Efficiency Ratio (SEER)-12 air conditioner/ Heating Season Performance Factor (HSPF) 7.5 heat pump (minimum)
- Conventional atmospherically vented or power-vented gas-fired water heater located in garage
- Ducts mastic sealed (leakage less than 5% of fan-flow)
- Ducts and air handler within conditioned envelope
- Compact duct distribution system
- Central air return with transfer grills or jump ducts at secondary spaces (balanced air-flows)
- Provide filtered supply-only ventilation as needed
- No unvented gas appliances (except a gas range with a range hood exhausting to the outside)

Secondary Recommendations

- Energy-efficient lighting.
- ENERGY STAR appliances.

Primary Recommendations for the Envelope

Double-Glazed Low-E Windows with Shading Coefficient of 0.4 or Less

Discussion

Spectrally selective, low-E coated, double-glazing is applicable to all hot-humid climate homes. A selective low-E coating greatly reduces the amount of incoming solar energy (it has a low Solar Heat Gain Coefficient [SHGC]).

The U-factor of the glazing is strongly influenced by the frames: uninsulated aluminum frames increase the conductivity of the overall window substantially (typically doubling the U-factor relative to the center of the glass). This may or may not increase the annual heat loss, depending upon the climate (windows with a higher U-factor may cool the house at night through radiation). However, thermal break aluminum or vinyl windows reduce the *peak* cooling load, which can help to reduce the size of the AC equipment.

Look for the NFRC ratings, which are slightly different from conventional ratings. The desirable glass has the following characteristics, which can be found on the label attached to all glass:

Desirable Low-E Glazing Characteristics for Hot-Humid Climates:

- Total unit U-value should be 0.35 or less if thermally broken aluminum or vinyl sash and frames are used. A typical U-value for aluminum sash is 0.6 or more.
- The SHGC should be 0.40 or lower.
- The low-E coating should be on the #2 surface, to reduce heat gain from the outside. This is typical for most low-E glazing.
- Because occupants enjoy seeing out through untinted glass, it is desirable to use (more expensive) "spectrally selective" glazing, which couples high visible transmittance (VT) with a low SHGC. A high VT will also decrease the use of electricity for lighting, reducing the cooling load and overall energy use. Glass is available having a VT over 0.65 coupled with an SHGC of 0.42, but it is not commonly used in residential windows. Cheaper low-E glazings have VT's as low as 0.35. Low values will result in a noticeable violet color to the glass.

Benefits Demonstrated in CARB/Building America Case Studies

- The cost-effectiveness of low-E glazing has been demonstrated in every CARB hot-humid climate project.
- The low-E coating provides the equivalent of another layer of glazing at a much lower cost.
- Low-E glazing makes it possible to dispense with registers located close to the windows, thus reducing the cost of air distribution.

Six-inch Poured-in-Place Concrete

Discussion

The hot-humid climate zone includes most of the areas in the country where hurricane-force winds are common. When designing for high-wind areas, stronger exterior walls are usually necessary. Also, as shown in Case Study #3, homes built of poured in place concrete or concrete masonry are commonly used for wind and vermin resistance, especially in Florida. Homes built with masonry walls and metal interior framing avoid all wood framing below the level of the top plate, reducing the risk of termite damage.

For larger builders, the investment in a set of prefabricated aluminum forms is likely to pay for itself at a reasonable return on investment by reducing the time of construction and the cost of the exterior finish. The smooth exterior surface created by the aluminum forms eliminates at least one base coat on the exterior stucco. Although CARB's experiment with a precast wall system was not cost-effective, precast systems (if the joints are properly treated) can also be used.

Polyisocyanurate foam board (polyiso foam) provides high thermal efficiency at a reasonable cost. The optimal thickness of the foam was determined through simulations to be ¾ in. in mid-Florida, resulting in a composite R-value of R-8.5, taking account of the reflectivity of the foil face, this higher R-value is achieved by creating an air space between the foil-faced polyiso foam and the gypsum board interior by inserting ¾-in.

strapping between the foam and the gypsum board. The foam is tacked in place with adhesive, then secured by nailing the strapping through the foam. According to the IRC, wiring can run horizontally in the ¾-in. void space providing that it is protected by 1/16-in. metal plates everywhere that it penetrates a piece of strapping.

Benefits Demonstrated in CARB/Building America Case Studies:

- Concrete walls poured in prefabricated aluminum forms resulted in noticeable savings for a production builder compared with concrete masonry units, and produced a strong, smooth, accurate, easily finished wall system.
- CARB has successfully demonstrated the use of ¾-in. foil-faced polyiso foam with ¾-in. wood strapping in Central Florida. This system proved to be substantially more energy-efficient than the conventional method used with concrete block, which employs radiant barrier paper without added insulation.

Eight-inch Concrete Block

Discussion

While concrete block is the common method of producing masonry homes because of its low cost, it has many disadvantages relative to concrete, especially that poured within aluminum forms. With its many voids, the block easily transmits water. Walls must be designed to dry toward the inside. Poly and foil-faced polyiso foam is not acceptable because it is a strong vapor retarder, so EPS is the recommended alternative (XPS can also be used if desired). Foil must not be used, to allow drying to the interior. Thicker EPS is required for two reasons: it has a lower R-value than polyiso; and the R-value of the reflective foil is lost.

Applications in CARB/Building America Case Studies:

CARB has not experimented with concrete block, but has observed the potential for water problems and has calculated a low R-value with the conventional insulation and interior finish application (steel studs, foil-faced paper, and gypsum board).

Exterior Stucco Finish

Discussion

Applying the stucco directly to the relatively smooth surface of the concrete wall is simplified versus application on concrete block. A primer is applied to the walls to improve adherence, and a one or two coat finish can be sprayed or troweled on the primed surface.

Benefits Demonstrated in CARB/Building America Case Studies:

Labor savings for the simplified stucco can be significant, helping to offset the higher cost or more efficient equipment and the better windows. In some of the prototypes with aluminum forms, the builder was able to apply only one coat of stucco over a primer.

Non-Combustible Air Gap Sealing at Attic

Discussion

Every opening into the attic for plumbing vents, bath fan exhausts, and electrical wiring needs to be gap sealed to prevent air movement between the attic and the living space. Most building codes consider this gap-sealing to be fire-stopping when it occurs around chimneys, ducts and pipes, and therefore require it to be non-combustible (mastic or foam products are available for this purpose). Although the code does not specifically require non-combustible fire-stopping at electrical wiring, inspectors may require that all gap sealing be done with non-combustible material.

Applications in CARB/Building America Case Studies:

Gap sealing is an essential part of a successful energy-efficient project. CARB has helped convince builders that the extra attention to this detail is worthwhile, partly by showing the significant gaps typical of a conventional project. Once the builder is convinced, the added effort becomes routine.

Conventional Wood-Truss Roof with OSB Sheathing.

Discussion

Stick-framed roofs are common in areas with low labor cost, for small homes (less than approximately 1,200 ft^2 of roof). However, stick framing (especially for hipped roofs) requires somewhat complex engineering that is carefully followed in the field, a requirement that is seldom met. Gang-nail trusses are engineered using sophisticated computer programs, and because they are fabricated in a plant, they have reliable characteristics, leaving little to chance. In high-wind areas, it is crucial to properly secure the trusses with hurricane clips or straps.

Applications in CARB/Building America Case Studies

All CARB projects are built with pre-engineered gangnail trusses. In one case, CARB demonstrated notable cost savings if the builder switched to trusses, but the builder chose to retain stick-framing.

Reflective Roofing Material.

Discussion

Studies by the Florida Solar Energy Center (FSEC) have shown that roofs that reflect sunlight stay cooler and maintain a cooler temperature in the attic. If ducts are located in the attic, reflective roofs are especially effective in reducing both energy consumption and peak cooling loads. Reflective roofs also reduce the "heat island" effect where highly absorptive roofs raise the ambient temperature in the local microclimate. White asphalt shingles have only a moderate cooling effect, but the shingles themselves do not get as hot and are likely to last longer than dark-colored shingles. To achieve real cooling effects, the roofing material needs to be either tile or metal, either of which can be painted with reflective paints. To achieve dark color, "selective" paint is available that

reflects much of the infrared component of the sunlight while absorbing enough light to create a dark color.

In areas where asphalt shingles are the norm, it is difficult to convince builders to switch to metal or tile solely on the basis of cooling effects alone. However, both types of roof are much more resistant to hail damage than are asphalt composition shingles, and both provide some protection from burning brands for homes exposed to wildfire damage. Algae does not form on either tile or metal roofs to the extent that it does on asphalt shingles. Finally, tile and metal roofing properly applied are more wind-resistant than asphalt shingles.

A full discussion of this subject is found in the *Journal of Light Construction*, June 2003, Pages 75 through 81 (order through www.jlconline.com). Also, a rating organization is up and running: the website for the Cool Roofs Rating Council, listing many rated products, is www.coolroofs.org.

Applications in CARB/Building America Case Studies

CARB has demonstrated reflective roofing in southern California, where tile roofs are normal. In Florida and Texas, low first cost and buyer resistance to white shingles have led builders to choose dark asphalt shingles despite the many advantages of metal or tile. However, higher-end homes are often roofed with tile or metal, and this feature is likely to trickle down to lower-cost homes in the future, as has happened in many hot-dry climate locations.

Building Envelope Water Management System

Discussion

The stucco covered concrete walls of the recommended best practices home eliminate many of the water management problems found in wood-frame construction. Figure II-3 shows the cast-in projection against which the window flange is nailed and sealed. The

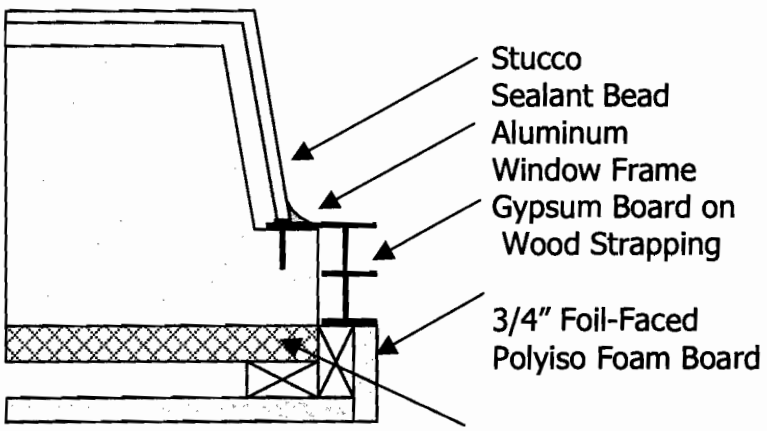


Figure II-3. Detail of window surround with cast-in "buck" to receive the window flange. Cast-in projection against which the window flange is nailed and sealed.

stucco finish then meets and bonds with the aluminum window frame. This detail is formed on all sides of the window; a marble or wood sill can replace the gypsum board at the sill detail.

Recommended Measures

Roof (Figure II-4)

1. Provide Adequate "Crickets" Behind Chimneys and Other Projections through the Roof
   There must be a way of sending water around the objects like chimneys and skylights that block the flow of water down the roof. Behind tall objects like chimneys, install the largest and steepest "cricket" (small gabled roof) that will fit. This will also prevent the buildup of plant debris.

2. Place Chimneys, Dormers, etc., away from Valleys and Adequately Separated from Each Other
   Water collects and runs down valleys. Running valleys together (for example, between closely spaced dormers) or placing a chimney or other obstruction in a valley almost guarantees water leakage. Plant debris collects in these places, holding water and accelerating the deterioration of the roofing.

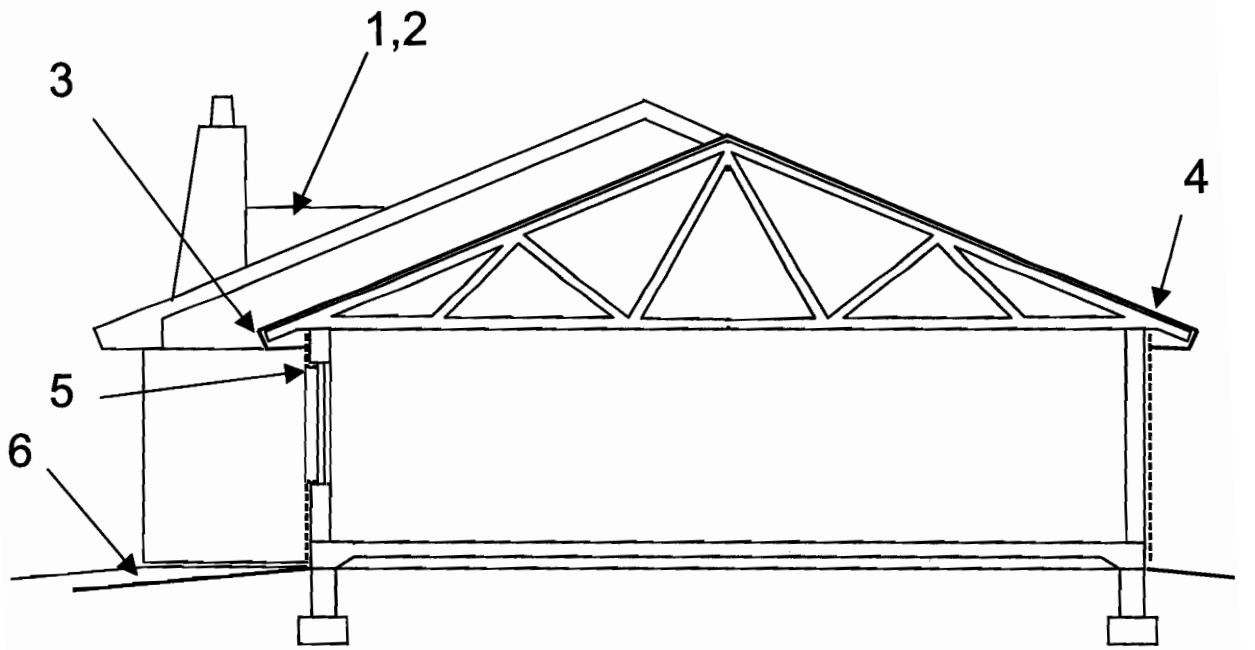


Figure II-4. Preventing water intrusion

3. Use "Kick-Out" Flashing at the Joint between an Eave and a Sidewall
Where a roof runs into a sidewall, "step flashing" is required at the joint. If the roof stops before the wall does, the water that collects against the step flashing will run in behind the siding unless it is directed back out onto the roof by "kick-out" flashing.

4. Use an Impervious Layer at Valleys

At eaves and valleys, an impervious layer of peel-and-stick modified bituminous flashing material should be installed under the roofing.

Why? During heavy rains, water concentrated in valleys, and can build up high enough to back up under the slates or shingles. An impervious layer drains any overflowing water to the eaves before it soaks into the roof sheathing.

5. Properly Flash around Windows and Doors

The bond between the stucco and aluminum frame cannot be relied upon to ensure water-tightness. A fillet of sealant, although far from an ideal form of sealant joint, is adequate to deflect any water that reaches the deeply inset windows. This sealant bead needs periodic replacement, which is straightforward. This detail would not work with vinyl windows, which expand and contract enough to break the bond between the sealant and the window frame. Also, aluminum windows are welded at the corners and typically do not leak, unlike vinyl and wood window frames, almost all of which leak at the corners.

6. Carefully Plan Grading around the Home to Ensure that Heavy Rainfall Will Find Its Way to Drains without Flooding the House

- Typical requirements are to grade away 6 in. in the first 10 ft
- Provide simple retaining walls where necessary
- In dead-flat land, mound up under slab with compacted gravel to ensure drainage away from building

Applications in CARB/Building America Case Studies

The above measures are all good practice, and taken together will help prevent moisture-related problems throughout the building envelope. Because CARB hot-humid-climate builders seldom have problems related to water management in walls, most of the recommendations relate to roofs, which are exposed to the torrential downpours characteristic of most hot-humid climate.

Primary Recommendations for the Equipment

Manual J / Manual D HVAC Sizing

Discussion

Air Conditioning Contractors of America has long published a simple, but effective, method of determining loads ("Manual J") and sizing ductwork ("Manual D"). These design tools are available in user-friendly computerized form for about $400 each. Also available is a linked program for drawing duct layouts.

Oversizing AC systems in hot-humid climates is likely to cause mold problems. Dehumidifying is an essential part of the cooling process. Unless humidity is removed from the air in the room, reducing its temperature will create condensation on any cool surface and create cold, clammy conditions. In addition, to compensate for the clamminess, the temperature is likely to be set much lower than would be the case if the space were drier, thus wasting energy.

It takes several minutes after the AC cycles on before any condensate actually leaves the living space through the condensate drain, which is an essential step in the dehumidifying process. When the AC unit is too large for the load, it will "short cycle" and shut off before any water leaves the living space. For maximum dehumidification and overall comfort, the unit should be sized as small as possible, while reducing the indoor temperature to tolerable (not ideal) levels during the hottest weather when it is running continuously. Manual J calculations will ensure that the unit is sized for this condition.

In addition to "right-sizing" the unit for optimum comfort, low-E glazing and better insulation allow further down-sizing of the AC unit(s), for a saving in initial cost. In larger homes, downsizing may allow one unit to replace two, for additional savings. This cost saving in part compensates for the extra cost of the low-E glazing that is necessary to allow the downsizing, in a classic case of "whole-house" interaction between building components.

Applications in CARB/Building America Case Studies

All CARB projects have been designed using Manual J / Manual D computerized calculation, except those special cases where a more sophisticated program has been used. CARB often finds that systems designed by HVAC contractors are dramatically oversized, as one safety factor is piled on another. It is important that the HVAC designer have sufficient information to account properly for all envelope efficiency measures, which often result in a downsizing of equipment and ductwork sizes.

SEER-12 Air Conditioner and HSPF-7.5 Heat Pump

Discussion

Until recently, SEER-10 air conditioning equipment has been standard across the country. Gradually, SEER-11 or SEER-12 equipment is becoming more widely used. Simulations show that SEER-12 equipment is nearly always cost-effective, and it is

nearly always required in order to meet ENERGY STAR™ standards. SEER-14 equipment is often cost-effective in those cases where the buyer directly compares operating costs with the cost of borrowing with the aim of reducing his total monthly outlay. As it is rare for owners to do this, SEER-14 equipment is typically judged "not cost effective," despite its potential to lower monthly ownership cost.

Heat pumps are preferable to electric resistance heating in all but the mildest of climates. A unit with a heating season performance factor (HSPF) of 7.5 or more will reduce the electric consumption during heating by more than 50% relative to electric resistance heating.

Applications in CARB/Building America Case Studies

For most builders upgrading to SEER-12 is a major step, and for the present, it is a practical goal. In the case of Mercedes Homes, after the initial prototype that incorporated a SEER-14 unit, further prototypes and final production homes used a SEER-11 AC/HSPF-7 heat pump unit.

Conventional Gas-Fired Water Heater Located in Garage

Discussion

Because of the dominance of hot weather, water heaters are best kept out of the living space, and in a place where their skin losses will not increase the cooling load. This also obviates the need for power-vented equipment, and makes gas-fired equipment attractive. There is no justification for electric resistance water heating except where rates are very low, or where natural gas is not available and propane is not desired or is prohibited. The heater can either be located free-standing in the garage, within a closet off the garage, or within a closet in the outside wall. The closet should be finished and insulated from the house. In all cases, ventilation grilles are required to provide combustion air for the unit.

Applications in CARB/Building America Case Studies

Water heaters in CARB hot-humid prototypes have been located freestanding in the garage or in a closet off the garage. Water heaters in attics are not desirable because of the difficulty of access and the consequences of leakage.

Ducts Mastic Sealed (Leakage less than 5% of Fan-Flow)

Discussion

Sealing ductwork is very important in the single-story, slab-on-grade homes with ductwork running exposed within the attic. CARB's recommended best practices involve moving the ductwork and air handler to within the conditioned envelope, eliminating losses to the attic. Even in this configuration, mastic sealing the ducts is a highly desirable measure. Properly sealed ducts make sure air gets to the spaces intended, rather than leaking into a plenum space. It also minimizes the chances of creating pressure differentials from space to space that would induce airflow through the envelope. The process of sealing each joint reduces the chances of unconnected ductwork, a surprisingly common mistake.

Tape is not recommended as an alternative to mastic. Various tapes are tested to UL 181 standards, which supposedly makes them reliable for use on metal or plastic ductwork. However, it has been found that some duct tape (which is not suitable for taping ducts) passes UL 181. Mastic provides the most reliable duct sealing method.

All ductwork, including the air handler compartment (which typically has many leaky joints) should be mastic sealed. A common goal for duct leakage, measured using a "duct blaster" test, is 5 to 6% leakage to the outside.

Applications in CARB/Building America Case Studies

Mastic duct sealing recommended for use in all CARB homes. Energy savings can be relatively modest, or substantial, depending upon how well constructed the ductwork system is to begin with. To be sure the sealing has worked, it is advisable to perform a duct blaster test.

Ducts and Air Handler within Conditioned Envelope

Discussion

The main force of CARB's efforts to protect ductwork from hot attics in hot-dry climates has been to bury ductwork within attic insulation. CARB is experimenting with buried ductwork in hot-humid climates. Although the technique shows promise, it remains controversial, and we have pursued other approaches. Working with Mercedes Homes in Melbourne, Florida, CARB developed a way of creating a plenum within the attic truss space to receive ductwork (see Case Studies). In its latest version, the bottom chord of the trusses are canted upward to form a vaulted space, which is then covered by the framers with sheathing board or a roll-out membrane. Small truss sections are then applied over the membrane or board to form the continuation of the bottom chord, in order to provide a level ceiling (Figure II-5).

CARB also has used dropped ceiling to house ductwork, again requiring framers to install a layer of sheathing board between the plenum and the attic. As part of a system of ceiling crops, CARB ran a main duct through a suspended box that functioned as part of a space divider and as a plant shelf. Dropped ceilings are typically unpopular with builders, which is the stimulus behind the development of the plenum truss (Figure II-6).

Applications in CARB/Building America Case Studies

The builder with whom this design was developed, Mercedes Homes, has not incorporated the idea into his production housing because of some added cost. However, the concept is ripe for further development and offers a straightforward way to incorporate almost all ductwork within the conditioned envelope. Testing has confirmed that the environment within the plenum is nearly identical to that in the house

Compact Duct Distribution System

Discussion

If low-E glazing is used and the home's envelope is relatively tight, it is possible to discharge conditioned air from inside walls or from ceiling diffusers up to 12 ft from the window wall in most cases without compromising comfort. Such "inside throw" layouts cut ductwork runs, saving money and reducing the amount of ductwork that needs to run outside the plenum truss.

Applications in CARB/Building America Case Studies

Compact duct distribution systems have played a central role in many CARB projects. It is a crucial part of efforts to bring ductwork inside the conditioned envelope by using the "plenum truss" approach.

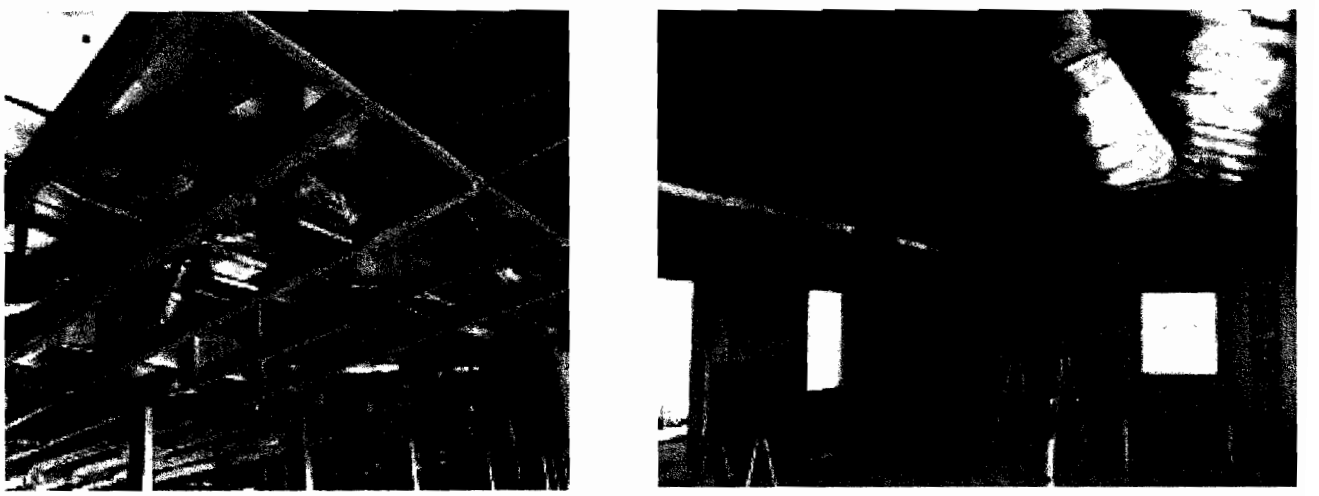


Figure II-5. Plenum truss after lining (left) and after ductwork and lower chord are installed (right)

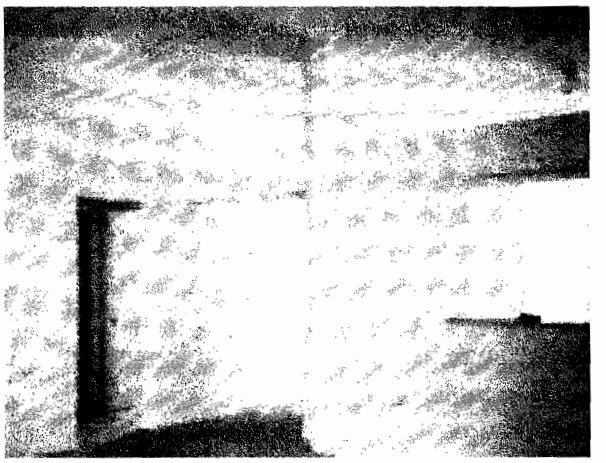


Figure II-6. Boxed-in main duct between kitchen and living room

Central Air Return with Transfer Grills at Secondary Spaces (Balanced Air-Flows)

Discussion

There is nothing wrong with adding a ducted return from each room, as long as the returns are not panned and as long as they remain within the conditioned envelope of the home. However, ducted returns are an unnecessary expense in most housing and are a definite liability if they run in the attic.

A more reliable and cost-effective approach is to provide a central return and make sure that there are transfer grilles or transfer ducts, of adequate size, that allow air to return from individual closed rooms to the central space. A common requirement is that the differences in static pressure between any two rooms remain below 2.5 Pascals. This is a low but achievable number; however, 3 pascals is the common target number.

The worst possible conditions occur when there is neither a ducted return nor a transfer grille (Figure II-7).

> *Why? If one space is pressurized, some other space will be de-pressurized. In both cases, air is forced through cracks into or out of walls and attics, increasing energy losses. Many examples of "soot" accumulation can be traced to pressure imbalances.*

The plenum truss provides an ideal way of transferring air from one space to another, merely by installing grilles into the plenum, which then functions as a return air plenum.

Applications in CARB/Building America Case Studies:

Besides using the plenum truss, CARB has used several different, cost-effective methods of transferring return air without compromising acoustic or visual privacy. A common solution is a high grille on one side of an interior wall cavity, and a low grille on the other. Sometimes rooms do not have any common wall with the main space (for example, a door at the end of a corridor). In these cases, grilles can often be put into and out of a closet; or grilles can be located opposite each other over the door.

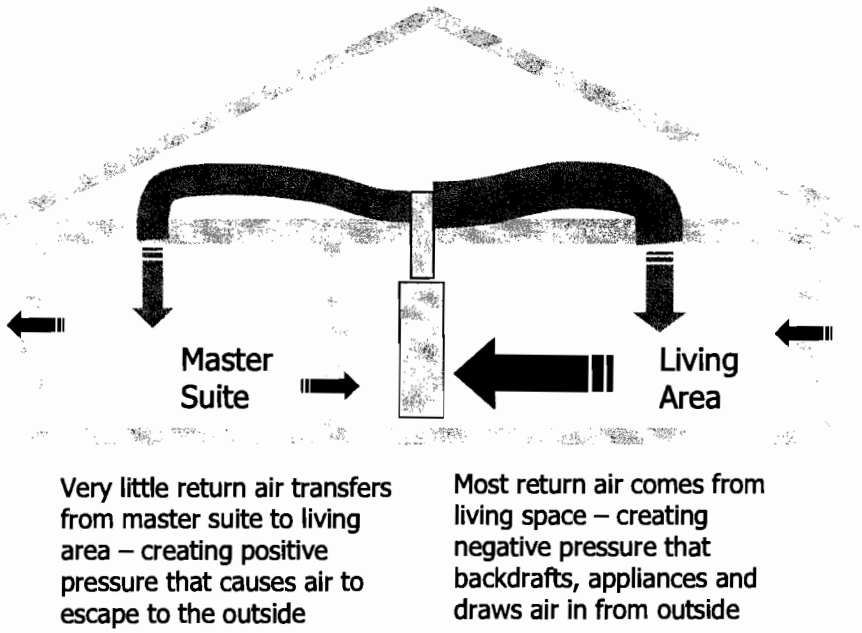


Figure II-7. The result of unequal pressures in a house because of lack of a ducted return or a transfer grille

Provide Supply-Only Ventilation

Discussion

Some level of ventilation is desirable in all homes, especially those with a tightly sealed envelope. Because the walls are of concrete and all openings through the ceiling into the attic are sealed, the CARB best practice home is likely to be very tight. One factor reducing the need for ventilation is that the only combustion heating appliance, the water heater, is located in the garage and gets makeup air directly from outdoors.

The range exhaust, bath fans, and dryer all discharge house air to the outdoors, creating a deficit that needs to be made up. CARB has found in poorly sealed wood-framed homes that despite the presence of an open 6-in. duct into the return air plenum, replacement air preferentially enters through crack and leaks, with virtually no air coming through the duct. Some of these leaks will be from the garage, potentially allowing car exhaust fumes to enter the home. The only proof against such leakage is to pressurize the home enough to prevent air from entering house from the garage, overcoming any wind pressure that is likely to occur. This would require a substantial amount of continuous ventilation, which would not only be very costly to operate, but would compromise comfort.

Hence, the first step in controlling ventilation air is to carefully seal the wall and carefully weatherstrip any openings between the garage and the home. Once this is done, ventilation becomes a matter of providing adequate comfort for a reasonable operating cost. CARB continues to examine systems involving sophisticated controls, but

recommends a simple, practical, and cost-effective solution: install a 6-in. sheet metal duct running as directly as possible from the outdoors to the return air plenum of the air handler. Whenever the air handler runs, approximately 50 CFM of outdoor air will be drawn into the house by the fan. If added ventilation is needed, the air handler can be run manually on its "fan" setting. A manual damper should be installed on this intake duct, to allow the homeowner to eliminate the ventilation if desired. Incoming air is automatically filtered in the air handler if the outside air duct runs to the return air plenum (Figure II-8).

Another option is a separate fan unit that draws in outside air, filters it, and distributes it to (typically) bedrooms. The unit operates independently of the central fan, but can be linked with the bath fans, range fan and dryer exhaust to guarantee filtered makeup air when these appliances are running.

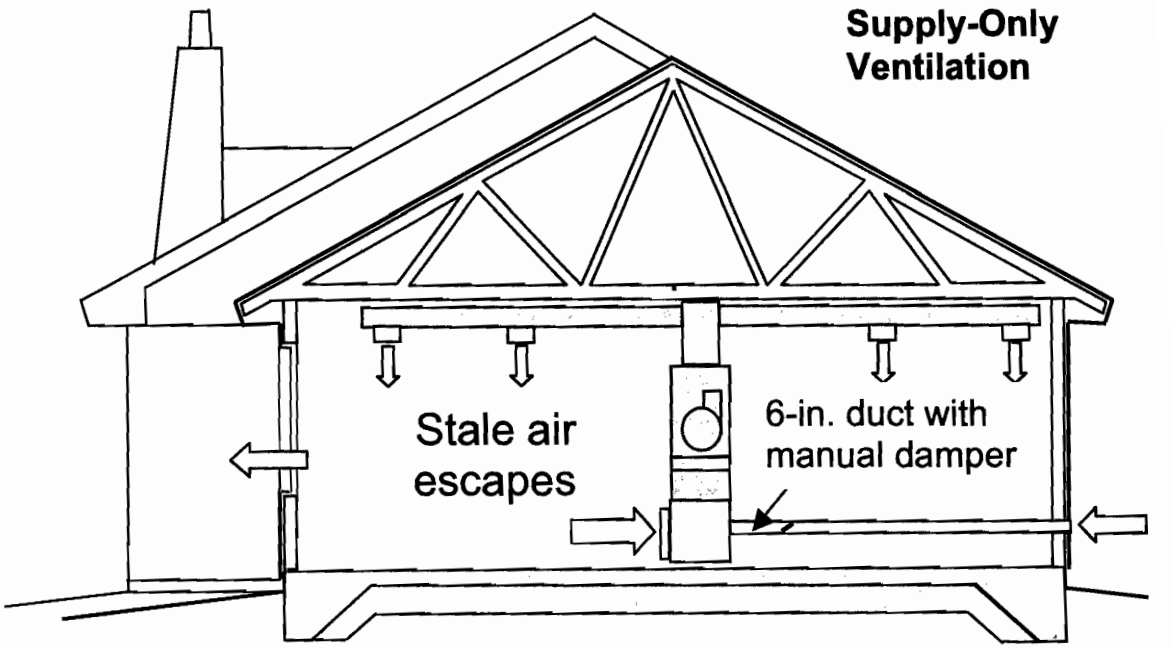


Figure II-8. Supply-only ventilation

No Unvented Gas Appliances (Except Gas Range with Range Hood Exhausting to the Outside)

Discussion

Unvented gas appliances, such as fireplaces or heaters, may or may not be a health hazard, depending upon whether the flame is properly adjusted. What is not controversial is that they are potentially highly destructive to the framing and finishes of the building. These devices create large quantities of water if they are run for extended periods, because the main products of complete combustion are water vapor and carbon dioxide. This water vapor can raise the interior relative humidity to unreasonably high levels. Combined with the supply-only ventilation required for hot-humid climates, highly humid indoor air can be driven into the construction, with the potential for rot.

Applications in CARB/Building America Case Studies

CARB recommends against the use of these devices, and insists that all gas ranges be equipped with a range hood that ventilates to the outside. These are basic safety and indoor air quality measures that should always be observed.

Secondary Recommendations

Energy-Efficient Lighting

Discussion

One of the most important ways in which energy is wasted (especially in hot climates, where the lighting load creates an additional cooling load) is the use of incandescent lamps. Until recently, however, most fluorescent lamps had disadvantages that limited their use to some bathroom and kitchen lights (with high-end homes dispensing with them altogether). These disadvantages are rapidly being eliminated by successive generations of compact fluorescent lamps. While some still exhibit a time delay before they are fully bright, their color can be quite authentic, especially when reflected from a recessed can, or diffused through the shade of a lamp. Lights that are seldom used can remain incandescent with little loss in energy. Also, fluorescent lamps typically do not work as well outdoors as incandescent lamps.

Applications in CARB/Building America Case Studies

Because of the past history of ineffective fluorescent lighting, CARB's builders have steered clear of fluorescent lighting, responding to market resistance to their use. As market acceptance grows, CARB will continue to suggest the increased use of fluorescent lamps in built-in fixtures.

ENERGY STAR Appliances

Discussion

Two of the most important appliances from a water-use and energy efficiency point of view are the washer and dryer, which are seldom supplied by the builder. However, the builder should include a gas line to make it possible for the homeowner to install a gas

dryer. In most cases, gas energy is less costly than electricity. The two main appliances supplied by the builder where efficiency is important are the refrigerator and the dishwasher. There are now hundreds of models of refrigerators that are ENERGY STAR rated, and their use should be routine. There are also many energy-efficient dishwashers available.

Applications in CARB/Building America Case Studies

CARB has had mixed success in encouraging builders to install ENERGY STAR appliances. Typically, as with McStain in Boulder, Colorado, ENERGY STAR appliances are requested by buyers in certain markets where energy performance is a major issue. In other cases, aesthetics or quiet operation governs, and the ENERGY STAR rating is not considered an important issue. This is gradually changing as ENERGY STAR becomes better known.

First Prototype Case Study: Four Generations of CARB / Mercedes Homes Concrete-Wall Prototypes

Date: Early 2000

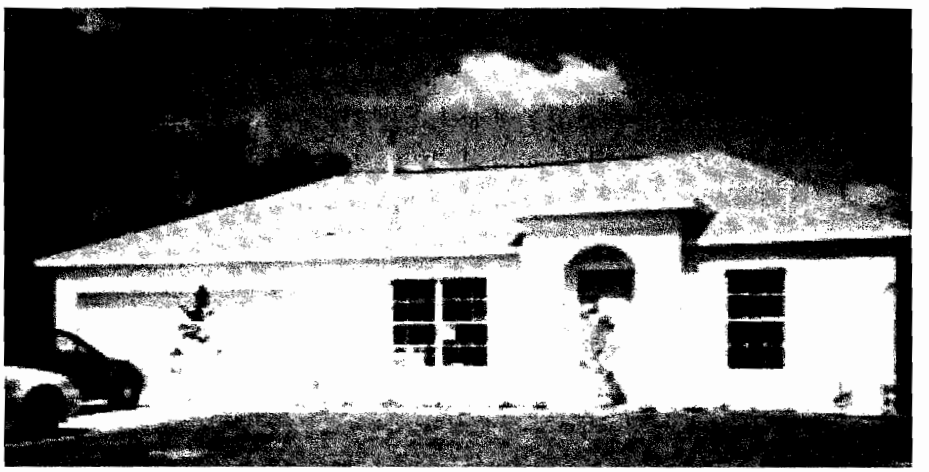


Figure II-9. A Mercedes concrete-wall prototype home

Background

The original impetus for this project was to take the information gained in the first CARB hot-humid climate test house (with Beazer Homes in Houston, Texas) and implement those findings in a second hot-humid climate zone project. The chosen location in central Florida, along with a climate similar to Houston, brings with it additional obstacles and opportunities for innovations.

Mercedes Homes joined CARB and agreed to develop a series of prototypes (Figure II-9). Headquartered in Melbourne, Florida, Mercedes is active in six Florida markets as well as Dallas-Fort Worth, Texas, and Charlotte, North Carolina. When the project started in 1997, Mercedes ranked 55th among the top 100 volume builders and has rapidly climbed in volume in the last three years (Table II-1).

Most sales are to entry-level or first-time move-up buyers. In central Florida, where Mercedes was founded in 1984, single-family home construction is dominated by site-built concrete-block exteriors. Popular with buyers because of their resistance to hurricane force winds and subterranean termites, concrete-block homes are labor intensive to construct and not particularly energy efficient. On-going shortages of skilled masons and a desire to increase factory prefabrication and energy efficiency led Mercedes Homes on a search for a viable substitute to block work for its homes. Before CARB's involvement, Mercedes had actively pursued R & D projects on its own, focused solely on the replacement wall system and had constructed three panelized concrete prototypes, all of which proved too costly for its current market niche. The company was also very interested in improving energy efficiency, the primary goal for CARB.

Using an existing model as the base case (Table II-2), CARB performed "REM/Design" computer modeling and based on estimated costs, determined that the prototype should have R-10 wall insulation and insulating low-e glazing.

Table II-1. Mercedes Ranking in Volume Builders

Item	1997	2001	2002	2003
Ranking	55	59	47	24
Homes Built	1450	1927 (1200+ in central and northern FL)	2493	3066
Revenue	175 million	275 million	396 million	575 million

Table II-2. Initial Base Case

Item	Specification
Home model	2,078 ft^2 Morgan Cove four bedroom, elevation 'D'
Foundations	Uninsulated concrete slab on grade
Exterior walls	8-in. reinforced concrete masonry with pre-formed concrete headers and perimeter bond beam
Roof structure	Prefabricated wood trusses at 24 in. on-center
Wall cladding	Two-coat stucco, no primer
Wall interior finish and insulation	¾-in. wood strapping with foil rated at R-4.2, covered with gypsum wallboard
Attic insulation	R-19 blown-in fiberglass
Natural gas	Not available
Heat pump	SEER-11, HSPF 7
Air handler location	Garage
Ductwork	R-6 insulated flex ducts running in attic
Window frames	Painted aluminum, non-thermally-broken
Glazing	Single glazed, grey tint
Water heater	Electric resistance

Alternate Wall Systems

Background

Before the search and evaluation of potential alternate wall systems, a performance-based specification was developed to limit and focus the selection process. The ultimately selected exterior wall system would need to be:

- Marketable to consumers used to masonry construction
- Able to withstand sustained hurricane-force winds
- Resistant to termites and other wood-destroying insects
- Energy efficient
- Cost effective
- Able to be factory panelized or pre-fabricated.

This specification and preliminary research into available alternate systems led to the initial selection of four distinct assemblies for further evaluation.

Insulated Concrete Forms

The ICF wall system studied for the Mercedes prototype is manufactured by Lite-Forms International of Sioux City, Iowa. The forms consist of an inner and an outer layer of 2-in.-thick Owens Corning extruded polystyrene separated by plastic spacers 12 in. on-center. This panel-type ICF system allows the outer surface to be stripped for reuse after the cast-in-place concrete is set. The exterior raw concrete surface would then receive a sprayed stucco finish virtually identical in appearance to the standard block product. On the interior, the XPS is routed out for the electric romex wiring, and the interior gypsum board finish is screwed to the plastic form flanges originally used to hold the foam forms in place.

Autoclaved Aerated Concrete

The second system given closer scrutiny was Ytong's Value Panel AAC system. The 8-ft x 2-ft x 8-in.-thick solid panels were to be pre-engineered based on shop drawings and installed in vertical planks along the perimeter of the slab. The AAC panels require no additional insulation in this climate and receive the two-coat exterior stucco finish similar to concrete block. Electric wiring can run in channels routed into the block or between ¾-in. furring strips (the prevailing practice in central Florida). Interior gypsum board is nailed directly to the panels or to the furring strips.

Panelized Light-Gauge Steel Framing with Flexible Stucco

The 18- or 20-gauge steel studs would be placed 24 in. on-center, aligning directly under the roof trusses for direct axial bearing. Then a 6-in.-deep stud is required to resist the design wind load of 40 PSF and a maximum axial truss load of 1700#. The steel walls

would be pre-panelized in a plant setting, with 5/8-in. cement-board exterior sheathing manufactured by PLYCEM screw attached before delivery to the site. The field-applied exterior finish would be an elastomeric synthetic stucco product manufactured by GRAILCOAT, LLC. This product is flexible, waterproof, able to bridge joints in the panels, and can give the finished look of traditional stucco. The GRAILCOAT is a single-coat sprayed application.

The steel-wall panels would be insulated with 6-1/4-in. fiberglass insulation with an R-value of 21. The calculated whole wall R-value, taking into account the thermal conductivity of the steel, was R-10, meeting the upgrade target. Two-dimensional thermal flow modeling using "ALGOR" confirmed that an interior thermal break between the steel flange and the gypsum board finish would not be required in this climate.

Ficon Panels

Further research uncovered FICON panels, pre-assembled by Ficon, Inc., of Picayune, Mississippi, a company with 15 years experience in panelized commercial buildings. FICON panels are welded, not screwed. In place of cement board panels screwed to the exterior flanges, protruding flange anchors attached to the outer flange of the studs are set directly into 1-1/4-in. deep, wet concrete poured onto a smooth form. The result is steel framing integrally tied to a smooth 5000-psi concrete plate with no additional mechanical fastening. FICON panels can be fabricated up to 20 ft in length and provide all the shear resistance required in the high-wind zone around Melbourne.

Of the several systems investigated, Ficon panels seemed the most promising and were chosen for the prototype.

Revised Base Case

Mercedes Homes decided to shift prototype development to a simpler starter home that they felt would be more representative of their market strategy. The revised base case would be the recently developed Nicole Isle Deluxe, Elevation "D." This plan contains 1504 ft^2 of living space comprised of three bedrooms, two baths, an eat-in kitchen, and a vaulted-ceiling great room. There is also a two bay garage and a rear covered porch. The building specifications are identical to the original base case.

Additional Right-J computer modeling was performed for various insulation and glazing alternates. The results are shown in Table II-3.

Table II-3. Base-Case Home Results

Option	Specifications	Peak load	Required HVAC
Base Case	Single-glazed grey-tint windows, R-5 walls, R-19 ceiling, AHU in garage, ducts in the attic, SEER 10 equipment	32,571 Bthu	3.0 tons
Alternate 1	Insulated Low-E windows, R-10 walls, R-19 ceiling, AHU in conditioned space, *ducts in conditioned space*, SEER 12 equipment	21,733 Btuh	2.0 tons
Alternate 2	Insulated Low-E windows, R-10 walls, *R-30* ceiling, AHU in conditioned space, *ducts in the attic*, SEER 12 equipment	22,667 Btuh	2.0 tons
Alternate 3	Insulated Low-E windows, R-10 walls, R-19 ceiling, AHU in conditioned space; *50% of ducts in conditioned space*, SEER 12 equipment	23,867 Btuh	2.0 tons

Final Building Specifications

Based on the performance trade-offs determined by the above analysis and the cost and performance trade-offs of the alternate wall systems researched, the final prototype specifications were based on Alternate 3 and are listed in Table II-4. It should be noted that the compact, highly efficient floor plan, the limited glazing area, the strict rectilinear building footprint, (resulting in a high floor area to building envelope area ratio) and the mild climate tended to diminish the effects of improving the envelope performance. Therefore, strategies that may be cost effective given more complex (or less efficient) building forms are not cost effective in this home.

Table II-4. Final Prototype Specifications Based on Alternate 3

Home model	Nicole Isle Deluxe, Elevation "D", 1504 ft^2
Foundation	Slab on grade, uninsulated
Wall construction	FICON panels with 1-1/4-in. 5000 psi concrete-plate facing
	Specified: 18-gauge steel studs at 24 in. on-center
	Actually installed: 16-gauge steel studs at 16 in. on-center
Exterior finish	Grailcoat elastomeric synthetic stucco
Roof construction	Prefabricated roof trusses at 24 in. on-center
Interior partitions	25-gauge steel studs at 24 in. on-center
Windows	Soft-coat, low-E, double-insulated glass in non-thermal-break aluminum frames (SHGC = 0.55)
Wall insulation	6-1/4-in. full-width, unfaced fiberglass blankets. Effective whole-wall R-value equals R-10.5
Ceiling insulation	Unfaced, friction fit, R-19 fiberglass blankets
Ducts and AHU	Air-handler enclosed in an insulated, air-sealed closet at the corner of the garage within the conditioned space; approximately 50% of the duct surface area within the conditioned space, the remainder exposed to the attic; single central return is ducted directly off of the air-handler return plenum
HVAC	Modeled: SEER 12 heatpump, 2-ton capacity
	Actually installed: SEER 13, non-CFC (Puron)
ENERGY STAR	Maximum allowable 43.8 MMBtu/year
	Upgraded design uses 35.2 MMBtu/yr; easily qualifies for ENERGY STAR (actual HERS score = 90)
	Base Case uses 46.1 MMBtu/year, does not qualify for ENERGY STAR
Percentage Saving	31.5% annual savings in cooling energy
	38.5% annual savings in heating energy

Building Design and Engineering

This was the first time the FICON panel wall system was used in a residential application, so careful coordination was required. Based on the stock building plans, shop drawings were produced by the panel fabricator for review by the CARB design team and by Mercedes (Figure II-10). The plans were approved with only minor modification, and panel fabrication proceeded. The slab foundation edge detail required minor modification to properly receive the FICON panels, with a recessed edge detail designed and coordinated between FICON and Mercedes (Figure II-11). Top plate and roof truss connections were similarly designed and engineered.

Concurrently, CARB designers and HVAC engineers worked to cost-effectively integrate the duct system into the house plan. It was during this task, where the 8-ft ceiling at the master bedroom offered obstacles to full integration via soffits or drops. It was decided to place a portion of the duct system on the bottom chords of the trusses and to insulate over the ducts. This configuration is controversial because of concerns about condensation on the ducts in a hot-humid attic during the cooling season. To assess the outcome, CARB monitored temperature and relative humidity at the duct surfaces under the insulation. If successful, the buried duct approach would offer a simple, easy-to-engineer alternative to true inside-the-envelope HVAC, without the necessity of architectural integration and the associated costs. When installed with tight connections and minimal leakage, a buried duct system would offer near-equivalent performance to true inside-the-envelope duct installations, while reducing cost and simplifying engineering. Results showed small, but measurable, amounts of condensation except where ducts were deeply buried (at a dropped ceiling). Because results did not show the entire absence of condensation needed to convince builders, simply burying the ductwork without other measures to eliminate condensation was deemed not advisable.

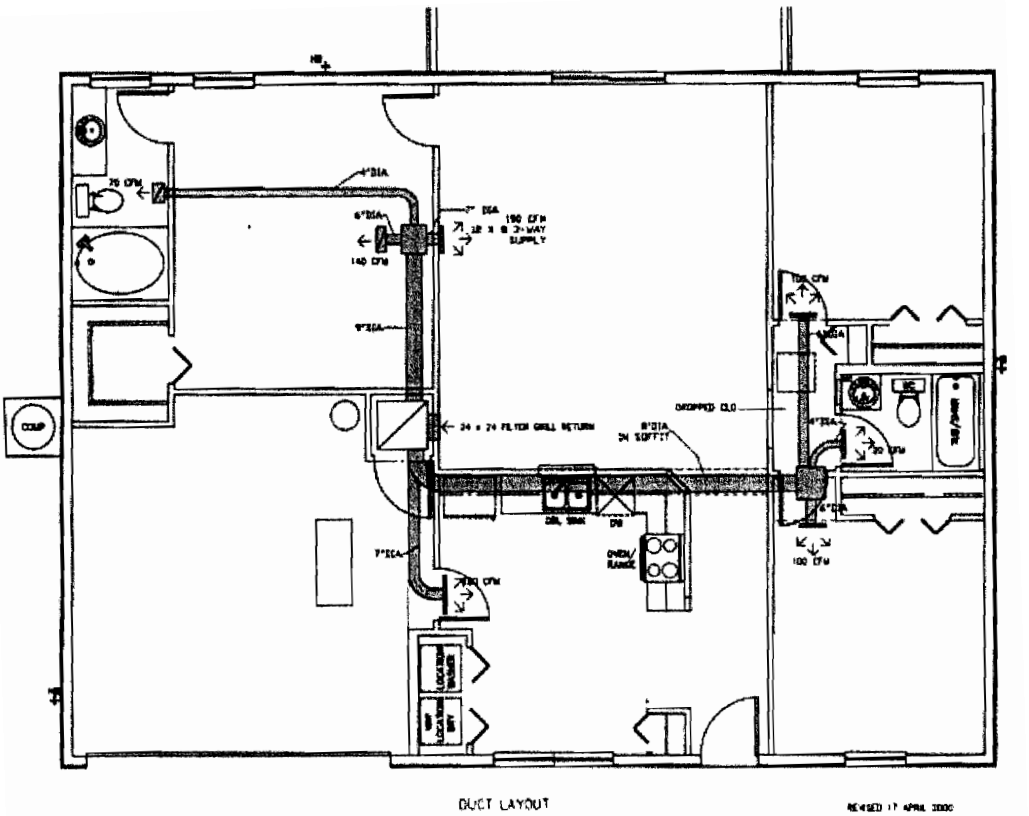


Figure II-10. Duct system layout

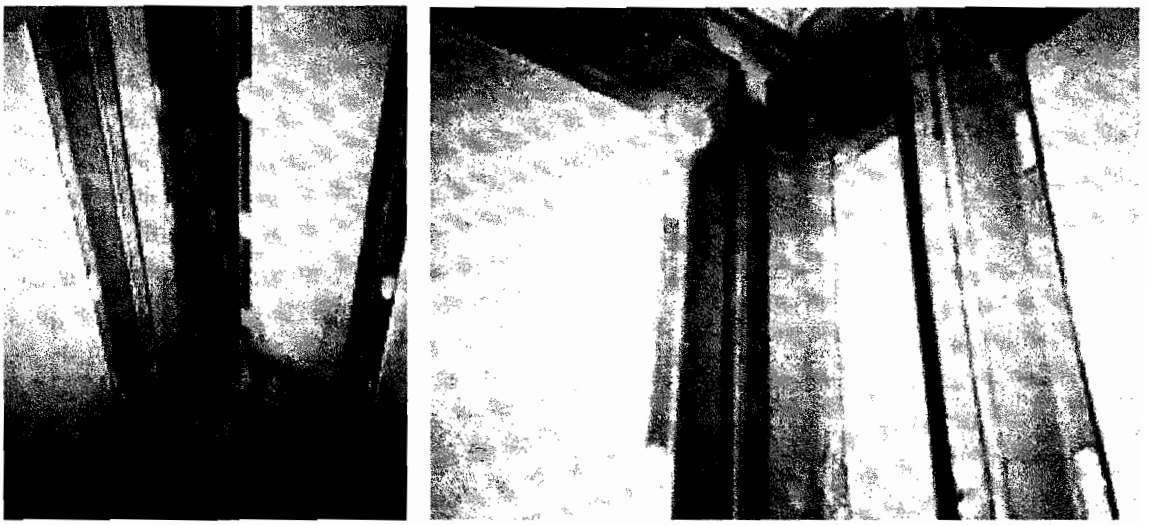


Figure II-11. Ficon panels joining at a corner. Sill is at left, head at right.

The remainder of the building design and engineering did not deviate substantially from standard practice and, as such, no additional significant design/engineering efforts were required. This simplified process was an intentional decision meant to reduce the builder's learning curve and enable the builder to more quickly adopt the innovations across the entire product line.

Construction Process and Analysis

As the slab-on-grade foundation differed little from standard practice, preparation and installation went smoothly. Normal production builder delays had stalled the start of the foundation, so the FICON panels had already been fabricated several weeks before the foundation installation. The timing thus allowed the panels to be shipped from the plant in Mississippi on a just-in-time manner, arriving just as the slab finishing was proceeding. After the required 5-day cure, Mercedes proceeded with the wall panel installation using a crane set procedure. All wall panels were set and secured in under 5 hours. Because of variation in the slab-edge recess, it became necessary to grind down one concrete panel edge to achieve a flush exterior condition. Additionally, one panel corner broke, requiring a patch, and leveling shims were needed at several locations. For a first time use and installation by the builder, the process was seen as relatively smooth and glitch free. Unlike the CMU walls it replaced, the FICON panels do possess much less tolerance for deviation, making an accurate slab installation essential.

Once the walls were assembled, double top plates were bolted to the top steel wall channel. The double plate was necessitated by the 16-in. on-center framing, which did not allow the direct truss bearing as called for in the original specifications. The walls also varied from specification in that the steel framing is 16 gauge, not 18 gauge, as called for. FICON admits to being overly conservative in the panel engineering for this first

residential project and concedes that a 24-in. on-center, 18-gauge steel wall panel is more than adequate and would have cut costs significantly. This over-engineering increased the anticipated production and shipping costs of the panels to a point where they would not be economically viable for this particular building type. Before the first prototype was completed, it had become clear that the Ficon system would not work in production, and CARB and Mercedes were already working on the second prototype, using poured-in-place concrete (see next section).

After the top plates were set, trusses were lifted into place using the same crane used for the panels. The total time required for the wall and roof truss installation was 2 days. This is a full 4 days less than required by the traditional concrete block method. Another advantage over block construction is the elimination of mid-course building inspections, which delay the progress. The FICON system enables the building inspector to make his first post-foundation site visit after the building shell is fully assembled.

The roof trusses for this home, and nearly all of Mercedes products, are clear span, with no interior load bearing. In this manner, the interior partitions proceed after the shell is complete. The non-load bearing partitions are 25-gauge steel studs at 24-in. on-center. Mercedes has employed several techniques of integrating the steel into typical residential partition construction, including using wood sills and plates, and using steel sills with wood blocking for trim attachment. For this project the latter was employed, with door openings being framed with standard 2 x 4s, a very efficient and trade-friendly technique. In lieu of screws for steel-to-steel attachment a hand held "crimper" was used to securely bond the steel members together without the use of fasteners.

Although the high performance low-E windows installed in this home are a major contributor to the overall level of energy efficiency, their installation did not vary at all from standard practice and, therefore, presented no real obstacles in terms of installation.

The installation of the HVAC system was a substantial departure from current Mercedes standard practice and, as such, did present some difficulties. None of the encountered difficulties were, however, technical in nature but were a result of resistance on the part of the HVAC contractor. Even though full engineering drawings and installation instructions were provided, the HVAC subcontractor installed a substantially conventional system. The ducts installed in the attic were not placed on the bottom truss chords, but were suspended from the web members. The contractor argued that the ducts must be suspended by code. Code documentation was subsequently provided showing that ducts must be *supported* not *suspended*, and that ceiling joists qualify as supports. Mercedes then forced the HVAC contractor to remove and correct the duct installation in accordance with the specifications. Additionally, at a site visit during the rough framing stage, it was observed that the ducts at the bedroom wing could be further consolidated into a existing ceiling drop. This was accomplished and recorded into the design drawings and specifications (Figure II-12).

Because this particular HVAC contractor was not trained in high-pressure refrigerant (Puron) systems, a separate Mercedes subcontractor from the Orlando region was brought in to complete the installation. Apparently the connection between the return plenum (first contractor) and the air-handler (second contractor) was not adequately sealed, resulting in an unexpected return side leak that showed up during field testing.

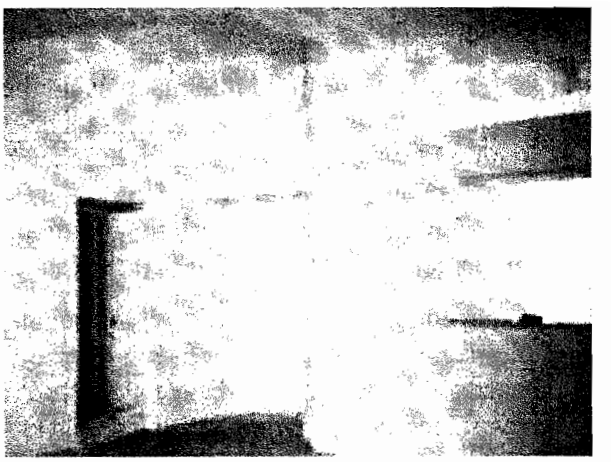


Figure II-12. Photo of boxed-in ductwork main crossing main living area, running from air handler to bedrooms

A minor deviation from the specifications was also observed relative to the attic insulation. The insulation contractor failed to bury the ducts in the prescribed R-19 insulation at the area over the master bedroom. The Mercedes job superintendent brought the insulation installer back to complete the work as specified.

Code Compliance

The FICON panel-wall system, in its first-ever residential application, was a major departure from anything Mercedes had tried before or from anything the local building department had ever seen before. As such, full engineering documentation on the wall system's structural performance was submitted to the building department with the building permit application. The supporting engineering data and the FICON panels' obvious structural attributes combined to elicit a fast approval for the permit application.

Although not specifically reviewed during the permit process, the issue of the duct supports was broached and resolved during the construction process. The HVAC installer claimed that the Florida code specifically required that all ducts installed in the attic be suspended from the truss web members. A conversation with the Brevard County Building Department clarified this view and cited the applicable code statute. Paragraph 410.1.ABCD.3.3.6.4 states that ducts must be *supported* at intervals not greater than 5 ft, and that the supports must be at least 1-1/2-in. wide. It further states that ceiling joist (truss bottom chords) may be considered supports.

There is apparently no specific code reference to the issue of burying ducts under the insulation, so this innovation posed no code compliance concerns.

Sales and Marketing

Mercedes from the beginning was concerned that the selected wall system not have attributes that could be seen as a downgrade in a market where buyers expected masonry construction. The choice of the steel/concrete wall panels effectively answered that concern.

What Mercedes learned from this project is that the CARB systems-engineering approach gives them an additional valuable marketing advantage, that of substantially higher energy efficiency at no additional cost. In this instance, the cost of the better windows is offset by the down-sized HVAC system, while the thermally protected ducts and air-handler cost the same as the standard set-up. Mercedes felt that its market would respond to the energy efficiency pitch and planned to implement it state wide. Marketability was viewed as higher than the standard base-case construction methodology, partly as a result of the higher energy efficiency, but also through the buyer-perceived improvements in strength and storm resistance. The cycle time for building construction was also reduced compared to the base case, mostly attributable to the panelized wall system.

The first prototype was completed in May 2000, with short-term field testing performed in a 2-week span immediately following completion. Concurrently, as this first prototype design and specifications were being developed, CARB and Mercedes Homes worked on the plans for the second prototype, initially intended to utilize Insulated Concrete Forms (ICFs).

Second Prototype Case Study

Date: mid 2000

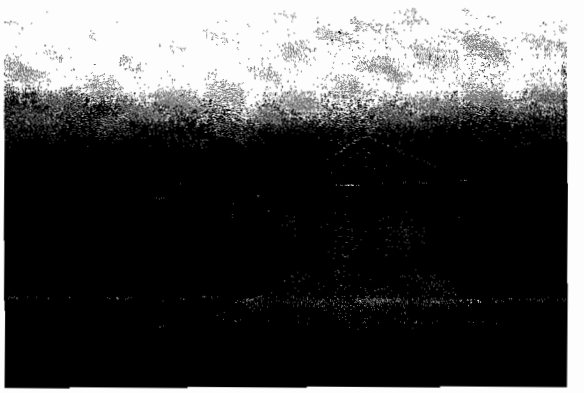


Figure II-13. The best-selling SF Michele II house built by Mercedes

Product and System Research

For this second prototype home, Mercedes chose a larger design, the best-selling 2000-ft^2 Michele II to test the new specifications (Figure II-13; Table II-5).

Although the FICON wall system from the previous home was viewed as an excellent performer in terms of speed of erection, strength, energy performance, and marketability, the installed cost of the system proved too high. Insulated concrete forms (ICFs) were given a second hard look to determine if they could provide performance similar to the FICON house at a more cost-effective price point. Once real-cost information was obtained, Mercedes decided it too was not cost-effective for its market segment. Poured-in-place concrete, a material in which Mercedes had some experience, was selected as the replacement.

Unlike insulated concrete forms, poured-in-place concrete walls require the installation of insulation after the concrete forms are stripped. After reviewing the options, including computer modeling with Rem/Design, foil-faced, ¾-in. polyisocyanurate was selected. The rigid insulation boards are to be adhered directly to the interior surface of the concrete before installation of the interior partitions, eliminating cutting and fitting, and providing a continuous thermal barrier.

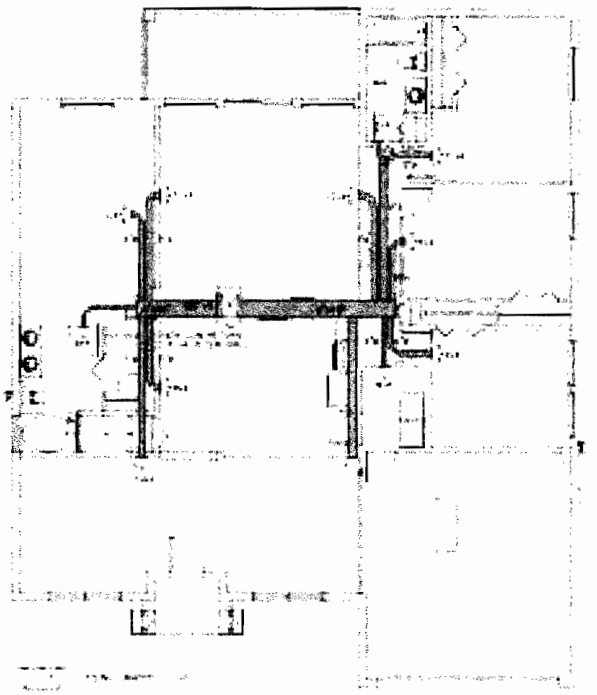


Figure II-14. Plan of second prototype home showing central air handler with boxed-in ductwork across the main living space

The decision to go with the fully inside-the-envelope HVAC system and the architectural integration necessary for that methodology forced the project planners to modify the plan for the interior air-handler installation and for the dropped-duct chases (Figure II-14). The earlier decision to utilized 9-ft-tall exterior walls and flat ceilings throughout allowed the HVAC integration to be accomplished easily. The 12-in.-deep duct drops were arranged in a manner sympathetic to the plan, as well as functional to the air-distribution requirements. Placing a soffit between the kitchen and greatroom provided a break in the ceiling plane between the two spaces and provided a chase for the main supply trunk. A coffered ceiling detail was used at the master bedroom for the master bedroom and greatroom supply ducts. Similarly, the bedroom hall was dropped with the three bedrooms and the hall bath supplied through high wall registers directly off that hallway. The biggest change to the existing plan was the placement of the air-handler in a utility closet in the kitchen. The closet placement, between the kitchen and greatroom, also serves architecturally as a space divider in the otherwise open plan. The engineering aspect of the altered HVAC configuration required no special analysis, and resulted in a compact, substantially downsized system.

The use of 6-in. poured concrete in lieu of the standard CMU required modest re-engineering, but is a system familiar to Mercedes and, therefore, presented no obstacles (Figure II-15). Other changes in the second prototype were simple specification changes and required no additional engineering. As successful as this second prototype was, reaching ENERGY STAR performance levels with a 20-day reduction in construction time and a cost savings of several hundred dollars over standard practice, the significant

Table II-5. Final Second Prototype Specifications

Item	Specification
Home model	2000-ft^2 Michele II
Foundation	Slab-on-grade, un-insulated
Wall construction	6-in. poured in place concrete, 9-ft-high, conventional forms
Wall finish	Two-coat sprayed-on stucco
Roof construction	Prefabricated roof trusses at 24 in. on-center
Interior partitions	25-gauge steel studs at 24 in. on-center
Windows	Double-glazed, soft-coat low-E in non-thermal break aluminum frames, SHGC = 0.55
Wall insulation	¾-in. foil faced polyisocyanurate, R-5.4
Ceiling insulation	R-19 loose fill fiberglass
HVAC	Tempstar heatpump, 11 SEER, 2.5-ton
Ducts	Fully inside conditioned space in 1-ft. drops below 9-ft ceiling plane. Duct chases are air-sealed from the attic with1/8-in. laminated fiber sheathing
Air handler	Interior mechanical closet
ENERGY STAR	Maximum allowable: 54.9 MMBtu/year; Actual 48.1 MMBtu/year; Base case 64.4 MMBtu/year
Energy saving	47% HVAC energy savings
	Cooling energy reduction 40%
	Heating energy reduction 72%
	HERS Score = 87.5

amount of architectural plan/HVAC coordination required did not provide Mercedes with the flexibility they need to expand the concept across its full product line. This limitation led to the development of the six pre-production homes, the Third Prototypes.

The combination of load-reducing specifications allowed the use of a 2.5-ton heat-pump in the prototype versus the 4-ton unit required in the base-case home.

Construction Process Analysis

The slab construction did not alter from builder standard and proceeded on schedule and without incident. The forms for the poured 6" concrete walls followed immediately after slab completion and were installed in several hours. The concrete pour followed the next day, with the forms stripped after a 24-hour cure period. The cycle time for the exterior walls was three days—two days less than the standard block method. After form stripping, some addition prep work was required to the concrete surface prior to the stucco application. This problem was addressed through the use of better forms in the next set of buildings.

After the intervening weekend, the clear-span, flat-bottom chord trusses were installed. As these trusses are simpler than most Mercedes currently uses (no scissors, vaults, or other architectural features), the installation and tie-down saved additional time. Once the home was weathered-in, (roofing on, windows installed), the next step was the installation of the polyisocynanurate insulation to the interior of the concrete walls.

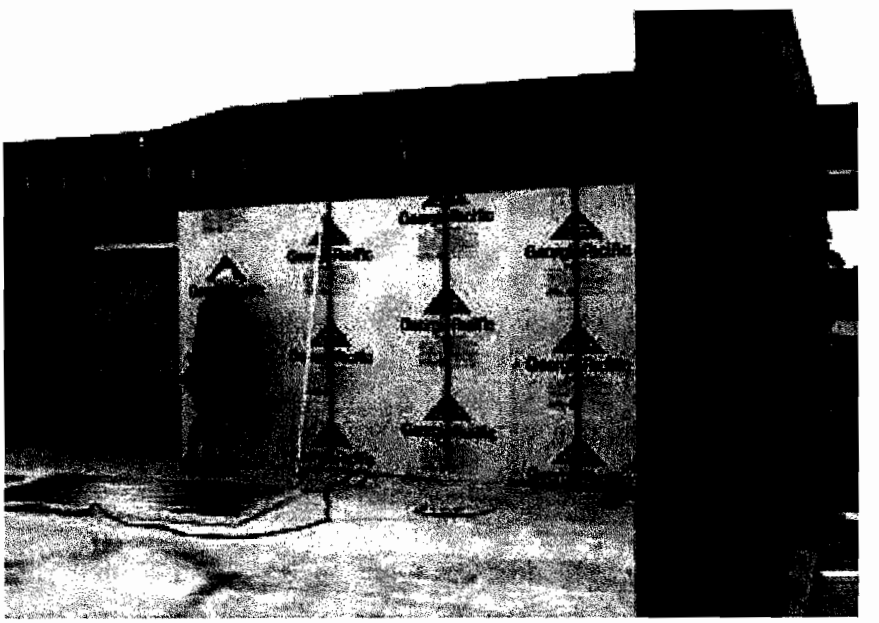


Figure II-15. Eight-foot-long panels of insulation being applied over 9-ft-high poured walls, held in place by strapping. In production, there was little or no extra cost for 9-ft-long insulation. (The roof in the picture belongs to the adjacent house.)

Because the ¾-in. rigid insulation was installed before the interior partitions, only minimal cutting and fitting was required. The insulation boards were adhered continuously along the interior surface of the building perimeter forming a complete, non-broken surface with no thermal breaks. The insulation boards used measured 4 in. x 8 ft, so a yet-faster installation is anticipated when Mercedes switches all its production to this manner. The resulting higher purchasing power will cause 4-ft x 9-ft boards to drop in cost to the per-square-foot equivalent of the stock 4 x 8 boards.

The next step in the process is the installation of sole plates for the interior partitions. Before the light-gauge steel partitions were installed, the plates were used to identify where the ceiling drops would later be installed. Once identified, a laminated fiber sheathing air-barrier was applied to the truss bottom chords at the drop locations. The light-gauge steel studs were then installed at 24 in. on-center. The extra step of installing the air barrier before the partitioning assures that a continuous air barrier would exist between the attic and the duct chases. This method proved to be fast, simple, inexpensive, and production-friendly. Initially, the framing sub was skeptical about the framed-down drops, saying they would increase cost. After it was pointed out that the use of flat ceilings throughout the house would save considerable time and material versus the vaulted ceilings now used, the framer reversed his opinion and said the new procedure would not cause a cost increase.

Following the partitioning was the HVAC installation. The compactness of the system and ease at which it was accessed by the installer ensured a fast, accurate installation. Instead of running the ducts in the attic, as is the norm, the HVAC sub-contractor could do the entire installation from a ladder on the main level. Initially skeptical, the subcontractor is now convinced of the logic in this approach. A substantial savings was, however, obtained on the materials side of the subcontract, where a 4-ton system was downsized to 2.5 tons, and the amount of ductwork was reduced by a similar ratio. In total, the new HVAC system cost approximately $600 *less* than a standard installation.

Code Compliance

The one major departure from standard practice that had relevance to code compliance was the use of the poured-concrete exterior walls in lieu of the block walls. One of the significant deficiencies of using CMU for the wall systems is the onerous inspection process. After the block is laid up, but before the cores are grouted, the bottom block at each slab-to-vertical-steel rod connection must be visible to the inspector. This means breaking a hole in one block every 4 feet along the perimeter to allow inspection. After inspection, the holes are blocked and the cores grouted solid. Another inspection is then required at the completion of the bond beam at the top of the wall. With the poured system, the forms and steel are inspected before pour, with the next inspection after the trusses are installed, a much more streamlined process.

Cost and Performance

Two primary objectives of this prototype were proven out following this post-construction analysis. One objective was to reduce the total cycle time required to

complete a house. This second prototype reduced the complete cycle to 80 days from 100; nearly a 3-week savings. Second, and perhaps most important, was to reach ENERGY-STAR levels of performance, without an increase in first cost. The final analysis demonstrated that the cumulative savings achieved from the down-sized HVAC, compact duct distribution, the concrete walls, and the simplified trusses, more than offset the increase costs for the better windows and the additional air barrier at the duct drops. Mercedes Homes reports a net savings of several hundred dollars for the prototype over the base-case, not counting the savings achieved through the cycle time reduction. Factoring in the real dollar savings achieved through cycle time reduction, Mercedes estimates the actual cost of construction for the prototype was up to $1,000 less than that of the base-case control house. Thermal performance was also excellent (Table II-5).

Sales and Marketing

Mercedes' initial aim from a marketing standpoint was to be able to actively market a home with ENERGY STAR level of performance, and storm and decay resistance, at a comparable cost to its existing products. By establishing a cost basis for the advanced-systems-engineering construction and by verifying projected performance level, this prototype project proved to Mercedes that its marketing goal was reachable. Based on the observable success demonstrated with this and the previous prototype, Mercedes committed to re-tooling its central Florida product line to incorporate the new strategies. This commitment is given form in working with CARB on the development of six new models introduced in central Florida in the fall of 2000 and statewide in spring 2001.

Testing of the Second Prototype

Testing included blower door and duct blaster testing, There was no side-by-side control house; a typical Mercedes Home of similar size and with standard construction specifications was used for comparison.

The objectives of the testing in this instance was to confirm the relative tightness of the envelope as this home utilized a completely new wall system, and to confirm the tightness of the duct system. Weather conditions prevented a short-term cooling energy use evaluation.

Envelope and duct leakage testing was performed. The home was very tight with an envelope leakage of 1249 cfm at 50 Pascals or 0.133 natural air changes per hour using the Sherman-Grimsrud methodology. The duct leakage was found to be 107 cfm to the outside, or 9 percent of the rated air handler flow. This leakage is high given that the ducts are intended to be within the conditioned space. The first-time installation of the laminated fiber sheathing air barrier at the drop locations was not ideal.

None then less the resulting tightness of the concrete wall system was validated which helped convince the builder that the prototype concrete wall system is an excellent choice based on performance for this climate zone.

Third Prototype Case Study

Date: 2001

Figure II-16. A Mercedes home

Pre-Production Houses Concepts and Development

Based on the prototype successes outlined above, CARB and the Mercedes Homes product development team set out to develop specifications for a new series of homes which Mercedes could then offer statewide by all its divisions (Figure II-16). The goal of this product development was the same as the previous prototypes: ENERGY STAR performance in a production friendly, durable, marketable package, with no increase in first cost. The homes offered and their prices, including land, were Keri Isle at $108,900; Bradley Isle at $111,900; Lindsey Isle at $142,900; and Nicole Isle Deluxe at $86,900. Two of the home models were deemed too complicated and were discontinued.

Convinced by the cost, performance, and marketability success of the poured concrete walls, Mercedes made a substantial capital investment in a modular aluminum concrete-form system and brought a concrete-form crew in-house on a full-time basis. These highly sophisticated forms feature modular window forms that create cast-in bucks for their standard window sizes and are 9 feet in height (Mercedes's new standard) (figures II-17 and II-18). When stripped, the forms leave an exceptionally clean surface requiring only minimal prep work before the sprayed-on one-coat stucco application. The finished walls take an average of 2 days to complete (versus 6 days for the block walls) and cost several hundred dollars less, primarily as a result of the savings in using one-coat stucco versus the two-coat stucco application required over block work.

For the pre-production houses, it was decided to replace the insulated-glass soft-coat low-E windows used in the two prototypes with a new product recently introduced to the

market by two major glass manufacturers: pyrolytic hard-coat low-E with the ability to be installed monolithically (single-glazed). Although the R-value of the glass is lower than the traditional insulated soft-coat windows, the relatively mild climate in central Florida and the conservative amount of glazing in the Mercedes houses (10% to 13% of floor area) made this approach viable with a further reduction in cost with only a minor drop in performance. The SHGC of the glazing is only slightly higher than that of the double-glazed low-E7 product used on the first two prototypes.

The most significant change from the second prototype was the manner in which the pre-production houses accommodate the inside-the-envelope HVAC. Rather than coordinating ceiling drops with the architectural plan, an entirely new approach was proposed. This approach, dubbed the "Plenum Truss" system, takes advantage of the 9-ft walls and flat ceilings of the new Mercedes models and uses a series of specially designed trusses (Figure II-19) to provide an air-sealed chase above the flat ceiling, but below the attic insulation.

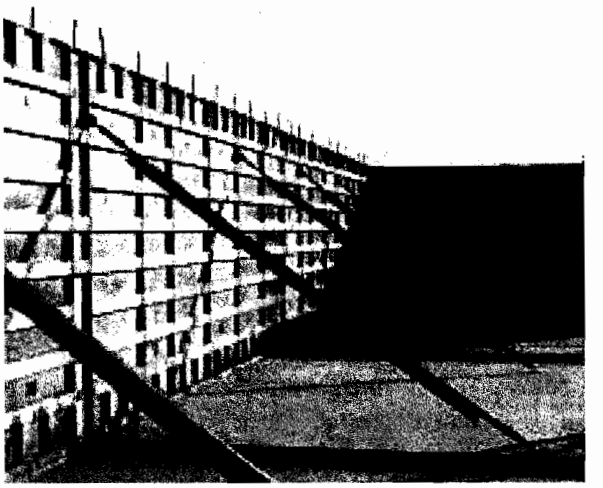


Figure II-17. Prefabricated aluminum forms in place and braced

Figure II-18. Wall forms stripped, with window form in place

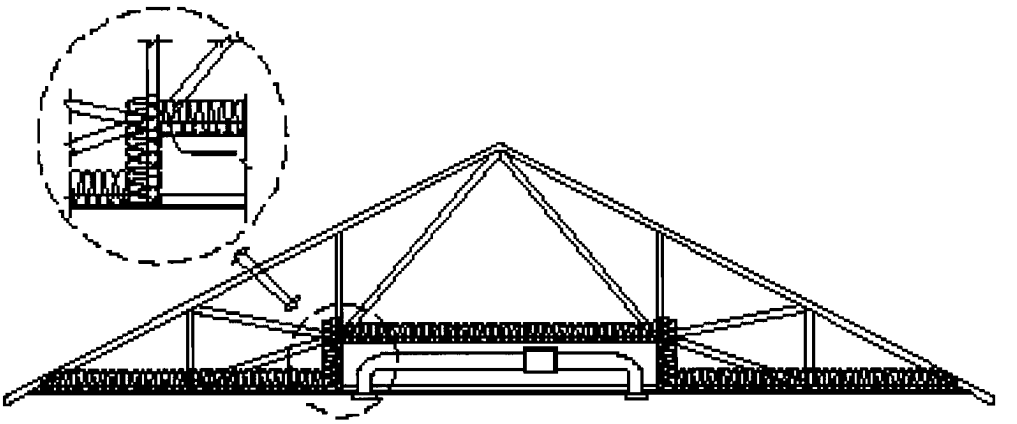


Figure II-19. Specially designed trusses

The area defined by the plenum truss chase was superimposed on the floor plans of the six new houses under development and refined to provide HVAC distribution coverage to all interior spaces, using as small an area as possible. All six floor plans are shown at the end of this section (figures II-24, II-25, and II-26).

Once the plenum area was resolved, trusses were laid out for each of the six plans and the individual trusses were engineered (figures II-20 and II-21). The materials and methods utilized to provide the air barrier between the attic and the chase were given careful study and consideration. Cost, strength, durability, ease of installation, heat and moisture resistance and transfer, production friendliness, and simplicity attributes were weighed and judged to determine the selected method. Although CARB designers and engineers preferred a reinforced infiltration barrier product in 8-ft-wide rolls, Mercedes opted for a laminated fiber sheathing product for the first four homes. The last two homes received the roll product. This topic is discussed further in the section "Construction Process Analysis."

The final specifications of the pre-production houses are summarized in Table II-7.

Table II-7. Final Specifications of the Pre-production Houses

Foundation	**Slab-on-grade, un-insulated.**
Wall construction	Six-in. poured-in-place reinforced concrete, 9 ft high, using modular aluminum forms. One-coat spray-on stucco finish
Wall finish	One-coat sprayed-on stucco
Roof construction	Plenum space roof trusses at 24 in. on-center
Interior partitions	25-gauge steel studs, 24 in. on-center
Windows	Single-glazed, pyrolytic, low-E glass in aluminum frames
Wall insulation	¾-in. polyisocyanurate, R-5.4
Ceiling installation	R-19 blown-in fiberglass
HVAC	Tempstar heat pump, SEER 11 (Capacity varies by plan)
Ducts	100% inside-conditioned-space, located in plenum truss space
Air handler	Interior Mechanical Closet

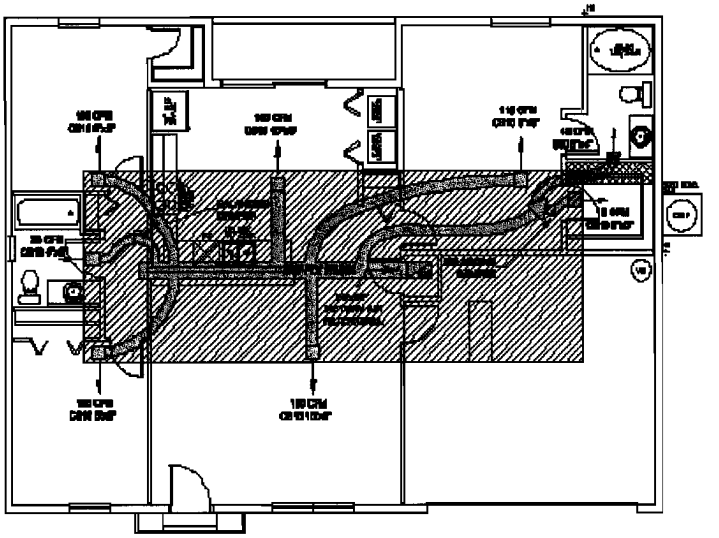


Figure II-21. Plan showing extent of plenum truss (shaded)

Construction Process Analysis

The six pre-production houses vary in three significant ways from their predecessor, the second hot-humid prototype, (1) the glazing, and (2) the duct distribution and (3) the wall forms. The first pre-production house experienced some problems with the concrete pour because of the size of the aggregate and the workability of the mix. The large aggregate stones deformed the mesh reinforcing, requiring some remediation. The stiff concrete formulation likewise slowed the process. After adjusting the mix and aggregate, the pours in the remaining five houses proceeded without incident. The time required for setting up forms, pouring concrete, and stripping forms stabilized at three days—a savings of 3 full days over standard block wall installation.

The custom trusses were set in the same manner as with block walls and required no additional coordination. The perimeter rigid insulation was installed in full size sheets before any interior partitioning, thereby eliminating cutting and fitting. The boards are temporarily adhered to the concrete and then mechanically fastened when the 1 x 2 at 24-in. on-center battens are placed over the insulation and shot through to the concrete. Using this method, the house can be fully weathered in with roof, windows, and insulation, with no additional inspection delays following the formwork inspection.

Originally, a one-coat spray-applied stucco was tried, over a primer. Only very minor prep work is required following the stripping of forms. This process alone saves the builder several hundred dollars over the standard two-coat finish applied to block work. Resistance from tradesmen caused Mercedes to revert to two-coat stucco, but with some savings resulting from the smoothness of the concrete.

Some difficulty was encountered in getting the window manufacturer Kinco to install the Pilkington Solar-E monolithic low-e product, mostly because of unfamiliarity and liability concerns. Pilkington engineers provided adequate reassurance to allow Kinco to

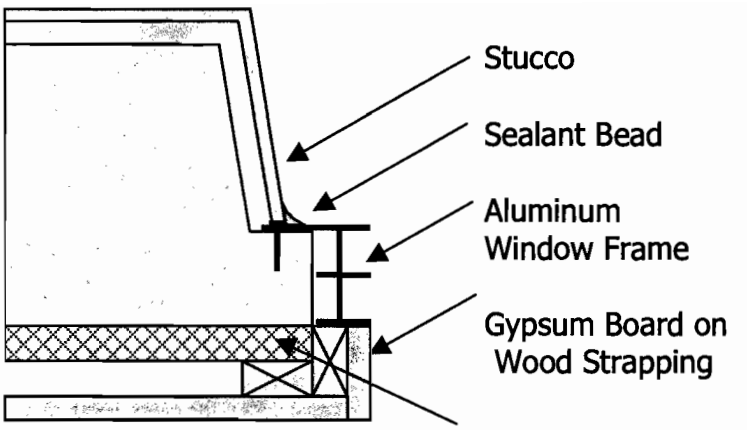


Figure II-22. Detail of window jamb

proceed. It was subsequently discovered that the glass in several of the windows was installed backwards, requiring correction.

The actual window installation was simplified over past procedures. The concrete window forms create cast-in-place bucks and a sloped sill. The aluminum window flanges are fastened directly to the concrete without wood bucks or blocking, another labor and material saving (Figure II-22).

The area of greatest difficulty was encountered in installing the air-barrier between the attic and the plenum duct space. Although originally specified to be a reinforced rolled product, Mercedes chose instead to use a laminated fiber sheathing produced by "Thermoply." This resulted in many more joints and seams than envisioned, and additional cutting, fitting, and patching. Also encountered was a lack of understanding by the mechanical subs who thought nothing of cutting holes in the barrier. Additional installation instructions were produced for the supervisors and installers, this time using the rolled fabric material (Figure II-23). This process was found to be more acceptable, but still not fully grasped by the installers, and therefore not as fast, accurate, or complete as intended. Mercedes estimates the additional cost for the plenum trusses and barrier installation to be several hundred dollars. Given the inefficiencies observed in the first six applications, CARB estimates that a somewhat more refined process with a trained crew could get the additional cost down to $200, at or below the upper limit of cost effectiveness. The installation of the HVAC systems proceeded relatively smoothly. The ease of working on the floor below the plenum was obvious as compared to the typical attic installation. After an initial learning curve, estimates for duct installation time savings were 33%, another potential cost savings. The remaining mechanicals, partitioning, and finishing followed existing standard practice, and were not substantially affected by the new processes.

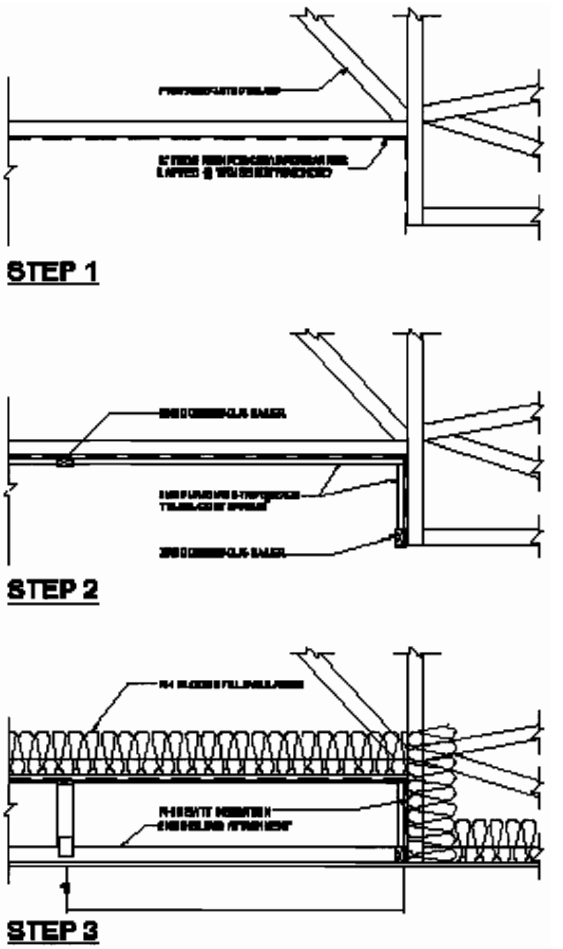


Figure II-23. Plenum lining detail

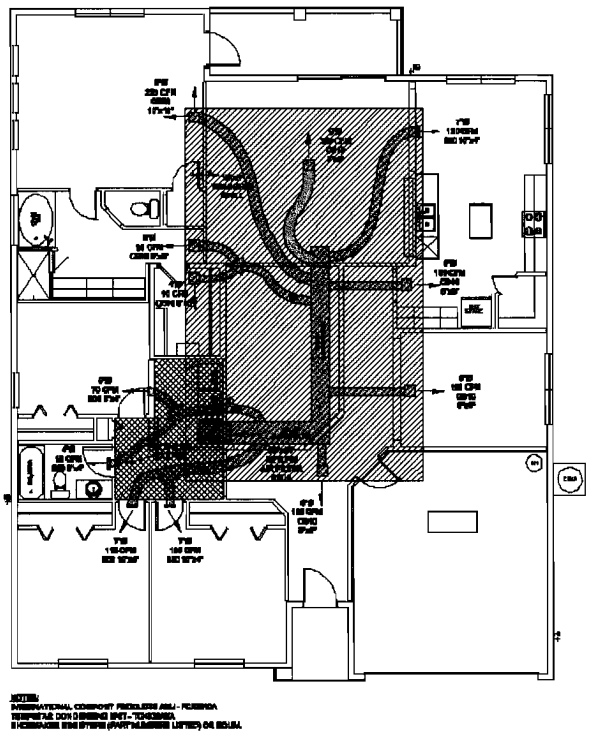
Cost and Performance

The primary objective of this project was to improve the energy performance of a standard Mercedes production home while reducing the construction cycle time, without incurring an increase in initial cost. Initial computer modeling of the six designs using the final pre-production house specifications show that the homes will all exceed ENERGY STAR levels of performance with HERS Ratings of 86 or higher. ENERGY STAR performance testing provided by Florida Power & Light's Built Smart Program confirmed the modeled analysis with all homes receiving ENERGY STAR certification. In terms of actual construction time, the six pre-production houses mirrored the experience of the second prototype, achieving a reduction in total construction time of 10 to 20 days, a substantial improvement. It should be noted that the potential cost savings for that time reduction, such as a decrease in finance and interest costs, are not considered in reviewing the hard cost impacts of the new methods, and when considered, further improve the cost equation. Mercedes has requested that CARB not quote specific costs, but has agreed to allow us to present a more broad cost equation analysis. The cost savings for the poured concrete walls over the standard block walls is about $100. Going to a one-coat stucco application versus the two-coat required for the block walls is a far more substantial savings, amounting to hundreds of dollars.

The cost increase for the single-glazed low-E windows over the standard windows averages about $300 per house. The savings provided by downsizing the HVAC system (allowed by the reduced cooling and heating load) an average of 1 ton is $400. Current cost estimates for the added cost of the plenum truss system is about $700. In total, the current cost savings for the pre-production houses is approximately $200 over standard practice, clearly meeting the original objectives of this project.

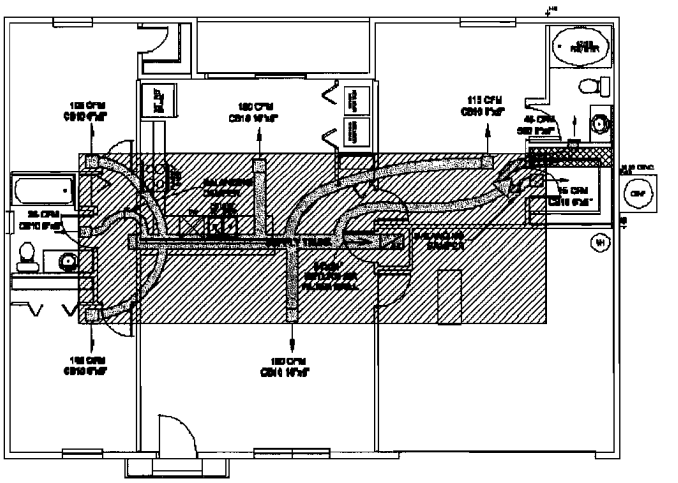
Community-Scale Implementation

Anxious to apply the newly developed technology across its Central Florida market area, Mercedes designated three new subdivisions to receive the new houses. A total of 175 new CARB houses were completed in 2001. However, as the homes tested by Florida Power & Light achieve ENERGY STAR status with no credit given for the inside-the-envelope ducts (a deficiency in its program which is based on the Florida Energy Code) and the fact that the plenum truss requires additional refinement for community-scale implementation, Mercedes launched those three subdivisions without the plenum truss. Mercedes also found that the single-glazed windows with an exposed low-E surface was too hard to keep clean and switched back to double-glazed low-E windows, again in non-thermally broken aluminum frames.



LORA ISLE 2414

Figure II-24. Plenum Truss Duct System layout (Lora Isle Model)



KERI ISLE "00" 1365_01

Figure II-25. Plenum Truss Duct System layout (Keri Isle Model)

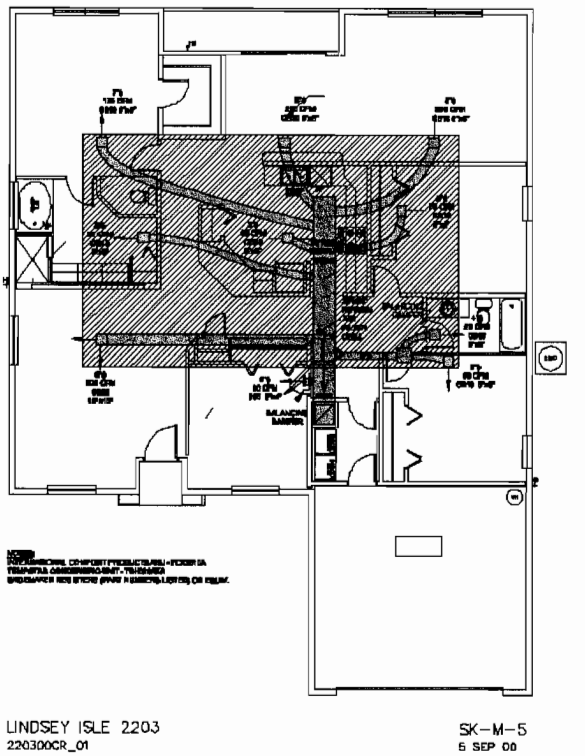


Figure II-26. Plenum Truss Duct System layout (Lindsey Isle Model)

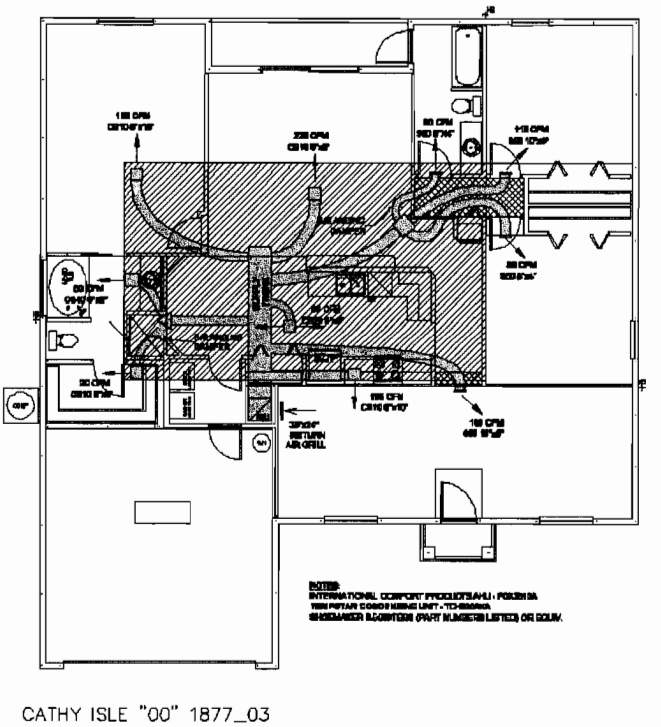
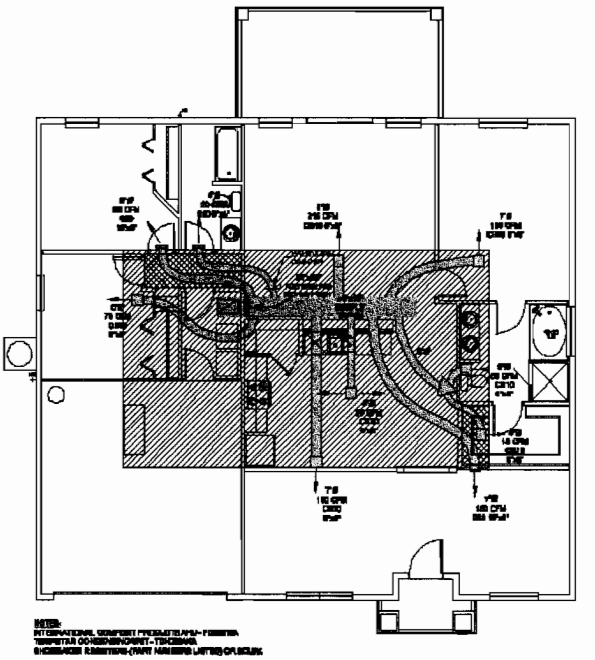
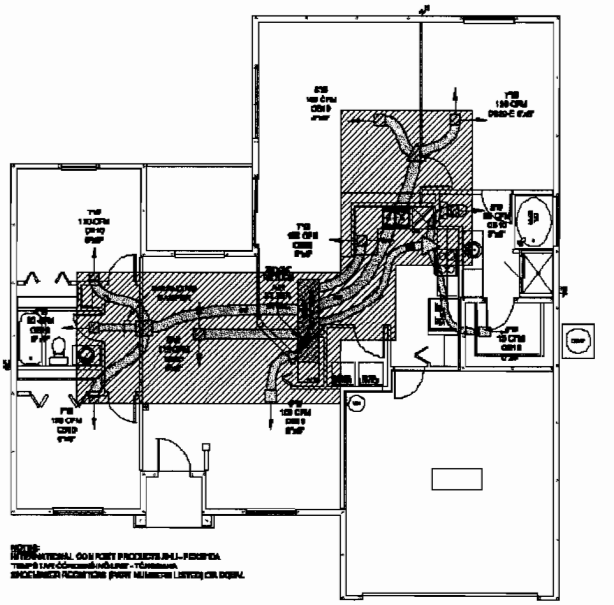


Figure II-27. Plenum Truss Duct System layout (Cathy Isle Model)



MICHELE ISLE "00" 1813_00

Figure II-27. Plenum Truss Duct System layout (Michele Isle Model)



BRADLEY 1828

Figure II-28. Plenum Truss Duct System layout (Bradely Model)

Fourth Prototype Case Study

Date: 2002

Figure II-29. Mercedes Homes fourth prototype under construction

Figure II-30. Mercedes home fourth prototype finished

Summary

Three design objectives were defined to explore, test, and evaluate higher performance building systems for Mercedes Homes, located in Melbourne, Florida (figures II-29 and II-30): refine the "plenum truss," the first version of which was demonstrated earlier; continue and refine the production use of poured concrete walls; and explore the effects of the use of double-glazed low-E windows. Besides these three innovative system design strategies, an inside-the-envelope air handler and two ways of accomplishing return-air transfer were also demonstrated and evaluated. The reference house is defined (in this case builder standard practice), and a comparison made of final performance/cost tradeoffs with current builder practice, including leakage comparison, overall energy performance comparison, cost comparison, and AC equipment-sizing comparison. Finally, recommendations are made for future improvements in design details, construction practices, and quality-control practices, including air sealing, exploring alternate plenum liners, downsizing AC equipment, and exploring the effects of the production use of double glazed low-e windows.

Design Objectives

Refine Plenum Truss

The initial design of the plenum truss had a rectangular cross-section, which increased the board footage of material in the trusses relative to a conventional truss. Also, it required the installation of vertical insulation around all four sides of the truss. This, combined with the absence of credit (given by the ENERGY STAR rating program in use in Florida) for the savings resulting from the use of the truss, caused Mercedes to proceed with production without the use of the plenum truss. A new design was developed using less wood and eliminating vertical walls at the side. This design was incorporated into a prototype and tested.

Continue and Refine Production Use of Poured-Concrete Walls

The poured-concrete wall assembly developed in the pre-production prototypes was so successful that Mercedes purchased a second set of aluminum forms. An objective of this prototype design was to examine how the system was working in the field in production.

Explore Effects of Production Use of Double-lazed Low-e Windows

Because of the difficulty in keeping the single-glazed low-E glazing clean, and as evidence of the company's commitment to energy conservation, Mercedes decided to switch to double-glazed low-E windows (in un-insulated aluminum frames) for their production. An objective of the prototype design was to test the effects of this change and assess whether it justified a down-sizing of the AC capacity.

Summary of Innovative System-Design Strategies

Concrete Wall Assembly with Two-Coat Stucco

Because of the smoothness of the concrete when cast in the aluminum forms, Mercedes was able to eliminate a base primer coat under the finish stucco, saving hundreds of dollars on the stucco subcontract. As described above, after some difficulties at the beginning, the mix and aggregate were adjusted to create a smooth casting operation without disturbing the rebar cages.

Inside, a ¾-in. layer of polyisocyanurate R-Max insulation with an R-5.4 rating is adhesive-applied to the wall. Over this is 1X strapping at 24 in. on-center and around openings, supporting ½-in. gypsum wallboard. As is standard, inspector-approved practice in Florida homes with masonry exterior walls, electrical wiring runs just behind the gypsum board in the ¾-in. space formed by the strapping, into shallow-work boxes.

Low-E Double Glazing

Windows are supplied by Kinco and have a soft-coat Cardinal low-E coating. Frames are uninsulated aluminum, which when calculated according to the standard NFRC algorithm

degrades the U-factor of a typical window by 100%, from about 0.35 to about 0.7. This change has little effect on energy use because of the small contribution conductive heat gain and loss make to energy consumption in this mild climate. It does, however, increase the peak load relative to thermally insulating frames. Vinyl frames were priced-out as an alternative due to their better thermal qualities. These were considered and rejected because of concerns about their reliability in hurricanes. The selected windows have a SHGC (center of glass) of 0.35. To account for the aluminum frame CARB calculated an actual SHGC of 0.40

Inside-the-Envelope Air Handler

As in earlier prototypes, the air handler was brought into the utility room from the garage, reducing duct system air leakage, reducing conductive heat loss, and avoiding any possibility of drawing contaminated air from the garage into the system.

Plenum Truss Housing Most of the AC Ductwork; Attic Ductwork Buried Under Insulation

This, the second version of the plenum truss, has a triangular cross-section. Not only does this eliminate the need for vertical insulation on the long sides of the plenum, but it reduces the amount of wood in the truss nearly to that of a standard truss (Figure II-31).

As in the previous design, the framers attach a membrane to form the "roof" of the plenum, effectively sealing it from the attic (see discussion of performance and recommended improvements below). CARB's arguments in favor of a rolled membrane were again passed over in favor of foil-faced cardboard sheets of "Energy Brace." This done, 2 x 4 runners were attached to provide nailing for the small inserted frames that support the ceiling, which were added next, completing the plenum.

Ductwork was then installed between the ceiling frames and the plenum roof and ends, except for one section at Bedroom #4 and the adjacent hall, where ducts had to run outside the plenum. Based on previous monitoring that showed little or no condensation at ductwork under the insulation, these ducts were covered over with R-30 blown-in attic insulation.

Through-the-wall return air-transfer grilles were installed at each bedroom. In addition, grilles were installed between the master bedroom and the plenum and between the plenum and the central space that was served by the central air return, for a performance comparison with through-the-wall grilles.

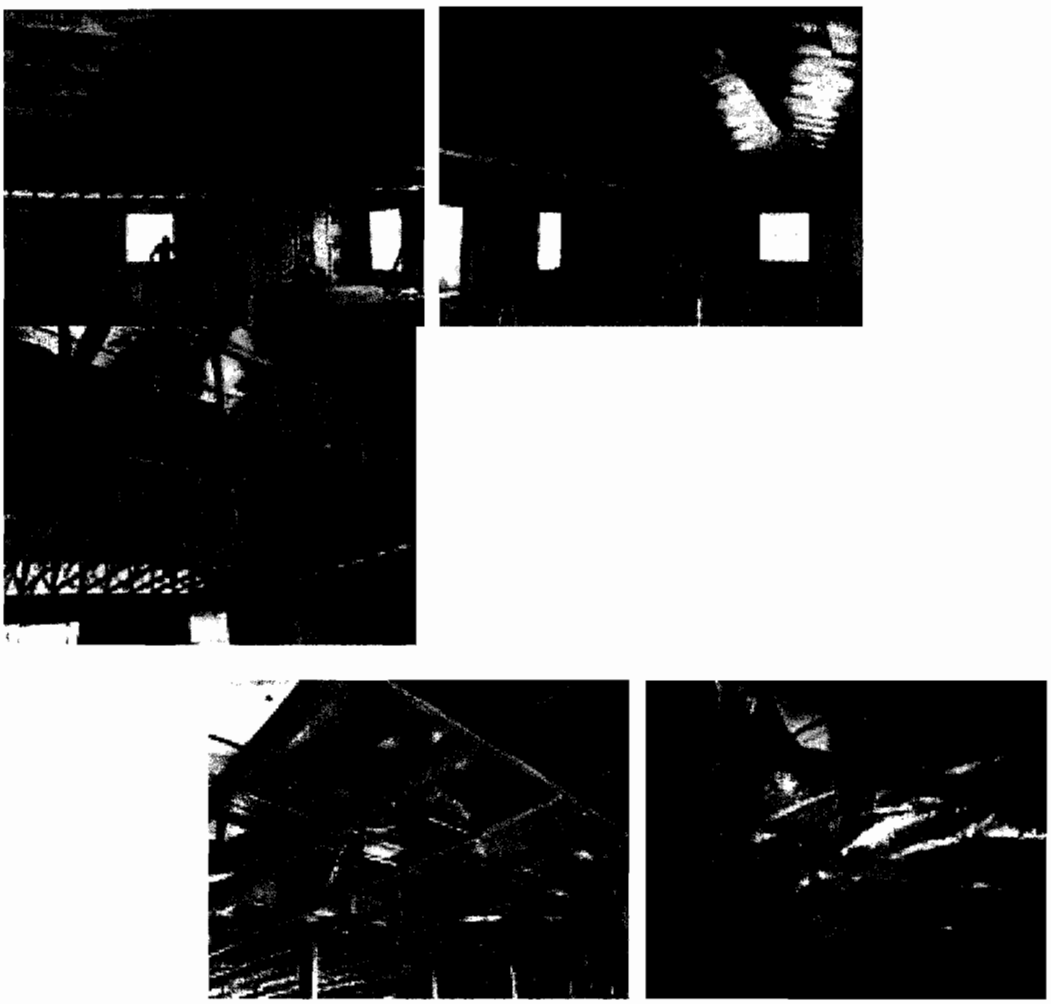


Figure II-31. The revised plenum truss at successive stages of construction

Definition of Reference House

Plan Type

The plan, which Mercedes calls the "Michelle Isle Deluxe," has 2,078 ft^2 of living space on one floor (slab on grade, with no insulation at the slab edge), 4 bedrooms, with an attached two-car garage. The elevations feature a hipped roof with 12-in. overhangs all around, a hipped-roofed covered porch at the rear, and a gabled entry portico in front. As is typical with Mercedes' plans, it is "binuclear," with bedrooms on both sides of a band of central living spaces. This plan type works exceptionally well with the plenum truss concept because of its compactness.

Wall System

Until the CARB prototypes led them to switch to poured concrete, Mercedes followed the prevailing approach in this area of Florida in using 8-in. hollow CMU walls with precast concrete headers and a cast-in-place bond beam. Because of the irregularity of the outside surface, a two-coat minimum stucco application was necessary to create a smooth exterior. Inside, 1X furring strips are attached to the block walls and covered with a foil-faced paper radiant barrier, which is rated at R-4.

Glazing

Single-glazed gray-tinted glass windows in uninsulated aluminum frames were used, as is common in Florida.

Air Handler Location

In the first CARB prototype, the air handler (which in standard practice is located in an inside corner of the garage) was simply walled off from the garage and made accessible from the inside, effectively bringing it into the conditioned space. In the present design, the air handler is moved closer to the center of the plan, next to the washer and dryer in the utility room.

Ductwork

Ductwork followed standard practice in being located in the attic, using R-6 insulation.

Insulation Levels

Outside walls had a claimed insulation level of R-4, although the actual level was likely lower. The attic was insulated with R-19 blown-in fiberglass.

Comparison of Final Performance and Cost Tradeoffs with Current Builder Practice

Leakage Rate

Overall, the house had an ELA of 141-in.^{2} Plenum leakage, most of which could easily be closed, amounted to and ELA of 24-in.^{2} Duct leakage to the outside was very low (less than 3%), showing the effectiveness of the "inside-the-envelope" design of the prototype (Figure II-30).

The graph shows that the air within the plenum truss is very close in temperature and humidity to that in the space below, proving that the ducts in the plenum are effectively within the conditioned space.

Overall Energy Performance Comparison

There are several different homes that need to be compared, listed in order of increasing performance:

- Regional standard practice simulated with REM-Rate
- Builder standard practice simulated with REM-Rate
- Prototype simulated with REM-Rate
- Modified prototype (with SEER-12 AC equipment) simulated with REM-Rate

Table II-8 summarizes the performance of the prototype compared with regional practice and with builder practice, showing an overall heating and cooling source energy decrease of 41% and 37%.

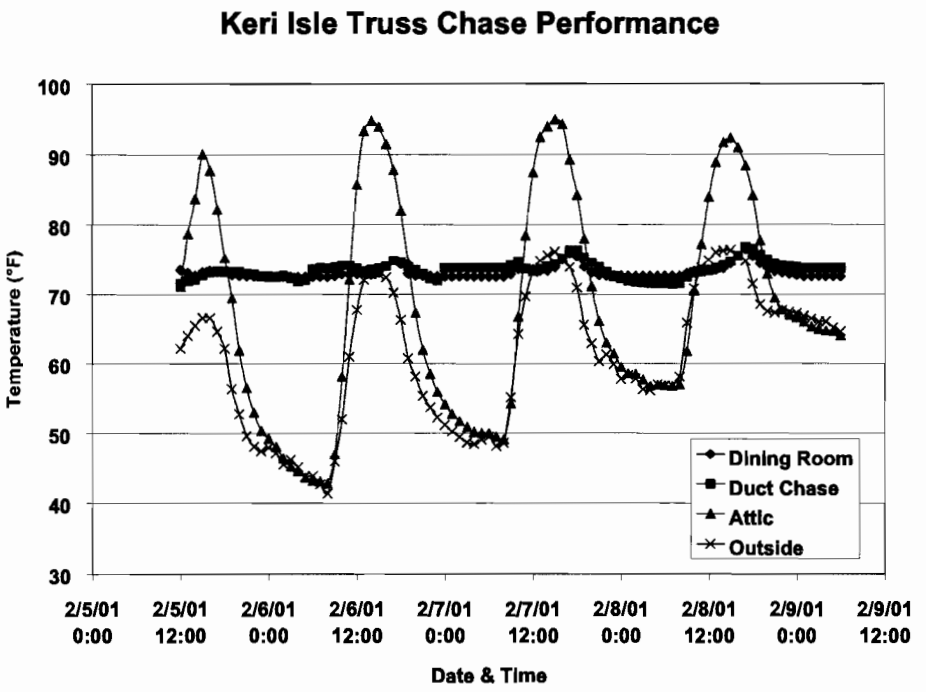


Figure II-30. Keri Isle truss chase temperatures

Table II-8. Comparison of Energy Performance Keri Isle as-built

	Regional Standard Practice		Builder Standard Practice		Prototype As-Built		% Source Energy Savings	
	therm (kWh)	Source Energy (MMBtu*)	therm (kWh)	Source Energy (MMBtu*)	therm (kWh)	Source Energy (MMBtu*)	Over Regional Practice	Over Builder Practice
Whole House								
Natural Gas	442	45	442	45	347	35	21%	21%
Electricity	12757	155	12211	149	10380	126	19%	15%
Total		200		194		162	19%	17%
Space Conditioning								
Heating	203	21	203	21	108	11	47%	47%
Cooling	6015	73	5469	67	3638	44	40%	33%
Total		94		87		55	41%	37%

Table II-9. Comparison of Energy Performance Keri Isle SEER 12 AC

	Regional Standard Practice		Builder Standard Practice		SEER 12 Prototype		% Source Energy Savings	
	therm (kWh)	Source Energy (MMBtu*)	therm (kWh)	Source Energy (MMBtu*)	therm (kWh)	Source Energy (MMBtu*)	Over Regional Practice	Over Builder Practice
Whole House								
Natural Gas	442	45	442	45	347	35	21%	21%
Electricity	12757	155	12211	149	10050	122	21%	18%
Total		200		194		158	21%	19%
Space Conditioning								
Heating	203	21	203	21	108	11	47%	47%
Cooling	6015	73	5469	67	3308	40	45%	40%
Total		94		87		51	45%	41%

* The data Source Energy in Btus is as defined in NREL's "Building Analysis House Performance Procedures, Sept. 2001."

Table II-9 summarizes the performance of a hypothetical modified prototype in which the SEER-11 AC equipment being used was raised to SEER-12. In this case, the prototype decreased the overall heating and cooling source energy by 45% and 41% compared respectively with the regional and builder standard practice.

NREL measured and simulated the performance of the Keri Isle and Lora Isle products, using DOE-2, showing a 28% and 35% reduction compared with standard builder practice. These data correlate well with the prototype performance simulated by REM-Rate. The lower energy reductions in those two houses relative to this prototype was primarily the result of using single-sheet low-E glazing, as opposed to double-sheet low-E glazing in the present prototype.

Cost Comparison

While Mercedes does not wish to publish exact figures, the following approximations will give a good sense of the overall costs.

Concrete wall

Saving of about $100 compared with CMU (taking account of reduction in construction time of about 3 days).

Stucco

Eliminating one coat saves $400 for this plan.

Low-e windows

Additional cost for this plan over the standard single glazed tinted windows is $713.

Redesigned plenum truss

Adds about $700 for dropped ceiling framing and liner – trusses cost the same. Potential cost in production = $350.

Downsizing AC by one ton

Saves $450 for a full ton at current prices.

Overall cost increase

About $213

Cost savings to the homeowner are shown in Table II-10, which compares the prototype to current builder practice.

AC Equipment Sizing

The reduction in duct leakage, increased wall and attic insulation, and especially the use of double low-E glazing greatly lowered the peak AC demand, while improving comfort.

As a result, the AC equipment could be downsized from 3 tons to 2 tons (over 1,000 SF/ton). However, the buyer requested gas heating; the smallest unit available delivered 1,200 CFM, which required a 3-ton AC unit, so that the potential cost savings from downsizing was not realized in the prototype. The oversizing is probably not great enough to cause mold problems, although it will undoubtedly reduce comfort by increasing the average interior relative humidity.

Recommendations for Future Improvements in Design Details, Construction Practices and Quality Control Practices

Air Sealing

While the house had a low infiltration rate and the ductwork had a very low leakage rate, almost all the leakage in the ductwork and about a third of the overall house leakage rate could be eliminated by simple sealing measures at various penetrations through the plenum ceiling. We measured an equivalent leakage area of around 25 in^2, consisting of gaps around security wiring, gas piping, and the combustion air intake pipe. These could easily be closed.

Explore Alternate Plenum Liners

Although the builder feels a solid board is preferable as the ceiling liner of the plenum, we feel that a rolled-out membrane of some kind, held in place by 1 x 2 strapping, would save both time and material cost.

Downsize AC Equipment

As noted above, the builder should choose the right sized AC equipment, not only to save money, but to avoid potential comfort and mold problems. We feel that proper customer education could overcome the perceived loss of quality from a smaller AC unit.

Table II-10. A Comparision of the Prototype to Current Builder Practice

Item	Annual Cost (Dollars)			Annual Consumption (Therms, kWh)		
	Current Practice	Prototype	% Saved	Current Practice	Prototype	% Saved
Natural Gas	221	174	21	442	347	21
Electricity	1098	934	15	12211	10380	15
Heating	101	54	47	203	108	47
Cooling	491	327	33	5469	3638	33
Other	787	787	0			
Heat + Cool	592	381	36			
Total Cost	1318	1108	16			

Part III: Best Practices for Achieving 30% - 40% Space Conditioning Energy Savings in Single-Family Detached Homes in a Hot-Dry Climate

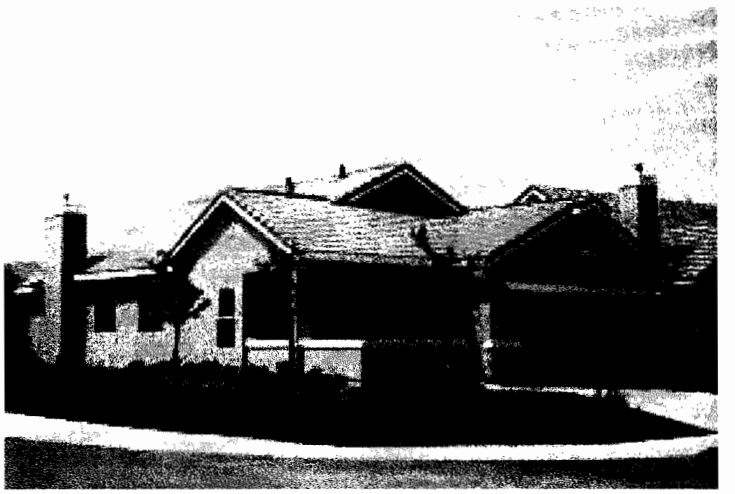


Figure III-1. A CARB house built in a hot-dry climate

Background and Introduction

The Consortium for Advanced Residential Building (CARB), one of the Building America teams, has worked with several hot-dry climate builders on home designs that achieve at least a 30% savings relative to the Model Energy Code (MEC) (Figure III-1). This report describes the recommended best practices to achieve these savings without compromising health or safety.

A list of Primary Recommendations and one of Secondary Recommendations is included, followed by a discussion of each item on the list. Case studies drawn from CARB's Building America experiences are presented as examples. Because most homes in this region are one-story slab-on-grade construction, as are all the ones dealt with by CARB, the recommendations are tailored to this form of construction.

Primary Recommendations

Envelope

- Double-glazed, low-E windows with Solar Heat Gain Coefficient (SHGC) of 0.4 or less
- Exterior wall framing and sheathing
  - 2 x 4 studs at 16 in. on-center with traditional stucco on 1-in. EPS, with ½-in. EPS over ½-in. OSB at shear wall panels, or
  - 2 x 6 studs at 24 in. on-center with full ½-in. OSB sheathing and any cladding

- Lumber-saving framing details (open corner details, ladder bracing at T-intersections, right-sized headers, no headers at non-bearing partitions, studs at 24 in. on center at interior partitions)
- Unfaced cavity insulation, and air sealing, achieving blower door tightness criterion of 1/4 CFM at 50 Pascals per square foot of building envelope area
- Building envelope water management system
- Reflective roofing material

Equipment

- Manual-J / Manual-D HVAC sizing
- SEER-12 air conditioner with 0.85 SHR
- AFUE 80 gas furnace
- Conventional atmospherically vented gas-fired water heater located in garage
- Ducts mastic sealed (leakage to outside less than 5% of fan-flow)
- Ducts buried under attic insulation
- Compact duct distribution system
- Central return air register with transfer grilles at secondary spaces (maximum pressure difference between spaces with doors closed = 2.5 Pa)
- Provide filtered supply-only ventilation
- No unvented gas appliances (except a gas range with a range hood exhausting to the outside).

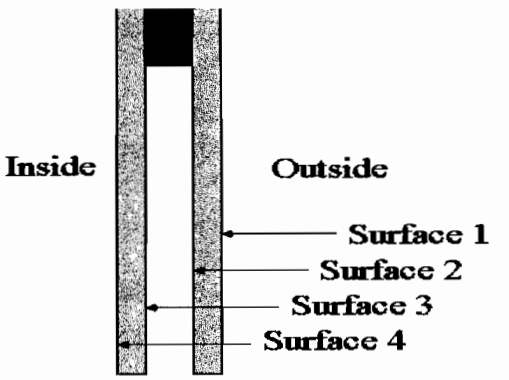


Figure III-2. Low-e double-glazed windows

Secondary Recommendations

- Energy-efficient lighting
- ENERGY STAR appliances
- Plenum truss

Primary Recommendations for the Envelope

Low-E Windows

Discussion

Selective low-E coated double-glazing is applicable to all hot-dry climate homes. A selective low-E coating on surface 2 greatly reduces the amount of incoming solar energy (it has a low Solar Heat Gain Coefficient [SHGC]) (Figure III-2).

The U-factor of the glazing is strongly influenced by the frames: uninsulated aluminum frames increase the conductivity of the overall window substantially (typically doubling the U-factor relative to the center of the glass). This may or may not increase the annual heat loss, depending upon the climate (windows with a higher U-factor may cool the house at night through radiation). However, thermal break aluminum or vinyl windows reduce the peak cooling load, which can help to reduce the size of the AC equipment.

Look for the NFRC ratings, which are slightly different from conventional ratings. The desirable glass has the following characteristics, which can be found on the label attached to all glass:

Desirable Low-E Glazing Characteristics for Hot-Dry Climates

- Total unit U-value should be 0.35 or less, only for thermally broken or vinyl sash and frames.
- The SHGC should be 0.40 or lower.
- The low-E coating should be on the #2 surface, to reduce heat gain from the outside. This is typical for most low-E glazing.
- Because occupants enjoy seeing out through untinted glass, it is desirable to use (more expensive) "spectrally selective" glazing, which couples high visible transmittance (VT) with a low SHGC. A high VT will also decrease the use of electricity for lighting, reducing the cooling load and overall energy use. Glass is available having a VT more than 0.65 coupled with an SHGC of 0.42, but it is not commonly used in residential windows. Cheaper low-E glazings have VTs as low as 0.35. Low values will result in a noticeable violet color to the glass. Benefits Demonstrated in CARB/Building America Case Studies
- The cost-effectiveness of low-E glazing has been demonstrated in every CARB hot-dry climate project.

- The low-E coating provides the equivalent of another layer of glazing at a much lower cost.
- Low-E glazing makes it possible to dispense with registers located close to the windows, thus reducing the cost of air distribution.

Exterior Wall Framing and Sheathing:

- 2 x 4 studs with 1-in. EPS and Conventional Stucco with ½-in. OSB and ½-in. EPS at Shear Panels, or
- 2 x 6 studs at 24 in. on-center with Full OSB Sheathing

Discussion

Because of the almost universal use of two- or three-coat conventional stucco in the hot-dry areas of the west, 2 x 4 studs at 16 in. on-center with 1-in. EPS foam is the most common form of sidewall construction. The closer stud spacing is required because the EPS is too flexible to span 24 in. without cracking the two-coat stucco. Three-coat stucco is seldom used outside southern California, where the 16-in. stud spacing is typically used for seismic resistance. If using three-coat stucco outside seismic zones, consider 2 x 4 studs at 24 in. on-center, with EPS sheathing.

Over the EPS is a layer of #30 felt (which is about as heavy as the 15-pound felt use decades ago – note that it is *number*-30 felt, not 30-*pound* felt) and wire stucco lath applied with washers. In wetter climates, two layers of felt are desirable. The outer layer tends to stick to the stucco, so that any water that gets past the outermost water barrier (stucco or sealant) cannot drain between the stucco and the paper—hence the need for a second layer of paper. This problem does not typically arise in hot-dry climates, where precipitation typically occurs as short periods of intense rain, between which the wall can dry to the inside. Therefore, the second layer of paper is seldom used. In any area where sustained rainfall can occur (for example, the Los Angeles basin where several successive days of heavy rain can occur), two layers of felt are strongly recommended.

For all other claddings, a wall of 2 x 6 studs at 24 in. on-center with full OSB sheathing provides about the same R-value and uses less lumber than 2 x 4 studs at 16 in. on-enter when EPS sheathing is employed, assuming in both cases that measures are taken to reduce unnecessary studs—see next item. The entire outside wall is sheathed with OSB, which greatly increases the shear resistance of the home relative to one sheathed only where necessary for wind and seismic resistance. Cladding that is nailed to the studs and is not rated for nailing at 24 in. on-center (as conventional vinyl siding) needs to be nailed to the sheathing at least once between studs.

In hot-dry climates, the use of exterior wall panels in lieu of sheathing and added cladding is quite feasible for affordable housing—its primary disadvantage is their appearance. Such panels provide the required shear resistance for wind or seismic loading. Fiber-cement panels are ideal for this purpose. Wall panels of all kinds are span-rated, and their shear resistance depends on the nailing pattern. Check these rating before choosing sheathing or exterior finish panels.

A single top plate can be used with 24-in. on-center 2 x 6 studs providing:

- The wall meets seismic and wind loads
- Each joint in the plate is bridged by a 0.036-in. galvanized plate 3-in. x 6-in., with six 8x nails on each side (per IRC R602.3.2 Exception)
- The trusses are centered on the studs within a tolerance of ± 1 in. (per IRC R602.3.2 Exception).

If a double plate is used, trusses can be located anywhere (per IRC R602.3.3 Exception 1).

One concern with the use of 24-in. on-center studs is the capability of the interior finishes to span the extra distance between studs.

> *Why? To achieve the strength that ½-in. gypsum board has spanning studs at 16 in. on-center, you would need 5/8-in. gypsum board to span 24 in.*

In practice, the lower strength of ½-in. board does not pose a problem for most homebuyers. Interior partitions using studs at 24 in. on-center and covered with ½-in. gypsum board are in wide use. For custom or luxury levels of construction, it is recommended that 5/8-in. gypsum board be used with 24-in. on-center studs.

Applications in CARB/Building America Case Studies

- CARB has not used studs at 24 in. on-center in hot-dry climates, because all the projects have had stucco finish.
- Because of the mismatch between 16-in. studs and 24-in. trusses, in-line framing was not used.

Lumber-Saving Framing Details

Discussion

Many lumber-saving details are possible that not only reduce cost, but save energy, along with saving timber.

Open Corner Details

As shown in Figure III-3, the three studs normally used at an outside corner can be rearranged to create an open cavity that can be insulated later (in the conventional box arrangement, the cavity must be insulated by the framers; typically this is not done). The stud that provides nailing for wallboard can be replaced by a 1 x 6 or by drywall clips.

Ladder Bracing at T-Intersections

As shown in Figure III-4, the conventional method of framing at a T-intersection creates an uninsulated cavity. It also uses more material than necessary. Replacing the two studs normally used with three to four pieces of blocking saves lumber provides a use for cut-off lumber pieces and allows insulation to continue through the T-intersection. The blocking can be replaced by a 1 x 6 (as shown), and drywall clips can be added between the blocking for additional attachment points.

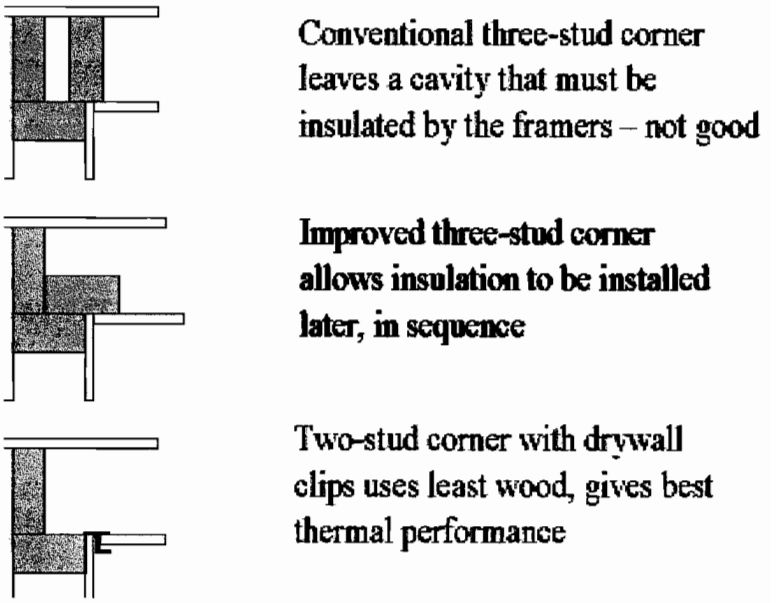


Figure III-3. Open corner details

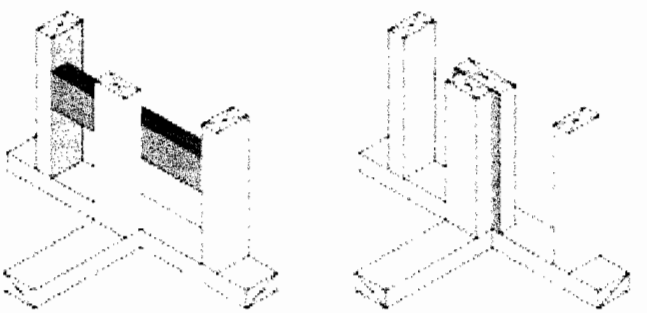


Figure III-4. T-Intersection details that allow insulation to run by

Right-Sized Headers

For production convenience, builders commonly use the same (maximum) header size for all openings. This is wasteful of expensive large-dimension framing and increases heat loss because headers conduct more heat than does an insulated cavity. Simply using two (or three) header sizes for different width openings resolves this problem with a minimum of extra measuring.

No Headers at Non-Bearing Partitions

It is a waste of material to use headers at non-bearing partitions. This practice results from concern that framers will not take the time to check whether or not the partition is bearing. Better supervision, better plans, and insistence on plan-checking allow such headers to be dispensed with.

Studs at 24 in. On-Center at Interior Partitions

As discussed above, ½-in. gypsum board over studs at 24 in. on-center does not seem to concern buyers, at least for production housing (even high-end products).

Applications in CARB/Building America Case Studies

As part of its "value engineering" work for several builders, CARB has demonstrated the cost and energy savings of lumber-saving framing details.

In one case (Del Webb), earlier value-engineering consulting by SWA established the practice, so that the measures were already in place when CARB began work with them.

Air Sealing

Discussion

The widespread use of stucco over EPS sheathing in the western United States results in remarkably tight homes without extensive gap sealing. One energy consultant calculated an *average* ACHn (natural air changes per hour) of 0.28 among new builder homes in the Phoenix area. Also, the absence of serious moisture and mold problems reduces the incentive for air sealing. However, other factors are at work that indicates the need for better gap sealing in the wall between the house and the garage. Dryer, range, and bath exhaust fans can depressurize the house, causing air to migrate in through gaps in this wall. This problem is of concern for indoor air quality, and most "green builder" programs give points for separating the garage from the house, providing a separate fan-powered exhaust from the vicinity of the air handler, or installing a CO detector in the living space. CO detectors are sometimes problematic because of reliability problems, but weather stripping the door to the garage and carefully gap sealing the common wall is strongly recommended. Of much greater concern is sealing the return air ductwork and the air handler, if it is located within the garage, and this issue is discussed in the following section.

Air-Sealing Techniques

There are many sealing products available, each suited for a particular job:

- Foam guns (Figure III-5)
    - This foam is the all-purpose sealing tool for nearly any gap
    - Low-expansion foam is available in cans that attach to inexpensive application guns
    - These guns feature a screw-plunger that closes off the nozzle and keeps the gun clean between uses
    - There is also a can of cleaner that can be attached to the gun
    - For large gaps, high-expansion foam is available
- Sill sealer
    - The gap under the mud sill can be foamed with low-expansion foam
    - An alternative recommended product is by Protecto Wrap called the "Triple Guard" (Figure III-5).

Figure III-5. Foam gun (left) and sill sealer (right)

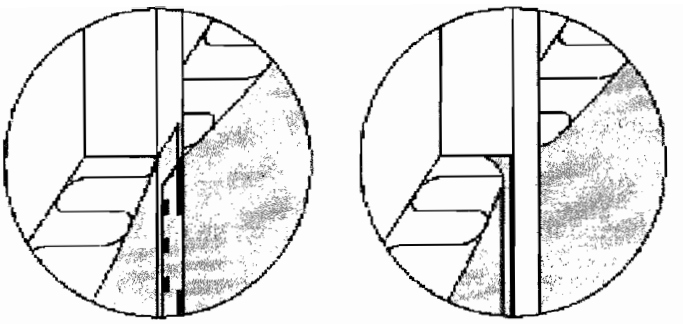


Figure III-6. Vapor retarder installation

Vapor Retarder

Kraft or foil facings on fiberglass batts are not recommended unless they are carefully installed (Figure III-6):

- Facings should be "face stapled, not "inset stapled," to avoid the puckers between the studs and insulation that occur with inset stapling
- Face staples must be set flush with the studs to allow proper installation of drywall.

Applications Demonstrated in CARB/Building America Case Studies

CARB homes in hot-dry climates have not used vapor retarders, as they were built under the UBC, which does not require them. For future homes built under the IRC, the above recommendations will be made.

Building Envelope Water-Management System

Discussion

Hot-dry climates by definition do not have persistent wet weather. As a result, detailing practices that would be disastrous in the northeast or northwest are used without problems. Cement stucco bonds to the window frame without the need for sealant. The screed at the base of the wall contains weep holes to drain any water that gets behind the stucco (although these probably don't work with a single layer of building paper, as discussed earlier). Typical homes with hardboard siding and trim have simple flashings, typically over windows and doors, with sealant added where needed for extra protection.

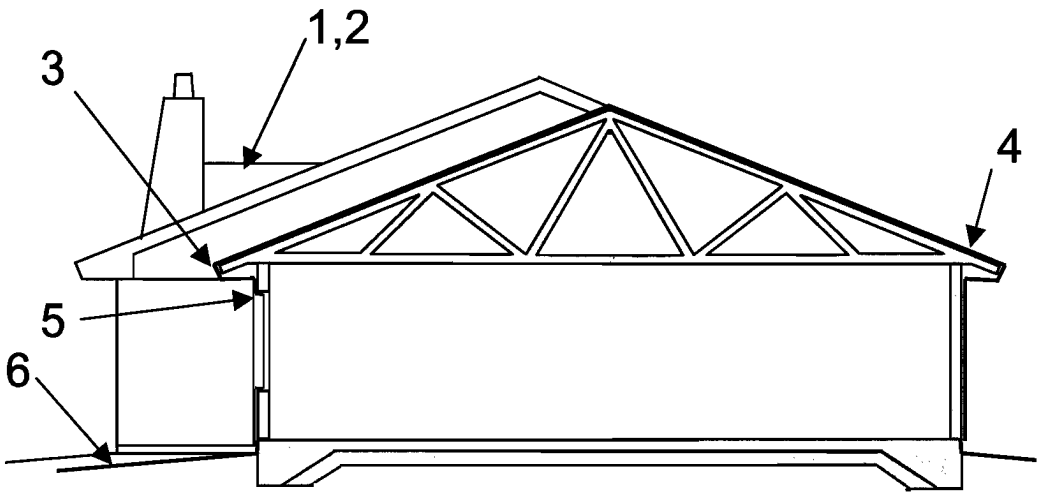


Figure III-7. Water-management recommendations

Recommended Water-management Measures (Figure III-7)

Roof

1. Provide Adequate "Crickets" Behind Chimneys and Other Projections through the Roof

   There must be a way of sending water around the objects like chimneys and skylights that block the flow of water down the roof. Behind tall objects like chimneys, install the largest and steepest "cricket" (small gabled roof) that will fit. This will also help prevent the buildup of snow.

2. Place Chimneys, Dormers, etc., away from Valleys and Adequately Separated from Each Other

   Water collects and runs down valleys. Running valleys together (for example, between closely spaced dormers) or placing a chimney or other obstruction in a valley almost guarantees water leakage. During winter, snow will collect in these tight spaces and cause ice dams.

3. Use "Kick-Out" Flashing at the Joint between an Eave and a Sidewall

   Where a roof runs into a sidewall, "step flashing" is required at the joint. If the roof stops before the wall does, the water that collects against the step flashing will run in behind the siding unless it is directed back out onto the roof by "kick-out" flashing.

4. Use an Impervious Layer at Valleys

   At eaves and valleys, an impervious layer of peel-and-stick modified bituminous flashing material should be installed under the roofing.

   - *Why? During heavy rains, water concentrated in valley and can build up high enough to back up under the slates or shingles. An impervious layer drains any overflowing water to the eaves before it soaks into the roof sheathing.*

5. Properly Flash Around Windows And Doors

   A useful measure to prevent rotting sills (especially in areas where several days of rain can occur in sequence) is to lap the #30 felt over the window flanges in such a way as to maintain the drainage plane (Figure III-8). Felt can also be laid on the sill and up the jambs in such a way as to minimize the entry of water. For extra-safe flashing, use a peel-and-stick flashing membrane, which can be shaped as needed to flash at window sills. Do not tape over the bottom window flange, but leave an opening for water to get out.

6. Carefully plan grading around the home to ensure that heavy rainfall will find its way to drains without flooding the house

   - Typical requirements are to grade away 6 in. in the first 10 ft
   - Provide simple retaining walls where necessary.

   Many communities require a detailed contour plan showing drainage; make one even if it is not required.

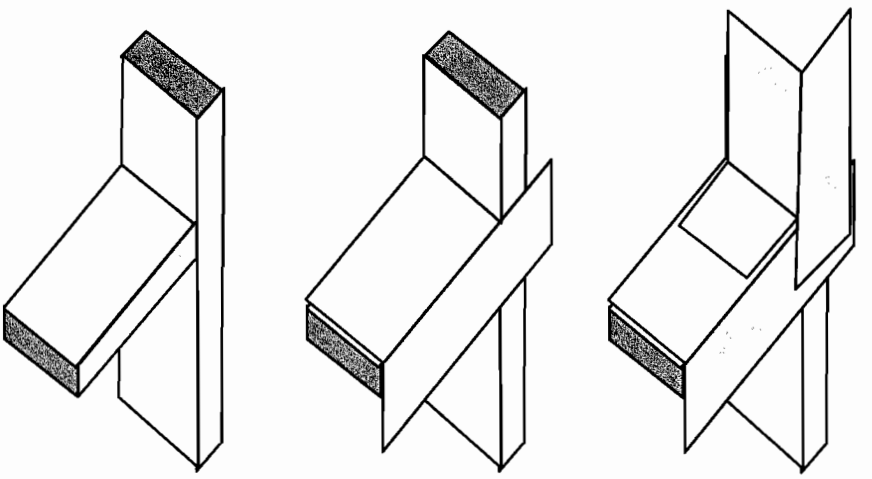


Figure III-8. Sequence of applying #30 felt at a window sill

Applications in CARB/Building America Case Studies

The above measures are all good practice and, taken together, will help prevent moisture-related problems throughout the building envelope. Because CARB builders in hot-dry climates seldom have problems related to water management in walls, most of the recommendations relate to roofs, which are exposed to the torrential downpours characteristic of most hot-dry climate.

Reflective Roofing Material

Discussion

Ductwork running in a hot attic is one of the largest cooling loads in a hot-dry climate home. SWA has measured a substantial temperature rise between the air handler and the registers, when flex ducts insulated to R-4.2 level ran in a hot attic. CARB's primary thrust in resolving this problem has been two-fold: (1) developing the "plenum truss," which provides space for ductwork within the conditioned envelope without requiring dropped ceilings, and (2) burying ductwork under attic insulation. The latter technique is recommended below.

Even if some of the ductwork is protected from attic heat (as recommended below), it is not practical to cover all the ductwork, so reducing the temperature in the attic is highly desirable. Careful testing by the Florida Solar Energy Center (FSEC) shows that either radiant barrier sheathing or a reflective roof can substantially reduce attic temperatures. Of the two techniques, CARB believes that reflective roofs are the more desirable. A radiant barrier on the underside of the roof sheathing noticeably increases the temperature of roof shingles. If these are not white or near-white (unpopular colors), they will tend to be "cooked" by the radiant barrier, with unknown effects on their life.

The "classic" way to create a reflective roof is by using glazed light-colored tiles or glossy light-colored painted steel panels. New products have recently appeared that provide improved reflectivity from dark-colored roofs, through the use of spectrally selective paints (that perform similarly to spectrally selective glazing). In all cases, reflective roofs help reduce the "heat island" effect in densely populated areas.

A full discussion of this subject is found in the *Journal of Light Construction*, June 2003, pages 75 through 81 (order through www.jlconline.com). Also, a rating organization is up and running; the Web site for the Cool Roofs Rating Council, listing many rated products, is www.coolroofs.org.

Applications in CARB/Building America Case Studies

CARB has not had the opportunity to use reflective roofing, as suitable products are just coming on the market. CARB has also not used radiant barrier sheathing in hot-dry climates, for the reasons stated above.

Primary Recommendations for the Equipment

Manual J / Manual D HVAC Sizing

Discussion

Air Conditioning Contractors of America has long published a simple, but effective, method of determining loads ("Manual J") and sizing ductwork ("Manual D"). These design tools are available in user-friendly computerized form for about $400 each. Also available is a linked program for drawing duct layouts.

While oversizing AC systems in hot-dry climates is not likely to cause mold problems (as oversizing does in hot-humid climates), larger units are more expensive. Even when properly sized, it is often possible to reduce the size by making energy-saving improvements to the home. In a classic case of "whole-house" interaction, the savings in downsizing air conditioning units can be used to help defer the cost of the added duct insulation and better glazing, which complete the circle by making the down-sizing possible in the first place.

Applications in CARB/Building America Case Studies

All CARB projects have been designed using Manual J / Manual D computerized calculation, except those special cases where a more sophisticated program has been used. CARB often finds that systems designed by HVAC contractors are dramatically oversized, as one safety factor is piled on another. It is important that the HVAC designer have sufficient information to account properly for all envelope efficiency measures, which often result in a downsizing of equipment and ductwork sizes.

SEER-12 Air Conditioner with 0.85 SHR

Discussion

Until recently, SEER-10 air-conditioning equipment has been standard across the country. Gradually, SEER-12 equipment is becoming more widely used. Simulations show that SEER-12 equipment is nearly always cost-effective, and it is nearly always required in order to meet ENERGY STAR standards. SEER-14 equipment, while cost-effective for special projects where longer paybacks are acceptable, is typically too costly for production or affordable housing. However, at today's reduced interest rates SEER-14 equipment is very likely to be cost-effective as the monthly additional carrying cost is reduced relative to the savings provided. Unfortunately, buyers typically do not make the connection between energy savings and the cost of a mortgage; and they especially do not understand that break-even occurs with longer paybacks when interest rates are low.

Applications in CARB/Building America Case Studies

On special projects (for example, Beazer's solar-powered homes in Sacramento), CARB has been able to include SEER-14 equipment. For most builders, however, upgrading to SEER-12 is a major step and, for the present, it is a practical goal. In the case of Del Webb (at the time very skeptical that energy savings sell), it was not possible to convince them to upgrade from SEER-10 to SEER-12.

AFUE 80 Gas Furnace

Discussion

For hot-dry climates, winters are typically cold enough to warrant the use of gas as a fuel (rather than electric resistance heating); they are not cold enough to warrant the expense and maintenance problems of higher efficiency equipment.

Applications in CARB/Building America Case Studies

Except for experiments with individual prototypes (that were not followed up in production by the builder), CARB hot-dry climate projects have used AFUE 80 furnaces.

Conventional Gas-Fired Water Heater Located in Garage

Discussion

Because of the dominance of hot weather, water heaters are best kept out of the living space, where their skin losses will not increase the cooling load. This also obviates the need for power-vented equipment and makes gas-fired equipment attractive. There is no justification for electric-resistance water heating except where rates are very low. The heater can either be located free-standing in the garage, within a closet off the garage, or within a closet in the outside wall. The closet should be finished and insulated from the house. In all cases, ventilation grilles are required to provide combustion air for the unit.

Applications in CARB/Building America Case Studies

Water heaters in CARB hot-dry climates have been located freestanding in the garage or in a closet off the garage.

Ducts Mastic Sealed (Leakage Less Than 5% of Fan Flow)

Discussion

Sealing ductwork is very important in the single-story, slab-on-grade homes characteristic of hot-dry climates, where ductwork typically runs in the attic (or in the case of CARB prototypes, under attic insulation or inside the conditioned envelope). Properly sealed ducts make sure air gets to the spaces intended, rather than leaking into a plenum space. It also minimizes the chances of creating pressure differentials from space to space that would induce airflow through the envelope. The process of sealing each joint reduces the chances of unconnected ductwork, a surprisingly common mistake.

Tape is not recommended as an alternative to mastic. Various tapes are tested to UL 181 standards, which supposedly makes them reliable for use on metal or plastic ductwork. However, it has been found that some duct tape (which is not suitable for taping ducts) passes UL 181. Mastic provides the most reliable duct sealing method.

All ductwork, including the air handler compartment (which typically has many leaky joints) should be mastic sealed. A common goal for duct leakage, measured using a "duct blaster" test, is 5 to 6% leakage to the outside.

Benefits Demonstrated in CARB/Building America Case Studies

Mastic duct sealing recommended for use in all CARB homes. Energy savings can be relatively modest or substantial, depending upon how well-constructed the ductwork system is to begin with. Well-sealed ducts perform better (they send the air where it is designed to go), and they minimize the infiltration of air from garages and attics. Another advantage is that having to go seal all the ducts makes it much more likely that all duct joints will be connected; unconnected ducts are surprisingly co[redacted] the sealing has worked, it is advisable to perform a duct-blaster test (F[redacted]

Ducts Buried under Attic Insulation

Discussion

CARB has been experimenting with burying ductwork under attic insulation since 1996 and has recently helped persuade the California Title 24 program to accept the practice. Cost analyses have indicated that the added cost would be from zero to $100 for a typical home. By mounding blown-in attic insulation, small ductwork can be covered to an R-30 level. Various techniques are possible for covering larger ducts and plenums, but these add cost and in low-pitched roofs are impractical to achieve. CARB's recommendation is to bury as much of the ductwork as possible without special effort (such as wrapping with fiberglass batts). Some cost is saved by the HVAC subcontractor in not having to suspend the ductwork within often-tight quarters. Different diffuser boots might be desirable, allowing the ducts to enter from the side instead of the top, thus keeping them closer to the ceiling.

Benefits Demonstrated in CARB/Building America Case Studies

A noticeable reduction in duct skin loss is possible with no change in construction cost.

Compact Duct Distribution System

Discussion

If low-E glazing is used and the home's envelope is relatively tight, it is possible to discharge conditioned air from inside walls or from ceiling diffusers up to 12 ft from the window wall in most cases without compromising comfort. Such "inside throw" layouts cut ductwork runs, saving money and reducing the amount of ductwork that needs to be protected from attic heat.

Applications in CARB/Building America Case Studies

Compact duct distribution systems have played a central role in many CARB projects. It is a crucial part of efforts to bring ductwork inside the conditioned envelope by using the "plenum truss" approach described below.

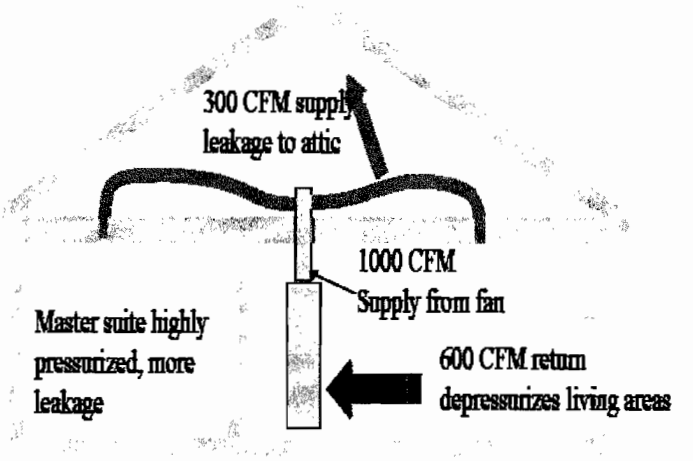


Figure III-9. Duct distribution and pressure zones

Central Air Return with Transfer Grills at Secondary Spaces (Balanced Air-Flows)

Discussion

There is nothing wrong with adding a ducted return from each room, as long as the returns are not panned and as long as they remain within the conditioned envelope of the home. However, ducted returns are an unnecessary expense in most housing and are a definite liability if they run in the attic.

A more reliable and cost-effective approach is to provide a central return and make sure that there are transfer grilles or transfer ducts, of adequate size, that allow air to return from individual closed rooms to the central space. A common requirement is that the differences in static pressure between any two rooms remain below 2.5 Pascals. This is a low, but achievable, number.

The worst possible conditions occur when there is neither a ducted return nor a transfer grille.

> *Why? If one space is pressurized, some other space will be de-pressurized. In both cases, air is forced through cracks into or out of walls and attics, increasing energy losses. Many examples of "soot" accumulation can be traced to pressure imbalances.*

Applications in CARB/Building America Case Studies

CARB has used several different, cost-effective methods of transferring return air without compromising acoustic or visual privacy. The most workable is a high grille on one side of an interior wall cavity and a low grille on the other. Sometimes rooms do not have any common wall with the main space (for example, a door at the end of a corridor). In these

cases, grilles can often be put into and out of a closet, or grilles can be located opposite each other over the door.

Provide Supply-Only Ventilation where Needed

Homes in hot-dry climates are typically not ventilated, despite often being very well sealed. The newly adopted residential ventilation standard ASHRAE 62.2 does not require mechanical ventilation in hot-dry climates and in most of California (in areas with less than 4500 heating degree-days). However, care is needed to make sure there is adequate "makeup" air to replace the air exhausted from the home by various appliances. One factor reducing the need for ventilation in hot-dry climates is that combustion appliances are seldom located within the living space, but rather are in the attic or garage.

No criterion is agreed upon to decide when a home should include supply-only ventilation. A reasonable rule of thumb that CARB recommends (until a better-established number is available through building science) is that supply-only ventilation in a hot-dry climate should be included for homes with a natural infiltration rate of about 50 CFM or less. This is equivalent to an ACHn of 0.28 air changes per hour for a 1,200-ft^2 home with 9-ft ceilings.

When needed, the supply-only (positive-pressure) ventilation device can be as simple as a 6-in. flex or sheet metal air intake duct from outside to return air plenum, with a manual damper. Because of the prevalence of dust and pollen in dry climates, CARB recommends positive ventilation, including the ability to filter the incoming air, as well as timer controlled exhaust ventilation at source points.

No Unvented Gas Appliances in Conditioned Space (except Gas Range with Range Hood Exhausting to the Outside)

Discussion

Unvented gas appliances, such as fireplaces or heaters, may or may not be a health hazard, depending upon whether the flame is properly adjusted. What is not controversial is that they are potentially highly destructive to the framing of the building. These devices create large quantities of water if they are run for extended periods, because the main products of complete combustion are water vapor and carbon dioxide. This water vapor can raise the interior relative humidity to unreasonably high levels. Hot-dry home construction is predicated on prevailing dry conditions, and the introduction of substantial amounts of humidity, especially during winter, could be detrimental to the home's structure. This is especially a problem in the typically tightly constructed stucco homes found in the West.

Applications in CARB/Building America Case Studies

CARB recommends against the use of these devices and insists that all gas ranges be equipped with a range hood that ventilates to the outside. These are basic safety and indoor air quality measures that should always be observed.

Secondary Recommendations

Energy-Efficient Lighting

Discussion

One of the most important ways in which energy is wasted is the use of incandescent lamps. Until recently, however, most fluorescent lamps had disadvantages that limited their use to some bathroom and kitchen lights (with high-end homes dispensing with them altogether). These disadvantages are rapidly being eliminated by successive generations of compact fluorescent lamps. While some still exhibit a time delay before they are fully bright, their color can be quite authentic, especially when reflected from a recessed can, or diffused through the shade of a lamp. Lights that are seldom used can remain incandescent with little loss in energy. Also, fluorescent lamps typically do not work as well outdoors as incandescents.

Applications in CARB/Building America Case Studies

Because of the past history of ineffective fluorescent lighting, CARB's builders have steered clear of fluorescent lighting, responding to market resistance to their use. As market acceptance grows, CARB will continue to suggest the increased use of fluorescent lamps in built-in fixtures.

ENERGY STAR Appliances

Discussion

Two of the most important appliances from a water-use and energy efficiency point of view are the washer and dryer, which are seldom supplied by the builder. However, the builder should include a gas line to make it possible for the homeowner to install a gas dryer. In most cases, gas energy is less costly than electricity. The two main appliances supplied by the builder where efficiency is important are the refrigerator and the dishwasher. There are now hundreds of models of refrigerators that are ENERGY STAR rated, and their use should be routine. There are also many energy-efficient dishwashers available.

Applications in CARB/Building America Case Studies

CARB has had mixed success in encouraging builders to install ENERGY STAR appliances. Typically, as with McStain in Boulder, Colorado, ENERGY STAR appliances are requested by buyers in certain markets where energy performance is a major issue. In other cases, aesthetics or quiet operation governs, and the ENERGY STAR rating is not considered an important issue. This is gradually changing as ENERGY STAR becomes better known.

Plenum Truss

Discussion

The main force of CARB's efforts to protect ductwork from hot attics in hot-dry climates has been to bury the ductwork. In Florida's hot-humid climate, CARB has developed

another strategy that was originally conceived in its work with Del Webb, developing a plenum within the truss space to receive ductwork. In its latest version, the bottom chord of the trusses is canted upward to form a vaulted space, which is then covered by the framers with sheathing board or a roll-out membrane. Small truss sections are then applied over the membrane or board to form the continuation of the bottom chord in order to provide a level ceiling (Figure III-10).

Applications in CARB/Building America Case Studies

The builder with whom this design was developed, Mercedes Homes, has not incorporated the idea into his production housing because of some added cost. However, the concept is ripe for further development and offers a straightforward way to incorporate almost all ductwork within the conditioned envelope. Testing has confirmed that the environment within the plenum is in fact very close to that in the house.

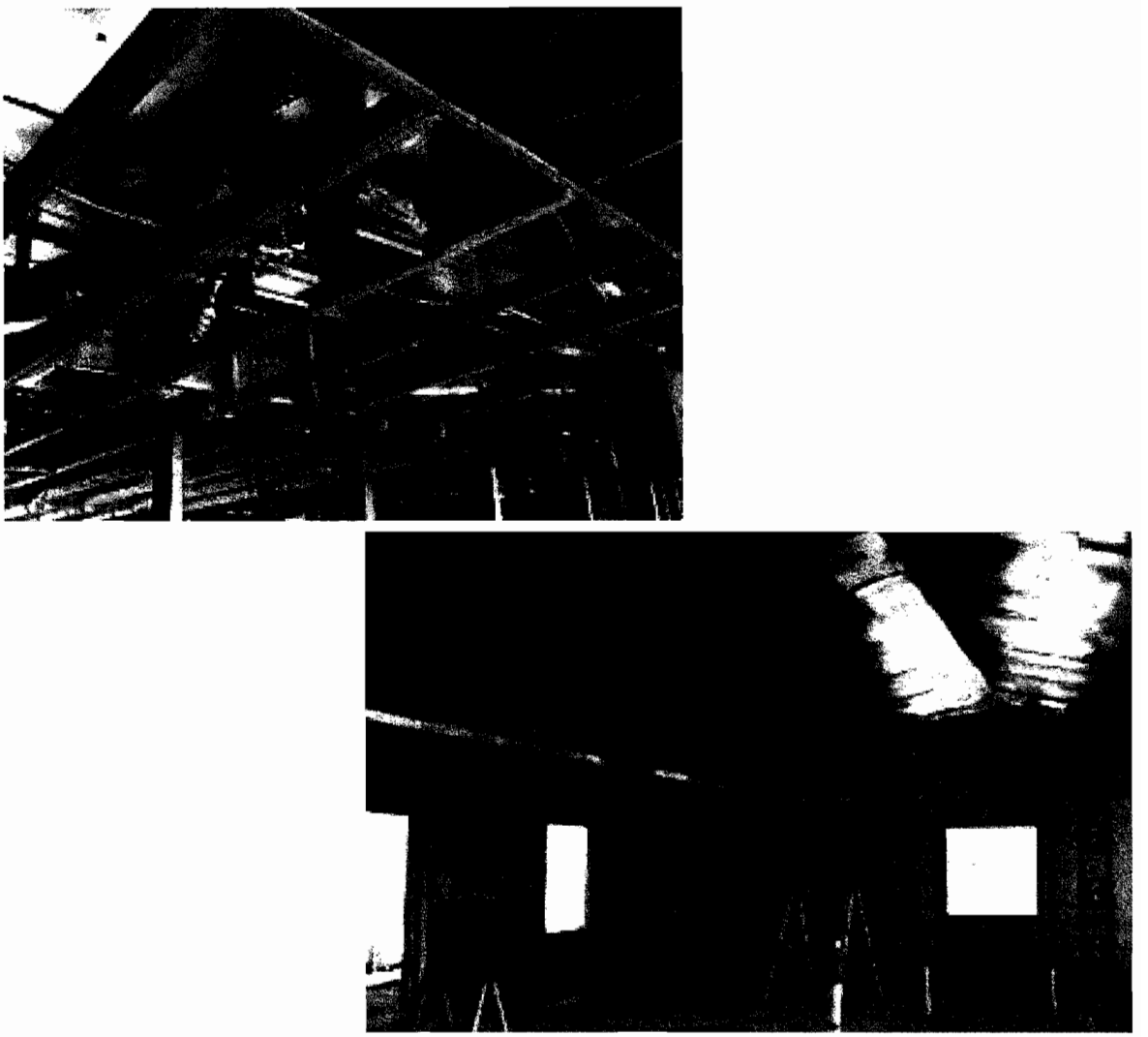


Figure III-10. CARB's plenum tress

Case Study #1: Beazer, Southern California

Introduction

Steven Winter Associates (SWA), which manages CARB, performed the initial work with Beazer Southern California in 1998 under the auspices of the U.S. Department of Housing and Urban Development's (HUD) PATH program. That project – designing, building, and publicizing a high efficiency production home model in Simi Valley, California—established SWA's credibility in the eyes of the Beazer senior management and became the basis for ongoing product improvement efforts under CARB. These efforts have culminated in the adoption of a wide range of high-performance CARB-inspired specifications across the division's entire production of more than 700 homes annually.

Systems Engineering and Building Specifications

The initial specifications were those being employed by Beazer at the start of CARB involvement in the spring 1998. Changes to the basic specifications occurred in two steps: initial prototype construction and production implementation. A synopsis of the original building specifications follows:

Foundation:	Slab-on-grade, uninsulated
Wall Construction:	2 x 4 frame, 16 in. on-center exterior and interior
Exterior Finish:	Three-coat stucco over #30 building felt over 6-in. on-center horizontal wire
Roof Construction:	Engineered trusses at 24 in. on-center
Windows:	Dual-pane tinted glass in aluminum frames
Wall Insulation:	Kraft-faced R-13 fiberglass
Ceiling Insulation:	Unfaced R-19 blankets
HVAC:	Horizontal AFUE 0.80 gas furnace with SEER 10 A/C condenser (Most plans have two systems)
AHU Location:	Air-handling unit in attic
Ducts:	R-4.2 insulated flex ducts, in attic and vertical chases to first floor

Using these specifications, a base-case plan was selected. The Roseman is a two-story home containing 2,734 ft^2 of living space with four bedrooms (figures III-11 and III-12). The home was selected as one of the best sellers in the Simi Valley market and also as it was representative of most plans in the Beazer plan inventory, thus allowing easier concept implementation across the entire product line.

CARB performed DOE 2.1 fuel and energy use analysis, as well as equipment-sizing analysis. The tabulated results of that analysis showed that the home needed 3.5 tons of AC on the second floor and 4 tons on the first; the total annual energy bill would be $1,614, of which $1,270 was electricity and $344 was gas.

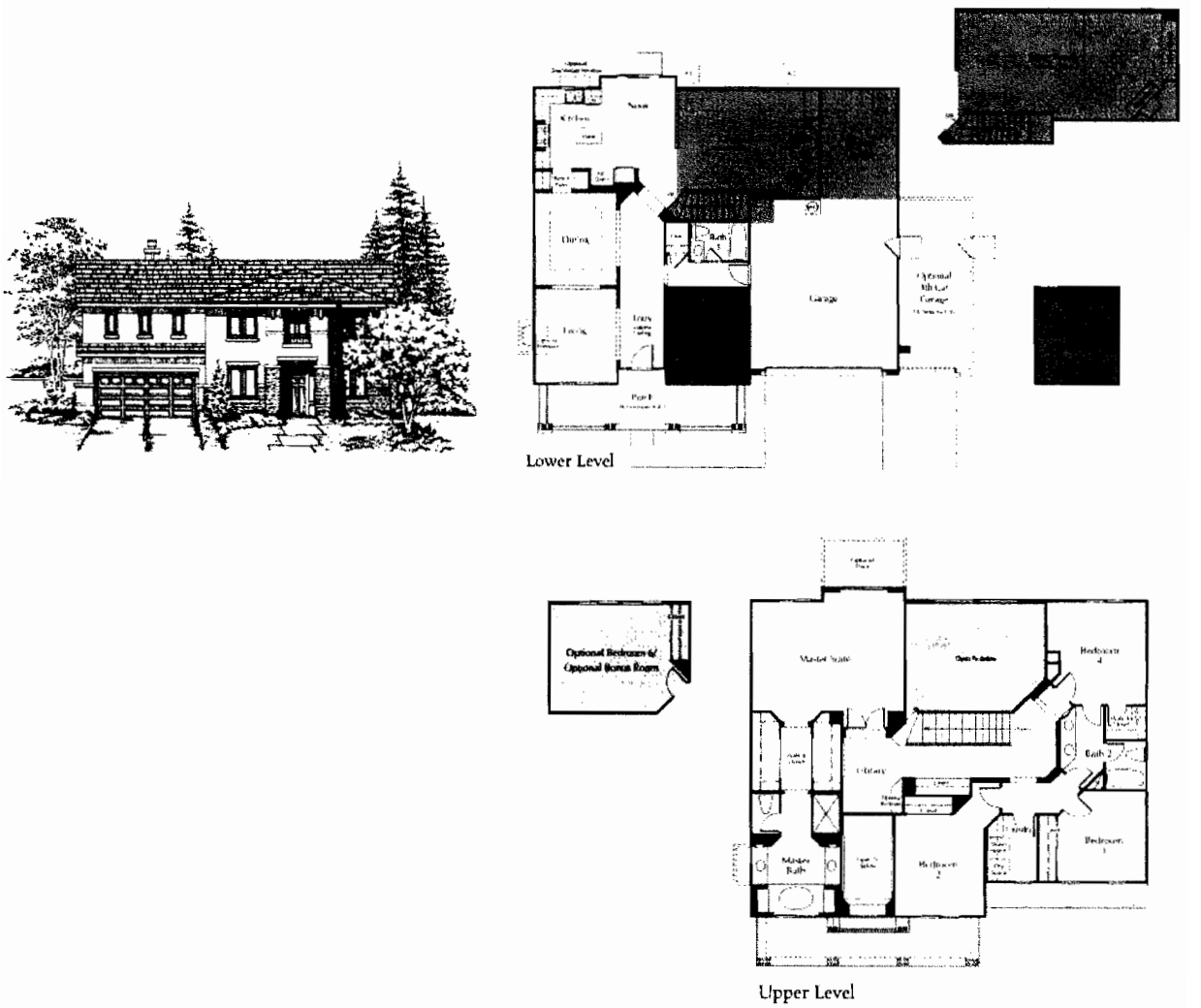


Figure III-11. The Roseman is a two-story home

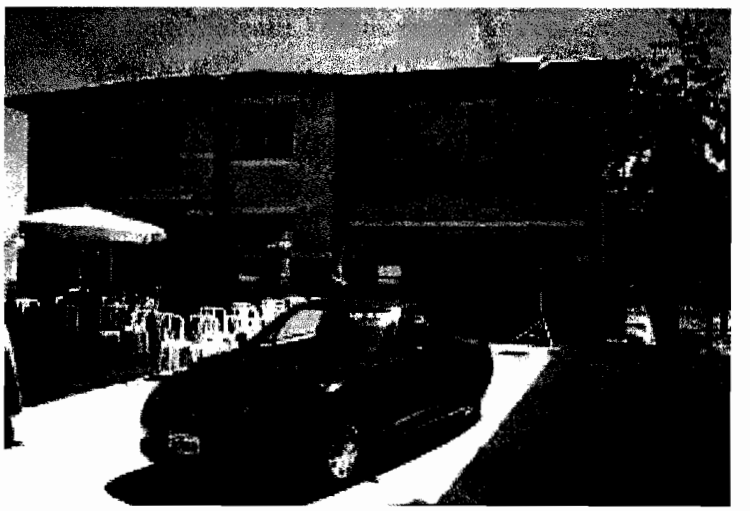


Figure III-12. The Roseman

Based on the 35% decrease in annual heating and cooling costs this represents a 0.3-year payback on initial investment.

This prototype included many other features that are not relevant for this case study. However, they led to a delay before Beazer began working with CARB to develop more "production friendly" changes to their product line. Beginning in the early spring 2001, Beazer contacted CARB to begin work on three new home plans for its upcoming development in Stevenson Ranch, California. With state Title 24 changes eminent, Beazer wanted its new product to meet and exceed those requirements, ahead of the implementation date to "set us apart in the market place."

Using the mid-sized of the three plans for Stevenson Ranch, (3,446 ft^2 two-story), CARB performed a systems-engineering analysis using REM/Design software and Beazer supply-cost information. A package of recommended specifications was arrived at and accepted by Beazer. The primary performance related specifications follow. Again, changes from the base case specification are shown in italics:

Foundation:	Uninsulated, slab-on-grade
Wall construction:	2 x 4 frame @ 16 in. on-center *with foam air sealing package*
Exterior finish:	Three-coat stucco over #30 building felt, *over OSB shear panels, and horizontal wire 6 in. on-center*
Roof construction:	Pre-engineered trusses at 24 in. on-*center (w/ radiant barrier at specific California Climate Zones)*
Windows:	Insulated *soft-coat low-E in vinyl frames (SHGC = 0.33)*
Wall insulation:	Unfaced R-13 fiberglass batts
Ceiling insulation:	*R-38* loose fill fiberglass
HVAC:	*Attic mounted horizontal gas furnaces with SEER 12 A/C condensers (two systems)*
Ducts:	*Mastic sealed* R-4.2 flex ducts *(less than 6% leakage)*

Based on these specifications and plan 3446 in Climate Zone 12, cooling energy savings is 50% and heating energy savings is 15% compared to base case specifications. In addition, required cooling capacity is reduced by 3 tons to 4.5 tons total.

These specifications, which were initially implemented in the Stevenson Ranch subdivision, have been adopted across all Beazer Southern California's communities (with minor variation based upon C.E.C. Climate Zones) beginning on January 1, 2002. In addition to the performance-related specifications, Beazer has adopted a CARB-recommended ventilation strategy for all its new homes. The exhaust-only package consists of Panasonic 90 cfm bath fans on automatic timer controls in all full baths.

Cost Considerations for Upgraded Specifications

Using cost figures obtained through the Beazer purchasing department the cost impacts are as follows:

*	Low-E windows	+ $690
*	R-38 attic insulation:	+ $150
*	Radiant barrier	+ $400
*	Down-sized HVAC ($500/ton)	- $1500
*	SEER 12 ($150/ton)	+ $675
*	Duct sealing	+ $200
Total cost impact		**+ $615**

Additional Changes of Interest to the Builder

Beazer and their HVAC contractor expressed great interest in converting from two separate AC systems to a single-zoned HVAC system. CARB partner Honeywell supplied WestPac, the HVAC contractor, and had previously agreed to be involved in the new system development.

In addition, CARB visited two in-progress subdivisions in Palmdale, Country Club Ridge, and The Greens for the purpose of visually observing current practice with the newly implemented specifications. Among the energy-related observations were the following (Figure III-14):

- Steel shear panels were used, creating a major thermal "short-circuit." CARB recommended the use of Simpson Strong-Tie's "Strong-Wall" shear wall panel throughout.
- The vinyl windows were of poor quality.
- The bottom truss chords were 2 x 4 (not 2 x 6 as thought by the builder), making buried duct installation more feasible.
- Much of the PEX water piping was located in exterior walls, and piping and supply manifolds were exposed to the attic, posing a significant potential freeze problem. (Plumbing on future projects was kept in inside walls.)

- Framing box-downs (at arches for example, Figure III-15) were not air-sealed to separate them from the unconditioned attic. Also, holes through the top plates for pipe, wire and duct penetrations were not sealed.

Open-web trusses were suggested to provide superior access for ducts, but the builder felt they were too expensive when compared with TJI's.

Blower-Door Testing

In order to verify building envelope performance, CARB conducted a site visit and performed blower-door testing at one Beazer model home in the Palmdale region, after improved air-sealing protocol had been established. The blower door testing results from a 3,209-ft^2 Country Club Vista model corresponds with an estimated natural infiltration rate of 0.15 $ACH_{nat.}$, confirming the effectiveness of the air-sealing measures. In addition, duct-blaster results obtained from the WestPac, the HVAC subcontractor, verified that the system was performing as specified with total leakage less than 5% of fan flow.

Table III-1. Blower-Door Testing Results

"C" Regression Coefficient	"n" Regression Coefficient	CFM at 50 Pa	ACH at 50 Pa
173.6	0.60	1791	3.68

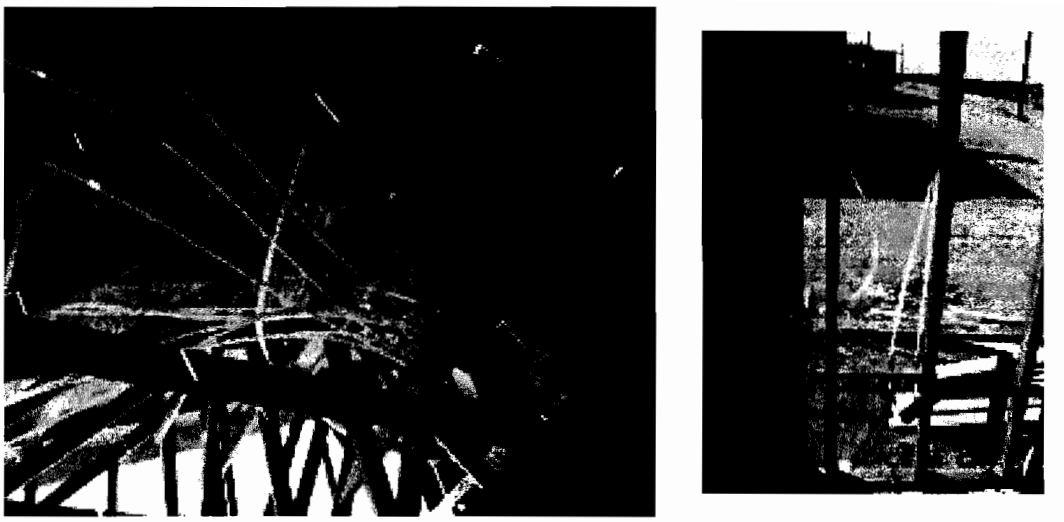


Figure III-13. Domestic hot-water piping (PEX tubing) located in attic and exterior walls

On-Going and Future Work with Beazer Southern California

With the above specifications implemented division wide, CARB is working with Beazer on the next generation of system-engineering building improvements. Primary to this work is the study and implementation of an insulation-buried HVAC duct strategy along with the use of single-zoned HVAC systems in lieu of the now-standard dual non-zoned installations. Our early studies show an average ½-ton HVAC system capacity reduction is allowable as a result of peak load reduction using the buried duct strategy. The zoned single-system strategy appears to represent a significant cost savings to the builder. Assuming constant capacity, the single-zoned configuration could save up to $1,500 per home without a decrease in overall comfort or performance.

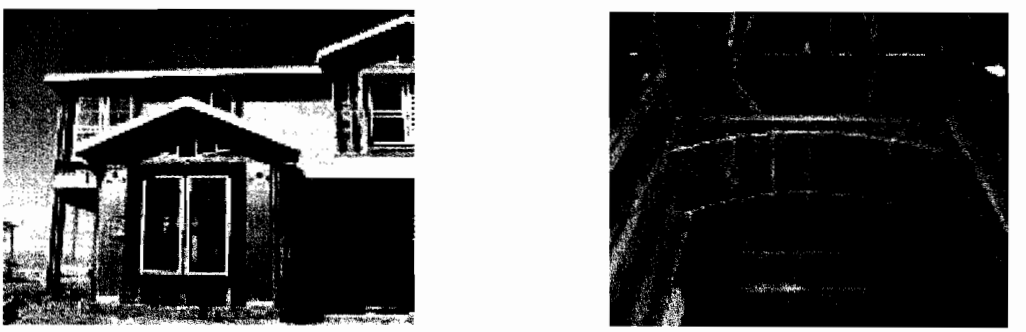


Figure III-14. Framing box-downs are not air-sealed

Case Study #2: Beazer Homes, Sacramento, California

Background

The focus of this project is to explore cost-effective, energy-efficient strategies in the context of single-family residential construction in central California and to implement the successful strategies on a community scale. Based on recent experience with a similar Building America/CARB project in Houston, Texas, and a project in planning at the mid-Atlantic seaboard, Beazer Homes U.S.A. has agreed to participate in this project and in the research of construction materials and methods capable of dramatically increasing energy efficient without an increase in first cost.

Beazer Homes U.S.A. produces approximately 7,000 homes a year nationally and is the largest volume builder in the Sacramento region. All Beazer homes in this market are single-family detached and are marketed to first-time, move-up, and empty-nest buyers. Home sizes range from 1,400 ft^2 up to over 3000 ft^2. Ninety percent of these production homes are single-story.

Standard Specifications

All homes produced by Beazer Homes Northern California utilize the same basic specifications. Based on a standard selected plan, buyers are offered myriad options for customization, including front elevations, interior arrangements, and pre-fab fireplaces.

All homes are built on slab-on-grade foundations. The foundations are not post-tensioned, but are heavily reinforced to counter the seismic design loads. Other than potential seismic activity, the soils are relatively stable and not subject to thermal or moisture-content swelling. Numerous and substantial steel tie-downs are formed in the slab both at the perimeter and at interior shear wall locations. In practical terms, each foundation is custom engineered.

Exterior wall framing is stick built 2 x 4 at 16 in. on-center. The seismic shear panels (at both exterior and interior locations) are specifically engineered and detailed. The manufacturer, size, location, number, and attachment of each mechanical tie-down are specified. The remainders of the exterior walls are essential in-fill, although they do resist imposed axial load from the roof trusses. All wall-framing material is Douglas-Fir, including solid 4-by header stock. Exterior corners and partition-to-exterior wall tee intersections utilize three studs. The homes generally employ either 9- or 10-ft ceiling heights. Interior wall framing is also primarily 2 x 4 at 16 in. on-center. Headers are typically installed at all openings, even non-load bearing locations.

Roof framing is composed of pre-fabricated roof trusses placed 24 in. on-center. Nearly all trusses have flat bottom chords (flat ceilings) with additional spatial volume generated by the 9- or 10-ft-high walls. Roof truss tie-downs are also specifically engineered for each application and are detailed, like the shear walls on the structural plans.

Exterior walls are finished with cement stucco. Before stucco application, horizontal wires are run over the exterior framing at 12 in. on-center, and #30 building paper is placed over the wire. One-inch EPS foam insulation is then placed over the building paper, to which chicken wire mesh is then attached. The stucco is a traditional two-coat cement-based application and develops a thickness of ½ in. Beazer has expressed concern about the durability of the EPS foam under the stucco and has asked that in the course of this project alternates be explored.

The exterior wall is completed by the installation of 3-½-in. unfaced fiberglass batt insulation and ½-in. interior gypsum board. R-30 unfaced friction fit fiberglass batts are installed at the ceiling level, and ½-in. gypsum board is attached to the bottom truss chords.

The windows used by this division consist of high-performance soft-coat low-E glass (shading coefficient = 0.46) installed in aluminum non-thermal break single-hung frames. Glazing areas are typically generous, 18 to 24% of floor area. (Beazer has expressed resistance to lowering glazing area, so that option was not pursued.)

Standard HVAC systems consist of an attic-mounted gas-fired horizontal furnace with a DX cooling coiling connected to an exterior SEER 10 condensing unit. The furnaces are natural draft rated at 80.0 AFUE. All ductwork is R-4.2 flex and is attic run. Except for the largest of homes, a single, ducted, ceiling mounted return is utilized. Duct surface area exposed to the attic is generally in the range of 17% of floor area.

Base Case

For the purposes of this study, it was decided to use an investigation technique that would allow for objectively measured results against a known standard. A base case/control strategy is therefore employed. This method will provide for direct side-by-side energy-use testing and cost comparison.

The model chosen for the base-case is the one-story 1,872-ft^2 Memories Plan #1. It represents a mid-sized home in the Beazer inventory that would allow successful innovations to be easily implemented into other standard plans, both larger and smaller. Plan #1 contains three bedrooms and two baths. Other spaces include a kitchen/greatroom, laundry and formal living room/dining room space. In its standard configuration, this home also has a two-bay garage with an additional tandem garage space.

The location selected to build the prototype is the Memories subdivision approximately 5 miles west of downtown Sacramento. The site is directly contiguous with the Reflections subdivision, which features slightly smaller homes. Memories is marketed as a move-up community.

Prototype Alternatives

Using REM/Design EEBA Residential Energy Analysis Software v8.43 and Wrightsoft Right-Suite Residential v4.1.27, alternate HVAC and envelope specifications were explored in order to determine the operating cost savings (i.e., energy savings) of the explored options. The process explores the benefits of applying single variables to the

Base Case, for example **Alt. 1** (installing ducts within conditioned space), **Alt. 2** (upgrading to SEER 12 air conditioner), and **Alt. 3** (upgrading to vinyl-framed windows). These variables are then combined to compound these benefits. In modeling combinations of variables, consideration is given to those most likely to be cost-effective. Subsequent computer runs indicate energy savings and load reductions and point to cost tradeoffs of various combinations. From these results, the combination with the highest cost/benefit can be identified.

Alt. 4 combines two variables (upgrading to vinyl windows, removing rigid insulation) to reveal an energy-saving measure that may result in significant construction cost savings and is key to the cost/energy balance to be reached. **Alt. 5** retains full R-17 insulation combined with all three variables to indicate greatest energy savings, albeit with cost increase. **Alt. 6** shows that the cost-savings of keeping the aluminum windows represents an energy penalty compared with **Alt. 7**, which trades the rigid insulation for a modest upgrade to vinyl windows.

The dry Sacramento climate carries a relatively small latent cooling load, allowing use of equipment with a sensible heat ratio (SHR) of 0.85, instead of the conventional 0.70 SHR used in most climates. Together with the other energy-saving measures, this allows a 2-ton air conditioner to comfortably cool the house, bringing the cost of an efficient SEER 12 unit within reach.

Base Case: R-17 wall insulation, aluminum windows, 10 SEER A/C, ducts in unconditioned space

Peak sensible A/C load is **22,802 Btuh**, required A/C is **3.0 tons****

Alternate 1: R-17 wall insulation, aluminum windows, 10 SEER A/C, ducts in conditioned space

Peak sensible A/C load is **19,949 Btuh**, required A/C is **2.5 tons****

*Energy Savings Heating: 11% Cooling: 6%
Heat/Cool: 8%

Alternate 2: R-17 wall insulation, aluminum windows, 12 SEER A/C, ducts in unconditioned space

Peak sensible A/C load is **22,802 Btuh**, required AC is **3.0 tons****

*Energy Savings Heating: 0% Cooling: 17%
Heat/Cool: 10%

Alternate 3: R-17 wall insulation, vinyl windows, 10 SEER A/C, ducts in unconditioned space

Peak sensible A/C load is **22,802 Btuh**, required A/C is **3.0 tons****
*Energy Savings Heating: 16% Cooling: 0%
Heat/Cool: 6%

Alternate 4: R-13 wall insulation, vinyl windows, 10 SEER AC, ducts in unconditioned space

Peak sensible A/C load is **23,688 Btuh**, required AC is **3.0 tons****

*Energy Savings Heating: 11% Cooling: -1% Heat/Cool: 3%

Alternate 5: R-17 wall insulation, vinyl windows, 12 SEER AC, ducts in conditioned space

Peak sensible A/C load is **19,949 Btuh**, required AC is **2.5 tons****

*Energy Savings Heating: 29% Cooling: 30% Heat/Cool: 30%

ENERGY STAR Compliant

Alternate 6: R-17 wall insulation, aluminum windows, 12 SEER AC, ducts in conditioned space

Peak sensible A/C load is **19,949 Btuh**, required AC is **2.5 tons****

*Energy Savings Heating: 15% Cooling: 29% Heat/Cool: 24%

ENERGY STAR Compliant

Alternate 7: R-13 wall insulation, vinyl windows, 12 SEER AC, ducts in conditioned space

Peak sensible A/C load is **20,706 Btuh**, required AC is **2.0 tons*****

*Energy Savings Heating: 24% Cooling: 29% Heat/Cool: 27%

ENERGY STAR Compliant

Notes:

* Energy savings compared to base case.

** at 0.70 Sensible Heat Ratio (SHR)

*** at 0.85 Sensible Heat Ratio (SHR)

A review of the above computer simulations results revealed that, all else being equal, the house performed better without foam sheathing and with vinyl windows, than with the foam sheathing and non-thermal break aluminum windows. The simulations suggest that the removal of the foam sheathing produces a very minimal performance penalty and that the aluminum windows produce a significant heating season penalty. This result was found to be somewhat surprising; therefore, additional analysis was performed using DOE2.1E energy-analysis software to isolate the impact of the above variables. The result of that simulation confirmed the earlier REM/Design analysis in that the heating load was indeed negatively impacted by the aluminum windows, and the foam sheathing did little to impact the heating and cooling loads.

Prototype Final Specifications

The results of the above computer simulations were reviewed and analyzed from a first-cost standpoint. It is the goal of this final analysis to determine the most effective manner of substantially improving the performance of the prototype house, as measured against the base case, without an increase in first cost. The result of this approach is the prototype final specifications and is as follows:

Foundation:	Slab-on-grade, uninsulated
Wall construction:	2 x 4 wood frame, 16 in. on-center site built. Traditional cement stucco facing installed over wire mesh on lapped building paper. O.S.B. sheathing at engineered shear wall locations.
Roof construction:	Prefabricated roof trusses at 24 in. on-center
Interior partitions:	2 x 4 wood framing at 16 in. on-center. O.S.B. sheathed at engineered shear wall locations.
Windows:	Insulating glass, high-performance, Low-E single hung in vinyl frame. Solar Heat Gain Coefficient = 0.39
Wall insulation:	Unfaced 3-1/2-in. fiberglass batts R-13
Ceiling insulation:	Unfaced, friction fit R-30 blankets.
HVAC:	SEER 12 air-conditioning condensing unit, 2-ton capacity. Upflow natural draft 80.0 AFUE natural-gas furnace.
Ducts and AHU:	The air-handler (furnace) located in the garage (central to the plan). All supply ducts located in air-sealed drops below the bottom truss chords within the conditioned space. Compact distribution w/ interior throws.

Modeled Prototype Performance

The combination of specifications, as described above in **Alternate 7**, (4e in Appendix A), qualifies the prototype as an ENERGY-STAR-rated home with a modified end use load (MMBtu/year) of 52.3, as compared to the maximum allowable usage of 55.8 MMBtu/year.

The same house with the base-case (standard) specifications would fail to qualify for ENERGY STAR with a calculated MMBtu/year of 59.6, again compared to the maximum allowable usage of 55.8 MMBtu/year.

REM/Design calculates a 29.7% annual savings in cooling energy and a 24.3% savings in heating energy for the prototype over the same house with standard specifications.

Test Objectives

The objective of this short-term test is to evaluate and compare the energy performance of the new Beazer Homes Northern California prototype house and a base-case house, both located in a residential development near Sacramento, California. The specific features to be evaluated in the prototype house include ducts within conditioned space (interior chase below truss bottom chords), impact of vinyl versus aluminum windows, exterior wall thermal performance, and downsized SEER-12 heat pump.

Case Study 3: Second (PV) Prototype

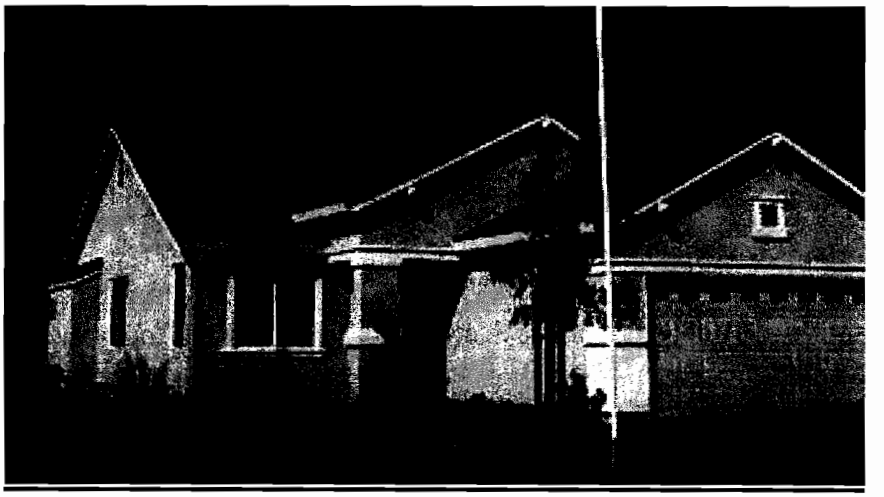


Figure III-16. A Beazer Northern California home

Background

CARB's work with Beazer Homes Northern California under the Building America Program began in September 1999 at the request of Ian McCarthy, President and CEO of Beazer Homes U.S.A., Inc. The Northern California division, operating out of Roseville, a suburb of Sacramento, is Beazer's largest and most profitable division, accounting for 1,200 housing starts a year. All Beazer Northern California homes are single-family detached and are marketed to first-time, move-up, and empty-nester buyers. Home sizes range from 1,200 ft^2 to over 3000 ft^2. Ninety percent of these homes (Figure III-16) are single story.

Our initial meeting with representatives of the Northern California division resulted in an understanding that CARB would assist them in implementing cost-effective energy-efficient strategies on a community-wide scale through the use of the design / build / test / redesign / build / test / implement paradigm.

Initial Standard Specifications

At the inception of this initiative, all Beazer Homes Northern California products utilized the same basic specifications. These specifications are detailed in Case Study 2

First Prototype Specifications

Using RemDesign software several alternate specification combinations were explored to arrive at the best specification package in terms of cost and performance for the 1,872-ft^2 home selected as the base-case. That package consisted of upgrading to SEER 12, improving the windows to a high-performance, soft-coat, low-E in vinyl frames and placing the ducts in conditioned space. In addition, because of the dry climate conditions, a higher sensible heat ratio (SHR) of 0.85 was specified for the HVAC system. This

combination of features allows the HVAC system to be downsized to 2 tons from the original 3 tons and, therefore, offset the cost of the higher efficiency equipment. The first prototype specifications are identical to Case Study 2 with the following exceptions:

Windows

Insulated soft-coat low-E (SHGC = 0.34), vinyl frames

In terms of performance, these changes produce an annual 30% reduction in cooling energy, 29% reduction in heating energy, and a 30% reduction in total HVAC energy use.

Delayed Implementation

Architecturally, the integration of the ducts into the plan was worked out with a great deal of sensitivity and was thought by CARB to actually enhance the architecture of the floor plan by creating lower ceiling transitions between the front public spaces and the rear family areas, as well as in the bedroom hallway. Subsequent positive review of the plan by the homes architects, Bloodgood-Sharp-Buster, reinforced this analysis. Additionally, the HVAC subcontractor, Buetler Air-Conditioning, reviewed the proposed arrangement from an installation/performance standpoint and agreed with CARB's assessment that substantial benefits existed over standard practice. None-the-less, Beazer's marketing concerns remained, as well as their assertion that placing a home different from the standard offerings into a master-planned community was problematic. They essentially halted the project.

Even though this development was seen as a major obstacle from the CARB perspective, critical information was gained on how the Beazer Northern California division operates, which in turn allowed us to refocus our efforts to on what they viewed as a more "production-friendly" strategy.

Initial Specification Changes

To allow across-the-board implementation of proposed strategies, CARB reviewed "plug-and-play" specification options that would provide Beazer the performance improvements they were seeking without changing production methodologies. This investigation resulted in CARB recommending three specification changes to the homes: soft-coat low-E windows in vinyl frames, SEER 12 condensing units, and ducts mastic sealed to 6% leakage or less. These recommendations were presented to Beazer in October 2000, roughly 1 year from the initiation of the project, along with Rem-Design computer simulations showing a 25% overall reduction in heating and cooling energy use over standard practice. These changes would also cause the homes to perform well in excess of HERS 86. By mid-November, Beazer had confirmed that they would begin to phase in the new specification package in new developments starting in January 2001. As this process unfolded, events occurred causing huge spikes in energy costs and rolling black-outs across California. These events in turn prompted Beazer to embark on a much more ambitious initiative of very high performing homes culminating in their "Power House" program.

The SMUD "Power Roof" Program

Sacramento Municipal Utility District (SMUD) has long been a progressive electrical utility in promoting energy efficiency and providing builders with incentives to improve their homes in particular with respect to reducing cooling energy use and peak demand loads. A current program, "SMUD Advantage Home," has enjoyed great builder participation largely through its easy-to-meet requirements and the $500 subsidy offered to builders who participate. To achieve more aggressive results, SMUD has introduced a separate program to promote distributed generation through residential photovoltaic installations called "Solar Advantage Roof." The program offers builders two options: EPV Modules and Atlantis SunSlates.

For option #1, the EPV Modules, SMUD proposes to sell installed 2-kW systems complete with modules, inverter, associated wiring, and electrical components for $2.40/watt. The EPV Modules are the less-efficient amorphous non-crystalline type of PV system, which generates approximately 4.7 watts/ft^2. The 2-ft x 4-ft modules are arrayed in panels of four modules each and are installed on raised channels above the roof surface. A 2-kW system requires 48 modules covering 408 ft^2.

For option #2, SMUD proposes to sell a complete SunSlates PV system including the Atlantis SunSlates, inverter, and associated wiring, without installation for $2.60/watt. The SunSlates utilize crystalline technology and generate approximately 10 watts/ ft^2. Additionally, the SunSlate product is itself a roofing product, being laminated directly to fiber-cement shingles, and is functionally and aesthetically compatible with the concrete roof tiles standard to the region.

Beazer "Power House"

After reviewing the two options provided by SMUD, Beazer decided to opt for the second, more-expensive system, because of its simplicity and aesthetic appeal and to first offer it to homebuyers at its "Roseview" subdivision. Working with CARB and SMUD, Beazer decided to standardize the SunSlates PV system at 3.3 kW. This had the potential advantage of being able to handle all or nearly all of the annual electrical load required by the home, creating a "zero net electrical house," something Beazer was eager use as a marketing tool. To assure these claims could be met, further improvements were made to the Power House home specifications, including a SEER 14 condensing unit, R-38 attic insulation, and air ducts placed on the lower truss chords and insulated over. The final specifications are outlined below:

Foundation:	Uninsulated slab-on-grade
Wall construction:	2 x 4 wood frame 16 in. on-center. Traditional stucco over wire, 1-in. EPS foam, wire mesh, #30 building paper and horizontal support wire
Roof construction:	pre-fab wood trusses 24 in. on-center
Windows:	Insulated soft-coat low-E in vinyl frames (SHGC = 0.33, U = 0.36)
Walls:	Unfaced fiberglass batt and 1-in. EPS foam (R = 17)

Ceiling insulation:	Blown fiberglass, R-38
HVAC:	SEER 14 condensing unit, AFUE 80 horizontal gas furnace, attic mounted
Ducts:	R-4.2 flex ducts, insulation buried at truss bottom chords.

Without consideration of the PV system, the houses built to these specifications far exceed ENERGY STAR requirements with a modified end-use load of (MMBtu/year) of 33.5 compared to 35.9 to reach HERS 86.

Photovoltaic Power Generation

For the Sacramento region, with a southern exposure on a 6/12 roof pitch, a 3.3-kW Sunslate system will generate 5900 kWh annually, based on manufacturer- and SMUD-provided data. Preliminary analysis indicated that this generation capacity would be adequate to offset yearly electric usage for many of Beazer's more modest sized offerings, including the five models being offered at Roseview (Figure III-17). Table III-2 and Figure III-18 illustrate the simulated energy consumption of the Beazer 1330 model versus monthly power generation of the 3.3-kW SunSlates PV system.

Figure III-17. Illustration of five Beazer 1330 models being offered at Roseview with 3.3-kW Sunslate PV sytems

Table III-2. Simulated energy consumption of the Beazer 1330 Model versus monthly power generation of the 3.3-kW SunSlates PV system

Month	Simulated kWh Consumption w/ SEER 14	PV kWh Production for Southern Orientation
January	407	269
February	373	359
March	412	510
April	416	608
May	429	661
June	503	647
July	653	658
August	629	641
September	510	564
October	522	483
November	397	314
December	432	249
Total	5683	5963

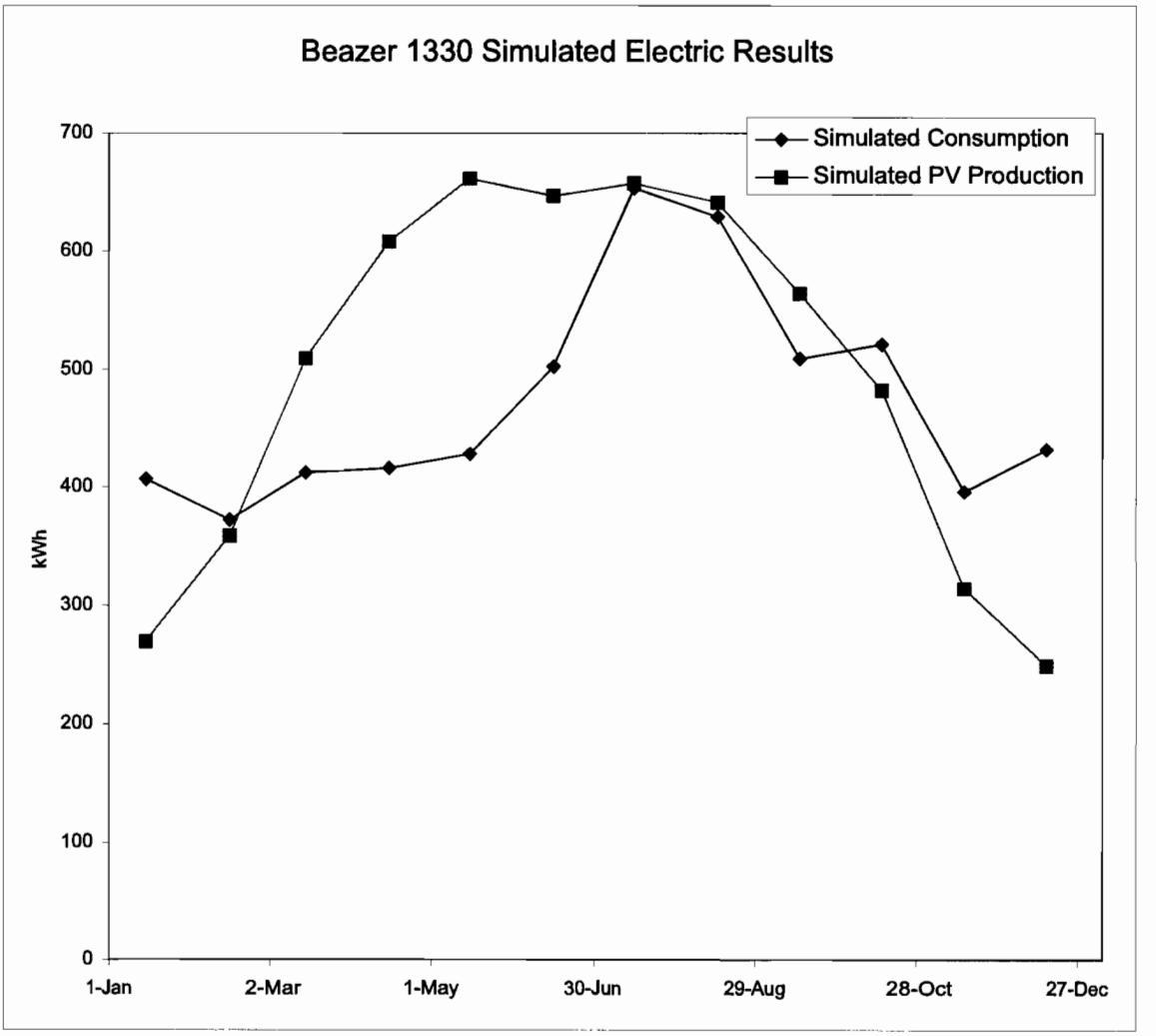


Figure III-18. Graph of simulated energy consumption of the Beazer 1330 Model versus monthly power generation of the 3.3-kW SunSlates PV system

From the above analysis, we see that the yearly PV output of 5,963 kWh exceeds the yearly electrical consumption of the 1330 plan home by 280 kWh, resulting in a "zero-net-electrical" house. Similar analysis of the other plans offered at Roseview find that the two smallest plans, the 1043 and the 1165, require 4440 kWh and 5449 kWh, respectively, both lower than the annual PV output. The largest plan, the 1474, requires 6394 kWh annually, exceeding the PV generation of the 3.3-kW system by 401 kWh.

Current Implementation

Including the very substantial cost subsidies provided by SMUD for the photovoltaic systems, Beazer is offering the option to its buyers for $11,200, essentially a direct pass-along cost. The initial community for this option, Roseview, is a starter home neighborhood, thus most of the prospective buyers are young and tight on cash for down payments. The result is that as attractive as the heavily subsidized option is, most buyers cannot afford it, or at least think they can't. As of November 1, 2001, four homes have received the PowerHouse option, three models and a spec house. It should be noted that the spec house sold very quickly after being placed on the market, indicating a potential avenue to increased sales that is making the PV system standard on some of the offerings. Beazer has not yet embraced this approach, but the division president is very enthusiastic about getting substantial numbers of PV houses built and this may be a viable method of accomplishing that.

The second Beazer community offering the PowerHouse option is Piazzo Del Sol, a neighborhood of somewhat larger and more expensive homes just west of Sacramento. The homes will feature the same specs as in Roseview and the same 3.3-kW system. Slabs have been started and reservations are being accepted, but no information of the number of PV options is available. A third community, Highland Green, directly adjacent to Roseview is to start shortly with six plans in a size range between the first two PV communities. It is hoped that marketing and sales information from these three different subdivisions can be used to focus and refine the PowerHouse program to maximize sales.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Executive Services and Communications Directorate (0704-0188). Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ORGANIZATION.

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
July 2004	Subcontract Report	December 2002–December 2003

4. TITLE AND SUBTITLE
Builder System Performance Package Targeting 30% - 40% Savings in Space Conditioning Energy Use

5a. CONTRACT NUMBER
DE-AC36-99-GO10337

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Consortium for Advanced Residential Buildings

5d. PROJECT NUMBER
NREL/SR-550-34560

5e. TASK NUMBER
BET4.8004

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
CARB
Steven Winter Associates
50 Washington Street
Norwalk, CT 06854

8. PERFORMING ORGANIZATION REPORT NUMBER
KAAX-3-33441-01

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

10. SPONSOR/MONITOR'S ACRONYM(S)
NREL

11. SPONSORING/MONITORING AGENCY REPORT NUMBER
NREL/SR-550-34560

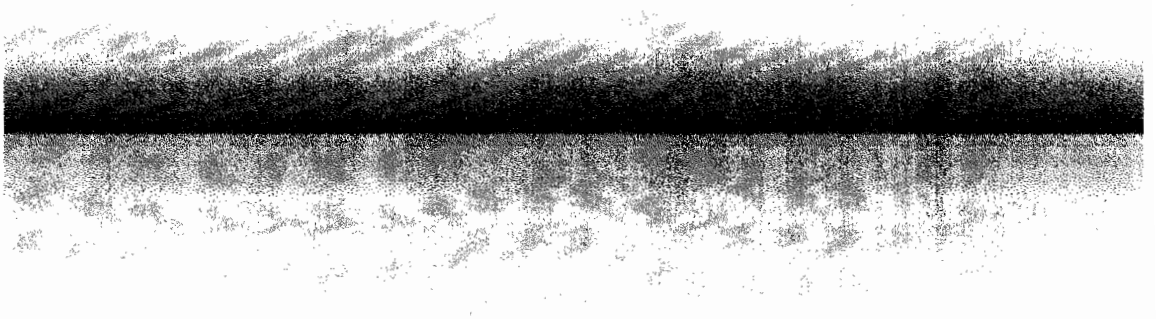
12. DISTRIBUTION AVAILABILITY STATEMENT
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

13. SUPPLEMENTARY NOTES
NREL Technical Monitor: M. Eastment

14. ABSTRACT *(Maximum 200 Words)*
The Consortium for Advanced Residential Building (CARB), one of the Building America teams, describes recommended best practices to achieve 30% - 40% energy savings without compromising health or safety in houses built in cold climates, hot-humid climates, and hot-dry climates.

15. SUBJECT TERMS
Building America; energy-efficient houses; CARB, Consortium for Advanced Residential Buildings; U.S. Department of Energy; DOE

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
Unclassified	Unclassified	Unclassified	UL		19b. TELEPONE NUMBER *(Include area code)*



A Strong Energy Portfolio for a Strong America

Energy efficiency and clean, renewable energy will mean a stronger economy, a cleaner environment, and greater energy independence for America. Working with a wide array of state, community, industry, and university partners, the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy invests in a diverse portfolio of energy technologies.

Research and Development of Buildings

Our nation's buildings consume more energy than any other sector of the U.S. economy, including transportation and industry. Fortunately, the opportunities to reduce building energy use—and the associated environmental impacts—are significant.

DOE's Building Technologies Program works to improve the energy efficiency of our nation's buildings through innovative new technologies and better building practices. The program focuses on two key areas:

- **Emerging Technologies**
  Research and development of the next generation of energy-efficient components, materials, and equipment
- **Technology Integration**
  Integration of new technologies with innovative building methods to optimize building performance and savings

For more information contact:
EERE Information Center
1-877-EERE-INF (1-877-337-3463)
www.eere.energy.gov

U.S. Department of Energy
Energy Efficiency and Renewable Energy

An electronic copy of this factsheet is available on the Building America Web site at **www.buildingamerica.gov**

Visit our Web sites at:

www.buildingamerica.gov | www.pathnet.org | www.energystar.gov

Building America | PATH | ENERGY STAR

Building America Program
George S. James • New Construction • 202-586-9472 • fax: 202-586-8134 • e-mail: George.James@ee.doe.gov
Terry Logee • Existing Homes • 202-586-1689 • fax: 202-586-4617 • e-mail: terry.logee@ee.doe.gov
Lew Pratsch • Integrated Onsite Power • 202-586-1512 • fax: 202-586-8185 • e-mail: Lew.Pratsch@hq.doe.gov
Building America Program • Office of Building Technologies, EE-2J • U.S. Department of Energy • 1000 Independence Avenue, S.W. • Washington, D.C. 20585-0121 • **www.buildingamerica.gov**

Building Industry Research Alliance (BIRA)
Robert Hammon • ConSol • 7407 Tam O'Shanter Drive #200 • Stockton, CA 95210-3370 • 209-473-5000 • fax: 209-474-0817 • e-mail: Rob@consol.ws • **www.bira.ws**

Building Science Consortium (BSC)
Betsy Pettit • Building Science Consortium (BSC) • 70 Main Street • Westford, MA 01886 • 978-589-5100 • fax: 978-589-5103 • e-mail: Betsy@buildingscience.com • **www.buildingscience.com**

Consortium for Advanced Residential Buildings (CARB)
Steven Winter • Steven Winter Associates, Inc. • 50 Washington Street • Norwalk, CT 06854 • 203-857-0200 • fax: 203-852-0741 • e-mail: swinter@swinter.com • **www.carb-swa.com**

Davis Energy Group
David Springer • Davis Energy Group • 123 C Street • Davis, CA 95616 • 530-753-1100 • fax: 530-753-4125 • e-mail: springer@davisenergy.com • deg@davisenergy.com • **www.davisenergy.com/index.html**

IBACOS Consortium
Brad Oberg • IBACOS Consortium • 2214 Liberty Avenue • Pittsburgh, PA 15222 • 412-765-3664 • fax: 412-765-3738 • e-mail: boberg@ibacos.com • **www.ibacos.com**

Industrialized Housing Partnership (IHP)
Subrato Chandra • Florida Solar Energy Center • 1679 Clearlake Road • Cocoa, FL 32922 • 321-638-1412 • fax: 321-638-1439 • e-mail: subrato@fsec.ucf.edu • **www.baihp.org**

National Association of Home Builders (NAHB) Research Center
Tom Kenney • National Association of Home Builders (NAHB) Research Center • 400 Prince George's Boulevard • Upper Marlboro, MD 20774 • 301-430-6246 • fax: 301-430-6180 • toll-free: 800-638-8556 • **www.nahbrc.org/**

National Renewable Energy Laboratory
Ren Anderson • 1617 Cole Boulevard, MS-2722 • Golden, CO 80401 • 303-384-7433 • fax: 303-384-7540 • e-mail: ren_anderson@nrel.gov • **www.nrel.gov**

Tim Merrigan • 1617 Cole Boulevard, MS-2722 • Golden, CO 80401 • 303-384-7349 • fax: 303-384-7540 • e-mail: tim_merrigan@nrel.gov • **www.nrel.gov**

Oak Ridge National Laboratory
Pat M. Love • P.O. Box 2008 • One Bethel Valley Road • Oak Ridge, TN 37831 • 865-574-4346 • fax: 865-574-9331 • e-mail: lovepm@ornl.gov • **www.ornl.gov**

Produced for the U.S. Department of Energy (DOE) by the National Renewable Energy Laboratory, a DOE national laboratory.
July 2004 • NREL/SR-550-34560
Printed with a renewable-source ink on paper containing at least 50% wastepaper, including 20% postconsumer waste.

Efficient Solutions for Existing Homes

Building America
U.S. Department of Energy
Research Toward Zero Energy Homes

HOME PERFORMANCE WITH ENERGY STAR

Case Study:

Green Home Solutions by Grupe
Lodi, CA

Grupe's first Home Performance with ENERGY STAR retrofit.

Innovative New Home Builder in California Enters Whole-House Retrofit Market

In July Green Home Solutions by Grupe completed its first Home Performance with ENERGY STAR retrofit of a 22-year-old, 3-bedroom home in California's Central Valley. The home marks the first foray into the retrofit market for the award-winning Sacramento area production builder, who was constructing over 300 homes a year prior to 2007. "We see retrofitting as a whole new market for us, and we are excited about the potential," said Mark Fischer, the chief financial officer and a senior vice president at Grupe.

Fischer heard about Home Performance with ENERGY STAR at the 2008 EEBA (Energy and Environmental Building Association) national conference in Phoenix in September. "After the conference, I started reading about it, and by January of this year, we decided we were going to try it." said Fischer.

Home Performance with ENERGY STAR, a national program from the EPA and DOE, promotes a comprehensive, whole-house approach to making energy-efficiency improvements. The program is available in cities where a local sponsor (typically a utility company, state agency, or local association promoting energy efficiency) has agreed to partner with ENERGY STAR. The local sponsor recruits home improvement contractors and trains them to perform comprehensive home assessments and best-practice improvements based on whole-house building science.

The California Building Performance Contractors Association (CBPCA) is currently the only organization in the state providing contractor training for Home Performance with ENERGY STAR. The training is funded primarily by Pacific Gas and Electric, Southern California Edison, and the Sacramento Municipal Utility District according to Pat Colburn, director of CBPCA's Support Services.

"Our signature training is called the Green Home Energy Upgrade. It is a 9-day course divided into three 3-day segments or levels. At the end of the third level, our participants can take the written test from the Building Performance Institute (BPI)," said Coburn. All four BPI specialty written tests are offered on the third day of level three. Participants can be certified in one or all of these specialty areas: Building Analyst Professional, Envelope Professional, Heating Professional, and Air Conditioning/Heat Pump Professional.

Once trained, the participating contractors provide recommendations and services to homeowners to make their homes more comfortable and energy efficient, while reducing their utility bills and protecting the environment.

BUILDER PROFILE

The Grupe Company, DBA
Green Home Solutions

3255 West March Lane
Stockton, CA 95219
(209) 473-6000

Founded: 1966

Employees: 70

New Homes per Year: 300-400
In July, completed 1st Home Performance with ENERGY STAR retrofit

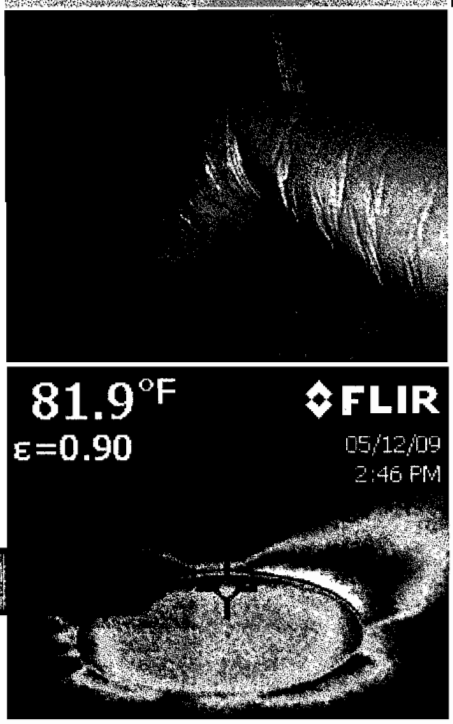
Featured Project: A home in Lodi, CA, in California's Central Valley

Home Built: 1987

Square Footage: 2,129 sq. ft.

"For the homeowner calls and emails I get, I always ask them, 'How did you find us [the CBPCA]?' They say the majority of time that they came to us by going to the ENERGY STAR website, which is huge for us. ENERGY STAR is a brand name. It is a known and respected name. People who don't get answers from utilities, go to ENERGY STAR."

Pat Colburn, Director of Support Services with the California Building Performance Contractors Association (CBPCA)



(top) The old ducts were leaky and drooped from their hangers with kinks that blocked airflow.

(bottom) The energy audit showed 14 recessed (can) lights that were not insulated and had significant air leakage.

Home Performance with ENERGY STAR: A Whole-House Approach

Rather than focusing on a single problem, like an old heating or cooling system, not enough insulation in the attic, or leaky windows, Home Performance with ENERGY STAR looks at how improvements throughout your home can work together to give you the best results. The Benefits of Home Performance with ENERGY STAR include

- Utility bill savings of 20% or more
- Fewer drafts and more comfortable rooms
- Work performed by specially trained contractors
- Third-party quality assurance to make sure work gets done right
- Reduced greenhouse gas emissions to protect the environment

Unlike typical home energy audit programs, the goal of Home Performance with ENERGY STAR is to turn recommendations into improved homes. Participating contractors complete the needed renovations or team with other participating contractors who can. Another important element of the home performance approach is that, upon project completion, the contractor assesses the home's performance again to document that improvements were properly installed to achieve the promised energy savings. Finally, all participating contractors are subject to quality assurance reviews by the third-party sponsor to ensure that projects meet program standards and homeowners receive high-quality work.

In January and February of 2009, Grupe trained seven of its staff in the Home Performance with ENERGY STAR approach. "The classes offered by CPBCA are staggered over time, so to save time, we hired Rick Chitwood, one of their trainers, directly," said Fischer. "He came out and spent two straight weeks with us. It was great."

At the end of the two weeks, the participating Grupe staff took the Building Performance Institute test. "Then, we went out and bought the equipment. We bought the blower door equipment, the infrared camera, the duct blaster, the smoking machine…then we started going into homes and learning how to use it," says Fischer. "In July of this year, we completed our first job."

The Process—One Home Performance with ENERGY STAR Retrofit from Start to Finish

Grupe's retrofit is a 2,129-square-foot home built in 1987 in Lodi, in California's Central Valley. The homeowners were interested in learning the results of an energy audit because their furnace was old and needed to be replaced, and they thought they were paying a lot in electricity bills. They also complained of the living room supply registers blowing too strongly in both heating and cooling modes.

Conducting a Comprehensive Energy Audit

"Even before we go out to the house, we ask for homeowner's gas and electric bills for a year to assess how much they are spending to heat and cool their home," said Fischer.

In this case, the electric bill for a year was $5,566 (with a high of $687 in August) and the gas bill was $826 (with a high of $155 in January). The home used on average 1,470 kWh per month, which is high compared to 800 kWh, the average monthly utility bill for a home of its size in California's Central Valley.

Armed with this information, the Grupe team began their onsite assessment. "We follow the Home Performance with ENERGY STAR guidelines. It takes between 4 and 8 hours to do the assessment, and we charge $500 to $1000 dollars depending on the size of the home," says Fischer. The homeowner pays this fee and gets it back if the builder does the work.

Following the Home Performance with ENERGY STAR guidelines, the onsite team conducted blower door tests to determine air leakage; used infrared cameras to show heat and air infiltration areas; checked for insulation levels and gaps in the attic/ceiling, walls, floor; studied the types and conditions of the windows; studied details of the mechanical heating and cooling systems; documented details of the water heating system; checked all appliances and lights; conducted combustion appliance testing for safety and health; checked for signs of moisture infiltration; measured humidity levels; measured water consumption levels; and documented ventilation needs.

Making Recommendations

Once the energy audit was complete, the Grupe team prepared a detailed proposal with cost estimates and met with the homeowners to review their findings and recommendations. In this case, the homeowner agreed to all of the recommendations at a total cost of approximately $17,000.

The homeowners did investigate federal, state, and local rebates and financial incentives for their Home Performance with ENERGY STAR retrofit. They received $2,600 in tax credits and rebates, including a federal energy efficiency tax credit of $1,500 and a $750 utility rebate from Lodi Electric Company. For those interested in rebates and financial incentives for Home Performance with ENERGY STAR, the Database of State Incentives for Renewables and Efficiency (DSIRE) can be accessed at www.dsireusa.org. This site provides a comprehensive source of information on state, local, utility, and federal incentives and policies that promote renewable energy and energy efficiency. Established in 1995, DSIRE is an ongoing project of the North Carolina Solar Center and the Interstate Renewable Energy Council funded by the U.S. Department of Energy.

Doing the Home Performance with ENERGY STAR Retrofit

The work began with sealing the home. During the initial assessment, Grupe discovered that the damper in the living room fireplace would not close completely, which resulted in significant heating and cooling loss. Because the homeowners did not use the fireplace, Grupe sealed the fireplace with a product called "Chimney Balloon," which must be removed if the fireplace is ever used.

The home had R-30-rated blown fiberglass insulation in the attic except for the cathedral ceiling over the family room which contained R-22 fiberglass batt. An assessment showed that settling had occurred and the blown fiberglass was not at proper depth to provide R-30, nor were the batts in good contact with the drywall in the cathedral ceiling. Grupe removed the fiberglass, sealed air gaps, re-installed the fiberglass, and covered this with blown-in cellulose to reach an R-49 level.

Tests showed the duct system had 15% leakage. The ducts were suspended from the roof framing system in the attic; these ducts drooped and had kinks in several places that restricted air flow. The Grupe team removed the hanging ductwork and installed new R-8 insulated ducts that were mastic sealed and laid on the trusses and then covered with the blown cellulose insulation.

The importance of a whole-house approach to retrofitting became apparent in the recommendations for heating and cooling. The original 80,000-BTU furnace was manufactured by Rheem in 1985 and was oversized by a factor of 1.9 times as the existing heating load was 41,763 BTUs. The 4-ton cooling system was manufactured by Bryant in 2000 and was designed for a load of 48,000 BTUs; it was also oversized by almost 2 tons as the existing cooling load was 30,515 BTUs.

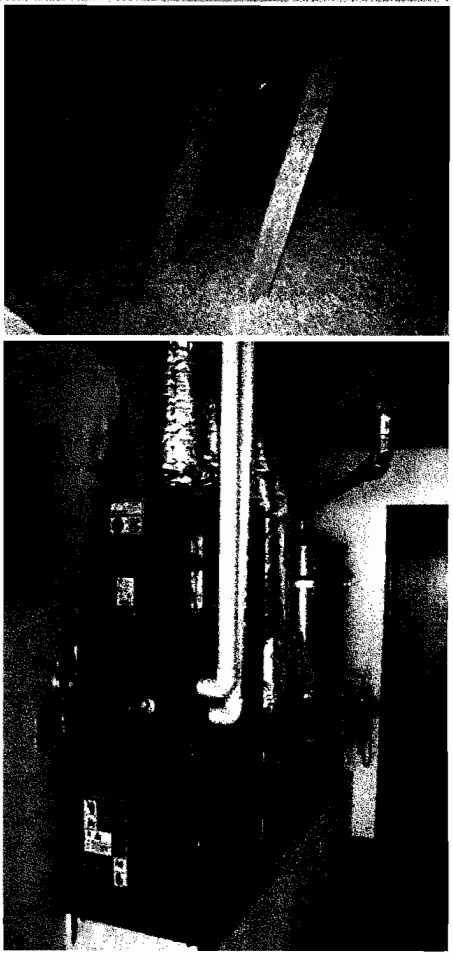
As replacements, the team installed a new Lennox 2.5-ton sealed combustion, two-stage variable speed gas furnace/air handler with an efficiency rating (AFUE) of 95% and a new Lennox 2.5-ton, 15.5 SEER/12.5 EER air conditioning unit, a Lennox HC-10 filtering system, and a new Lennox ComfortSense 5000 touch screen setback thermostat. The new furnace and air conditioner are more than adequate to handle the post-retrofit heating load of 37,020 BTUs and cooling load of 26,029 BTUs. In addition to saving money, these properly sized units solved the homeowners' comfort complaint of excessive air blowing in the living room.

The original dual-pane, aluminum-framed windows were in good condition. To save money, these windows were not replaced, instead the glass in six of the windows facing west and south was covered with a high-end window film called NV-15; the film, which is made by 3M, reduces solar gain to 0.29 SHGC. Software calculations showed this change reduced the home's cooling load by 3,500 BTUs.

Recessed lights, if not properly sealed and insulated, can cause significant air leakage. Grupe replaced 14 recessed can lights with new insulated can lights and sealed these properly.

With the house tightly sealed, Grupe installed a "Fresh Vent" ventilation system to provide continuous ventilation into the home at the recommended air exchange rate of 0.35 air changes per hour (ACH).

The team replaced an inefficient swimming pool heater and pump for a predicted energy savings of 3,000 watts per day in the winter and 5,000 watts per day in the summer.



(top) New ducts were covered with blown-in cellulose for added insulation.

(bottom) New Lennox 2½-ton sealed combustion, two-stage variable speed furnace/air handler.

More than half of the over 66 million single-family homes in the United States were constructed before modern energy codes existed. Many of these homes have no wall insulation, high levels of air infiltration, inefficient heating and air conditioning, and inefficient water heaters and appliances. In fact, over 40% of households report at least some winter drafts, and 62% complain of a room that is too warm in the summer.

Home Performance with ENERGY STAR website

Key Energy-Saving Features

Attic insulation
R-30 blown fiberglass and R-22 batt fiberglass plus blown cellulose to R-49

Central gas furnace
Lennox 2.5-ton sealed combustion, two-stage variable speed gas furnace/air handler with an efficiency rating (AFUE) of 95%

Air conditioning unit
New Lennox 2.5-ton, 15.5 SEER/ 12.5 EER air conditioning unit

Duct leakage
1,115 cfm, 5.1% leakage

Duct insulation
R-8, properly sealed, buried in blown cellulose

Pool pump and heater
More efficient, saving 3,000 watts/day summer, 5,000 watts/day winter

Lighting
CFL bulbs

Windows
0.29 SHGC coating added

Conducting Follow-up Testing

"Now this is the really exciting thing," says Ron Rugani, Grupe's vice president for construction, "to do the diagnostic testing to see what you've got, then to go in there and make the improvements, then to go back and test again. We are able to see some really significant improvements."

The original duct blaster test, which measures duct leakage, showed 15% leakage. The test with the new system showed 5.1% leakage. The original blower door test showed leakage at 2,478 cfm_{50}, which Rugani explained is actually not bad for a house of this age, as standard air leakage for a house of this size is about 2,257 cfm_{50}. By extensive caulking and sealing, "we took this leakage from 2,478 to 1,115 cfm_{50}, a 55% reduction," said Rugani.

Such a tight house creates the need for a good ventilation system. "The good thing about providing ventilation is that now you control the air that you are bringing in," says Rugani. "When you have a leaky house, you have no control. It is coming from the attic, through the walls, and from areas that are probably not the best things to breathe. With a ventilation system, when we bring air into the house, we can control and temper it, filter it, and provide good air for the occupant. We did this by providing a ventilation system with the new heating and air conditioning system that brings in fresh air, mixes it with the conditioned air, and ventilates the home."

As part of the assessment tests, the team took air flow measurements of 1,143 in cooling mode at each of the registers for the 4-ton system. In the test out, the 2.5-ton system delivered 1,095. "We were delivering almost as much air after with a ton and a half less capacity," says Rugani.

In addition to these tests and more, any house retrofitted under the Home Performance with ENERGY STAR program is subjected to spot inspections by trained whole-house contractors.

Construction leaders like Rugani are not shy about their support for Home Performance with ENERGY STAR. "I think it is fantastic. It is a great opportunity to do great things for homes to make them more comfortable and more energy efficient. I really like that we [Grupe] can do our part to make homes more efficient and do our part to reduce the carbon footprint of homes."

The Bottom Line

"Both Pacific Gas and Electric Company and California make energy efficiency the top priority when it comes to combating climate change," explains Charles Segerstrom, manager of Pacific Gas and Electric Company's (PG&E) Energy Centers. "We have the most aggressive energy efficiency goals anywhere. The California Public Utilities Commission has set a goal of 40 percent in residential energy savings by 2020 and 20 percent by 2015."

"Home Performance with ENERGY STAR provides the consistency and standardization that are critical as we continue to develop a green economy," said Segerstrom. "Such standardization is necessary in order to achieve the deep energy-efficient retrofits that result in significant energy savings."

For information about Home Performance with ENERGY STAR training in California, visit www.cbpca.org

To find your state sponsor for Home Performance with ENERGY STAR, go to **www.energystar.gov** Then, click on *Home Performance with ENERGY STAR.* From here, click on the link labeled "contractors participating in a locally sponsored Home Performance with ENERGY STAR Program." Or, Google: *Home Performance with ENERGY STAR Locations.*

For more information about Home Performance with ENERGY STAR, visit **www.energystar.gov/homeperformance**

For additional information, contact:
Theresa Gilbride
theresa.gilbride@pnl.gov

PNNL-SA-68406

Building AMERICA SM
U.S. Department of Energy

Research that Works

May 2005 • NREL/TP-550-37731

The Hathaway "Solar Patriot" House: A Case Study in Efficiency and Renewable Energy

Paul Norton
National Renewable Energy Laboratory

Ed Hancock and Greg Barker
Mountain Energy Partnership

Paul Reeves
Partnership for Resource Conservation

U.S. Department of Energy
Energy Efficiency and Renewable Energy
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

Building Technologies Program

The Hathaway "Solar Patriot" House: A Case Study in Efficiency and Renewable Energy

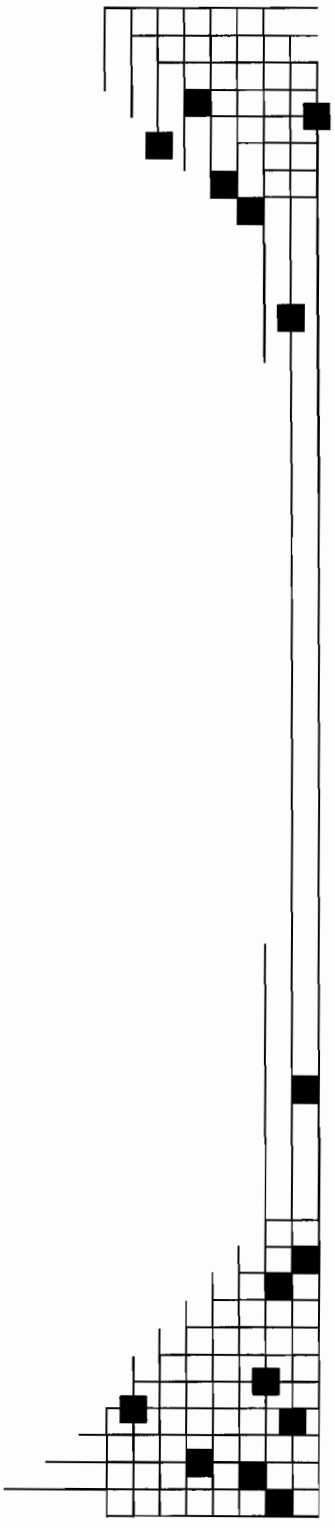
Technical Report
NREL/TP-550-37731
May 2005

Paul Norton
National Renewable Energy Laboratory

Ed Hancock and Greg Barker
Mountain Energy Partnership

Paul Reeves
Partnership for Resource Conservation

Prepared under Task No. BET5.8004



National Renewable Energy Laboratory
1617 Cole Boulevard, Golden, Colorado 80401-3393
303-275-3000 • www.nrel.gov

Operated for the U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
by Midwest Research Institute • Battelle

Contract No. DE-AC36-99-GO10337

NOTICE

This report was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or any agency thereof.

Available electronically at http://www.osti.gov/bridge

Available for a processing fee to U.S. Department of Energy and its contractors, in paper, from:

U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
phone: 865.576.8401
fax: 865.576.5728
email: mailto:reports@adonis.osti.gov

Available for sale to the public, in paper, from:

U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
phone: 800.553.6847
fax: 703.605.6900
email: orders@ntis.fedworld.gov
online ordering: http://www.ntis.gov/ordering.htm

Printed on paper containing at least 50% wastepaper, including 20% postconsumer waste

Table of Contents

1 Abstract 1
2 Introduction 1
2.1 The Context 1
2.2 The "Solar Patriot" House 2
2.3 The Hathaway House Specifications 3
2.4 Study Objectives and Overview 7
3 Short-Term Testing 8
3.1 Air Exchange Characteristics 9
3.2 Heat Pump Coefficient of Performance (COP) 15
3.2.1 Heating Mode COP 15
3.2.2 Cooling Mode COP 16
3.2.3 Water-Heating COP 17
3.3 Other Short-Term Measurements and Observations 21
4 Long-Term Monitoring 21
4.1 Monitoring System and Data being Collected 21
4.2 Results from the Entire Monitoring Period 24
4.3 Results from the Calendar Year 2002 and 2003 29
4.4 Average Hourly Profiles 30
5. Simulated Energy Performance 37
5.1 Improving Accuracy: Modeling Specific Systems 38
5.2 Building Confidence: Comparing Monitored Data and the Simulation Results 38
5.3 Putting Performance in Context: Simulation Results 41
5.4 What if . . . Investigating Possible Improvements 43
6. Discussion 45
6.1 On the Path to Zero Net Energy 45
6.2 Systems Operations and Interactions 46
6.3 Modeling and Monitoring Approach 46
7. References 48

List of Figures

Figure 1. The "Solar Patriot" home on the National Mall in Washington, D.C. 2

Figure 2. The Solar Patriot house at its permanent location in Purcellville, Virginia (photo by Ed Hancock) 3

Figure 3. Floor plans for the first and second floors of the Hathway House 5

Figure 4. Duck supply trunk entering attic and continuing to trunk above the framing for the finished space 6

Figure 5. Supply register for attic space (top photo) and supply duct descending to ceiling register for second floor (bottom photo) 6

Figure 6. Alden Hathaway and blown-in cellulose insulation in attic 7

Figure 7. Blower door installed in the Hathaway House 8

Figure 8. Comparison of tracer gas ACH measurements to ACH modeled using blower door ELA measurement 14

Figure 9. Space-heating COP determined from monitored data (fan power not included) 16

Figure 10. Space-cooling COP determined from monitored data (fan power not included) 17

Figure 11. Coefficient of performance (COP) of heat pump for water heating 18

Figure 12. Domestic hot-water (DHW) COP determined from monitored data 19

Figure 13. Total energy consumption by end use for the entire monitoring period - September 2001 to February 2004 24

Figure 14. Monthly energy consumption by end use 25

Figure 15. Monthly electrical energy (AC) produced by the PV system 26

Figure 16. Monthly net electrical energy bought 27

Figure 17. Monthly electrical energy (DC) produced by each of the three PV arrays and average outdoor temperature (west and east are arrays on the roof of the home) 28

Figure 18. Energy produced by the PV system and net energy bought from the grid for 2002 and 2003 29

Figure 19. End-use percentages for 2002 and 2003 30

Figure 20. Outdoor temperature average hourly profile 31

Figure 21. First-floor indoor temperature average hourly profile 31

Figure 22. Irradiance in the plane of the collector average hourly profile 32

Figure 23. DC power from the PV system average hourly profile 32

Figure 24. Total power use average hourly profile 33

Figure 25. Net power bought from the grid average hourly profile 33
Figure 26. Power used for space conditioning average hourly profile 34
Figure 27. Heat-pump power used for water heating average hourly profile 34
Figure 28. Hot water draw average hourly profile 35
Figure 29. Clothes washer power use average hourly profile 35
Figure 30. Clothes dryer power use average hourly profile 36
Figure 31. "Other" power use average hourly profile .....
Figure 32. DOE2 model of the Hathaway House, the dark area simulates the shading of the home by the garage and breezeway roof 37
Figure 33. Monitored data vs. simulation results for total energy using Building America assumptions and TMY2 data 39
Figure 34. Monitored data vs. the adjust model results, whole-building energy use 40
Figure 35. Energy use by end-use category, beyond the Hathaway prototype 44

List of Tables

Table 1. Summary of Specifications for the Hathaway House 4
Table 2. Results of Blower Door and Duct Testing 10
Table 3. Register and Exhaust Fan Flow Results 12
Table 4 Flow-Plate Measurements of the Total Air-Flow Rate at the Air-Handler 13
Table 5. Energy Balance for Domestic Hot Water (DHW) System 20
Table 6. The COP in Each Mode 20
Table 7. Data Monitored at the Hathaway House 23
Table 8. Summary of End-Use Site Energy 42
Table 9. Summary of End-Use Source Energy and Savings 42
Table 10. Energy Savings of Energy Efficiency Measures 42
Table 11. Energy Reduction by End-Use Compared to the Building America Benchmark 43

List of Terms

AC	alternating current
ACH	air changes per hour
ASES	America Solar Energy Society
BEopt	Building Energy Optimization simulation model
BESTEST	simulation software
cfm	cubic feet per minute
COP	coefficient of performance
DC	direct current
DHW	domestic hot water
DOE	U.S. Department of Energy
DOE2	simulation software
EF	Energy Factor
ELA	equivalent leakage area
EPA ENERGY STAR®	Environmental Protection Agency Energy STAR program
HVAC	heating, ventilation, and air conditioning
HP	heat pump
HSPF	Heating Seasonal Performance Factor
IR	infrared
LBNL	Lawrence Berkeley National Laboratory
MEC	1995 Model Energy Code
NREL	National Renewable Energy Laboratory
Pa	Pascal
PV	photovoltaic
SEER	Seasonal Energy Efficiency Rating
SF6	sulfur hexafluoride
TMY	typical meteorological year
TRNSYS	TRaNsient SYstem Simulation program
UA	overall heat-transfer coefficient (U) times area (A)
ZEH	zero energy home

Acknowledgments

We express our gratitude to George James and Ed Pollock, U.S. Department of Energy, for the leadership and resources needed to complete this work. Many thanks to Alden Hathaway and the whole Hathaway family for inviting us into their home for testing and monitoring. Many thanks also to Tim Merrigan and Craig Christensen of the NREL Zero Energy Homes team for their comments and insights. We are indebted to Ren Anderson, Mark Eastment, and Ron Judkoff of NREL for their thoughtful reviews and comments and Nancy Wells of NREL for her technical editing and document preparation work support.

We would like to acknowledge the help of two James Madison University students – Ashley Abbott and Kenneth Armstrong for their valuable assistance in instrumenting the Hathaway house.

1. Abstract

This report details the monitored and modeled performance of a solar home outside of Washington, D.C. We modeled the home energy performance using DOE2.2, performed numerous short-terms tests on the home, and monitored its occupied performance for 29 months. The home used modular construction, solar water heating, a ground-coupled heat pump, efficient appliances, and compact fluorescent lighting to reduce its energy consumption by 35% compared to the Building America research benchmark home. The addition of 6kW of photovoltaics (PV) increased the savings to 67% compared to the Building America research benchmark. A more efficient shell to reduce space conditioning loads would have brought the home closer to its zero energy goals. However, even with efficient lighting and appliances, the lights, appliance and plug loads were a significant energy consumer. About 4 kW of PV was required to meet the needs of these loads alone. To achieve the zero energy goal with no further efficiency increases, the Hathaway house would need about 2.6 kW of PV in addition to the 6.0 kW it now has. Applying advanced efficiency measures available or being developed, such as heat-recovery ventilation, superinsulation, and electrochromic windows, could reduce the heating, cooling, and domestic hot water (DHW) energy use to less than 1700 kWh per year, an 88% reduction in these loads from the Building America Benchmark. At this efficiency level, the appliance and plug loads come to dominate energy consumption and account for nearly 70% of the total energy use. This analysis points out that even with highly effective energy-savings technologies (pushed beyond levels currently practical), whole-house energy use reduction by efficiency measures is only about 60% without also reducing the energy use of appliances and plug loads largely considered outside the designer's jurisdiction.

2. Introduction

This report details the monitored and modeled performance of a solar home outside of Washington, D.C. The home uses modular construction, solar water heating, a ground-coupled heat pump, efficient appliances, and compact fluorescent lighting to reduce its energy consumption by 35% compared to the Building America research benchmark home[1]. The addition of $6kW_p$ of photovoltaics (PV) increased the savings to 67% compared to the Building America research benchmark.

2.1 The Context

How clean is clean enough? How efficient is efficient enough? These will be among the defining questions of the 21st century. As the human population pushes past 6 billion on the way to 9 billion by 2050[2] we are faced with increasing environmental consequences . . . mass species extinction; toxic air, water, and land pollution; and global warming to name a few. Many of these consequences are related to our energy use and choices. It is clear that we will need to reduce our per capita environmental impact, at least in relation to our population growth if we wish to stabilize or reduce environmental degradation.

About a fifth of all energy consumed in the United States is consumed in the home.[3] This represents a huge opportunity to reduce our energy consumption and make cleaner choices for the energy we do consume. The U.S. Department of Energy's Building America Program is

working to increase the energy efficiency of new and existing homes while increasing comfort, durability, and resource efficiency. As part of this program, we pursue opportunities to research highly efficient homes with the goal of understanding what works, what doesn't work, and what are the most economic ways to reach very high efficiency targets.

2.2 The "Solar Patriot" Home

Imagine a home that produces as much energy as it consumes each year. That was the design goal of the "Solar Patriot" home constructed on the National Mall in Washington, D.C., as part of the American Solar Energy Society (ASES) annual conference in the spring of 2001 (Figure 1).[4,5,6,7] The home was designed by owner Alden Hathaway of the Environmental Resources Trust and builder Don Bradley of Solar Strategies Development Corporation. Construction of the home on the National Mall was accomplished in part with support from the Department of Energy (DOE)[8] through the National Renewable Energy Laboratory's (NREL)[9] Zero Energy Homes (ZEH) Program.[10] After exposing more than 30,000 people to the potential of marketable, highly efficient, solar homes while it was on display on the National Mall, the home was moved to its permanent location outside of Washington, D.C., in Purcellville, Virginia. The Hathaway family moved into the home in August 2001. The following month staff from NREL visited the home and, with support from the DOE's Building America Program,[11] installed a data-collection system to measure the performance of the home. In addition to the measured performance, a detailed computer simulation of the house was created using DOE2.1 home energy simulation software. This simulation was also used in conjunction with a newly developed NREL research tool called Building Energy Optimization (BEopt) that uses DOE2.1 and the TRaNsient SYstem Simulation (TRNSYS)[12] Program to explore optimum combinations of energy efficiency measures to reach energy savings goals. This report combines the information from all of these efforts to investigate the performance of the Hathaway house and use it as a case study for exploring highly efficient and zero energy homes.

Figure 1. The "Solar Patriot" home on the National Mall in Washington, D.C.

2.3 The Hathaway House Specifications

The home is modular construction consisting of four modules. After its debut on the National Mall, it was moved to its permanent location in a rural area of Purcellville, Virginia (Figure 2.) The home was placed on an insulated full basement constructed from Superior Wall™ precast concrete panels.

A building-integrated PV system was added to a standing-seam metal roof on the home and a detached garage was built to the east of the home. Collectors for an active solar water-heating system were placed on the roof of the garage along with a second PV array. The house was equipped with a ground-coupled heat pump system that supplies heating and cooling as well as backup water heating. A summary of the home specifications is given in Table 1. Floorplans are given in Figure 3.

Figure 2. The Solar Patriot house at its permanent location in Purcellville, Virginia (Photo by Ed Hancock)

Table 1. Summary of Specifications for the Hathaway House.

Location	Purcellville, Virginia 22132
Builder	Don Bradley, Solar Strategies Development Corporation
Conditioned floor area	2880 ft^2 on two floors. Note that the basement and the third floor are both insulated and equipped with supply registers, but they were not being used as conditioned space during the time of this study.
Orientation	Front of home faces 10 degrees west of magnetic south (approximately true south)
Wall construction	2x6 framing, 24-in., on center (OC), R-19 fiberglass batt insulation with R-5 insulating sheathing
Basement wall construction	Superior Wall™ precast concrete panels, 8-ft ceiling 1-1/2-in. of concrete, 1 in. of rigid polystyrene foam (R- 5), R-19 fiberglass batts between 2.25-in. x 7-in. concrete ribs
Window type	Seven-D Industries, Inc., Series 9000, double-glazed, U = 0.35, SHGC = 0.37 (south-facing windows have approximately 24-in. overhangs)
Space-conditioning system	Direct Axxess® ground-coupled heat pump with horizontal ground heat-transfer piping buried 10 ft under the front (south) yard of the home. Home is also equipped with a wood-burning fireplace.
Water-heating system	Two Duke Solar CPC-2000 compound parabolic concentrator collectors (4.5-m^2 total collector area) connected to a single 80-gallon storage tank. Backup water heating is accomplished with the ground-coupled heat pump.
Appliances	Refrigerator, clothes washer, and dishwasher are ENERGY STAR®-rated. Clothes dryer and oven are electric. Stove is propane.
Lighting	Compact florescent lighting is used throughout the home
PV Systems	Grid connected with battery back-up (no maximum power point tracker) Home array: Nominal 4 kW Unisolar amorphous Garage array: Nominal 2 kW BP Solar monocrystalline Inverters: Two Xantrex Model SW Series II inverters

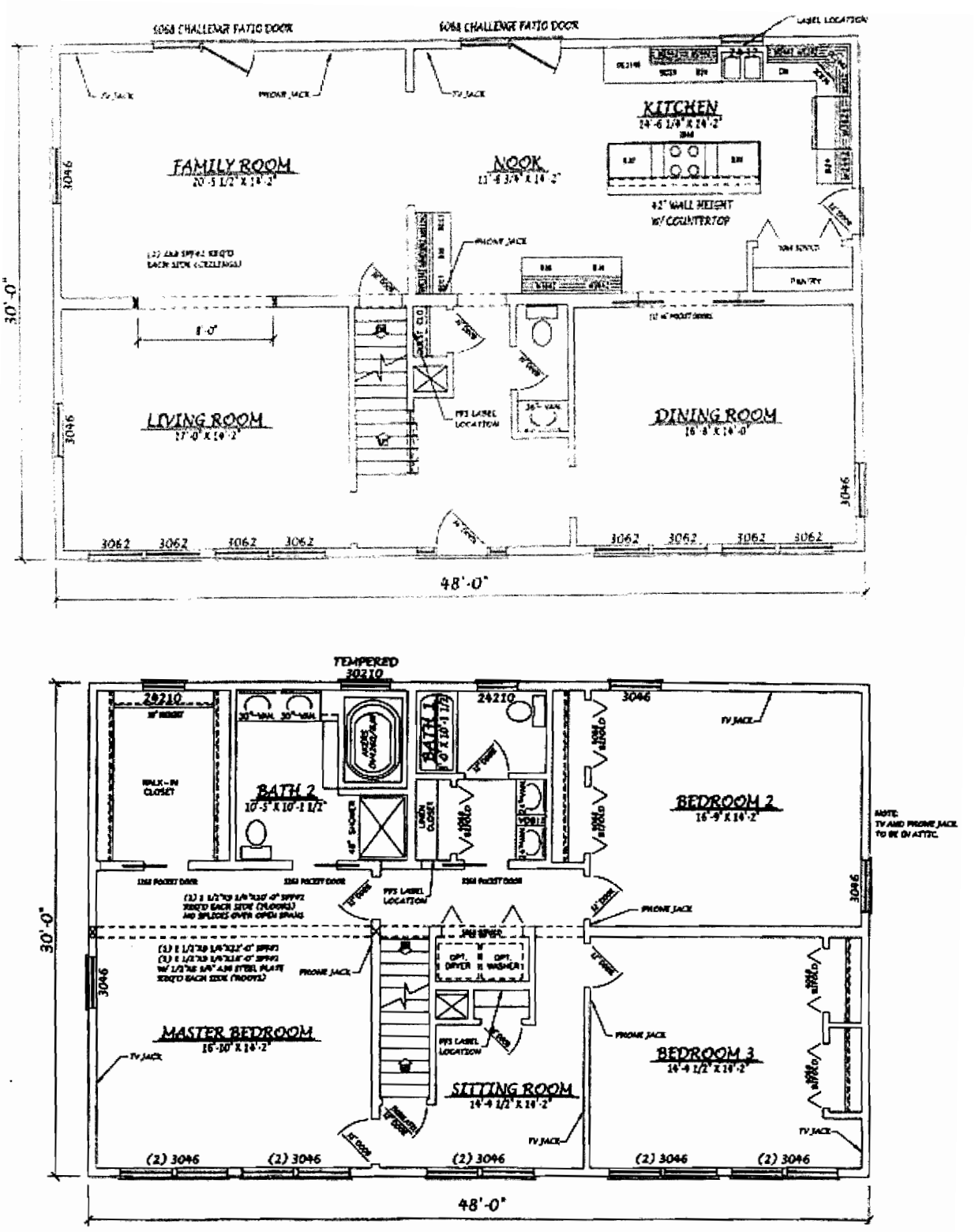


Figure 3. Floor plans for the first and second floors of the Hathaway House

A utility room in the basement of the home contains the air handler, the heat pump, the water tank, breaker boxes, and PV inverters, charge controllers, and batteries. The ducts for the basement and first floor run in the floor between the basement and the first floor. A central supply trunk runs vertically through the home in the chase beside the stairs (see Figure 3 for the location of the chase). This supply trunk runs all the way to above the space in the attic that will eventually be finished and then runs the length of the house in this space (Figures 4 and 5) to the peak where supply ducts descend back along the roof sheathing to supply air to the second floor and attic. As shown in Figures 4 and 5, the floor of the attic is insulated with fiberglass batts. In the winter of 2003 the walls and ceiling of the framed-in attic space that will eventually be finished were insulated with sprayed-in cellulose (Figure 6). As of publication, the attic space was completed and was not being heated. Likewise the basement is insulated, but is not being actively conditioned.

Figure 4. Duck supply trunk entering attic and continuing to trunk above the framing for the finished space

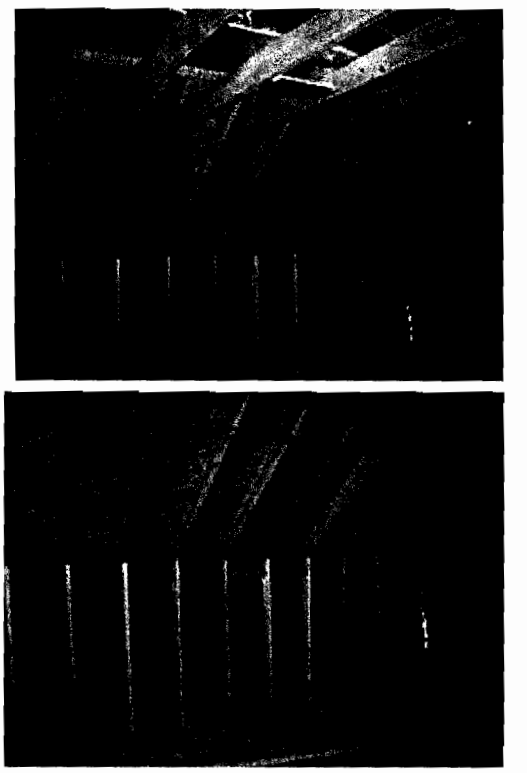


Figure 5. Supply register for attic space (top photo) and supply duct descending to ceiling register for second floor (bottom photo)

Figure 6. Alden Hathaway and blown-in cellulose insulation in attic

The 6-kW PV system is grid connected with a battery back-up that supplies power to the house during blackouts The controller does not include a maximum power-point tracker.

The house has a unique single-tank water-heating system using the ground-coupled heat pump to back-up the solar water heater. During the day, the solar system exclusively warms the water in the 80-gallon storage tank. A timer controls the back-up heating from the heat pump. In the early morning hours, just before the Hathaways awake, the heat pump is used to raise the temperature of the water, preheated by the previous day's solar gain, to the setpoint temperature. The heat-pump water heating is then shut off. The Hathaway's morning water use leaves the water in the tank at a temperature cool enough to take advantage of the solar heat gain for the remainder of the day.

2.4 Study Objectives and Overview

This study was funded by the Department of Energy's Building America program (www.BuildingAmerica.gov). The Building America program is engaged in research with builders throughout the country to reduce energy consumption in new homes by an average of 30% to 90% while increasing comfort and durability and decreasing material waste. In the past 8 years, 26,000 energy-savings homes have been built as part of the program. The program is now focusing its substantial technical expertise and experience on cost effectively achieving higher energy-savings ratios. The Hathaway Solar Patriot house is an example of a home that was designed to achieve a high level of energy savings through energy-efficient features and to meet the remaining electrical energy needs through the use of solar energy (PV). The home provides an excellent case study for the Building America program. Building America's long-term

research goal is to develop cost-effective, production-ready homes that achieve zero net energy by the year 2020. A net zero energy home produces as much energy as it consumes on an annual basis.

The objective of the research outlined in this report is to answer the following questions:

1. Does the home meet its design objective of reaching zero energy? Is so, how? If not, why not?
2. How do the features of the home contribute to its overall energy efficiency?
3. How much energy does the home consume compared to the Building America benchmark?
4. What would be the most cost effective ways to improve the energy efficiency of the design?

We used a combination of short-term tests, long-term monitoring, and computer simulation to answer these questions.

3. Short-Term Testing

Throughout the study, short-term tests were used to measure characteristics of the home that are not easy to determine from plans or specifications. Some of the results of these tests were later used to improve the accuracy of the computer simulations of the home and the confidence in the results from those simulations. Short-term tests also provide a quality check on some aspects of the home (such as air tightness and duct leakage) and assure that energy features (the PV system for example) are operating properly. The short-term tests performed on the Hathaway house are listed below then discussed in detail.

Air-exchange Characteristics

- Shell leakage measurement (blower door and tracer gas)
- Duct leakage measurement (duct blaster and tracer gas)
- Register flow measurement (flow hood)
- Air handler flow measurement (flow plate)

Heat-Pump Coefficient of Performance (COP)

Other Short-term Measurements and Observations

- IR photography
- Fireplace operation

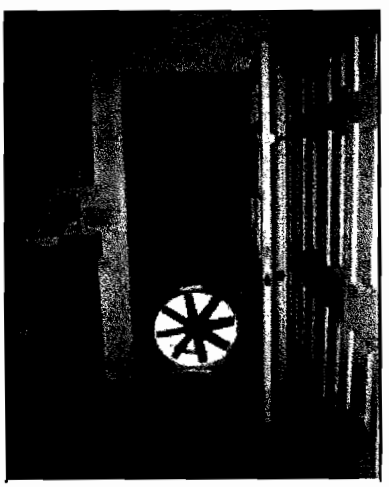


Figure 7. Blower door installed in the Hathaway House

3.1 Air Exchange Characteristics

On September 18, 2001, Glenn Chinery of the EPA's ENERGY STAR® Homes Program and Don Mauritz of Lawrence Berkeley National Laboratory (LBNL) joined NREL staff at the Hathaway house. Glenn and Don brought a blower door to test the air tightness of the home and ducts. While they were there, we also used the blower door in conjunction with a duct blaster to measure the duct leakage. The blower door was placed in the kitchen door as shown in Figure 7.

The conditions for the tests were as follows:

- Attic door was closed and sealed (because the attic was unfinished at that time)
- Attic registers were taped closed
- Basement door was open and included in the measurement
- Fireplace flue was closed
- Unused PVC conduits in the basement were taped closed
- Outside air was relatively still with occasional mild breezes.

TECTITE blower-door software from The Energy Conservatory was used to determine the equivalent leakage area (ELA) of the home. The results of the blower door and duct blaster tests are given in the Table 2.

Table 2. Results of Blower Door and Duct Testing

	With duct registers taped CLOSED	With duct registers OPEN	Difference
Blower Door Results			
CFM at 50 Pa	2241	2326	85
ACH* at 50 Pa	3.73	3.88	0.15
ELA ($in.^2$ at 4 Pa)	132.5	146.8	14.3
Correlation Coefficient (r^2)	0.99935	0.99639	
Flow Coefficient (C)	197.7	227.0	
Exponent (n)	0.621	0.595	
Average Annual Infiltration**			
Average annual ACH	0.17 to 0.19	0.18 to 0.20	
Climate Factor (C)	20 to 23	20 to 23	
Height Factor (H)	0.8	0.8	
Wind Shielding Correction Factor (S)	1.2	1.2	
Leakiness Correction Factor (L)	1.0	1.0	
Duct Blaster Results @ 25 Pa			
Total (cfm)	555		
Total to outside*** (cfm)	219		

* air changes per hour

** Estimated using the LBNL infiltration model and the assumed factors shown

*** Measured with house pressurized to 25 Pa with the blower door

In the past, some modular homes have not achieved good air tightness because of leakage where the modules came together (the "marriage walls"). With less than four air exchanges per hour (ACH) at 50 Pascal depressurization, the Hathaway house had good air tightness. The projected average annual ACH is about 0.2. The addition of mechanical ventilation to the home should be considered. The ASHRAE standard 62.2, *Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings*,[13] would recommend mechanical ventilation for this home.

We measured the air flow rates at the registers throughout the house using an Alnor Low-Flow Balometer with a range of 10 to 500 cfm and a rated accuracy of $\pm$ 3% of reading + 2 cfm. The flow rate of the supply registers on the first floor was measured with no filter, a dirty filter, and a clean filter in the air handler. The results of these measurements are given in Table 3.

Table 3. Register and Exhaust Fan Flow Results

Room (Register)	Measured Air Flow Rates (cfm)		
	Without filter	With dirty filter	With clean filter
Supply Registers			
Dining room (1)	94	76	86
Dining room (2)	87	67	88
Entry	46	37	46
Living room (1)	89	66	83
Living room (2)	92	76	90
Family room (1)	*80*	*60*	*70*
Family room (1)	28	21	22
Breakfast room ("Nook")	58	48	54
Kitchen (1)	*30*	*20*	*25*
Kitchen (2)	70	51	63
First floor total	**674**	**522**	**627**
Master Bedroom (1)	71		
Master Bedroom (2)	79		
Master closet	38		
Master bathroom	48		
Hall bathroom	46		
NE bedroom	76		
SE bedroom (1)	73		
SE bedroom (2)	73		
Office ("Sitting room")	71		
Second floor total	**575**		
Basement (1)	80		
Basement (2)	80		
Attic (1) - closed	0		
Attic (2) - closed	0		
Total for all supply registers	**1409**		
Return Registers			
1st floor entry	> 500		
2nd floor entry	> 500		
Office ("Sitting room")	238		
Master Bedroom	65		
Exhaust Fans			
1st floor bathroom	13		
2nd floor hall bathroom	46		
Master bathroom	33		

Table 4. Flow-Plate Measurements of the Total Air Flow Rate at the Air Handler

Filter Condition	Return Reference Pressure (Pa)	Air-flow Rate (cfm)
Dirty filter	34	1434
No filter	53	1795
Best filter	41	1580
New filter	47	1672

We measured the total air-flow rate at the air handler fan using a Energy Conservatory *True Flow* flow plate in the air filter slot. We measured the flow rates for different air filters and with different levels of filter dirt accumulation (Table 4).

The "dirty" filter condition was for the filter condition as found at the start of the testing. It was an inexpensive ($1.50) glass-fiber filter that had not been changed for an extended time. The "best" filter was an expensive ($15) pleated-fabric filter that was intended to have significantly improved filtration, but also had a higher pressure drop. The "new" filter was a direct replacement for the inexpensive original filter. The measurements indicated that the dirty filter reduced the system flow rate by about 240 CFM or about 15% compared to the new filter. We recommended that Mr. Hathaway replace this filter about once every 3 weeks of normal operation.

The Alnor flow-hood measurements indicated a similar reduction in air flow rate as the filters were changed. The total of the supply flows measured at each register with the flow hood was about 20% less the total flow measured with the flow plate.

The total duct leakage for the home was quite high at 555 cubic feet per minute at 25 Pa pressurization. This was approximately 35% of the total air-handler flow. A tight duct system will leak at a rate of less than 10% of the total air-handler flow rate. Separate supply and return leakages were not measured. We measured the duct leakage to the outside by pressurizing the home to the same pressure as the ducts (25 Pa) and measuring the leakage from the ducts. The leakage to the outside was 219 cfm, approximately 14% of the total air-handler flow rate. [redacted]ecause the basement was included as indoor space in the blower door and duct blaster tests, the leakage to the outdoor was likely occurring in the attic. The effect of duct leakage will be discussed further in the Section 5: Simulated Energy Performance.

A Bruel and Kjaer multi-point tracer gas-monitoring system was installed in the Hathaway home to measure air exchange rates from March 2-4, 2002. Sulfur hexafluoride (SF6) was periodically injected and mixed to a nearly uniform concentration. The decay in concentration of SF6 indicated the rate of air exchange with the outside expressed as ACH. Two sampling points were located on the first floor, two on the second floor, and one in the basement. The average of the

ACH in the four zones from the first and second floor is plotted in the time-series graph in Figure 8. Included in this graph is the calculated ACH using the LBNL model as described in the ASHRAE Handbook of Fundamentals 1997. The inputs to this model include the ELA from the blower door test, measured wind speed, outside temperature, and inside temperature during the tracer gas test. The LBNL model generally predicts the lower range of the measured air exchange rates. The measured higher air exchange rates on Saturday midday, Saturday evening, and Sunday midday were correlated with use of the fireplace and with family activity. This may imply that fireplace use causes increased air infiltration, or that increased infiltration may be caused by doors opened during family activity, or that the LBNL model is not accurate at this level of detail.

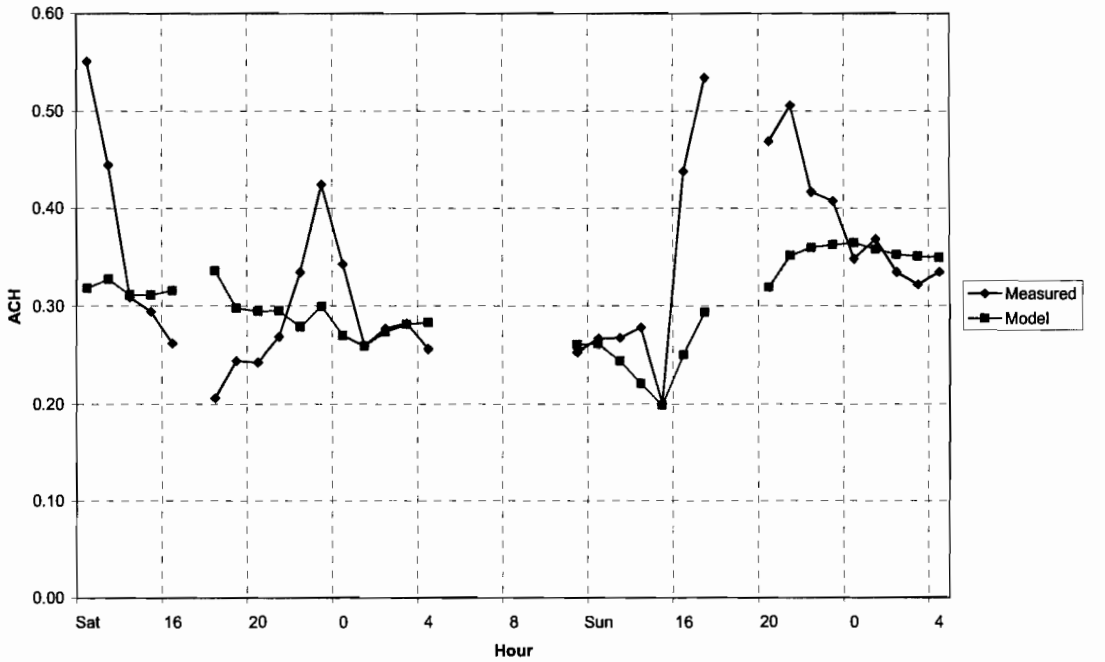


Figure 8. Comparison of tracer gas ACH measurements to ACH modeled using blower door ELA measurement

3.2 Heat-Pump Coefficient of Performance (COP)

A ground-coupled heat pump was chosen to efficiently meet the home's space heating, space cooling, and back-up water-heating needs. We were interested in performing a check of this systems coefficient of performance (COP). To estimate the COP during space-heating operation, we measured air flow and temperatures before and after the coil in the air handler. For selected hours of operation we used the flows and the changes in temperature to estimate delivered energy and compared this to the energy consumption of the heat pump. Because we measured only the sensible load, we estimated the latent load resulting from the moisture removed from the air during cooling to derive the COP in the cooling mode. The COP for water heating was calculated from tank temperature increase, measured tank losses, and heat-pump energy consumption.

3.2.1 Heating Mode COP

To measure the air-supply temperatures, we installed thermocouples in the supply air ducts in the basement mechanical room. The supply ducts branch into three parts immediately downstream from the air handler. The two branches supplying the first floor and basement had a location available to install the thermocouples at least 10 feet downstream from the air handler to allow for adequate mixing of the air. In these two branches, one thermocouple was installed in each branch. We used a hot wire anemometer to check for uniform air-temperature distribution at these locations before installing the thermocouples. In the branch that supplies the second floor and attic, the only easily accessible location for thermocouple installation was about 1.5 feet downstream from the air handler. Three thermocouples were installed across the section of the duct to account for any non-uniformity of air temperature. These three thermocouples were measured in parallel at the data logger to indicate an average temperature. Readings from these thermocouples while the heat pump was in heating mode indicated that all of the supply temperatures were within about 1°F of each other, implying a relatively uniform temperature leaving the heating coil. The return air temperature was assumed to be equal to the average of the indoor temperatures measured on the first and second floors. We used the results of the air-handler flow rate test described in section above for the airflow in the COP estimates. Mr. Hathaway changed his air filter frequently, so the clean filter airflow rate was used for the COP estimates. Monitored data for hours when the heating system was on nearly continuously and when the system did not deliver heat to the hot-water system were used to calculate the COP of the heat pump in heating mode. The results for the 65 hours during the monitored period that met the criteria stated above are shown in Figure 9. The average heating COP is 3.6, not including the supply fan power. If the supply fan power is included in the COP definition, the average heating COP is 2.9.

We expected heat pump COP to be a function of ground temperature in the geothermal field and air temperature inside the house. The presence of the heat-extraction tubes may also affect the local ground temperature. As shown in Figure 9, the average calculated heating COP values in November and December were somewhat higher than the values determined for March. Whether this is a seasonal trend or a longer-term trend influenced by the introduction of the ground-source heat pump has not been determined

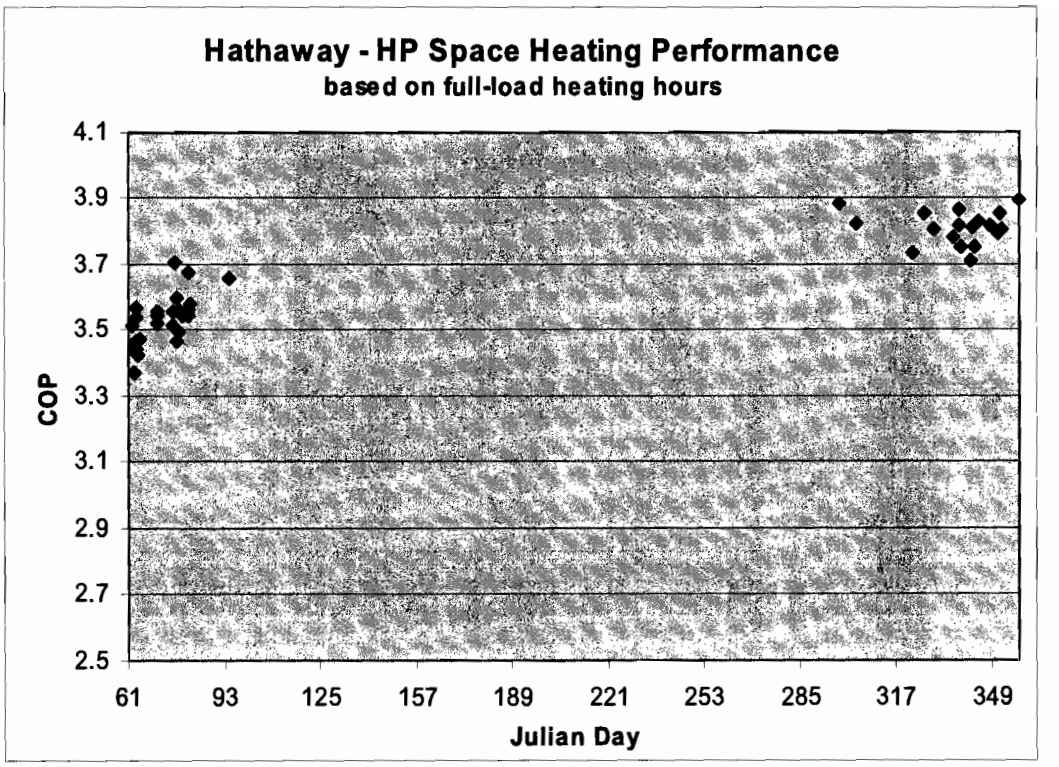


Figure 9. Space-heating COP determined from monitored data (fan power not included)

3.2.2 Cooling Mode COP

A direct calculation of the cooling COP of the heat pump system could not be made because the latent load of the cooling coil was not monitored. The COP of the sensible load only can be determined in a manner similar to the heating performance analysis above. The result of this analysis is shown in Figure 10. In this case, the average sensible cooling COP was 2.6 without and 2.1 with the fan power included. Assuming a sensible heat ratio of 0.8, the total cooling COP without and with fan power included is 3.2 and 2.6, respectively. The average outdoor temperature coincident with the cooling performance calculations was 85°F. To model the system performance in cooling mode, an estimate of the latent load resulting from moisture removal was added to the sensible heat COP calculation.

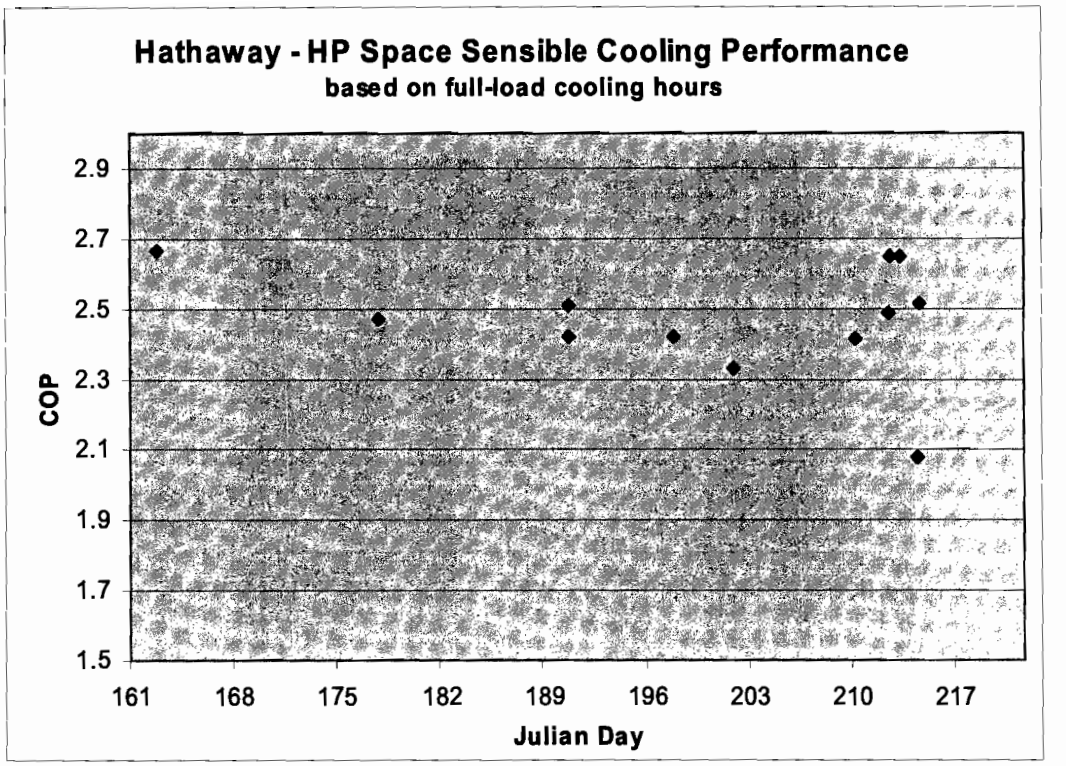


Figure 10. Space-cooling COP determined from monitored data (fan power not included)

3.2.3 Water-Heating COP

The ground-source heat pump, along with an active solar hot-water system, provided heat to a 80-gallon domestic hot-water tank. Extensive monitoring of the system allowed for the determination of the tank loss, hot-water load, the HP performance and, ultimately, the overall HP/Solar system performance.

We measured the water-storage tank temperature using a thermocouple attached to tank inside its insulation. We used the rate of change in hot-water storage tank temperature with respect to time (C/min), the nominal volume of water in the tank (80 gallons [303 kg]), and the heat capacity of water (4.18 kJ/kg) to calculate the heat flow in watts. The COP was the ratio of the thermal output of the heat pump to the electric input. The COP was expected to change as a function of water temperature and ground temperature. The ground temperature changed seasonally and may appear relatively constant over the period of a month, but the water temperature changed (from cold to warm) during every cycle of the heat pump. The COP for water heating was initially calculated from 1-minute data to observe the change in COP as a function of water temperature. Figure 11 shows that the measured COP in water heating mode is about 2.0 at 20°C water and about 1.4 at 45°C water temperature.

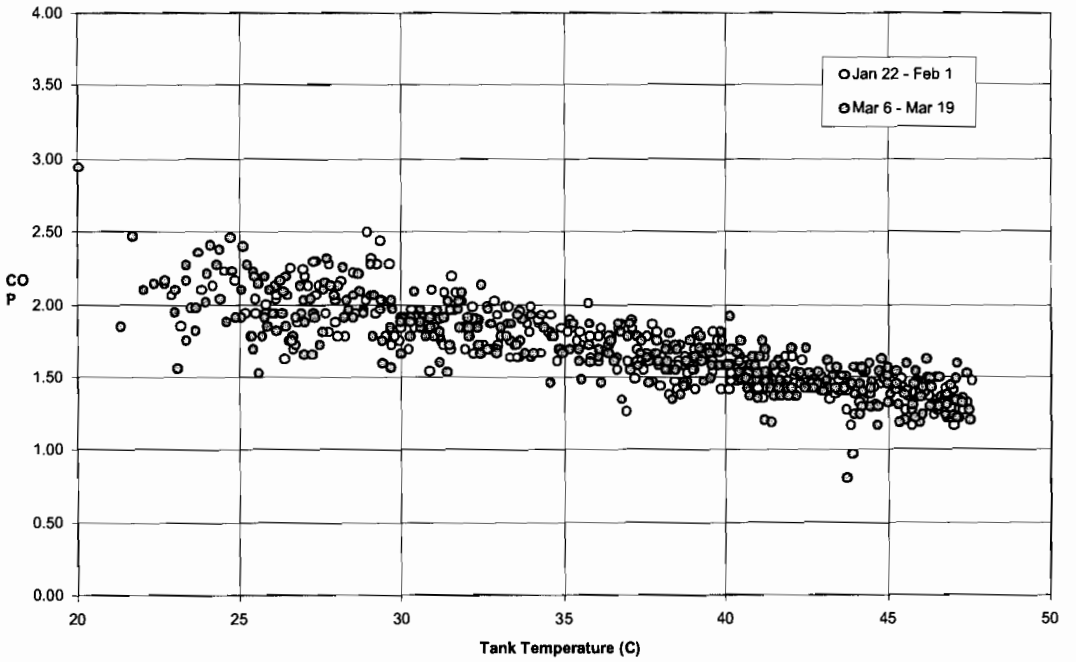


Figure 11. Coefficient of performance (COP) of heat pump for water heating

The tank UA (overall heat transfer coefficient [U] times area [A]) was determined by examining the hourly tank temperature and the basement temperature. During periods with no hot water usage and with no solar energy added to the tank, the tank UA could be estimated as the tank heat loss (as determined by the temperature drop of the tank) divided by the temperature difference between the tank and the basement. A plot of the calculated tank UA for every hour clearly showed a common value of 3.0 BTU/hr-F. This tank UA lead to an average tank loss of 132 BTU/hr during the monitored period.

The monitored data was examined to find periods when the heat pump charged the 80-gallon tank, without any significant hot water draw or solar heating contribution. The load of the hot water tank during these periods was defined only by the temperature rise of the water in the tank and the heat loss from the tank. The power use of the heat pump during these periods was used to determine the HP COP when charging the hot-water tank.

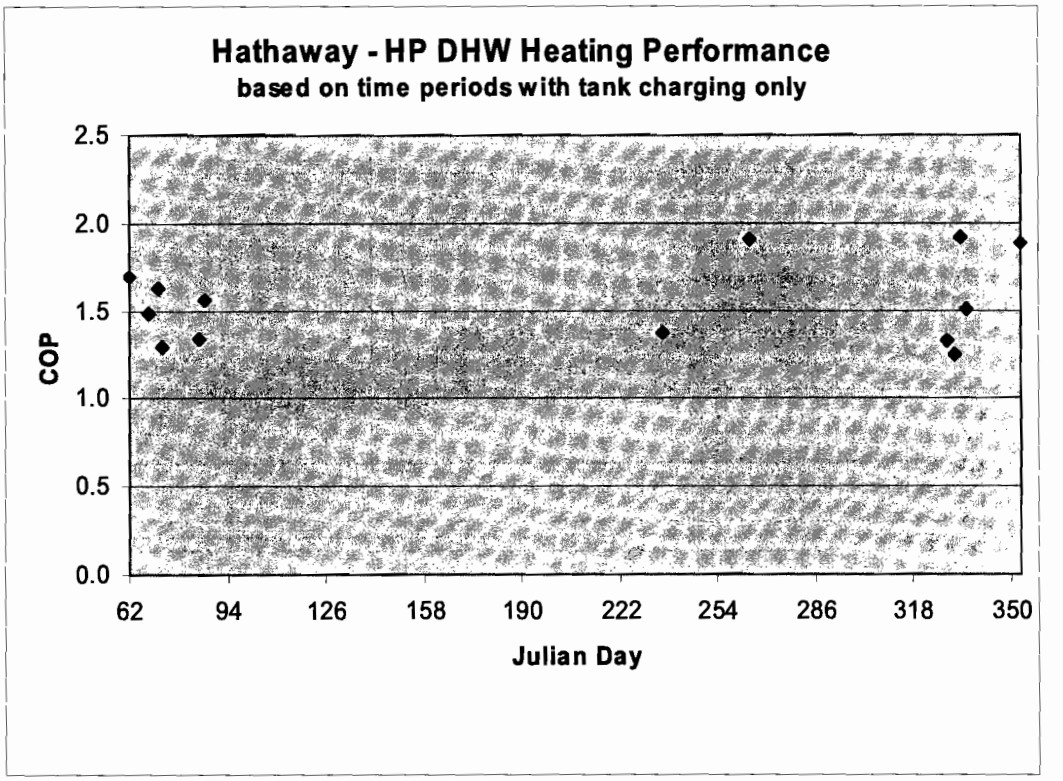


Figure 12. Domestic hot-water COP determined from monitored data

The average COP for the thirteen periods identified in Figure 12 was 1.55. This performance was consistent with the 1-minute measurements discussed above and was comparable to dedicated air-to-water heat-pump water heaters.

The actual hot-water energy demand was met by a combination of the solar collectors and the heat pump. As shown in Table 5, the total system COP of 3.5 included the heat-pump energy and solar-pumping energy used to deliver heat to the storage tank. This overall COP clearly varied as a function of weather conditions and use patterns.

Table 5. Energy Balance for Domestic Hot Water system

Component	Value		Source/Description
Hot Water Load			
load of hot water used	8797329	BTU	based on monitored flow and deltaT data
load resulting from heat loss from tank	1153305	BTU	based on monitored temperature data
total heating load	9950634	BTU	sum of above components
HP energy used to heat water	576	kWh	based on monitored power data
HP energy delivered to water	3051232	BTU	based on an average HP_{dhw} COP of 1.55
Solar energy delivered to water	6899402	BTU	total load minus HP energy delivered
Solar Energy Fraction	**69%**		fraction of DHW heating load delivered by solar
Solar pump energy used	256	kWh	from monitored data
COP of delivered solar energy	*7.9*		(solar energy delivered)/(pump energy used)
COP of total system	***3.5***		(DHW energy delivered)/(energy used)

The COP of the heat pump and solar water heating systems in each operating mode is shown in Table 6:

Table 6. The COP in Each Mode

Operating Mode	Measured Average COP
Space Heating	3.6
Space Cooling	3.2
Water Heating at 20°C	2.0
Water Heating at 45°C	1.4
Water Heating (average)	1.55
Solar water heating	7.9
Overall water heating	3.5

3.3 Other Short-Term Measurements and Observations

Infrared (IR) Imaging. We used an infrared (IR) camera to examine the insulated surfaces of the house to determine whether any insulation might be missing or impaired. Several small (about 1-2 ft^2) areas in the ceiling were identified as locations where insulation batts in the attic had been moved during construction. Most of these areas were easily found in the attic and were repaired. One larger area (about 20 ft^2) was identified in the ceiling above the southeastern bedroom. It was located below the attic flooring and was not immediately repaired. The total amount of missing insulation was not a large percentage of the total area of the house. Repairing these areas was not expected to have a significant influence on energy use for heating and cooling, but it will be useful to correct these minor problems.

Fireplace Operation. Mr. Hathaway reported that he used his wood-burning fireplace during heating months to reduce electricity used for space heating. The fireplace was probably used nearly every evening during cold weather and more frequently on weekends. The fireplace uses outside air for combustion and has a fan to circulate room air around the firebox.

Propane Stove. The Hathaway's oven is electric and is included in this analysis. However, propane is used for their kitchen stove. We did not collect information on the propane consumption. The kitchen stove energy consumption is not included in this analysis.

4. Long-Term Monitoring

The short-term tests at the Hathaway house revealed much about the shell of the home and the operation of some of its subsystems (which will be discussed in section 6). Measuring the long-term performance of the whole house and its subsystems required the installation of a system that continuously monitors the changing conditions of the home such as energy use, PV energy production, temperatures, hot water use, etc. In September 2001, we installed sensors inside and outside the Hathaway house to monitor its performance. This monitoring continued through February 2004.

The energy consumed in a home is greatly affected by climate, thermostat settings, number of occupants, energy-use pattern of the occupants, the home design, and the equipment and appliance selection. The precise energy use of a home for a specific year and specific occupants cannot be predicted. Instead, predictions are based on typical weather data and typical occupant behavior. Monitored energy-use data reflect the influence of all of the factors listed above. Depending on the level of detail of the monitoring, some of these influences can be disaggregated.

This section of the report summarizes data collected from the home from September 2001 to June 2003.

4.1 Monitoring System and Data Being Collected

Data from the installed sensors are collected using a Campbell Scientific CR10X data logger. The data logger is equipped with a Campbell SDM-SW8A pulse multiplexer and a Campbell ATM25T thermocouple multiplexer. Further information on the hardware used is contained in

Appendix 7.1. The system is connected by modem to a phone line in the home and data is downloaded daily.

In designing the data collection system, we focused on understanding the performance of the PV system, the solar water-heating system, the heat pump, and the main home appliances. The home was equipped with sensors for the 39 measurements listed in Table 7.

We had planned to directly measure the power production from the PV system on the AC side of the inverters. This measurement was not possible because of the wiring set-up. AC power from the PV system was not isolated in any of the wiring. We were measuring DC power from the PV system and applying the efficiency vs. power curve provided by Trace to estimate the AC power supplied by the PV system.

Table 7. Data Monitored at the Hathaway House

- Solar radiation (W/m^2)
  - In the plane of the collectors at the array on the house roof
  - Vertical south-facing
- Energy (kWh)
  - Energy entering the home from the grid
  - Energy exiting the home to the grid
  - Heat-pump energy consumption
  - Clothes-dryer energy consumption
  - Clothes-washer energy consumption
  - Air-handler fan energy consumption
  - Kitchen-oven energy consumption (stove is propane)
- Temperatures (°C)
  - Outside air temperature (from T and RH sensor)
  - Outside air temperature (thermocouple)
  - House PV array temperature
  - Garage PV array temperature
  - Attic air temperature
  - Second-floor air temperature
  - First-floor air temperature
  - Basement air temperature
  - Supply-air temperature
  - Cold-water temperature
  - Hot-water temperature
  - Temperature after the mixing valve
  - Temperature of glycol fluid to the solar water collector
  - Temperature of glycol fluid from the solar water collector
  - Temperature of water from tank to heat pump
  - Temperature of water from heat pump to tank
- DC electrical measurements
  - Voltage of west house PV array (V)
  - DC current from west house PV array (A)
  - DC power from west house PV array (W)
  - DC current from east house PV array (A)
  - DC power from east house PV array (W)
  - DC current from garage PV array (A)
  - DC power from garage PV array (W)
  - Battery voltage (V)
  - Current to or from battery bank (A)
  - Current to well pump (A)
- Other measurements
  - First-floor relative humidity
  - Outside relative humidity
  - Hot-water consumption (liters)
  - Solar water heater pump run time (minutes each hour)

4.2 Results from the Entire Monitoring Period

The energy consumption by end use for the entire 30-month monitoring period is shown in Figure 13. Space conditioning (HP,space; HP,standby; and AHfan) accounted for about half of the total energy consumption. Water heating (HP,DHW and SolPumps) accounted for less than 10% of the total energy consumption. The clothes washer and refrigerator in the home were ENERGY STAR-rated, highly efficient appliances. Even with efficient appliances, the energy consumption from all the major appliances (Fridge, Washer, Dryer, and Oven) accounted for 17% of the total energy consumption. The stove was propane and was not included in this accounting.

Perhaps the most sobering result of this end-use accounting is the size of the "other" category. The energy consumption in the "other" category was calculated by subtracting every submetered category from the total house energy consumption. Despite submetering of the largest energy using appliances in the home, the "other" category was a whopping 23% of total energy consumption. This "other" category contained items such as lighting, computers, televisions and radios, toaster oven, microwave, hair dryers. Lighting was not submetered because it was distributed through many circuits in the home. However, this home already used compact fluorescent lights in every fixture, so the lighting energy should be quite low. The remainder of items in the "other" category was quite difficult for building scientists and researchers to reduce. As we continue to reduce space conditioning, water heating, and major appliance energy consumption, this "other" category will become an increasingly larger portion of the energy consumption pie.

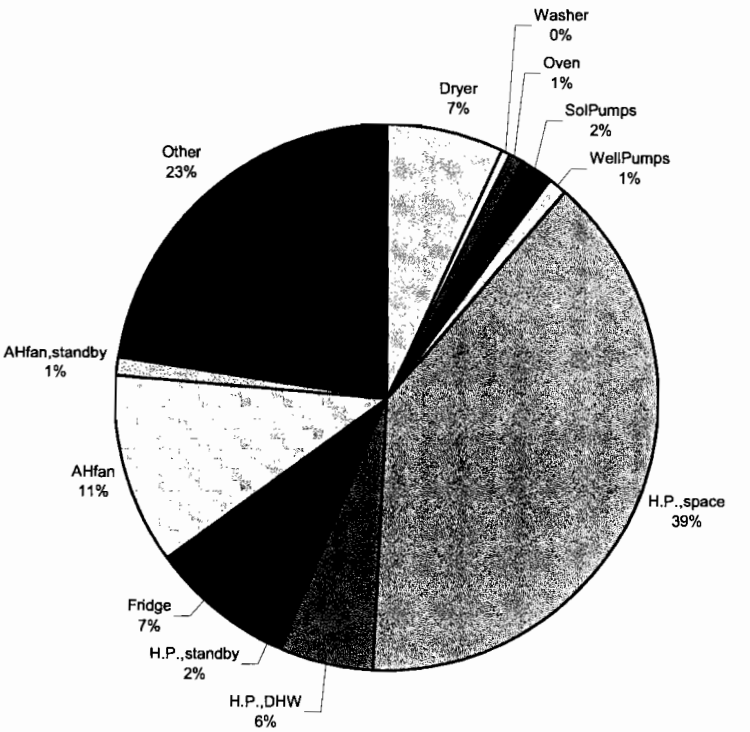


Figure 13. Total energy consumption by end use for the entire monitoring period – September 2001 to February 2004

The monthly energy consumption by end use is shown in Figure 14. The substantial "other" category was relatively constant from month to month. Notice that the water-heating energy (HP, DHW) was several times larger in the first 3 months of data collecting than it was for the rest of the data-collection period. During those first 3 months, the water-heating mode of ground-coupled heat pump was switched on and off manually. It was switched on early in the morning and left on until all morning showering was completed. By the time it was switched back off, it had already heated the water in the single 80-gallon storage tank. Because the storage tank water was warm at the beginning of the day, the solar collectors were effectively defeated. This problem was alleviated by using a timer to control the heat-pump water-heating mode. By adjusting the run time of the heat pump in water-heating mode, the family was able to assure sufficient hot water supply for morning showering without leaving the storage tank full of heated water at the beginning of the day. The change reduced water-heating energy consumption dramatically.

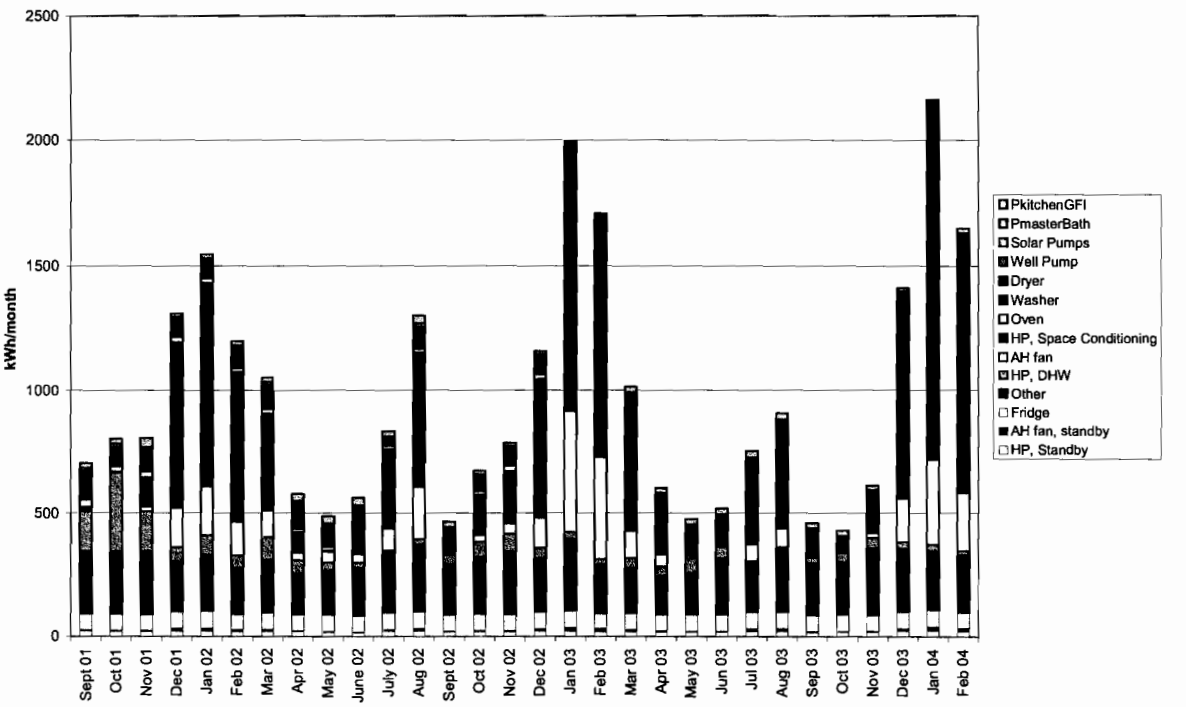


Figure 14. Monthly energy consumption by end use

Figure 15 shows the AC electrical energy produced by the PV system. The PV system was oriented due solar south and tilted at about 49 degrees – near optimum for year-round energy production. The system was equipped with a battery back-up system that was kept charged to supply the home with power for essential needs during blackouts. The system was not equipped with a maximum power point tracker. With the exception of May 2002 (when there was a short interruption in service from one of the inverters) the PV system appeared to be operating as expected. Because there were fewer sunlight hours in the winter than the summer, the PV production was naturally lower in the winter. It is interesting to note how much the monthly PV power varied from year to year as a result of variations in the weather. For example, the PV system output in October 2002 was little more than half of the output in October 2001. In October 2002 much lower solar radiation levels were recorded in the plane of the collectors than in October 2001. (It was a cloudy October.) This should give pause to those who use TMY data to predict PV energy output. Without solar radiation measurements, low PV output like that seen in October 2002 could be misinterpreted as a problem with the system.

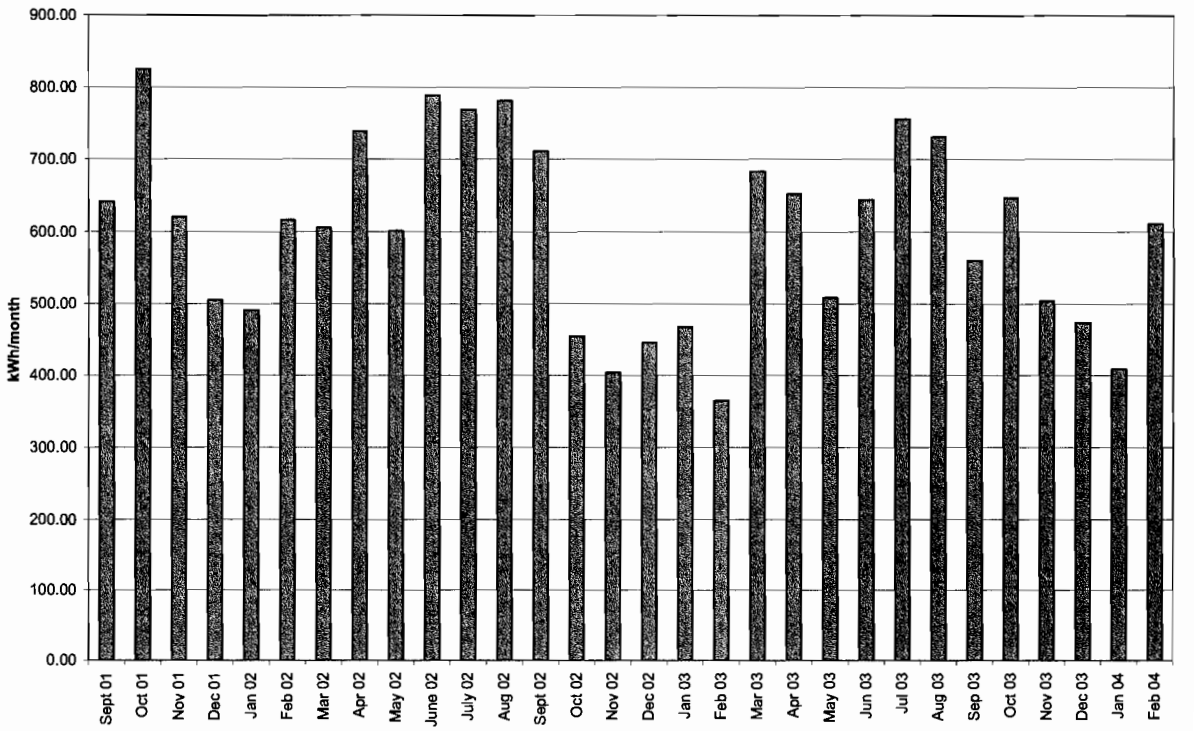


Figure 15. Monthly electrical energy (AC) produced by the PV system

The total monthly energy consumption minus the monthly PV AC energy production yielded the net monthly electrical energy purchased, shown in Figure 16. During 8 months of the data-collection period the home produced more electricity than it consumed. These months occurred in the spring and fall "swing seasons" when the outdoor conditions are near the inside temperature setpoint and little space-conditioning energy was required to maintain comfort. In the summer and winter, the space-conditioning energy needs overwhelmed the PV production, and the home required more energy than it produced. The PV system appeared to be able to meet the needs of the auxiliary water heating, the major appliances, and the "other" category, but not the entire space-conditioning load. Because the space-conditioning equipment was already nearly the most efficient electrical equipment available, this indicated that it may be a good idea to look at more efficient shell designs, a better air-distribution system, or a larger PV array if we wish to reach zero net annual electrical energy consumption. We will revisit this topic in the section on building energy simulation.

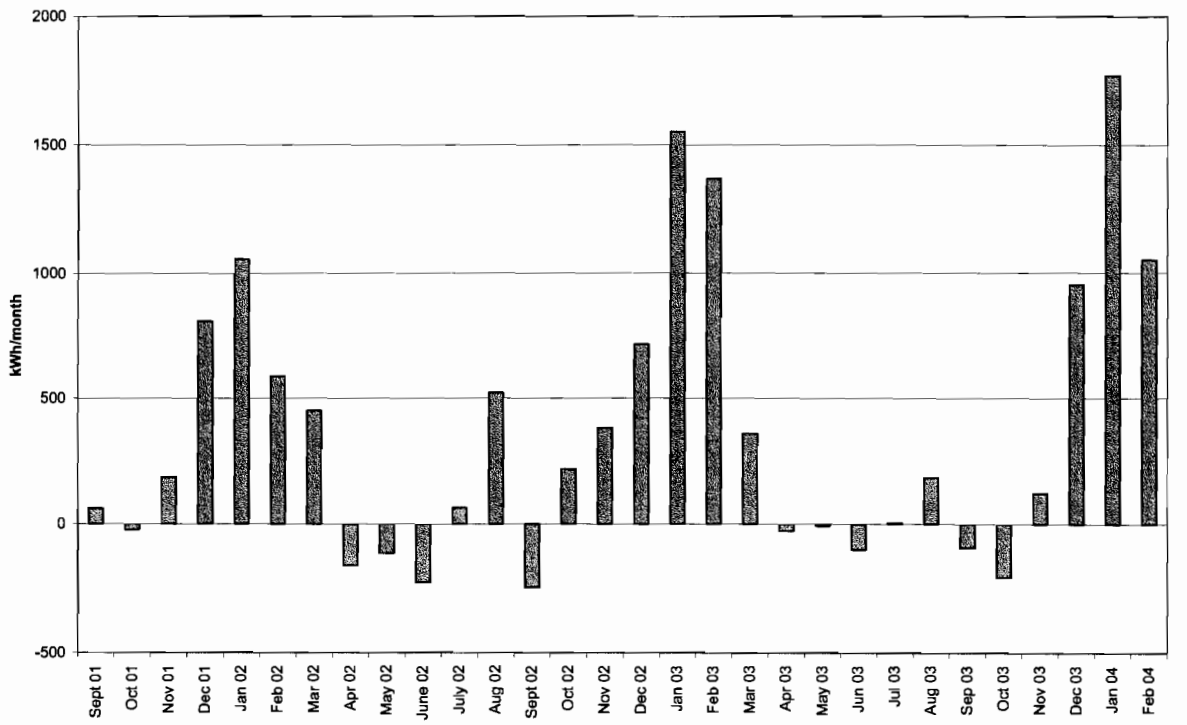


Figure 16. Monthly net electrical energy bought

The Hathaway house had three PV arrays employing two different technologies. The two arrays on the roof of the homes were both composed of building-integrated peel-and-stick amorphous silicon modules from Uni-Solar. The array on the garage roof was composed of rack-mounted monocrystalline panels from BP Solar. The maximum power point voltage behaved differently with temperature for these two different technologies, but the Hathaway array was operated at a constant voltage. In addition, the difference in physical characteristics of the arrays may have shed snow differently. Therefore, we would expect the outputs from the three arrays, each nominally rated at 2 kW, to differ. Figure 17 shows the monthly DC output from each array. Although they were nearly identical, the energy output from the east and west arrays on the home differed by an average of about 10% with the east array consistently outperforming the west array. We have no ready explanation for this difference other than variation in module-to-module output manufacturing variability. The garage-array energy output was usually less, but sometimes more than the output from the home arrays. This variation was likely a result of the variation of maximum power-point voltage with temperature. In general, for the Hathaway house operating voltage of about 53 to 54 volts, the monocrystalline array performed better with respect to the amorphous arrays during months when the average outdoor temperature was low.

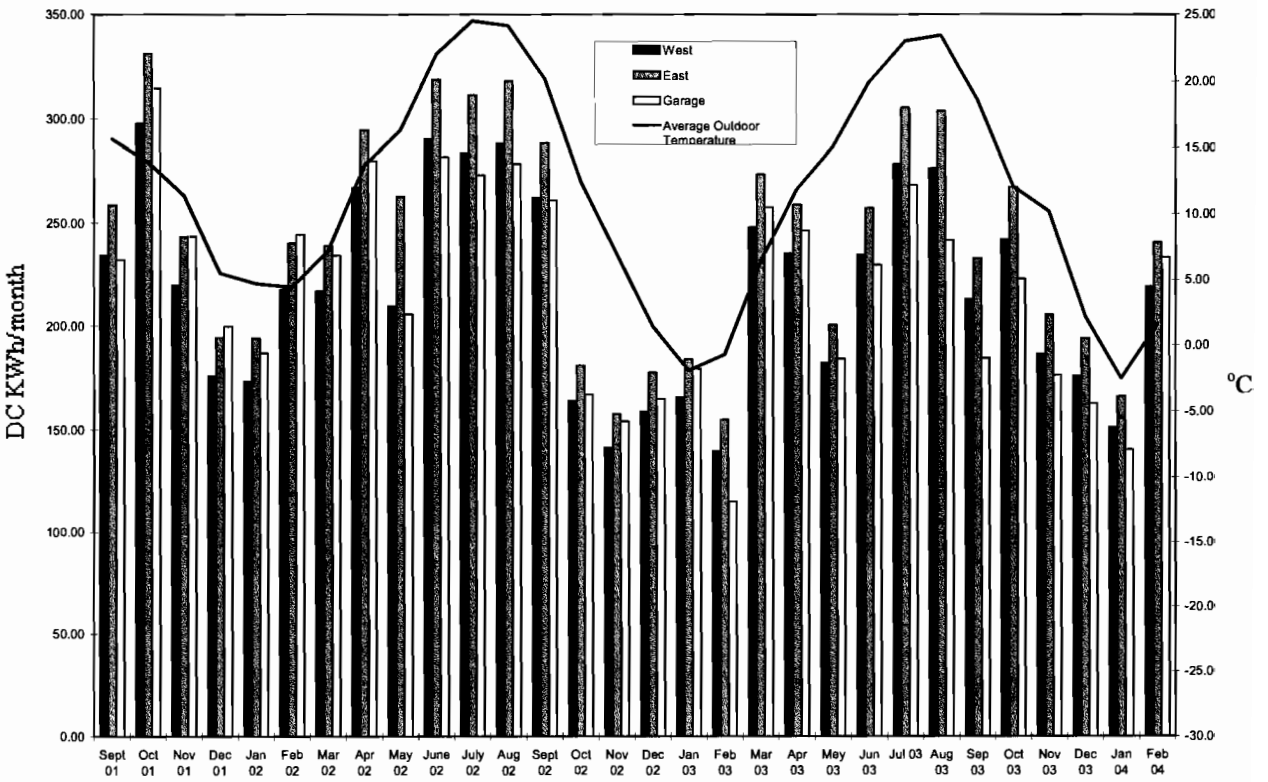


Figure 17. Monthly electrical energy (DC) produced by each of the three PV arrays and average outdoor temperature (west and east are the arrays on the roof of the home)

4.3 Results from the Calendar Year 2002 and 2003

The two arrays summed to a nominal 6 kW of rated capacity. The average daily power production from the array in 2002 was about 20.3 kWh/day. This equates to an equivalent of about 3.4 equivalent full sun hours per day.

The average daily power production from the array in 2003 was about 19.2 kWh/day. This equated to an equivalent of about 3.2 equivalent full sun hours per day.

A home that is designed to have net zero net energy consumption for standard occupants under TMY weather data may not have zero net energy consumption with any specific occupants on any given year. Also, a home that achieves zero net energy consumption in one year, may not achieve it in other years even with the same occupants as a result of to year-to-year variations in available solar radiation. The Hathaway house design did not use rigorous energy simulation and optimization to attempt to achieve zero net energy. The approach employed by the builder and the homeowner was empirically based on past experience. The home did, however, achieve impressive efficiency and a very low net energy consumption. The total PV production and net purchased energy for calendar years 2002 and 2003 are shown in Figure 18. During 2002 the home produced an outstanding 70% of the total electrical energy used in the home.

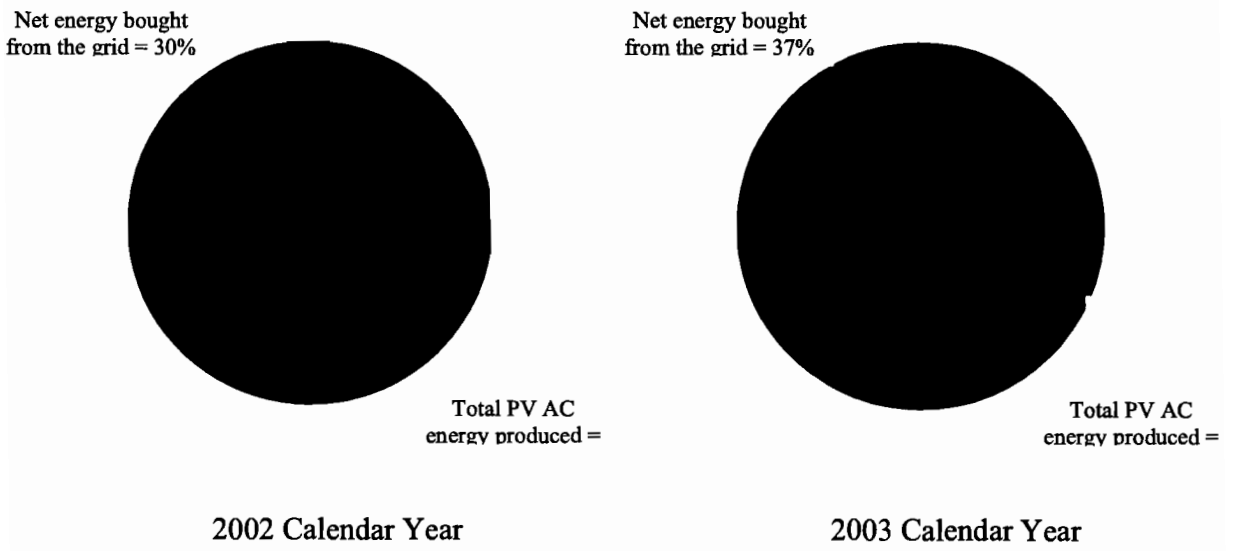
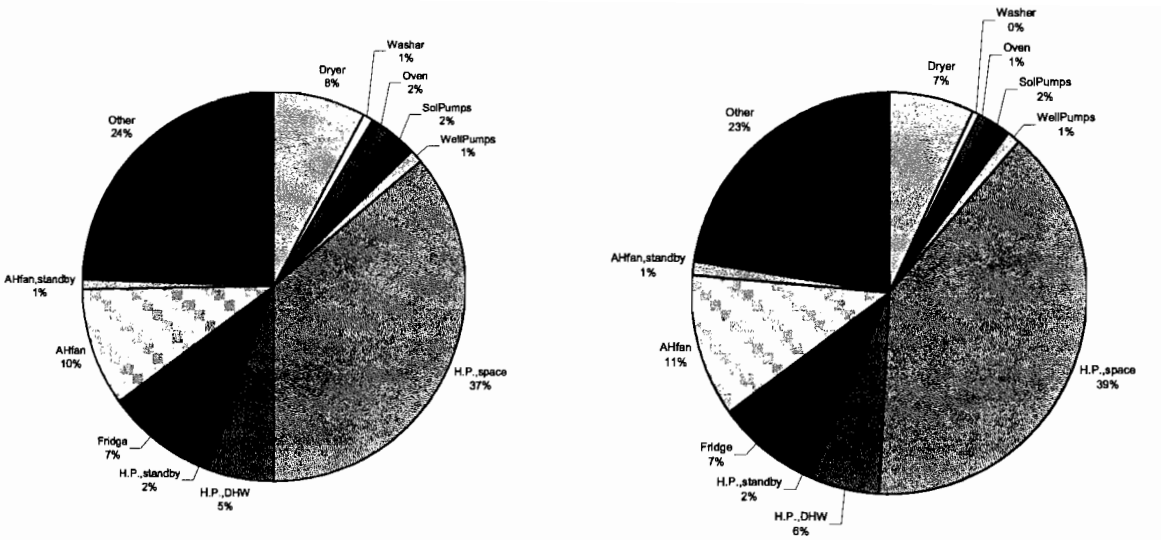


Figure 18. Energy produced by the PV system and net energy bought from the grid for 2002 and 2003



2002 Calendar Year

2003 Calendar Year

Figure 19. End use percentages for 2002 and 2003

Figure 19 shows the percentage of energy used for each monitored end use in the 2002 and 2003 calendar years. Although there are some very minor shifts, the relative end use consumption was nearly identical for the two time periods.

4.4 Average Hourly Profiles

Hourly profiles chart the monthly average of a measurement for each hour of the day. They provide insight into the average variation of a quantity over the course of a day and the shift in daily profile from month to month. The hourly profiles for selected temperatures, energy uses, hot water use, and solar radiation are shown in Figures 20 to 31.

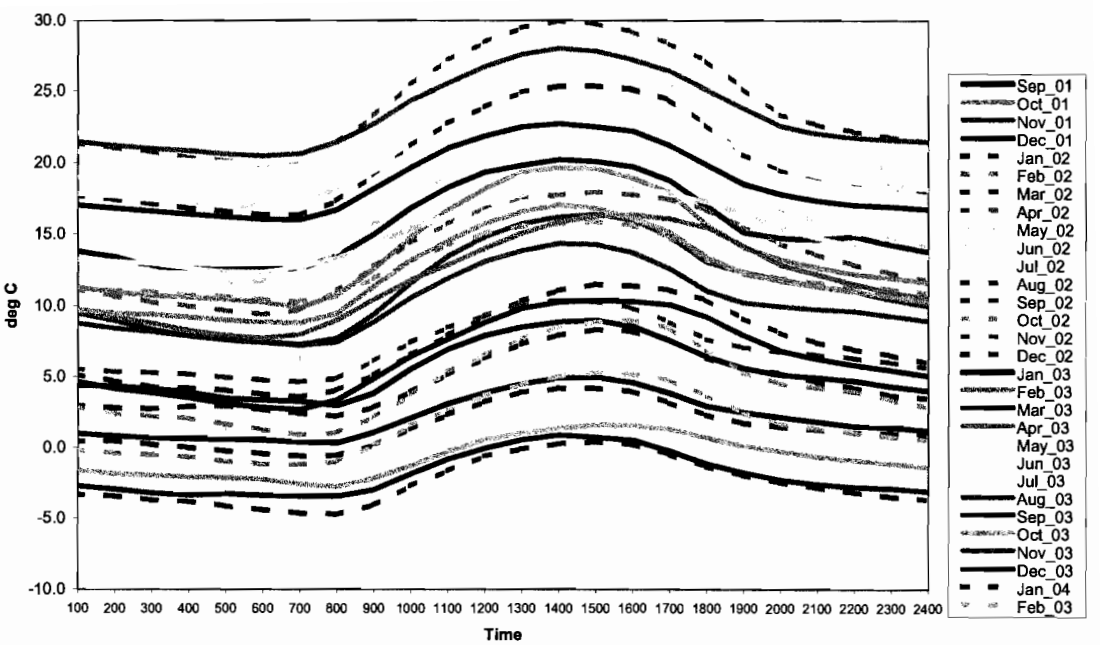


Figure 20. Outdoor temperature average hourly profile

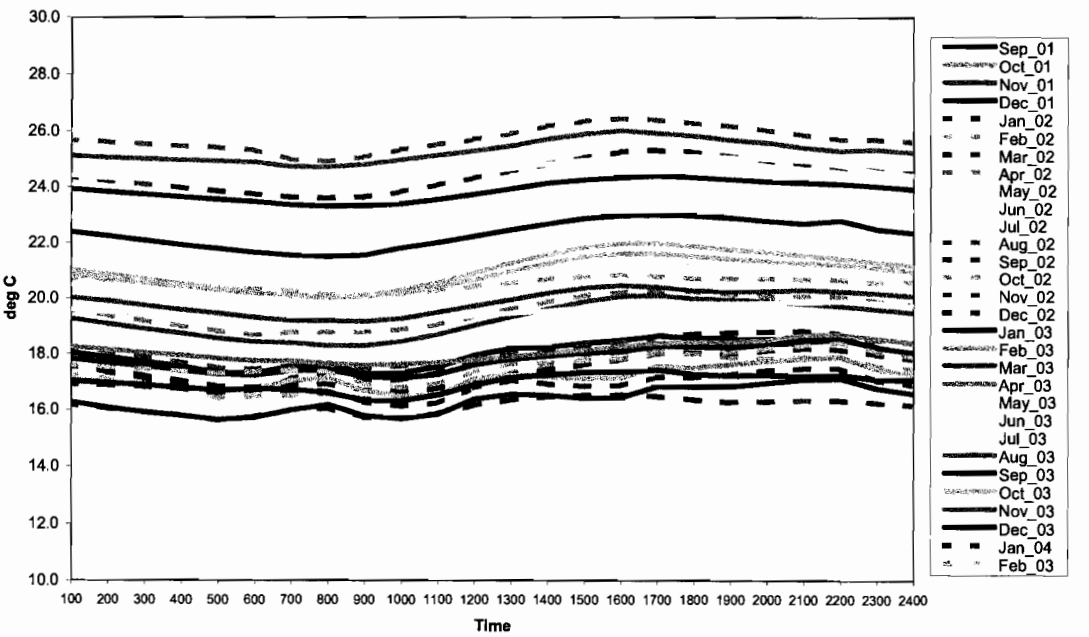


Figure 21. First-floor indoor temperature average hourly profile

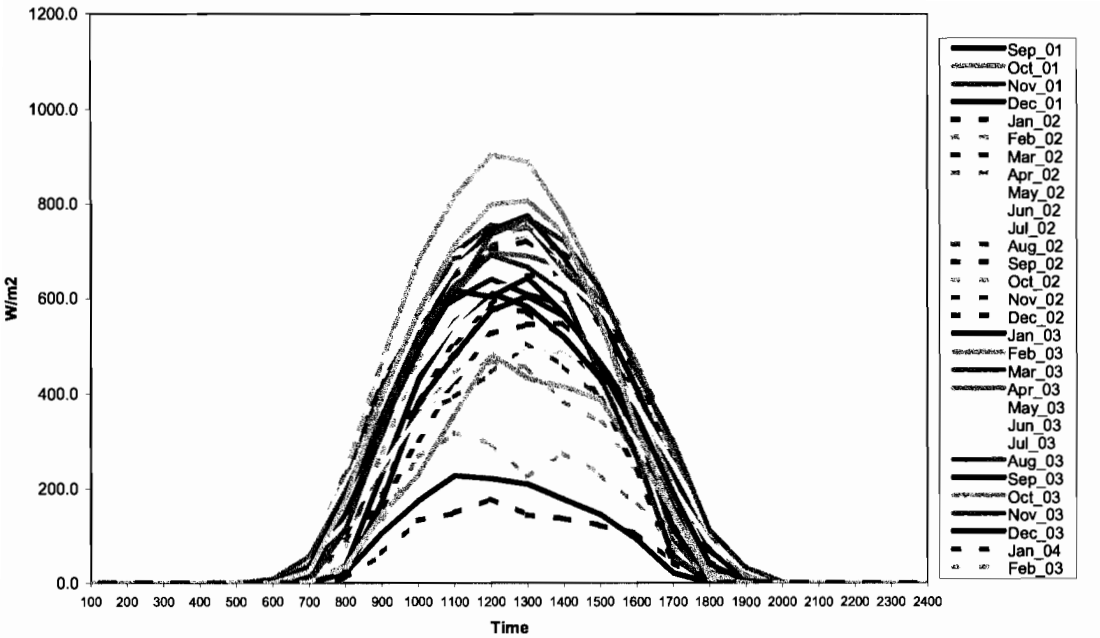


Figure 22. Irradiance in the plane of the collector average hourly profile

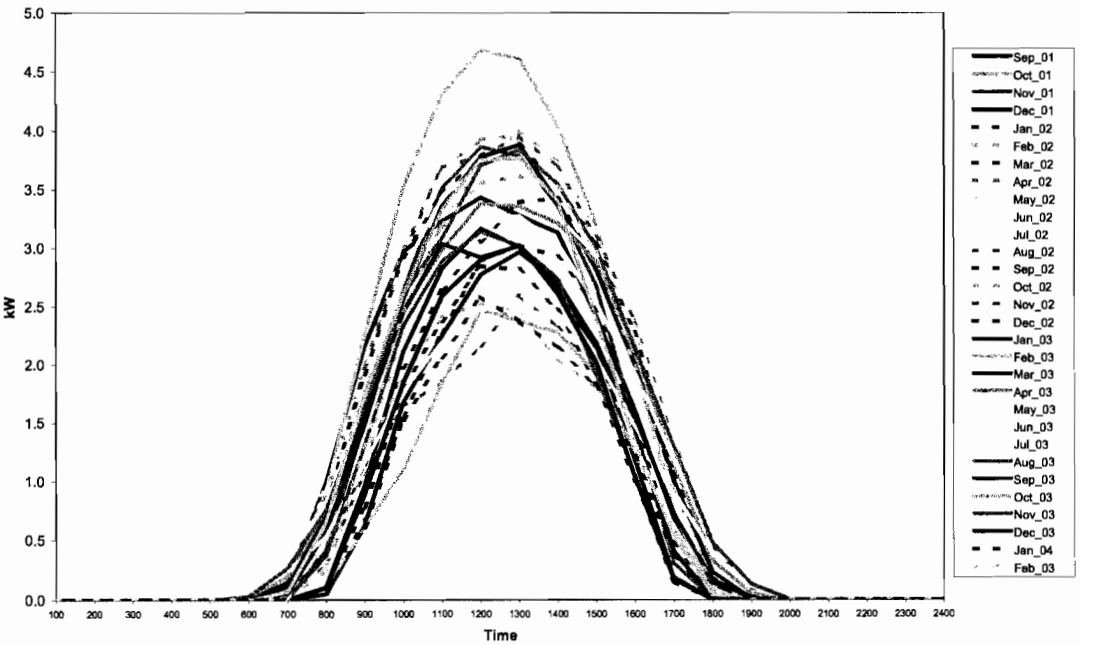


Figure 23. DC power from the PV system average hourly profile

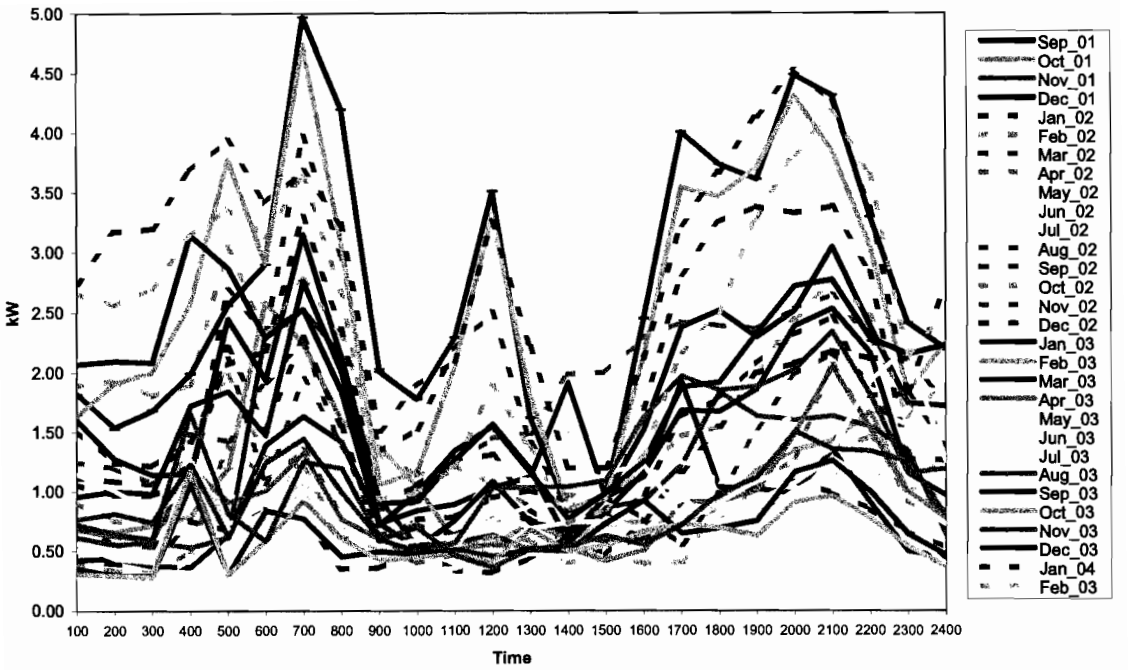


Figure 24. Total power use average hourly profile

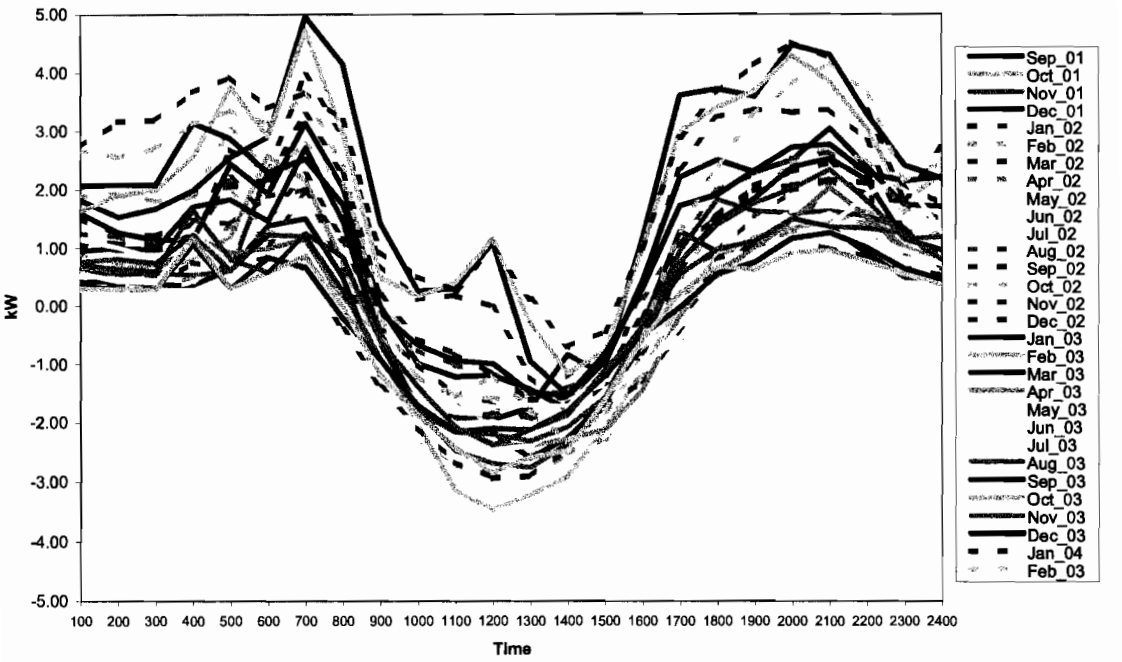


Figure 25. Net power bought from the grid average hourly profile

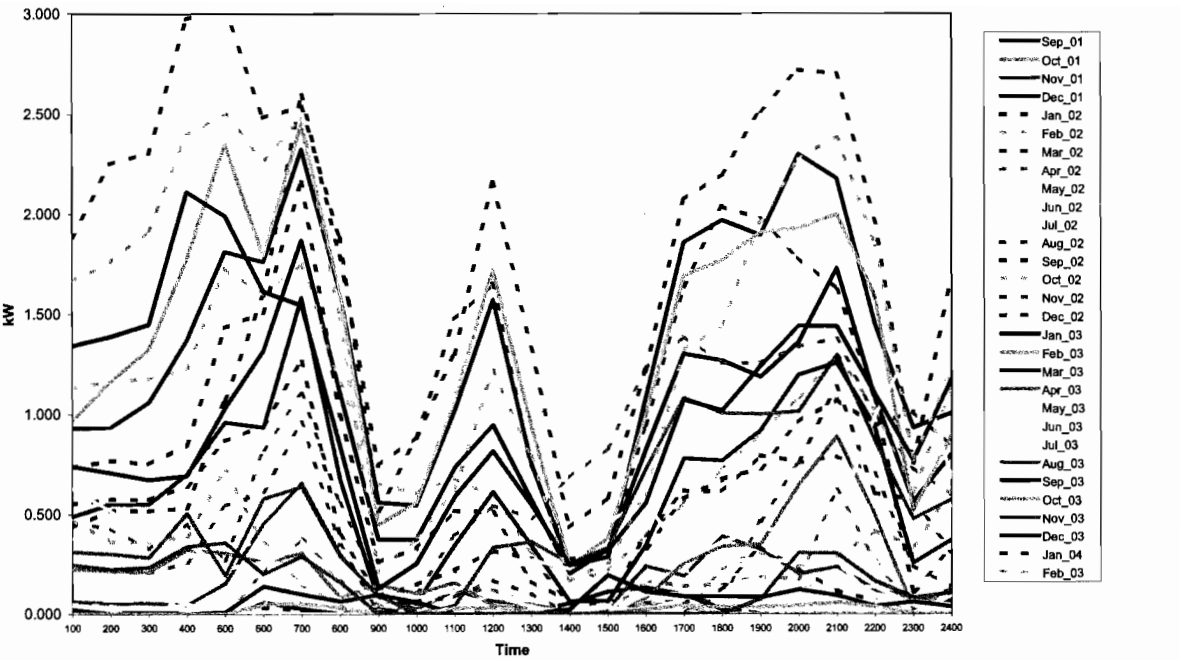


Figure 26. Power used for space conditioning average hourly profile

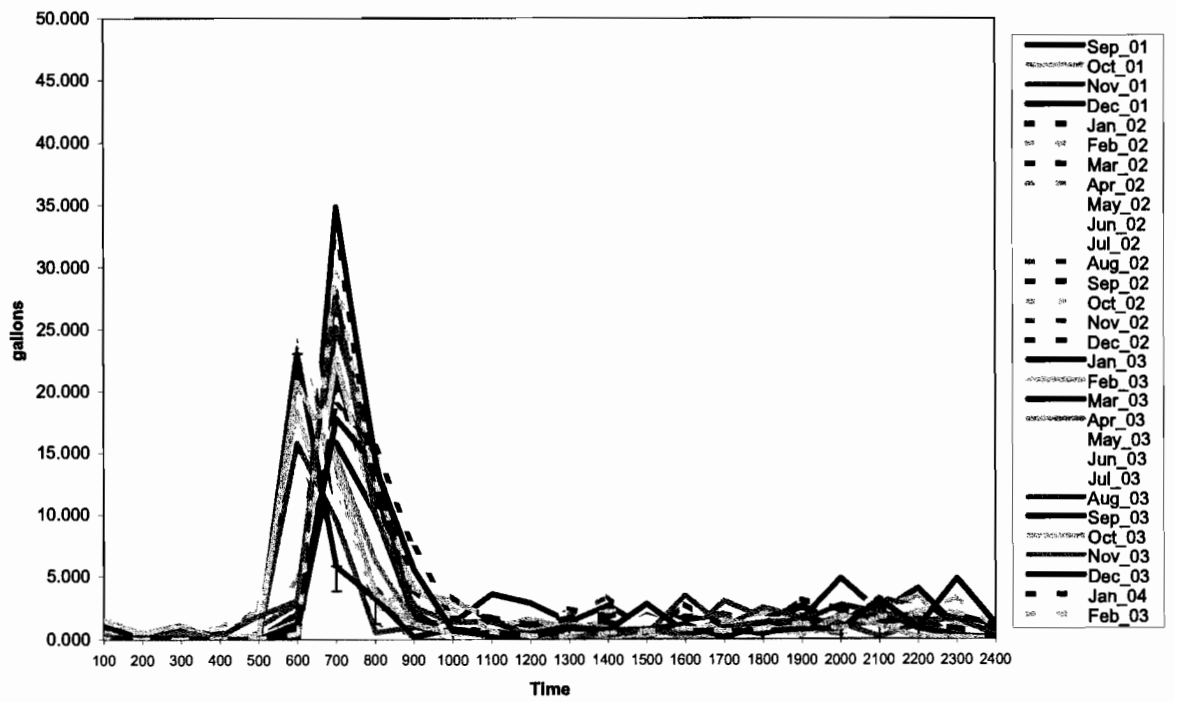


Figure 27. Heat-pump power used for water-heating average hourly profile

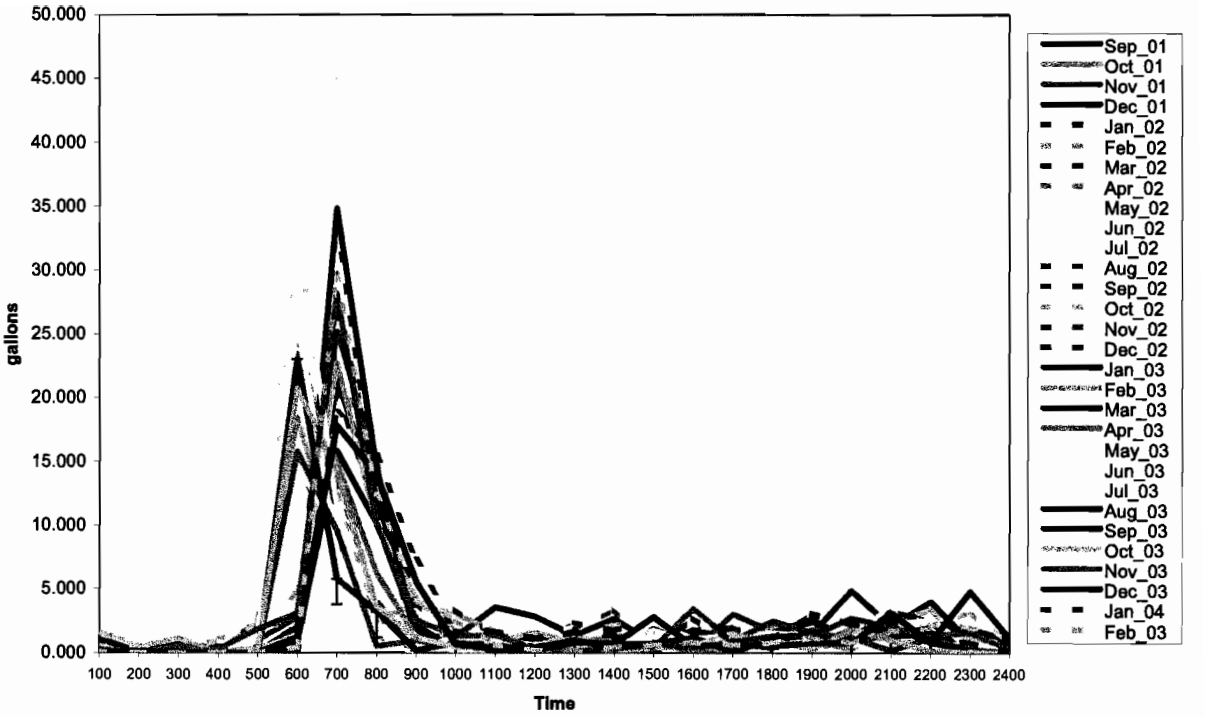


Figure 28. Hot-water draw average hourly profile

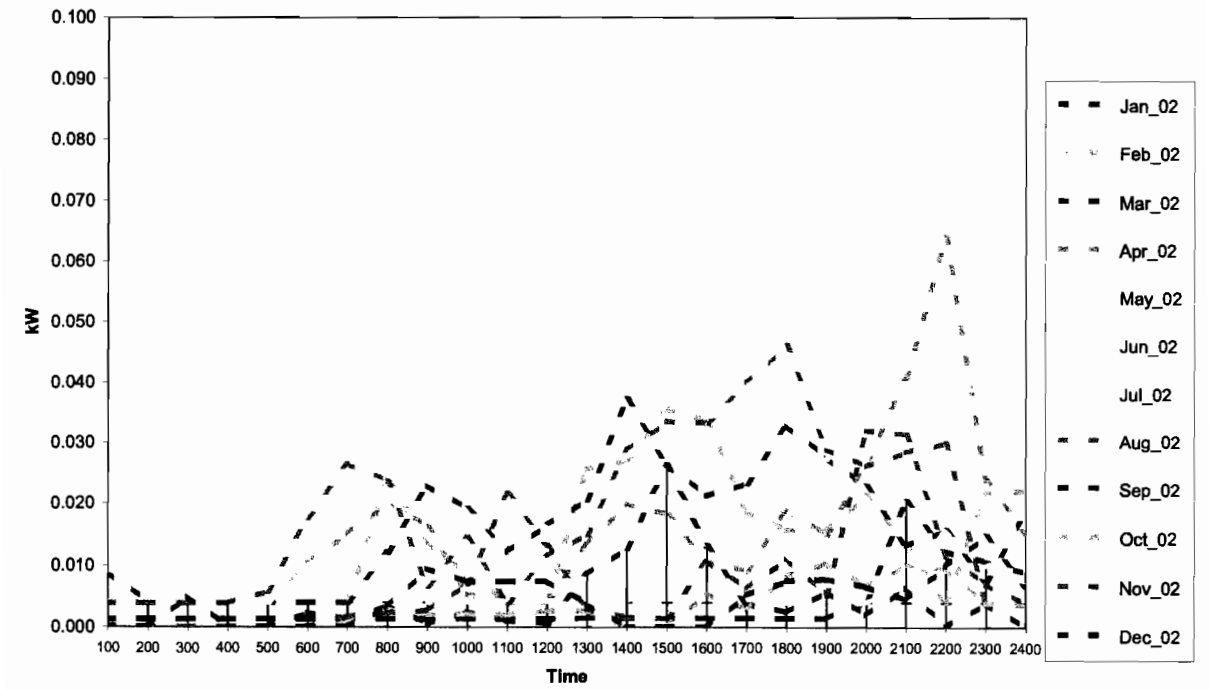


Figure 29. Clothes washer power use average hourly profile

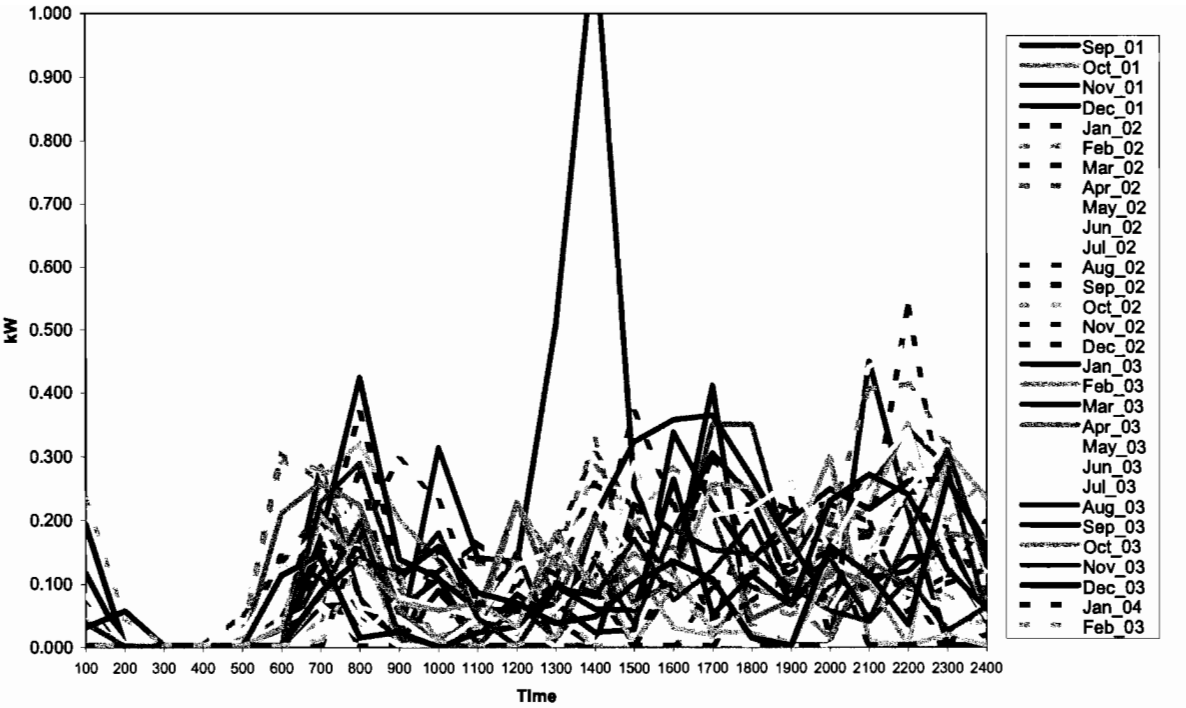


Figure 30. Clothes dryer power use average hourly profile

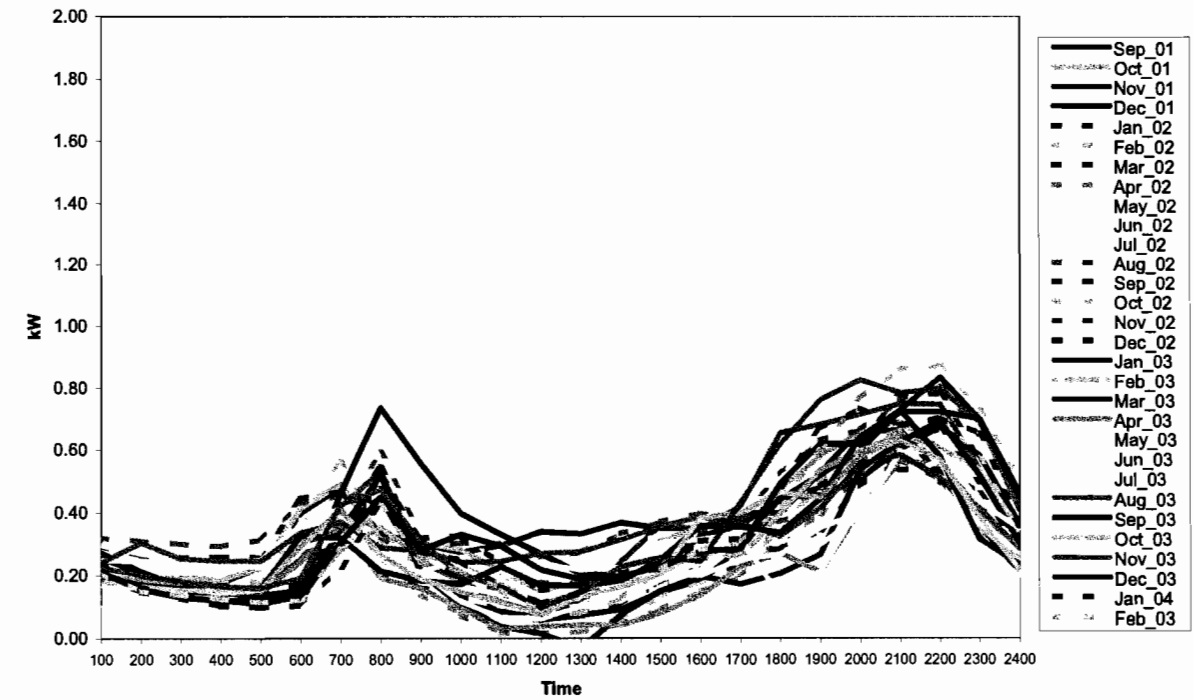


Figure 31. "Other" power use average hourly profile

Some interesting observations from the hourly profile data are listed below:

- The net power bought from the grid (Figure 25) showed a marked dip in the middle of the day. This was a result of the contribution from the PV system, which peaked midday (Figure 23). Many homes of this type could reduce the overall peak requirements on the energy grid, which would be a real benefit for the electrical utility.
- The power use in the "other" category (Figure 31) almost never went to zero. At 4:00 am, the home was still consuming and average of between 100 and 300 watts.
- The average indoor temperature (Figure 21) varied seasonally from a high of nearly 80°F in July and August to a low of around 62°F in January and February. These January and February temperatures were well below those typically found in homes.
- Most hot water (Figure 28) was used in the early morning hours.

5. Simulated Energy Performance

We modeled the Hathaway house energy performance using DOE2 simulation software.[14] DOE2 is a widely used and accepted building energy-analysis program that was developed by the U.S. Department of Energy's Lawrence Berkeley National Laboratory. DOE2 has been subjected to the BESTEST software validation procedure.[15] [16] The program uses a virtual model of the home based on the actual materials, size, shape, orientation, shading, mechanical systems, etc., of the test home. It subjects this virtual model to hourly weather data for the location of the home to calculate the hourly energy consumption of the home. This hourly data is summed to give the annual energy consumption of the home. The energy consumption is then compared to a other virtual models, called the "base cases," that closely resembles the test home, but do not have all the energy-saving features of the test home. The different base cases used for comparison to the Hathaway house are discussed in section 6.3. Details on the modeling approach used by NREL in the Building America program can be found in reference.[1] Images of the DOE2 model are shown in Figure 32.

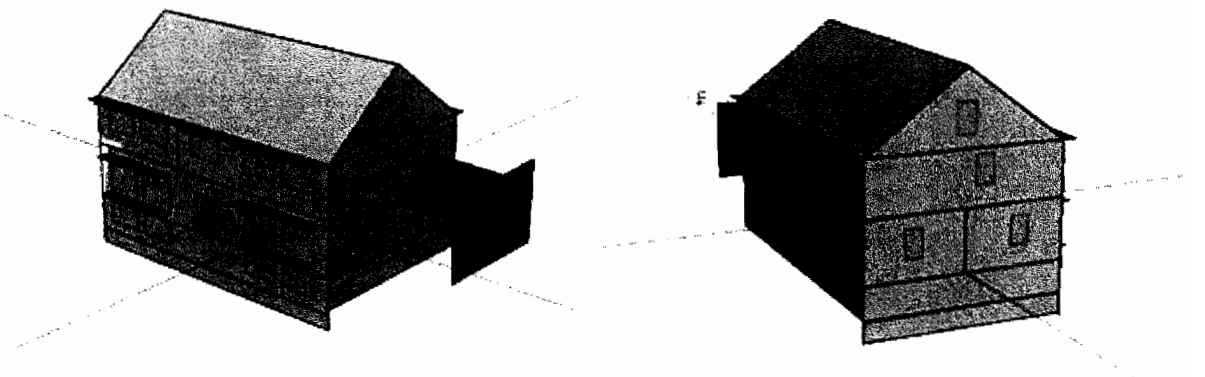


Figure 32. DOE2 model of the Hathaway House, the dark area simulates the shading of the home by the garage and breezeway roof

5.1 Improving Accuracy: Modeling Specific Systems

The residential system models available in DOE2 do not include a direct-expansion, ground-coupled heat pump, solar water heating system, or PV system as is found in the Hathaway house. The long-term monitored data, therefore, was essential in characterizing the performance of these systems.

The measured COPs of the heat pump in heating and cooling modes discussed in section 3.2 were used to characterize the performance of the heat pump in the DOE2 model. While this performance level of the heat pump is a function of the weather experienced during the monitored period, the overall average measured system performance was used in place of a component-based simulation within the model. Although this approach was a simplification, it allowed us to use the measured COP in the simulation.

For water heating, a simplified approach based on the overall average COP of the solar/heat pump system (calculated in section 3.2) was implemented in the DOE2 model. The actual measured energy contribution of the PV system for calendar year 2002 was incorporated into the whole-house energy analysis independently of the DOE2 analysis. Note that the DOE2 analysis was driven using TMY2 weather data, but the PV performance is based on the actual 2002 weather.

5.2 Building Confidence: Comparing Monitored Data and Simulation Results

The Building America prototype simulation model is based on the description of the house "as-built" along with standardized behavior and controls as defined in the Building America Performance Analysis Procedures.[17] The model of the physical building attempts to be as true as possible to what was actually built and installed in the prototype house. The use of the building, however, and the energy consumption associated with it, must rely on established assumptions regarding average occupant behavior and typical hourly weather data.

Monitored Data and the Building America Prototype. There is no reason to expect that the occupants of any particular house will behave according to the Building America benchmark operating conditions. While the mean behavior of the occupants (in the better sense of the adjective) is expected to be close to the behavior assumed for Building America, behavior may vary to a large degree. Comparing the monitored data (largely influenced by actual behavior) and simulation results (largely driven by assumed behavior) was, therefore, mainly a comparison of the actual occupants to the "assumed" occupants.

Figure 33 below shows a monthly comparison of total electricity used at the Hathaway house in the year 2002 (not accounting for PV generation) and the total electric use of the Hathaway prototype simulation model based on TMY2 weather and standard occupant behavior. The model predicts that the house would use 62% more electricity than it actually used for the annual period.

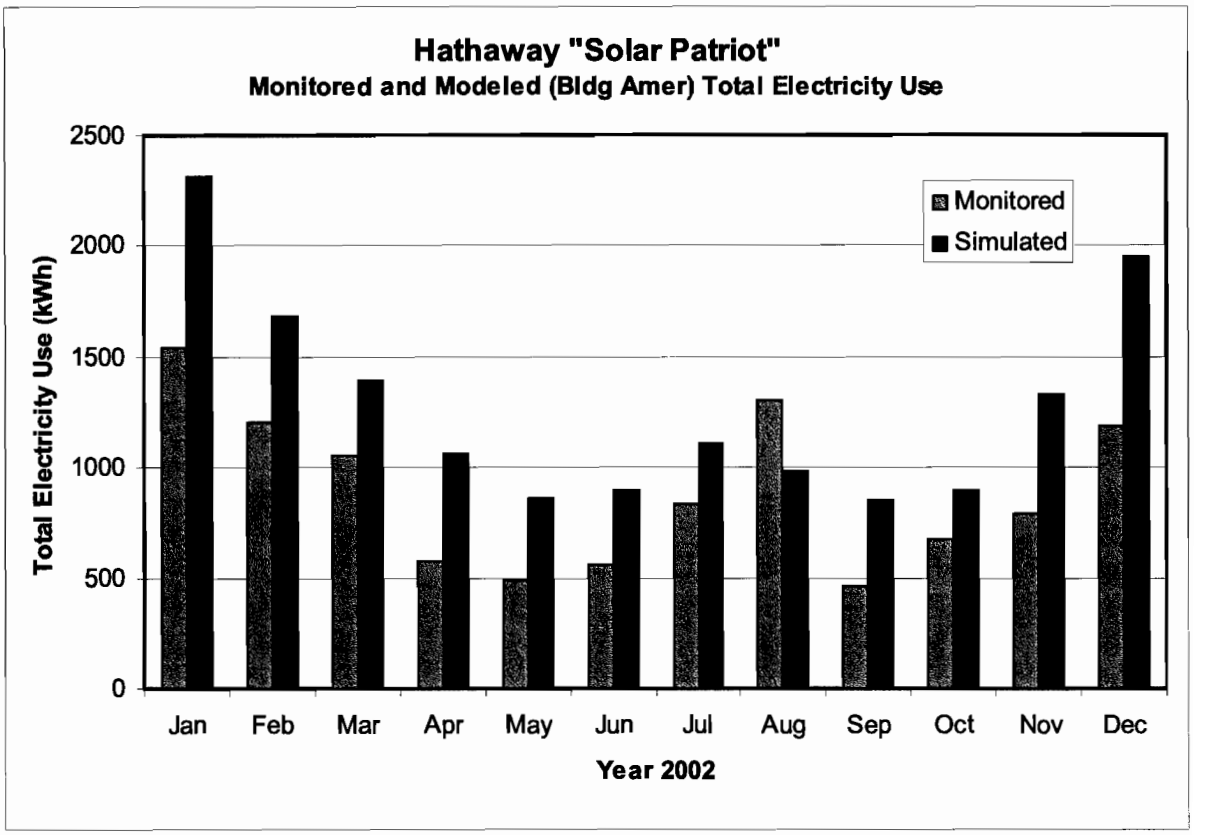


Figure 33. Monitored data vs. simulation results for total energy use using Building America assumptions and TMY2 data

The model predicts that the HVAC system would use approximately 23% more energy than was realized for the year and predicts that non-HVAC electricity use (lights, appliances, plug loads) would be nearly 65% more than was observed. Overall, the simulation predicted 44% higher whole-house annual energy consumption than was measured in the home in 2002.

Some investigation was warranted to discover if differences in the standard assumptions and the actual operating conditions could explain this large discrepancy.

Monitored data and the "Adjusted" Building America Prototype. Weather data used for the Hathaway site (TMY2 weather data for Sterling, Virginia) was significantly different than actual weather during February and October of the monitored period.

Based on the monitored data, the "behavior" of the occupants and the operation of the house were adjusted in simulation in the following ways:

- Internal Gains: plug loads were reduced by about 40% to match the monitored data

- HVAC Control: thermostat schedules were adjusted monthly to match observed actual setpoints (which were significantly lower in the heating season than assumed). Also, the thermostat schedule accounts for two week-long vacation periods.
- DHW Load: a slight adjustment was made so that the simulated hot-water volume used matched the observed volume.
- Infiltration: The average infiltration was adjusted based on measured data.

When the actual behavior of the Hathaway house occupants and the measured 2002 weather was used to drive the simulation model, the predicted and observed energy use was much closer. The annual total energy use was less than 5% different between the model results and the monitored data.

The simulation continued to overpredict the energy consumption in some months – especially the winter months. Some of this difference in energy use was explained by the occupants' use of wood to heat the house in the winter months.

Overall, it appears the simulation of the Hathaway prototype building was quite accurate. Differences in the monitored data and the Building America prototype simulation results shown in Figure 33 were mostly a result of differing assumptions regarding occupant behavior and weather rather than inaccuracies in the model of the home.

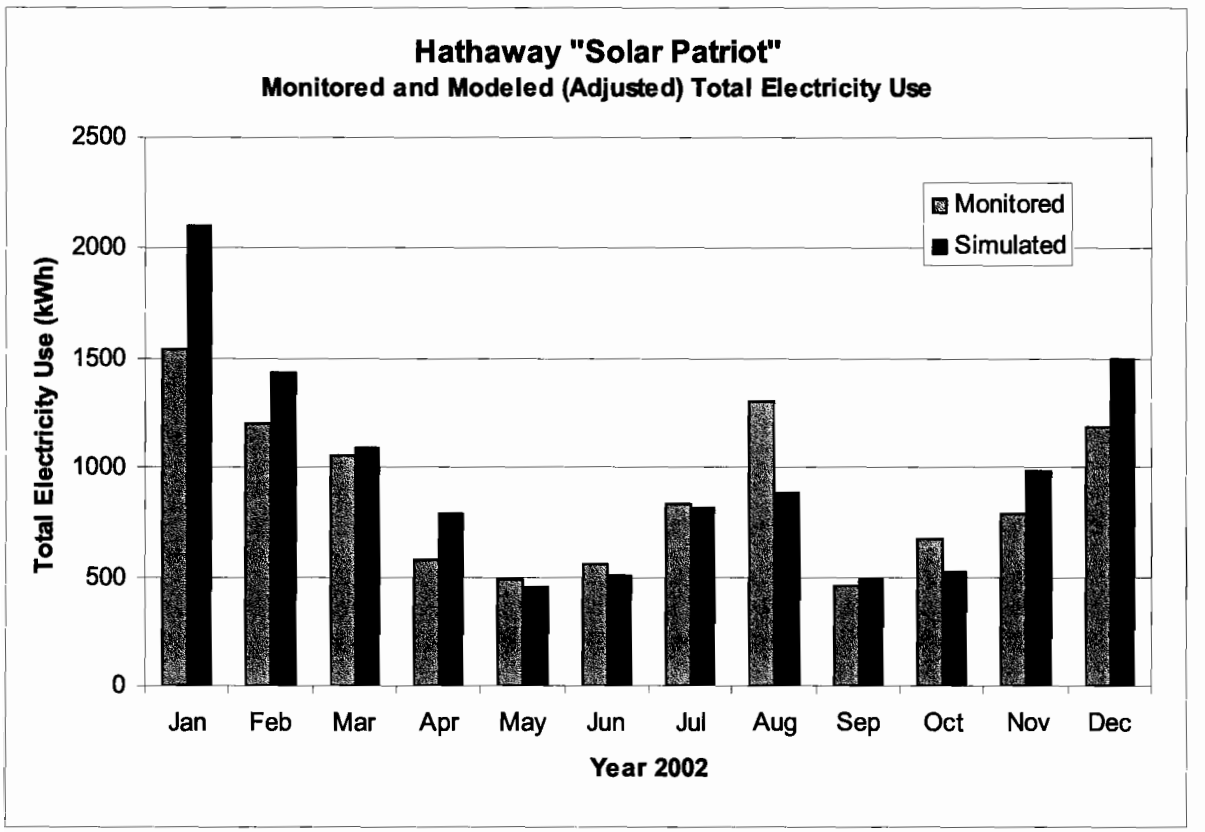


Figure 34. Monitored data vs. the adjusted model results, whole-building energy use

5.3 Putting Performance in Context: Simulation Results

The modeled energy performance of the Hathaway house was compared to two theoretical houses with the same basic architectural features and floor plans. One base case for comparison, called the Regional Standard Practice home, is constructed as a standard new home in the same area as the Hathaway home according to the knowledge and judgment of the authors. The other base case was the Building America Benchmark version 3.1. This Benchmark was designed to represent 1990s typical construction and to be in compliance with the 1995 Model Energy Code (MEC). The basic characteristics of these base case homes are given below:

Regional Standard Practice:
(assumes natural gas is not available on site)

Building Shell:	2 x 4 frame walls - R11 fiberglass insulation and wood sheathing R30 ceiling insulation R7 basement wall insulation double-pane clear windows with aluminum frames Standard air-infiltration (0.51 ACH average)
HVAC:	10 SEER 5-ton air-conditioner 6.8 HSPF heat pump with electric backup
DHW:	Electric DHW, 40 gallons, EF = 0.88

Building America Benchmark 3.1:
(assumes natural gas is not available on site)

Building Shell:	2 x 4 frame walls – overall R factor = 12.2 R33.3 ceiling insulation R17 basement wall insulation double-pane Low E windows with U = 0.40 Standard air-infiltration (0.51 ACH average)
HVAC:	10 SEER 5-ton air-conditioner 6.8 HSPF heat pump with electric backup
DHW:	Electric DHW, 40 gallons, EF = 0.88

The Building America program has created a standard set of three output tables that are used with any building modeling effort. The standard output tables for the Hathaway house modeling are given in Tables 8 through 10.

Table 8. Summary of End-Use Site Energy

	Annual Site Energy					
	BA Base		Region Standard		BA Prototype	
End-Use	kWh	therms	kWh	therms	kWh	therms
Space Heating	6276	0	7195	0	5030	0
Space Cooling	3540	0	2005	0	1092	0
DHW	3522	0	3525	0	987	0
Lighting	3110		3110		1204	
Appliances + Plug	7227	0	7227	0	7017	0
OA Ventilation	0		0		0	
Total Usage	23675	0	23062	0	15330	0
Site Generation	0	0	0	0	7402	0
Net Energy Use	23675	0	23062	0	7929	0

Table 9. Summary of End-Use Source Energy and Savings

	Annual Source Energy			Source Energy Savings			
				Percent of End-Use		Percent of Total	
	Base	Region	Proto	BA	Reg	BA	Reg
End-Use	MBTU/yr	MBTU/yr	MBTU/yr	Base	Base	Base	Base
Space Heating	64	74	52	**20%**	30%	**5%**	9%
Space Cooling	36	21	11	**69%**	46%	**10%**	4%
DHW	36	36	10	**72%**	72%	**11%**	11%
Lighting	32	32	12	**61%**	61%	**8%**	8%
Appliances + Plug	74	74	72	**3%**	3%	**1%**	1%
OA Ventilation	0	0	0	**0%**	0%	**0%**	0%
Total Usage	243	236	157	**35%**	34%	**35%**	34%
Site Generation	0	0	-76			31%	32%
Net Energy Use	243	236	81	67%	66%	67%	66%

Table 10. Energy Savings of Energy Efficiency Measures

	Site Energy		Source Energy		National Average Energy Cost		Regional Standard (Local Costs) Energy Cost		Measure	Package
Increment	kWh	therms	MBTU	Savings %	$/yr	Savings %	$/yr	Savings %	value ($/yr)	savings $/yr
Base (Bldg America)	23675	0	242.6		$ 2,368		$ 2,332			
Base (Regional Std Practice)	23062	0	236.3	3%	$ 2,306	3%	$ 3,053			
Base (Builder Std Practice)	27851	0	285.4	-18%	$ 2,785	-18%	$ 2,743			
Base + Improved walls	25642	0	262.7	-8%	$ 2,564	-8%	$ 2,526	8%	$ 217.6	$ 218
Base ++ Low-E Windows	23140	0	237.1	2%	$ 2,314	2%	$ 2,279	17%	$ 246.4	$ 464
Base ++ Smaller A/C (5 -> 4 tons)	22806	0	233.7	4%	$ 2,281	4%	$ 2,246	18%	$ 32.9	$ 497
Base ++ Inc. Bsmt Wall Insulation	22499	0	230.5	5%	$ 2,250	5%	$ 2,216	19%	$ 30.2	$ 527
Base ++ Ground Source HP (+DHW)	18380	0	188.3	22%	$ 1,838	22%	$ 1,810	34%	$ 405.7	$ 933
Base ++ Solar DHW	17202	0	176.3	27%	$ 1,720	27%	$ 1,694	38%	$ 116.0	$ 1,049
Base ++ Lighting, Appl. & Plug	15330	0	157.1	**35%**	$ 1,533	35%	$ 1,510	45%	$ 184.4	$ 1,233
Site Generation										
Base ++ PV	7928	0	81.2	67%	$ 793		$ 781	72%	$ 729.0	$ 1,962

5.4 What if . . . Investigating Possible Improvements

The Hathaway house reduced total energy use by 35% as compared to the Building America Benchmark (not including the contribution of the PV system). The energy-use reduction by end-use is given in the second column of Table 11. While impressive in its application of individual technologies, the overall result leaves two-thirds of the energy use untouched.

Lighting and DHW energy use was reduced by a large fraction and was close to the limits of practical energy-saving technologies. The space-conditioning energy use could be reduced further by eliminating some of the heating and cooling loads with more efficient shell technology, as well as by applying even more efficient space-conditioning equipment. The appliance and plug load category was nearly untouched by the energy-reduction measures.

Table 11. Energy Reduction by End-Use Compared to the Building America Benchmark[1]

Category	Hathaway Prototype	"Super Building"
Indoor Lighting	61%	61%
Appliances and Plug Loads	3%	3%
Space-Heating Equipment	20%	96%
Space-Cooling Equipment	69%	89%
DHW Equipment	72%	72%
Exterior Lighting	71%	71%
Total	**35%**	**58%**

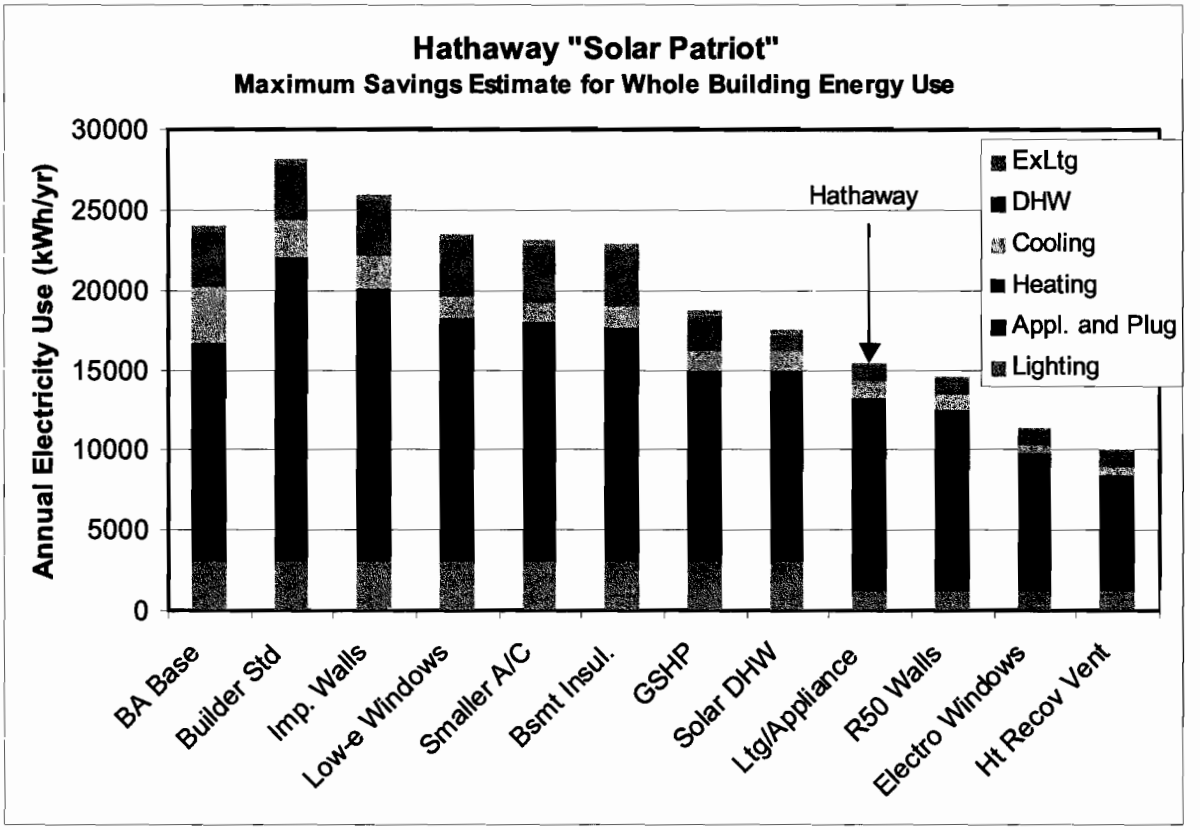


Figure 35. Energy use by end-use category, beyond the Hathaway prototype

Figure 35 shows the change in energy use with each added technology. The column labeled "Ltg/Appliance" is the Hathaway prototype model. The last four columns apply additional technologies in an attempt to reduce the heating and cooling loads as much as practical (and beyond). In the end, the heating, cooling and DHW energy use was reduced to less than 1700 kWh per year, an 88% reduction.

The last column in Table 11 shows the energy savings for the "Super House" that includes all the technologies in Figure 35. The application of building shell and other measures currently not cost effective, including super-insulated walls, electrochromic glazing, and highly effective heat recovery ventilation, can eliminate much of the remaining space-conditioning load. However, the appliance and plug loads come to dominate energy consumption and account for nearly 70% of the total energy use.

This analysis points out that even with highly effective energy-savings technologies (pushed beyond levels currently practical), whole-house energy-use reduction for efficiency measures is only about 60% without reducing the energy use of appliances and plug loads largely considered outside the designer's jurisdiction.

6. Discussion

The 2020 research goal for the Building America program is to develop cost-effective production-ready homes that achieve zero net energy. The Hathaway house is an early example of a home on the path to zero net energy. A zero net energy home is one that produces on-site as much energy as it consumes on an annual basis. The goal of this home was to achieve zero energy. Through energy efficiency and solar energy the home achieved remarkable performance – reducing its whole house energy needs 35% and meeting nearly 70% of the remaining electricity needs with solar electricity.

6.1 On the Path to Zero Net Energy

The Hathaway case study provides many insights into the path to commercially viable zero energy homes. It also raises more questions than it answers.

It is clear that modeling tools will be required to sift through the many options for approaching zero energy and choose the options that achieve the goal as cost effectively as possible for the climate zone and builder preferences. The target is most certainly not a singularity but a spectrum of options. For example, many different shell designs such as wood frame, structural insulated panels, insulated concrete forms, and others may be parallel paths to the zero energy goal. The most appropriate path may depend on costs, local codes, local material availability, builder preferences, and market preferences. Similar parallels exist in equipment strategies.

The zero energy home design approach will likely employ typical occupant behavior assumptions and typical annual weather data. A home designed to consume zero net energy under these assumptions may be a net consumer or a net producer with any real occupants in any specific year. In fact it could easily be a net producer one year and a net consumer the next. The task of the designer is to evaluate the range of possible home construction details near the economically optimum design and choose one most appropriate for the circumstances. Hence the design will be a combination of science and art.

A tool, call the Building Energy Optimization (BEopt) program is currently under development at NREL. This tool will allow researchers to choose possible shell and equipment options and automatically run hundreds or thousands of hourly building energy simulations to identify the lowest cost combinations to achieve a given energy savings goal for a specific home geometry in a specific location. The program is being designed to allow the user to investigate not only the optimal design, but also designs that are near the optimal.

The Hathaway house did not have the advantage of energy modeling during the design phase and yet achieved impressive energy efficiency. Subsequent analyses indicate that a more efficient shell to reduce space-conditioning loads would have brought the home closer to its zero energy goals. However, even with efficient lighting and appliances, the lights and appliance and plug loads were a significant energy consumer. About 4 kW of PV were required to meet the needs of these loads alone. To achieve the zero energy goal with no further efficiency increases, the Hathaway house would need about 2.6 kW of PV in addition to the 6.0 kW it had during this study.

6.2 Systems Operations and Interactions

The Hathaway house included several advanced systems including PVs, solar water heating, and a ground-coupled heat pump. The PV system worked well during the monitoring period consistently delivering the expected performance with no maintenance issues. In May 2002 the power output of one of the PV inverters was interrupted when the homeowner inadvertently threw a fuse during a tour. We noticed the drop in power in the data, informed the homeowner, and the power was quickly restored. This in an advantage of monitoring home performance, but it also raises the question of how long it would take an average homeowner to notice if their PV system was not operating properly.

The ground-coupled heat pump also performed well throughout the monitoring period with an average heating COP of 3.6 and cooling COP of 3.2. System performance data from the manufacturer list a COP of about 4.1 for heating for a horizontal tube field and a ground temperature of 55°F. The average water-heating COP of the system was about 1.55, which is similar to dedicated air-source heat-pump water heaters. Early in the project, the water-heating energy for the household was much higher than expected. In talking with the Hathaways, we learned that they switched the heat pump to heat the water in the storage tank until well after their morning hot water draws. Because the tank was now hot at the beginning of the day, the solar water-heating system operated at a very low efficiency. The situation was corrected by adding a timer to the water heating mode of the heat pump. The time was set to top off the tank temperature before the morning hot water draws. The morning use of hot water then left the tank filled with cooler water and the solar water heater operated much more effectively. The overall energy use for water heating dropped dramatically when this strategy was implemented in November 2001 (Figure 14).

Although the heat pump worked well, the overall energy performance of the space-conditioning system was reduced because of high air-handler fan energy consumption. The air handler consumed more than 25% as much energy as the heat pump. This was a result of two factors: the occupants sometimes ran the air-handler fan when the heat pump was not operating to mix the air in the home, and the air handler did not use an efficient ECM motor.

6.3 Modeling and Monitoring Approach

We use a combination of computer modeling, testing, and monitoring to understand the performance of prototype houses. As a Building America project, the performance of a home is required to be measured against the Building America Benchmark home. The benchmark home is based on construction practices of the mid-1990s. To make the comparison, the prototype home and the matching benchmark home must be modeled to compare their energy performance. Therefore, modeling is an essential tool to track the progress of homes toward the Building America program goals for energy savings.

Computer models provide other useful information that cannot be gained by testing or monitoring. The model provides *generalized* energy performance of a home; performance that is based on *average* occupancy behavior and *typical* weather patterns. In contrast, monitoring provides information on the performance of the home with *specific* occupants and *actual* weather conditions. The model can also be used to generate "what-if" scenarios (as discussed in section 5.3) to see how the home would perform if it incorporated different building techniques and

energy technologies. These attributes make the model a powerful tool for understanding the performance of the home. So why not just create a computer model and skip testing and monitoring?

Testing and monitoring data increase confidence in the computer model. There are some areas, such as shell leakage or performance of newly developed equipment, that are difficult to know in advance and, therefore, difficult to accurately model. In these cases, the measurements become input to the model and improve its accuracy. Measurements also provide a reality check for the computer simulation. If the simulation can accurately predict the behavior of the home given the measured inputs, it again increases our confidence in the model. Finally, testing and modeling provide information on home performance that modeling cannot provide. Testing and monitoring provides quick feedback on the performance of new technologies. It provides insights into equipment installation issues, interaction between occupants and technology, and occupant behavior. It can also provides the means to interpret higher level results such as energy bill comparison.

Modeling, testing, and monitoring nicely complement each other and provide different insights into the performance of the home. We have found that a combination of them tailored to the objectives of the project is the best approach to understanding advanced homes.

7. References

[1] Hendron, B., et. al., 2004, Building America Research Benchmark Definition, Version 3.1, NREL/TP-550-36429, Golden, CO: National Renewable Energy Laboratory

[2] World Population Prospects: The 2002 Revision, February 2003, ESA/P/WP.180, United Nations Population Division.

[3] United States Energy Information Administration, see http://www.eia.gov/.

[4] Rastelli, Linda, Jan/Feb 2002, "Energy Independence—With all the Comforts," *Solar Today*, Boulder, CO: American Solar Energy Society, Vol. 16, No. 1.

[5] Sklar, Scott, Sept/Oct 2001, "Solar House Goes to Washington," *Home Energy Magazine*, Berkeley, CA.

[6] Home Buyer Publications, Inc., Mar/Apr 2001, "Solar Patriot on Parade on the National Mall," *Building Systems Magazine*, Lakewood, CO.

[7] "Solar Home add to Earth Day landscape," April 18, 2001, *Environmental News Network*, www.enn.com.

[8] For more information on the Building Energy Program of the Department of Energy see www.eere.energy.gov/buildings

[9] For more information on the Center for Buildings and Thermal Systems at the National Renewable Energy Laboratory see www.nrel.gov/buildings_thermal

[10] This program no longer exists as a separate entity. It is part of the Building America program. For more information on the current research pertaining to zero energy homes see www.buildingamerica.gov.

[11] For more information on the Building America Program see www.buildingamerica.gov

[12] Klein, S., et al., 1996, TRNSYS: A Transient System Simulation Program – Reference Manual, Solar Energy Laboratory, University of Wisconsin.

[13]American Society of Heating, Refrigeration and Air Conditioning Engineers, 2004, *Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings, Fourth Public Review*, ASHRAE Standard 62.2, Atlanta, GA: American Society of Heating, Refrigeration and Air Conditioning Engineers.

[14] Lawrence Berkeley National Laboratory, DOE2.2 Building Simulation Software, Berkeley, CA: Lawrence Berkeley National Laboratory. available at http://www.osti.gov/estsc/ or http://www.doe2.com

[15] Judkoff, R., and Neymark, J., 1995, International Energy Agency Building Energy Simulation Test (BESTEST) and Diagnostic Method, NREL/TP-472-6231, Golden, CO: National Renewable Energy Laboratory.

[16] Judkoff, R., and Neymark, J. Home Energy Rating System Building Energy Simulation Test (HERS BESTEST) Volumes 1 and 2, Nov 1995, NREL/TP-472-7332.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Executive Services and Communications Directorate (0704-0188). Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ORGANIZATION.

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
May 2005	Technical Report	

4. TITLE AND SUBTITLE
The Hathaway "Solar Patriot" House: A Case Study in Efficiency and Renewable Energy

5a. CONTRACT NUMBER
DE-AC36-99-GO10337

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Paul Norton, Edward Hancock, Greg Barker, Paul Reeves

5d. PROJECT NUMBER
NREL/TP-550-37731

5e. TASK NUMBER
BET5.8004

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

8. PERFORMING ORGANIZATION REPORT NUMBER
NREL/TP-550-37731

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)
NREL

11. SPONSORING/MONITORING AGENCY REPORT NUMBER

12. DISTRIBUTION AVAILABILITY STATEMENT
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

13. SUPPLEMENTARY NOTES

14. ABSTRACT *(Maximum 200 Words)*
This report details the monitored and modeled performance of a solar home outside of Washington, D.C. We modeled the home energy performance using DOE2.2, performed numerous short-terms tests on the home and monitored its occupied performance for 29 months. The home uses modular construction, solar water heating, a ground-coupled heat pump, efficient appliances and compact fluorescent lighting to reduce its energy consumption by 35% compared to the Building America research benchmark home. The addition of 6kW of photovoltaics increases the savings to 67% compared to the Building America research benchmark. A more efficient shell to reduce space conditioning loads would have brought the home closer to its zero energy goals. However, even with efficient lighting and appliances, the lights, appliance and plug loads are a significant energy consumer. About 4 kW of PV are required to meet the needs of these loads alone. To achieve the zero energy goal with no further efficiency increases, the Hathaway house would need about 2.6 kW of PV in addition to the 6.0 kW it now has.

15. SUBJECT TERMS
Building America; DOE2.2; solar home; solar patriot; hathaway house; energy performance; case study; PV; photovoltaics

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
Unclassified	Unclassified	Unclassified	UL		19b. TELEPHONE NUMBER *(Include area code)*

A Strong Energy Portfolio for a Strong America

Energy efficiency and clean, renewable energy will mean a stronger economy, a cleaner environment, and greater energy independence for America. Working with a wide array of state, community, industry, and university partners, the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy invests in a diverse portfolio of energy technologies.

Research and Development of Buildings

Our nation's buildings consume more energy than any other sector of the U.S. economy, including transportation and industry. Fortunately, the opportunities to reduce building energy use—and the associated environmental impacts—are significant.

DOE's Building Technologies Program works to improve the energy efficiency of our nation's buildings through innovative new technologies and better building practices. The program focuses on two key areas:

- **Emerging Technologies**
  Research and development of the next generation of energy-efficient components, materials, and equipment
- **Technology Integration**
  Integration of new technologies with innovative building methods to optimize building performance and savings

For more information contact:
EERE Information Center
1-877-EERE-INF (1-877-337-3463)
www.eere.energy.gov

U.S. Department of Energy
Energy Efficiency and Renewable Energy

An electronic copy of this publication is available on the Building America Web site at **www.buildingamerica.gov**

Visit our Web sites at:

www.buildingamerica.gov | www.pathnet.org | www.energystar.gov

Building America U.S. Department of Energy | PATH | ENERGY STAR

Building America Program
George S. James • New Construction • 202-586-9472 • fax: 202-586-8134 • e-mail: George.James@ee.doe.gov
Terry Logee • Existing Homes • 202-586-1689 • fax: 202-586-4617 • e-mail: terry.logee@ee.doe.gov
Lew Pratsch • Integrated Onsite Power • 202-586-1512 • fax: 202-586-8185 • e-mail: Lew.Pratsch@hq.doe.gov
Building America Program • Office of Building Technologies, EE-2J • U.S. Department of Energy • 1000 Independence Avenue, S.W. • Washington, D.C. 20585-0121 • **www.buildingamerica.gov**

Building Industry Research Alliance (BIRA)
Robert Hammon • ConSol • 7407 Tam O'Shanter Drive #200 • Stockton, CA 95210-3370 • 209-473-5000 • fax: 209-474-0817 • e-mail: Rob@consol.ws • **www.bira.ws**

Building Science Consortium (BSC)
Betsy Pettit • Building Science Consortium (BSC) • 70 Main Street • Westford, MA 01886 • 978-589-5100 • fax: 978-589-5103 • e-mail: Betsy@buildingscience.com • **www.buildingscience.com**

Consortium for Advanced Residential Buildings (CARB)
Steven Winter • Steven Winter Associates, Inc. • 50 Washington Street • Norwalk, CT 06854 • 203-857-0200 • fax: 203-852-0741 • e-mail: swinter@swinter.com • **www.carb-swa.com**

Davis Energy Group
David Springer • Davis Energy Group • 123 C Street • Davis, CA 95616 • 530-753-1100 • fax: 530-753-4125 • e-mail: springer@davisenergy.com • deg@davisenergy.com • **www.davisenergy.com/index.html**

IBACOS Consortium
Brad Oberg • IBACOS Consortium • 2214 Liberty Avenue • Pittsburgh, PA 15222 • 412-765-3664 • fax: 412-765-3738 • e-mail: boberg@ibacos.com • **www.ibacos.com**

Industrialized Housing Partnership (IHP)
Subrato Chandra • Florida Solar Energy Center • 1679 Clearlake Road • Cocoa, FL 32922 • 321-638-1412 • fax: 321-638-1439 • e-mail: subrato@fsec.ucf.edu • **www.baihp.org**

National Association of Home Builders (NAHB) Research Center
Tom Kenney • National Association of Home Builders (NAHB) Research Center • 400 Prince George's Boulevard • Upper Marlboro, MD 20774 • 301-430-6246 • fax: 301-430-6180 • toll-free: 800-638-8556 • **www.nahbrc.org/**

National Renewable Energy Laboratory
Ren Anderson • 1617 Cole Boulevard, MS-2722 • Golden, CO 80401 • 303-384-7433 • fax: 303-384-7540 • e-mail: ren_anderson@nrel.gov • **www.nrel.gov**

Tim Merrigan • 1617 Cole Boulevard, MS-2722 • Golden, CO 80401 • 303-384-7349 • fax: 303-384-7540 • e-mail: tim_merrigan@nrel.gov • **www.nrel.gov**

Oak Ridge National Laboratory
Pat M. Love • P.O. Box 2008 • One Bethel Valley Road • Oak Ridge, TN 37831 • 865-574-4346 • fax: 865-574-9331 • e-mail: lovepm@ornl.gov • **www.ornl.gov**

Produced for the U.S. Department of Energy (DOE) by the National Renewable Energy Laboratory, a DOE national laboratory.

May 2005 • NREL/TP-550-37731

Printed with a renewable-source ink on paper containing at least 50% wastepaper, including 20% postconsumer waste.

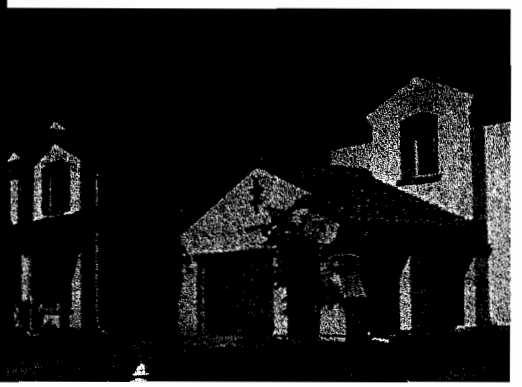
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

BUILDERS CHALLENGE

Building America SM
U.S. Department of Energy
Research Toward Zero Energy Homes

High-Performance Builder Spotlight

Pulte Phoenix Cabrillo Point



Attention to Detail Gets the Seal of Approval

Attention to detail is helping Pulte Phoenix meet the U.S. Department of Energy's Builders Challenge in 69 new homes under construction at Cabrillo Point in the Phoenix suburb of Glendale, Arizona.

> "One benefit of our participation in Builders Challenge has been the free publicity. The local paper has done several articles mentioning Cabrillo Point, and Home Depot invited us to participate in a green products event they hosted. It has definitely generated a lot of interest."
>
> **CHRIS KELLY,** Vice President of Operations for Pulte Phoenix Division

The builder is achieving HERS index scores of 68 and 69 on the homes, thanks to an extra snug building envelope which includes blown cellulose wall and ceiling insulation plus an additional exterior sheathing of rigid foam insulation under the stucco exterior. Other air sealing details include foam caulking of all wall, floor, and ceiling penetrations for wiring and pipes; mastic sealing the ducts; putting in air barriers around duct chases, behind tub and shower surrounds, and around fireplace inserts; air sealing between the garage and house; and caulking the top plate and sill plate. Jump ducts are used between rooms to balance pressure and temperatures from room to room, reducing drafts and hot or cold spots. To meet Builders Challenge requirements, every home is frame inspected, insulation inspected, and duct blaster and blower door tested for air leakage. Thorough visual inspections are conducted by both the HERS rater and Pulte's on-site supervisor to ensure that all specified equipment is installed and insulation and air sealing are correctly applied.

Chris Kelly, Vice President of Operations for Pulte Phoenix Division, notes that the energy-efficient equipment and measures alone won't ensure energy savings—the key is how they are applied. "You really have to make sure your own employees and your framing and installation contractors understand how this needs to be done." Pulte conducts subcontractor training at the job site throughout the year.

Dollars and Sense

Pulte Phoenix estimates it spends about $3,000 to $4,000 per house over a standard construction Pulte Home (which is built to an Environments for Living Gold level and meets ENERGY STAR) to meet the Builders Challenge and Environments for Living Green standards. Part of this additional cost is the high-efficiency clothes washer, clothes dryers, refrigerators, ranges, and dishwashers that Pulte includes to make sure the homes meet the water and energy saving requirements of the *Environments for Living* Green program.

Pulte has in the past been able to command a premium for its high-performance homes. Sales of all homes in Phoenix are down 45% from 2007; however, Kelly notes that "Cabrillo Point is definitely seeing higher-than-average traffic because it is meeting the Builders Challenge."

BUILDER PROFILE

Pulte Phoenix West Division
www.pulte.com

Founded: Pulte Phoenix West Division formed in 2003. Pulte Phoenix [redacted] formed over 20 years ago. Pulte [redacted] was founded in 1950 in Michigan.

Employees: 160 in Pulte Phoenix West Division not counting subs

Development:
Cabrillo Point, Glendale, Arizona

Size: 69 single-family homes
(1,479 - 2,436 sq. ft.)

Price range: $240-$336,000

Number of homes built by the division:
Over 1,200 annually

Energy efficiency commitment: All homes built by division *Environments for Living* Certified Gold level or higher since 2007

U.S. DEPARTMENT OF
ENERGY

Energy Efficiency &
Renewable Energy

10/2009 | PNNL-SA-69010

KEY FEATURES

HERS index score of 69

Third party inspection of every home – duct blaster, blower door, visual inspection of framing, equipment and insulation installation

Environments for Living
Green level energy use guarantee

Blown cellulose wall insulation to R-13, Ceiling insulation to R-30

Panelized framing at Pulte's offsite facility

Exterior R-4 foam board insulation under exterior stucco layer with a #15 felt for drainage plane to the inside of the foam board.

High-performance low-emissivity, dual-pane, vinyl-framed windows

Jump ducts for pressure balancing

Air sealing of building envelope

SEER 14 air conditioning and sealed combustion gas furnace with mastic sealed ducts

Filtered, fresh air intake ducted to air handler

ENERGY STAR appliances

Hard wired carbon monoxide detectors

Compact fluorescent lighting

Low-flow showerheads and faucets, dual-flush toilets

Low VOC paints, finishes, and adhesives

Kelly recommends builders investigate federal and local rebates and incentives, which can offset costs for the builder as well as the buyer. Many municipalities also offer waived fees and expediting of plans approval for green and energy-efficient projects.

Pulte buyers know they are getting more in a Builders Challenge home the minute they step into the Cabrillo Pointe sales office. "We've got big displays with the Environments for Living guarantee and the Builders Challenge HERS scale to show buyers how our homes compare to typical construction." Pulte's sales staff go through frequent trainings to make sure they understand the homes' energy-efficient features. Pulte conducts radio and TV advertising that focuses on energy savings and has received free advertising in the form of articles by the local newspaper describing its energy-saving efforts. Pulte offers Cabrillo Pointe homeowners a heating and cooling use guarantee.

The Bottom Line

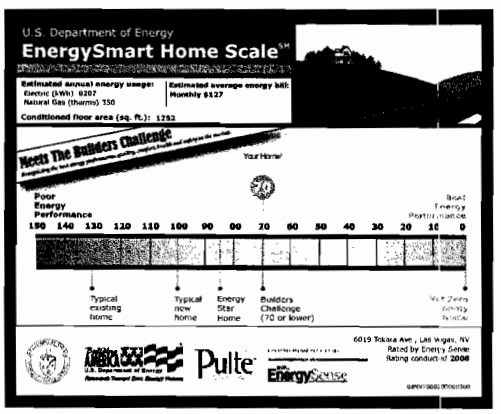
Kelly sees DOE's Builders Challenge program with its easy-to-understand HERS index score as a way to unify builders' energy-efficiency efforts and simplify things for buyers. "Many builders have their own energy-efficiency programs and each one is called something different. I think it will help the whole industry if everyone is talking the same language. The U.S. Department of Energy is known and respected. It lends credibility if you can say you are meeting the DOE's Builders Challenge standard, as opposed to meeting a program criteria you came up with yourself," said Kelly.

U.S. Department of Energy Builders Challenge

DOE has posed a challenge to the homebuilding industry—to build a new generation of high-performance homes using proven innovations and to work toward the ultimate goal of providing cost-neutral, net-zero energy homes by 2030. Homes that qualify for this Builders Challenge must meet a 70 or better on the EnergySmart Home Scale (E-Scale). The E-scale allows homebuyers to understand—at a glance—how the energy performance of a particular home compares with others. Through the Builders Challenge, participating homebuilders will have an easy way to differentiate their best energy-performing homes from other products in the marketplace, and to make the benefits clear to buyers.

The figure to the right shows a sample E-Scale for Pulte Homes. The E-scale is based on the well-established Home Energy Rating System (HERS) index, developed by the Residential Energy Services Network. To learn more about the index and HERS Raters visit www.natresnet.org.

To learn more about the Builders Challenge and find tools to help market your homes, visit www.buildingamerica.gov/challenge.



Building AMERICA
U.S. Department of Energy
Research Toward Zero Energy Homes

For more information visit www.buildingamerica.gov. The website contains expanded case studies, technical reports, and best practices descriptions.

The Building America Program

Building America is a private/public partnership sponsored by DOE that conducts systems research to improve overall housing performance, increase housing durability and comfort, reduce energy use, and increase energy security for America's homeowners. Building America teams construct test houses and community-scale projects that incorporate systems innovations. The teams design houses from the ground up, considering the interaction between the site, building envelope, mechanical systems, and other factors, and recognizing that features of one component in the house can greatly affect others. More than 40,000 energy-efficient houses have been built by the seven teams to date.

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

BUILDING TECHNOLOGIES PROGRAM

Measure Guideline: Summary of Interior Ducts in New Construction, Including an Efficient, Affordable Method to Install Fur-Down Interior Ducts

D. Beal, J. McIlvaine, K. Fonorow, and E. Martin
BA-PIRC

November 2011

Building AMERICA
U.S. Department of Energy

NOTICE

This report was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or any agency thereof.

Available electronically at http://www.osti.gov/bridge

Available for a processing fee to U.S. Department of Energy
and its contractors, in paper, from:
U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
phone: 865.576.8401
fax: 865.576.5728
email: mailto:reports@adonis.osti.gov

Available for sale to the public, in paper, from:
U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
phone: 800.553.6847
fax: 703.605.6900
email: orders@ntis.fedworld.gov
online ordering: http://www.ntis.gov/ordering.htm

Printed on paper containing at least 50% wastepaper, including 20% postconsumer waste

Measure Guideline: Summary of Interior Ducts in New Construction, Including an Efficient, Affordable Method to Install Fur-Down Interior Ducts

Prepared for:

Building America

Building Technologies Program

Office of Energy Efficiency and Renewable Energy

U.S. Department of Energy

Prepared by:

D. Beal, J. McIlvaine, K. Fonorow, E. Martin

BA-PIRC / Florida Solar Energy Center

1679 Clearlake Rd

Cocoa, Florida, 32922

NREL Technical Monitor: Stacey Rothgeb

Prepared under Subcontract No. KNDJ-0-40339-00

November 2011

[This page left blank]

Contents

List of Figures v
List of Tables vi
Executive Summary viii
1 Introduction 1
1.1 Purpose 1
1.2 Previous Publications 1
1.3 Definition of Interior Ducts 1
1.4 Styles of Interior Ducts 1
1.4.1 Fur-up Chase 1
1.4.2 Fur-down Chase 2
1.4.3 Sealed Attic or Crawlspace 2
1.5 System Advantages and Disadvantages 3
1.5.1 Fur-up Chase 4
1.5.2 Fur-down Chase 5
1.5.3 Sealed Attic or Crawlspace 6
2 Document Inspections 7
2.1 Floor Plan Appropriate for Implementation 7
2.2 Non-Energy Advantages 10
2.2.1 Indoor Air Quality 10
2.2.2 Equipment Life 10
2.2.3 Aesthetics 11
2.2.4 Occupant Comfort 11
2.3 Risk Identification 11
2.3.1 Duct Leakage Overview 12
2.3.2 Assumption That Since the Chase is Sealed, the Ducts Can Be Leaky 14
2.3.3 Trade Sequence and Interference 14
2.3.4 Code Issues 14
3 Trade-offs 15
3.1 Cost vs. Performance 15
3.2 Cost and Issues for the Various Systems 15
3.2.1 Sealed Attic 15
3.2.2 Sealed Crawlspace 18
3.2.3 Fur-up Chases 19
3.2.4 Fur-down Chase 19
3.3 System Interaction 21
3.3.1 Effect of HVAC System Runtime 21
3.3.2 Return Pathways 22
3.3.3 Trade Interactions 22
4 Summary of Implementation of Various Methods 22
4.1 Integrating the New Strategy Into Current Construction Processes 22
4.1.1 Locate Chase 23
4.1.2 Before Construction of the Chase 23
4.1.3 General Chase Construction Guidelines 25
4.1.4 Protecting the Chase After Completion 27

4.2 Chase Design 28
4.2.1 Identify Chase Path 28
4.2.2 Involve All Subcontractors Whose Work May Impact the Chase Integrity 29
4.3 Field Inspection 29
4.3.1 Multiple to Daily, Inspections Needed 29
4.4 Introduction of Detailed, Simplified and Inexpensive Method of a Fur-down Chase 29
4.4.1 Install Ceiling/Chase Drywall 30
4.4.2 Install Duct Work 30
4.4.3 Finish Chase Construction 31
4.4.4 A Method to Reduce the Size of the Chase 31
4.4.5 Transom Returns 32
4.5 Verification 32
4.5.1 Blower Door Testing 33
4.5.2 Duct Blaster Testing 33
4.5.3 Room to Main Body Pressure Balancing 33
References **34**
Acknowledgments **35**

List of Figures

Figure 1. Fur-up chase installed after rough framing. 2
Figure 2. Fur-down chase after rough framing. 2
Figure 3. An unvented attic constructed by air sealing the roof deck with foam insulation. Note how the attic duct is now within the home's air and thermal barrier 3
Figure 4. A sealed crawlspace by air sealing the foundation walls with foam insulation. 3
Figure 5. Poorly insulated fur-up chase sides. 4
Figure 6. Modified truss work necessitated by fur-up chase. 5
Figure 7. Fur-up chase deliberately used for wiring runs. Also note the poor overall insulation of the chase. 5
Figure 8. A fur-down chase used for architectural detail. 5
Figure 9. Air Handler Closet 8
Figure 10. Fur-down chase in hallway. Note the restricted space for the chase due to the 8 ft ceiling height. Note the space-saving, light gauge metal framing at the bottom of the chase. 9
Figure 11. Free-standing chase in open area of floor plan. 10
Figure 12. Air handler and duct system installed in a conventional attic. A relatively large volume of air becomes trapped in the system between runtime events, and can encounter significant heat gain/loss to the point where it can cause comfort issues when introduced into the home's interior. 11
Figure 13. A jump duct through the attic. This will provide return air, over the interior wall. Note this is not an interior duct unless the attic is sealed. 13
Figure 14. Transom return pathway, through the wall, over doorway of a master bedroom. 13
Figure 15. Fur-down chase above dropped ceiling. 20
Figure 16. Example of a perimeter chase. 20
Figure 17. Free-hanging chase across an open space. Note separation of space accented by chase 21
Figure 18. Floor plan, showing the area to have a fur-down chase installed, highlighted in grey 23
Figure 19. Paint tags alerting crews to the location of the proposed chase. 24
Figure 20. Supply duct location marked in the side of a fur-down chase 24
Figure 21. Air handler closet ceiling sealed with duct board. 25
Figure 22. Duct work strapped in place prior to finishing the framing of the chase. 26
Figure 23. Finish framing for chase. 26
Figure 24. Air-sealing a fur-up chase. 26
Figure 25. Chase side wall supply sealing detail. 27
Figure 26. Ceiling drywall installed at fur-down chase top. Drywall is slid through a ¾"+ gap between the wall top plate and the truss bottom chord, ensuring a good air barrier. 30
Figure 27. Duct work hung with 2" strapping after chase ceiling drywall installed and sealed. 31
Figure 28. Chase sides and bottom installed. 31
Figure 29-31. (Left to right) Connecting flex duct to a trunk line for a supply run-out results in a wide chase. Instead, a supply outlet constructed from a duct board box can be directly affixed to the trunk. This permits construction of a much narrower chase 32

Unless otherwise noted, all figures were created by the BA-PIRC team.

List of Tables

Table 1. Impact of roof pitch on volume and heat transfer area. 17
Table 2. Cost comparison of two interior duct methods for differing roof pitch, Partner 1..... 17
Table 3. Cost Comparison of two interior duct methods, Partner 2. 18

Unless otherwise noted, all tables were created by the BA-PIRC team.

Definitions

A/C	**Air Conditioning**
ACCA	**Air Conditioning Contractors of America**
AH	**Air Handler**
FSEC	**Florida Solar Energy Center**
HUD	**Housing and Urban Development**
HVAC	**Heating, Ventilation, and Air Conditioning**
IAQ	**Indoor Air Quality**
IECC	**International Energy Conservation Code**
Manual D	**ACCA Manual for Residential Duct Systems**
Manual J	**ACCA Manual for Residential Load Calculation**
MHLab	**Manufactured Housing Lab**
RBS	**Radiant Barrier System**
RH	**Relative Humidity**
SEER	**Seasonal Energy Efficiency Ratio**
VOC	**Volatile Organic Compound**

Executive Summary

This document illustrates guidelines for the efficient installation of interior duct systems in new housing. Interior ducts result from bringing the duct work inside a home's thermal and air barrier. Architects, designers, builders, and new home buyers should thoroughly investigate any opportunity for energy savings that is as easy to implement during construction, such as the opportunity to construct interior duct work. In addition to enhanced energy efficiency, interior ductwork results in other important advantages, such as improved indoor air quality, increased system durability and increased homeowner comfort.

While the advantages of well-designed and constructed interior duct systems are recognized, the implementation of this approach has not gained a significant market acceptance. This guideline describes a variety of methods to create interior ducts including the fur-up chase method, the fur-down chase method, and interior ducts positioned in sealed attics or sealed crawl spaces.

As communication of the intent of an interior duct system, and collaboration on its construction are paramount to success, this guideline details the critical design, planning, construction, inspection, and verification steps that must be taken. Involved in this process are individuals from the design team; sales/marketing team; and mechanical, insulation, plumbing, electrical, framing, drywall and solar contractors.

1 Introduction

1.1 Purpose

This document illustrates guidelines for the efficient installation of interior duct systems in new housing. Architects, designers, builders, and new home buyers should thoroughly investigate any opportunity for energy savings that is as easy to implement during construction as implementing interior duct work. In addition to enhanced energy efficiency, interior ductwork results in other important advantages, such as improved indoor air quality, increased system durability, and increased homeowner comfort.

While the advantages of well-designed and constructed interior duct systems are recognized, the implementation of this approach has not gained a significant market acceptance. Homes in hot climates are still typically designed and built with duct systems in the attic. This guideline describes a variety of methods to create interior ducts, including a cost-effective method used by four builders in the Gainesville, FL, area to construct interior ducts in more than twelve site-built homes.

1.2 Previous Publications

This guideline summarizes two previous peer-reviewed Florida Solar Energy Center (FSEC) papers:

Fonorow, K., Jenkins, D., Thomas-Rees, S., and Chandra, S. "Low Cost Interior Duct Systems for High Performance Homes in Hot Climates", ACEEE Summer Study on Energy Efficiency in Buildings, August 15-20, 2010, in Pacific Grove, CA.

McIlvaine, J, Beal, D., and Fairey, P. "Design and Construction of Interior Duct System" Florida Solar Energy Center FSEC-PF-365-01, April 2001, Revised July 2002, Presented at the Affordable Comfort Conference 2001, April 30-May 5, 2001, Milwaukee, WI.

1.3 Definition of Interior Ducts

Duct work is used to transport conditioned air to and from occupied rooms. Typically, this duct work is in unconditioned space, such as the attic or crawlspace. Interior ducts result from bringing the duct work inside a home's thermal and air barrier. This concept involves positioning the entire forced air system, including the air handler, within the conditioned space—particularly within the air and thermal boundary. The primary challenges of this approach involve establishing an air barrier around the ducts and integrating the new detail into the design and construction process.

1.4 Styles of Interior Ducts

1.4.1 Fur-up Chase

A modified truss system can create a space for a sealed and insulated duct chase above the ceiling. Observed from the living area, the fur-up chases are hidden by the finished ceiling, whereas from the attic, they appear as a boxed out area covered with insulation (Figure 1).

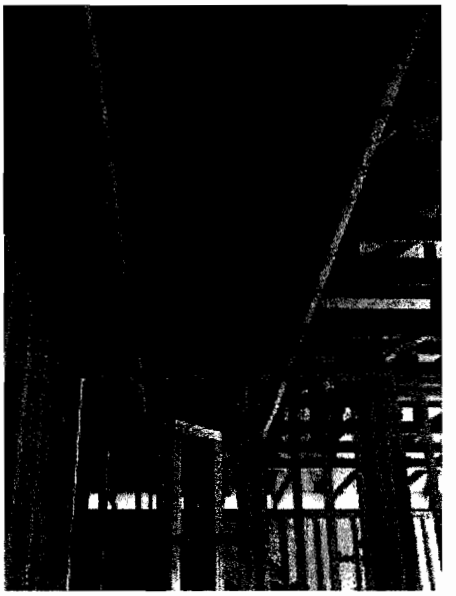


Figure 1. Fur-up chase installed after rough framing.

1.4.2 Fur-down Chase

A fur-down chase of framed soffits creates space for ducts to be installed below the ceiling. Chases furred-down into the conditioned space generally occupy the upper portion of hallways, run along walls, and/or cut across open living areas as architectural elements (Figure 2).

Figure 2. Fur-down chase after rough framing.

1.4.3 Sealed Attic or Crawlspace

A sealed space for ducts can be created by moving the air and thermal barrier to the exterior plane of the attic or crawlspace. Relocating the thermal and air barriers of the house to the outer

edges of the structure creates either an insulated roof deck (Figure 3) or foundation walls (Figure 4). The space containing the ducts is not vented to the outside and is often conditioned. This quasi-conditioned space, within the home's air and thermal barrier, can be a good location for a duct system.

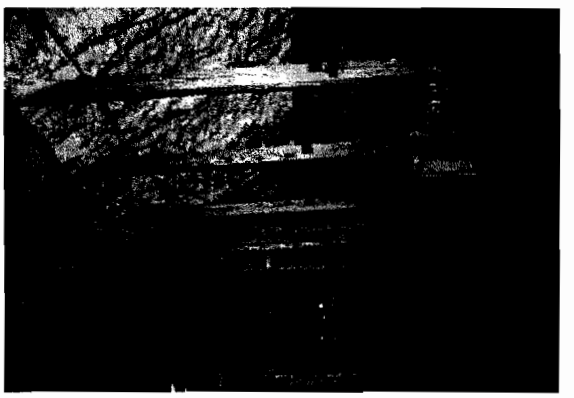


Figure 3. An unvented attic constructed by air sealing the roof deck with foam insulation. Note how the attic duct is now within the home's air and thermal barrier

Figure 4. A sealed crawlspace by air sealing the foundation walls with foam insulation.

1.5 System Advantages and Disadvantages

Interior duct work can curtail or eliminate some of the negative effects of duct leakage. Benefits include energy savings, improved indoor air quality, and increased system life. A significant body of literature exists to support the implementation of interior duct systems. An excellent literature review of the subject and demonstration of interior ducts for site built production housing in the Pacific Northwest is available (Lubliner, Kerr, Gordon, and Murray 2008). In this marine climate, simulations show that compared to base case leaky ducts, interior ducts can save between 9% and 28% in heating energy costs and between 8% and 17% in cooling energy costs (Hales and Baylon 2010). For manufactured housing in hot humid climates, prototype homes with interior ducts were built by two manufacturers, and experiments were conducted to determine savings, which yielded up to 20% savings (Moyer, N., Stroer, D., Hoak, D., McIlvaine, J., and Chandra, S., 2008). Changing from sealed ducts in a vented attic to an interior fur-down system resulted in cooling energy savings of 17% for a SEER 21 HVAC and 11% for a SEER 13 HVAC. These results were determined in controlled experiments using a 1,600 sq. ft. HUD-code manufactured home research facility at the Florida Solar Energy Center facilities in Cocoa, FL, and is also discussed later in this guideline (Cummings and Withers. 2010).

On the other hand, interior duct implementation requires a greater degree of trade coordination, which can be difficult to facilitate. This coordination is best accomplished by a site meeting after house dry-in. This meeting should include the designer, sales/marketing professionals, and mechanical, insulation, plumbing, electrical, framing, drywall and solar contractors. Oversight duties are increased for the site supervisor. A quality installation is difficult to establish and maintain throughout the construction process.

There can be additional costs for materials, such as foam insulation, custom trusses for a fur-up installation, or additional framing and drywall. A more expensive duct system (duct-board versus flex-duct) may be required due to space limitations.

Payback is impacted by other efficiency improvements, often to the point of negative cash flow, depending on the expense of the method employed. Therefore, cost benefits are seldom the sole motivation for implementation.

1.5.1 Fur-up Chase

Fur-up chases are hidden from view once the home is built and the attic is insulated. As a result, duct size and ceiling heights are less of an issue than encountered in fur-down chases.

A fur-up chase is a kneewall into the attic, and must be insulated like a kneewall. The sides of the chase are difficult to insulate (Figure 5), and damage may not be easy to detect. In addition, any misstep in the attic can result in future damage to the structure. If trusses are used, a new truss package is needed (Figure 6). Since fur-ups are more obvious from the attic than fur-downs, they are more likely to be targeted for wiring and plumbing runs, compromising the required air and thermal barrier (Figure 7). Overall, the chase needs to be carefully inspected before the builder releases the house.

Figure 5. Poorly insulated fur-up chase sides.

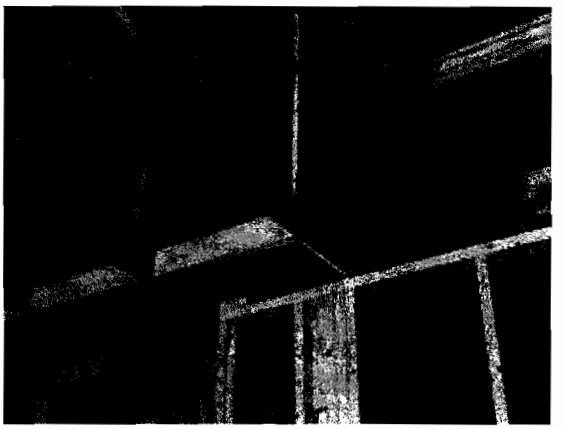


Figure 6. Modified truss work necessitated by fur-up chase.

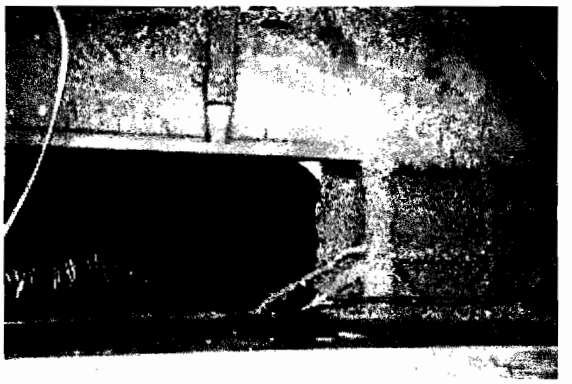


Figure 7. Fur-up chase deliberately used for wiring runs. Also note the poor overall insulation of the chase.

1.5.2 Fur-down Chase

Fur-down chases are more visible than fur-up chases, and can add architectural detail. By inserting dropped soffits in strategic areas, one can define the character of the interior spaces (Figure 8).

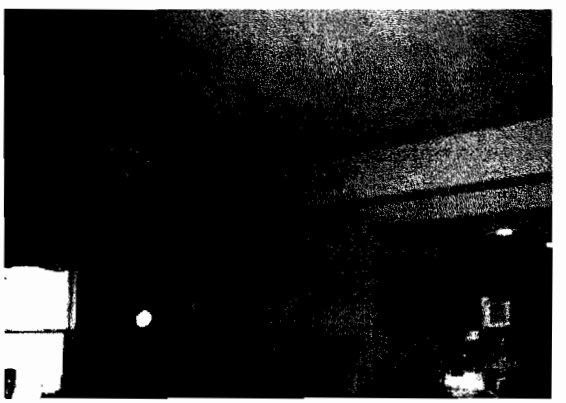


Figure 8. A fur-down chase used for architectural detail.

Multiple job site visits from the framers and the drywall crew are often required when building the chase. Due to size limitations, fur-down chases often need rigid ductboard duct; flex duct often results in a chase that is too large to maintain aesthetics. Ceiling heights cannot be less than

7'0" to meet code and allow for door framing. For homes with 8' ceilings, that allows 12"or less for the ducts and the structure of the chase. This type of duct system also limits register size and placement.

1.5.3 Sealed Attic or Crawlspace

A sealed attic or crawlspace is very easy to implement in new construction, often no more than a specification change and a new subcontractor. If installed correctly, quality spray foam installations easily maintain the integrity of the air barrier and thermal barrier. They also provide for a very airtight attic or crawlspace. The purpose of foam insulation is usually evident, and its location is often far from other trades' work areas. As a result, there is less post-installation damage, and small breaches can easily be repaired with canned foam.

However, foam is significantly more expensive than conventional insulation products, which, in combination with thickness limitations of the applied foam, often leads to lower R-value installations than found with conventional insulation. When insulating a roof deck, due to the roof's pitch, there is more area to be insulated than if the insulation is conventionally located at the attic floor.

In foam installations. the ceiling drywall (or crawlspace ceiling) is not typically insulated (R-value of drywall less than 0.5, versus a typical attic floor of R-19 or more). This space's temperature needs to be kept within a few degrees of the interior space. If the sealed attic is unconditioned, the temperature differences between the attic and the living spaces will rise, resulting in massive heat flux into the house (a 1° temperature difference across drywall(R -0.5) is equivalent to a 38° temperature difference or more across an R-19 ceiling), defeating the effort of sealing the attic to save energy. Typical methods of keeping the sealed attic cool include supply and return ducts in the space, or registers installed in the chase to allow room air to passively enter the chase.

In crawlspaces, the difficulty is less temperature-related and more moisture-related. If a sealed crawlspace is adopted and conditioned, great care must be taken to provide a long-lasting seal. The effect of workmen crawling on 6-mil poly ground cover products is usually a rip, ruining the moisture barrier that the system is relying on. In hot-humid climates, humidity levels can quickly build up in a crawlspace with a poorly sealed floor (Beal and Chasar, 2006). In these and other poorly carried out crawlspace sealing efforts where conditioned supply (and return) air is ducted to the crawlspace, very poor indoor air quality in the house can result. If contemplating a sealed crawlspace, consider a more substantial floor covering. There are products available that more resemble a pool liner than 6-mil poly, and should provide a long lasting seal. A concrete "rat slab" for the floor of the crawlspace would be ideal. Sealing around any piers and pipes in the crawlspace is also challenging, and care must be taken to insure a thorough job.

Building code officials are now beginning to recognize the validity of sealing attics and crawlspaces, but the local authority should be consulted to ensure that no code issues arise with a sealed attic or crawlspace. Be especially attentive to fire codes, as foam is unlikely to meet fire resistance standards, often requiring sealing with a second coating, or encapsulation in drywall to provide the necessary fire resistance rating. A sealed crawlspace is not a viable option in areas where heavy flooding is a concern.

2 Document Inspections

2.1 Floor Plan Appropriate for Implementation

Let the guiding principal for building an interior duct system be the establishment and maintenance of an air barrier between the duct system and the exterior of the building. After an air barrier is established, a thermal barrier in the same location is needed.

In situations where a sealed attic or crawlspace is selected, the floor plan is not a significant factor in the implementation of interior ducts as this construction detail is amenable to most floor plans. These sealed assemblies allow the duct system to be installed as it typically would be, but the system benefits from being "interior" by virtue of the new location for the air and thermal barrier.

In ranch-style homes (homes with all bedrooms grouped together at one end of the house and incorporating a main hallway), a chase can run the length of the hallway (flanked by bedrooms) and extend out into the main living area. In split-plan homes (homes with bedrooms on either end of the house and separated by the main living area) a duct chase can run from the master bedroom area, across the main living area, and into the other bedrooms. Whereas the hallway fur-down makes use of the upper portion of the hall walls (Figure 10), chases in open areas are built out from one wall and down from the ceiling framing (Figure 8), or are free-standing chases built down from the ceiling (Figure 11).

Prior to committing to an interior duct system with a chase, a sizing calculation must be performed to ensure the chase can accommodate large enough ducts to deliver the required air. Space issues can occur in houses with an 8' ceiling height. With information derived from the HVAC designers' ACCA Manual J and D calculations, the home designer can finalize plans that consider the size requirements and path of the distribution system.

The air handler can be located either centrally or at one end of the chase, but as the heart of the duct system, it must be inside the conditioned space. Unless a sealed attic or crawlspace will be the air handler's home, this requires the construction of an air handler closet (Figure 9). Building America researchers have found that the idea of a sealed air handler closet is not often understood (McIlvaine, Beal and Chandra, 2009). In hot-humid climates where gas heating is used, the inexpensive, naturally aspirated furnace unit is often placed in an interior closet, and combustion make-up air is provided by leaving the ceiling of the air handler closet open to the attic. This practice carries over into heat pump or A/C combined with strip heat installations, as it has become a regional standard practice. This has obvious impacts on the houses' air and thermal barriers and must be dealt with prior to contemplating an interior duct system. The following is an implementation Checklist for Moving AHU from the Attic to an Interior Closet:

- ☐ Develop closet design with mechanical contractor
  - o Revise Manual J and Manual D calculations
  - o Size return opening per Manual D calculations
  - o 8" recommended clearance on all sides of air handler to improve accessibility
  - o Condensate location may need to be moved
- ☐ Integrate closet design with floor plan
  - o Reflect changes on mechanical, electrical, and plumbing plans
  - o Truss design and layout must accommodate supply plenum

- Provide closet elevations as needed
  - Show return grill rough opening dimensions
  - Indicate filter location
  - Locate thermostat, condensate drain line path
  - Locate outside air ventilation duct and damper
- Provide section of closet to explain construction
  - Show drywall (green board ok) lining for entire closet including ceiling
  - Show framing details for AHU platform – constructed inside drywall lining
  - Show blocking for return air grill
  - Indicate air sealing points
    - Seal all edges and seams in drywall lining with code-approved sealant – recommended materials include drywall mud, mastic, fire rated caulk, and fire rated foam
    - Seal around supply plenum
    - Seal between all framing members in rough opening for return grill
    - Seal all wiring and plumbing penetrations through the drywall and AHU platform

☐ Develop quality assurance checklist for interior AHU closet

☐ Call subcontractor attention to new details
- All changes should be reflected in construction documents, specifications, and emphasized in a cover letter
- With slab-on-grade floors, plumber must install condensate drain line before slab is poured

☐ Provide materials (drywall and sealant) for roughing out and finishing closet prior to mechanical rough-in

☐ Complete quality assurance checklist for interior AHU closet prior to mechanical rough-in

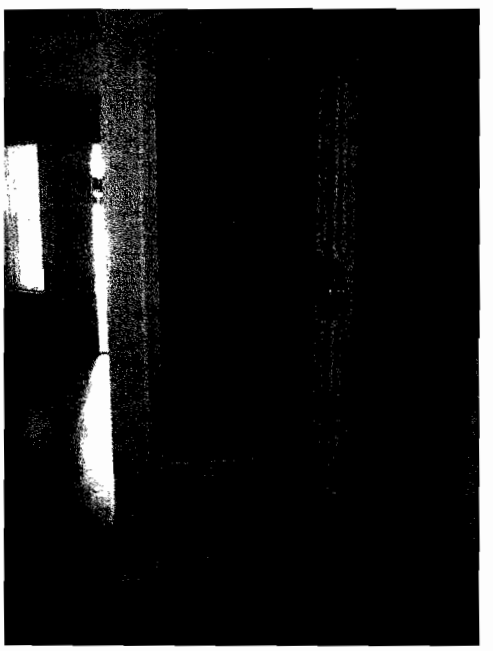


Figure 9. Air Handler Closet

To locate a fur-up or fur-down chase in a specific design, start by examining the plan for an obvious path. To avoid long run-out ducts, the chase should trace a path down the center of the house and go to all spaces to be served. Otherwise, small supply runs in unconditioned spaces or excessive chase construction will be required to reach distant rooms. Align the central chase with closets, cabinets, or transverse halls to achieve coverage of all rooms.

As in all duct systems, adequate return ducting must be provided. To avoid an entire extra chase, ducted returns are not recommended. A passive system using transfer ducts of some type is preferred. For a guide on duct sizing, including return ducts, transfer ducts and supply ducts, please find Building Science Corporation's Information Sheet at: http://www.buildingscience.com/documents/information-sheets/information-sheet-transfer-grilles-and-ducts. This Information sheet is linked to several other documents that go into great detail about duct sizing and its ramifications. A very crude, but effective, rule of thumb for passive return sizing (a central return with passive returns from each room, as opposed to a fully ducted return) is to allow 1.5 times the return area as the total supply area.

Often it is tempting to use the chase as a "ducted" return to the air handler, as the chase goes to all rooms. This practice is not currently recommended because reliable sealing of the chase from surrounding unconditioned spaces has proven difficult to achieve. Any leakage in the chase air barrier can cause severe return leaks. This is similar to the difficulties found with using building cavities as ducts, such as panned floor joists. Additionally, even if the chase is properly sealed from the surrounding unconditioned space, the chase would need to be significantly larger to accommodate the necessary return air flow.

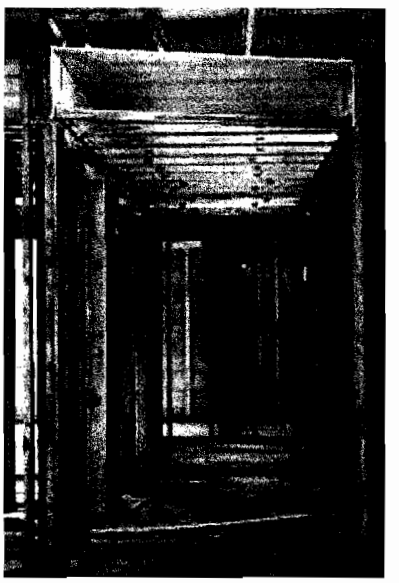


Figure 10. Fur-down chase in hallway. Note the restricted space for the chase due to the 8 ft ceiling height. Note the space-saving, light gauge metal framing at the bottom of the chase.

Figure 11. Free-standing chase in open area of floor plan.

Be sure that the mechanical contractor takes the location of the ducts into consideration for system sizing calculations and the size of the chase (less than 12" clearance for 8' ceilings) (Figure 10) for duct sizing calculations. The duct design should incorporate sizing and design considerations to allow adequate air distribution into all rooms. Fur-down chase systems are difficult to use with a perimeter duct installation, as the chase typically runs down the center of the building for ease of construction.

The top of a fur-down chase should be uninterrupted by framing. Miscellaneous bracing that interrupts the upper air barrier creates additional cutting, fitting, and sealing work. In most cases, the air barrier will be made of an air-tight material (e.g. drywall, rigid insulation) sealed at the edges and seams, and the thermal barrier will consist of ceiling insulation installed over the top of the chase plus the insulated sides for fur-ups.

Though floor cavities between upstairs and downstairs are often thought of as being in conditioned space, it is rarely the case. The floor cavity is often not bound by a definitive air barrier. However, with careful attention to sealing and insulating the perimeter of the floor cavity, ducts in floor cavities can be a viable interior duct option. Historically, the EPA ENERGY STAR for New Homes Program has mandated sealing the band joist between floors.

2.2 Non-Energy Advantages

2.2.1 Indoor Air Quality

IAQ is improved by eliminating duct leakage. Unconditioned areas, such as attics and crawlspaces, harbor dirt and allergens which duct leakage can force into the conditioned space, either through duct leakage or via pressure imbalances caused by inadequate return pathways. A properly executed interior duct system eliminates duct leakage and its related infiltration and exfiltration problems.

2.2.2 Equipment Life

Equipment life will be improved by eliminating the dirt, contamination, moisture and heat the system is exposed to in unconditioned attics and crawlspaces. Component life is increased by removing equipment from areas of excessive thermal excursions, dirt, and moisture.

2.2.3 Aesthetics

A fur-down chase has the potential for enhancing home aesthetics by adding architectural interest and defining interior spaces (Figure 11). A sealed attic or crawlspace can provide an alternate "interior" location for the air handler (and water heater), which in turn, increases usable floor space in the home.

2.2.4 Occupant Comfort

An interior duct system can improve occupant comfort by eliminating pulses of hot/cold air upon equipment start. In cases where the duct systems, and sometimes the air handler, are located in an extreme environment such as a hot or cold vented attic or crawlspace, the air initially delivered into the conditioned space on equipment start can be uncomfortably cold or warm (Figure 12).

Figure 12. Air handler and duct system installed in a conventional attic. A relatively large volume of air becomes trapped in the system between runtime events, and can encounter significant heat gain/loss to the point where it can cause comfort issues when introduced into the home's interior.

2.3 Risk Identification

Once the decision is made to build an interior duct system the builder must make a clear and consistent commitment. Then, this commitment must be communicated to all of the relevant trades and all involved parties (trades, designers, architects, etc.) must be dedicated to this task. Two critical trades are the home and HVAC design professionals. The best opportunity to minimize costs while ensuring an aesthetically pleasing outcome is during the preliminary schematic design phase of the home. Failures here will likely result in a poorly implemented end product.

An interior duct system should be planned during a home's design stage, prior to interior framing, since it would be difficult, but not impossible, to implement after this stage. An interior duct system is not often suitable for retrofit unless a sealed attic or crawlspace is created.

2.3.1 Duct Leakage Overview

Conventional forced air heating and cooling systems employ an air distribution system that includes an air handler and a duct system. The air handler is designed to remove air from the house, condition it, and supply it back to each room.

Duct leakage can occur on either the supply side or the return side of the air handler, as well as in the air handler itself. Both supply and return leaks cause air to move in unplanned, unpredictable ways, usually through unconditioned spaces and often bypassing air, thermal, and moisture barriers, as well as air filtration systems.

2.3.1.1 Supply Leak

When supply ducts are located outside the home's air barrier leak, they create a negative pressure within a house because more air is being removed from the interior than is being supplied back to the interior. This negative pressure results in air being drawn from outside and/or unconditioned spaces (uncontrolled infiltration) through holes in the home's air barrier potentially leading to:

- Back drafting of atmospheric combustion devices
- Introduction of outside air pollution, pollen, and other allergens
- Introduction of airborne particles (dust, insulation, building material particles) from floor, wall, ceiling cavities
- Degraded comfort (temperature, humidity)
- Greater space conditioning load
- Reduced system life.

Supply leaks also spill conditioned air into unconditioned spaces, wasting energy and creating the potential for mold growth, condensation, and rot.

2.3.1.2 Return Leak

When return ducts leak, part of the return air is drawn from the outside or unconditioned spaces instead of the interior. This air can be dirty, and it often bypasses the system's filter. The leakage creates a positive pressure in the house because more air is being supplied than is being removed. The positive pressure forces air through holes in the home's air barrier (uncontrolled exfiltration). Return duct leakage leads to:

- Lowered heating and cooling capacity with degraded comfort.
- Introduction of outside and/or unconditioned air into the air handler, with its attendant moisture, dirt, and pollutants.
- Increased conditioning load
- Reduced system life.

2.3.1.3 Inadequate Return Paths

In rooms that can be isolated from a central return by door closure (bedrooms, studies, bonus rooms, etc.), a return pathway for the supply air must be provided. An inadequately returned room accumulates internal pressure when the door is closed during air handler operation. In turn, the main body of the house is placed under negative pressure. These pressure differences exist even if the duct system is leak-free. The pressure excursions seen are further exacerbated by tight construction techniques that reduce infiltration/exfiltration paths. For sizing guidance, please

refer to Building Science Corporation's Information Sheet at: http://www.buildingscience.com/documents/information-sheets/information-sheet-transfer-grilles-and-ducts. This Information sheet is linked to several other documents that go into great detail about duct sizing and its ramifications

Adequate return pathways must be provided to all occupied rooms where doors may be closed for extended periods of time. Door undercutting and other crude methods rarely provide adequate area to accommodate the amount of supply air. A ducted return system must be carefully sized to avoid pressure imbalances due to mismatched flow rates. For a ducted return to be considered an interior duct system, it needs to be in a chase, or a sealed attic or crawlspace. For these reasons, a passive return system with jump ducts (Figure 13), transoms (Figure 14), or through-the-wall transfers combined with a central return are recommended. A crude sizing rule-of-thumb for passive returns is to allow 1.5 times the net free area of return as supply.

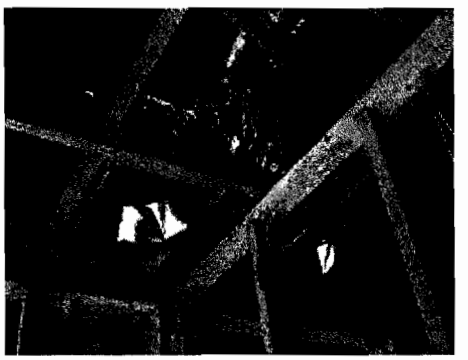


Figure 13. A jump duct through the attic. This will provide return air, over the interior wall. Note this is not an interior duct unless the attic is sealed.

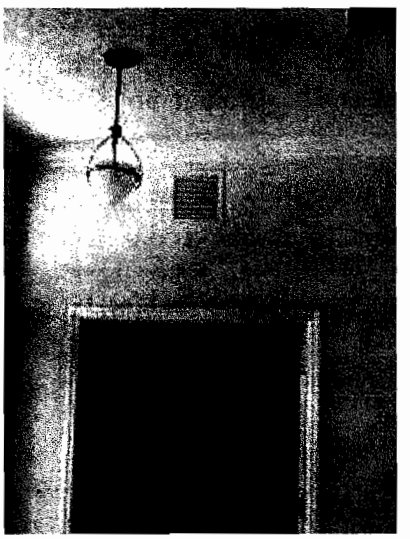


Figure 14. Transom return pathway, through the wall, over doorway of a master bedroom.

2.3.1.4 Total Duct and Duct Leakage to the Outside

Duct leakage can occur anywhere in a duct system. Leakage that remains in the conditioned space, for instance leakage around registers poorly sealed to the wall or ceiling, or leakage from

an air handler installed in an interior air handler closet, is known as leakage to the inside. Of significant concern is the duct leakage that results in air leaking to or from areas outside of the conditioned space, which is known as leakage to the outside.

Typical home energy audits should make two measurements of duct leakage: 1) total leakage, which includes both leakage to the inside and outside and 2) leakage to the outside, a measurement that excludes the leakage to the inside. Correctly installing ducts in the interior of the building should eliminate duct leakage to the outside.

2.3.2 Assumption That Since the Chase is Sealed, the Ducts Can Be Leaky

The authors and the builder partners of this study agree that it is easier to create an air tight duct system than it is to create an airtight chase. They also agree that it would be a mistake to assume that tight duct systems are not needed when the ducts are placed in an interior chase. Leaky ducts placed in leaky chases will not provide the desired energy or health benefits; whereas, an airtight duct system in a leaky chase still derives some of the energy benefits of interior ductwork without causing the building durability and health problems typically associated with leaking duct work. As it is very hard to insure that the chase will be isolated from ambient conditions, insulated duct work should still be used to avoid any condensation potential from humid air entering the chase.

2.3.3 Trade Sequence and Interference

Installation of a fur-up/down chase will alter the order of trades on the job. As a result, carpentry and drywall workers must construct the chase prior to their normal schedule.

Often the proposed location of the chase is likely to interfere with other trades. Therefore, the chase location should be identified prior to construction to avoid interference. Typical problems arise when other trades viewing the chase fail to understand its purpose and use the space for their wire (electrician, phone, and cable/alarm installers) or pipes (plumbers and the HVAC contractor). Hence, it is important to protect the chase from other contractors who may want to use it as a convenient run. Otherwise, the resulting holes will compromise the air barrier and defeat the intent of the chase.

Communication is an important factor in preventing this issue. Advisory notices to cable, security, and phone installers should be posted in conspicuous locations such as the panel box, attic access hatch, wiring service entrance, etc. Since these notices cannot clearly identify the location of the air boundary, they should advise the installer to seal any penetrations to drywall made from unconditioned spaces. Though it should be standard practice, and is often required by code, virtually all services that are installed post-occupancy are never inspected.

2.3.4 Code Issues

The 2009 International Energy Conservation Code (IECC) recognizes sealed crawlspaces (402.2.9) and attics (402.2.2), but not all municipalities have adopted this (or any) energy code. If contemplating a sealed crawlspace, ensure that there is no flooding issue in the location selected, as flood concerns are of higher importance than energy concerns. Sealed attics can also present code issues, especially due to fire codes. If the attic or crawlspace is defined as conditioned space (or, in some cases, merely served by supply and returns) the foam may have to comply with NFPA 2009 12.5.5.3 requirements for fire resistance, combustibility, and smoke

release standards (NFPA 286, ANSI/UL 1715 and 1040, and FM4880 are test standards to look for). Sealed attics have the potential to increase the conditioned square footage of the house, therefore affecting its tax base. Failure to pre-approve the design features desired can result in slow permitting and failed inspections. Ultimately, it can result in abandonment of the attempt due to lack of communication with local officials. It is typically more difficult to beg forgiveness from code officials than to seek approval prior to construction.

Ceiling height can be a code issue with fur-down chases, mainly in houses with 8' ceilings. Minimum duct sizes can challenge the typical 7' ceiling height code requirement. To minimize the space needed for the chase structure, detail the smallest available framing member that will support the weight of the drywall (for the bottom of chase) and ducts (if not supported by straps). This might be 2 x 2s or light gauge metal framing (Figure 10).

3 Trade-offs

After opting for an interior duct system, the next decision is to determine which method will be pursued. The implementation methods are either via chase constructions, or sealed attic/crawlspace systems.

3.1 Cost vs. Performance

The initial cost of an interior duct system is somewhat fixed by the floor plan of the home. However, although interior duct work can lead to energy savings, the magnitude of the resulting energy savings from this measure is affected by the home's heating/cooling load. As the home becomes more energy efficient through envelope or other improvements that reduce heat gain/loss, the cooling and heating portion of the home's energy consumption drop proportionally. Therefore, for a given floor plan, the payback period to recoup the added cost of the interior duct system is dependent on the overall efficiency of the home. As the home's other systems become more efficient, an interior duct system becomes less financially appealing.

Higher efficiency, multi-capacity HVAC units may operate for nearly twice as many hours per day as single-capacity systems. Conductive and air leakage losses of the duct system can have a greater impact on these types of systems because conditioned air remains in the ductwork for longer periods of time.

3.2 Cost and Issues for the Various Systems

3.2.1 Sealed Attic

Sealed attics constructed with a spray foam are easy to implement, easy to inspect, and fairly obvious in their function. For attic installations, the roof deck and soffit area needs to be sealed to provide the "interior" space for the ducts (and sometimes air handler). Sealed attics and crawlspaces also provide more desirable areas for storage than their vented counterparts. Additional framing and air barrier material is often needed to separate the attic over the living space from the attic over garages and porches.

In foam installations the ceiling drywall (or crawlspace ceiling) is not typically insulated (R-value of drywall less than 0.5, versus a typical attic floor of R-19 or more). This space's temperature needs to be kept within a few degrees of the interior space. If the sealed attic is

unconditioned, the temperature differences between the attic and the living spaces will rise, resulting in massive heat flux into the house (a 1° temperature difference across drywall (R -0.5) is equivalent to a 38° temperature difference or more across an R-19 ceiling), defeating the effort of sealing the attic to save energy. Typical methods of keeping the sealed attic cool include supply and return ducts in the space, or registers installed in the chase to allow room air to passively enter the chase.

If the attic or crawlspace is defined as conditioned space (or, in some cases, merely served by supply and returns) the foam may have to comply with NFPA 2009 12.5.5.3 requirements for fire-resistance, combustibility, and smoke release standards (NFPA 286, ANSI/UL 1715 and 1040, and FM4880 are test standards to look for).

Currently, foam products are significantly more expensive than conventional blown insulation products. This cost difference is further exaggerated by the roof's pitch. The steeper the roof's pitch, the larger the area that must be insulated. Further, this increased surface area is now the thermal barrier, resulting in a larger heat transfer area between the conditioned space and the ambient.

These factors are quantified in Table 1. One of the builder partners in this research builds a 5000 ft^2 house with 10' ceilings. This partner implemented interior ducts both through a fur-down chase (technique outlined in section 4) and through sealed attics. The impact of roof pitch on conditioned volume and heat transfer area becomes significantly noticeable when examining these houses. Homes with two different roof pitches, 9 in 12 and 4 in 12, each with 5000 ft^2 of interior floor space and 10' ceilings, are illustrated in the following table.

Important Definitions

- **Interior Ducts**: Involves positioning the entire forced air system, including the air handler, within the conditioned space - particularly within the air and thermal boundary.
- **Fur-up Chase:** Space for a sealed and insulated duct chase above the ceiling; it is hidden from view once the home is built and the attic is insulated. These systems often involve modified truss systems to accommodate the chase.
- **Fur-down Chase:** Creates space for ducts to be installed below the ceiling and generally occupies the upper portion of hallways and/or cuts across open living areas, etc. as architectural elements.
- **Sealed Attic or Crawlspace:** Created by moving the air and thermal barrier to the exterior plane of the attic or crawlspace. The space containing the ducts is not vented to the outside and is often conditioned. Easy to implement in new construction.
- **Duct Leakage:** Can occur on either the supply side or the return side of the air handler, and in the air handler itself. Supply and return leaks cause air to move through unconditioned spaces and bypass air, thermal, and moisture barriers.
- **Supply Leak:** Spills conditioned air into unconditioned spaces, wasting energy and creating the potential for mold growth, condensation, and rot. When supply ducts are located outside the home's air barrier, negative pressure can draw outdoor air inside a house.
- **Return Leak:** When return ducts leak, part of the return air is drawn from the outside or unconditioned spaces instead of the interior. Return duct leakage leads to: reduced heating and cooling capacity with degraded comfort; introduction of outside and/or unconditioned air into the air handler, with its attendant moisture, dirt, and pollutants, increased conditioning load, and reduced system life.
- **Blower Door Testing**: Involves depressurizing the house to a standard pressure with respect to the outside, usually 50 Pascals. Depending on the pressure size, a determination can be made regarding the integrity of the interior duct system.
- **Duct Blaster Testing**: Two tests can be performed with the duct blaster, one that measures the leakage of the entire duct system—both into the interior and exterior of the house, and a second test that measures the duct leakage to the exterior of the building only.

Table 1. Impact of roof pitch on volume and heat transfer area.

Parameter	Unvented Attic 9:12 Roof	Interior Ducts 9:12 Roof	Unvented Attic 4:12 Roof	Interior Ducts 4:12 Roof
Floor Area (ft^2)	5,000	5,000	5,000	5,000
House Volume (ft^3)	50,000	50,000	50,000	50,000
Roof Pitch (Rise/run)	9/12	9/12	4/12	4/12
Additional Volume (ft^3)	37,000	0	16,500	0
Heat Transfer Area (ft^2)	7,800	5,000	5,270	5,000

Material cost is an additional concern. For the same builder and house plan as shown in Table 1, Table 2 shows the cost breakdown for a sealed attic created via a spray foam roof deck versus using radiant barrier sheathing (RBS) decking, and conventional R-38 attic insulation combined with interior duct work via a fur-down chase. Quotes were solicited in the spring of 2010 in the Gainesville FL, area. R-21 spray foam insulation was quoted at \$1.54/ft^2 of applied area, and R-38 conventional attic floor, blown insulation was quoted at \$0.50/ft^2 of applied area. Radiant Barrier System (RBS) decking added \$0.19 ft^2 of installed decking.

The 5000 ft^2 home used as an example in Tables 1 and 2 had significant duct systems, due to the home size and design, and need for two HVAC systems, resulting in a cost of \$0.70 ft^2 for the interior ducts. These prices can be further reduced by judiciously decreasing the amount of chase and by also eliminating any return chase via the use of passive transom returns from each closeable room. Another partner builder built a 2250 ft^2 home with passive returns and implemented interior ducts for \$0.39 ft^2, as shown in Table 3.

Table 2. Cost comparison of two interior duct methods for differing roof pitch, Partner 1.

Parameter	Unvented Attic 9:12 Roof	Interior Ducts 9:12 Roof	Unvented Attic 4:12 Roof	Interior Ducts 4:12 Roof
Floor Area (FA, ft^2)	5000	5000	5000	5000
Heat Transfer Area (HTA, ft^2)	7,800	5000	5,270	5000
Insulation R-Value	21	38	21	38
Insulation Cost (\$/ft^2 HTA)	\$1.54	\$0.50	\$1.54	\$0.50
Insulation Cost (\$)	\$12,000	\$2,500	\$8,100	\$2,500
Insulation Cost (\$/ft^2 FA)	\$2.40	\$0.50	\$1.62	\$0.50
Interior Chase System Cost (\$)	N/A	\$3,500	N/A	\$3,500
Int. Chase Syst. Cost (\$/ft^2 FA)	N/A	\$0.70	N/A	\$0.70
Radiant Barrier Cost (\$/ft^2)	N/A	\$0.19	N/A	\$0.19
Radiant Barrier Cost (\$)	\$0	\$1,480	\$0	\$1,000
Total Cost (\$)	\$12,000	\$7,480	\$8,100	\$7,000
Total Cost (\$/ft^2 FA)	\$2.40	\$1.50	\$1.62	\$1.40

Table 3. Cost Comparison of two interior duct methods, Partner 2.

Parameter	Unvented Attic	Interior Duct
Floor Area (FA, ft²)	2,250	2,250
Roof Pitch	7/12	7/12
Heat Transfer Area (HTA, ft²)	2,520	2,250
R-Value	21	38
Insulation Cost ($/ft² HTA)	$1.54	$0.50
Insulation Cost ($)	$3,880	$1,125
Insulation Cost ($/ft² FA	$1.72	$0.50
Interior Duct System Cost ($)	N/A	$875
Interior Duct System Cost ($/ft² FA)	N/A	$0.39
Radiant Barrier Cost ($/ft²)	N/A	$0.19
Radiant Barrier Cost	$0	$480
Total Cost ($)	$3,880	$2,480
($/ft² Floor Area)	$1.72	$1.10

3.2.2 Sealed Crawlspace

When flood concerns are not an issue, a sealed crawlspace (Figure 4) offers clear energy and moisture advantages to a home. Since a home in a hot-humid climate benefits from ground coupling, crawlspace floor insulation impairs cooling efficiency. This method provides a significant savings in materials when insulating the walls of a crawlspace versus the floor of the house over the crawlspace. Additionally, by correctly sealing the crawlspace's earthen surface with a Class 1 vapor retarder, a significant source of interior moisture is eliminated. When contemplating a sealed crawlspace, all ground covers are not created equally. Six-mil poly is fairly fragile flooring; any trades people (or storage motivated homeowners) can quickly tear the poly, allowing ground moisture into the crawlspace, a significant moisture source (Beal and Chasar, 2006). There are crawlspace floor coverings that are similar in strength to a pool liner, or for the most secure and permanent method a thin "rat slab", with a vapor barrier included, under the crawlspace is an ideal solution.

When air conditioning was first developed for residential use, building designers placed an emphasis on maximizing ventilation and other passive cooling strategies. Due to a lack of insulation, these early HVAC designs dictated placement of supply air outlets overhead to enhance convective distribution. Outlets were also placed near heat sources, such as windows, to avoid hot spots in the rooms served. This bias still exists today, especially the trend to keep cooling ducts overhead. Placing ducts in sealed crawlspaces will require floor registers.

Efficient enclosure and assembly technologies enabling more even temperature distribution throughout a home have reduced the existence of hot spots, however these technologies, coupled with efficient HVAC equipment operating at lower air flow rates, may dictate a return to overhead systems in cooling-dominated climates. This may be required to reduce temperature stratification in the rooms served. In hot-humid climates, supplemental humidity control strategies further lower the system air flow rates, exaggerating the potential problem.

Due to implementation ease and obvious energy and material savings, sealed crawlspaces with duct work installed therein warrant further investigation in hot-humid climates. Sealed

crawlspaces, by their construction, are easily made into interior space. Hence, they are ideal locations for an interior duct system.

Sealed crawlspaces are clearly not applicable in areas subject to drainage or flooding issues that mandate vented crawlspaces, or post and pier foundations. Always be certain that a sealed crawlspace as designed will meet all codes (FIRE CODE) and pass local inspection.

3.2.3 Fur-up Chases

Fur-up chases offer the advantages of interior duct work without the size restraints that aesthetics and practicality dictates for a fur-down system. Once the ceiling below the chase is installed, all evidence of the chase is hidden from view as the chase is in the attic.

Fur-up chases require modification of the truss package (if trusses are used) for the house, and therefore must be carefully preplanned (Figure 6). Large chases may require significant truss engineering. The designer and HVAC contractor must work in tandem to achieve good results in a fur-up system.

Due to its hidden nature, a fur-up chase is susceptible to unnoticed damage. Accidental or deliberate breaching of the chase air barrier, creating an air pathway into the attic, is often difficult to recognize, which leads to the ducts actually being exposed to the attic environment instead of isolated from it (Figure 7).

Critical Take-Aways for Fur-Up Chases:

- The first step after completing the design work is to have the chase ceiling sheet rock installed as indicated in the design plan.
- The supply ductwork is installed under the drywall after being fabricated and sealed on the ground as much as practical.
- After the duct work is sealed and hung, the rest of the chase is constructed and installed to provide nailing surfaces for the remaining drywall.
- A method to reduce the size of the chase - By field fabricating a shallow duct board box and affixing it directly to the trunk line, the width of the chase can be reduced by almost a foot (Figure 29 and 30). This improved method provides better air flow, greater design opportunities, and reduced costs.

Insulation of the fur-up chase's sides is difficult to apply and maintain (Figures 5 and 7). The chase sides are effectively knee walls that are part of the house's air and thermal barrier. The chase sides need to be insulated, preferably to the same level as the rest of the attic, without gaps or voids, and bound on all six sides with an air barrier. The product used needs to remain in place for the life of the chase.

3.2.4 Fur-down Chase

A fur-down chase is defined by its continuous air barrier between the chase and the attic above. By concentrating on a continuous air barrier at the top of a fur-down chase, this method can be successfully implemented at a fairly low cost. Section 4.4 outlines a simple, affordable method of creating a compact fur-down chase for an interior duct system. It was implemented by two of Building America's builder partners in Gainesville, FL.

Fur-down chases comprise three typical categories:

- *Chases above a dropped ceiling in a hallway, foyer, etc.* - In this case, both sides of the chase are formed by the walls of the space. The bottom of the chase has to be framed (Figure 15)

- *Perimeter chases along one edge of a room* - In this case, one side of the chase is formed by a wall. The other side has to be framed using the ladder type approach. Framing contractors are familiar with this type of framing, which they call a "step up ceiling". It is sometimes used to create architectural interest (Figure 16).

    - If the chase runs along an exterior wall, the wall needs to be insulated before the chase drywall is installed. If blown-in cellulose or foam insulation is used, ensure that the space behind the drywall is completely filled when insulation is installed. For blown-in insulation, the taller the cavity, the more difficult it will be to fill completely.

- *Free hanging chases that go across an open space* - In this case, no walls are involved so both sides and the bottom of the chase need to be framed (Figure 17).

Figure 15. Fur-down chase above dropped ceiling.

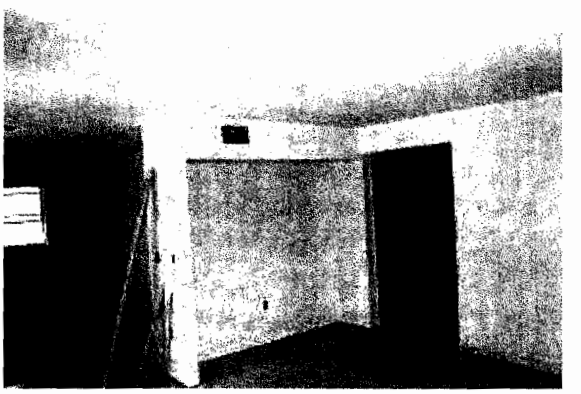


Figure 16. Example of a perimeter chase.

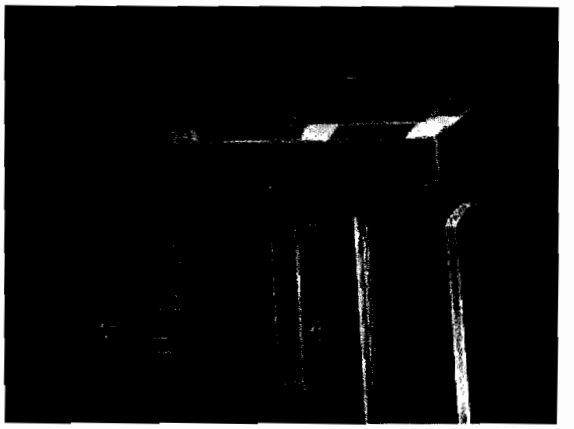


Figure 17. Free-hanging chase across an open space. Note separation of space accented by chase.

3.3 System Interaction

3.3.1 Effect of HVAC System Runtime

Variable speed compressors combined with multi-speed air handler fans are becoming common in modern, higher efficiency HVAC equipment. To increase efficiency, modern high efficiency HVAC systems can vary their capacity and air flow over a wide range instead of cycling on at full capacity and then cycling off when the thermostat is satisfied. Units designed for hot-humid climates often feature a dehumidification mode that increases latent removal by reducing air handler fan speed to extremely low levels.

These higher efficiency, multi-capacity HVAC units operate for nearly twice as many hours per day as single-capacity systems. Conductive and air leakage losses of the duct system can have a greater impact on these types of systems because conditioned air remains in the ductwork for longer periods of time.

A comparison of interior and attic duct systems was completed in an FSEC experimental facility, a 3-bed 2-bath, 1600 ft^2 double-wide manufactured home with a sealed crawl space and a vented attic (Cummings and Withers, 2010). Two heat pump air handler units, a SEER 21 and a SEER 13, were installed side-by-side within the conditioned utility room of the house. The lab has two duct systems—one in the attic and one in an interior fur-down chase. Both systems are reasonably tight. The heat pumps can be attached to either duct system. Using the best-fit equations and a typical summer day with an average outdoor temperature of 82°F, the following energy savings have been found:

- For the SEER 21 system, switching from the attic duct system to the indoor duct system saves 17.3% when employing RH control (45% set-point). Conversely, it can also be stated that switching from the indoor duct system to the attic duct system increases cooling energy use by 20.9%.
- For the SEER 21 system (no RH control active), switching from the attic duct system to the indoor duct system saves 16.8%. Conversely, it can also be stated that switching from the indoor duct system to the attic duct system increases cooling energy use by 20.2%.

- For the SEER 13 system, switching from the attic duct system to the indoor duct system saves 11.2%. Conversely, it can also be stated that switching from the indoor duct system to the attic duct system increases cooling energy use by 12.6%.

It is reasonable that the energy penalty associated with using the attic duct system would be much greater for the SEER 21 system compared to the SEER 13 system because the SEER 21 system run time is nearly twice as great as that of the SEER 13 unit (72% of the time for the SEER 21 system versus 38% for the SEER 13 system during hot and humid weather). Therefore, conductive heat transfer from the attic to the duct interior operates for nearly twice the length of time for the SEER 21 unit.

3.3.2 Return Pathways

As with all duct systems, adequate return air pathways must be provided. In sealed attics and crawl spaces, duct work can be configured with ducted returns or passive returns using jump ducts (Figure 13) or transoms (Figure 14). It is important to carefully consider how returns will be handled in an interior duct system that relies on chases. If jump ducts or ducted returns are used, more chase will be needed, and overall system cost and complexity will increase. Transoms, or over-the-door returns, and through-the-wall returns, do not add any chase requirements. For a thorough sizing discussion please refer to Building Science Corporation's Information Sheet at: http://www.buildingscience.com/documents/information-sheets/information-sheet-transfer-grilles-and-ducts. This Information sheet is linked to several other documents that go into great detail about duct sizing, return methods, and their ramifications.

3.3.3 Trade Interactions

Due to the nature of constructing an effective chase, it is built early in the construction process, which exposes it to subsequent damage from other trades people involved in the construction process. In sealed attic/crawlspace systems, the location of the air and thermal barrier is often removed from the areas where other trades are typically working, and its function is usually obvious. Such systems are not likely to be mistaken for an architectural detail and used by other trades to run their wires or pipes. Diligent inspection and constant oversight by an informed site supervisor are necessary to ensure that all trades people involved with the process (not just the crew bosses) are aware of the chase and its function. Even after the house is completed, the chase area is subject to damage when the new homeowners have alarm, cable and telephone service installed. Therefore, homeowner awareness of the chase's function is another important part of successfully implementing an interior duct system.

4 Summary of Implementation of Various Methods

4.1 Integrating the New Strategy Into Current Construction Processes

If a sealed attic or crawlspace is chosen, these areas become obvious and easy places to implement an interior duct system. On the other hand, if a conventional insulation system is chosen and a chase is going to be constructed, attention and planning are required from the moment the decision to build a chase is made.

4.1.1 Locate Chase

Indicate the chase and air handler location on both the mechanical drawings and dimensional drawings (Figure 18). After drafting the chase layout on the plans, detail it in sections for clarity, indicating materials, critical dimensions, and sealing details.

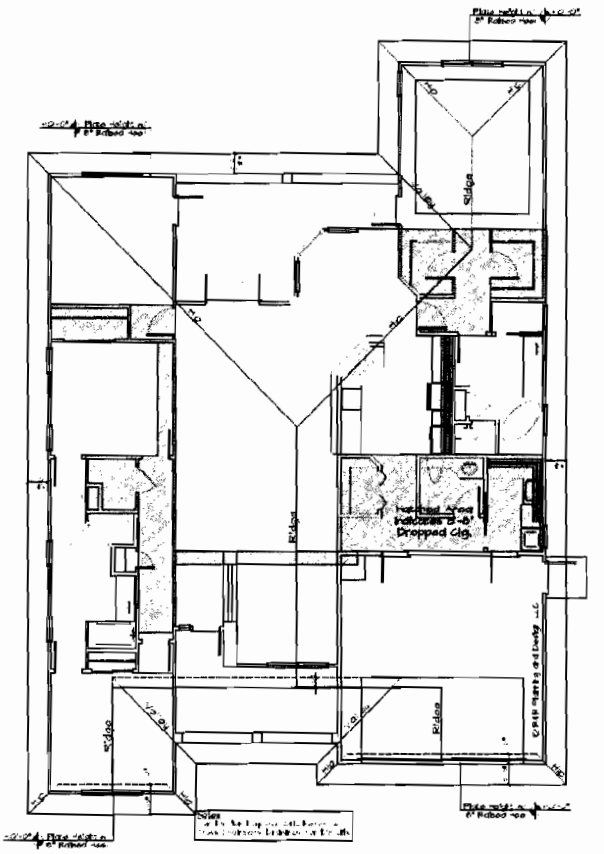


Figure 18. Floor plan, showing the area to have a fur-down chase installed, highlighted in grey.

Clearly communicate both the intent and specifications to all crews working with the chase by providing each group with the plans and detail. This activity may comprise framing, drywall, insulation, and finishing crews as well as the mechanical contractor. Include the electrical and plumbing contractors who need to either avoid putting holes in the chase or fill any hole they create.

Be sure that the mechanical contractor takes the location of the ducts into consideration for system sizing calculations and for the size of the chase (less than 12" clearance for 8' ceilings, Figure 10) for duct sizing calculations. The duct design should incorporate sizing and design considerations to allow adequate air distribution into all rooms. Fur-down chase systems are difficult to use with a perimeter duct installation, as the chase typically runs down the center of the building. Fur-down chases also limit register size and placement.

4.1.2 Before Construction of the Chase

Clearly indicate the chase location at the construction site. Much of the chase is built after rough framing and before the mechanical rough-in. A copy of the mechanical system plan showing the

duct chase location in hatch marks should be posted in the house for reference. Mark the location of the chase after rough framing. As an example, the construction supervisor responsible for the chase could spray paint the floor along the bottom plate of all the walls where the chase is to be built. The supervisor starts at the air handler and traces the path of the chase to its end (Figure 19). After the chase is installed, mark the location of supply registers (Figure 20).

Figure 19. Paint tags alerting crews to the location of the proposed chase.

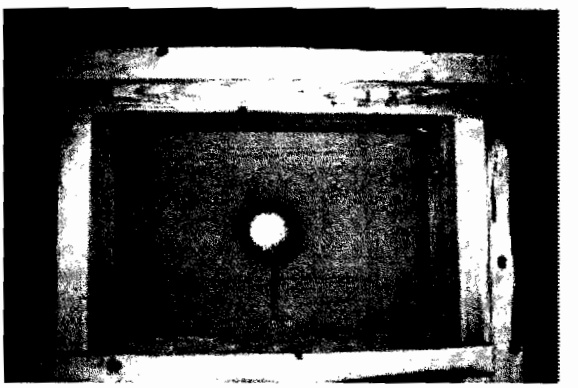


Figure 20. Supply duct location marked in the side of a fur-down chase.

Make sure that materials for building the continuous air barrier (and later thermal barrier) are available when needed. If any special materials are required, confirm that they are on hand (light gauge metal framing for the chase support, etc.). To facilitate the construction of a sealed and insulated air handler closet, enabling an air handler that would otherwise be located in an attached garage to be located in "interior" space, some of Building America's partners have the HVAC contractors construct the air handler closet ceiling with duct board (Fonorow, et al. 2006). This method improves the sealing achieved at this potential leakage point by having the trades people involved with the installation perform the sealing (Figure 21). Not only are these individuals familiar with the material they are using, but they also possess the necessary tools and sealants for completing the task.

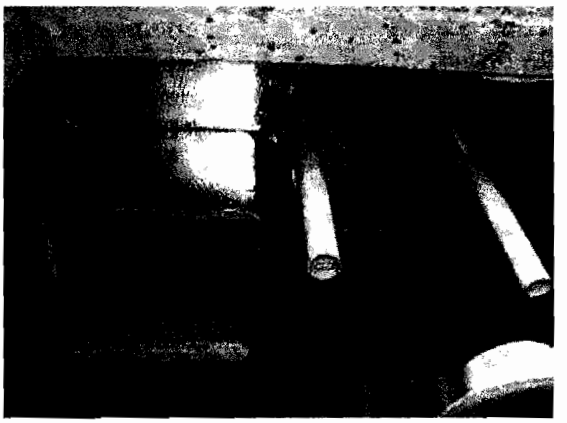


Figure 21. Air handler closet ceiling constructed with duct board.

4.1.3 General Chase Construction Guidelines

Let the guiding principal for building an interior duct system be the establishment and maintenance of an air barrier. After an air barrier is established, a thermal barrier in the same location is needed. The chase's ceiling air barrier should be placed first in a fur-down installation. Then all joints and seams should be sealed with code-approved sealant, including the gap between the air barrier and the top plates of adjacent walls. At this point, the chase's principle air barrier is complete. The rest of the chase will be finished later when the rest of the house is drywalled.

Reference to Other Guidelines, Codes and Standards

- The 2009 International Energy Conservation Code (IECC) recognizes sealed crawlspaces (402.2.9) and attics (402.2.2), but not all municipalities have adopted this (or any) energy code.
- Exposed foam should meet NFPA 2009 12.5.5.3 requirements for fire-resistance, combustibility, and smoke release standards (NFPA 286, ANSI/UL 1715 and 1040, and FM4880 are test standards to look for).
- The local authority should be consulted to ensure that no code issues arise with a sealed attic or crawlspace. A sealed crawlspace is not a viable option in areas where heavy flooding is a concern.
- With information derived from the HVAC designers' ACCA Manual J and D calculations, the home designer can finalize plans which consider the size requirements and path of the distribution system.

Next, the mechanical system is roughed in, and the rest of the chase is framed. Much of the duct system can be assembled on the floor and then lifted and strapped into place (Figure 22). The remaining chase framing is placed within the chase's air barrier such that it will not interrupt the house air barrier (Figure 23).

The joints and seams of the chase must be sealed (Figure 24), including any penetrations in the chase that intersect an unconditioned space. Note that unconditioned spaces are any cavity or room that is not served by the mechanical system. These include obvious spaces such as attics, garages and storage rooms as well as hidden areas (e.g. wall and floor cavities).

The penetration in the chase wall for the supply run-out can intersect an unconditioned space or interior wall cavity. To prevent air from travelling down from the attic between the drywall and the top plate, either the joint between the chase wall and the interior wall framing must be sealed, or the joint between the top plate and the drywall must be sealed (Figure 25). Without this

continuous air barrier, any duct leakage will be in communication with an unconditioned space, either the attic directly or the interior wall cavity. This type of sealing is especially important in the air handler closet since the return side of the air handler induces strong negative pressures, significantly increasing the leakage through any gaps. The simplified fur-down method outline described in section 4.4 of this guideline provides a solution to this issue.

Figure 22. Duct work strapped in place prior to finishing the framing of the chase.

Figure 23. Finish framing for chase.

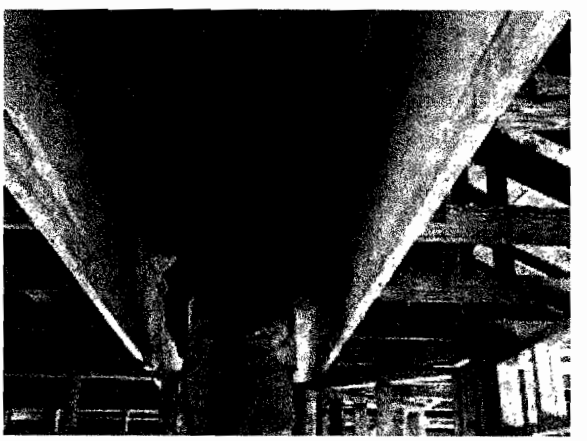


Figure 24. Air-sealing a fur-up chase.

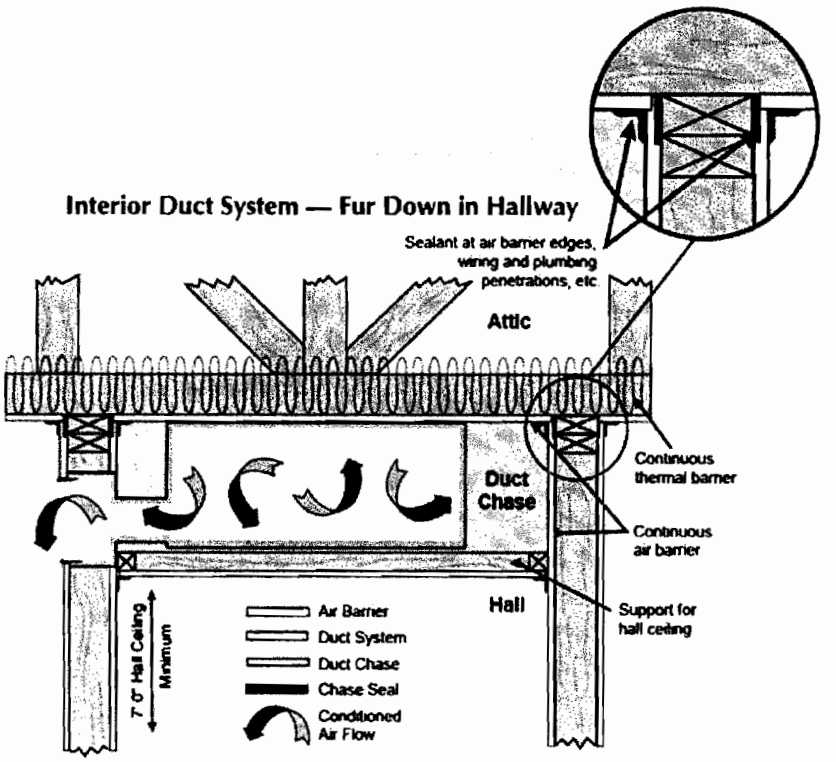


Figure 25. Chase side wall supply sealing detail.

A supervisor who understands the intent of the chase should regularly check progress and follow the chase construction to completion, meaning the ducts are all installed, holes have been sealed, and the chase is ready for close-in. The chase is closed in as the house gets dry-walled.

4.1.4 Protecting the Chase After Completion

Protect the chase from cable, phone and other installers who may want to use it as a convenient way to run wires. The holes that typically result will compromise the air barrier. Identifying the chase as a space intended to be separate from surrounding unconditioned spaces is difficult at best. Communication is again an important factor.

Advisory notices to cable, security, and phone installers should be posted in conspicuous locations such as the panel box, attic access hatch, wiring service entrance, etc. Since these notices cannot clearly identify the location of the air boundary in the attic, they should advise the installer to seal any penetrations to drywall made from unconditioned spaces. Though it should be standard practice and is often required by code, virtually all services that are installed post-occupancy are never inspected.

4.2 Chase Design

4.2.1 Identify Chase Path

Identify the path of the chase or (insulation in case of a sealed attic or crawlspace) on floor plans (Figure 18). The best opportunity to minimize costs while ensuring an aesthetically pleasing outcome is during the preliminary schematic design phase. With information derived from the HVAC designers Manual J and D calculations, the designer can finalize plans which consider the size requirements and path of the distribution system. Thus, less duct material will be used due to preplanning that often involves elimination of many supply runs through the use of side wall supplies connected directly to the main trunk-line. When using side wall supply registers, care must be used to insure that the register is designed to be used on a wall, as opposed to ceiling registers, whose throw patterns will be inappropriate for wall use.

Ducts brought into the conditioned space should include both the return and supply systems to provide maximum efficiency for the effort. In order to reduce the size and amount of chase required, as well as avoiding duct sizing mismatches between the supplies and returns, a passive return system using transoms over the doors (Figure 14) is recommended. The transoms must be sized to ensure that occupiable rooms that can be isolated from the main return by doors are maintained at a nearly negligible difference in pressure with respect to the home (< 2.5 Pascals) when the mechanical system is operating. Returns should be sized at least 1 ½ times larger than the corresponding supply duct areas. The supply ducts should be sized by ACCA Manual D. Detailed sizing information is available from Building Science Corporation's Information Sheet at: http://www.buildingscience.com/documents/information-sheets/information-sheet-transfer-grilles-and-ducts. This Information sheet is linked to several other documents that go into great detail about duct sizing and its ramifications.

Critical Take-Aways

- ✧ Indicate the chase and air handler location on both the mechanical drawings and dimensional drawings
- ✧ Before construction of the chase, clearly indicate the chase location at the construction site.
- ✧ Let the guiding principal for building an interior duct system be the establishment and maintenance of an air barrier. After an air barrier is established, a thermal barrier in the same location is needed.
- ✧ After completion, protect the chase from cable, phone and other installers who may want to use it as a convenient way to run wires.
- ✧ Identify the path of the chase or (insulation in case of a sealed attic or crawlspace) on floor plans
- ✧ Involve all subcontractors whose work may impact the chase integrity
- ✧ Multiple to daily inspections needed - Critical times for site supervision are during the drywall installation that will form the air barrier and support the thermal barrier between the chase and attic.
- ✧ Two critical trades are the home and HVAC design professionals. The best opportunity to minimize costs while ensuring an aesthetically pleasing outcome is during the preliminary schematic design phase of the home. Failure here will result in a poorly implemented end result.
- ✧ An interior duct system should be planned during a home's design stage, prior to interior framing, since it would be difficult, although possible, to implement after this stage. An interior duct system is not often suitable for retrofit unless a sealed attic or crawlspace is created.
- ✧ Adequate return air pathways from closable rooms to the air handler must be provided, regardless of duct system style.
- ✧ All return duct work can be eliminated by using over-the-door transom or through-the-wall returns from bedrooms.

Another benefit is that by eliminating all ducted returns, labor and material costs are reduced. In addition, the system's overall operating static pressure is reduced, reducing the fan motor power requirements and allowing for less wear on the air handler fan motor.

From a residential designer's perspective, incorporating the chases within the space should be negligible in terms of complicating the design process. In fact, as previously mentioned, adding dropped soffits in strategic areas can help define the character of the interior spaces.

4.2.2 Involve All Subcontractors Whose Work May Impact the Chase Integrity

The next step is to have a team meeting on-site after the home has been "dried in". The objective is to minimize the need to alter or redo work due to a lack of knowledge of the requirements. One of the partner builders prefers to lead a meeting that provides him with the opportunity to clearly communicate that the home will be built differently compared to the normal practice of having ducts in the attic. The builder also expresses his expectations regarding quality of workmanship and the importance of a collaborative effort in accomplishing his goals. Key trades represented in the meeting included the designer, sales/marketing professionals, and mechanical, insulation, plumbing, electrical, framing, sheet rockers and solar contractors. Questions raised in the discussion are quickly answered by the appropriate representative. Generally after the construction of the first prototype home, additional team meetings for subsequent homes are generally unnecessary as long as the site work force remains the same.

4.3 Field Inspection

4.3.1 Multiple to Daily Inspections Needed

The integrity of the air barrier between the interior and the attic is paramount. The first and most critical inspection of the process is the initial installation of ceiling drywall. The site supervisor must be aware that even if the subcontractors and employees are informed about the chase and its function, the actual workers on the job site may be unaware of this component. Indeed, it only takes a moment to defeat the integrity of any fur-up or down installation. Critical times for site supervision are during the drywall installation that will form the air barrier and support the thermal barrier between the chase and attic.

4.4 Introduction of Detailed, Simplified, and Inexpensive Method of a Fur-down Chase

The main obstacle to successfully implementing interior duct work via fur-down chases has been the inability to thoroughly seal the chase from the above unconditioned attic. The chase is difficult to seal at the multitude of wall/ceiling intersections (Figure 25).

By keeping the top plate of the non-load bearing interior walls ¾" + from the bottom chord of the roof trusses, ceiling drywall can be slipped though this space. Intersections of the ceiling and wall framing members are eliminated and the ceiling drywall (and upper air barrier of the chase) can be continuous. By eliminating the leakage paths to the unconditioned space, any remaining chase leakage is contained to the inside of the house.

All return duct work is eliminated by using a central return plenum under the air handler and over the door transom returns from bedrooms. This configuration has the added benefit of

reduced labor and material costs. Sections 4.4.1 through 4.4.5 provide a more detailed discussion of this approach.

4.4.1 Install Ceiling/Chase Drywall

The first step after completing the design work is to have the chase ceiling sheet rock installed as indicated in the design plan. Interior walls are mounted as if an interior duct system will not be included in the configuration. The exception, however, is that a second top plate is not installed where the chase is to be situated. By keeping the top plate of the non-load bearing interior walls ¾" + from the bottom chord of the roof trusses (Figure 26), the drywall can be slipped though this space. A second top plate or pieces of blocking for rigidity of interior walls can be installed later. This provides a very easy method to create an excellent air barrier between the conditioned and unconditioned space, as it virtually eliminates intersections of ceiling and wall framing, which are difficult to seal. In addition, it causes any remaining chase leakage (the sides and bottom) to leak to the inside of the house, eliminating the negative impacts of leakage to the outside. This process also eliminates the need for much of the excess wood ordinarily required to support the chase drywall, and removes much of the excess drywall waste created from cutting small pieces for creating an air barrier in small spaces. It also reduces labor costs; however, it does require an additional visit from the drywall contractor, for the home will not be ready for the rest of the drywall until a later stage of construction.

Figure 26. Ceiling drywall installed at fur-down chase top. Drywall is slid through a ¾"+ gap between the wall top plate and the truss bottom chord, ensuring a good air barrier.

4.4.2 Install Duct Work

The supply ductwork is installed under the drywall after being fabricated and sealed on the ground as much as practical. The main supply trunk lines and supply ducts are then hung from the drywall using 2" nylon strapping material (Figure 27). Rigid ductboard ducts are used whenever possible, and are sometimes required due to chase height limitations, as previously discussed. Studs in the interior walls that obstruct the chase are adjusted or removed. Nailers are fitted to allow for attachment of the drywall. This process can be planned in advance, and walls can be framed to accommodate the chase; however, it may be easier to make adjustments after the framing crew completes their work.

Figure 27. Duct work hung with 2" strapping after chase ceiling drywall installed and sealed.

4.4.3 Finish Chase Construction

After the duct work is sealed and hung, the rest of the chase is constructed and installed to provide nailing surfaces for the remaining drywall (Figure 28).

Figure 28. Chase sides and bottom installed.

4.4.4 A Method to Reduce the Size of the Chase

To provide supply ducts off the main truck line, duct installers typically will cut a hole in the trunk line and insert a collar to accept a section of flex duct. The other end of the flex duct will be connected to the supply boot. This method results in a chase that is wider than necessary (Figure 29). By field fabricating a shallow duct board box and affixing it directly to the trunk line, the width of the chase can be reduced by almost a foot (Figure 30 and 31). This improved method provides better air flow, greater design opportunities, and reduced costs.

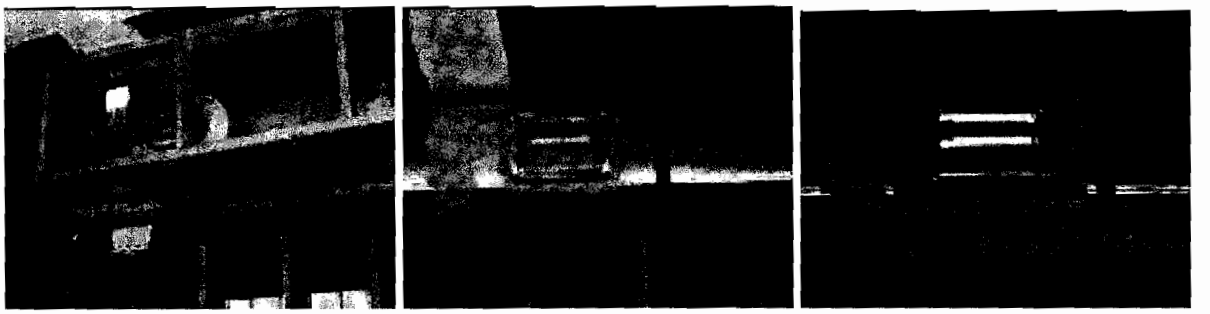


Figure 29-31. (Left to right) Connecting flex duct to a trunk line for a supply run-out results in a wide chase. Instead, a supply outlet constructed from a duct board box can be directly affixed to the trunk. This permits construction of a much narrower chase.

4.4.5 Transom Returns

All return duct work is eliminated by using over-the-door transom returns from bedrooms (Figure 14). The transoms must be sized to ensure that occupant rooms with doors that can be isolated from the main return are maintained at a negligible difference in pressure (<2.5 Pascals) than the main interior space when the mechanical system is operating. The returns were sized to be at least 1½ times larger than the room's cumulative supply duct areas. The supply ducts were sized by Manual D.

Another benefit is that by eliminating all ducted returns, labor and material costs are reduced. In addition, the system's overall operating static pressure decreases, which allows for less wear on the air handler fan motor and less electricity used. Partner builders adopting transom returns have not received any noise or light-related complaints in over 300 homes constructed with over-the-door transom returns. Pressure mapping during the final commissioning should be performed to confirm that the return air system is working as designed.

4.5 Verification

Verification of an interior duct system can be executed during house pressure testing. Standardized testing protocols require pressurization of the house and duct system. During this operation, the chase or sealed attic/crawlspace can be checked to verify its location, either interior or exterior, or somewhere in between.

Contractor/Homeowner Safety

Supply leaks can cause negative pressure in home, which results in air being drawn from outside and/or unconditioned spaces (uncontrolled infiltration) through holes in the home's air barrier potentially leading to:

- ✧ Back drafting of atmospheric combustion devices
- ✧ Introduction of outside air pollution, pollen, and other allergens
- ✧ Introduction of airborne particles (dust, insulation, building material particles) from floor, wall, ceiling cavities

One of the many verification services provided by an energy rater and some HVAC contractors is duct system and envelope pressure testing. This testing uses calibrated fans to determine how much air is required to change the pressure in the house or duct system with respect to the outside air. The main purpose is to establish the home's envelope and duct system air tightness, but it can also be used to verify the integrity of an interior duct system. Testing apparatus are two calibrated fans: a blower door to pressurize the house, and a duct blaster to pressurize the duct system.

4.5.1 Blower Door Testing

Typical blower door testing involves depressurizing the house to a standard pressure with respect to the outside, usually 50 Pascals. When the house is subjected to this depressurization, the pressure in the area with the duct work (foamed attic/crawlspace or chase) can be checked with respect to the house. If there is no pressure difference between the house and chase, the duct area is truly interior. In other words, it is completely inside the pressure boundary of the house. Depending on the pressure size, a determination can be made regarding the integrity of the interior duct system.

4.5.2 Duct Blaster Testing

Two tests can be performed with the duct blaster, one that measures the leakage of the entire duct system - both into the interior and exterior of the house, and a second test that measures the duct leakage to the exterior of the building only. The results of the second test, leakage to the outside, are important regardless of duct style; leakage to the outside is energy lost as well as the cause of pressure differences described earlier that can lead to other building science problems related to moisture management, comfort, and indoor air quality.

The original idea for designing interior duct systems was to eliminate duct leakage to the outside. If the crawlspace/attic or chase is completely sealed from the outside, there can be no duct leakage to the outside. Obviously, leakage results here indicate that the duct system is connected to the outside in some fashion, indicating a breakdown in the air barrier in the chase or sealed attic/crawlspace.

4.5.3 Room to Main Body Pressure Balancing

Adequate return air pathways from closable rooms to the air handler must be provided, regardless of duct system style. While operating the HVAC system's air handler, fan pressure mapping of the various closable rooms in the house with respect to the main body of the house should be performed. If any pressures between rooms and the main body of the house exceed 2.5 Pascals, remedial action should be taken to reduce the pressure to less than 2.5 Pascals.

Critical Take-Aways

- The 2009 International Energy Conservation Code (IECC) recognizes sealed crawlspaces (402.2.9) and attics (402.2.2), but not all municipalities have adopted this (or any) energy code.
- Exposed foam should meet NFPA 2009 12.5.5.3 requirements for fire-resistance, combustibility, and smoke release standards (NFPA 286, ANSI/UL 1715 and 1040, and FM4880 are test standards to look for).
- The local authority should be consulted to ensure that no code issues arise with a sealed attic or crawlspace. A sealed crawlspace is not a viable option in areas where heavy flooding is a concern.
- With information derived from the HVAC designers' ACCA Manual J and D calculations, the home designer can finalize plans which consider the size requirements and path of the distribution system.

References

Building Science Corporation. "Transfer Ducts and Grilles for All Climates," BSC Information Sheet 604. November 2008. http://www.buildingscience.com/documents/information-sheets/information-sheet-transfer-grilles-and-ducts/files/bscinfo_604_transfer_grilles.pdf

Cummings, J., C. Withers. "Energy Savings and Peak Demand Reduction of a SEER 21 Heat Pump vs. a SEER 13 Heat Pump with Attic and Indoor Duct Systems - Phase 1 Report," Florida Solar Energy Center, Rpt: FSEC-CR-1877-10, Dec. 22, 2010

Hales, D., and D. Baylon. "Moving Ducts into Conditioned Space: Getting to Code in the Pacific Northwest." *ASHRAE Transactions*, 116, Part 1.

McIlvaine, J., D. Beal, S. Chandra, "Gulf Coast High Performance Affordable Housing Demonstration Project." Florida Solar Energy Center, Rpt: FSEC-CR-1791-09, Feb. 05, 2009 http://fsec.ucf.edu/en/publications/pdf/FSEC-CR-1791-09.pdf

Fonorow, K., Chandra, S., Martin, E., McIlvaine, J., "Energy and Resource Efficient Communities through Systems Engineering: Building America Case Studies in Gainesville, FL." Proceedings of the 2006 Summer Study on Energy Efficiency in Buildings, American Council for an Energy Efficient Economy, Asilomar, CA., August 2006. http://www.baihp.org/pubs/aceee_fonorow/index.pdf

Beal, D., D. Chasar, "Measured Crawlspace Conditions in a HUD-code Home." Florida Solar Energy Center, Rpt: FSEC-PF-418-06, Jul. 24, 2006 http://securedb.fsec.ucf.edu/pub/pub_show_detail?v_pub_id=4263

Lubliner, M., Kerr, R., Gordon, A., and C. Murray. "Moving Ducts Inside: Big Builders, Scientists Find Common Ground." Proceedings ACEEE 2008. http://www.energy.wsu.edu/documents/AHT_ACEEE%20Ducts%20inside%5B1%5D.pdf

Moyer, N., Stroer, D., Hoak, D., McIlvaine, J., and Chandra, S., "Research Results from A Few Alternate Methods of Interior Duct Systems in Factory Built Housing Located In the Hot Humid Climate", Sixteenth Symposium on Improving Building Systems in Hot and Humid Climates, December 15-17, 2008, Dallas, TX. http://www.fsec.ucf.edu/en/publications/pdf/FSEC-PF-444-08.pdf

Acknowledgments

The previous work was sponsored by the U.S. Department of Energy (DOE), Office of Energy Efficiency and Renewable Energy, and the Building America Program under cooperative agreement number DE-FC26-06NT42767.and DOE, National Energy Technology Laboratory (NETL), Cooperative Agreement DE-FC26-99FT40642. The support and encouragement of Mr. George James, Mr. Terry Logee, Mr. Ed Pollock, Mr. Esher Kweller and Mr. William Haslebacher is gratefully acknowledged. This support does not constitute DOE endorsement of the views expressed in this paper.

The authors acknowledge the leadership and support of Dr. Subrato Chandra, the project manager for this research conducted under the Building America Industrialized Housing Project. In addition, the authors appreciate the cooperation and support of our builder and developer partners, especially Tommy Williams Homes, Bentwood Custom Homes in Dallas TX, Durham County Habitat for Humanity, NC, and Broward County Habitat for Humanity, FL, in performing this work. We appreciate the editorial assistance from Ms. Danielle Daniel of FSEC and Ms Andy Fonorow of Florida H.E.R.O.

EERE Information Center
1-877-EERE-INFO (1-877-337-3463)
www.eere.energy.gov/informationcenter

U.S. DEPARTMENT OF **ENERGY** Energy Efficiency & Renewable Energy

DOE/GO-102011-3421 • November 2011

Printed with a renewable-source ink on paper containing at least 50% wastepaper, including 10% post-consumer waste.

Building AMERICA SM

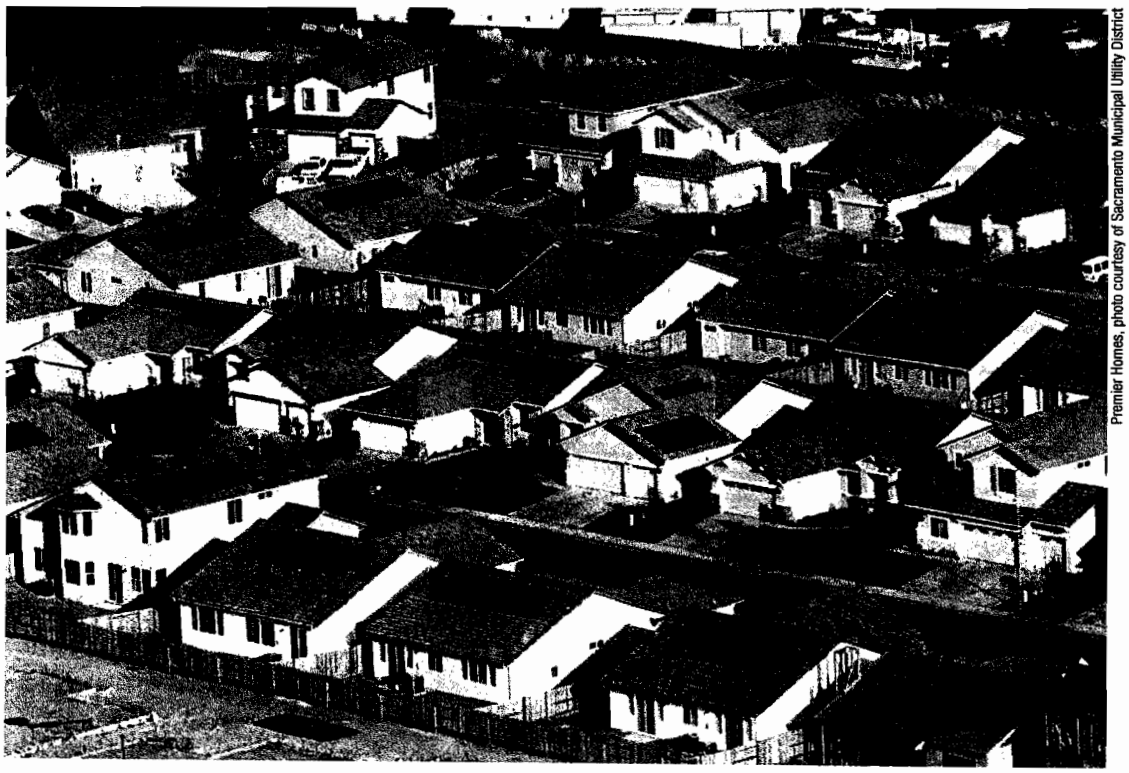
U.S. Department of Energy

Research Toward Zero Energy Homes

Research that Works

January 2006 • NREL/SR-550-38201

Building America Residential System Research Results: Achieving 30% Whole House Energy Savings Level in Hot-Dry and Mixed-Dry Climates



Premier Homes, photo courtesy of Sacramento Municipal Utility District

U.S. Department of Energy
Energy Efficiency and Renewable Energy
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

Building Technologies Program

Building America Residential System Research Results: Achieving 30% Whole House Energy Savings Level in Hot-Dry and Mixed-Dry Climates

January 2005 – November 2005

Building Industry Research Alliance (BIRA)
Stockton, California

Building Science Consortium (BSC)
Westford, Massachusetts

Consortium for Advanced Residential Buildings (CARB)
Norwalk, Connecticut

Davis Energy Group (DEG)
Davis, California

Florida Solar Energy Center (FSEC)
Cocoa, Florida

IBACOS
Pittsburgh, Pennsylvania

National Association of Home Builders Research Center (NAHBRC)
Upper Marlboro, Maryland

National Renewable Energy Laboratory (NREL)
Golden, Colorado

NREL Technical Monitor: R. Anderson, R. Hendron, M. Eastment, and A. Jalalzadeh-Azar

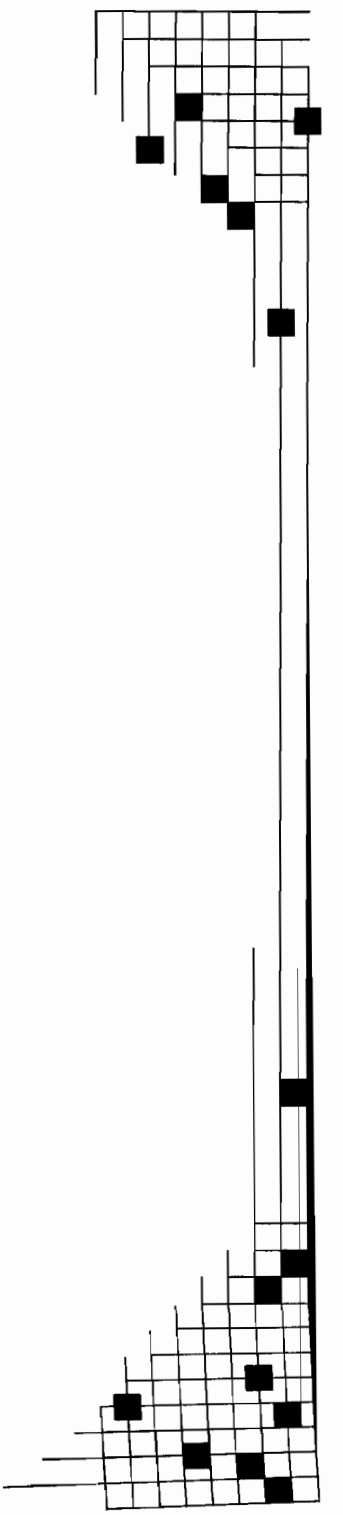
Prepared under Subcontract No(s). KAAX-3-32443-07, KAAX-3-33411-07, KAAX-3-33412-07, KAAX-3-33410-07

National Renewable Energy Laboratory
1617 Cole Boulevard, Golden, Colorado 80401-3393
303-275-3000 • www.nrel.gov

Operated for the U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
by Midwest Research Institute • Battelle

Contract No. DE-AC36-99-GO10337

Subcontract Report
NREL/SR-550-38201
January 2006



NOTICE

This report was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or any agency thereof.

Available electronically at http://www.osti.gov/bridge

Available for a processing fee to U.S. Department of Energy
and its contractors, in paper, from:
U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
phone: 865.576.8401
fax: 865.576.5728
email: mailto:reports@adonis.osti.gov

Available for sale to the public, in paper, from:
U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
phone: 800.553.6847
fax: 703.605.6900
email: orders@ntis.fedworld.gov
online ordering: http://www.ntis.gov/ordering.htm

This publication received minimal editorial review at NREL

Printed on paper containing at least 50% wastepaper, including 20% postconsumer waste

Table of Contents

Table of Contents iii
Abstract xi
Building America Residential System Research Results: Achieving 30% Whole House Energy Savings Level in Hot-Dry and Mixed-Dry Climates 1
Introduction 1
About Building America 1
Purpose 1
Background 5
Electronic Reporting of System Research Results 9
Identification of Component Development Needs 9
Documentation and Resource Development 9
Building America's Research Goals 10
30% Whole-House Energy Savings 11
System Approach to Least-Cost Energy Savings 13
Integrated Design Process 13
Analysis and Design Optimization 13
Building America Research Benchmark 14
Analysis Methods 15
Performance Verification 17
System Design and Construction Process 18
Climate Analysis 18
Key Climate Elements that Affect Building Design 18
Site Development 19
Orientation Impacts 19
Landscaping 20
Water Management 20
System Design Approach 21
Integrated Design Process 21
Energy Analysis 25
Passive Design Strategies for Minimizing Cooling and Optimizing Heating 27
Indoor Air Quality Strategies 29
Indoor Air Quality Strategies 29
Heating and Cooling Equipment and Distribution Strategies – Creating Conditioned Space for HVAC Systems 34
First Costs, Cost Tradeoffs, and Owner Annualized PITI + Energy 36
Water Management 38
Reducing Construction Waste 41
Two-Foot Module Design 41
Value Engineered or "Advanced" Framing 42
Compact Duct Systems 45
Recycling of Construction Materials 46
Quality Project Management Approach 47

Education / Training 48
Operational Evaluation 50
Performance Standards—Design, Specifications, Scopes 51
Verification 52
Commissioning 54
Feedback Loops 55
Quality Management Summary 55
Building Component Design Details 56
Building Enclosure Integrity 56
Control of Heat Flow 56
Control of Airflow 57
Control of Moisture 59
Specific Recommendations 61
Envelope Systems 62
Foundation Systems 62
Slab on Grade 62
Crawl Space 62
Building Enclosure Integration Strategies 63
Walls 63
Floors 64
Roof/Ceiling/Attic 65
Space Conditioning and Ventilation Systems 69
Forced Air 69
Ventilation 70
Air Distribution 70
Mechanical, Electrical, and Plumbing Systems 74
Lighting 74
Major Appliances 75
Water Heating and Distribution Systems 76
Onsite Power Systems 79
Cost Analysis 79
Life-cycle Cost Analysis 79
First-Cost Impacts 90
Key Cost Tradeoffs 91
Research Results and Conclusions 92
House Case Studies 100
Development: Sahara Lake 100
Development: Armory Park del Sol 114
Development: Gamlen House 119
Community-Scale Case Studies 128
Development: Premier Gardens 128
Development: Lakeside 133
Development: Windemere 138
Appendix A: Passive Solar Design Considerations 144
Appendix B: Detailed *BEopt* Analysis Results 149
Appendix C: List of Key Trade-based Certifications 164

Appendix D: National Housing Quality Rating Table 169
Table D.1. Leadership 169
Table D.2. Strategic Planning 171
Table D.3. Customer Satisfaction 172
Table D.4. Performance Management 175
Table D.5. Human Resources 177
Table D.6. Quality Construction Processes 179
Table D.7. Supplier Partnerships 181
Appendix E. National Housing Quality Survey 182
Appendix F. SNAPSHOT Form 185

Definitions

AC	air conditioning
ACCA	Air Conditioning Contractors of America
ACEEE	American Council for an Energy Efficient Economy
ACH	air changes per hour
ACT2	Advanced Customer Technology Test for Maximum Energy Efficiency
AFUE	Annual Fuel Utilization Efficiency
AH	air handler
AHU	air-handler unit
ALA	American Lung Association
ASHRAE	American Society of Heating
BAP	Building America program
BECT	Building Energy Code Training
BEopt	Software for identifying optimal building design
BESTEST	A benchmark for building energy simulation: Building Energy Simulation Test and Diagnostic Method
BII	Building Industry Institute
BPI	Building Performance Institute
BPM	brushless permanent magnet
CA_{Ef}	California Energy Factor
CA_{AFUE}	California Annual Fuel Utilization Efficiency
CAD	computer-aided design
CDCU	Community Development Corporation of Utah
CEC	California Energy Commission
CFL	compact fluorescent bulbs
CFM	cubic feet per minute
CMU	concrete masonry unit
COP	coefficient of performance
CRI	color-rendering index
CT	color temperature

DHW	domestic hot water
DOE	U.S. Department of Energy
DOE-2	Building energy analysis program that can predict the energy use and cost for all types of buildings
ECM	electronically commutated motor
EDHA	Eastern Dakota Housing Alliance
EEBA	Energy and Environmental Building Association
EEM	Energy-efficient mortgages
EER	Energy Efficiency Rating
EF	energy factor
EFL	Environments for Living®
EGUSA	Energy-Gauge USA software (FSEC's residential front-end user interface for DOE-2.1E simulation tool)
ELA	effective leakage area
EPA	U.S. Environmental Protection Agency
EPS	expanded polystyrene
ERV	Energy recovery ventilation
FF	framing factor
FFA	finished floor area
FG	fiberglass
GenOpt	generic optimization program
HVAC	heating, ventilation, and air conditioning
HERS	Home Energy Rating System developed by RESNET
HM	heat mirror
HPL	high-performance lighting
HRV	heat recovery ventilators
HSPF	Heating Seasonal Performance Factor
HUD	U.S. Department of Housing and Urban Development
IAQ	Indoor air quality
ICF	insulated concrete forms
IDEC	Indirect-Direct Evaporative Cooler
IDP	Integrated Design Process
IECC	International Energy Conservation Code

IEQ	Indoor Environmental Quality
IOSEU	incremental overall source energy use
JWM	John Wesley Miller
LSL	linear strand lumber
MBH	1,000 Btu/hr
Mcf	million cubic feet
MEC	Model Energy Code
MEF	modified energy factor
MERV	Minimum Efficiency Reporting Value
Micropas	software tool for showing compliance with the California Residential Energy Standards
NAECA	National Appliance Energy Conservation Act
NAHB	National Association of Home Builders
NASEO	National Association of State Energy Officials
NATE	North American Technician Excellence
NHQ	National Housing Quality
NREL	National Renewable Energy Laboratory
NZEH	net zero energy home
OA	outdoor air
OASys	an indirect/direct evaporative cooler
oc	on center
OSB	oriented strand board
PA or Pa	Pascal
PATH	Partnership for Advancing Technology in Housing
PEX	cross-linked Polyethylene tubing
PITI	principal, interest, tax, and insurance
PNNL	Pacific Northwest National Laboratory
PSC	permanent split-capacitor motors
PV	photovoltaics
R-Value	A measure of thermal resistance used to describe thermal insulation materials in buildings
R.A.P.	return-air pathway
RE	recovery efficiency

RESNET	Residential Energy Service Network
RH	relative humidity
SA	supply air
SEER	seasonal energy efficiency ratio
SHGC	solar heat gain coefficient
SHW	solar hot water
SIP	Structural insulated panels
SLA	specific leakage area
SMUD	Sacramento Municipal Utility District
TAB	testing, adjusting, and balancing
TEP	Tucson Electric Power
TIM	thermally interrupted metal
TMY2	Typical Meteorological Year weather data
TNAH	The New American Home
TOU	time of use
TRNSYS	A multidisciplinary software system for preliminary design, analysis, and evaluation of space transportation systems
TXV	thermostat expansion valves
UL	Underwriter's Laboratory
U-Value	The thermal transmittance of a material, incorporating the thermal conductance of the structure along with heat transfer resulting from convection and radiation.
UA	heat loss coefficient
VOC	volatile organic compounds
WUFI	Modeling program for simulating heat and moisture transfer
XPS	extruded polystyrene
ZEH	zero energy home
ZNE	zero net energy

Abstract

The Building America program conducts the system research required to reduce risks associated with the design and construction of homes that use an average of 30% to 90% less total energy for all residential energy uses than the Building America Research Benchmark. This includes research on homes that will use zero net energy on annual basis.

To measure the program's progress, annual research milestones have been established for five major climate regions in the United States (Table A). The system research activities required to reach each milestone take from 3 to 5 years to complete and include research in individual test houses, studies in pre-production prototypes, and research studies with lead builders that provide early examples that the specified energy savings level can be successfully achieved on a production basis. As additional homes are completed at each performance level, future studies will be conducted to confirm the average energy savings of large numbers of homes and the impacts of improved housing quality on builder warranty and callback costs.

Two criteria are used to evaluate progress toward annual Building America research goals:

At a minimum, system energy savings must be achievable at neutral cost relative to the Building America Research Benchmark.

System solutions must be "production-ready" and meet minimum constructability, reliability, durability, and availability requirements to be implemented successfully by lead builders.

This report summarizes research results for the 30% energy savings level and demonstrates that lead builders can successfully provide 30% homes in the Hot-Dry / Mixed-Dry Climate Region on a cost-neutral basis. These research results represent the early starting point for the construction of increased numbers of high-performance homes. The broad diffusion of 30% homes in the Hot-Dry / Mixed-Dry Climate Region will depend upon a number of other factors in addition to the research results presented in this report. Those factors include the level of technical support provided by federal, state, and local deployment programs, the consumer cost of energy, and the development of policy incentives that support implementation of whole-house residential energy-efficiency strategies.

Table A. Target Energy Savings for Five Major Climate Regions in the United States

Target Energy Savings	Marine	Hot Humid	Hot-Dry / Mixed-Dry	Mixed Humid	Cold
30%	2006	2007	2005	2006	2005
40%	2008	2010	2007	2008	2009
50%	2011	2015	2012	2013	2014

Building America Residential System Research Results: Achieving 30% Whole House Energy Savings Level in Hot-Dry and Mixed-Dry Climates

Introduction

About Building America

Purpose

The objective of the Building America Program is to develop innovative system engineering approaches to advanced housing that will enable the housing industry in the United States to deliver energy-efficient, affordable, and environmentally sensitive housing while maintaining profitability and competitiveness of homebuilders and product suppliers in domestic markets. For innovative building energy technologies to be viable candidates over conventional approaches, it must be demonstrated that they can cost-effectively increase overall product value and quality while significantly reducing energy use and use of raw materials when used in community-scale developments. To make this determination, an extensive, industry-driven, team-based, system-engineering research program is necessary to develop, test, and design advanced-building energy systems for all major climate regions of the United States in conjunction with material suppliers, equipment manufacturers, developers, builders, designers, and state and local stakeholders.

Building America research results are based on use of a team-based systems research approach, including use of systems research techniques[1] and cost and performance trade-offs that improve whole-building performance and value while minimizing increases in overall building cost. Figure 1 shows the Building America system research approach in its most basic form. Building America is an analysis-focused research program that specifically targets technical barriers that limit residential system energy performance. Building America applies system-research approaches to the development of advanced energy-efficient residential buildings using system-performance studies in test houses, pre-production houses, and community-scale developments. Research includes analysis of system performance and cost tradeoffs as they relate to whole-building energy performance and cost optimization, including interactions between advanced envelope designs, mechanical and electrical systems, lighting systems, space-conditioning systems, hot water systems, appliances, plug loads, energy-control systems, and onsite power generation systems. Use of a systems approach creates process innovations that improve efficiency and flexibility of housing production and increase control over component interactions that improve house efficiency and performance.

Use of a systems approach also accelerates adoption of new technologies by increasing integration between the design and construction process, increasing system performance, increasing system cost effectiveness, and increasing system reliability and durability. Community-scale evaluation of advanced system concepts in partnership with builders,

[1] Systems Research is research focused on understanding cost, performance, and reliability interactions between different system components.

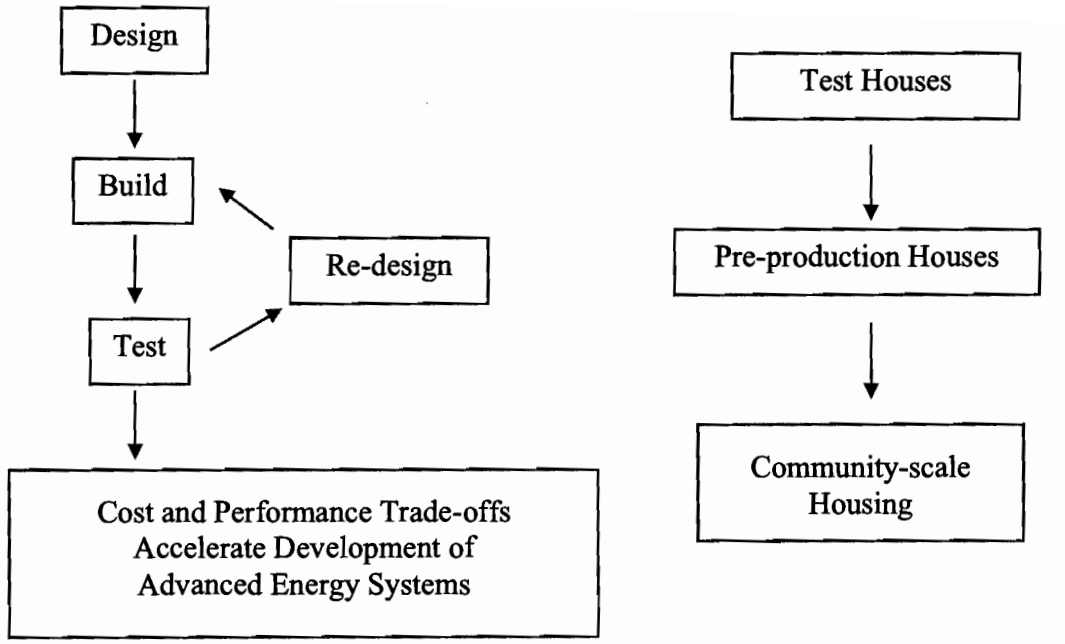


Figure 1. Overview of Building America's systems-engineering approach. The development of production-ready results covering the range from test houses to community-scale housing takes 3 to 5 years.

contractors, and state and local governments, provides opportunities for early adopters and industry leaders to directly contribute to key results from the research program. A systems approach for development of advanced residential buildings is defined to be any approach that utilizes comprehensive examination and analysis of overall design, delivery, business practices, and construction processes, including financing, and that performs cost and performance tradeoffs between individual building components and construction steps that produce a net improvement in overall building value and performance. A systems approach requires integrated participation and team building among all interested parties in the building process including developers, architects, designers, engineers, builders, equipment manufacturers, material suppliers, community planners, mortgage lenders, state and local governments, utilities, and others.

The final products of each Building America research project include performance measurements and cost/performance evaluations in test houses, pre-production homes, and community-scale developments. These measurements and evaluations lead to development of innovative system concepts that can be applied on a production basis by the industry partners and stakeholders involved in the program. The range of innovative system concepts considered in projects include onsite power systems, innovative envelope systems, advanced mechanical and lighting systems, advanced space-conditioning systems, efficient water heating systems,

renewable energy systems, efficient appliances, energy control systems, and design and construction strategies. Performance results from the evaluation of these systems are presented to a broad residential building science audience via development of technical papers, the Building America Web site, and presentations at major building industry conferences.

Building America industry teams and team leads continuously evolve and increase the partners and stakeholders that participate in their projects so that the number of buildings and systems influenced by the program continues to grow over time.

The overall objective of the Building America research program is to develop integrated energy efficiency and onsite/renewable power solutions that can be successfully used on a production basis to reduce whole-house energy use in new homes by an average of 50% by 2015 and 90% by 2025 relative to the Building America Research Benchmark[2], including homes that are capable of achieving zero net energy (ZNE) use on an annual basis.

The key system research questions addressed by Building America research teams include the following:

- Evaluation of overall system cost tradeoffs relative to current systems. What are the system's incremental costs and how will the system affect overall building costs?
- Evaluation of overall system benefits relative to current systems. What overall value is delivered by the system to builders? To contractors? To consumers? (Examples of system benefits include utility bill savings, contribution to whole-house energy-savings goals, increased durability, reduced warranty and callback costs, increased comfort, reduced construction waste, increased labor productivity, increased water efficiency, increased safety and health, reduced peak loads)
- Evaluation of the expected market impact of new residential energy systems. What fraction of the residential housing market will be directly affected by research results? What are barriers to broad market use? What research can be done to reduce barriers to broad use?
- Evaluation of the constructability of new residential energy systems. What are barriers and risks associated with the use of new systems? Can results be implemented on a production basis? What additional research is required to develop a clear description of whole-house system-performance requirements and key system design details that minimize barriers and risks and maximize benefits?
- Evaluation of the potential community-scale benefits of advanced residential energy systems. What additional benefits will result when systems are implemented on a community scale?

Taken together, these research questions frame the overall difficulty of resolving the risks associated with use of advanced energy systems, help to define the systems research required to integrate new systems seamlessly into a production construction process and emphasize the importance of documenting the performance benefits of advanced systems.

---

[2] The Research Benchmark provides a detailed description of all residential energy uses and serves as the reference point for the energy savings goals in Building America research project. More information about the Benchmark can be found on the Building America website: www.buildingamerica.gov. Hereafter in this report, it is referred to as the Benchmark. Hendron, R. 2005. *Building America Research Benchmark Definition, Updated December 29, 2004*. NREL/TP-550-37529. Golden, CO: National Renewable Energy Laboratory.

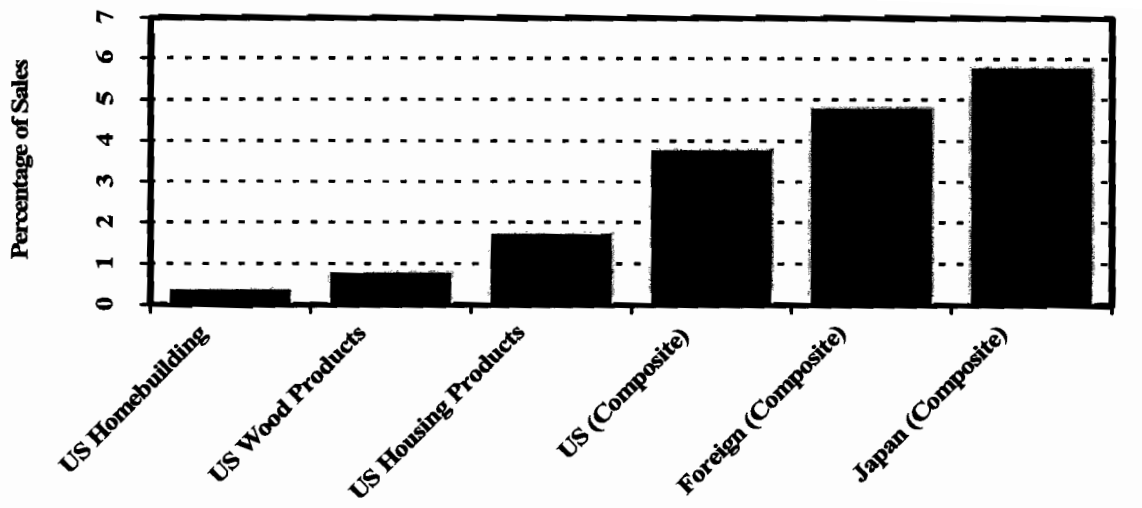


Figure 2. Research and Development expenditures[3]

Construction of new homes requires the combined efforts of a large number of suppliers and contractors whose efforts are coordinated by a large number of builders. Because of the high costs of failure, the residential construction industry is highly risk-intolerant and first-cost sensitive. Development of new systems and corresponding changes in design and the relatively low level of R&D investment further complicate construction practices by the housing industry.

Figure 2 compares R&D expenditures for various residential markets. The key market barriers to development of advanced residential energy systems are the large number of market players, the relatively low level of investment in R&D relative to other sectors of the economy, and strict requirements for market acceptance based on achievement of low incremental costs and high reliability.

The key technical barriers to the development of advanced residential energy systems are the large number of technical performance requirements that must be met before a new system can be implemented on a production basis. These technical performance requirements are driven by regional differences in building energy loads and construction techniques. Systems that work well in Cold Climates may not be applicable in hot climates. Systems that work well in Hot-Dry Climates may not function well in Hot-Humid Climates.

A recent study by the RAND Corporation for HUD's Partnership for Advancing Technology in Housing (PATH) entitled, *Building Better Homes: Government Strategies for Promoting Innovation in Housing,*[4] concludes that,

> ... the housing industry is large and complex, involving many public and private entities. The interests, roles, and capacities of each participant and the relationships they share have shaped the housing industry into what it is today...Instead of trying to identify barriers and asking the industry to change

[3] The United States homebuilding industry invests 0.25% of sales in research compared to $3.8% for all market sectors (Business Week R&D Scoreboard, June 28, 1993).

[4] RAND, Building Better Homes: Government Strategies for Promoting Innovation in Housing, 2003

itself (or asking the government to change it), this study seeks to identify options to accelerate innovation within the housing industry as it exists today. It begins by critically examining the concept of innovation and how it might be better understood within the context of the housing industry. What results is a departure from the linear model of innovation that assumes logical and unidirectional movement from research to development, demonstration, and deployment to one that recognizes much greater interactive dynamics in the innovation process. Research in this model is a base for knowledge, which contributes to invention, development, demonstration, and deployment. Moreover, all these activities or stages in the innovation process are affected by market forces."

Because of the strong interaction between technical and market barriers, a linear research approach that begins with basic R&D and ends with technology deployment is not likely to be successful when applied to residential systems. A market-driven, system-based research approach can provide valuable benefits to builders, consumers, and utilities while simultaneously resolving market and technical barriers to innovation.

Pulte Homes Southwest Division has used technical assistance from the Department of Energy's Building America program to create what one residential expert calls "the best production house in the world," which won the 2001 National Association of Home Builders' Energy Value Housing Award. In Tucson, Phoenix, and Las Vegas, Pulte Homes has worked with the Department of Energy to redesign the energy features of its basic models. Using advanced insulation techniques, highly efficient equipment and windows, and right-sized heating and cooling systems, the homes look the same, but perform so well they use half the energy for heating and cooling at virtually no increase in construction costs. The whole-building/systems engineering approach used in the Building America program allows builders to add more insulation and more efficient windows while reducing the size of the heating and cooling equipment. The trade-off means no added cost to the builder, better value for the buyer, reduced electric load for the utility and improved affordability.

Background

Building America was started in 1995 (Table 1) to conduct the systems research required to develop residential energy efficiency solutions that achieve 30%-100% savings when used on a production basis by builders of new homes. The long-term 2025 research goal for the program is to develop cost-effective system designs that can result in Net Zero Energy Homes (NZEH).[5] In the past 10 years, Building America has made significant progress on the path to NZEH, including the completion of more than 30,000 homes.

Building America research participants have developed an in-depth systems research process by combining operations research[6] and systems engineering.[7] The first step of the systems-research

[5] A net zero energy house is a house that produces as much energy as it uses on an annual basis through integration of energy efficiency solutions and onsite power systems.

[6] Operations Research is research aimed at understanding the best way to operate a system to maximize performance, based on system constraints.

[7] Systems Engineering is engineering based on knowledge from systems research aimed at maximizing the performance and durability of a system, subject to operating constraints.

Table 1. Building America Background

Start date	1995
Target market(s)	New, single-family residential buildings
Accomplishments to date	1. Developing the Benchmark Definition 2. Developing protocols for validating whole-house energy performance 3. Documenting research and publishing *Houses That Work*, *Builder Guides*, and *Best Practices* 4. Increasing the number of ENERGY STAR® homes
Current activities	Developing integrated cost-effective, whole-building strategies to enable new, single-family residential buildings to use 30% less total energy than the Benchmark in the Cold and Hot-Dry/Mixed-Dry Climate regions.
Future directions	Continuing to develop the strategies for new, single-family residential buildings to use 40%-100% less energy than the Benchmark in the Marine, Hot-Humid, Hot-Dry/Mixed-Dry, Mixed-Humid, and Cold Climate regions
Projected end date(s)	2025

process is to use operations research techniques to identify the technology pathways that will achieve the target energy savings in each region for the lowest potential installed cost. From these results, the optimal efficiency targets can be identified and technologies can be developed that will meet the energy-savings needs cost effectively in all climate regions. The second step in the systems research is to implement the optimal technology pathways through systems engineering in homes. The systems-engineering step will identify challenges and barriers unanticipated by the optimization. The combination of operations research and systems engineering ensures that the solutions created meet the energy savings and cost goals and can be used on a production basis. Figure 3 shows a more detailed look at the Building America systems research approach.

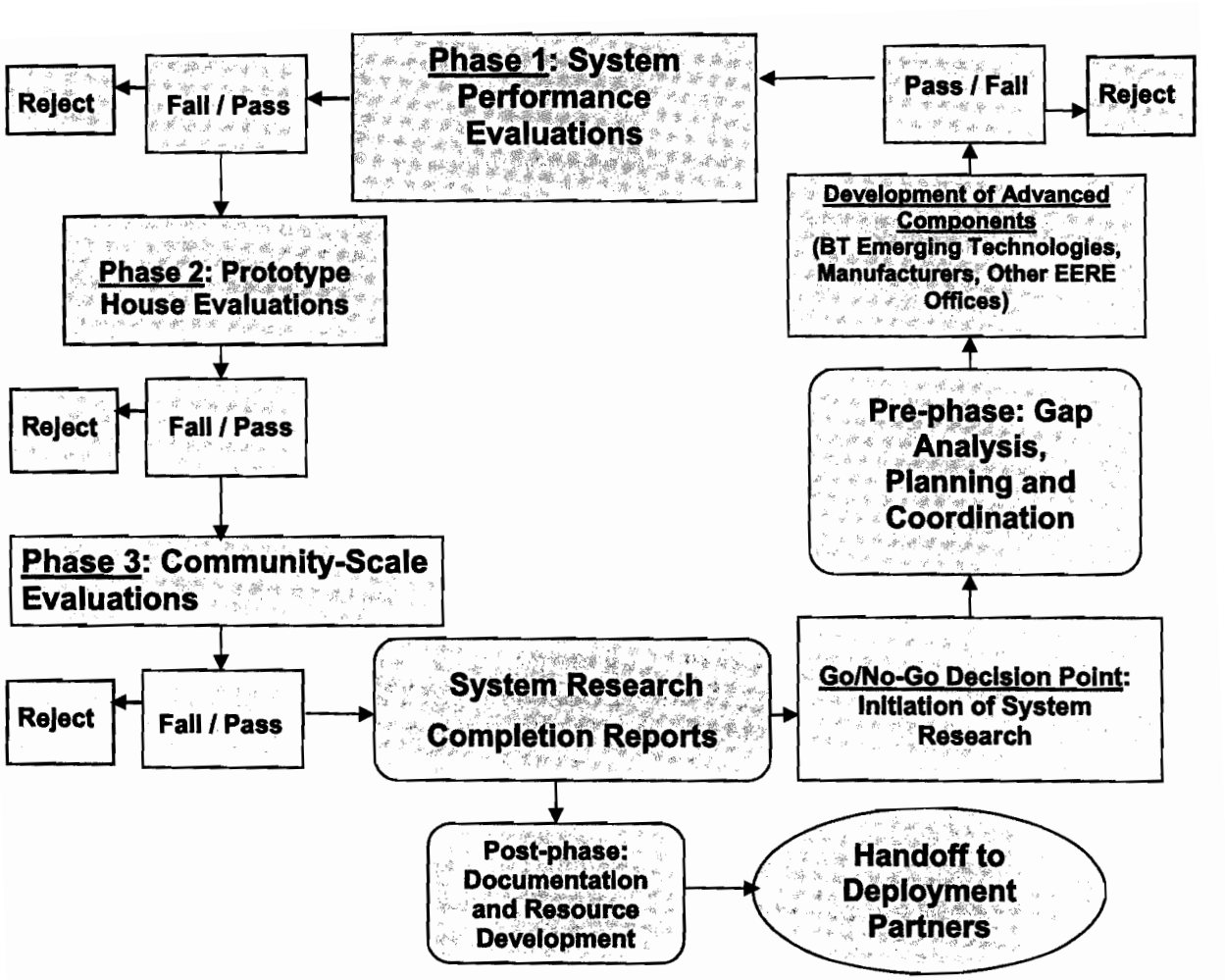


Figure 3. A more detailed look at the Building America system research strategy

The systems research described above is applied in three phases for each climate zone. During the three phases, which are conducted in parallel to allow feedback between phases, Building America acts as a national residential energy systems test-bed where homes with different system options are designed, built, and tested at three levels of system integration, including research houses, production prototype houses, and evaluations in community-scale housing to validate the reliability, cost effectiveness, and marketability of the energy systems when integrated in production housing. After completion of the community evaluations, a low level of technical support may be provided as needed to ensure successful implementation of system research results at each performance level targeted by the program. A detailed summary of the three phases of the system research process is captured in Table 2.

The three system-engineering stages overlap one another to allow issues to be quickly resolved as they are identified. The three system-research stages currently take about 3 to 4 years, but for more advanced energy efficiency levels at and above 40% whole-house savings, the systems-research process is expected to take additional iterations of whole-house testing before implementation in production ready homes. At the 50% whole-house level and above, the system research stages are expected to take 4 to 5 years to complete.

Table 2. Residential Integration Systems Research Approach

Phase 1 – System Evaluations
In Phase 1, the Building America Consortia design, construct, and test subsystems for whole-house designs in research houses to evaluate how components perform. The focus of Phase 1 is to evaluate and field-test prototype subsystems to determine the most reliable and cost-effective solution for a given performance level and climate.
Phase 2 – Prototype Houses
In Phase 2, the successful Phase 1 subsystems are designed and constructed by production builders working with the Building America Consortia to evaluate the ability to implement the systems on a production basis. The focus of Phase 2 research is to move the research prototype house and building practices to the point that they are production-ready and capable of being integrated with production construction techniques practiced by today's builders.
Phase 3 – Community Evaluations
In Phase 3, the Building America Consortia provide technical support to builder partners to advance from the production prototypes to evaluation of production houses in a subdivision. The results are documented in a case-study report. Several of these reports are distilled into a final research report that describes the system design and construction practices needed to achieve a particular level of energy savings within each climate zone targeted by the program.

Electronic Reporting of System Research Results

Final research results from the program are reported electronically via the Building America Website (www.buildingamerica.gov). Research results include project data, research reports, case studies, research highlights, and background information on the research program and its participants. The website also includes a document database and reference materials on the performance analysis and measurement procedures.

Identification of Component Development Needs

The three-phase systems-engineering approach (Table 2) requires identification of future system needs to allow the lead time required to develop and evaluate options to meet those needs. Before initiation of Phase 1 studies in research houses, components must be developed and evaluated to determine their potential to fill gaps between the performance of current systems and future whole-house performance goals. The component research requires significant lead time in some cases and focuses on communication of system-integration needs and requirements to component developers. Building America's role is to provide inputs to component developers that help to identify residential system integration needs, requirements, and gaps based on annual residential cost/performance studies using the BEopt analysis method.[8] Components must be developed for Phase 1 and have to meet minimum requirements for energy performance, reliability, and cost effectiveness before they are included as part of the residential integration activities in Phases 2 and 3.

Documentation and Resource Development

At the completion of Phase 3, the research results are documented in technical research reports that serve as references for students, educators, building scientists, architects, designers, and engineers. For the research results to be successfully transferred to additional important participants in the housing industry, they must be translated into a format appropriate for dissemination to developers, builders, contractors, homeowners, realtors, insurance companies, and mortgage providers.

This post-Phase-3 DOE activity fosters movement of the research and building techniques of the Building America Program to the market and establishes voluntary collaborations with housing and financial industries to make the nation's houses more energy-efficient and affordable. This final stage of the process focuses on documentation of best practices and development and evaluation of resources to hand-off DOE building-research findings to private- and public-sector implementation programs. This work supports activities that improve the energy efficiency of public and privately owned single-family housing. The program coordinates presentations at technical conferences on peer-reviewed, validated, research results and facilitates validation, field-testing, and evaluation of the post-phase-3 documentation.

The Building America resource development effort creates "Best Practices" manuals from the Phase-3 research reports that are designed for builders, manufacturers, homeowners, realtors, educators, insurance companies, and mortgage providers. The Best Practices manuals summarize best-practice recommendations in illustrated text that is targeted to a specific

[8] Analysis of System Strategies Targeting Near-Term Building America Energy-Performance Goals for New Single-Family Homes, Anderson, Ren et al. November 2004, NREL/TP-550-36920.

audience to make it easily assimilated and that synthesize research findings into energy-efficient processes for the building industry. To facilitate construction of affordable homes designed for non-profit organizations and small builders, Building America plans to make floor plans and section details available through the web and other means.

Building America's Research Goals

Building America's energy-saving goals form the core of the research effort and have been staged to complete an additional 10% of incremental savings every 3-5 years (Table 3).

To ensure meeting the interim targets along the path to Zero Energy Homes, Building America has also specified the interim performance targets for each climate region (Table 4).

In addition to energy savings, Building America has additional system performance goals that are critical to the success of the systems research process. These include the following:

- Accelerating the development and implementation of advanced-energy systems in new and existing residential construction through application of systems-engineering research projects by cross-cutting industry teams

Table 3. Building America Research Goals[9]

Characteristics	Units	Year				
		2007	2010	2015	2020	2025
Average Source Energy Savings	%	30	40	50	70	90
Cost	$	Zero or Less Net Cash Flow[10]				

Table 4. Building America Performance Targets by Climate Region

Target (Energy Savings)	Marine	Hot Humid	Hot-Dry / Mixed Dry	Mixed Humid	Cold
30%	2006	2007	2005	2006	2005
40%	2008	2010	2007	2008	2009
50%	2011	2015	2012	2013	2014

[9] Year of completion of annual performance targets in six climate regions. Energy savings are measured relative to Building America Research Benchmark. The targets in Table 4 are updated on an annual basis dependent on technical progress and funding.

[10] Life cycle cost, see the benchmark report: Hendron, R. (2005). *Building America Research Benchmark Definition, Updated December 29, 2004*. 43 pp., NREL Report No. TP-550-37529.

- Reducing residential building construction site waste, increasing the use of recycled materials, reducing construction cycle time, increasing system durability and reliability, and reducing warranty and call-back costs
- Developing innovative technologies and strategies that enable the housing industry in the United States to deliver environmentally sensitive, quality housing on a community scale while maintaining profitability and competitiveness of homebuilders and product suppliers
- Increasing housing value and affordability for homeowners in the United States.

30% Whole-House Energy Savings

Building America's current research activities target 30% total energy savings in new single-family homes in six climate regions. Residential buildings include a limited number of different end uses with many similarities in a particular climate region. Therefore, a climate region approach is appropriate because residential system solutions can be easily replicated on a regional basis. The climate regions defined by Building America can be seen in Figure 4.

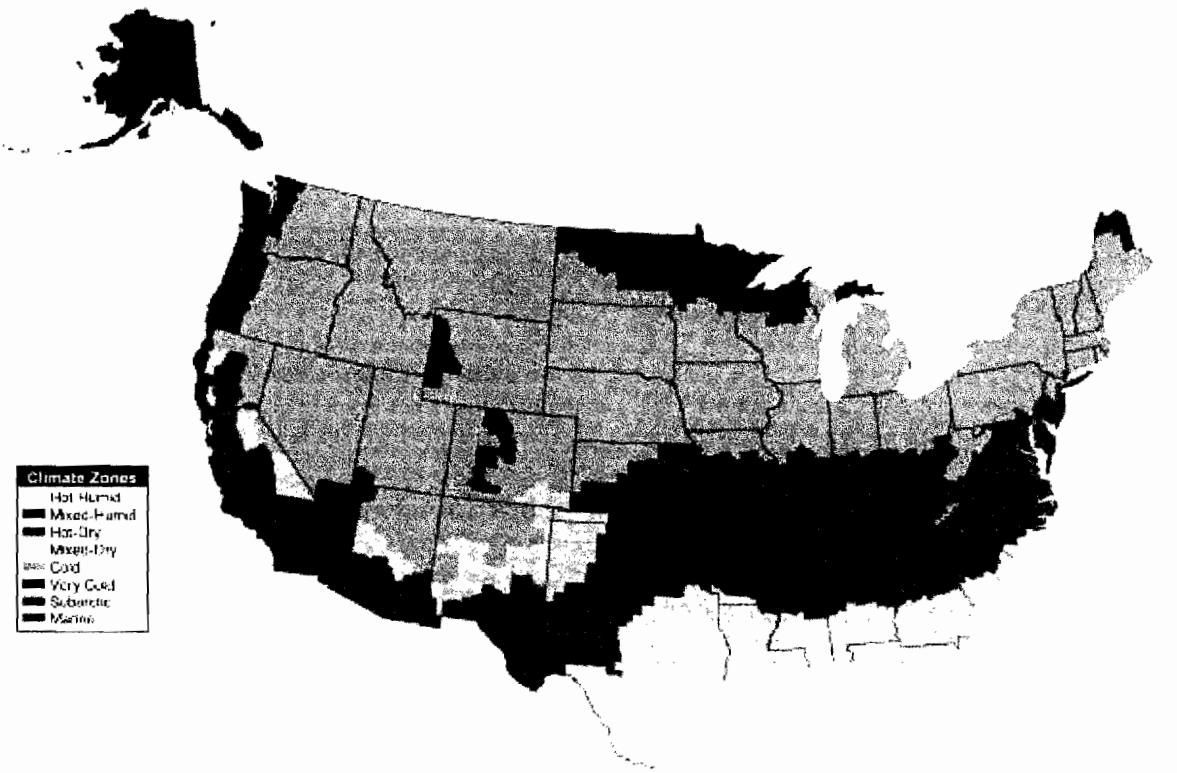


Figure 4. Building America climate regions

Because of limited resources, Building America is targeting six of the eight climate regions, including Marine, Hot-Humid, Hot-Dry/Mixed-Dry, Mixed-Humid, and Cold. The Hot-Dry and Mixed-Dry Climates have been combined into a single climate target for Building America planning purposes because of the similarities of the solutions for the two climates. The severe Cold and Subarctic Climate regions have been omitted because of limited resources and the lack of residential growth in those regions.

From 2003 to 2005, Building America has developed the following solutions to use 30% less total energy than the Benchmark for the Hot-Dry/Mixed-Dry and the Cold Climate regions. These climate regions present opportunities for research because of the number of new homes being built and the relationships established with builder partners. The number of new homes and builder partners for each climate region can be seen in Figure 5. Building America will focus on developing the 30% solutions for the Mixed-Humid and Marine regions in 2006.

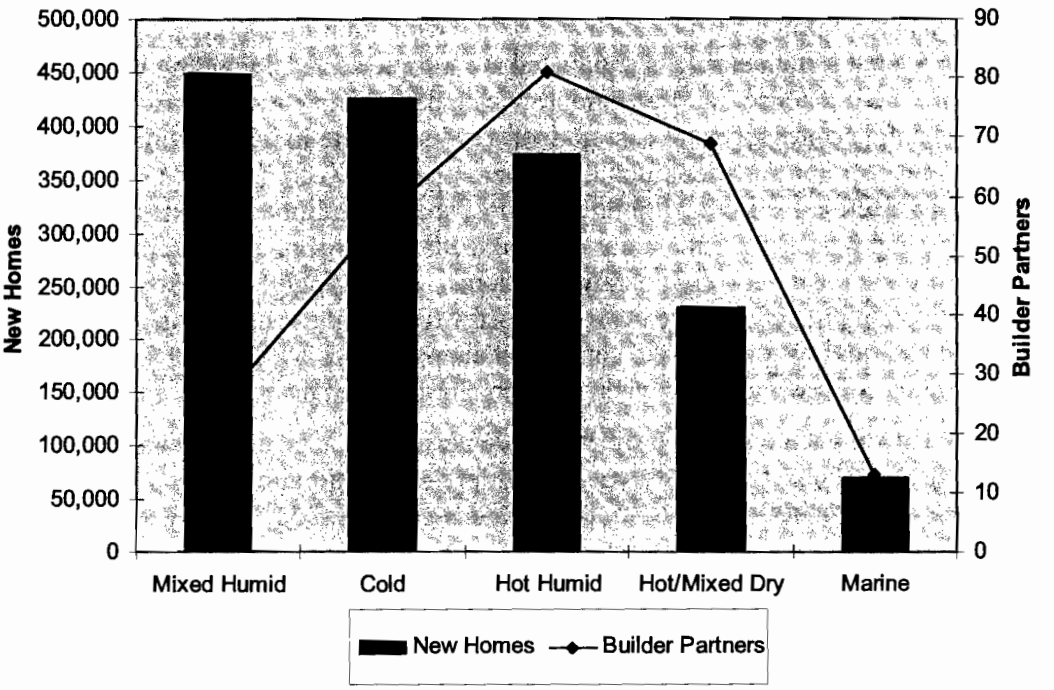


Figure 5. New homes [11] and builder partners[12] by climate region

[11] July 1, 2002, to July 1, 2003. U.S. Census Bureau Housing Unit Estimates (HU-EST2003-04), "Annual Estimates of Housing Units for Counties: April 1, 2000, to July 1, 2003," Last revised September 2, 2004.
[12] "House Counts by Climate Zone (detailed)," U.S. Department of Energy, Building America House Performance Database, January 5, 2005.

Through 2025, Building America will continue to develop the strategies for new, single-family residential buildings to use 30%-100% less total energy in the Marine, Hot-Humid, Hot-dry/Mixed-Dry, Mixed-Humid, and Cold Climate regions over the full range of house sizes, styles, and price points.

The purpose of this report is to provide an overview of 3 years of Building America system research that led to the development of homes that save 30% relative to the Benchmark.[13] Based on the research results and case studies included in this report, the Building America Research teams have demonstrated that 30% homes can be reliably designed and constructed by production builders in Cold Climates. The actual rate of adoption of the research results contained in this report will depend upon a number of factors, including residential energy costs and national, state, and local incentives for the use of energy-efficient construction techniques.

System Approach to Least-Cost Energy Savings

Integrated Design Process

Building America's team-based systems-research approach, including use of systems-engineering and operations research techniques, provides opportunities for cost and performance trade-offs that improve whole-building performance and value, while minimizing increases in overall building cost. Systems engineering is conducted at multiple scales, including individual test houses, pre-production houses, and community-scale developments. Systems research includes analysis of system performance and cost tradeoffs as they relate to whole-building energy performance and cost optimization, including interactions between advanced envelope designs, mechanical and electrical systems, lighting systems, space-conditioning systems, hot water systems, major appliances, miscellaneous electric loads, energy control systems, renewable energy systems, and onsite power generation systems. Accordingly, the best practice recommendations in this report have been demonstrated to cost effectively increase overall product value and quality compared to conventional approaches, while significantly reducing energy use and use of raw materials when used on a production basis.

The final products of each research project include performance measurements and cost/performance evaluations in prototype houses, pre-production homes, and community-scale developments, and climate-based system research design/technology packages, including system performance specifications. These measurements, evaluations, and system-performance packages are the basis of the recommendations provided in this report.

Analysis and Design Optimization

The research path to future residential energy savings extends from a base case (e.g., a current-practice building, a code-compliant building, or some other reference building) to a ZNE building with 100% energy savings. To ensure a well-defined reference for evaluation of energy

[13] The Research Benchmark provides a detailed description of all residential energy uses and serves as the reference point for the energy savings goals in Building America research project. More information about the Benchmark can be found on the Building America website: www.eere.energy.gov/buildings/building_america/PA_Resources.html.

savings and progress toward multi-year goals, a detailed Benchmark[14] building definition has been developed for use by all participants in Building America research projects. A standard reporting format for research results has also been developed to facilitate comparisons of performance between different research projects.

The Benchmark is generally consistent with the 1999 Home Energy Rating System (HERS) Reference Home, as defined by the National Association of State Energy Officials/Residential Energy Services Network (NASEO/RESNET), with additions that allow the evaluation of all home energy uses. The Benchmark represents typical standard practice in the mid-1990s, when DOE initiated the Building America program. Additional documentation to support the use of the Benchmark, including spreadsheets with detailed hourly energy usage and load profiles, can be found on the Building America Web site.[15] As Building America teams develop innovative new technologies and systems approaches that move the program toward its research goals, the Benchmark will be re-evaluated and refined periodically to ensure that energy savings from these features are accurately credited. Many other valid techniques and definitions have been developed by other organizations, and they can be very useful to builders for specialized applications. For example, the HERS rating procedure (RESNET 2002) must be followed to obtain an ENERGY STAR® rating for building energy efficiency. Also, it might be necessary to determine whether or not a prototype meets the International Energy Conservation Code (IECC)[16] or Model Energy Code (MEC),[17] which could apply if adopted by the state or local government.

Building America Research Benchmark

The Benchmark was developed to track and manage progress toward the Building America multi-year whole-building energy savings goals for new construction, using a fixed reference point. To provide a context for the potential impacts of research projects on local and regional markets at a given point in time, energy usage is also compared with current Regional Standard Practice and Builder Standard Practice. Standard occupant profiles for use in conjunction with these reference houses have also been developed based on review of the available literature; the intent is to represent typical occupant behavior. Additional analysis and end-use monitoring[18] are required to evaluate energy savings for specific occupants whose individual behavior could vary from the average profiles defined in the Benchmark. In general, relative savings for an individual user are expected to be approximately the same as those for an average user.

Energy savings can be defined in terms of site energy (used at the building site) or source energy (sometimes called primary energy). For electricity purchased from a utility, site energy can be converted to source energy to account for power plant generation efficiency and electrical transmission and distribution losses. The source-to-site energy ratio for electricity typically has a value of about 3, depending on the mix of electrical generation types (coal-fired, natural gas

---

[14] Hendron, R. 2005. *Building America Research Benchmark Definition, Updated December 29, 2004*. NREL/TP-550-37529. Golden, CO: National Renewable Energy Laboratory.

[15] www.eere.energy.gov/buildings/building_america/pa_resources.html.

[16] International Energy Conservation Code®: 2003 Edition with 2004 Supplement. Country Club Hills, IL: International Code Council, Inc. 2003, 2004.

[17] MEC 1995, Council of American Building Officials (CABO) 5203 Leesburg Pike, Falls Church, VA 22041

[18] Norton, P.; Hancock, E.; Barker, G.; Reeves, P., et.al. 2003. The Hathaway "Solar Patriot" House: A Case Study in Efficiency and Renewable Energy. NREL/TP-550-37731. Golden, CO: National Renewable Energy Laboratory

combined cycle, nuclear, hydropower, etc.) For the purpose of Building America analysis, national average site-to-source multipliers of 3.16 for electricity, 1.02 for natural gas, and 1.00 for all other fuels are used. From the view of all stakeholders in the building process, site and source energy are both important. Source energy has been chosen as the basis for tracking progress toward the Building America energy-saving targets and is also used as the basis of the cost/performance tradeoffs analyzed in this report. Site energy savings are also calculated as part of ongoing research projects and included in project evaluations because of their importance in determining specific utility bill savings.

Analysis Methods

A key issue in any building energy analysis is which tool or program to choose to estimate energy consumption. An hourly simulation is often necessary to fully evaluate the time-dependent energy impacts of advanced systems used in Building America houses. Thermal mass, solar heat gain, and wind-induced air infiltration are examples of time-dependent effects that can be accurately modeled only by using a model that calculates heat transfer and temperature in short time intervals. In addition, an hourly simulation program is also necessary to accurately estimate peak energy loads. Because of the large number of users, public availability, and level of technical support, DOE-2 is the most commonly used hourly simulation engine for systems analysis studies performed under the DOE Building America program.

EnergyGauge[19] is a frequently used interface for DOE-2; it has been tailored specifically to residential buildings. EnergyGauge can also automatically calculate HERS scores and evaluate compliance with the IECC performance path. Teams are also encouraged to use other simulation tools when appropriate for specialized building simulation analysis, provided the tool has met the requirements of BESTEST[20] in accordance with the software certification sections of the RESNET/HERS Guidelines.[21]

Building energy simulations are often used for trial-and-error evaluation of "what-if" options in building design (i.e., a limited search for an optimal solution). In some cases, a more extensive set of options is evaluated and a more methodical approach is used. For example, in the Pacific Gas and Electric ACT2 project,[22] energy-efficiency measures were evaluated using DOE-2 simulations in a sequential-analysis method that explicitly accounted for interactions. With today's computer power, the bottleneck is no longer simulation run time, but rather the human time to handle input/output. Computerized option analysis has the potential to automate the input/output, evaluate many options, and perform enough simulations to explicitly account for the effects of interactions among combinations of options. However, the number of simulations still needs to be kept reasonable, by using an efficient search technique rather than attempting exhaustive enumeration of all combinations of options. Even with simulations that run in a few seconds, run time for an exhaustive study of all possible combinations is prohibitive for the millions of combinations that can result from options in the ten or more categories needed to accurately describe a residential building. Several computer programs to automate building

[19] This is available for purchase from the Florida Solar Energy Center (http://energygauge.com/).
[20] www.eere.energy.gov/buildings/tools_directory/software.cfm/ID=85/pagename=alpha_list
[21] Residential Energy Services Network (RESNET). 2002. "Mortgage Industry National Home Energy Rating Systems Accreditation Standards." Chapter 3, pp. 29-54. San Diego, CA: RESNET.
[22] Davis Energy Group. ACT2 Stanford Ranch Site, Final Design Report. Davis, CA: Davis Energy Group.

energy optimization have been recently developed. For example, EnergyGauge-Pro[23] uses successive, incremental optimization (similar to the ACT2 approach) with calculations based on the "energy code multiplier method" for Florida. GenOpt[24] is a generic optimization program for use with various building energy simulation programs and user-selectable optimization methods.

To evaluate the cost required to reach a specific energy target, energy and cost results can be plotted in terms of annual costs (the sum of utility bills and mortgage payments for energy options) versus percent energy savings (Figure 6). The optimal least-cost path can then be determined by connecting the points for building designs that achieve various levels of energy savings at minimal cost (i.e., that establish the lower bound of results from all possible building designs). Alternatively, net present value or other economic figures of merit could be chosen. Inclusion of even a modest number of possible options for major system choices can lead to a very large number of possible building designs. One of the key challenges in developing a practical analysis method is to develop an approach that quickly focuses on the combinations that are nearest to the least-cost limit. To address these challenges, NREL is currently developing the BEopt Analysis Method.

Points of particular interest on the least-cost path are shown in Figure 6 and can be described as follows: from the Benchmark at point 1, energy use is reduced by employing building efficiency options (e.g., improvements in space-conditioning systems, hot water systems, lighting systems, thermal distribution systems, etc.) A minimum annual cost optimum occurs at point 2. Additional building efficiency options are employed until the marginal cost of saving energy for

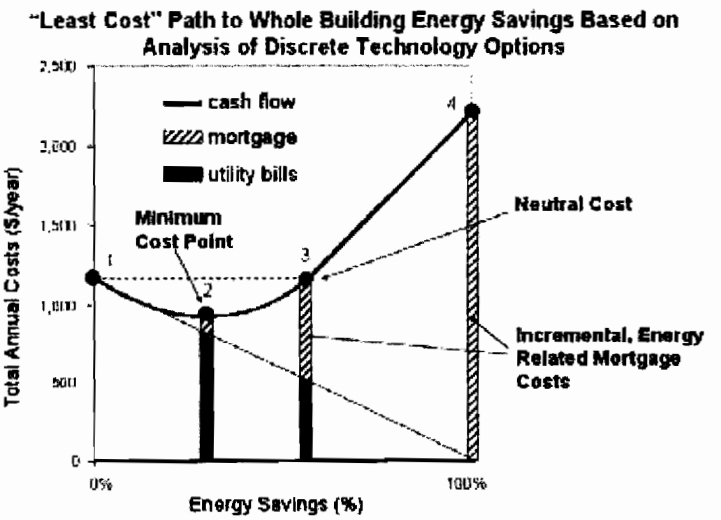


Figure 6. Least-cost curve calculated using the BE-opt analysis method

[23] Florida Solar Energy Center. EnergyGauge Pro. Cocoa, FL: Florida Solar Energy Center (http://energygauge.com/FlaRes/features/pro.htm).

[24] Wetter, M. "GenOpt®, "Generic Optimization Program," Seventh International IBPSA Conference, Rio de Janeiro, Brazil. (www.ibpsa.org/bs_01.htm).

these options equals the cost of producing power onsite at point 3. In this study, residential PV systems are used as the system option for onsite power. As research on distributed energy systems continues, it is anticipated that other onsite power technologies will also become available for residential-scale projects. From point 3 on, the building design does not change and energy savings are solely a result of adding additional onsite power capacity, until ZNE is achieved at point 4.

The horizontal dashed line in Figure 6 defines solutions that provide energy savings at an annual cost that is less than or equal to the utility cost for the reference house when energy improvements are financed as part of a 30-year mortgage. All solutions in a vertical region below the neutral cost line are essentially equivalent from an energy-savings perspective. The specific design package chosen by a builder to achieve a specific energy-savings level will depend on a number of factors, including material and equipment cost and availability and overall homeowner preferences.

Performance Verification

Modeling provides the generalized energy calculations necessary to compare a prototype house to the Benchmark. Because weather, occupant behavior, and miscellaneous electric loads can dramatically affect actual energy use, it is essential that simulations be used to separate the objective performance of a prototype house from the effects of these uncontrolled variables. Modeling also allows the evaluation of "what-if" scenarios, where alternative design features are compared to those of the as-built prototype house.

However, short-term field evaluations of actual prototype building systems provide information that modeling alone cannot. Field testing increases confidence in building models by improving simulation accuracy in areas that are difficult to know without direct measurements, such as duct and envelope air leakage, solar collector efficiency for solar hot water (SHW), and even the whole-building heat loss coefficient (UA). Common measurement techniques include tracer-gas tests, blower-door and duct-blaster tests, infrared imaging, current-voltage traces for photovoltaic systems (PV), and co-heating tests. Other tests are often developed based on the specific design features and uncertain performance characteristics of the house.

The intent of short-term testing is to characterize the performance of unoccupied building and systems under controlled conditions, not under the idiosyncratic control of random occupants. Short-term tests may be repeated seasonally to characterize performance changes from winter to summer. These tests can also help identify equipment installation issues, operational problems, or malfunctions at an early stage before the occupants are inconvenienced.

HERS raters are a valuable resource for continuing the process of energy-efficient construction with builders. Many Building America teams have successfully partnered with local HERS raters to provide initial testing, construction monitoring, and performance-verification testing services during the construction of test homes. The relationship between the builder and rater may continue after the test home, with the rater providing services, including ongoing performance verification and, in some cases, design and engineering services, depending on the rater's skill set.

The current RESNET HERS scoring system, which has been undergoing substantial change over the past few years, is of questionable value to builders participating in the Building America program, because they are generally most interested in whether they meet the overall energy

efficiency goals of the program and not necessarily just achieving a score. It is not clear in the long run how builders will embrace and promote numeric scores provided by a system where the basis of the scoring system is periodically adjusted to reflect changes in codes or adding other energy end uses that make up the score. In this respect, a prescriptive set of criteria may be more valuable to builders – criteria such as those being developed by the Building America Program and the 2006 version of the EPA ENERGY STAR Homes® program with certain performance criteria pertaining to building and space-conditioning distribution system tightness targets. Whole-house energy-performance analysis maybe the best approach for the industry instead of a scoring system that periodically changes, is not comprehensive of all energy uses (which can cause confusion with homeowners), and is not easily marketed by the builder.

Long-term field measurements provide valuable insights into the actual performance of the home under realistic conditions, including interactions between occupants and technology. Ultimately, it is essential for Building America to demonstrate that houses can meet the target levels of energy efficiency in reality and not just on paper. However, individual long-term tests under occupied conditions must always be put in the context of the specific occupants. Number of occupants, thermostat settings, operation of windows and interior shades, hot water and appliance-use patterns, and lifestyle are all important drivers of energy consumption. The recommended approach is, therefore, to compare measurements with simulated energy use based on actual occupant behavior and weather conditions and to make adjustments to the simulation based on the results of this comparison if justified. An adjusted energy savings analysis can then be performed based on actual instead of theoretical operating conditions.

Long-term monitoring activities are still ongoing for the houses designed to meet the 30% savings target discussed in this report. The results will be reported in future technical publications, and the lessons learned will be used to inform future projects at the same or higher energy-savings target. Building America is committed to long-term energy savings, health and comfort, durability, and reliability of its system design recommendations at each performance level, and we will continue to track the performance of our prototype houses for several years to come.

System Design and Construction Process

Climate Analysis

Key Climate Elements that Affect Building Design

Houses should be designed and constructed in a manner that is suited to their environment, both exterior and interior. Sun, rain, temperature, humidity, sunlight, and wind are major environmental loads that act on houses.

The recommendations in this research report are applicable to houses constructed in Hot-Dry and Mixed-Dry climate regions. The climate regions have been defined as follows[25]:

> Hot-Dry: A hot-dry climate is generally defined as a region that receives less than 20 in. (50 cm) of annual precipitation and where the monthly average outdoor temperature remains above 45°F (7°C) throughout the year.

[25] www.eere.energy.gov/buildings/building_america/climate_zones.html

Mixed-Dry: A Mixed-Dry climate is generally defined as a region that receives less than 20 in. (50 cm) of annual precipitation, has approximately 5,400 heating degree days (50°F basis) or less, and where the average monthly outdoor temperature drops below 45°F (7°C) during the winter months.

It should be noted that a section of the Hot-Dry region, stretching from deserts in southern California to Phoenix, Arizona, experiences a period of 5-6 weeks in late summer with moderately high humidity that is uncharacteristic of this otherwise Hot-Dry region.

Individual locations within the broad general regions and zones described above can vary significantly. For a specific location, designers and builders should consider local weather records, local experience, and the micro-climate around a building. Elevation, incident solar radiation, wind, shade of adjacent buildings, being located on the north side of a mountain, nearby water and wetlands, vegetation, and undergrowth can all affect the micro-climate.

Site Development

Orientation Impacts

To achieve the 30% level of energy savings, it is not necessary to orient homes in any particular direction. In many instances, the builder does not have any influence over lot orientation, and the house will face the street as laid out by the developer. The predominant window placement will typically be to the street and the back of the house. If it is possible to consider orientation at the site development level of the homebuilding process, one virtually no-cost option for improving energy performance is to subdivide for solar orientation. Alternately, on larger lots that do not have to "respect the street," site planning can be undertaken to optimize the orientation of the house for passive solar benefit. An example of land planning and lot layout to allow for passive solar orientation is shown in Figure 7.

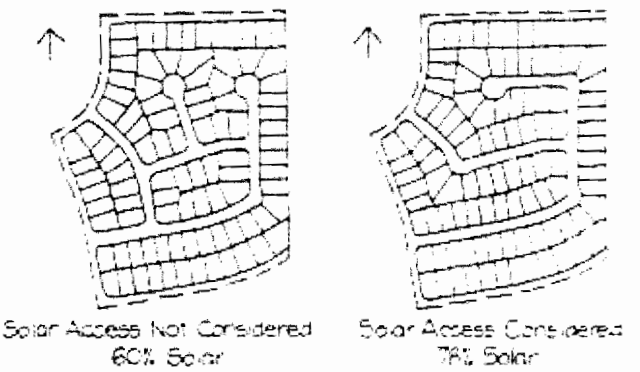


Figure 7. Subdivision site plan for solar orientation[26]

[26] Shelley Dean and Fuller, *Energy Principles in Architectural Design* Architects California Energy Commission 1981.

Landscaping

While not a required strategy for achieving 30% whole-house savings, evaluating the vegetation on a lot and retaining trees that provide beneficial shading can be a low- or no-cost way to improve energy performance, predominantly by providing shade in the cooling season and helping to buffer or direct beneficial prevailing winds. Shade trees block summer sunlight before it strikes windows, walls, and roofs, dissipating absorbed heat to the air where it can be carried away by the breeze. It is most effective when located next to windows, walls, and air conditioners, and when located on the side of the home receiving the most solar exposure in summer. Shade to the southwest and west is especially important for blocking peak solar gain in the summer in late afternoon. Trees more than 35 feet from the structure are probably too far away for shade. Trees to the north of a house in a cold climate can help block cold north winds, reducing one driving force for air infiltration. Trees, shrubs, and vines not only block sunlight, but also can cool the nearby air beneath the canopy or behind the plant by as much as 15°F because of natural evaporation from the plant's leaves.

Water Management

In natural settings, most precipitation infiltrates into the ground, while a small portion runs off on the surface and into receiving waters. This surface runoff water is classified as storm-water run off. As area are constructed and urbanized, surface permeability is reduced, resulting in increased storm water run-off volumes that are transported via urban infrastructure (e.g., gutters, pipes and sewers) to receiving waters. These storm water volumes contain sediment and other contaminants that have negative impact on water quality, navigation and recreation. Furthermore, conveyance and treatment of storm water volumes require significant municipal infrastructure and maintenance.

Reduction and treatment of run-off volumes decrease or eliminate contaminants that pollute receiving water bodies. Minimizing the need for storm water infrastructure also reduces construction impacts and the overall ecological footprint of the building. Finally, infiltration of storm water on site can recharge local aquifers, mimicking the natural water cycle.

Strategies. Storm-water management strategies that prevent or reduce the pollution of water include the following:

- Reduce impervious surface: The most effective method to minimize storm water run-off volume is to reduce the amount of impervious area. By reducing impervious area, storm-water infrastructure can be minimized or deleted from the project. To minimize the impervious surface and to encourage the natural process of evaporation and infiltration, consider such methods as designing a smaller building footprint; clustering or concentrating developments to reduce the amount of paved surfaces such as roads, parking lots and sidewalks; and paving with pervious materials, such as poured asphalt or concrete with incorporated air spaces or concrete unit-paving systems with large voids that allow grass or other vegetation to grow between the voids.
- Storm-water harvesting: Capture storm water from impervious areas to reuse within the building. Storm-water harvesting from roofs and hardscapes can be used for non-potable uses, such as sewage conveyance, fire suppression, and industrial applications.

- For storm-water volumes that must be conveyed from the site to a receiving water body, design treatment practices to match the needs of the location and the specific drainage area. Design storm-water facilities to remove contaminants and release the volumes to local water bodies. Utilize biologically based and innovative storm-water management features for pollutant load reduction, such as constructed wetlands, storm-water filtering systems, bioswales, bioretention basins, and vegetated filter strips.
- Use vegetated buffers around parking lots to remove runoff pollutants, such as oil and grit.
- Specify and install water-quality structures for pretreatment of runoff from surface parking areas. Do not disturb existing wetlands or riparian buffers when constructing ponds at the lowest elevations of a site.
- Design storm-water runoff to flow into vegetated swales rather than into structured pipes for conveyance to water-quality ponds. Swales provide filtration for storm water volumes and require less maintenance than constructed storm-water features.

System Design Approach

Integrated Design Process

Typically a house goes through the following design process:

- **Conceptual Design Development.** Planning Stage where the price range, square footage, number of stories, lot sizes, general features, and styles are determined.
- **Preliminary Design Development.** Develop floor plan sketches, number of bedrooms, major options, basic circulation, and function locations, as well as some elevation concepts.
- **Design Development.** Preliminary structural, mechanical, electrical, plumbing, and Compliance.
- **Construction Documents Development**. Final working drawings ready for bidding, submittal. Back-checking and coordination by consultants.
- **Construction and Commissioning.**

An Integrated Design Process (IDP) ensures that all the key players and design consultants, including the architect, planner, mechanical engineer, landscape architect, energy consultant and the site engineer, work together starting with the conceptual design stage, even though the role of each may be limited for a particular design stage. The IDP is a key aspect in achieving the systems-design approach.

An IDP approach may seem to be an expensive approach, but in the long run the overall costs and advantages significantly outweigh the traditional approach. For example, the mechanical engineer may be involved in the project much later and be asked to design the mechanical system with the already defined constraints of attic/plenum space – resulting in an inefficient HVAC distribution system.

By developing a better IDP, builders are able to incorporate the 30% improvement level strategies more effectively with less disruption of their normal construction process and do so more cost effectively. While use of an IDP at the 30% improvement level for builders is quite

desirable, it will be even more important at higher energy performance levels, 40%, 50%, and 70% reduction.

Approaches to an IDP will vary with different builders, as their relationships with design professionals, suppliers, and the trades are often different. For example, a builder with an in-house architectural staff, that prepares all new house designs, may have a different level of control and continuity of design as compared to a builder that works with an independent architectural firm. Approaches to the IDP are evolving in Building America's programs, and a single, clearly defined process has not been established.

An example of this is HVAC system because HVAC designers need to provide input as early as possible. They need to tell the architect which architectural features cause comfort issues and are difficult or impossible to overcome with typical HVAC practices. They also need to make sure the architect allows adequate space to run ducts. Many architects have had to re-design plans enough times as a result of HVAC issues that they know fairly well how to accommodate HVAC items. Still many problems commonly arise that could be avoided through earlier input and better coordination.

To continue with our example, Table 5 shows the main trades and consultants who are affected by the HVAC system. The first column lists the item or issue and each subsequent column how each trade is affected by it.

As shown from the matrix, all trades are intertwined in the design and building process. This matrix could be easily applied to the builder, electrician, plumber, etc. As homes become more efficient, it will be critical that all involved in the system will need to coordinate their efforts to ensure quality control and to employ quality assurance tools and processes through the IDP.

One model of the information flows and actions associated with an integrated design process are shown in Figure 8. Some of the key activities of the integrated design process is setting a performance standard, identifying and integrating all systems in the house from the predesign stage through construction documentation, and having feedback loops in the design process from key participants in organization and trade base.

Setting Performance Standards. To implement an IDP process, the team needs to have a set of standards to which the building will be expected to achieve. The first step in setting a performance standard is to understand the customer base and what level of performance they are receptive to. Targeted customer and market-area surveys help to give as clear a picture as possible of the factors that motivate home sales in general and home purchasing patterns for the target market. This data is used to direct the design of new products and respond to market pressures. The ability to survey, synthesize, and extract meaning from customers and the market can provide a significant advantage to builders, in that they have a better understanding of market and can apply this knowledge to fulfill unmet needs. If the market is indicating a need for greater energy efficiency, durability, improved indoor air quality, or comfort, then the adoption of Building America performance packages may be appropriate as the standard.

Similarly, the builder must determine what level of quality and performance their housing will achieve. This may have to do with moisture performance, comfort, increased durability, and reduced risk. All of these issues are typically addressed by following the recommendations included in this report.

Table 5. Matrix of Trades

Item	Architect	Builder/Framer /Structural Engineer	HVAC Installer	Energy Consultant	Electrical	Plumber	Drywall or insulation
FAU location	Roof pitch, furnace closets, clearance in garage	Truss design, platform, clearance, closets, bollards, attic access framing	Type of FAU (upflow, horizontal), clearance, timing of installation	Modeling correct location of ducts for computer model	Power, service light control wiring, etc.	Condensate lines, gas piping	Insulation under platform may be different
Equipment size, load calculations	Clearances, # of systems, building features	Structural impacts (weight)	Materials, labor, costs	Energy features impact sizing	Electrical loads		
Supply register locations	Aesthetics, clearances	Register boot support	Materials, labor				Sealing around registers
Return grille locations	Aesthetics, noise issues	Framed openings	Materials, labor				Sealing around grilles
Condenser locations and line set	Aesthetics, noise issues	Clearance, accessibility to yard (set-back issues), 2x6 walls, chases	Materials, labor, serviceability		Power, service disconnect		
Attic access	Aesthetics	Framed opening, truss issues	Access, serviceability				
Routing B-vent	Chases, clearances, aesthetics (on roof)	Framed chases, roof cap	Materials, labor, installation			No conflicts with vent	
Chases, soffits, and drops	Aesthetics, feasibility	Framing, clearances for ducts, conflicts	Materials, labor, installation			No conflicts with ducts	
Thermostat location	Aesthetics		Materials, labor, installation		Wiring		Seal hole for wires
Equipment efficiency			Materials	Efficiency determined by energy consultant			
Combustion air	Attic vent calcs, routing for CA ducts	Adequate attic vents (roofer)	Ducting, if any				

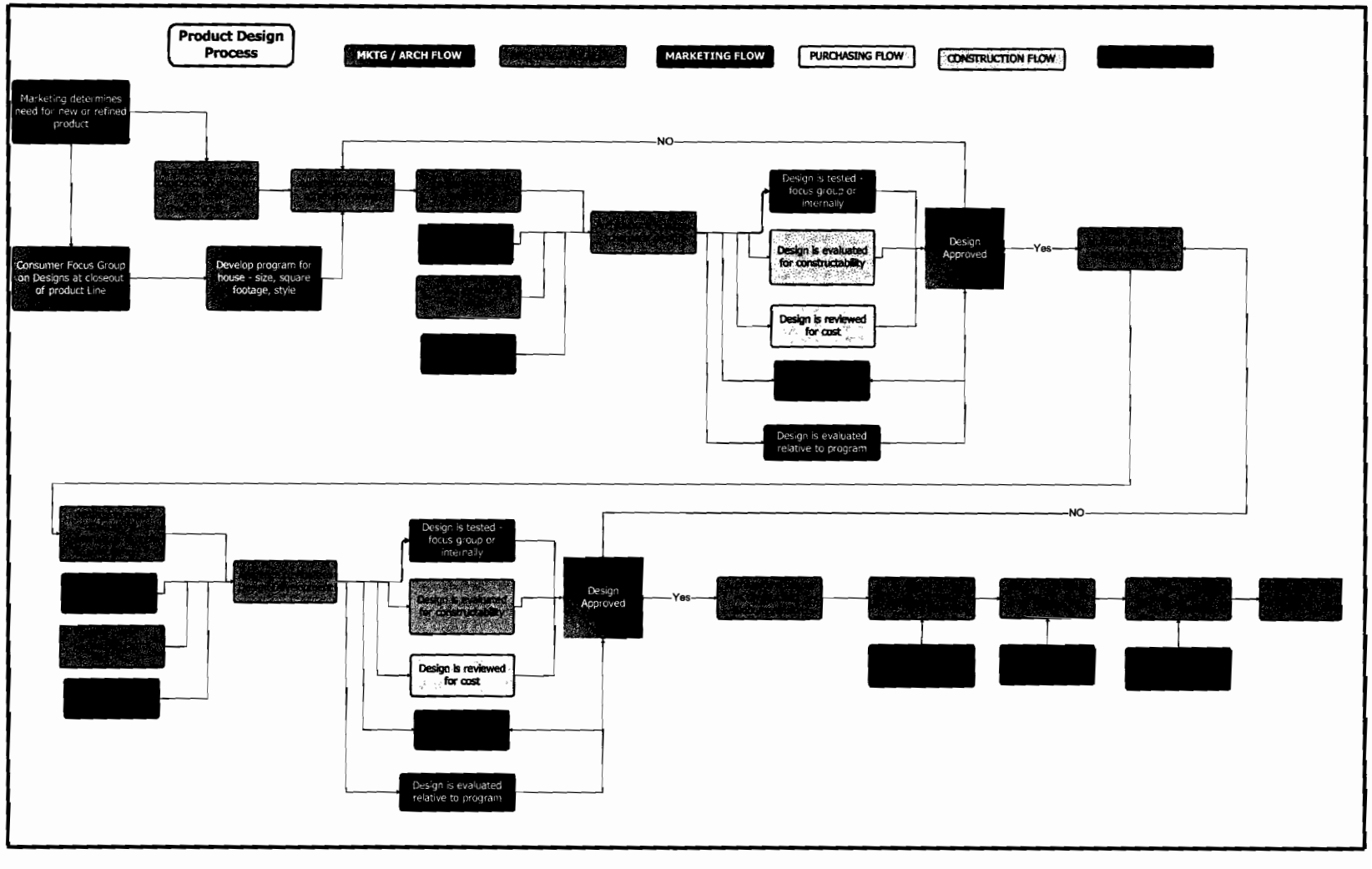


Figure 8.[27] Model of the information flows and actions associated with an integrated design process (IDP)

[27] IBACOS, Inc. KAAX-3-33410-06 B.2, Community Scale Process Research Results. Pittsburgh: IBACOS. November 2004.

Set Goals Early in the Design Stage. By creating specific high-performance goals early in the design process, the design and construction team and their external vendors all have a clear understanding of the intent and performance metrics associated with a product line. As designs are being developed, all systems and strategies are considered, and feedback is solicited. This allows for early identification of potential conflicts or opportunities for alternate solutions before designs are finalized.

The goal setting also demonstrates to vendors that the builder has committed to a level of performance, and all parties will need to play their role in seeing that it is achieved. A recognized best practice found by many of the Building America teams is a commitment to vendors to participate in long-term relationships, as opposed to simply forming relationships based on the lowest bid. This allows for mutual trust and respect to be built and the opportunity to improve and innovate is increased.

Gain Team-Based Feedback during Design. When asked about the most important design issue in its success in achieving higher performance levels, one participating builder identified framing as the area that they spend the most time on. The location of every stud, floor truss, and roof truss must be specifically located and coordinated with all other trades in order to make installation of other systems go smoothly and efficiently. This has been true throughout the Building America program. Builders may want to consider use of advanced CAD and panelization programs for generating a specific set of architectural and framing plans for each house type. It is important to work with the framing and HVAC contractors to identify conflicts and develop solutions before houses go into production.

This process is continually being refined, and a best practice by some builders is to create a single system design that would be approved, installed, and warranted by any installing contractor. This can apply for many systems in the house, including but not limited to framing, electrical, plumbing, and HVAC. For example this level of up-front design with the HVAC system helps control consistency and allows for better performance through proper sizing and design. It is important to have proper load calculations, equipment selection, and duct layouts with documentation that is somewhat transparent, so that HVAC vendors can evaluate system design options and agree upon a final solution. At this point, design changes can also be made to floor plan and framing layouts that can facilitate duct installation. While there is never a perfect solution for all parties, this level of discussion between the vendors, design, and construction greatly enhances the opportunity to "get it right." This process can be applied for virtually any system in the house.

Energy Analysis

From a purely energy perspective, the section of this report entitled System Approach to Least-Cost Energy Savings describes the process involved with optimizing Building America Houses. It must be noted that energy cannot be evaluated in a vacuum, and other issues have to be considered in the design process. In order for higher levels of efficiency to be accepted by builders and consumers, other key attributes of the house must be addressed. The systems-design approach is a process by which all the various subsystems in the house are evaluated and their interrelationships are understood, planned, and optimized. All of these systems must be designed and applied to realize both energy-related and non-energy performance benefits associated with occupant health, safety, comfort and long-term building durability and

efficiency. To only achieve energy efficiency without meeting these other criteria could cause consumer dissatisfaction and ultimately rejection of higher levels of energy efficiency, because the occupant's other expectations of a new house are not being met.

In a general sense, Building America houses include increased levels of thermal insulation, higher-performance windows, significant air sealing, a strategy that eliminates the possibility of introducing the by-products of combustion into the house, a mechanical ventilation system, a properly sized and engineered space-conditioning system, higher efficiency space-conditioning and water-heating appliances, and may also include improvements in the efficiency of the appliances and lighting. The extent to which any of these strategies must be implemented varies by climate zone and the level of energy performance the builder seeks to achieve. A systems-design approach helps assure that the energy-related aspects of the project are being satisfied in conjunction with the non-energy benefits and is done in a way that optimizes the synergies of the various systems in the house.

An important part of getting to the 30% energy savings, or any other level of energy saving,-is to be able to evaluate alternative combinations of energy features before homes are built. Energy-simulation software, also referred to as computer or simulation models, are used to estimate energy performance of buildings quickly and inexpensively long before anything is purchased or constructed. Builders can access the costs of the various combinations of energy features to determine the most cost effective way of achieving the desired energy savings level early in the design process.

Very often, energy savings of homes only refers to savings of heating and cooling energy, or heating, cooling, and water heating. It is important to note that in the 30% savings level referenced throughout this report and throughout the Building America Program, references are made to whole-house energy savings, including all the energy used in the home for heating, cooling, water heating, and all the appliances and miscellaneous electrical uses, often referred to as plug loads.

The other challenge in energy analyses is to be able to compare energy studies done from one person to another, in fact from company to company, across the country. For this purpose, the Building America Program has developed a Benchmark, so that assumptions made in conducting energy analyses across the country can be standardized, enabling results to be fairly and reasonably compared.

The Benchmark guidelines are used to define a base-case house for determining levels of energy savings in conducting energy analyses. The Benchmark is generally consistent with mid-1990s standard practice, as reflected in the Home Energy Rating System (HERS) Technical Guidelines (RESNET 2002), with additional definitions that allow the analyst to evaluate all residential end-uses, an extension of the traditional HERS rating approach that focuses on space conditioning and water heating. A series of user profiles, intended to represent the behavior of a "standard" set of occupants, was created for use in conjunction with the Benchmark.

Energy simulations are conducted using software such as Energy Gauge, Energy 10, DOE 2.2, TRNSYS and Micropas, to predict the yearly energy consumption in homes.[28] Energy

[28]DOE's list of energy simulation software can be found at www.eere.energy.gov/consumerinfo/reading_resources/v103.html

simulations are run for both the Benchmark, as well as the designed home. The design home consists of enhanced energy-efficient features and systems. The detailed energy-simulation results are used to compute the energy savings of the designed home compared to the Benchmark base case.

Passive Design Strategies for Minimizing Cooling and Optimizing Heating

To achieve a 30% whole-house energy savings, it is not necessary to undertake any specific passive solar-design strategies. It should be recognized that proper orientation of the building and implementation of passive solar strategies can be a low or no-cost method to significantly improve the energy performance of a house.

An almost invisible way of incorporating a "passive" strategy that is beneficial in all climate zones is the use of low-SHGC glazing in all fenestration units. This product generally has little impact on the visual characteristics of the window, and incorporating it does not require aesthetic redesign of the house. The 2004 Supplement to the 2003 International Residential Code requires a SHGC of 0.4 in the Hot-Dry, Mixed-Dry, Marine, Hot-Humid, and southern parts of the Mixed-Humid climate zones. Relatively low (0.30) SHGC glazing has been used successfully in 30% improvement homes in all climate zones. While a low SHGC unit reduces beneficial heating season solar gain, Building America teams have found that where no attention is paid to passive solar design, low-SHGC windows generally provide a cost-effective option for builders, when all the systems interactions benefits are considered. The following are the reasons for this:

- Traditional production-builder house models are oriented in any direction. Using lower SHGC glazing in all windows assures an overall reduction of the heat gain during the cooling season, regardless of how the house is placed with respect to the sun. This reduction in heat gain avoids some of the need for air conditioner operation, which is a net energy savings.
- Air-conditioning equipment is sized based on peak load. Using lower-SHGC glazing reduces peak load and, in turn, reduces air-conditioning unit sizes. Smaller air-conditioning systems have lower airflows rates and, therefore, require smaller ducts. Lower airflow rates also require smaller fans, which use less electricity to operate. Reducing the size of the air-conditioning (AC) system also means cost savings to the builder, which can be reinvested in other energy upgrades.
- The heating season heat gain penalty from the use of lower SHGC glazing only occurs on cold, sunny days. As seen in Figure 8A, there is comparably little solar resource across much of the northern United States in the winter months; thus, there is little opportunity for beneficial solar gain. In those areas of the Cold Climate zone where there is a good winter solar resource, higher SHGC windows may be considered, but need to be carefully designed to avoid overheating south-facing rooms on sunny winter days and need to be properly shaded to reduce solar heat gain in the summer months
- Use of lower SHGC glazing, by cutting the solar gain that varies in direction throughout the day, helps maintain more uniform room temperatures throughout the house. Even with zoned systems, it is not possible to control all room temperatures individually, and solar gain is one of the largest factors causing overheating and room-to-room imbalances.

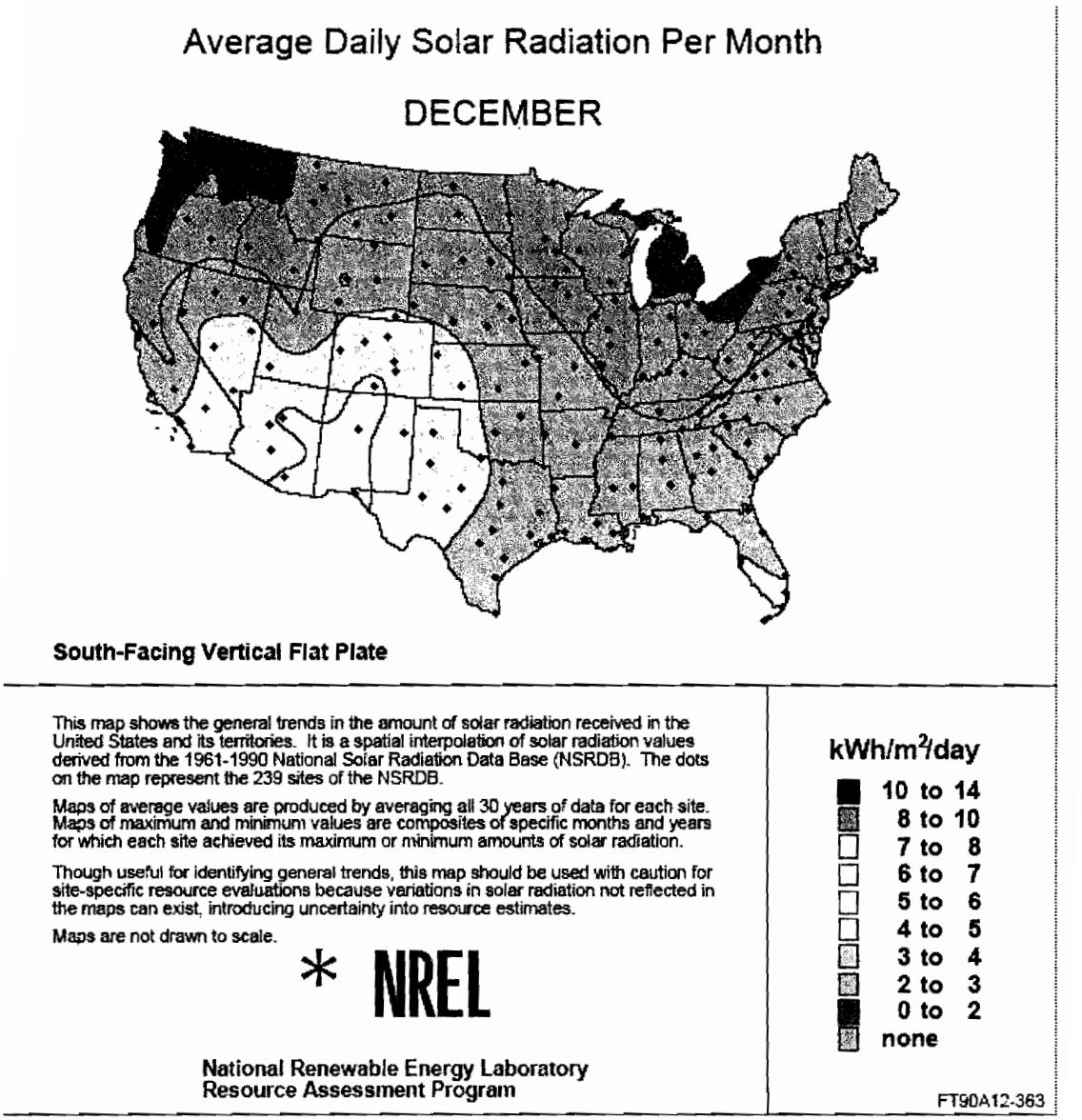


Figure 8A. Average south-facing vertical flat-plate radiation in December for the United States

Indoor Air Quality Strategies

The Environmental Protection Agency ranks poor indoor air quality among the top five environmental risks to public health. Levels of air pollution inside the home can be 2 to 5 times higher (and occasionally 100 times higher) than outdoor levels. If too little outdoor air enters a home, pollutants can accumulate to levels that can pose health and comfort problems. Unless they are built with special mechanical means of ventilation, homes that are designed and constructed to minimize the amount of outdoor air entering the home may have a higher pollutant levels.

Providing good indoor air quality (IAQ) at the 30% improvement level is important to maintain customer health and comfort and may minimize the possibility of high humidity levels and associated mold growth. Because 30% houses will have higher levels of insulation (which affects envelope hygrothermal characteristics) and because they will be reasonably air tight (which will affect internal moisture gain and removal), good IAQ requires a more proactive approach. Good IAQ requires control of indoor moisture, CO_2, CO, NO_2, SO_2, ozone, particulates, dust-mite dropping, odors, and other hazardous airborne contaminants. There are several approaches to good IAQ: (1) control the generating source, (2) remove the contaminant from the indoor air by ventilation or air filtration; and/or, (3) physical cleaning (vacuuming, dusting, etc.)

Source Control. Source control is the most positive approach in the 30% improved homes. A number of means of source control have been employed:

- Control of moisture to remove one of the key support elements for mold growth. This is a broad subject and includes application of all of the following principles:
    - Proper flashing details for windows, doors, wall/roof junctions, penetrations of all sorts (pipes, ducts, skylights, etc.), attachments (such as porches and decks), offsets and projections (such as bay windows) to control the entry of bulk water.
    - Control of envelope condensation potential through appropriate insulation and vapor permeability of layers. Appropriate designs must be applied for all components of the building envelope, including walls, roof, and foundations. The section of this report entitled Cost Analysis discusses climate-specific assemblies. In addition, a builder may utilize other regionally specific guidelines, such as the EEBA Builders Guides.[29] At a more detailed level, static analysis techniques or dynamic models such as WUFI[30] can be used. It should be noted that currently WUFI analysis will handle many wall and roof configurations, but it is not capable of foundation analysis. While ongoing research projects are adding to our knowledge of the hygrothermal performances of different forms of foundation insulation, following the practices outlined in the section of this report entitled Cost Analysis should result in good moisture performance.
    - One wood-frame wall construction detail that has proven quite effective for condensation control is to use an exterior insulating sheathing in addition to the traditional cavity insulation. During the heating season, this helps to raise the

[29] Lstiburek, Joseph. 2004. Energy and Environmental Building Association. Builder's Guide to Hot Dry Mixed Dry Climates: A Systems Approach to Designing and Building Homes that are Healthy, Comfortable, Durable, Energy Efficient and Environmentally Responsible. Westford, MA: Building Science Press.
[30] WUFI 2D, Version 2.1. Simulation of heat and moisture transfer. September 2000.

temperature of the interior surface of the sheathing (the first condensing surface) above the indoor air dew point. During periods of hot, humid weather, it acts as a vapor retarder and helps prevent moist outdoor air from entering the wall, which reduces the potential for condensation on the backside of the interior gypsum board in air-conditioned homes. For specific design considerations of this wall assembly, see further detail in the section of this report entitled Building Enclosure Integration Strategies, Walls Section.

- Foundation waterproofing, damp-proofing, and capillary moisture control are important moisture-management actions taken at the 30% improvement level. Failure to properly control moisture in crawlspace and full-basement constructions can result in high relative humidity in these spaces, which can lead to mold and mildew growth. Recommendations include the following:
  - Exterior foundation waterproofing/damp-proofing with a drainage layer and footing drain, to intercept and drain off exterior water. The drainage layer is often an impervious plastic mat, fiberglass, or foam insulation board, or uniformly graded gravel. The insulation board offers the advantage of combining exterior foundation insulation (the most beneficial location for foundation insulation) with a good drainage material.
  - After a large rainfall or after water has been applied for irrigating grass or plantings near the house, moisture can accumulate below and next to a footing. Moisture movement, by capillary action, can occur from this location through to the concrete footing and, from there, the moisture can be transferred into the slab or concrete or block foundation wall. Water stains on the perimeter of the slab or at the interior of the foundation wall can result and are not only unsightly, but they also offer an environment for mold growth to occur. This moisture pathway may be controlled by forming a continuous capillary break between the ground and the concrete foundation system. With monolithic slab-on-grade construction, polyethylene sheeting should be placed under the entire slab and footing up to grade. With footings poured independent of slabs or with foundation walls, a bituminous damp-proof coating, masonry capillary-break paint, or a layer of poly can be used to isolate the footing from the remainder of the assembly.

- Air-leakage control is another key method of reducing IAQ pollution sources. Air leaking in from the outdoors may carry outdoor air pollutants (including vehicle exhaust and plant pollens) into the house, but outdoor air is typically (though not always) considered a fresh air source. What outdoor air does bring, in hot humid weather, is moisture that can condense on internal building components that may then support mold growth. In winter, air leakage outward through the building envelope can bring relatively moist indoor air into contact with cold surfaces. Building envelope air sealing (in addition to reducing energy consumption) is valuable to reduce moist-air migration that could lead to mold growth under both summer or winter conditions and reduce occupant exposure to outdoor pollutants.
- Sealing against air leakage is primarily for thermal reasons, but when coupled with appropriate mechanical ventilation, this procedure also assists in providing good IAQ for

the occupant. Extensive air sealing is one of the primary 30% improvement strategies. It includes a range of recommendations to builders, including the following:

- Develop a continuous air barrier with interior gypsum board on walls and ceilings, giving attention to sealing at edges and joints, around penetrations and electrical boxes (including ceiling recessed downlights). Particularly important is to get sheathing continuity behind bathtubs and showers, at fireplaces, soffits, stairways, and at the band joist.
- Develop an air barrier with exterior sheathing using taped and caulked joints.
- Use foam seal (non-expansive) around window and doorframes.
- Construct well-sealed attic access hatches.
- Take particular care to seal all contact surfaces between attached garages and the occupied house. This must include sealing at all penetrations and the provision of gasketed, self-closing doors between garage and house.

- Seal forced-air distribution systems. Leaky duct systems contribute to poor IAQ in several ways. Leaky ducts can cause pressure imbalances, which can draw air from the outdoors, building cavities, or attached garage spaces. In addition, pressure imbalances can move moisture laden air into building cavities where the water vapor can condense, causing a habitat for mold and mildew. Specific strategies and techniques associated with the proper design and construction of air distribution systems can be found elsewhere in this report.
- Control of radon and other soil gasses. The principal method of controlling the entry of these gases into a house is through the use of under-slab ventilation. House pressurization can be effective for this purpose as well, but is difficult to implement and control with current HVAC technologies. Under-slab ventilation typically takes the form of modest depth of uniformly graded crushed stone (i.e., with good void spaces) 4 in. to 8 in. deep, in which is embedded an array of perforated plastic drainpipe and covered with a poly air/vapor barrier. The piping is linked by a header, to which is connected a vertical vent pipe leading up through the house and out at the roof. This system is often installed as a precaution even when no evidence of radon has been shown, as it is far easier to do this than to come back later and retrofit an under-slab venting system. Usually, the vent goes through the roof and functions as a passive vent. It is designed, however, for the subsequent installation of an exhaust fan should the need for a more positive ventilating action be demonstrated. An electrical outlet for a possible future fan installation is located in the attic or basement adjacent to the vent pipe. Further information on sub-slab ventilation systems can be found in the EPA's *Model Standards And Techniques For Control of Radon in New Residential Buildings*[31]
- Combustion Safety. To avoid the possibility of the introduction of the by-products of combustion being brought into the house, several components associated with combustion safety must be addressed in the 30% improved house. Because these houses are generally quite air tight, natural-draft appliances are not recommended. The basic recommendations are as follows:

[31] Environmental Protection Agency. Model Standards and Techniques for Control of Radon in New Residential Buildings. Environmental Protection Agency Website. www.epa.gov/radon/pubs/newconst.html.

- **Furnaces.** Use sealed-combustion units or draft-induced units with dedicated make-up air so that the combustion process is atmospherically decoupled from the house itself.
- **Tank or Tankless Domestic Hot Water (DHW) Heaters.** Use sealed-combustion, direct-vent, or power-vented types that are atmospherically decoupled from the house.
- **Fireplaces.** If fireplaces are installed (gas-fired or solid-fuel-burning) are installed, use units that directly vent the by-products of combustion to the outdoors, are equipped with tight-fitting glass doors, and preferably use outside air for combustion.
- **Gas Appliances.** Eliminate unvented gas appliances, except cooking appliance, which should be vented to the outdoors by a ducted-range hood.

- Finishes. Finishes such as paints, sealers, adhesives, fabrics, and surface-covering roll goods (i.e., vinyl wall coverings) are all potential sources of indoor air pollutants, including various volatile organic compounds (VOCs). Most of the liquid-applied materials dissipate rather rapidly as they dry. Leaving windows open as they are applied and dry removes the high initial concentrations. After this initial "dry-out" period, a properly designed ventilation system will continue to bring in fresh air and remove further off-gassing of pollutants. Thus, for any but highly sensitive occupants, the selection of special, low-VOC, materials and finishes is not seen as necessary to achieve the 30% whole-house energy-savings level. Should a homeowner have IAQ sensitivity needs, then the application of the American Lung Association (ALA) Health House Specifications[32] or specifications to meet the EPA's Indoor Air Quality (IAQ) Label[33] would be appropriate.
- Relative Humidity Control. The control of indoor relative humidity (RH) is another key strategy to maintain good IAQ. The desirable range of indoor RH is from 20% in winter to 65% in summer, with a preferable range of 30% to 50%. Ventilation strategies play a key role in maintaining these ranges and are discussed more fully in the ventilation section of this report. However, a variety of ventilation forms, including heat-recovery ventilators (HRVs) or energy recovery ventilation (ERVs), are used to remove excess humidity in the winter and ERVs, dehumidifying ventilators, dedicated dehumidifiers, and advanced HVAC control systems are used to control excess humidity in the summer. The importance of winter or summer humidity control, of course, varies with climate region.
- Pollutant Removal and/or Dilution. Ventilation and air cleaning are the principle methods of airborne pollutant removal or dilution. Ventilation system design and strategies are treated more fully in another section of this report, but key features relative to good IAQ in 30% improvement houses will be noted here.
  - Whole-house mechanical ventilation in accordance with ASHRAE Standard 62.2[34] is recommended. Any of a number of system configurations can meet this requirement and include the following:
    - Passive inlet direct to the return-air duct with appropriate dampers and controls

[32] American Lung Association. Builder Guidelines. American Lung Association® (ALA) Health House®. www.healthhouse.org/build/Guidelines.asp October 1, 2004.
[33] Environmental Protection Agency. Indoor Air Quality Label. Environmental Protection Agency Website. www.epa.gov/iaq/energystar/label_specifications.html. 2004.

[34] ANSI/ASHRAE 62.2-2004, Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings

- Dedicated supply fans designed for continuous operation
- HRVs or ERVs
- Dedicated central dehumidifier with ventilation.

- Whole-house ventilation air should be distributed to all the primary occupied spaces in the house, particularly bedroom and living areas. This is typically accomplished by ducting ventilation air into the heating/cooling duct system. For this distribution to be continually effective, however, the HVAC system must be periodically cycled, even in no heating/cooling periods. Dedicated ventilation distribution ductwork is occasionally used, particularly if no forced-air system exists, but it is a more costly option. Fresh-air intakes should be provided with nominal filtration to prevent the entry of insects and large particulates.
- For good IAQ, the HVAC return air stream should be filtered with a 4-in. standard filter or a new Minimum Efficiency Reporting Values (MERV)[35] 6 or 8 normal-thickness filters. Ventilation air should also pass through this filter, if possible. Filters should be easily accessible for cleaning or replacement and the filter slot should be designed so that there is no air bypass around the filter when the HVAC system is operating.
- It is important to provide local exhaust fans for bathrooms, range hoods in the kitchen, and exhaust fans in other areas where pollutants may be generated (utility, hobby rooms, etc.). All of these fans must be ducted to outdoors via the most direct path.
- Ventilation technology has developed significantly in recent years, but a few areas remain problematic:
  - It is difficult to find low-airflow ventilation units, particularly HRVs and ERVs.
  - Design of distribution systems is a challenge. Using HVAC ductwork requires cycling the central fan, which increases the electric consumption. Dedicated ventilation ductwork is quite small and must be well designed to function properly. The ventilation air from a dedicated ventilation fan (i.e., ERV, HRV) may not be fully distributed to all rooms when only the ventilation airflow is being moved through the larger ducts of the central space-conditioning system.
  - Builders do not like the additional cost of installing a ventilation system and often have a difficult time explaining why it is needed to the consumer.
  - Ventilation controls are often difficult to integrate with the HVAC system because the products are not usually designed for integration. A newer generation of integrated ventilation and space-conditioning controls are beginning to be introduced by major manufacturers, and it is anticipated that this trend will continue in the future with more options becoming available to builders.
  - Ventilation should be accomplished in the most energy-efficient manner, balancing fan energy consumption with the cost of conditioning the ventilation air.

[35] See www.filters-for-home.com/mrev.htm for MERV definitions.

- Physical Cleaning. Builders have very little control over occupant behavior and, as such, there are limited strategies a builder can incorporate in this area. One primary opportunity is in the installation of a whole-house vacuum system that exhausts to the outdoor, which limits the reintroduction of dust in the house. Another is the inclusion of a discussion of maintaining good indoor air quality in an owner's manual for the house, including cleaning practices as they relate to indoor air quality.

Heating and Cooling Equipment and Distribution Strategies – Creating Conditioned Space for HVAC Systems

For the 30% improvement house and all new home construction, it is highly recommended that the heating and cooling system be designed according to industry standard methodologies, most notably ACCA Manual J,[36] S,[37] D,[38] and T.[39] With the use of low-SHGC glass, it is practical to design each house model of a builder's line for the worst orientation without significant penalty in other orientation. The use of low-SHGC glazing reduces the solar component of the cooling load and helps to level the cooling load and minimize variations resulting from orientation. Whenever practical, the design should be specific to an individual house and its orientation. System implications based on variations with orientation are a result of the different solar loads and, for system design purposes, do not affect heating loads. The impact is primarily on the cooling system design as a result of solar load through windows.

Heating and Cooling Equipment. The preference is for a single heating/cooling unit to serve the entire house, frequently utilizing a zoning system with multiple fan speeds and variable output. This is an efficient approach and allows the closest tailoring of unit size to peak and part-load conditions. In some cases, especially homes of more than 2,500 ft^2, two or more units may be needed to meet the load or to serve distinct zones in the house. With the better thermal envelope of the 30% improved house, a single HVAC unit may often be feasible where two were used before. A single HVAC unit with zoning dampers and controls is also better able to adapt to major load differences. It is strongly recommended that the air-handler unit be located within the conditioned space of the house. When located in unconditioned space, as in vented attic or garage locations, the units are exposed to full winter and summer temperature conditions and experience major thermal losses, because HVAC units are poorly insulated and have significant air leakage.

More detailed discussion of heating and cooling equipment selections are given in the section of this report entitled Space Conditioning and Ventilation. In the 30% improvement house, the recommendation is to use a sealed-combustion furnace or draft-induced unit with dedicated make-up air so that the combustion process is atmospherically decoupled from the house itself and located in conditioned space, for efficiency and combustion safety reasons.

---

36 ACCA. 2003. Manual J: Residential Load Calculation 8th Edition. Arlington, VA: Air Conditioning Contractors of America.
37 ACCA. 1995. Manual S: Residential Heating and Cooling Equipment Selection. Arlington, VA: Air Conditioning Contractors of America, Washington, D.C.
38 ACCA. 1995. Manual D: Residential Duct Systems. Arlington, VA: Air Conditioning Contractors of America, Washington, D.C.
39 ACCA. 1993. Manual T: Air Distribution Basics. Arlington, VA: Air Conditioning Contractors of America, Washington, D.C.

A high-efficiency electric heat pump may also be an effective choice for heating, although because of the source energy conversion a Heating Season Performance Factor (HSPF) of approximately 9.7 is necessary to match the source energy efficiency of a 92% AFUE furnace. Where the thermal envelope of the house has been significantly improved, the heating load may be dramatically reduced; therefore, the cost effectiveness of a gas furnace and all the associated piping and utility infrastructure costs need to be weighed against the potential increase in source energy consumption associated with using a heat pump with a HSPF lower than 9.7.

Air conditioners in Hot-Dry/Mixed-Dry climates should have SEER ratings of 13 or greater, which will be code minimum starting in 2006. It should also be noted that there is a wide range of cooling requirements in the Hot-Dry/Mixed-Dry climate zone, and the SEER rating should be evaluated based on annual hours of operation. In general, the greater the cooling need, the higher the SEER rating should be. From a design standpoint, if the architecture of the home incorporates passive strategies for cooling-load reduction (such as shaded south-, west-, and east-facing glass, minimized unshaded west-facing glass, or a design that incorporates low-SHGC glazing and a small number of windows) cooling system run hours can be reduced, and smaller capacity equipment will be appropriate. In this climate zone, designers should also recognize that because of the minimal latent loads, some of the latent capacity in the equipment can be used for sensible load. In general, the sensible capacity equals the total capacity when the design wet-bulb temperature of the return air is less than 59°F. Designers need to check the mean coincident wet-bulb temperature at outdoor design conditions and select equipment based on this. This strategy helps to prevent oversizing of the equipment.

Air Distribution Systems. To achieve a 30% whole-house energy reduction, a number of requirements apply to design of the duct system:

- Design should be in accordance with ACCA Manual D.
- Ductwork should be located within the thermal envelope of the house; in some climate zones they may be buried in attic insulation.
- Ducts should not be located in exterior walls.
- Ducts must be air-sealed using UL 181-approved mastic or equivalent for the particular duct type
- "Panning" between joists and the use of stud cavities for supply or return air is not recommended.
- Ducts may be of galvanized sheet metal, duct board, or flex duct.
- There must be continuity of the vapor barrier on insulated ducts not running inside conditioned spaces.

Sometimes duct systems need to run in unconditioned spaces. For a discussion of the treatment of these ducts, see the section entitled Space Conditioning and Ventilation Systems.

To accommodate heating and cooling units and duct systems within the thermal envelope of the house, a number of techniques may be employed. This typically affects the architectural design of the house and should be considered at the early schematic phase of design. Keeping

ducts inside the conditioned space may also involve framing systems that allow ducts to be run through it, such as an open-web floor-truss system. Alternately, dropped soffits, tray ceilings, and lower ceiling heights in "service" function rooms like baths, hallways, and closets can accommodate ducts inside the envelope. Strategies include the following:

- Locate ducts within an insulated, non-vented, conditioned crawl space or basement
- Locate within an insulated "cathedralized" attic
- Locate in open-web floor trusses
- Develop chase walls to accommodate duct risers
- Design closets inside the conditioned space for locating the air handler in houses using slab-on-grade construction.

More specific discussion of many of these recommendations is found in the Section entitled Space Conditioning and Ventilation Systems.

Where a boiler or water heater is used for space heating, a hydronic distribution system is necessary. These are particularly suited to cold-climate applications where there may not be a need for air conditioning and the associated duct-distribution system. Their most common configuration is a radiant floor or baseboard convection units. If a radiant floor system is selected in a slab-on-grade installation, it is required that the slab be insulated from the ground and at the slab edge with at least R-10 (2-in.) of rigid insulation. Slab edges need to be insulated because they are exposed to cold exterior conditions. If a boiler or water heater serves a fan coil and ducted system, all recommendations for ducts noted above apply. Hydronic systems are described in more detail in the section of this report entitled Space Conditioning and Ventilation Systems.

First Costs, Cost Tradeoffs, and Owner Annualized PITI + Energy

Useful and representative costs information for 30% improvements has not been easy to determine. In many cases, these are pilot homes and are the first of this level of energy performance that have been done by a builder. Thus, the energy-use-reduction construction strategies are new to the builder and costs do not represent a mature purchasing structure or experienced installation practices. Furthermore, there are often compensating or beneficial attributes of the improvement strategies that are not realized until multiple houses are built. An example is the ease of air sealing that is inherent with spray-foam insulation systems that replaces tedious hand-caulk and foam-gun sealing done by laborers. Until a builder experiences the change, it is usually not valued.

Some of the common cost tradeoffs that builders in the Building America program have used include the following:

- Reduced costs associated with advanced framing
- Reduced costs associated with downsizing space-conditioning equipment and simplifying air-distribution systems
- Increased costs for higher performance windows and insulation and air-sealing packages, that enable the reduction in HVAC system size

- Substituting insulating sheathing for structural-panel sheathing increases wall-insulation levels at low or no incremental cost
- Increased cost of installing mechanical ventilation
- More usable floor space in slab-on-grade construction through the use of tankless water heaters instead of tank type water.

Builders who commits to evolving their organizations to the consistent production of quality high-performance homes face a transition period. Figure 9 illustrates how the organization will typically change through phases and the corresponding change in first costs.

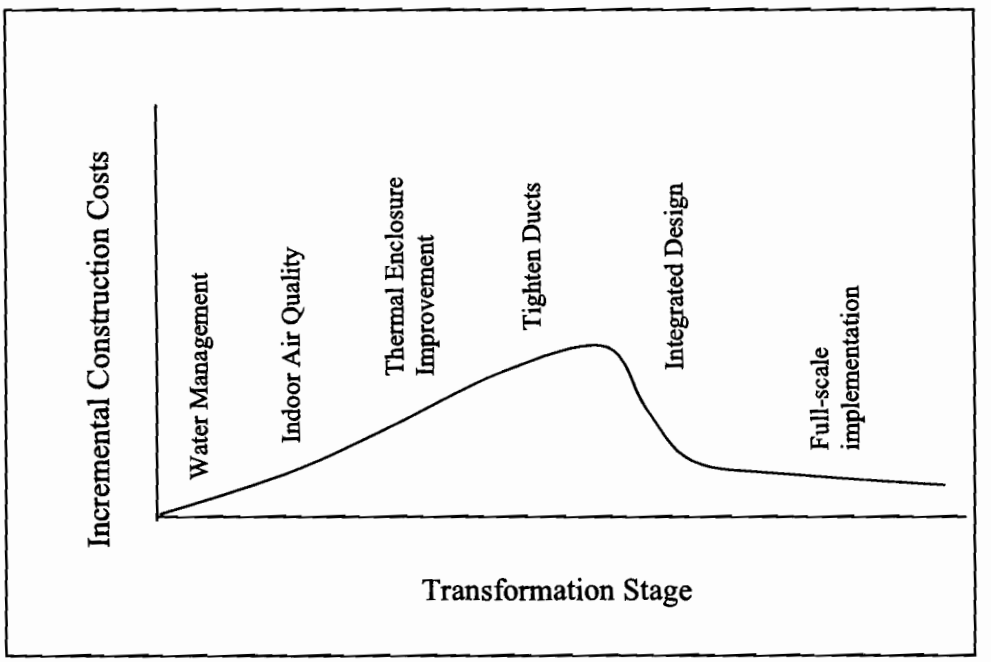


Figure 9. Incremental Cost versus Transformation Stage Curve

The transition strategy outlined here provides a logical progression to higher-performance housing, but builders need to be prepared to make an investment in other costs associated with implementing a high-performance package, including staff and vendor training, product redesign, collateral development, and testing. Each of these issues will be discussed and suggestions made as to best practices in order to minimize costs.

If the steps taken to transform a company are followed, a builder will have a transitional period where higher costs will be incurred. It is only at the last step, where integrated designs are developed, that a builder can realize immediate construction cost savings. If the total operational costs of running a homebuilding business are considered, potential cost savings should begin to accrue from the first step.

Water Management

Many warrantee issues are associated with water intrusion; therefore, a solid water-management plan can reduce future costs, limiting the reserves builders need to put aside for future claims. Analysis of past history of water damage issues, both short-term and long-term, can help quantify the per-house costs associated with the "status quo" versus an improved water-management strategy.

The improvements to the indoor air quality, thermal enclosure, and duct sealing will all require additional expense. It is, therefore, important to successfully integrate these strategies as quickly as possible. This is where relationships with vendors are critical. Builders must be willing to support the trades during the transition; however, trades must take some level of responsibility for adapting and developing cost-effective solutions for delivering improved performance cost effectively. Examples of this include rethinking duct installations to allow for prefabrication and sealing of major components or panelization of structural systems to speed erection, cut cycle time, and reduce costs. In addition, vendors must have continuing-education costs built into their overhead structure.

A diagrammatic Incremental Construction Cost versus Transformation Stage curve on a per-house basis for a builder might be seen in Figure 9.

It should be noted that this curve is diagrammatic by nature and will vary from builder to builder and by region. For example, if a builder has already addressed water management, then there is no expected incremental cost associated with this practice. Also note that the tail end of the curve still shows some increase in costs. This represents the most conservative scenario, where a builder has already optimized many aspects of their houses (i.e., integrated advanced framing or does not significantly oversize HVAC equipment). For the consumer, this added cost is offset by reduction in utility bills and, as discussed in the section of this report entitled Systems Approach to Least Cost Energy Savings, should prove to be net cost neutral or even put the consumer at a net positive monthly cash flow.

To achieve the goals of a high-performance home transformation, builders and vendors must embark on a training program that engages all levels of the companies. Training must be provided for different levels of employees within the company and for the different departments within the company.

The integrated design process comes with some inherent additional costs, especially if the builder takes responsibility for HVAC system design, as opposed to having the vendors do a "design build" system. The advantages of the builder doing the design are that a greater level of consistency can be achieved, and documentation exists for site supervisors to readily check work. It does involve additional costs, either through contracting with outside designers or by training and utilizing internal resources to cover systems integration, including HVAC, framing integration, and detailing. In addition, the cost of re-bidding work involves time and expense on the part of the builder's purchasing department, the trades, and their suppliers. For this reason, it is best that as a builder transitions to a high-performance approach, they do it as part of their ongoing product-redesign process, where many of these activities are already budgeted for. Unfortunately, this can lead to a disparity in the builder' marketing approach because some product may meet the new standards and others may not during the transition period. Builders must evaluate the volume they are building, the number of plan types, the current redesign cycle, and the uniformity of marketing message they wish to project when doing this cost-benefit analysis.

During the transformation, builders will need to be measuring how well they are doing compared to the performance goals they set. This measuring requires undertaking some level of performance testing. Typically, this performance testing will be 100% during the initial steps in order to gain insight into the effectiveness of various practices and techniques being used in the field. As vendors become adept at achieving performance targets, some builders have chosen to decrease testing activities, while others have chosen to maintain 100% testing as a quality-control measure. In either case, performance testing is a cost that needs to be budgeted for.

Some cost data have been developed from recent Building America 30% improvement level projects. The extent of improvement work varies considerably depending on the thermal performance quality of a builder's basic model. These costs are also generally not representative of mature costs and, in some instances, are reduced because materials have been donated by manufacturers.

Table 6 is one example of the incremental costs associated with achieving 39% energy savings in houses for one community in Sacramento, California. The case study for this project, Premier Gardens, is included later in this report.

The cost of the energy efficiency improvements less the cost of the photovoltaic system is $3,355, and the monthly and annual utility savings are $38 and $453, respectively. The simple payback for these homes will be 7.41 years; however, the owners are realizing more than $34 per month in positive cash flow.

Table 6. Illustrative Incremental Costs of a 39% Energy-Saving House

	Energy Features Benchmark Building		Energy Features Premier Gardens	
ENVELOPE: (Insulation U-Values or R-Values)				
Roof (attic)	R-30		**38 (U-value = 0.025)**	
Roof (at furnace)	R-30		**19 (U-value = 0.047)**	
Wall (Exterior)	U-value = 0.076		**13+1 inch EPS (U-value = 0.067)**	(25% Framing factor)
Wall (Kneewall)	U-value = 0.076		**13 (U-value = 0.102)**	(25% Framing factor)
Floor (above garage)	N/A		N/A	
Floor (cantilever)	N/A		N/A	
Attic Radiant Barrier	No		No	
Low Air Infiltration	No		**Yes**	
GLAZING:				
U-Factor			**Dual Pane Vinyl Frame Windows w/ Spectrally Selective Glass**	
Slider (horz)*	0.673		**0.37**	
Slider (vert)*	0.673		**0.37**	
Fixed*	0.673		**0.33**	
Patio*	0.673		**0.34**	
SHGC				
Slider (horz)*	0.581		**0.32**	
Slider (vert)*	0.581		**0.32**	
Fixed*	0.581		**0.35**	
Patio*	0.581		**0.33**	
HVAC SYSTEM:				
Furnace: AFUE	0.78		**0.91**	
A/C: SEER	10 SEER		**14 TXV**	
Duct Insulation / Location	5.00		**13.0 (buried in insulation)**	
Duct Testing	No		**Yes**	
ACCA Manual D	No		**Yes**	
WATER HEATING:				
Water Heater Size	40 gal		**Tankless System**	
Energy Factor	0.54		**0.82**	
Distribution Type	Standard		**Pipe Insulation**	
External Wrap	R-12		**None**	
Solar Credit	None		None	
3rd Party Inspections and Testing (In ComfortWise Program)			**Yes**	
Gas dryer stub			**Yes**	
Fluorescent lighting (screw-in lamps)			**Yes, all downlights**	
2.4kW PV System			**GE Energy**	
			Total Estimated Incremental Cost with PV(after rebate)	
			Incremental Cost without PV	
CASH FLOW	**Total Incremental Cost**	**$10,780.00**		
	Estimated Monthly Energy Savings	**$107**		
	Monthly Amortized Cost	**$72.32**	At a 7% interest rate For 30 years	
	Net Monthly Savings	**$34.68**		

Reducing Construction Waste

Research conducted by the National Association of Home Builders (NAHB) and the NAHB Research Center shows that 87.7% of the 1.7 million homes built in the United States in 1999 were stick-framed, that a "typical" home consumes slightly more than 13,100 board feet of framing lumber (about three-quarters of an acre of forest), and that the wood scrap pile for the construction of this "typical" home is approximately 2 tons.

The following combination of factors have worked to increase the consumption of wood in home building:

- **Single-family detached units.** A single-family detached home uses more wood per household than multi-family housing. According to NAHB, single-family detached units went from about 71% of overall housing starts to nearly 80% between 1978 and 2001.
- **Home size.** In the past 40 years, the median new home size in the United States has increased from 1,365 ft^2 to well over 2,000 ft^2, this despite the fact that household size has actually decreased by 20%.
- **Complexity.** Not many of today's homes are simple in form. Jogs, dormers, vaulted ceilings, convoluted roof lines, and elaborate staircases are common in new homes.
- **Safety standards.** We require more of our structures today, particularly in regions with seismic and wind considerations. Re-engineering for these loads has resulted in some increase in wood-se requirements, but has also spawned site practices that simply "throw more wood" at the problem.
- **Lumber versus labor.** Just as the relative value of materials versus labor seems to have reversed (today, materials are "cheap"—it's the labor that is "dear"), the typical skills set of both designers and framers has diminished, leading to waste at the front and tail ends of wood construction.
- **The nature and structure of the industry.** Home building is like no other production process in the 21st century. Nearly all of the 1.7 million homes built each year are site-built, making home building one of the most fragmented of industries in the United States. It is the journeymen framers—not architects, engineers or even general contractors—who control what and how much wood goes where on the job site. And most training occurs informally, by word-of-mouth, during production.

Two-Foot Module Design

Starting with foundation layout, the house footprint should be based on 2-foot increments, often with significant savings in both framing members and sheathing and always with a lot less waste. Sheet goods come in 4 ft by 8 ft dimensions. Layouts should be based on the fundamental unit dimensions of the materials used. Work by the NAHB Research Center found that the wood savings are dependent on the starting dimension.

Value Engineered or "Advanced" Framing

There are a number of substantial advantages to optimized framing: it saves time and money up front, it improves homebuyer satisfaction, its saves money and energy over the long term, and it improves builder image.

More than 7,000 homes built by Building Science Consortium production builders have used advanced framing. The resultant savings in waste are the products of "systems-thinking" and a breakdown of age-old myths about how wood framing works.

The following sections are descriptions of the major optimized framing techniques, with appropriate references from the *International Residential Code,*®[40] cited in brackets.

Frame 24 in. on-center. The prevailing practice is to frame walls, floors, and often roofs at 16-in. centers. However, 24-in. centers are structurally adequate for most residential applications. Even when the stud size must be increased from 2x4 to 2x6, changing spacing from 16 to 24 in. can reduce framing lumber needs significantly. See Figure 10 for an example.

Align framing members and use a single top plate. Double top plates are used principally to distribute loads from framing members that are not aligned above studs and joists. By aligning framing members vertically throughout the structure, the second plate can be eliminated. Plate sections are cleated together using flat-plate connectors. For multistory homes that are framed with 2x4s, this may increase the stud size on lower floors to 2x6; however, there is still typically a net decrease in lumber used. [Section R602.3.2. of the Code: A single top plate is listed as an acceptable option for in-line framing and with properly tied joints.] Figure 11 illustrates the alignment of framing and use of single top plates.

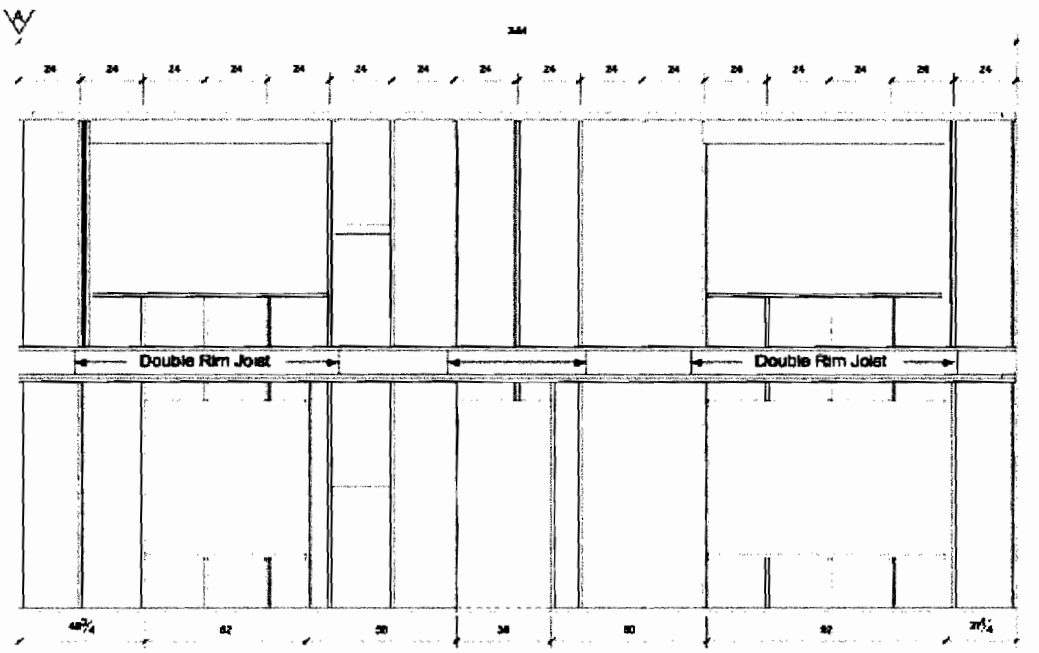


Figure 10. Advanced framing layout showing 24-in. stud centering

[40] International Residential Code®: 2003 Edition. Country Club Hills, IL: International Code Council, Inc. 2003.

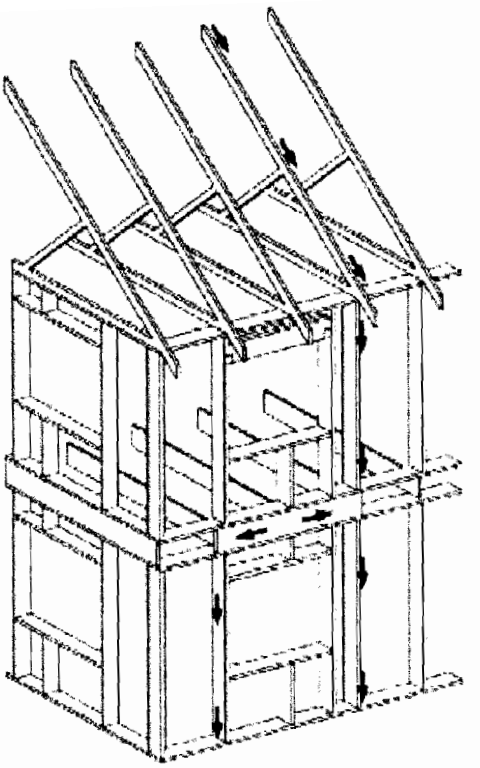


Figure 11. Advanced framing showing truss alignment with stud framing and single top plates

Size headers for actual loading conditions. Headers are often oversized for the structural work that they do. Doubled-up 2x6 (or 4x6) headers end up in non-load-bearing walls. Doubled-up 2x12 (or 4x12) headers end up in all-load-bearing walls, regardless of specific loading conditions. "Load-tuned" headers should be in the vocabulary and practice of all engineers, architects, builders, and framers. (Section R602.7.2 of the code. This section states that non-bearing walls do not need structural headers.)

Ladder-block exterior wall intersections. Where interior partitions intersect exterior walls, three-stud "partition post" or stud-block-stud configurations are typically inserted. Except where expressly engineered, these are unnecessary. Partitions can be nailed either directly to a single exterior wall stud or to flat blocks inserted between studs. This technique is called "ladder blocking" or "ladder framing." This also creates room for more insulation. Figure 12 shows a ladder-block configuration.

Use two-stud instead of three-stud corners. Exterior wall corners are typically framed with three studs. The third stud generally only provides a nailing edge for interior gypsum board and can be eliminated. Drywall clips, a 1x nailer strip or a recycled plastic nailing strip can be used instead. Using drywall clips also reduces opportunities for drywall cracking and nail popping, frequent causes of builder callbacks. [Figure R602.3(2) of the code shows let-in 1x4 bracing in place of sheathing and has a note at the bottom of the page for two-stud corners and drywall clips.] Figure 13 shows various stud corner arrangements.

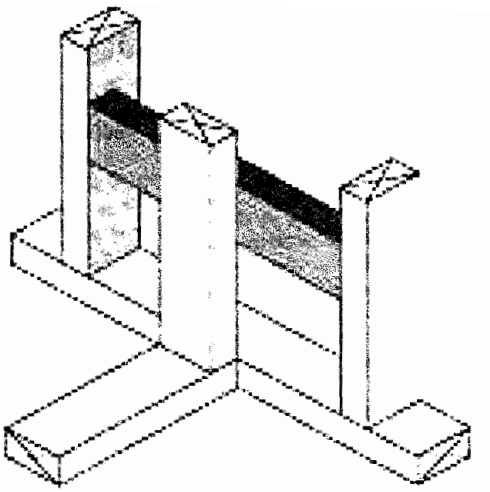


Figure 12. Example of ladder-block exterior wall intersections

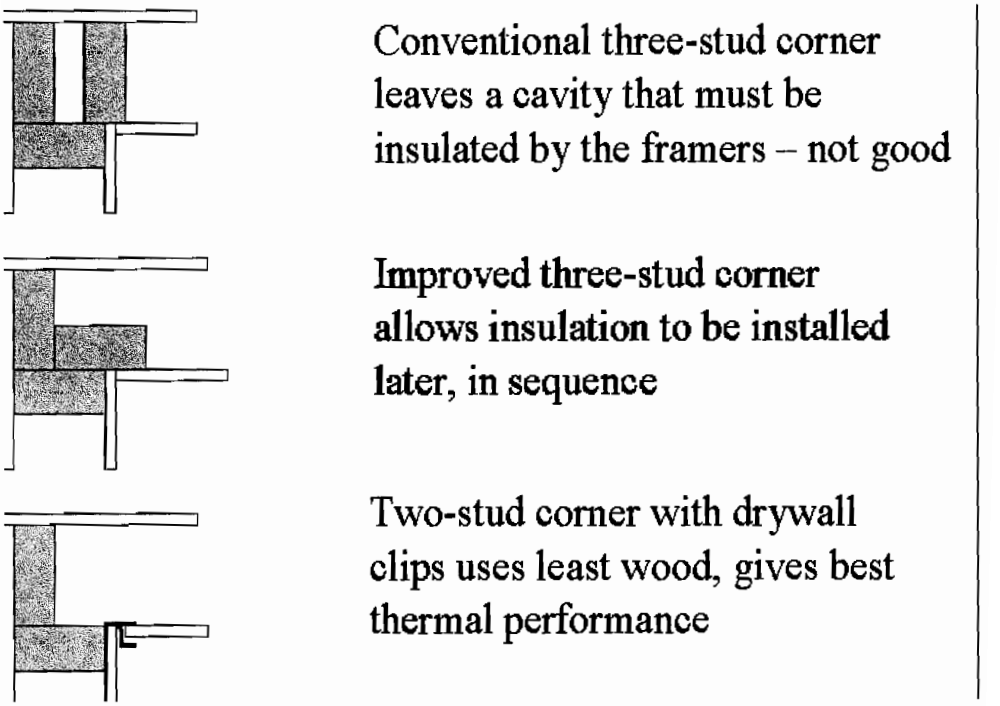


Figure 13. Wall stud corner configurations

Eliminate redundant floor joists. Double floor joists are often installed unnecessarily below non-load-bearing partitions. Nailing directly to the sub-floor provides adequate attachment and support. Partitions parallel to overhead floor or roof framing can be attached to 2x3 or 2x4 flat blocking.

Use 2x3s for partitions. Interior, non-load-bearing partition walls can be framed with 2x3s at 24 in. on-center or 2x4 "flat studs" at 16 in. on-center. [Section R602.5 of the code.]

Compact Duct Systems

A framing plan can do more than just lay out floor joists. There are opportunities to value-engineer the floor system and obtain a proper joist count, to ensure that all plumbing is coordinated with the floor framing, to ensure that all HVAC is coordinated with the floor framing, and to ensure that the "stack framing" concept is followed on the job site. Most importantly, all these issues are resolved on paper prior to casting the foundation. Figures 14 and 15 show compact duct system layouts.

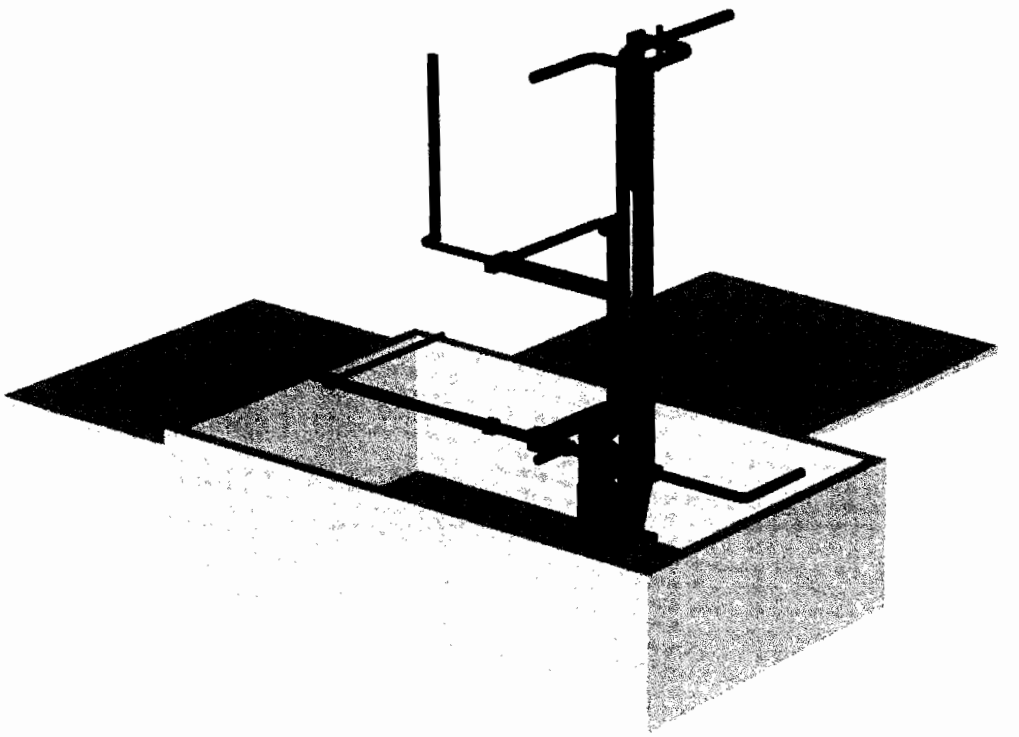


Figure 14. Three-dimensional example of compact duct system[41]

[41] Heating and cooling equipment shown in green, return duct shown in blue and supply ducts shown in brown.

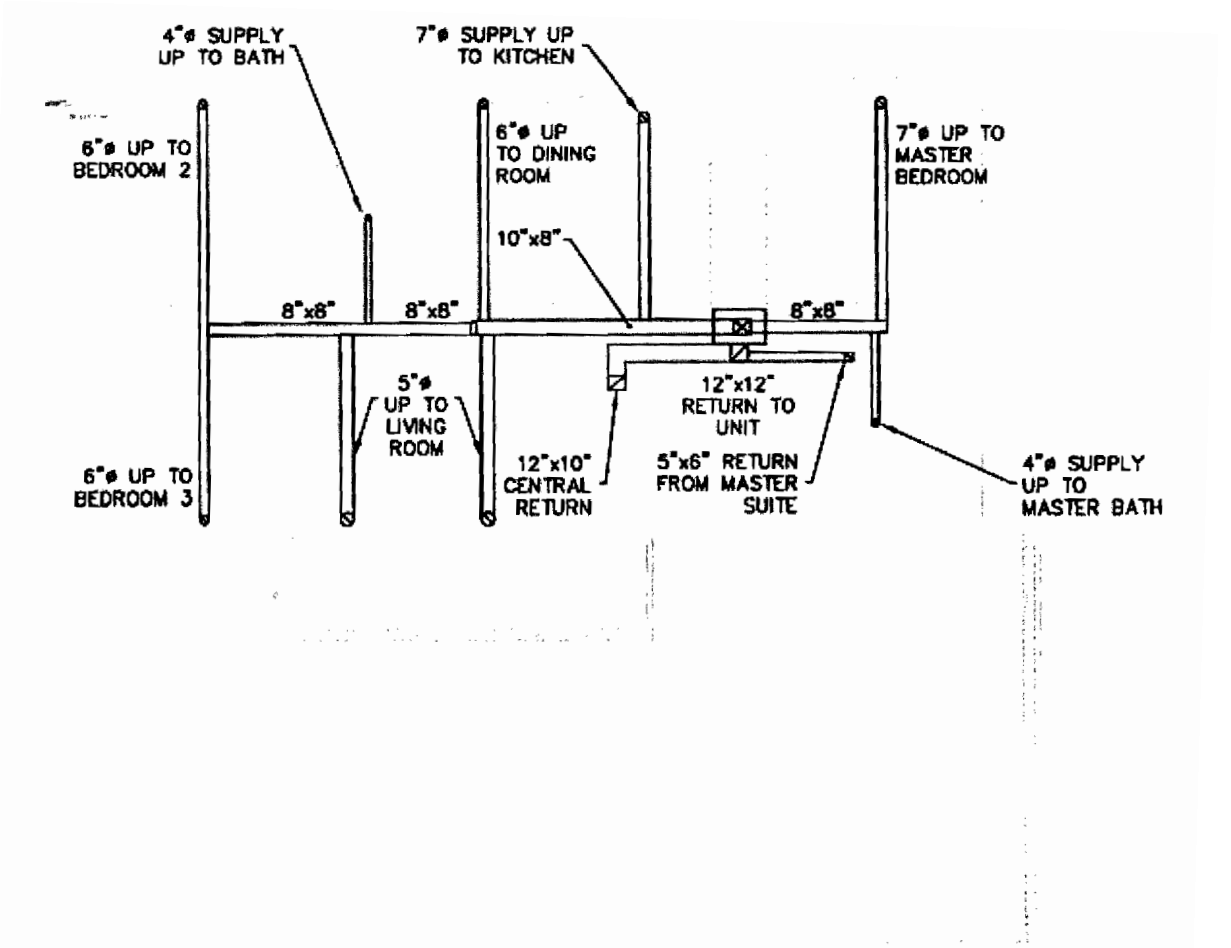


Figure 15. Example of a compact duct layout

Recycling of Construction Materials

No matter how efficient our use of wood, there will be some waste—cuts-offs from both solid-sawn lumber and sheathing. Even for the most efficiently framed buildings, wood waste will be one of the largest components of the new construction waste stream.

Reduced wood purchase and disposal costs. Actual field counts for a production builder in California have found a 40% reduction in the cost of a wall-framing package after implementing optimized framing methods: a purchase savings for the builder of more than $1,100 on each house. Another builder in Maryland reduces total wood waste disposal by 15% using efficient framing. Note that neither of these examples takes into account the labor savings from handling less wood and wood waste.

Reduced environmental impact. The annual toll for residential construction in the United States is 2 billion board feet of framing lumber and nearly 2.5 million tons of wood waste. That

translates into 1.1 million acres of clear-cut forest and 30-yard dumpsters lined up end-to-end from Phoenix to Chicago! Clearly, builders can achieve and claim significantly reduced global and local environmental impact with optimized framing.

On-site grinding. If you can grind your waste into wood chips it makes a great soil erosion control mat at job site entrances or bermed at the base of silt fences.

Quality Project Management Approach

A key component of high-performance system design and any high-performance construction process is quality project management. Quality management is a well-traveled term, but its definition can be elusive. In terms of Building America high-performance homes, the following definition is useful:

> Quality management is an ongoing effort to systematically and comprehensively improve methods and processes that yield an optimal combination of energy efficiency, comfort, durability, indoor air quality, and moisture management.

This definition recognizes quality management as an integral part of achieving 30% whole house energy savings. It emphasizes that improvements in energy efficiency must be accompanied by commensurate improvements or at least maintenance of other key performance attributes of the home to reflect a true systems-thinking approach. This definition also reflects the built-in cost-effectiveness of high-performance quality management as a risk-reduction strategy (comfort, durability, indoor air quality, and moisture management) for the builder. And finally, the definition encompasses homebuyer expectations of performance—with energy efficiency as just one of five performance attributes that any home should provide.

This definition also establishes the inherent relationship between quality and high performance. It is essentially this: While a quality home need not necessarily be a high-performance home, any high-performance home MUST be a quality home. For any Building America high-performance home builder to truly incorporate a systems approach, he or she must also incorporate a quality management approach.

The quality-management approach is an essential element of the Building America approach to homebuilding because it is *the* main vehicle for moving from science and concepts of high performance to implementation. The package of tools within the Building America quality management approach includes the following:

- Training/Education
  - For builders
  - For individual trades
  - Certifications
- Operational Evaluation (Modified NHQ[42])
  - Paper Review

[42] The NHQ (National Housing Quality) is the NAHB Research Center's National Housing Quality Program, discussed in detail later in this report. Building America team leader, IBACOS, modified the NHQ system to include criteria specific to housing performance.

- Key Player Interviews
- Performance-Based Standards
  - Design
  - Specifications
  - Scopes
- Verification Tools
  - Performance Testing
  - Inspections (Checklists)
- Feedback Loops

Although this package has not been developed from a single source or as a comprehensive system, it certainly could be used as a comprehensive quality project management approach. Each of these is discussed in detail below.

Education / Training

Builder and Subcontractor Training

Training has been found to be needed throughout the Building America program. Ongoing efforts within the industry will be necessary to develop, deploy, and continually update training programs to disseminate information from the Building America program if widespread implementation is to take place. While Building America has not been specifically charged with the development and deployment of training programs, this section discusses some of the opportunities, activities, and issues involved with training at the residential construction industry level.

Builders. The starting point for the quality management approach has always been builder training. These have included pre-construction training meetings and site training of trade contractors. Each Building America team has conducted such trainings, and their work in the context of Building America has led to any number of building-science-based training programs in the industry:

- **The Energy & Environmental Building Association's Houses That Work training program**. This public-private training partnership has trained hundreds of builders all across the country in the principles of climate-based high-performance building science. Several of the Building America teams have certified Houses That Work trainers. Although not explicitly portrayed as such, the Houses That Work trainings have many of the elements of quality management as listed above.
- **The Environments for Living®[43] (EFL) Diamond Class Training.** Long-time Building America partner, Masco Contractor Services, has developed a new 3-day builder training

[43] Environments for Living is a building-science-based, high-performance home-building program of Masco Contractor Services. The program was developed approximately 5 years ago in a public-private partnership with Building America.

program, a program that focuses on the principles of building science and their application in production homebuilding.

- **Colorado Built Green® 2005 training.** The new three-tier version of this program has criteria based specifically on the Building America program and best practices, as well as Tier II and III training patterned after Houses That Work.
- **Build IQ Best Practices.** An online training company, Build IQ, has been incorporating best practices from the Building America program for inclusion in their free and for-fee coursework. Build IQ delivers online training to top 100 homebuilders throughout the United States, including Pulte Homes, John Laing Homes, Beazer, Morrison, and others.
- **BECT (Building Energy Code Training).** Since 1995, BECT has helped the building industry keep up with changes in energy codes. The Building Industry Institute (BII) and their subcontractor, ConSol, under contract to the California Energy Commission (CEC) began a training program for large production builders in California and Nevada. The program has improved compliance with energy standards by improving builders' understanding and implementation of the energy codes.

  The BECT program has trained more than 3,000 contractors and subcontractors in the California and Nevada area since its beginnings in the mid 1990s. Through the BECT program, California is able to train builders in the following:

  - Current codes and issues
  - Upcoming code changes
  - Construction techniques that improve quality of construction
  - Common enforcement issues.

California's energy code has always been at the forefront of implementing energy-efficient standards in home building. The energy code's goal in the beginning was to increase energy efficiency of a home being built in California every 3 years by approximately 5%. But since the energy crisis, the percentage has been increased to 12% in 2001 and 15% in 2005. Having an infrastructure in place like the BECT program has greatly facilitated this dramatic change to the building industry.

Training – Trade Contractors. Each Building America team has conducted trade contractor training on climate-specific building science and systems thinking. Targeted trades have included framing, insulation, and HVAC. The EFL program conducts trade contractor building science training for framing and insulation contractors and is developing an HVAC training module. The BETC program in California also provides training to subcontractors.

Training – Certifications. The Building America program has led at least one of its builders to develop its own certification related to high performance. Artistic Homes of Albuquerque, New Mexico, certifies its entire sales staff under a high-performance training program. The program is called the High Performance Homes Sales Specialist.

It is not clear at this time if certification of high-performance homebuilding skills from a third party group such as the North American Technician Excellence (NATE) or the Building Performance Institute (BPI) would be used in the industry. There is time and expense on the part of the trade contractor and the individual technician to receive the certification, and this must

then be built into the price of doing business, which ultimately gets transferred to the Builder. There may be a correlation with better-trained technicians and reduced callbacks; however, this direct link has not been thoroughly researched or documented.

Feedback from builders who have participated in the Building America program reveals that one of the most difficult aspects of sustaining the delivery of high-performance housing is the continuous need for trade training and re-emphasizing the performance targets each trade must meet. This, in part, can be attributed to the high turnover in the building industry; however, it may be that a certification program for high-performance delivery of various key trade activities will be necessary for true transformation of the housing industry. A list of key trade-based certifications associated with delivery of high-performance housing can be found in Appendix B.

Operational Evaluation

Modified from the National Association of Homebuilders Research Center's National Housing Quality program, the Building America operational evaluation is a two-step process to help builders evaluate their own operations. The first is a paper review of all the documentation a builder has that is associated with its operations and the actual housing being built. The second is an interview with key individuals in the company. A reasonable list of the builders' primary source information for the first part of this evaluation includes the following:

- **Annual operating plan.** This includes company mission, vision, organizational values, goals for each department, strategic objectives, and reporting and other operational guidelines. The annual operating plan supports the long-range strategic plan, by documenting specific actions and goals that will help the company achieve the strategic plan.
- **Long-range strategic plan.** This includes the direction the company is headed, what types of barriers might exist, and how these barriers might be overcome. This document is a roadmap, which is made more specific in each year's annual operating plan.
- **Process maps.** These include any diagrammatic or written representation of the workflows operationally within the company.
- **Design documentation.** This category includes construction drawings, scopes of work, written specifications, contracts, field guides, etc., that communicate what should be built by the vendors.
- **Operational tools.** These include any sort of departmental tools used to facilitate business processes. For example, construction schedules or other field tools used by site supervisors to assist in the day-to-day management of construction or template letters and reports to assist in the standardization of company processes.
- **Training programs.** This includes any internally developed or externally developed program for continuing education of staff within the builders operations. The intent here is not to specifically review the content of all training programs, but to evaluate the general attitude, approach, depth, and breadth of training activities in the builder's organization.
- **Human resource manual.** This includes company policy, safety programs, benefits, and items documenting company culture.

- **Marketing materials.** This includes any type of material used to communicate the builder's message about their product to consumers.
- **Survey mechanisms and results.** These include any surveys done by the company or outside consultants, which can be for employees, customers, or vendors or can collect regional or local information on competitive information, such as sales prices or volume of construction.

A reasonable list of key builder staff to interview as part of the second step in an operational evaluation includes the following:

- Operations
- Marketing
- Sales
- Purchasing
- Construction
- Customer Service
- Human Resources
- Land Development.

This two-step process gives a comprehensive understanding of the builder's current operations. This evaluation process could be adopted internally by a builder or externally through the use of a consultant in order to identify what areas may need to be addressed if the builder is considering transforming their product line to achieve Building America high-performance home technology packages. The process is comprehensive, but not overly detailed—it takes approximately 20-30 hours for one person to work through, once all the data has been assembled. It can identify best practices and opportunities without dwelling on minutia. Appendix D contains the latest version of the modified NHQ two-step process as developed by IBACOS.

Performance Standards—Design, Specifications, Scopes

Quality is often compared to the three-legged stool (the stool is of little use without all three legs). In high-performance home building, quality is only achieved with performance standards for design AND materials (specifications) AND installation (scopes). Building America takes this premise one step further by stating that many performance standards must be climate-specific; indeed even lot-specific when local terrain and environments bring with them additional challenges, such as extreme slopes, expansive soils, coastal high winds and flooding, etc.

Design and Design Review. An effective means of assuring these goals are implemented during the planning stages of a project is through a design review of the project, this can be a key instrument in making sure the whole energy system is incorporated in the design. It is highly unlikely that a home will be designed singularly around the HVAC system, or window orientation, or its ability to resist heat. However, these are all factors that go into a home and are crucial in getting a house to achieve 30% whole-house energy savings. For this purpose, value engineering techniques must be employed to ensure that all the systems in the home cannot only be designed to perform at optimum levels but also be coordinated with those involved with

actual construction of the project to make sure that the homes are built practically and as intended when designed on paper.

Each of the Building America teams has conducted dozens of detailed design reviews, resulting in resources such as the Building America Houses That Work climate-specific Best Practices, the Houses That Work building profiles, the Noisette Home Performance Standards, the draft Risk Assessment Protocol, etc. The common ground among these design standards is that they respond to climate-specific protection of the energy efficiency, the comfort, the indoor air quality, the durability, and the moisture management of each high-performance home. Thus, they make up the first leg of the "quality stool"—high performance design.

Specifications. Specifiers, and subsequently purchasers, rarely take into account the overall performance of the home and its systems when making crucial material/component/subsystem choices. Standard specifications don't take into account individual component performance variations, much less the impact of single-component choices on assemblies or systems. Various Building America projects have addressed this issue. High-performance specifications were developed for the EcoVillage Townhome project in Cleveland Ohio.[44] These specifications could and should be modified and applied to other high-performance home projects.

Scopes of Work. Even with intelligent design and the right materials, quality can fall short of intended performance without the right installation. Production builders generally rely upon their scopes of work to achieve the installation required. But, as a rule, these scopes do not reflect systems thinking or climate-specific building science. More than one Building America team leader has developed project-specific mock-ups (for walls and window installation; for example BSC at EcoVillage, IBACOS at Summerset at Frick Park) or detailed installation procedures that could and should be used by high-performance builders in their scopes. BIRA, in conjunction with the Comfortwise program, has developed and posted high-performance specifications for several keytrades, including HVAC and insulation. It would not be difficult, for example, to take a well-known industry scopes resource, such as the NAHB BuilderBooks, *The Scopes of Work Program,*[45] and develop a customized Building America set of scopes as a comprehensive resource that integrates performance and quality.

Verification

Verification tools for both performance and quality include performance testing and inspection checklists. Clearly the first choice is almost always a quantitative test, such as any of the following:

- Using a blower door for measuring air tightness
- Using a calibrated fan system for measuring for duct tightness
- Using a flow hood for measuring supply and return airflows at registers and grilles
- Using a manometer for room-to-room pressurization

---

[44] Building Science Corporation. 2002. EcoVillage Sample Spec Language. www.buildingscience.com/buildingamerica/casestudies/ecovillage_specs.pdf.

[45] Haas Davenport, Linda. 2000. The Scopes of Work Program: Procedures and Standard to Increase Quality. Washington, D.C., BuilderBooks.com.

- Using a digital thermometer to measure room-to-room temperature variation
- Using a low-e detector to verify glazing properties.

The beauty of these tests is that quantitative metrics can be established that summarize the quality of design, materials, and installation for one or more performance attribute. Most performance tests for the residential building industry deal with energy efficiency directly and then may be indirectly reflective of other performance attributes, such as indoor air quality and comfort. But quantitative tests for other performance attributes, such as moisture management and durability, are generally not available, at least not in a cost-effective application. For verification of these performance attributes, a detailed inspection checklist and visual inspections act as a proxy determination of both quality and performance.

An important consideration in any quality management approach is the cost of verification. The primary determinants of at least the initial costs are the number of homes tested—ranging from one initial model home to 100% testing of every home built—and what entity does the testing—either in-house testing, 3rd-party testing, or some combination of the two. In general, for production builders, Building America has recommended a testing strategy similar to the EPA ENERGY STAR strategy of 1-in-7 random testing after a period of 100% testing to verify that key performance metrics are met on a consistent basis. But more than one Building America production builder has determined that either the pace at which they build or their reputation for quality (or both) makes 100% in-house testing and random 1-in-7 3rd-party testing the most cost-effective strategy in the long run and based on looking at the total costs and total benefits of a much more rigorous quality protocol. The Building America Best Practices Guides[46] produced by Pacific Northwest National Laboratory (PNNL) contain recommendations for testing protocols for each climate. In addition, a "SNAPSHOT" performance testing protocol and report process has been documented by Building Science Corporation and is included as Appendix F.

Each Building America team has made up prescriptive checklists to handle non-quantitative performance assessment, particularly for performance attributes, such as durability and moisture management. While it is difficult to address ALL of the variables that lead to customization of these lists—climate, lot, aspect, surrounding local features, building type, etc.—these checklists can be referenced as examples of how quality management of high-performance attributes are assessed and verified for builders seeking to achieve the Building America "standard." One of the difficulties that builders face with non-quantitative metrics and verification are the questions, "How do I know when enough is enough? When is our practice a best practice, substandard, or overkill?" Builders MUST use their local conditions and past product history (in terms of callbacks, legal claims, 1- and 2-year warranty trends) to intelligently manage durability and moisture. Proxy, qualitative tools can be applied—such as infra-red imaging of assemblies, water testing, and moisture meter readings—but these approaches have not been documented as part of the Building America body of research.

[46] Baechler, M. C.; Taylor, Z. T.; Bartlett, R.; Gilbride, T.; Hefty, M.; Love, P. M. 2005. Building America Best Practices Series: Volume 2. Builders and Buyers Handbook for Improving New Home Efficiency, Comfort, and Durability in the Hot-Dry and Mixed-Dry Climates, Revised. NREL Report No. 38360.

Commissioning

Building commissioning is a systematic process of ensuring that a building performs in accordance with the design intent, contract documents, and the owner's operational needs. Because of the sophistication of building designs and the complexity of building systems constructed today, commissioning is necessary, but not automatically included as part of the typical design and construction process. Commissioning is critical for ensuring that the design developed through the whole-building design process is successfully constructed and operated.

Building commissioning includes the following:

- Systematically evaluating all pieces of equipment to ensure that they are working according to specifications. This includes measuring temperatures and flow rates from all HVAC devices and calibrating all sensors to a known standard.
- Reviewing the sequence of operations to verify that the controls are providing the correct interaction between equipment.

In particular, building commissioning includes these activities:

- Engaging a commissioning authority and team
- Documentation
- Verification procedures, functional performance tests, and validation
- Training.

Building commissioning is not one of these:

- Construction observation (punch list)
- Start-up
- Testing, adjusting, and balancing (TAB)
- Final punch-out.

These activities are individual steps in the systematic process of commissioning, but by themselves these activities cannot meet the goals of building commissioning.

Commissioning HVAC systems is even more important in energy-efficient buildings because equipment is less likely to be oversized and must, therefore, run as intended to maintain comfort. Also, HVAC equipment in better-performing buildings may require advanced control strategies. Commissioning goes beyond the traditional HVAC elements. More and more buildings rely on parts of the envelope to ensure comfort.

Commissioning includes evaluating the building elements to ensure that shade management devices are in place, glazing was installed as specified, air-leakage standards have been met—these are the static elements of the building. Commissioning can also evaluate other claims about the construction materials, such as VOC emission content and durability. It is important that the products that were specified for the building meet the manufacturer's claims (and are appropriate for the project.)

Continuous commissioning ensures that the building operates as efficiently as possible while meeting the occupants' comfort and functional needs throughout the life of the building. Continuous commissioning differs from building operation and maintenance.

Benefits of building commissioning include the following:

- Energy savings and persistence of savings
- Improved thermal comfort with proper environmental control
- Improved indoor air quality
- Improved operation and maintenance with documentation
- Improved system function that eases building turn-over from contractor to owner.

Feedback Loops

Quality is a process ideally supported by feedback within the corporate structure and across the full range of product. Every department—design, construction, purchasing, warranty, sales, and marketing—should report performance successes and failures to every department for each and every product type, taking full advantage of feedback loops. In reality, many production builders set up little incentive for quality of product, erring in favor of quantity of product. But some builders are beginning to understand that it is not just how much profit a company can make, but how much profit a company retains, once the set-asides for warranty and claims are factored in. More than one builder is asking its managers a question like this:

> "If we are currently setting aside about $5,000 for each home we build to cover warranty and claims, how much quality management can we afford?"

Production builders in today's hot housing market are generally not having trouble making profits, just keeping them. If financial incentives can be created for quality of product, the reduction in warranty and claims can be used to finance the quality incentive structure. Feedback loops are a key element of any such quality management approach.

Quality Management Summary

In order to achieve whole-house energy savings of 30% or more, we are managing energy flows on, in, and through the structure to such a degree that we must manage the flow of air and moisture with equal attention. The links among energy efficiency, comfort, indoor air quality, durability, and moisture are not optional, they are built into the physics that builders face and the expectations buyers bring. Likewise, quality management is not an option when building high-performance homes. It is a process inherent to systems-thinking and systems-engineering. Without the quality management tools to implement the principles of physics and building science, higher performance in housing is simply an technical exercise, not a business proposition.

Building Component Design Details

Building Enclosure Integrity

A house is an environmental separator whose function is to separate the inside from the outside as required by the local environment and the wishes of its occupants. A house creates an interior environment that is different from the exterior environment. This interior environment should be controllable by the occupants in a manner that meets their needs.

In order to function as an environmental separator, the elements, components, assemblies, and sub-systems that comprise a house must meet specific objectives, including the following:

- Control of heat flow
- Control of airflow
- Control of rainwater
- Control of groundwater
- Control of water vapor flow.

Control of Heat Flow

The key strategy in the control of heat flow is the use of thermal insulation in a manner that continuously encloses the conditioned space. If a conditioned space is considered a cube, then all six surfaces enclosing the cube are encased by thermal insulation. In the typical home this means both the above- and below-grade walls are insulated: the attic ceiling/roof assembly and the foundation slab.

Fully insulating a basement slab is also not necessary to meet the 30% savings goal. However, it is a recommended approach for all new houses from a moisture-control perspective if basements are to be intended for occupancy. Installing carpets and other floor finishes over uninsulated concrete basement floor slabs often leads to problems with dust mites and mold in floor coverings.

With wood-frame construction, this means exterior walls framed with 2x6 framing where cavities are insulated with fiberglass batts, spray-applied cellulose, or low-density spray-applied foams. In addition, the exterior 2x6 framing is sheathed with rigid-foam insulating sheathing.

In general, insulating sheathing is not necessary to meet the 30% savings goal. However, insulating sheathing has other significant benefits, particularly in the areas of moisture control. Inwardly driven moisture from reservoir claddings, such as brick and stucco, can be controlled by insulating sheathing. Additionally, the use of insulating sheathing of sufficient thickness allows the removal of interior vapor barriers and vapor retarders, thereby enhancing the inward drying of the assembly. In other words "double vapor barriers" can be avoided.

Insulating sheathing also has cost advantages over oriented strand board (OSB) and plywood sheathings when coupled with innovative framing techniques for wind and seismic loadings.

Reducing heat-flow in wood frame construction can be accomplished by minimizing the amount of framing materials through which conductive heat transfer can occur, increasing the cavity

thickness to accommodate more thermal insulation, and using sheathing materials that provide thermal resistance.

Materials can be reduced at corners and where interior partition walls intersect exterior walls. Thermal bridging can be reduced at door and window openings through the use of insulated headers and using hangers to eliminate king studs and cripple studs. Stud spacing can also be increased to 24-in. spacing and point-loading trusses.

Increasing cavity thickness to accommodate more thermal insulation can be facilitated in wall framing by using thicker framing materials and at the intersection of roof trusses and exterior walls through the use of specialized trusses. In all truss and roof assemblies, baffles should be installed to prevent the wind washing of thermal insulation and to prevent insulation from blocking ventilation in vented roof assemblies.

Fenestration has minimum U-values of 0.3 and SHGC values of 0.4 or lower.

Control of Airflow

One of the key strategies in the control of airflow is the use of air barriers. Air barriers are systems of materials designed and constructed to control airflow between a conditioned space and an unconditioned space. The air barrier system is the primary air enclosure boundary that separates indoor (conditioned) air and outdoor (unconditioned) air. In multi-unit/townhouse/apartment construction, the air-barrier system also separates the conditioned air from any given unit and adjacent units. Air-barrier systems also typically define the location of the pressure boundary of the building enclosure.

The air-barrier system also separates garages from conditioned spaces. In this regard, the air-barrier system is also the "gas barrier" and provides the gas-tight separation between a garage and the remainder of the house or building.

Air-barrier systems keep outside air out of the building enclosure or inside air out of the building enclosure depending on climate or configuration. Sometimes, air-barrier systems do both.

Air-barrier systems can be located anywhere in the building enclosure – at the exterior surface, the interior surface, or at any location in between. In Cold Climates, interior air-barrier systems control the exfiltration of interior, often moisture-laden, air. Whereas exterior air-barrier systems control the infiltration of exterior air and prevent wind washing through cavity insulation systems.

Numerous approaches can be used to provide air-barrier systems in buildings. Rigid materials, such as gypsum board, exterior sheathing materials like plywood or OSB, and supported flexible barriers are typically effective air-barrier systems if joints and seams are sealed.

Spray-applied foam insulations can be used as interstitial (cavity) air-barrier systems. Damp spray-applied cellulose does not meet the performance requirements of air barrier materials or assemblies – it is an air retarder.

The significant advantage of exterior air-barrier systems is the ease of installation and the lack of detailing issues related to intersecting partition walls and service penetrations.

An additional advantage of exterior air-barrier systems is the control of wind washing that an exterior air seal provides with insulated-cavity frame assemblies.

The significant disadvantage of exterior air-barrier systems is their inability to control the entry of air-transported moisture into insulated cavities from the interior. As a result, most exterior air-barrier systems are insulated on their exterior side with rigid or semi-rigid insulations that are not sensitive to wind washing.

An advantage of interior air-barrier systems over exterior systems is that they control the entry of interior moisture-laden air into insulated assembly cavities during heating periods. The significant disadvantage of interior air-barrier systems is their inability to control wind washing through cavity insulation.

Installing both interior and exterior air-barrier systems can address the weakness of each.

The practice of using framing elements in conjunction with the interior gypsum sheathing can meet the requirements of a building envelope air-barrier system. In this approach, the primary responsibility for reduction of air-leakage openings is shared by both the framer and the gypsum-board installer.

Air leakage at the platform frame floor assembly can be reduced by sealing the rim joist to the frame wall or plate below and the sub-floor sheathing above. This is typically accomplished by using a continuous bead of sub-floor adhesive to seal the sub-floor sheathing to the rim joist and caulking to seal the bottom of the rim joist assembly to the plate below. Gaskets and other seals can also be utilized. Where floor trusses or other manufactured wood-product floor-system components are used (wood I-beams), solid rim joist material installed in a continuous manner should be provided to prevent air leakage at the rim joist assembly.

Air leakage between the bottom plates of exterior walls and the sub-floor sheathing is controlled by sealing the bottom plate to the sub floor. This is typically accomplished by installing a continuous bead of sealant or caulk under wall plates.

Air leakage at floor assemblies where cantilevers occur is also controlled at rim joist locations. Blocking utilizing wood or rigid insulation can be used with both exterior and interior cantilever floor assemblies. Where floor-framing members are installed parallel to exterior walls (or garage walls), solid rim-joist material can be installed directly over wall plates to provide for air barrier continuity.

Air leakage through sub-floor sheathing installed over unconditioned spaces, such as vented crawl spaces, unconditioned garages, or cantilevered floors over exterior walls, can be controlled by sealing all panel joints.

Tubs, shower stalls, and one-piece manufactured tub/shower enclosures installed on exterior walls can provide the single largest source of air-leakage areas when uncontrolled. Rigid sheathing material should be installed on the interior surfaces of exterior walls and sealed to framing and sub-floor sheathing before the installation of tubs and shower enclosures. Thin, non-insulating sheathings can be installed in a manner that allows the installation of interior gypsum board sheathing over sheathing edges without noticeably altering wall thickness. With one-piece manufactured tub/shower enclosures, the entire height of the interior surface of exterior walls should be sheathed. This usually requires the installation of cavity insulation before the installation of the interior sheathing.

Where fireplaces are installed on exterior walls, air leakage can be as significant as air leakage at tubs and shower stalls. Fireplace enclosure framing should be lined on the interior with rigid sheathing material. Such enclosures should be considered as small rooms that are conditioned.

Accordingly, they require a sealed top, bottom, and three sides. Gypsum board, plywood, wafer board, and foil-covered pressed paper can provide satisfactory performance when sealed. This will also greatly reduce callbacks from cold drafts coming from fireplaces.

Interior soffit assemblies above cabinetry on exterior walls or adjacent insulated ceilings and attics also require air sealing. Where the ends of soffit assemblies or framing boxing in mechanicals intersect exterior walls, the "footprint" of the soffit or framing against the exterior wall should be enclosed with sheathing.

Window and door openings can be sealed by the framer sealing the window or door unit to the rough framing with foam, caulk, or other sealant. Alternatively, the drywaller can return the gypsum-board interior finish to the window or door unit and seal the joint with caulk.

Interior utility chases or dead spaces between two closely spaced walls, dropped ceilings, and split levels require special attention. Sealing responsibilities are shared between framers and drywallers at dropped ceilings and split-levels. Blocking is installed and sealed by the framers; gypsum board is installed and sealed by the drywallers.

Attic access openings located within conditioned spaces should also be sealed as well as flue pipe penetrations.

Whole-house fans require a cover that can be installed during the heating season in an airtight manner. Some whole-house fan units come equipped with airtight covers. Those units that do not have covers c,an have removable covers site-manufactured in a similar manner to removable attic access covers.

Control of Moisture

Control of Rainwater. The fundamental principle of rainwater control is to shed water by layering materials in such a way that water is directed downwards and outwards from the building or away from the building. It applies to assemblies such as walls, roofs, and foundations, as well as to the components that can be found in walls, roofs, and foundations such as windows, doors, and skylights. It also applies to assemblies that connect to walls, roofs, and foundations such as balconies, decks, railings, and dormers.

Layering materials to shed water applies to the building as a whole. Overhangs can be used to keep water away from walls. Canopies can be used to keep water away from windows, and site grading can be used to keep water away from foundation perimeters.

All exterior claddings pass some rainwater. Siding leaks, brick leaks, stucco leaks, stone leaks, etc. Therefore, some control of this penetrating rainwater is required. In most walls, this penetrating rainwater is controlled by a drainage plane that directs the penetrating rainwater downwards and outwards.

Drainage planes are water-repellant materials (building paper, house wrap, foam insulation, etc.) that are located behind the cladding and are designed and constructed to drain water that passes through the cladding. They are interconnected with flashings, window and door openings, and other penetrations of the building enclosure to provide drainage of water to the exterior of the building. The materials that form the drainage plane overlap each other shingle fashion or are sealed so that water flow is down and out of the wall.

Materials that absorb and store rainwater when it rains located on the outside of buildings can create problems. They can act like reservoirs or sponges absorbing and holding water when exposed to rain. Stored water can migrate elsewhere and cause problems. Common reservoirs are brick veneers, stuccos, wood siding, wood trim, and fiber cement cladding.

The best approach to dealing with reservoirs is to eliminate them or disconnect them from the building. Back priming (painting all surfaces, back, front, edges and ends of wood siding, cement siding and all wood trim) gets rid of the moisture storage issue with these materials.

Back-venting brick veneers and installing them over foam sheathings disconnects the brick veneer moisture reservoir from the building. Installing stucco over two layers of building paper or over an appropriate capillary break, such foam sheathing, similarly addresses stucco reservoirs.

Control of Groundwater. The fundamental principles of groundwater control are to keep rainwater away from the foundation wall perimeter and to drain groundwater with sub-grade perimeter drains before it gets to the foundation wall. This applies to slabs, crawlspaces, and basements.

Concrete and masonry are sponges – they can wick water because of capillarity. This is the main reason that damp-proofing (the black tar-like coating) is applied to exterior basement walls. The damp-proofing fills in the pores in the concrete and masonry to reduce ground-water absorption. The damp-proofing is a capillary break. Under concrete floor slabs, the stone layer combined with polyethylene serves a similar function (they act as capillary breaks). Unfortunately, the capillary rise through footings is typically ignored. This can be a major problem if foundation perimeter wall are finished or insulated.

In new construction, a capillary break should be installed on the top of the footing between the footing and the perimeter foundation wall. This can be done by damp-proofing the top of the footing or by installing a membrane at this location.

The interior insulation and finishing approach must take into account the moisture migrating up through the footing. This is best accomplished by installing rigid foam insulation on the interior of the assembly to protect the interior finishes.

The best foams to use have a perm rating of greater than 1 perm for the thickness used. This means limiting extruded polystyrene insulation to less than 1-in. thickness for walls (more than 1 in. thick, and they do not breathe sufficiently) and making sure that the rigid insulation is not faced with polypropylene skins or foil facings. Additionally, because foams need to be protected from fire, and this is often done with gypsum board, only latex paint should be used on interior gypsum finishes (because it breathes).

Capillary control also applies to slab-on-grade construction and crawlspaces. Monolithic slabs need plastic ground covers that extend under the perimeter grade beam and upwards to grade. Additionally, the exposed portion of slabs must be painted with latex paint to reduce water absorption and a capillary break must be installed under perimeter wall framing.

Control of Water Vapor Flow. The fundamental principle of control of water in the vapor form is to keep it out and to let it out if it gets in.

The following things are discouraged:

- The installation of vapor barriers on both sides of assemblies (i.e., "double vapor barriers").

- The installation of vapor barriers, such as polyethylene vapor barriers, foil-faced batt insulation, and reflective radiant-barrier foil insulation on the interior of air-conditioned assemblies.
- The installation of vinyl wall coverings on the inside of air-conditioned assemblies.

The following things are encouraged:

- The construction of assemblies that are able to dry by diffusion to at least one side and in many cases to both sides.
- The ability to use insulating sheathings without the creation of "double vapor barriers."
- The ability to use of damp spray insulations with insulating sheathings without the creation of "double vapor barriers."

Specific Recommendations

- Soil surfaces shall be graded away from below-grade envelope surfaces.
- Materials next to below-grade envelope surfaces shall be free-draining and shall connect to a sub-grade drainage system through a filter media that will prevent fines build-up in the drainage system.
- A clay cap or other water-flow-resistant surface layer shall be installed to prevent surface water from draining into the free-draining material next to below-grade envelope surfaces.
- Below-grade surfaces shall be provided with a damp-proofing layer or coating that will be effective as a capillary break.
- All surfaces subject to wind-driven rain or snow shall be provided with a drainage plane or layer that will prevent rain-wetting of internal materials.
- Indoor relative humidity shall be maintained at the center of the room or as low as necessary to keep the room air next to cool/cold surfaces at less than 70% relative humidity.
- All building envelope assemblies should include at least one air barrier and one vapor retarder surface.
- All crawl space assemblies should have a continuous impermeable ground cover that functions as both an air barrier and vapor retarder.
- Provide air-barrier systems that control air movement from the interior.
- Locate vapor diffusion retarders toward the interior of building assemblies and avoid vapor diffusion retarders toward the exterior of building assemblies. Where low-permeance exterior sheathings are used, temperature of condensing surfaces under heating conditions should be controlled (use of insulating sheathings, external insulation), as well as interior vapor pressures.
- Provide secondary air barriers that control wind washing from the exterior.
- Control interior relative humidities during the coldest portion of the heating season (maintain below 35%).

- Allow wet or moist materials used in construction to dry toward the exterior.

Envelope Systems

Foundation Systems

The function of a foundation system is to hold up the building. This involves facilitating the transfer of loads from above-grade to the ground. Foundation systems, depending on their configuration and location, may also have to control other factors, such as heat flow, airflow, rainwater, groundwater, and water vapor flow.

Slab on Grade

Structure. In Hot-Dry/Mixed-Dry climates, the primary slab-on-grade approach involves a monolithic slab-grade beam assembly. Post-tensioning in some cases occurs.

Insulation and Air Infiltration. In Mixed-Dry climates, the perimeter of the concrete must be thermally isolated from the ground. This thermal insulation extends from the bottom of the grade beam to the top of the slab. A sill gasket also provides an air seal between the foundation and the frame structure on top.

In Hot-Dry climates, the perimeter of the concrete remains uninsulated.

Water Management, Drainage, Vapor Diffusion. As in all foundation systems, the perimeter grade must slope away from the foundation to reduce the saturation of ground adjacent the structure. With monolithic slab-grade beam assemblies, the entire concrete assembly must be isolated from the ground with a capillary break. This involves installing a polyethylene sheet membrane under the grade beam extending to grade. The exposed portion of the foundation above grade is damp-proofed using latex paint. The sill gasket functions as the primary capillary break between the stem wall and the frame structure. A polyethylene sheet membrane vapor barrier should be installed in direct contract with the concrete slab – a sand layer should never be installed between the polyethylene sheet membrane and the concrete slab.

Interaction with Mechanical Systems. Excessively long-duration interior negative pressures should be avoided. A depressurization limit of 5 Pascals is recommended for continuously operating exhaust appliances. A depressurization limit of 20 Pascals is recommended for intermittent operating exhaust appliances. Only sealed-combustion appliances should installed within the pressure boundary of the building enclosure. Passive sub-slab ventilation is recommended to reduce atmospheric air pressure soil gas drivers.

Crawl Space

Structure. In Hot-Dry/Mixed-Dry climates the primary crawl space approach involves conditioned crawl space construction. Vented crawlspaces are energy inefficient compared to conditioned crawl spaces and interfere with ground coupling where the ground can act as a heat sink during air conditioning.

Insulation and Air Infiltration. The perimeter of crawl spaces must be insulated. Interior rigid insulation is the insulation system of choice because it is not water sensitive. The interior location is preferred from both a constructability perspective and insect-resistance perspective.

This thermal insulation extends from the top of the footing to the underside of the floor framing. A sill gasket provides an air seal between the foundation and the frame structure.

Water Management, Drainage, Vapor Diffusion. As in all foundation systems, the perimeter grade must slope away from the foundation to reduce the saturation of ground adjacent the structure. All below-grade surfaces in ground contact should be damp-proofed. A continuous-sealed air barrier and vapor-barrier ground cover should be installed. If the interior crawl space grade is below the exterior grade a perimeter drain system is required. This perimeter drain works best when located on the exterior of the foundation assembly.

Interaction with Mechanical Systems. Excessive long-duration interior negative pressures should be avoided. A depressurization limit of 5 Pascals is recommended for continuously operating exhaust appliances. A depressurization limit of 20 Pascals is recommended for intermittent operating exhaust appliances. Only sealed-combustion appliances should be installed within the pressure boundary of the building enclosure. Passive sub-ground cover ventilation is recommended to reduce atmospheric air pressure soil gas drivers.

Conditioning of the crawl space should be accomplished by supplying conditioned air to the crawl space either via a dedicated duct or via transfer air from the house where a continuously operating exhaust fan is used as the pressure driver.

Building Enclosure Integration Strategies

Walls

The function of wall systems is to provide environmental separation between the interior and exterior, as well as transfer wind and seismic loads to the foundation. And similarly transfer loads from the roof to the foundation. As part of the provision for environmental separation, wall systems have to control heat flow, airflow, rainwater, and water-vapor flow.

Structure. In Hot-Dry/Mixed-Dry climates, the primary structural approach is site-built wood-frame-utilizing engineered elements, such as prefabricated lintels, headers, and sheet goods, such as OSB, plywood, and gypsum wallboard.

Resistance to shear loads as a result of wind and seismic events must be provided. The choice of construction or framing approaches addressing shear loads should reflect the local conditions. For example, houses constructed in low-wind zones can be constructed with wood frame assemblies with non-structural sheathings and metal cross braces or wood "let-in" braces. Whereas a similar home built in a higher wind zone, such as in a coastal wind zone, or built in a more severe seismic zone may have to be constructed with structural sheathing or inset shear panels.

The following are the principle means of controlling lateral loads:

- metal cross braces
- wood "let-in" braces
- structural sheathing such as plywood or OSB
- proprietary shear panels.

Insulation and Air Infiltration. The optimum approach to insulation involves 2 x 6 advanced frame walls with insulating sheathing replacing OSB or plywood sheathing. Cavity insulation is either unfaced fiberglass batt insulation or damp-sprayed cellulose.

Air-infiltration control is provided by an air barrier. An interior air barrier is used, specifically the interior gypsum sheathing combined with using framing elements, such as draft-stopping and fire-stopping components.

Water Management, Drainage, Vapor Diffusion. Rainwater management is provided by using the insulating sheathing as a drainage plane and integrating window and doors with the insulating sheathing to provide drainage plane continuity.

Vapor diffusion is addressed by not installing vapor barriers on the interior of assemblies constructed in Hot-Dry/Mixed-Dry Climates.

Interaction with Mechanical Systems. The tighter the building enclosure, the greater the pressure differential created with exhaust appliances. The use of an air barrier results in a tighter building enclosure.

Excessive long-duration interior negative pressures should be avoided. A depressurization limit of 5 Pascals is recommended for continuously operating exhaust appliances. A depressurization limit of 20 Pascals is recommended for intermittent-operating exhaust appliances. Only sealed-combustion appliances should installed within the pressure boundary of the building enclosure.

Floors

The function of floor systems is to provide environmental separation between the interior and exterior where they intersect the exterior enclosure, as well as to transfer wind and seismic loads to the foundation by functioning as a diaphragm and similarly transfer loads from the roof to the foundation. As part of the provision for environmental separation, floor systems have to control heat flow, airflow, rainwater, and water-vapor flow.

Structure. In Hot-Dry/Mixed-Dry climates, the primary structural approach is site-built wood framing utilizing engineered elements, such as prefabricated I-joists and sheet goods, such as OSB.

Insulation and Air Infiltration. The optimum approach to insulation involves using spray foam insulation on the interior of the rim joist assembly.

Air-infiltration control is provided by an air barrier. The air barrier is the rim joist assembly itself sealed to the framing elements above and below using sealant or spray-foam insulation.

Water Management, Drainage, Vapor Diffusion. Rainwater management is provided by using insulating sheathing installed exterior to the rim joist as a drainage plane and integrating this with the insulating sheathing of the frame assembly, either above or below the floor system to provide drainage plane continuity.

Vapor diffusion is addressed by not installing vapor barriers on the interior of assemblies constructed in hot-dry/mixed-dry climates.

Interaction with Mechanical Systems. The tighter the building enclosure, the greater the pressure differential created with exhaust appliances. The use of an air-barrier rim-joist assembly results in a tighter building enclosure.

Excessive long-duration interior negative pressures should be avoided. A depressurization limit of 5 Pascals is recommended for continuously operating exhaust appliances. A depressurization limit of 20 Pascals is recommended for intermittent-operating exhaust appliances. Only sealed-combustion appliances should be installed within the pressure boundary of the building enclosure.

Roof/Ceiling/Attic

The function of roof/attic systems is to provide environmental separation between the interior and exterior, as well as to transfer wind and seismic loads to the foundation by functioning as a diaphragm. As part of the provision for environmental separation, floor systems have to control heat flow, airflow, rainwater, and water vapor flow.

Structure. In hot-dry/mixed-dry climates, the primary structural approach is site-built wood-framing utilizing engineered elements, such as prefabricated roof trusses and sheet goods, such as OSB and plywood.

Insulation and Air Infiltration. The optimum approach to insulation involves blowing insulation on the top surface of ceiling gypsum board. This ceiling insulation level is maintained throughout the entire plane of the ceiling extending to the perimeter walls. Roof trusses are constructed in such a manner as to maintain the thickness of ceiling insulation directly above the top plates of the exterior wall framing. Baffles are installed to control wind washing.

Air infiltration control is provided by an air barrier. The ceiling gypsum board is installed to function as an air barrier. Dropped ceiling areas are draftstopped, ceiling light fixtures are selected to be airtight, and all penetrations through plates are air sealed.

In some hot dry climates, conditioned roof/attic construction may be warranted.

Water Management, Drainage, Vapor Diffusion. Traditional roofing materials, such as shingles, are used to provide rainwater management at the roof deck.

Vapor diffusion is handled by providing roof/attic ventilation and by not installing an interior vapor barrier.

Figures 16, 17, and 18 are examples of building envelope details for Albuquerque, New Mexico; Sacramento, California; and Tucson, Arizona.

Interaction with Mechanical Systems. Excessively long-duration interior negative pressures should be avoided. A depressurization limit of 5 Pascals is recommended for continuously operating exhaust appliances. A depressurization limit of 20 Pascals is recommended for intermittent operating exhaust appliances. Only sealed-combustion appliances should installed within the pressure boundary of the building enclosure. Passive sub-slab ventilation is recommended to reduce atmospheric air pressure soil gas drivers.

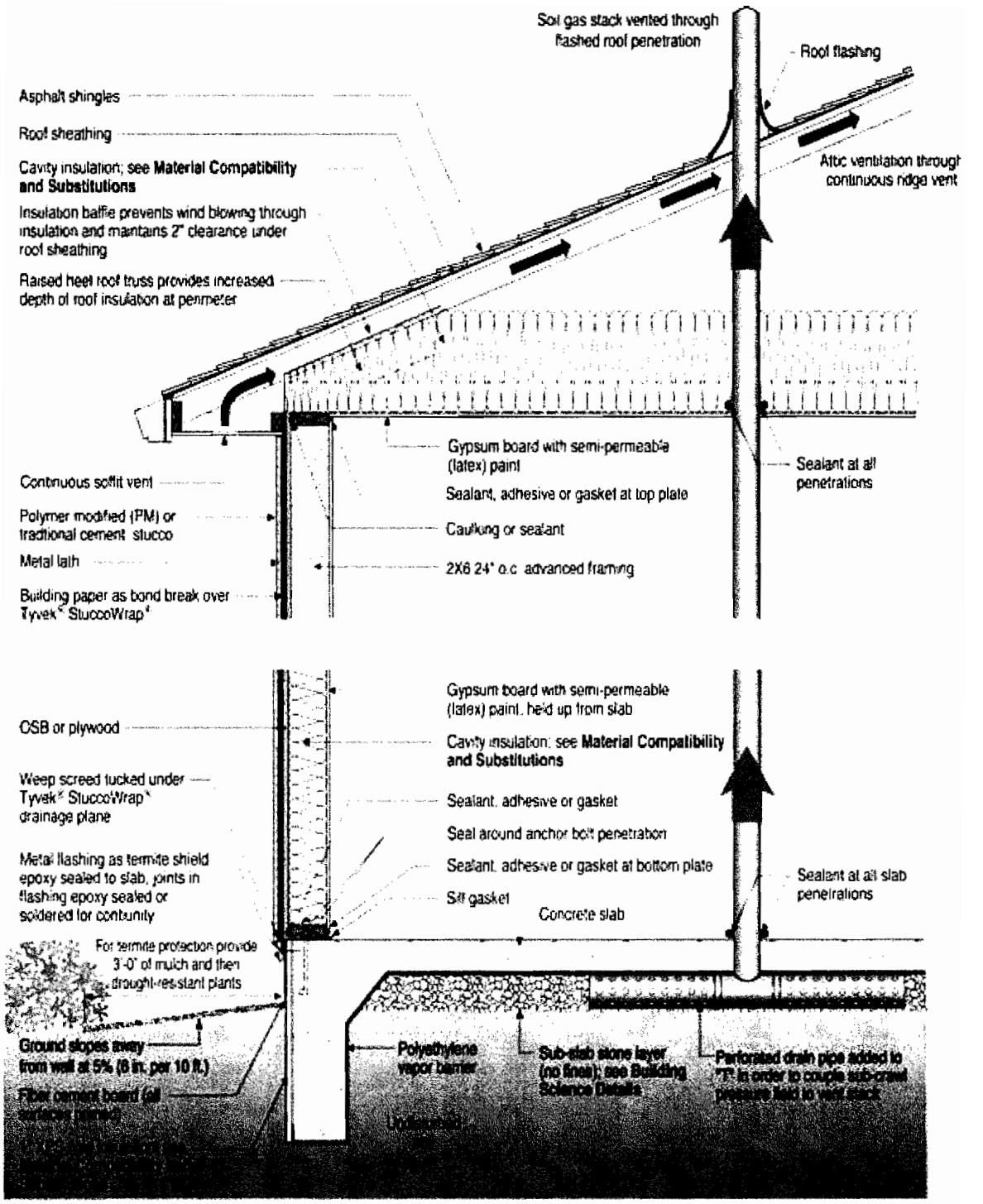


Figure 16. Example of building envelope details for Albuquerque, New Mexico

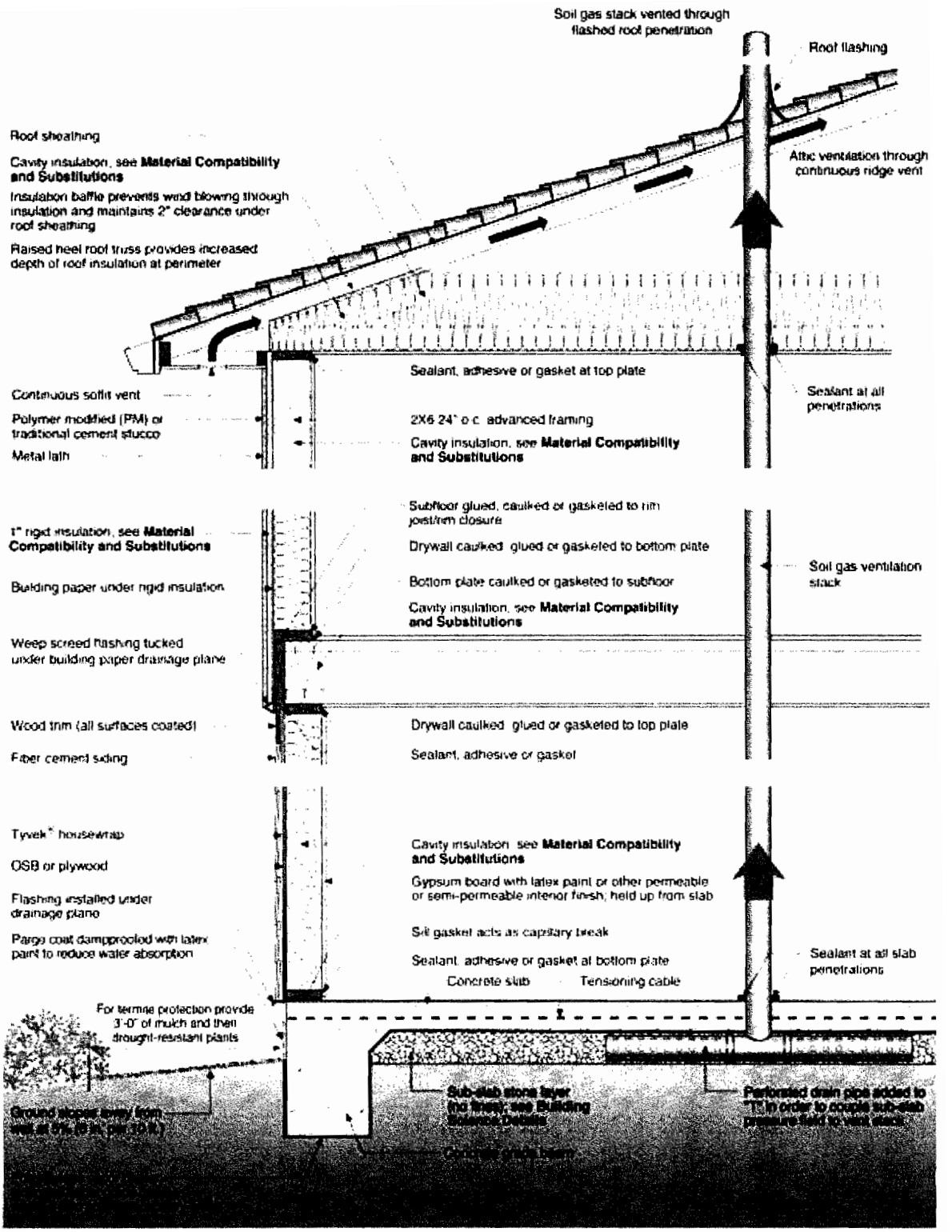


Figure 17. Example of building envelope details for Sacramento, California

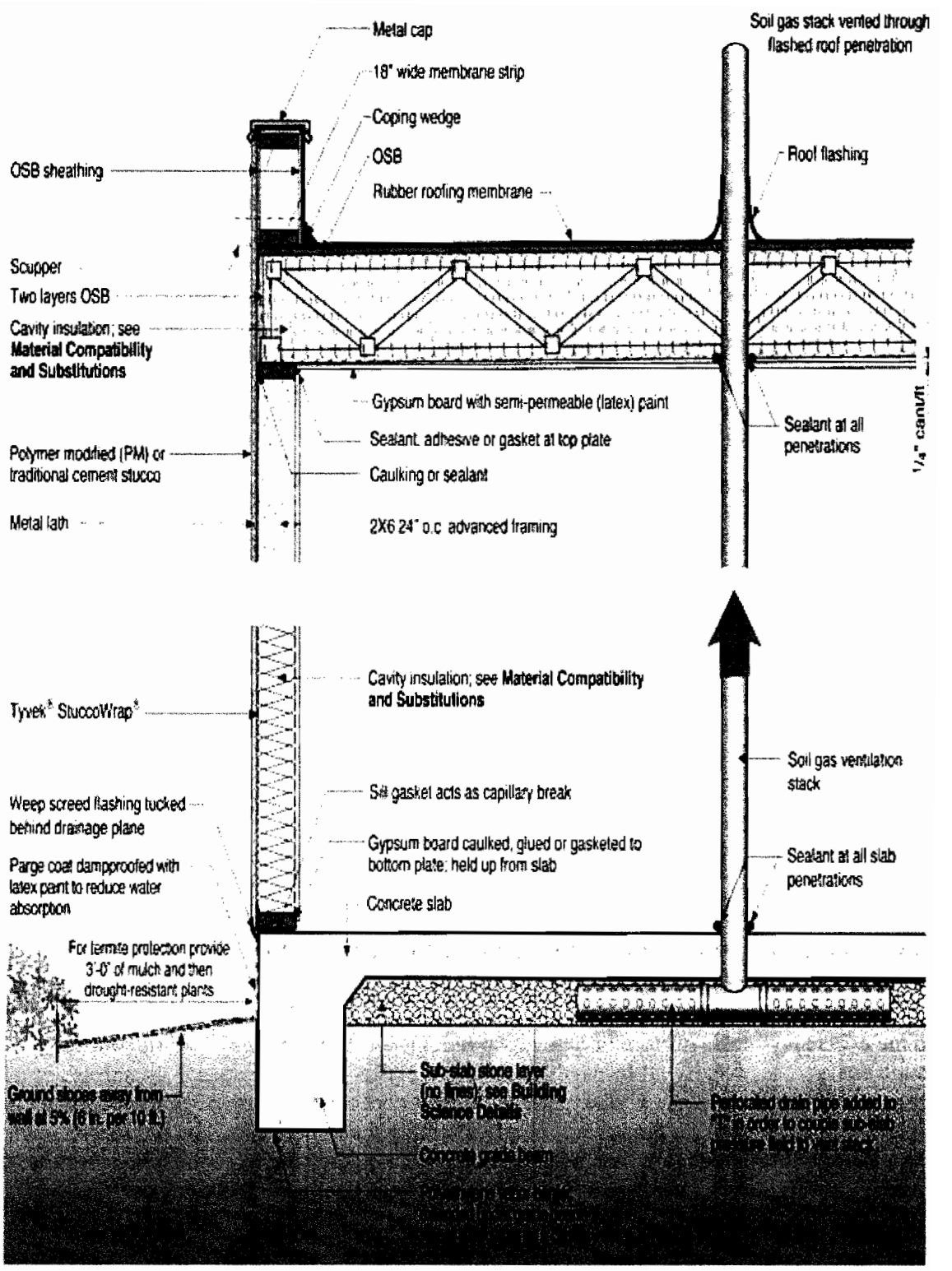


Figure 18. Example of building envelope details for Tucson, Arizona

Space Conditioning and Ventilation Systems

Forced Air

Forced-air heating and cooling systems are the most predominant type of system in today's residential new-construction market. This is driven primarily by the market for central air conditioning. According to census data, 77% of the homes constructed from 1990 to 1997 had central electric air conditioning. Central natural gas-fired furnaces were used in 47% of the new homes.

Cooling system efficiency is important in hot climates because air conditioning represents a larger share of annual building energy use than in other climates. However, the 30% performance goal is generally achievable by applying air conditioners that meet the 2006 federal (NAECA) standard of 13 SEER. This is particularly true if efficient duct systems are employed and if cooling loads are reduced by incorporating high performance (Low-E²) windows and architectural window shading in the design.

Selecting an efficient air conditioner is only part of the story. Right sizing of air conditioners (using ACCA Manuals J and S) will minimize operating efficiency losses resulting from cycling. Air conditioners and matching evaporator coils should be selected that have a sensible cooling capacity that meets or slightly exceeds the sensible cooling load from Manual J. Proper installation is required to ensure that air conditioners perform to their rated efficiencies. Fan speed taps should be adjusted to provide close to 400 cfm per ton of cooling capacity; lower airflows will provide more latent cooling capacity than is generally needed in hot-dry/mixed-dry climates, and higher airflows will waste fan energy. Improper refrigerant charge can significantly compromise air-conditioner efficiency. Thermostat expansion valves (TXVs), which dynamically adjust refrigerant flow, can compensate for improper charge and should be used instead of orifice-type expansion devices.

Relatively low heating loads in hot-dry/mixed-dry climates mean that high-efficiency (condensing) furnaces are not required to achieve the 30% target, though with declining costs for 90+ AFUE furnaces, they are an increasingly good value. Induced draft, direct-vent furnaces are desirable because they can be located in conditioned space, minimizing heat loss. Direct vent furnaces draw combustion air directly from outdoors rather than from the surrounding (unconditioned) space.

Air conditioning, heating, and, in some cases, ventilation systems, use the same fan to move air, so the efficiency of the furnace or heat pump indoor fan motor can have a large impact on year-round energy use. Nearly all furnace manufacturers offer "variable-speed" brushless permanent magnet (BPM) DC motors. Unlike permanent split-capacitor motors, BPM motors retain their high efficiency at reduced fan speeds, nearly attaining theoretical cube law reductions in energy use. Though they have more than a $200 price premium, they are a recommended means of lowering HVAC energy use, particularly with two-stage heating and cooling systems.

Though not critical to meeting the 30% performance level, locating the forced-air system (furnace/air handler and ducts) within the conditioned space will substantially improve whole-house performance. This approach minimizes the system inefficiencies associated with air leakage and thermal losses from the typically leaky system cabinets. Alternative locations for the furnace/air handler include a mechanical room, closet, or soffited area that is within conditioned space, or in an unvented or "cathedralized" attic. Few production homes are being

built over basements in Hot-Dry/Mixed-Dry Climates, but basements are also a good alternative location.

Air-conditioner energy use can be reduced by ventilating homes at night with cool outdoor air to reduce the temperature of building thermal mass. This technique can reduce cooling energy use by up to 35% where summer diurnal temperatures vary by 30°F or more, but ventilation cooling is not necessary to achieve the 30% savings target.

Ventilation

Most new homebuilders in Hot-Dry/Mixed-Dry Climates still rely on building leakage, intermittent use of bathroom and range-hood ventilation fans, and occupant use of windows and doors for maintaining indoor air quality. A California study to determine the adequacy of this approach is currently underway.

Despite the fact that ventilation systems increase energy use, with new homes being built to tighter air-leakage standards, a whole-house mechanical ventilation system that is capable of meeting the specifications of ASHRAE Standard 62.2 is recommended to assure adequate indoor air quality.[47] The relatively low indoor-outdoor temperature differences in Hot-Dry/Mixed-Dry climates do not justify the initial expense and operating cost of heat-recovery ventilators. The remaining choices for mechanical ventilation include systems that utilize the furnace fan to induce the flow of outdoor air into the HVAC system ducts and exhaust fans that operate continuously.

A supply-only system with a passive outside air inlet to the central air-handler's return with appropriate dampers and controls has been successfully employed in Building America homes. These systems have the disadvantage of using excessive fan energy during periods when there is no demand for heating or cooling, because most of the airflow is recirculated air and only a fraction is outside air. Advantages are that that the fresh-air volume can be adjusted to meet ASHRAE 62.2 requirements, outside air is filtered, and fresh air is delivered to every space.

Continuously operating exhaust fans located in a bathroom or central area of the house provide a lower cost solution. High-quality "low sone," efficient fans are typically used for this application. Because exhaust fans draw air from leaks in the building envelope, air is not filtered and may not be evenly distributed. A better solution that is in use by some contractors is to tie all bathroom exhaust ducts together and route them through a single, continuously operating, high-efficacy axial fan that is vented to the exterior. An approach that has also been used is to terminate a small fresh-air duct inside the return plenum, with a filter applied to the discharge opening. The filter is accessible through a hinged filter grill.

As with all mechanical systems, it is also important that ventilation systems be properly commissioned. Commissioning should include verification of fan operation and control settings and measurement of the outside air volume.

Air Distribution

For the 30% improvement, a number of requirements apply to design of the duct system:

---

[47] ASHRAE 62.2-2003. Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings. Atlanta, GA: American Society of Heating, Refrigeration, and Air Conditioning Engineers.

- Design should be in accordance with ACCA Manual D
- Ductwork should be located within the thermal envelope of the house or buried with insulation
- Ducts should not be located in exterior walls
- Ducts must be air-sealed using UL 181-approved mastic or equivalent for the particular duct type
- "Panning" between joists and the use of stud cavities for supply or return air is not recommended
- Ducts may be of galvanized sheet metal, duct board, or flex duct
- There must be continuity of the vapor barrier on insulated ducts not running inside conditioned spaces.

Sometimes duct systems need to run in unconditioned spaces.

To accommodate heating and cooling units and duct systems within the thermal envelope of the house, a number of techniques may be employed. This typically impacts the architectural design of the house and should be considered at the early schematic phase of design. Keeping ducts inside the conditioned space may also involve framing systems that allow ducts to be run through it, such as an open-web floor-truss system. Alternately, dropped soffits, tray ceilings, and lower ceiling heights in "service" function rooms like baths, hallways, and closets can accommodate ducts inside the envelope. Strategies include the following:

- Locate ducts within an insulated, non-vented, conditioned crawl space or basement
- Locate within an insulated "cathedralized" attic
- Locate in open-web floor trusses
- Develop chase walls to accommodate duct risers
- Design closets inside the conditioned space for locating the air handler in houses using slab on grade construction.

While the distribution system is important from an energy perspective, there are also health, safety, and indoor air quality issues to be considered. The following sections briefly discuss each, with recommended solutions.

Sealed Forced-Air Distribution Systems. Leaky duct systems, in addition to the energy losses introduced, may result in indoor-outdoor pressure imbalances that generate significant air leakage through the building envelope. For the 30% improvement house, extensive duct sealing is typically required. For metal ducts, UL 181-approved mastic is the only acceptable sealing method; for duct board, UL 181 tapes are accepted; and for flex duct, a combination of UL 181-approved mastic and strap ties should be used. The targets for total duct leakage is 5% of the high-speed system-cooling airflow in CFM, as tested at 25-PA reference pressure. To further reduce duct leakage, do not pan joists or use stud cavities for supply or return air. It is virtually impossible to seal building cavities properly to achieve the target tightness for forced-air systems.

Isolate the HVAC system from areas with potential pollutants. One of the most potentially hazardous IAQ problems arises when return ducts run through garage spaces where the opportunity exists to draw CO from automobile exhausts or other pollutants from hazardous chemicals often stored in the garage into the duct system and redistribute it throughout the house. Locating the HVAC unit in the garage is not recommended in the 30% improved houses, but it is not always possible to relocate the air-handling unit. If the air handler and return-air ducts must be located in the garage, any return-air ductwork and the air handler should be thoroughly sealed with UL 181-approved mastic, with a target leakage between the duct system and the garage of 0 CFM@25 PA. This yields the least possible opportunity for bringing garage air into the return system.

Pressure Balance the System. Pressure imbalances can cause air movement through the envelope when the HVAC system is operating, wasting energy and potentially causing moisture problems. Imbalanced airflows can also cause room-to-room or floor-to-floor temperature differences, leading to comfort complaints. Finally, imbalanced airflows can draw unwanted pollutants into the house, causing indoor air-quality problems. One key factor in eliminating room-room and indoor-outdoor pressure imbalances is the adequacy of the return air path. In homes with individual-room ducted returns, this is generally not a problem. Individual-room ducted return systems are historically typical in colder climates, but are losing favor because of their costs. From a cost-effectiveness standpoint, a well-designed central return system with individual room pressure relief is considered the standard for the 30% improvement house. To qualify as well-designed, the return system must incorporate adequate relief from each room where entry doors may be closed. Thus, return air recommendations include the use of ceiling "jump ducts," or transfer grills located in the walls. Door under cuts are generally not considered to be acceptable because they are often inadequate in area and/or blocked by the installation of carpeting. One important consideration in the installation of "jump ducts" or transfer grilles is to maintain a satisfactory acoustic separation between spaces. This is typically accomplished by the use of flex duct, duct lining with sound-absorbent material, a slightly circuitous path, or some combination of these strategies to block sound transmission.

Supply-Air Register Selection and Placement. The distribution of the heating or cooling air stream from the supply register to the return point is critical to maintaining comfort conditions within the room. In the 30% improvement house, envelope insulation, including window U-value and SHGC, and air sealing have been improved to such an extent that basic comfort needs are more easily met by the HVAC System. In particular, envelope surface temperatures are moderated to a considerable degree, which results in reduced radiant heat loss (or gain) to room occupants, improving comfort conditions. Similarly, solar gains through low-SHGC windows are reduced, considerably improving cooling season comfort conditions. With good air sealing, houses are much less drafty than those built to older construction standards.

All these reduced loads and improved comfort conditions mean room heating/cooling air volumes (at typical supply temperature) may be reduced. If typically sized registers are used, discharge velocities are reduced,and the air has less "throw" within the room. This is a new operating region for forced-air systems and presents a number of challenges to achieving a proper design for good comfort conditions.

In cooling-dominated climates, it has been typical to locate supply registers in the ceiling. This works well for cooling, but may present problems during heating periods. High sidewall and ceiling register placements have been used successfully in Building America projects. To attain

optimal performance and comfort, it is critical to properly select registers based on throw characteristics and the volume of air being delivered to the room. This may require designing at the upper limits of recommended face velocities and the purchase of "non-standard" register sizes. It may also require the use of registers with manually operable vanes to fine tune airflow for optimal comfort.

In general, high-sidewall applications have been used where the register is directed at the wall of dominant heat loss or gain (usually the wall with windows or glass doors) and the register is no more that 12 to 13 ft away. Ceiling diffusers with curved blades to help direct the airflow along the ceiling can be used where the wall opposite the dominant load exceeds 13 ft.

Research is currently underway in the Building America Program to understand the issues of air distribution in high-performances houses and to develop recommendations for supply and return apertures to achieve the best comfort conditions consistent with a highly energy-efficient system.

There are many issues to consider including the following:

- Register location and discharge pattern
- Discharge velocity
- Discharge temperature
- Effect of return location
- Stratification and mixing patterns
- Part-load operation, heating/cooling variation
- Impact of zoning systems
- Solar load variability
- Buoyancy issues
- Sound issues
- Register/nozzle configurations
- Register approach conditions – boots
- Dampening and control.

The recommendations that are developed from these ongoing investigations will enhance the current recommendations for houses achieving 30% whole-house savings and will likely be critical for houses at the 40% and greater improvement levels.

Duct insulation. If ducts cannot be brought within conditioned spaced, supply ducts should be insulated to R-8 minimum and return ducts to R-4 minimum. Research by the Building America Team CARB[48] has supported code credits for ducts in Hot-Dry and Mixed-Dry Climates that are buried in loose-fill attic insulation. This strategy should not be used in sections of this climate

[48] Dianne Griffiths et al. August 23, 2004. Insulation Buried Attic Ducts – Analysis and Field Evaluation Findings. American Council for Energy-Efficient Economy (ACEEE). 2004 ACEEE Summer Study on Energy Efficiency in Buildings. Pacific Grove, CA.

zone with seasonally high levels of humidity with a corresponding need for cooling because condensation can form on the outside of the duct vapor barrier and cause moisture problems in the home. Similarly, it is critical to make sure all metal fittings are well insulated to avoid condensation.

Mechanical, Electrical, and Plumbing Systems

Lighting

Compact fluorescent lamps, smaller versions of standard fluorescent lamps, use 70%-75% less energy than their incandescent equivalents, and they have brightness and color rendition comparable to incandescent lights. They cost more, but last 10 to 13 times longer than incandescents, making them very cost effective if used at least 2-3 hours per day. A wide variety of sizes and shapes are available with varying color-spectrum characteristics. Consult your local lighting supplier/designer, and install them wherever practical.

The following are near-term energy-savings opportunities for new homes. In some cases, these involve newly commercialized products that are just now entering the market, while in other cases these represent systems show great promise but need further refinement and field-testing:

- High-quality, high-output residential grade CFL downlights for kitchens and hallways
- Linear fluorescent bathroom vanity strips (vertical and/or horizontally mounted)
- Bathroom occupancy sensors with integrated LED nightlight
- LED porch lighting
- LED exterior security luminaire
- High-output LED walkway lighting
- Evaluation of energy-savings potential from incandescent dimming.

Home Lighting Facts. Compact fluorescent lamp use 70%-75% less energy than their incandescent equivalents. When replacing a 100-watt incandescent lamp, a 28-watt CFL can be used. Here are some facts about CFLs:

- Compact fluorescents last approximately 10,000 hours, which is 10 to 13 times the life of an incandescent lamp (expected life approximately 750 hours).
- Compact fluorescents are most cost-effective when used at least 2-3 hours per day.
- Although compact fluorescent lamps may appear different than the common incandescent, they fit most standard fixtures found in homes today. The screw-in base is the same on both lamps.
- The typical incandescent lamp wastes 90% of the energy it uses, producing heat rather than light.
- The latest compact fluorescent lamps have improved color rendition. The light is a warm tone that is almost identical to that of an incandescent lamp. Most people can't tell the difference.

Residential Lighting Controls. Residential lighting controls represents a significant opportunity for energy savings. Lighting controls generally refers to technologies that turn off (or turn down) lighting systems when they are not needed. Examples include occupancy sensors, photo sensors, dimmers, and timers.

Technologically, residential controls have improved greatly over the last several years, both in terms of the types of controls options available, as well as their quality and functionality. As the cost of these systems decrease because of increased demand for commercial applications, they become increasingly attractive for cost-effective residential applications.

Recognizing these technological and market advances, as well as the potential energy savings of these technologies, energy-code officials have begun to look more closely at residential lighting controls. The new 2005 Title 24 building code in California, which will go into effect on October 1, 2005, includes strong incentives for homebuilders to utilize occupancy sensors, photo sensors, and dimmers. In fact, many market watchers now anticipate that homebuilders will choose lighting control alternatives over energy-efficient luminaries to comply with this new code because the controls approaches are often more cost-effective.

Major Appliances

At the present time, the best practice recommendations for the 30% improvement house is to use ENERGY STAR-rated appliances. Within the ENERGY STAR-rated offerings, there are differences in performance levels, but these are probably not of significance at the 30% improvement level. It is also recommended that best-in-class appliance for non-ENERGY STAR-rated appliances be installed or recommended for purchase by the homeowner if not provided by the builder.

Program for Off-peak Operation. While not a mechanism for direct source energy reduction, peak-load shifting is a beneficial strategy from a consumer-utility cost perspective where time of use rates are in effect and can have electric utility system benefits by helping to reduce the need for peak power plants. The cost of energy consumption for appliances can be reduced by operating appliances during off-peak hours and refraining or minimizing their use, especially simultaneous use, during peak hours.

For example, using Whirlpool's energy management system for stand alone Time-of-Use (TOU) appliances delays the operation of the dishwasher, washing machine, and dryer can be delayed until the energy prices are lower (off-peak rate). An LED lets the consumer know if the rate is currently on- or off-peak. To delay until off-peak, the consumer can press a button and another LED illuminates to let them know that this appliance will start at a later time.

An alternative strategy is to minimize the amount of time that appliances are in the high-power mode by ensuring that the appliance is used in the lowest possible power mode when ever practical.[49]

[49] International Energy Agency. 2001. Things That Go Blip in the Night: Standby Power and How to Limit it. www.iea.org/textbase/nppdf/free/2000/blipinthenight01.pdf.

Water Heating and Distribution Systems

At the 30% improvement level, energy use for hot water heating becomes a significant component of total energy use. Consequently, the following guidance has been developed for the design and installation of DHW Systems:

> DHW heater sizing. The size of tank and first-hour draw pattern can have an impact on the overall energy consumption associated with hot water. Tank size is a function of first-hour rating, draw patterns, and incoming and outgoing water temperatures. The sizing method described below, takes into account the nominal population of a house, the main supply water temperature, and the efficiency of the DHW heating equipment.

Sizing Method for Tank-Type DHW Heater. Use this procedure for sizing tank-type domestic hot water heaters (Figure 19).

- Establish the design population of the house by taking the number of bedrooms + 1.
- Multiply this by the gallons/person for the climate zone where the house is located to get the first-hour rating for the water heater.
- Using the first-hour rating from Step 2, select a DHW heater that meets or exceeds this rating.
- For a tank-type gas heater, select a heater with an energy factor greater than 0.60. For a tank-type electric heater, select a heater that meets the current NAECA standard.

Heater Selection. The efficiency target for fuel-fired tank-type gas DHW heaters is 0.60 EF or higher. With the tight house construction of the 30% improvement level, these heaters should be either power vented (which forcibly discharges the products of combustion and draws combustion air from the house), direct vent with dedicated outside air for combustion, or sealed-combustion units that draw combustion air from outdoors and fan discharge combustion gasses outdoors. If electricity is used for heating water, a high-efficiency tank or tankless unit should be used.

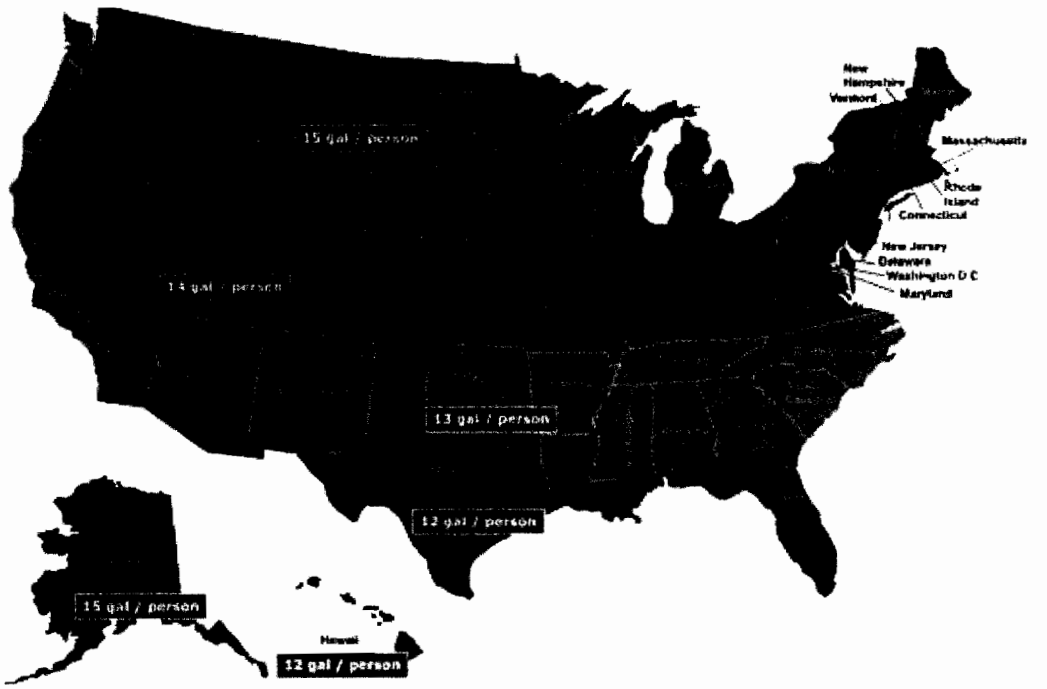


Figure 19. Domestic hot water tank sizing for 135°F tank temperature only

Tankless water heaters (about 0.84 EF) can provide significant advantages over the traditional storage tank water heaters for a number of reasons:

- **Energy savings:** Tankless water heaters have a higher energy factor compared to tank water heaters and are, therefore, a more energy-efficient option.
- **Space savings:** Tankless water heaters are dimensionally smaller and save space compared to storage tank water heater. This allows for installation in spaces with limited area or in locations closer to the point of use.
- **Longer life expectancy and favorable life cycle costs:** The tankless water heater has a life expectancy of 15 to 20 years compared to a typical 9 years for storage-tank water heaters. When the replacement of a tank water heater is combined with the lower operating costs, the life-cycle costs of a tankless water heater are generally lower than a tank-type water heater.

Some builders have chosen to install multiple gas-fired tankless units, which may require upsizing of the main gas service when coupled with other gas end-uses in the house (furnace, cooking appliances, dryer, etc.) This could be a significant barrier to widespread adoption, especially in areas with low gas pressures. By installing multiple units, builders are safeguarding against a call from homeowners that there isn't enough hot water, but may be overcompensating because of lack of experience with the tankless gas-fired technology.

Tank-type heaters offer the best efficiency with relatively steady, continuous-use patterns. If electricity is the energy source for water heating, additional improvements to other areas of the house will likely be needed to achieve the 30% savings levels, because there is very little room for improvement in electric water-heating efficiency compared to the possible efficiency gains using gas-fired technologies.

Stand-alone electric heat-pump water heaters offer better efficiency than electric resistance heaters, but they are complex, costly, and still evolving as a standard commercial product. They provide the best efficiency when their cold-air discharge can be used to augment home air conditions, which can be a benefit in cooling-dominated climates. Conversely, they can contribute to an additional heating load during the winter. Optimizing these relationships along with this performance variation as a result of supply-water temperature and load pattern is quite challenging. Primarily because of the early state of technology deployment and reliability, stand-alone heat-pump water heaters are not considered a practical choice at the 30% level. Should these units improve in reliability, and if volume manufacturing brings costs down, then they would be worth considering as part of the overall package.

If a ground-source heat pump is chosen for space heating and cooling, it is possible to use it to generate hot water, either through a desuperheater on the basic water-to-air heat pump or by using a water-to-water system where the heat pump can generate heated or chilled water to be used for space conditioning and domestic hot water. These systems can be effective, but the pricing varies dramatically by region and can be more complex than a traditional gas furnace with DX air-conditioning systems. In an area where no natural gas is available, this system is an option in all climate zones; however, it requires a skilled and experienced installer base and favorable pricing.

While not necessarily required to achieve the 30% whole-house energy-savings target, there are a number of reliable solar DHW heaters in the market. They represent a range of operating philosophies:

- Storage/non-storage
- Freeze-protected/drain-back
- Passive thermosystem/pumped cycle, etc.

With good design, these solar systems can all be effective sources of hot water, particularly in sunny climates. What most degrades the performance of solar DHW systems are the details of design, construction, operation, and maintenance. Research has found that simple set of characteristics, such as long pipe run from the collector plate combined with a short, infrequent usage pattern, can render the solar contributions nearly negligible. Primarily because of their high cost, solar DHW systems are not considered practical at the 30% improvement level.

Hot Water Distribution Systems. The hot water distribution system plays a surprisingly important role in the total energy efficiency of the DHW system. Thermal losses from the hot water distribution piping system while water is flowing and the losses associated with "stranded" hot water as it cools down once faucets are turned off can amount to a very substantial portion of total hot water energy use. Thus, guidance on the configuration of the system, its insulation, and patterns of use can help reduce the piping system component of DHW energy use.

Basic guidance on the layout of DHW piping suggests that the DHW source and major use points be as close to each other as practical. A good example of this would be the location of the DHW heater in a closet adjacent to the kitchen and laundry that are back-to-back. Short lines will minimize "stranded" losses, which can be considered detrimental during the cooling season. Locating tankless water heaters immediately adjacent to high-use clusters, such as a pair of bathrooms in a remote wing or a second floor, is an excellent way to reduce piping heat losses.

All DHW supply piping should be insulated with standard R-4 pipe insulation. It is readily available, inexpensive, and effective. This includes any hot water lines located in concrete slabs or underground. Increasing tank insulation to a minimum of R-12 by adding a tank insulation wrap can also reduce energy consumption.

Research has also shown that "parallel piped" or "homerun" plumbing systems using PEX piping and a central manifold can reduce energy consumption compared to traditional copper "tree and branch" plumbing systems.[50]

To avoid the waste of water as one "waits for the hot water to arrive" and to provide instantaneous hot water, there is growing use of recirculation systems that continuously circulate hot water through the entire system. This continuous circulation of hot water results in high loss of heat from the piping system, even if insulated, and is strongly discouraged in an energy-efficient house of any type.

If a recirculation system must be installed, a push-button type on-demand re-circulator will minimize the energy penalty associated with recirculation systems. The system circulates the water only when the hot water is needed. It is, thus, more energy efficient than the continuous recirculation system. The on-demand circulating pump briefly moves water out of the hot water pipe and back to the DHW heater down the cold water pipe until hot water is sensed at the faucet. This system eliminates the waste of water down the drain.

The on-demand circulator is primarily useful for use points that are a long way from the DHW source and represent a substantial water waste while waiting for the hot water to "arrive."

Onsite Power Systems

A number of on-site power production systems are currently available for Building America projects and others are in the research stage. Most have been used in Building America projects. These systems include the following:

- Photovoltaics
- Engine generator/combo systems
- Fuel cells.

The 30% improvement level can be achieved most cost effectively through the improvement of the envelope; the heating, cooling, and domestic hot water systems; and possibly the application of some lighting and appliance improvements. On-site power systems are very costly and are not recommended as a strategy to achieve the 30% savings level.

Cost Analysis

Life-cycle Cost Analysis

From a purely economic point of view, building energy optimization involves finding the global optimum that balances investments in efficiency versus utility bill savings. However, there are

[50] NAHB Research Center, Inc. November 2002. Performance Comparison of Residential Hot Water Systems. Upper Marlboro, MD: NAHB Research Center, Inc.

sometimes non-economic reasons for targeting a particular level of energy savings. Given a particular energy-savings target, economic optimization can be used to determine the optimal design (lowest cost) to achieve the energy-savings goal. The analysis presented below targets 30%-39% whole-house energy savings with respect to the Benchmark by using the BEopt analysis method to investigate cost tradeoffs associated with various residential energy efficiency and renewable energy technology options.

Building Characteristics Considered in This Study. For the Prototype building, a two-story 3,000-ft^2 and a single-story 1,500-ft^2 residential building were used for this study, with the front of the buildings facing east. While complex floor plan geometries can be analyzed, a simple square floor plan was implemented for the purposes of the current analysis. The buildings were modeled with a slab-on-grade foundation type. Both buildings were assumed to have three bedrooms and two bathrooms. The both buildings had 1-ft eaves. Window area was assumed to be 18% of floor area with 50% of the window area facing west, 25% of the window area facing east, 12.5% of the window area facing north, and 12.5% of the window area facing south. The non-uniform window distribution was utilized to represent a possible "worst case" window distribution from the available window distribution options currently included in the BEopt analysis method.. The energy options considered in the study include space-conditioning systems (up to SEER 18 and 92.5% AFUE in the current study), envelope systems, hot water systems, lighting systems, major appliances, and residential PV. The buildings use natural gas for the following end uses: cooking, water heating, and clothes drying. No options that would potentially reduce miscellaneous electric loads other than major appliances were included in the study. For the Phoenix example cases, air-conditioner capacities less than 1.5 tons were not considered nor were furnace capacities less than 50kBtu/hr. SEER10 air-conditioning equipment was included in this analysis for discussion purposes; however, after January 1, 2006, Federal minimum equipment efficiencies will mandate the use of SEER13 air conditioners.

Occupancy/Operational Assumptions. Occupancy and operational assumptions are as defined in the Benchmark and include time-of-day profiles for occupancy, appliance and plug loads, lighting, domestic hot water use, ventilation, and thermostat settings.

Base-Case Building. Results are calculated relative to the Benchmark, which defines baseline features. These features include wall, ceiling, and foundation insulation levels and framing factors; window areas; U-values and solar heat gain factors; interior shading; overhangs; air infiltration rates; duct characteristics; and heating, cooling, and domestic hot water system efficiencies.

Cost Assumptions. Each option has an assumed first-cost and lifetime (Appendix B). Costs are retail and include national average estimated costs for hardware, installation labor, overhead, and profit. Some are input as unit costs that are then multiplied by a category constant (e.g., ceiling insulation costs are input per square foot and multiplied by ceiling area by BEopt). Some inputs are energy-option specific (e.g., cost of solar water heating systems). Inputs can also be based on total costs (e.g., cost of wall constructions with different insulation values) because BEopt will calculate the differences between option costs.

Construction costs (wall insulation, ceiling insulation, foundation insulation, etc.) are typically based on R.S. Means[51] cost estimates. Window and HVAC costs are based on quotes from manufacturers' distributors. Appliance costs are based on manufacturers' suggested retail prices.

Building construction options (wall insulation, ceiling insulation, foundation insulation, windows, etc.) are assumed to have 30-year lifetimes. Equipment and appliance options typically have 10- or 15-year lifetimes. Lifetimes for lighting options (incandescent and compact fluorescent lamps) are modeled based on cumulative hours of use.

Utility costs are assumed to escalate at the rate of inflation (i.e., to be constant in real terms). The mortgage interest rate is 5% above the rate of inflation. The onsite power option used for this study was a residential PV system with an installed cost of $7.50 per peak Watt DC, including present value of future operation and maintenance costs. This cost is assumed to be independent of PV system size. Additional costs associated with mounting large PV arrays were not considered. For Phoenix, natural gas is assumed to cost $0.7986/Therm, and the cost of electricity was modeled as $0.0778/kWh.

Simulation Limitations. There are benefits that are not considered by the BEopt analysis method that will have an influence on the real-world design of a home, such as reduction in warrantee and liability exposure, increased customer satisfaction, and higher quality construction practices. The BEopt analysis method does not consider concerns with regard to indoor air quality, mold, and combustion safety. In a real-world design, these factors may lead the designer, engineer, builder, or architect to use equipment or construction practices that increase first cost without reducing utility bills in order to provide better indoor air quality, combustion safety, occupant comfort, or other design considerations that have high value to the builder or potential homebuyer. There are also some side effects that the simulations are not equipped to deal with, such as the costs of change in a builder's organization necessary to implement energy-efficient design approaches, the costs of moving a trade base to a different place, or termination of long-term relationships with a trade because the trade would not adopt energy-efficient practices. There is currently no methodology available to account for these effects in the simulation. Further development of a methodology to account for these effects and collection of appropriate data to inform the simulation would be necessary if there is interest in considering these effects.

The BEopt analysis method is relatively new to the Building America program, the case studies included in the Building America Systems Research Results section were not initially simulated with BEopt nor was BEopt used to guide the design process of the case study homes included in the Building America Systems Research Results section. The case studies are the result of years of field experience and design work done by Building America teams. Currently, this analysis method is being used for general programmatic guidance in an effort to understand at what cost and performance specifications efficiency and renewable technologies begin to look attractive when compared to other efficiency and renewable technologies. In its current form, the BEopt analysis method is useful for programmatic studies in terms of weighing the merits of certain efficiency and renewable technologies versus standard construction practices or other technologies using national average cost data, retail cost data, or projected costs for emerging technologies; however, cost of these technologies may be very different on a production-scale or

[51] Residential Cost Data – 18th Annual Edition. 1999. Kingston, MA: R.S. Means, Company, Inc.

custom-builde-scale, and the results shown here should not be taken as representative of all builders in this climate region.

As an example of what building efficiency options would lead to a combination of options that would achieve 30-39% whole-house energy efficiency relative to the Benchmark, an optimization was performed with the Phoenix TMY2[52] weather file. Figure 20 shows the 35% whole-house energy efficiency point that falls on the cost optimal curve for Phoenix.

[52] Typical Meteorological Year weather data, http://rredc.nrel.gov/solar/old_data/nsrdb/tmy2/

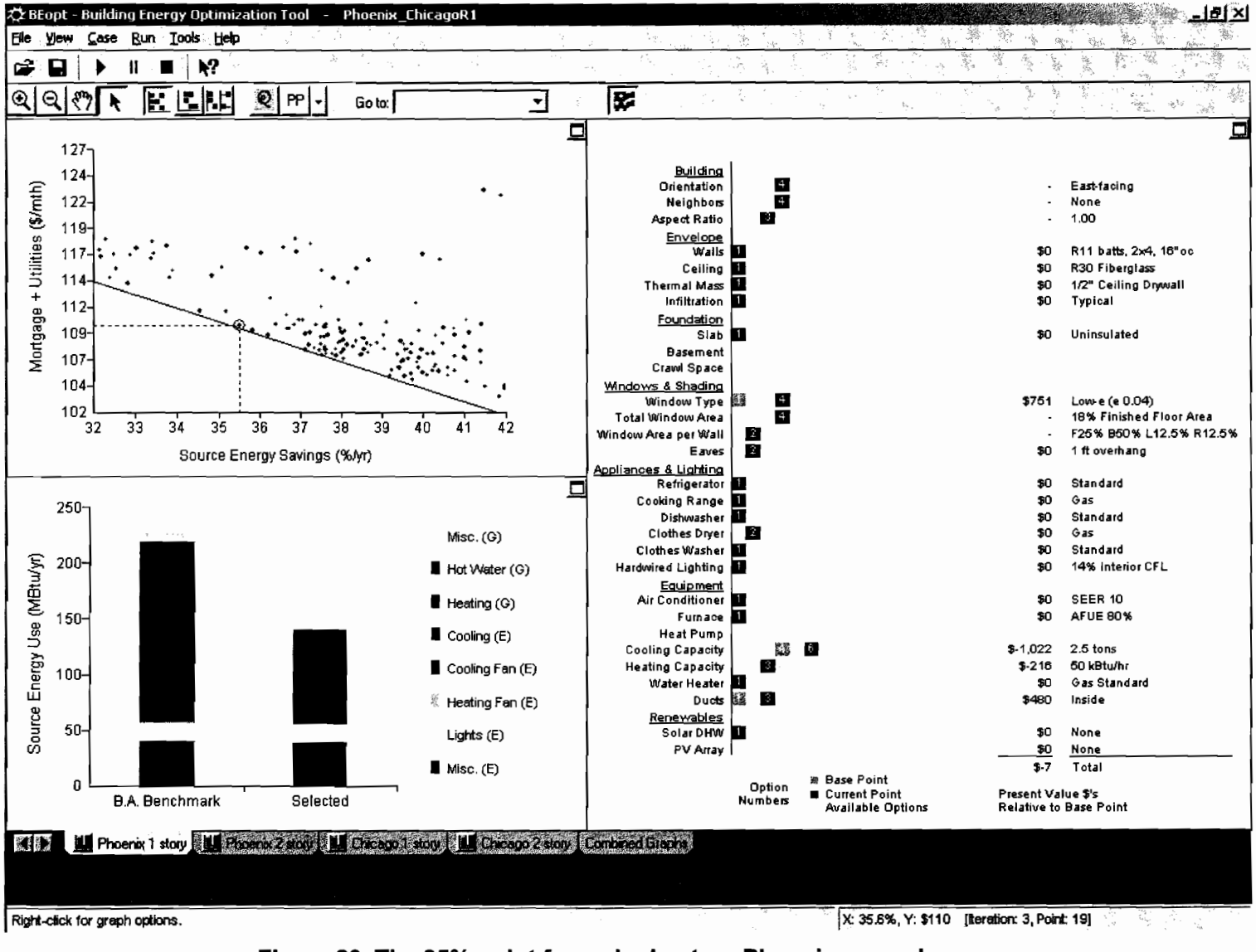


Figure 20. The 35% point for a single-story Phoenix example case

Based on the costs assumed as shown in Appendix B and within the limitations of the analysis method and the previously mentioned assumptions, the options selected in Figure 21 would represent a possible least-cost combination for 35% whole-house energy savings for a single-story residence in Phoenix, Arizona. Because costs may vary significantly across the Hot-Dry /Mixed-Dry Climate region, from builder to builder, and over time, the above is only an example that may not reflect the actual least-cost set of options that would apply to a specific home, builder and location.

At the high end of the whole-house energy-performance range considered here — 39% whole-house energy savings — the total monthly cost is slightly lower than the 35% example. Figure 21 shows an example combination that meets 39% whole-house energy savings compared to the 35% combination.

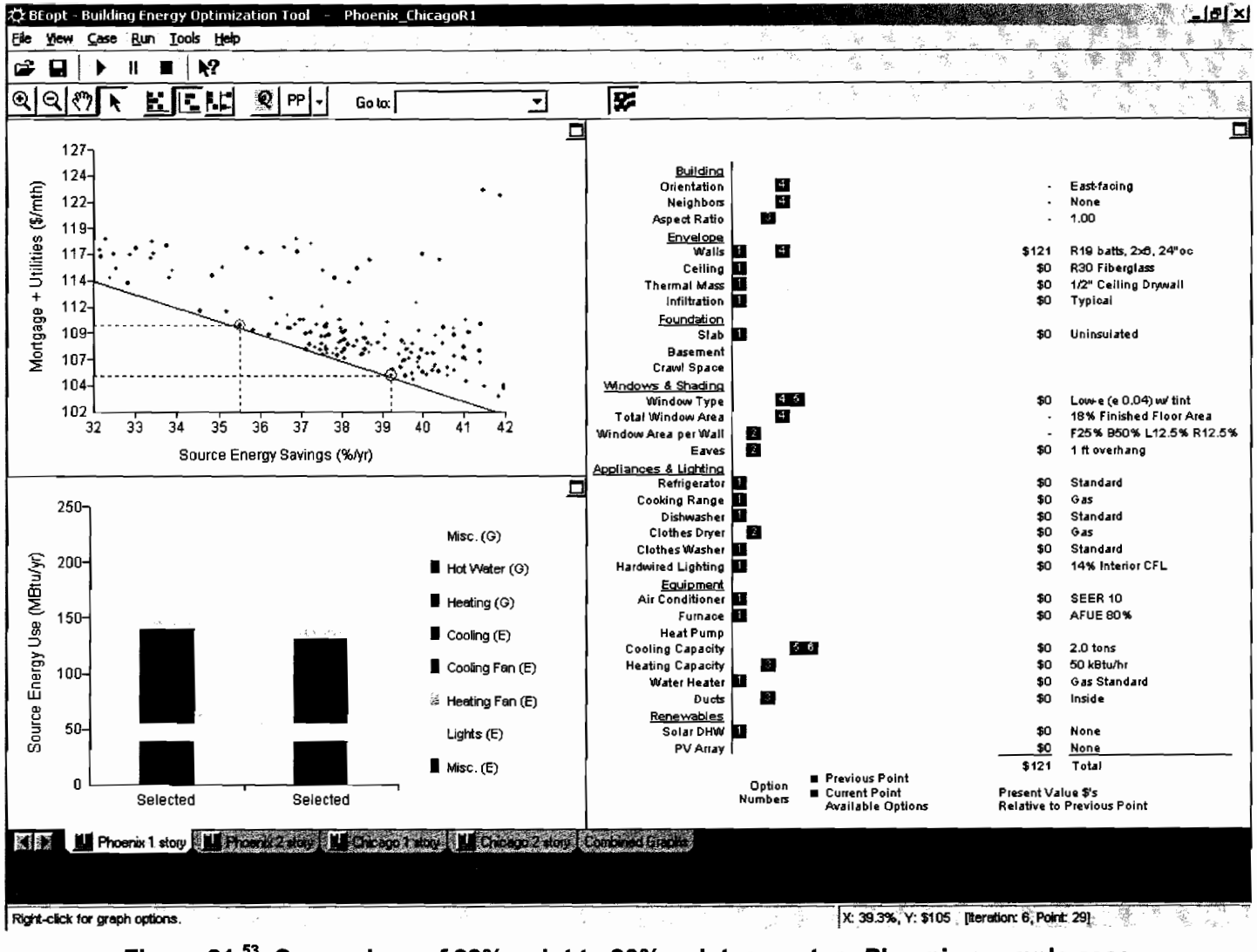


Figure 21.[53] Comparison of 39% point to 30% point, one-story Phoenix example case

[53] Note that costs shown in this figure are incremental relative to the 30% energy-savings point (shown in magenta)

The comparison of the 35% combination (represented in magenta) to the 39% combination (blue only) shown in Figure 22 demonstrates that by using additional exterior wall insulation and a lower-SHGC, low-e glass, the 39% combination is less expensive in terms of total cost per month than the 35% single-story example. There are some savings associated with the downsizing of the cooling equipment as a result of the envelope improvements.

Figures 22 and 23 look at the same points for the two-story case.

The comparison of the 35% combination (represented in magenta) to the 39% combination (blue only) shown in Figure 23 demonstrates that by utilizing a SEER-14 air conditioner, the 39% combination is not only more efficient but costs less per month than the 35% two-story example. A more specific comparison of the features of the 35% and 39% examples are shown in Table 7 for single- and two-story cases.

Table 7 shows some differences in the options selected between the one- and two-story cases for the energy-savings levels and points selected. The differences between one- and two-story examples at the 35% and 39% energy-savings level are limited to exterior wall construction, glazing types, and air-conditioner SEER rating. Within the limitations of the economic model included in the BEopt analysis method, the above example cases would represent a reduction in total monthly cost (mortgage cost – utility cost) when compared to the neutral cost line shown in Figure 6.

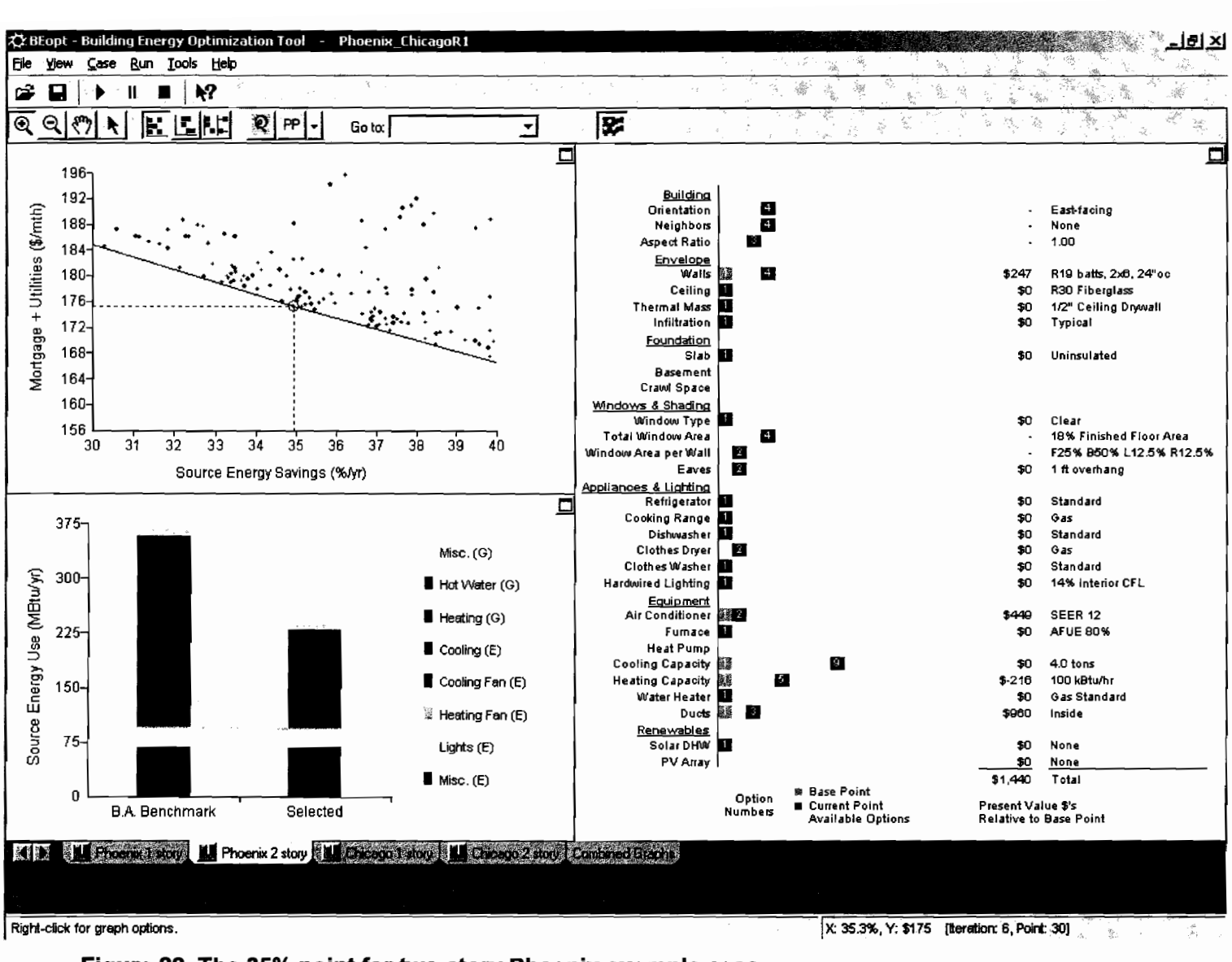


Figure 22. The 35% point for two-story Phoenix example case

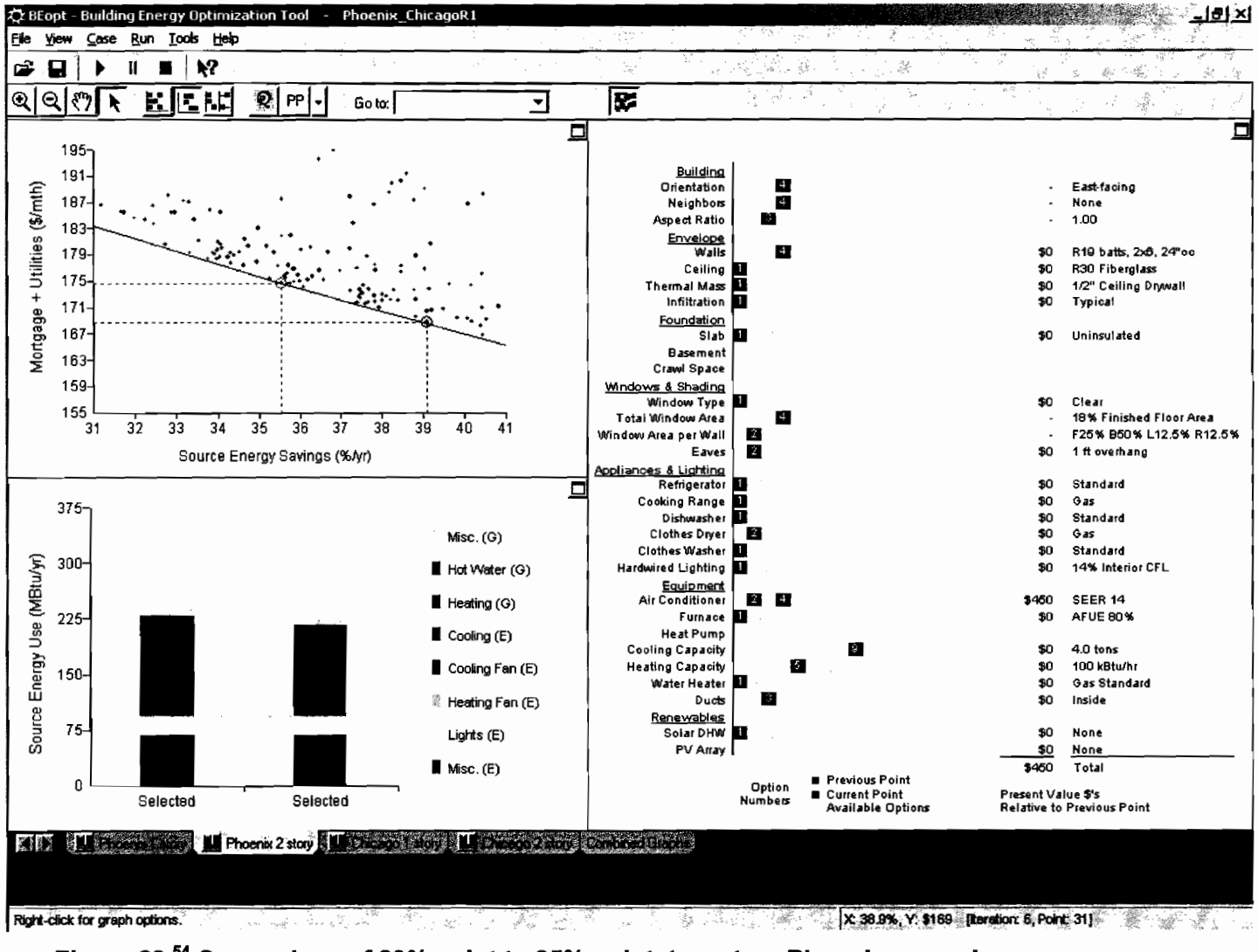


Figure 23.[54] Comparison of 39% point to 35% point, two-story Phoenix example case

[54] Note that costs shown are incremental relative to the 30% energy-savings point.

Table 7. Comparison of Single- and Two-Story Example Cases

CATEGORY	35% EXAMPLE		39% EXAMPLE	
Number of Floors	One Story	Two Stories	One Story	Two Stories
Walls	R-11, 2x4, 16 in. oc	R-19, 2x6, 24 in. oc	R-19, 2x6, 24 in. oc	R-19, 2x6, 24 in. oc
Ceiling	R-30 fiberglass	R-30 fiberglass	R-30 fiberglass	R-30 fiberglass
Thermal Mass	½-in. ceiling drywall	½-in. ceiling drywall	½-in. ceiling drywall	½-in. ceiling drywall
Infiltration	SLA = 0.0005	SLA = 0.0005	SLA = 0.0005	SLA = 0.0005
Basement	Uninsulated	Uninsulated	Uninsulated	Uninsulated
Glass Type	Two-pane, Low-e, U = 0.3, SHGC = 0.44 center of glass, insulated spacer, vinyl frame	Two-pane clear, U = 0.49, SHGC = 0.76 center of glass, insulated spacer, vinyl frame	Two-pane, Low-e, U = 0.29, SHGC = 0.29 center of glass, insulated spacer, vinyl frame	Two-pane clear, U = 0.49, SHGC = 0.76 center of glass, insulated spacer, vinyl frame
Window Area per Wall	270 ft^2, 12.5% N&S, 50% W, 25% E	540 ft^2, 12.5% N&S, 50% W, 25% E	270 ft^2, 12.5% N&S, 50% W, 25% E	540 ft^2, 12.5% N&S, 50% W, 25% E
Refrigerator	Standard: 671 kWh/yr	671 kWh/yr	Standard - 671 kWh/yr	671 kWh/yr
Cooking Range	45 Therms/yr	45 Therms/yr	45 Therms/yr	45 Therms/yr
Dishwasher	Standard, 462 kWh, eight place-setting capacity, 131.6 kWh/yr machine energy, 5.39-gal/day DHW	Standard, 462 kWh, eight place-setting capacity, 131.6 kWh/yr machine energy, 5.39-gal/day DHW	Standard, 462 kWh, eight-place setting capacity, 131.6 kWh/yr machine energy, 5.39-gal/day DHW	Standard, 462 kWh, 8 place setting capacity, 131.6 kWh/yr machine energy, 5.39-gal/day DHW
Clothes Dryer	Gas: 5.7 ft^3, 2.75 EF, 70.1 kWh/yr, 31.8 therms/yr	Gas: 5.7 ft^3, 2.75 EF, 70.1 kWh/yr, 31.8 therms/yr	Gas: 5.7 ft^3, 2.75 EF, 70.1 kWh/yr, 31.8 therms/yr	Gas: 5.7 ft^3, 2.75 EF, 70.1 kWh/yr, 31.8 therms/yr
Clothes Washer	Standard, 3.15 ft^3, 533 kWh/yr, 1.16 MEF, 65.6 kWh/yr machine energy, 4.63 gal/day DHW	Standard, 3.15 cuft, 533 kWh/yr, 1.16 MEF, 65.6 kWh/yr machine energy, 4.63 gal/day DHW	Standard, 3.15 ft^3, 533 kWh/yr, 1.16 MEF, 65.6 kWh/yr machine energy, 4.63-gal/day DHW	Standard, 3.15 ft^3, 533 kWh/yr, 1.16 MEF, 65.6kWh/yr machine energy, 4.63-gal/day DHW
Lighting	14% CFL, 1574 kWh/yr Hardwired, 331 kWh/yr Plug in	14% CFL, 2534-kWh/yr Hardwired, 571 kWh/yr Plug in	14% CFL, 1574 kWh/yr Hardwired, 331 kWh/yr Plug in	14% CFL, 2534 kWh/yr Hardwired, 571 kWh/yr Plug in
Air Conditioner	SEER 10, 2.5 Tons, 0.365 W/CFM AH Fan	SEER 12, 4 Tons, 0.365-W/CFM AH Fan	SEER 10, 2 Tons, 0.365W/CFM AH Fan	SEER 14, 4 Tons, 0.383 W/CFM AH Fan
Furnace	80% AFUE, 50 kBtu/hr	80% AFUE, 100 kBtu/hr	80% AFUE, 50 kBtu/hr	80% AFUE, 100 kBtu/hr
Ducts	Inside Conditioned Space, SA leakage = 1%, OA leakage = 0.23% of fan flow	Inside Conditioned Space, SA leakage = 1%, OA leakage = 0.23% of fan flow	Inside Conditioned Space, SA leakage = 1%, OA leakage = 0.23% of fan flow	Inside Conditioned Space, SA leakage = 1%, OA leakage = 0.23% of fan flow
Water Heater	Gas Standard, 40 gallons, 0.55 EF, 0.76RE	Gas Standard, 40 gallons, 0.55 EF, 0.76RE	Gas Standard, 40 gallons, 0.55 EF, 0.76RE	Gas Standard, 40 gallons, 0.55 EF, 0.76RE

First-Cost Impacts

For all of the 30% energy-savings level example cases, first costs are increased. Many builders are reluctant to design first-cost increases into their standard products. To many potential homebuyers, the first cost of a home can make or break a home sale. To address first-cost concerns associated with energy-efficient home designs, some builders have implemented guaranteed energy-bill programs that may influence some potential homebuyers, such that they would be more willing to absorb the additional first cost into a 30-year mortgage knowing that their monthly cash flow will ultimately be reduced when the utility bill is considered.

Builders who guarantee their homes are willing to tell buyers how much energy the home should use, and they guarantee these levels will not be exceeded. These guarantees are backed up with payments if limits are exceeded. Builders can work with insulation companies or other partners to offer guarantees or caps on their home's energy costs, or they may develop their own programs. Some cover room comfort by guaranteeing that the temperature at the thermostat will not vary by more than 3 degrees at the center of any room served by that thermostat. A Building America team helped to develop these programs.

Information on three of these programs can be found at:

- Environments for Living – www.eflhome.com/index.jsp
- Engineered for Life – www.us-gf.com/engineered.asp
- The Energy Use and Comfort Guarantee –www.artistichomessw.com/guarantee.htm."[55]

In some cases, homebuyers may be eligible for energy-efficient mortgages that allow potential home buyers to qualify for larger loans to compensate for additional first costs associated with energy-efficient options that are designed into a home. The Armory Park Del Sol in Tuscon, Arizona, case study featured later in this report is an example of a guaranteed energy bill program.

The following features for energy-efficient loans are taken from Fannie Mae, the nation's largest source of funding for mortgages. You can learn more about Fannie Mae at www.fanniemae.com.

- Energy-efficient mortgages (EEM) are available for both purchase and refinance in conjunction with most Fannie Mae first-mortgage products, including conventional fixed-rate and adjustable-rate mortgages.
- Monthly savings resulting from energy efficiency can be used to qualify borrowers for a larger mortgage. This means consumers can buy more home in the form of energy efficiency or other upgrades.
- The EEM can be used with many Fannie Mae mortgage products. The guidelines of the selected Fannie Mae mortgage apply, with the EEM allowing for the projected energy

[55] Building America Best Practices Volume 2, Builders and Buyers Handbook for Improving New Home Efficiency, Comfort, and Durability in the Hot-Dry and Mixed Dry Climates, September 2005, NREL/TP-550-36360, Page HOM-5.

savings to provide an adjustment to the loan-to-value and qualifying ratios that favor the borrower."[56]

Table 8 shows that the first cost associated with the 39% example case are larger than the first cost associated with the 35% example case. The first-cost increase (relative to the 35% example) is a result of the use of a SEER-14 air conditioner. At a 7% mortgage interest rate, an additional $1,738 first cost associated with energy-efficiency measures only represents an additional $12 per month for a 30-year loan term. It is important to note that the cost data used in this analysis may not be representative of actual builder or consumer costs in the Phoenix area or other Hot-Dry/Mixed-Dry climate areas. The actual first costs for a particular builder and potential homeowner in the Hot-dry/Mixed-dry climate area may vary substantially from Table 8. Variations in costs would affect the outcome of the optimization. Other examples of actual first costs associated with the construction of homes that meet the 30% - 39% savings criteria are found in the case studies section and in the First Costs, Cost Tradeoffs, and Owner Annualized PITI + Energy section.

Key Cost Tradeoffs

The analysis for a single- and two-story home in the Phoenix climate shows that the main trends that result in a home that saves 30% - 39% whole-house energy relative to the Benchmark show improved exterior wall constructions, ducts in conditioned space, and higher efficiency air conditioners. The results indicate that the main driver for energy and cost savings in the Phoenix climate are cooling load reduction strategies (better wall insulation, low-e glazing, and ducts in conditioned space) coupled with higher SEER air conditioners to reduce cooling energy use. One of the tradeoffs shown in most of the example cases is that the improved envelope allows for a smaller-capacity furnace to be installed, which offsets the first-cost.

Table 8. Incremental First Cost for the Two-Story Phoenix Example Cases

	PHOENIX, TWO-STORY	
Category	Incremental First-Cost 35% Example	Incremental First-Cost 39% Example
Walls	$317.00	$317.00
Air Conditioner	$303.00	$607.00
Furnace	-$146.00	-$146.00
Ducts	$960.00	$960.00
Total	$1,434.00	$1,738.00

[56] Building America Best Practices Volume 2, Builders and Buyers Handbook for Improving New Home Efficiency, Comfort, and Durability in the Hot-Dry and Mixed Dry Climates, September 2005, NREL/TP-550-36360, Page HOM-4.

Research Results and Conclusions

Through the use of systems engineering and operations research, the Building America program has shown that homes that save 30% whole-house source energy in Hot-Dry and Mixed-Dry Climates can be built on a cost-neutral basis by production builders. Table 9A shows a summary for energy-related features for the case studies included in the following section of this report and examples of results from use of the BEopt analysis method for Hot-Dry and Mixed-Dry Climates. While the specific combinations of technologies used in the case studies or shown in BEopt results may not be cost-optimal solutions for all areas and housing types covered by the Hot-Dry and Mixed-Dry Climate, the key features of the approaches demonstrated in each of these examples can be adapted as needed to provide homes that save 30% whole-house energy savings.

It should be also noted that the BEopt analysis method is subject to the limitations as described in the Cost Analysis – Life-cycle Cost Analysis section of this report and the case studies are the result of 3 years of field experience and design work done by Building America's research teams.

Table 9A. Summary of Energy Features for Case Studies and BEopt Results

Category	Case Studies						BEopt results			
	Merlin Contracting New American Home	JWM Armory Park Del Sol	Artistic Homes Gamlen Residence	Premier Homes Premier Gardens	Morrison Homes Lakeside	Centex Windemere Adventura/ Lunaria	35% point	Neighbor 4	35% point	Neighbor 5
Floor Area	Not Described	1916	2700	1503	2126-3672	2250-3800	1500	1500	3000	3000
# of Floors	3	1	1	1	1-2	2	1	1	2	2
Number of Bedrooms	4	2	4	3	4	Not Described	3	3	3	3
Number of Bathrooms	4	2	3	2	3	Not Described	2	2	2	2
Walls	Insulated Concrete Forms, 10-in. concrete with 2-5/8-in. XPS each side, R22	8-in. CMU, R-12 exterior rigid foam	2x6 24 in. oc, R23 cellulose + R-1.2 asphalt impregnated sheathing	2x4, R-13 Batt + 1-in. EPS sheathing	R-19	2x4 16-in. oc, R-15 blown-in fiberglass	R-11, 2x4, 16-in. oc	R-13, 2x4, 16-in. oc	R-19, 2x6, 24-in. oc	R-13, 2x4, 16-in. oc
Ceiling	SIP, 8-1/4-in. thick, R-30	R-38 fiberglass batt/I joists, flat roof	R-38 loose fill fiberglass	R-38	R-30 (two-story) / R-38 (1 Story)	R-48 blown in fiberglass	R-30 fiberglass	R-30 fiberglass	R-30 fiberglass	R-30 fiberglass
Thermal Mass	ICF exterior walls and ICF basement walls	8-in. CMU	Not Described	Not Described	Not Described	Not Described	½-in. Ceiling Drywall	Two 5/8-in. Ceiling Drywall Layers	½-in. Ceiling Drywall	½-in. Ceiling Drywall
Infiltration	Sealing at SIP to ICF joints, roof penetrations and all gaps	2.9 ACH_{50}	2.5 in^2 per 100 ft^2 of envelope	3.5 SLA	Not Described	3.9 SLA	SLA = 0.0005	SLA = 0.0005	SLA = 0.0005	SLA = 0.0005

Table 9A (continued). Summary of Energy Features for Case Studies and BEopt Results

Category	Case Studies						BEopt results			
	Merlin Contracting New American Home	JWM Armory Park Del Sol	Artistic Homes Gamlen Residence	Premier Homes Premier Gardens	Morrison Homes Lakeside	Centex Windemere Adventura/ Lunaria	35% point	Neighbor 4	35% point	Neighbor 5
Basement/Slab/ Crawlspace	Basement - Insulated Concrete Forms, 10-in. concrete with 2-5/8-in. XPS each side + waterproof coating and membrane, R-22	Slab = R-12 slab edge insulation	Conditioned Crawlspace = R-14, 2-in. Polyisocyanurate Rigid Insulation	Slab	Slab	Slab	Uninsulated	Uninsulated	Uninsulated	Uninsulated
Glass Type	Low-e, U = 0.36, SHGC = 0.35 Eight French Doors, U = 0.38, SHGC = 0.21, 45 ft^2 of single glazing, U = 1.11, SHGC = 0.86	Low-e, U = 0.32, SHGC = 0.30	Double-glazed Low-E^2 vinyl frame, U = 0.35, SHGC = 0.35	Slider: U = 0.36, SHGC = 0.30 Single Hung: U = 0.33, SHGC = 0.32 Fixed: U = 0.30, SHGC = 0.33 Sliding Patio Door: U = 0.34, SHGC = 0.30 French Door: U = 0.33, SHGC = 0.28	Spectrally Selective U = 0.36 sliders, 0.33 fixed, 0.354 patio door, SHGC = 0.33 sliders, 0.36 fixed, 0.35 patio door	Low-E2 Vinyl, U = 0.35, SHGC = 0.37	2 pane Low-e, U = 0.3, SHGC = 0.44 Center of Glass, insulated spacer, Vinyl frame	2 pane Low-e, U = 0.32, SHGC = 0.64 Center of Glass, insulated spacer, Vinyl frame	2 pane clear, U = 0.49, SHGC = 0.76 Center of Glass, insulated spacer, Vinyl frame	2 pane Low-e, U = 0.32, SHGC = 0.64 Center of Glass, insulated spacer, Vinyl frame
Window Area per Wall	Not Described	Not Described	Not Described	Not Described	Not Described	Not Described	270 ft^2, 12.5% N&S, 50% W, 25% E	270 ft^2, 12.5% N&S, 50% W, 25%E	540 ft^2, 12.5% N&S, 50% W, 25% E	540 ft^2, 12.5% N&S, 50% W, 25% E

Table 9A (continued). Summary of Energy Features for Case Studies and BEopt Results

Category	Case Studies						BEopt results			
	Merlin Contracting New American Home	JWM Armory Park Del Sol	Artistic Homes Gamlen Residence	Premier Homes Premier Gardens	Morrison Homes Lakeside	Centex Windemere Adventura/ Lunaria	35% point	Neighbor 4	35% point	Neighbor 5
Refrigerator	Not Described	ENERGY STAR	Not Described	Not Described	ENERGY STAR	Not Described	Standard - 671 kWh/yr	Standard - 671 kWh/yr	671 kWh/yr	671 kWh/yr
Cooking Range	Not Described	Not Described	Not Described	Not Described	Not Described	Not Described	45 Therms/yr	45 Therms/yr	45 Therms/yr	45 Therms/yr
Dishwasher	Not Described	ENERGY STAR	Not Described	Not Described	ENERGY STAR	Not Described	Standard, 462 kWh, eight place setting capacity, 131.6 kWh/yr machine energy, 5.39-gal/day DHW	Standard, 462 kWh, eight place setting capacity, 131.6 kWh/yr machine energy, 5.39-gal/day DHW	Standard, 462 kWh, eight place setting capacity, 131.6 kWh/yr machine energy, 5.39-gal/day DHW	Standard, 462 kWh, eight place setting capacity, 131.6 kWh/yr machine energy, 5.39-gal/day DHW
Clothes Dryer	Not Described	Not Described	Not Described	Gas Dryer stub	Not Described	Not Described	Gas - 5.7 ft^3, 2.75 EF, 70.1 kWh/yr, 31.8 therms/yr	Gas - 5.7 ft^3, 2.75 EF, 70.1 kWh/yr, 31.8 therms/yr	Gas - 5.7 ft^3, 2.75 EF, 70.1 kWh/yr, 31.8 therms/yr	Gas - 5.7 ft^3, 2.75 EF, 70.1 kWh/yr, 31.8 therms/yr
Clothes Washer	Not Described	Not Described	Not Described	Not Described	ENERGY STAR	Not Described	Standard, 3.15 ft^3, 533 kWh/yr, 1.16 MEF, 65.6 kWh/yr machine energy, 4.63-gal/day DHW	Standard, 3.15 ft^3, 533 kWh/yr, 1.16 MEF, 65.6 kWh/yr machine energy, 4.63-gal/day DHW	Standard, 3.15 ft^3, 533 kWh/yr, 1.16 MEF, 65.6 kWh/yr machine energy, 4.63-gal/day DHW	Standard, 3.15 ft^3, 533 kWh/yr, 1.16 MEF, 65.6 kWh/yr machine energy, 4.63-gal/day DHW

Table 9A (continued). Summary of Energy Features for Case Studies and BEopt Results

	Case Studies						BEopt results			
Category	**Merlin Contracting** **New American Home**	**JWM** **Armory Park Del Sol**	**Artistic Homes** **Gamlen Residence**	**Premier Homes** **Premier Gardens**	**Morrison Homes** **Lakeside**	**Centex** **Windemere Adventura/ Lunaria**	**35% point**	**Neighbor 4**	**35% point**	**Neighbor 5**
Lighting	Not Described	Incandescent / flourescent	Not Described	100% fluorescent	100% fluorescent	CFLs on all permanent fixtures except dining chandelier	14% CFL, 1574 kWh/yr Hardwired, 331 kWh/yr Plug in	14% CFL, 1574 kWh/yr Hardwired, 331 kWh/yr Plug in	14% CFL, 2534 kWh/yr Hardwired, 571 kWh/yr Plug in	14% CFL, 2534 kWh/yr Hardwired, 571 kWh/yr Plug in
Cooling	Four systems, SEER 16 Heat Pump, SEER 14.8, 15.9, and 15 condensing units, Total of 18 tons	SEER 12 heat pump	SEER 13	SEER14 w/ TXV	SEER14	SEER10	SEER 10, 2.5 Tons, 0.365 W/CFM AH Fan	SEER 10, 3 Tons, 0.365 W/CFM AH Fan	SEER 12, 4.00 Tons, 0.365 W/CFM AH Fan	SEER 12, 4.00 Tons, 0.365 W/CFM AH Fan
Heating	One heat pump, COP = 3.6 @ 47°F, Two 94% AFUE furnaces w/ two-speed air handlers, One 94% AFUE furnace with two-zone control dampers	8.6 HSPF heat pump	Combo System - 90%CA_{AFUE} in conditioned space	91% AFUE	92% AFUE	80% AFUE, variable-speed AH fan	80% AFUE, 50 kBtu/hr	80% AFUE, 75 kBtu/hr	80% AFUE, 100 kBtu/hr	80% AFUE, 100 kBtu/hr
Ducts	Inside conditioned space with UL181 mastic sealed joints	15 CFM Total Leakage @ 25Pa, in conditioned space	Sheet metal and flex duct in crawl space, 5% or less to outside	R-4.2 ducts insulation buried in attic ~ R-13 equivalent	R-6	R-4.2 flex ducts buried in R-48 attic insulation	Inside Conditioned Space, SA leakage = 1%, OA leakage = 0.23% of fan flow	Inside Conditioned Space, SA leakage = 1%, OA leakage = 0.23% of fan flow	Inside Conditioned Space, SA leakage = 1%, OA leakage = 0.23% of fan flow	Inside Conditioned Space, SA leakage = 1%, OA leakage = 0.23% of fan flow

Table 9A (continued). Summary of Energy Features for Case Studies and BEopt Results

	Case Studies						BEopt results			
Category	**Merlin Contracting** **New American Home**	**JWM** **Armory Park Del Sol**	**Artistic Homes** **Gamlen Residence**	**Premier Homes** **Premier Gardens**	**Morrison Homes** **Lakeside**	**Centex** **Windemere Adventura/ Lunaria**	**35% point**	**Neighbor 4**	**35% point**	**Neighbor 5**
Water Heater	75-gallon power vented, 55 MBH input, 0.50 EF	Batch Solar Water Heater with Tankless backup	Combo System - 0.86 CA_{EF}, 34 gal in garage	Tankless 0.82 EF, R4 insulation on trunk lines	Tankless 0.82 EF + pipe insulation	Tankless 0.82 EF, PEX home run piping	Gas Standard, 40 gallons, 0.55 EF, 0.76 RE	Gas Standard, 40 gallons, 0.55 EF, 0.76 RE	Gas Standard, 40 gallons, 0.55 EF, 0.76 RE	Gas Standard, 40 gallons, 0.55 EF, 0.76 RE
On-site Power system		1.5-kW grid-tied PV system		2.4-kW DC system, building integrated	2-kW roof integrated PV tiles	Optional				
Space Heating	77%	69%	47%	50%	44%	37%/19%	48%	65%	58%	57%
Space Cooling	50%	62%	55%	76%	78%	20%/43%	53%	48%	50%	53%
DHW	- 7%	0%	33%	43%	37%	54%/58%	11%	12%	57%	56%
Lighting	0%	25%	0%	74%	50%	67%/67%	0%	0%	0%	0%
Appliances + MEL	0%	1%	0%	3%	1%	0%/0%	6%	6%	4%	4%
Total Energy Use	**31%**	**37%**	**29%**	**39%**	**36%**	**30%/33%**	**35.6%**	**33.8%**	**35.3%**	**37.2%**

Table 9B is a summary of the case studies presented in this report. Figure 24 shows the location of the case studies presented in this report. Locations are indicated with stars.

Table 9B. Summary of Source Energy Savings by End-use as a Percentage of Total Energy Use for the Seven Hot-Dry/Mixed-Dry Case Studies

	Percent Source Energy Savings						
						Centex – Windemere	
End Use	Merlin Contracting New American Home	JWM Armory Park Del Sol	Artistic Homes Gamlen Residence	Premier Homes Premier Gardens	Morrison Homes Lakeside	Adventura	Lunaria
Space Heating	77%	69%	47%	50%	44%	37%	19%
Space Cooling	50%	62%	55%	76%	78%	20%	43%
DHW	-7%	0%	33%	43%	37%	54%	58%
Lighting	0%	25%	0%	74%	50%	67%	67%
Appliances + MEL	0%	1%	0%	2.5%	1%	0%	0%
Total Energy Use	**31%**	**37%**	**29%**	**39%**	**36%**	**30%**	**33%**
Number of Homes	1	6	1	71 complete, 475 total buildout	1 complete, 120 total buildout	6	19

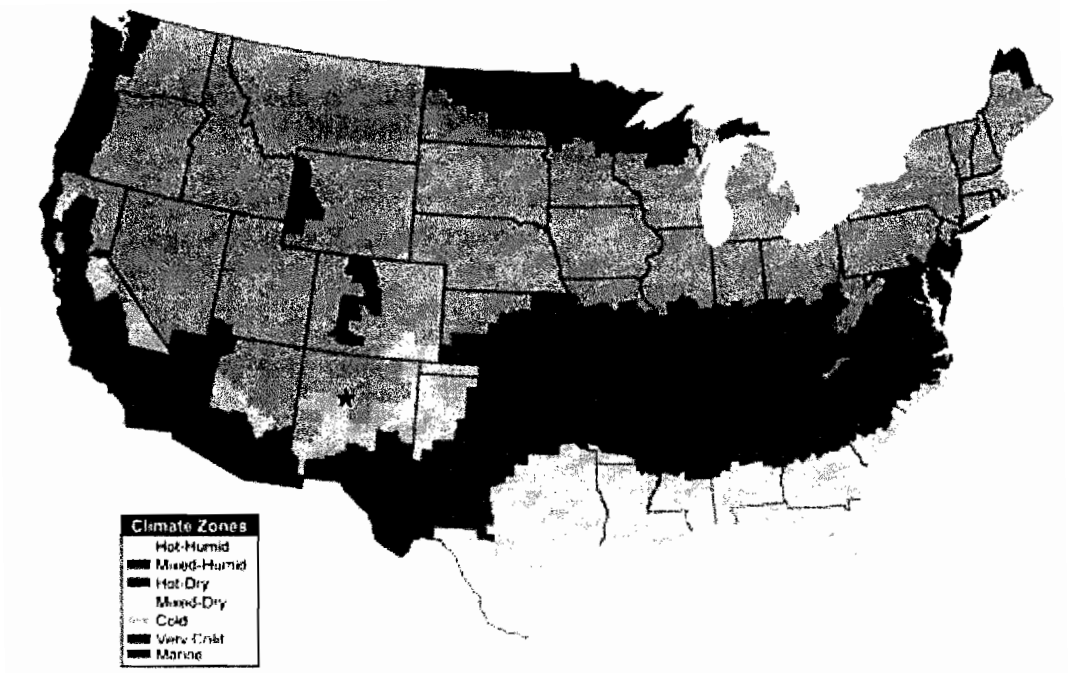


Figure 24. Location of 30% Hot-Dry and Mixed-Dry Climate case studies

House Case Studies

Development: **Sahara Lake**

Builder: **Merlin Contracting**

Location: **Las Vegas, Nevada**

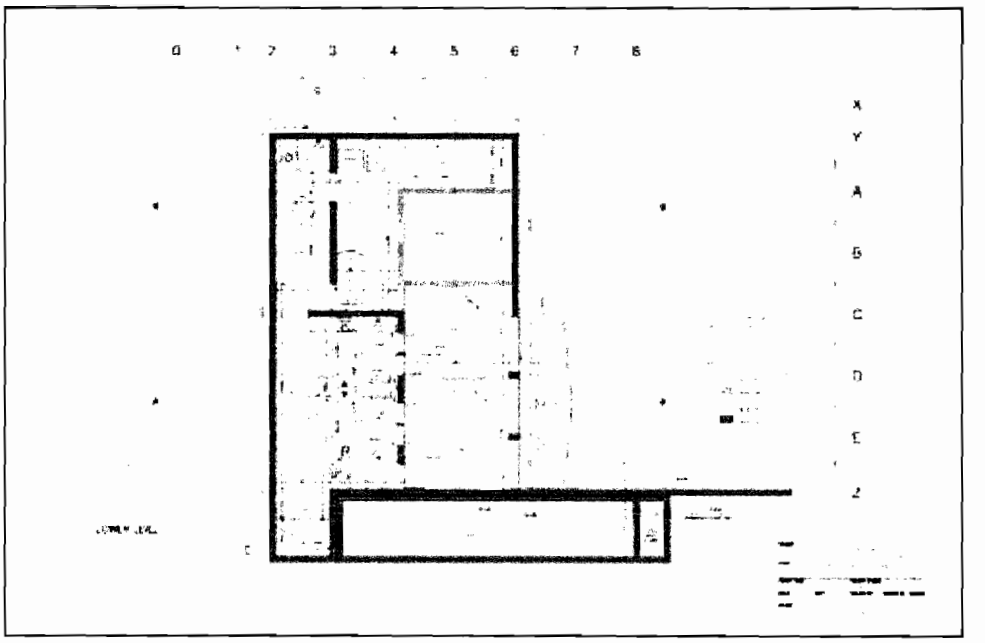
Within a high-pressure situation, the builders who construct The New American Home® (TNAH®) each year face unique obstacles: a frustratingly short and tight timeframe, designers and manufacturers they may have never worked with, products and practices they may be unfamiliar with, and materials that may not get specified right. On top of all this, The National Association of Home Builders (NAHB) requires that TNAH's builders construct houses to extremely high performance requirements, which adds its own set of challenges.

TNAH® is an annual showcase project co-sponsored by the NAHB's National Council of the Housing Industry and Builder Magazine. The NAHB began requiring that each home, beginning with TNAH® 2001, be built to extremely high energy-efficiency goals and other high-performance targets because they know it's important in the industry. IBACOS, through the Department of Energy's Building America program, has worked with the builders in the design and construction to ensure that each home meets specific performance goals.

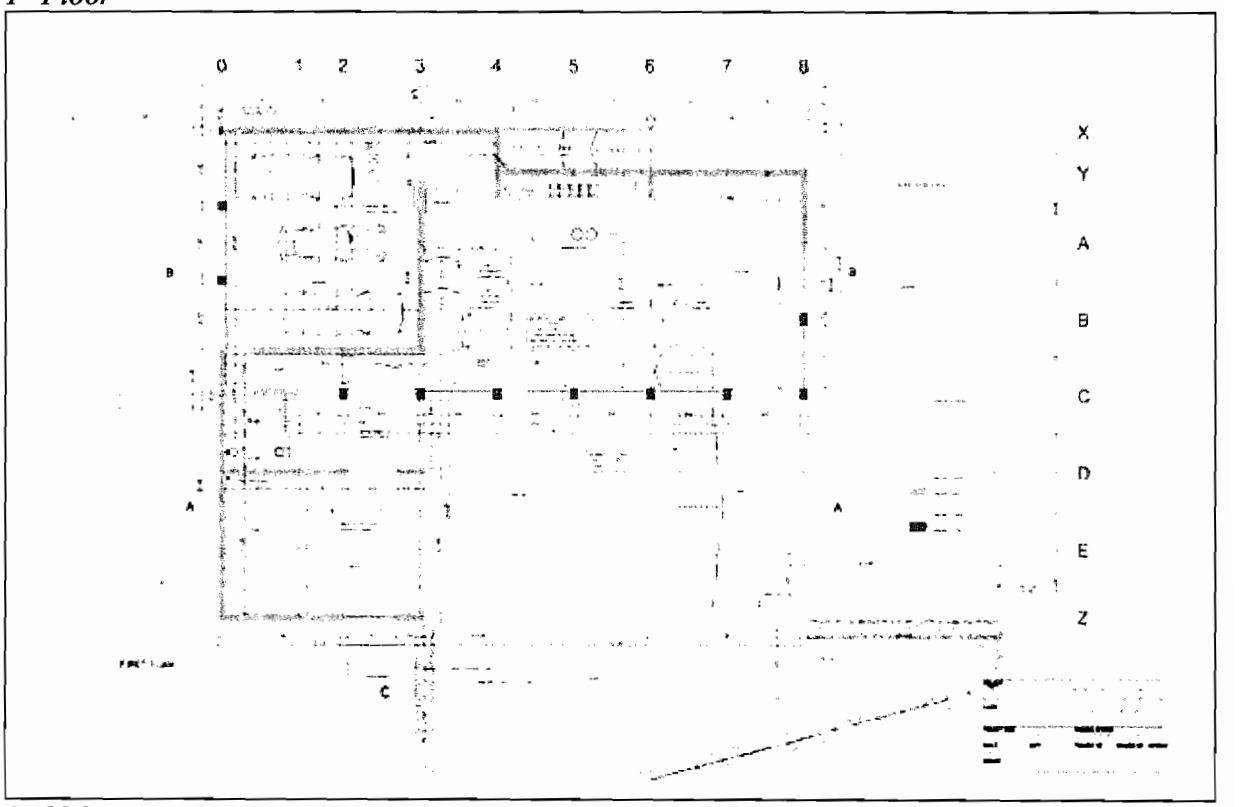
Merlin Contracting built TNAH® 2004 in the Sahara Lake community, just west of downtown Las Vegas. TNAH® 2004 was designed to reach a Home Energy Rating System (HERS) score of 90, a score well above the current ENERGY STAR® rating requirement of 86, and uses a number of high-performance technologies.

The rear elevation of the pilot home is the most dramatic face because it is looking over the lake and highlights the glazing for the high-ceiling living room. The rear of the house faces south.

Figures 25 and 26 are floor plans for this house at Sahara Lake in Las Vegas, Nevada (Figure 27)



1st Floor



2nd Floor

Figure 25. Merlin Contracting house floor plan, 1st and 2nd floor

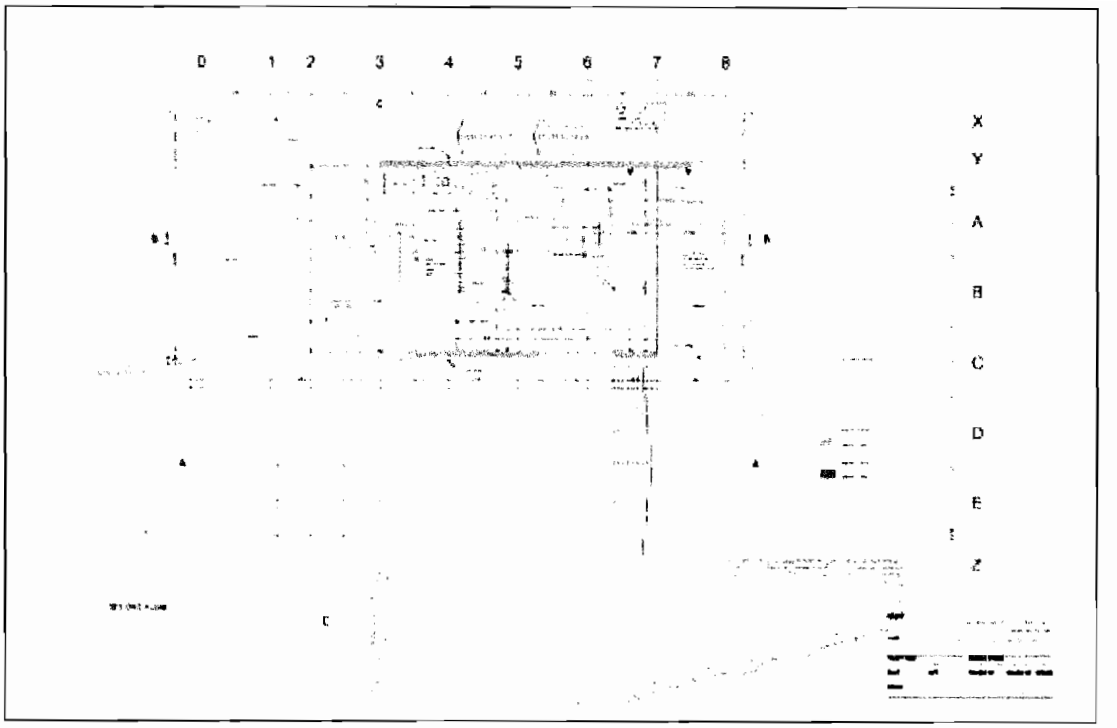


Figure 26. Merlin Contracting house floor plan, 3rd floor

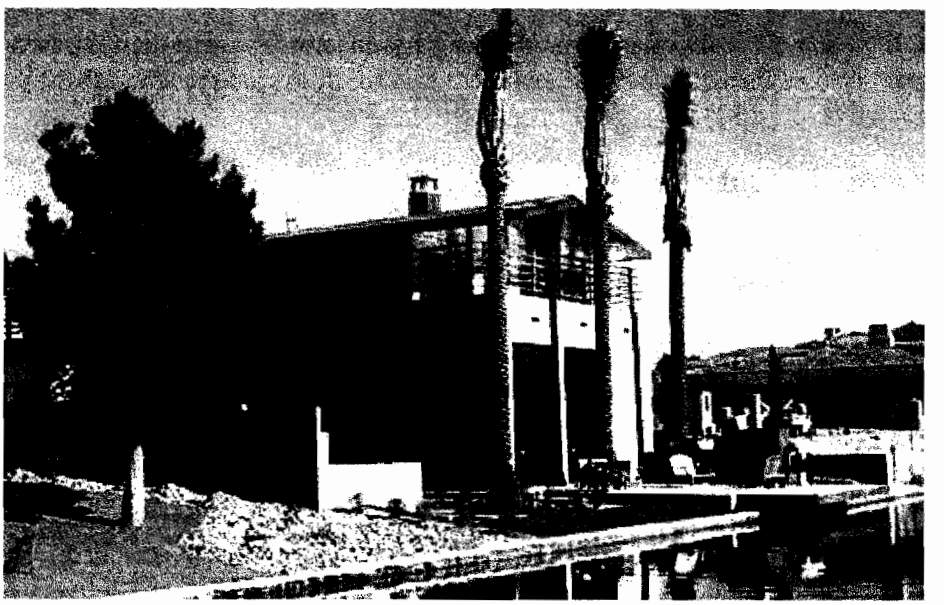


Figure 27. The New American Home at Sahara Lake, Nevada

House Specifications

The house is located on a lot on Sahara Lake, an exclusive community about 6 miles west of downtown Las Vegas. The 5,180-ft^2 home features a loft design that offers greater versatility for interior design and layout options.

As-Built Specifications

- Picture windows are from Loewen and are aluminum-clad, wood-framed, double-glazed, with a spectrally selective low-emissivity coating, U-value of 0.36, SHGC of 0.35. Eight sets of French doors, with U-values of 0.38 and SHGC of 0.21, were installed. The master shower has approximately 45 ft^2 of single glazing. A U-value of 1.11 and SHGC of 0.86 is assumed for these windows (Carmody 1996).
- Second-floor fenestration is shaded externally by 9-in. by 2-in. copper-clad wooden sunshades. External, operable, and electronically controlled shading covers first-floor west-side fenestration.
- All exterior walls above grade consisted of insulated concrete forms (ICF). The ICF system includes a 10-in. concrete core sandwiched by two 2-⅝-in. layers of extruded polystyrene (EPS) to give a thermal resistance of R-22 (Figures 28 and 29)
- Basement walls consisted of the ICF system covered by a waterproof coating and membrane (Figure 30)
- To improve building airtightness, a great deal of emphasis was placed on sealing the numerous penetrations through the building enclosure and any gaps at the roof-wall connection.
- Structural panels made up of an expanded polystyrene core bonded between two layers of OSB were used as the roof deck. Panels were 8-¼ in. thick and provided R-30 thermal performance (Figure 31).

Mechanical Equipment

- A total of four Lennox HVAC systems were installed to handle the five zones in the house; the second-floor system has a mechanical damper-zone control system. Three direct-vent natural-gas furnaces and a heat pump will be used for space heating, and each has a variable-speed blower. The three air handlers have a minimum 94% AFUE, and all of them are located in conditioned space. The condensing units provide two-stage operation and have efficiencies of SEER 14.8, 15, and 15.9. The heat pump has two speeds, is located in conditioned space, and has a COP rating of 3.6 at 47°F and 16 SEER.
- A 75-gallon power-vented domestic water heater, 55 MBH input, with an assumed EF of 0.50, was used because manufacturer's data was unavailable. Also included was an electronically controlled pump-and-valve assembly that provides rapid delivery of hot water to plumbing fixtures without the loss of cold water down the drain.
- All ductwork, which consists of flex and spiral galvanized metal, is within the conditioned space of the home. Ductwork was sealed with UL-181 approved water-based mastic sealant or appropriate caulking.

- A heat-recovery ventilator (HRV) provides mechanical ventilation on a balanced basis to first-floor HVAC systems.

Figure 28. Steel beams were used for structural framing and are anchored into the insulated concrete form wall.

Figure 29. Insulated concrete forms make up the exterior shell of the home.

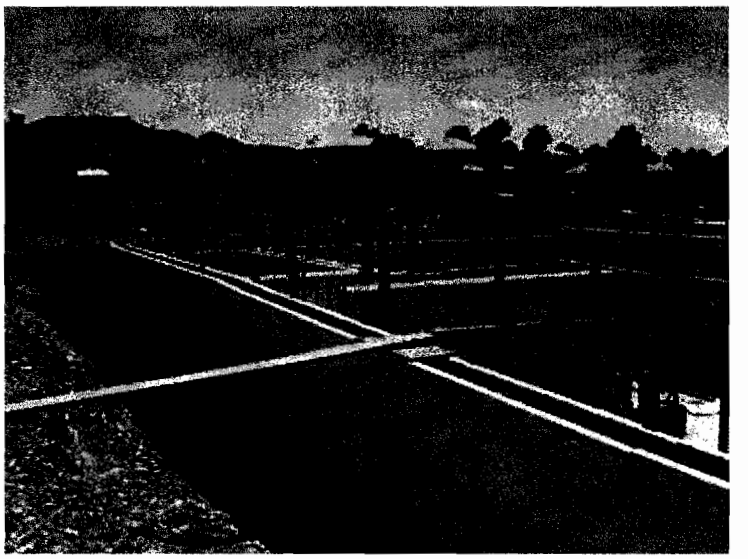


Figure 30. Insulated concrete forms were used to form the walls of the basement

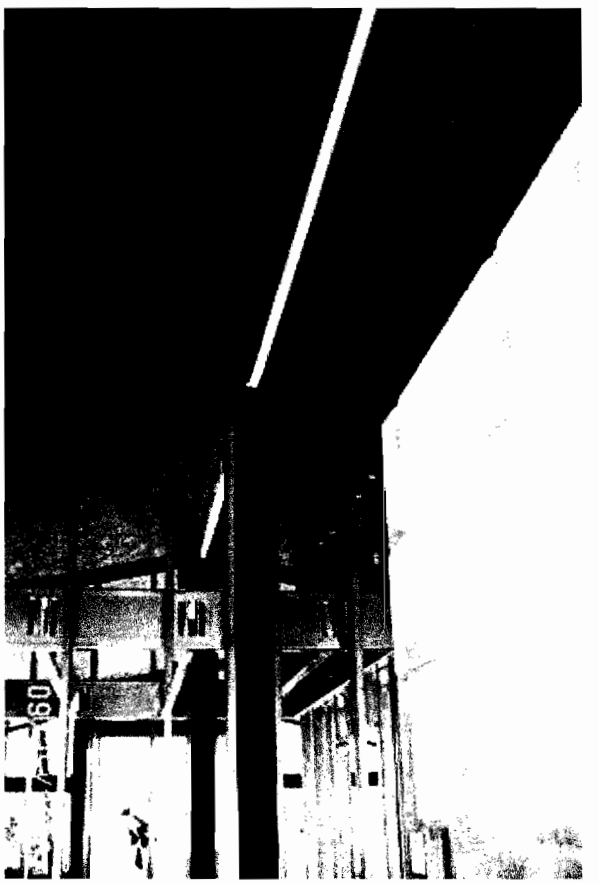


Figure 31. Structural insulated panels provide the air and thermal barrier for the roof

Innovations

Specific technologies used in TNAH® 2004 include a foundation system and above-ground exterior walls of insulated concrete forms; windows that limit solar heat gain; a roof system built with structural insulated panels; a heat-recovery ventilator for the ventilation system; and superior efficiency condensing units. The insulated concrete forms provide excellent insulation for the basement. Structural insulated panels provide the roof system with good insulation and airtightness characteristics. The heat-recovery ventilator ensures good indoor air quality in an efficient manner by tempering incoming hot outdoor air with cooler indoor air. The condensing units have a seasonal energy efficiency ratio (SEER) between 14.7 and 16 and provide excellent cooling capacity while using minimal energy.

As a result of these improvements and advanced technologies, the home will use 46% less energy for space heating and cooling, hot water, and lighting than the typical Las Vegas new home.

The Bottom Line

Through this project, builders get a unique opportunity to learn new ways to build quality homes, without worrying about the costs involved with a learning curve. This is something very valuable to Merlin Contracting, the builder of TNAH® 2004. As a custom homebuilder, their own bottom line doesn't matter as much as their customer's bottom line. "It's important for us to use their customer's money as wisely as possible," says Bart Jones, a principal in Merlin Contracting.

With their customer's bottom line in mind, they can't gamble on products or practices they're not familiar with. Knowing that something they tried through the TNAH® project works—or doesn't—eliminates guesswork and enables them to confidently make cost-effective recommendations to their customers. For example, based on their experience using Insulated Concrete Forms (ICFs) in TNAH® 2204, Merlin would recommend ICFs to their customers. "In fact, recently we did recommend that one client use ICFs for the wall system and are currently building his 20,000-ft^2 "French Country Cottage-style Compound" in Las Vegas using ICFs . This is something we wouldn't have done before because we'd never used it," said Bart Jones.

The NAHB's commitment to quality challenges builders to push the envelope further in the already high-pressure situation of building TNAH®. With the help of the DOE's Building America Program, builders are successfully meeting the challenge and learning valuable lessons in the process. The builders, and the industry as a whole, are seeing that the value added to their business—reduced warranty and callback expenses, reduced liability risk, and increased customer satisfaction—is worth the effort.

Key Features

- Low-emissivity solar-control windows
- Foundation and above-grade walls of insulated concrete forms that provide airtightness and R-22 thermal performance
- All air-handling equipment within conditioned space
- High-efficiency furnaces (minimum 94% AFUE) and condensing units (between 14.7 and 16 SEER)
- One heat pump with coefficient of performance (COP) of 3.6 and 16 SEER
- Heat-recovery ventilator delivers fresh air to return plenum
- Air-distribution system leakage to the outside target is 3% of system airflow or 216 cfm at 25 Pa.

Advanced Systems and Construction Methods

The builder was interested in the home at least reaching the ENERGY STAR® level of energy efficiency. In order to meet Building America objectives, IBACOS proceeded to design the home to achieve, at a minimum, a HERS 90 level. This level of energy efficiency matches that of the last three New American Homes®. The design featured several advanced systems including improved building enclosure insulation, enhanced building airtightness, higher-performance windows, external shading devices, high-efficiency heating and cooling equipment, and mechanical ventilation. Optimized HVAC and energy-efficient lighting strategies were recommended. The reasons behind each not being implemented are also discussed.

Construction Challenges

Building Enclosure Insulation

A 15-in.-wide ICF system, including 10-in.-wide concrete core and a thermal resistance value of R-22, was chosen as the structural and insulating system for the exterior walls and basement. Figure 28 and Figure 29 show the ICF systems under construction. The builder made this choice after a presentation by the Portland Cement Association on the system's merits, namely reduced construction time and increased durability, airtightness, and thermal performance over framed-wall systems. The mass of the ICF wall will also have an effect the impact of solar radiation. We suspect that this will result in a more gradual distribution of heat through the wall assembly, thereby lowering cooling load peaks and allowing for a more-uniform distribution of heat gain.

At first, the builder was considering using a poured-concrete foundation system insulated on the exterior with a rigid or semi-rigid insulation board to a minimum level of R-10. After an examination of the connection details that would be required at the top of the foundation wall with the ICF system, the logistics of having another subcontractor and the aforementioned benefits of ICFs, the builder choose to use the ICF system as the only structural system for the home.

Structural insulated panels (SIPS) made up of an EPS core bonded between two layers of OSB were used as the roof deck (Figure 30). Panels are 8.25 in. thick and provide R-30 thermal performance. The panels were placed within a structural steel skeleton and then fastened to the steel. The roofing material used is copper. The copper roofing was placed over two layers of 7/8-in.-thick plywood, which sat directly on the panels. We recommended that the roofing sit on battens, thereby allowing for the creation of an air space, which would limit heat gain to the roofing panels, limit the temperature of the copper, and allow the roofing and the panel to cool during cooler periods.

Building Enclosure Air-tightness

A great deal of emphasis was placed on sealing gaps in the building enclosure and the connections between the different components. The most prominent connection point between component systems was at the SIPS roof to ICF wall intersection. The air tightness of the roof system was also considered. The numerous penetrations through the building enclosure were sealed as well.

Recommendations on Building Enclosure. The site superintendent for the pilot home believed that construction time savings could be realized when using insulated concrete forms, especially if the house is designed structurally from the start based on this system. He noted that the less the design is architecturally complicated, the faster the installation of the ICF system. The EnergyGauge software estimated that the mass effect alone of the ICF system has a noticeable reduction in energy consumption, particularly the amount of energy in therms used for heating.

The use of SIPS was also well received because of its quick installation. Merlin may use this product again in vaulted-ceiling applications. Turning an attic into semi-conditioned space creates a haven for air handlers and ductwork away from the extremely hot temperatures associated with a vented attic. Leaky return-system ductwork in the attic no longer draws very hot air in the summer, which raises the temperature of air being delivered to the home. The result is that the air handler has to work longer for the setpoint temperature to be reached. Therefore, even where roof plans do not call for a vaulted or cathedralized ceiling, SIPS for the roof are recommended to create a conditioned space in the attic.

Because many of the homes Merlin builds sell for more than a million dollars and cost hundred of thousands of dollars to construct, they can more easily absorb any additional costs associated with advanced-building enclosure systems, such as ICF or SIPS. The energy-efficiency value of building-enclosure improvements, as presented in Tables 10 and 11, was the second highest of all improvements.

High-Performance Windows

Aluminum-clad, wood-framed windows with double glazing and a spectrally selective low-emissivity coating and U-values of 0.36 and SHGC of 0.35 were used for the project. The low U and SHGC values of these windows will result in reduced cooling and heating loads compared to the builders' standard window, which have U-values of 0.47 and SHGC of 0.50. Eight sets of French doors with U values of 0.38 and SHGCs of 0.21 were installed. Approximately 45 ft^2 of single glazing, with 25 ft^2 facing south and the rest facing west, exists in the second-floor master shower. A U-value of 1.11 and SHGC of 0.86 is assumed for these windows. Privacy control is an issue for the master shower.

Table 10. Summary of Predicted End-use Site Energy for Merlin Contracting Project

	Building America Benchmark		Builder Standard Home		Pilot Home As Built	
End-Use	KWh	therms	KWh	Therms	KWh	Therms
Space Heating	451	638	518	730	87	144
Space Cooling	12,114		19,556		6,075	
DHW		139		139		150
Lighting	4,599		4,599		4,599	
Subtotal	**17,164**	**777**	**24,673**	**869**	**10,761**	**294**
Equipment	669	150	669	150	669	150
Miscellaneous	8,962		8,962		8,962	
Total	**26,795**	**927**	**34,304**	**1,019**	**20,392**	**444**

Table 11. Summary of Estimated End-use Source Energy

End-Use	Annual Source Energy			Estimated Source Energy Savings			
				% of End Use		% of Total	
	BA Benchmark (MBTU)	Builder Standard (MBTU)	Pilot Home (MBTU)	BA Benchmark	Builder Standard	BA Benchmark	Builder Standard
Space Heating	70	80	16	77%	80%	14%	13%
Space Cooling	131	211	65	50%	69%	17%	31%
DHW	14	14	15	-7%	-7%	0%	0%
Lighting	50	50	50	0%	0%	0%	0%
Subtotal	**265**	**355**	**146**	45%	79%	31%	44%
Equipment	23	23	23	0%	0%	0%	0%
Miscellaneous	97	97	97	0%	0%	0%	0%
Total	**385**	**475**	**266**	**31%**	**44%**	**31%**	**44%**

Recommendation. In the hot climate of Las Vegas, the energy savings are obvious when using windows that have a low-emissivity coating compared to those that do not. Merlin should consider using these windows on all their homes and can sell the added benefit that upholstery fabrics are less likely to fade and that the temperature in the home will be more uniform from room to room. Upgrading to these windows will mean an additional cost, but the load reduction from the windows is key to optimizing the entire HVAC system and, thereby, reducing overall construction costs and increasing system efficiency. Window performance values of U = 0.35 and SHGC = 0.35, or better, are recommended for Las Vegas.

External Shading

Second-floor areas with fenestration are shaded externally by 9-in. by 2-in. copper-clad wooden sunshades. The roofing system was designed by the architect to extend over most of second-floor outdoor decks, thereby providing relief from the summer sun. On the west side of the first floor, externally mounted shade covers can roll down in front of glazing from its soffit location. The covers can be controlled to roll down as far as necessary to prevent solar heat gain. Internal shade covers are in place on south- and west-facing glazing.

HVAC Equipment Efficiencies

Four pieces of high-efficiency equipment serve the house through five zones, all situated within conditioned space. An air-source heat pump with a COP 3.6 at 47°F and 16 SEER serves the basement, which includes two bedrooms. A heat pump was selected for this zone in order to highlight Lennox's new system. Two two-speed air handlers with 94% AFUE and 14.8 and 15.9 SEER condensing units serve the first floor, with one unit dedicated only for the living room. For these units, an airtight mechanical room was built. Lastly, one air handler with 94% AFUE and 15 SEER and two zone-control dampers serve the second floor.

Recommendations. Merlin gained experience with using high-efficiency furnaces and condensing units in the pilot home. According to the builder's HVAC subcontractor, to upgrade to a high-efficiency 93% AFUE furnace costs about $400 more. To upgrade to a high-efficiency 16 SEER condensing unit from a 12 SEER unit costs about four times more – a significant price increase. Clearly, such a pricing structure by condensing unit manufacturers creates an obstacle to the use of 16 SEER equipment. Another reason Merlin does not use higher efficiency HVAC equipment is that their clientele are wealthy and are not usually concerned about spending less in utility costs. In any case, we recommend that subcontractors use higher efficiency HVAC equipment, 93% AFUE furnaces and 14 SEER condensing units.

Air Distribution

All ductwork in the home is inside the conditioned enclosure. In addition, to improve HVAC system airtightness, UL 181-approved mastic sealant was applied on all joints between all pieces of ductwork, as well as joints in the furnace and joints between ductwork and the furnace. Caulking material, specifically for galvanized ducts, was used on the joints in the second-floor air-distribution system. This approach was specifically used because of the exposed nature of the ductwork and the more presentable finish provided by the caulking-over-mastic sealant.

A detailed duct layout based on calculated loads and predicted air movement was developed to ensure that correctly sized ductwork could efficiently move air from the three air handlers and the heat pump. The builder chose instead to use the design from a local HVAC engineering firm that they use for all of their HVAC design services.

Mechanical Ventilation

The builder installed a heat recovery ventilator (HRV) to provide a balanced source of mechanical ventilation. The ventilator delivers air to the return plenum of the two first-floor air handlers. Our initial recommendation was to have an HRV installed on each floor. According to manufacturers' specification, the unit will deliver a total of 200 cfm of outdoor air on a continuous basis.

Recommendations. As Merlin increases the airtightness of their homes, mechanical ventilation will be needed. By explaining the benefits of such a system to enhancing indoor air quality, this need has become apparent to Merlin. The heat-recovery ventilator is a good choice for the Las Vegas climate, and we recommend that Merlin use them in future homes.

HVAC Optimization

An engineered HVAC system design was developed for the pilot home by IBACOS. The design determined that with the use of spectrally selective high-performance windows, good thermal performance in the foundation walls, exterior walls and roof, and an airtight building enclosure, the HVAC equipment did not need to have the capacity suggested by a conventional design based on ACCA Manual J (1992) calculations performed by the local HVAC engineering firm. The conventional design estimated that 18 tons of cooling capacity would be needed for the home, while our final design estimated that 13.5 tons would be sufficient. In addition, our design is based on a 70°F setpoint temperature used for cooling system design as requested by the builder and a lighting load of 2 watts per square foot of floor area, which is reflective of show home conditions in Las Vegas based on information obtained from a lighting survey conducted at TNAH® 2003. In addition, our design was based on smaller airflows occurring over a longer period of time and, thereby, minimized the start-up frequency of HVAC equipment and allowed units to reach the best operating efficiency.

In an effort to use the equipment we specified while still using the conventional design for the air distribution system, we recommended a plan to the local HVAC engineering firm to make some of the registers temporarily inactive and, thereby, reduce airflow to the particular room. The plan would allow for equipment change-outs to occur if larger capacity units were necessary, while allowing for the use of the conventional air-distribution system design. This plan was rejected as being too complicated and hard to implement.

The builder indicated that over-sizing of cooling equipment capacity was standard practice for their homes because it ensured that homeowners could always be adequately cooled. Apparently custom home purchasers are sometimes inclined to set temperatures very low in the summer, as low as 63°F. In the end, the builder choose to follow the complete conventional design approach, because it had a track record of keeping customers satisfied and was guaranteed in their eyes by the local HVAC engineering firm, even though it was stressed to them to have excessive capacity would be inefficient. If any of Merlin's customers had comfort complaints in their homes, the local HVAC engineering firm would do what was necessary, including replacing equipment, to

ensure the customer was satisfied. As the project neared completion, the builder had misgivings regarding not following our design approach, having had adequate time to consider the benefits of an optimized HVAC system design.

With respect to air distribution, our analysis determined that if the conventional design was followed, air movement would be noticeable by the occupants, and they would possibly experience discomfort as a result of drafts and frequent start-ups. For example, in the living room we recommended that 805 cfm of air be delivered, while the conventional design specified 1600 cfm.

Recommendation. According to heating and cooling load calculations, which took into account the improved thermal performance of the home through higher-performance windows, increased building airtightness and improved thermal enclosure, it was determined that 13.5 tons of cooling capacity could adequately condition the home. Instead of following our design, Merlin chose to follow the conventional design offered by their HVAC engineer and installed 18 tons of cooling equipment. Long-term monitoring equipment is being used to evaluate if temperature and humidity conditions are being maintained at a comfortable level. We expect that the frequency of HVAC equipment start-ups will be noticeable and that anecdotes from homeowners will reflect drafty and possible uncomfortable conditions in several rooms. We plan on sharing this monitoring information with Merlin and their HVAC engineer in an attempt to get them to optimize their HVAC design in future homes.

Energy-Efficient Lighting

IBACOS, in conjunction with a lighting designer from the General Electric Lighting Center, developed an energy-efficient lighting design for consideration by the architect. The design highlighted the use of compact fluorescent lamps and lighting distribution that improved the quality of lighting in each room. But, because of the showcasing aspects for this home, the architect opted to only work with a lighting manufacturer and their designers on the lighting design and the fixture and lamp selection. Consequently, many fixtures were selected for their aesthetic appeal only rather than considering their energy use and lamp longevity.

Recommendations. The houses built by Merlin contain many lighting fixtures. To reduce peak cooling loads and reduce energy use, we recommend that they use energy-efficient lighting where possible. The recommendations made in the energy-efficient lighting design developed for the pilot home should be followed in future projects.

The analysis determined that the pilot home as built will save 45% with respect to the Benchmark and 79% with respect to the Builder Standard Home for end-use source energy related to space heating, space cooling, domestic hot water production, and lighting. Total savings are 31% with respect to the Benchmark and 44% with respect to the Builder Standard Home. The total savings values reflect the fact that lighting and appliance energy use was constant between the three comparison homes.

Development: **Armory Park del Sol**

Builder: **John Wesley Miller Companies**

Location: **Tucson, Arizona**

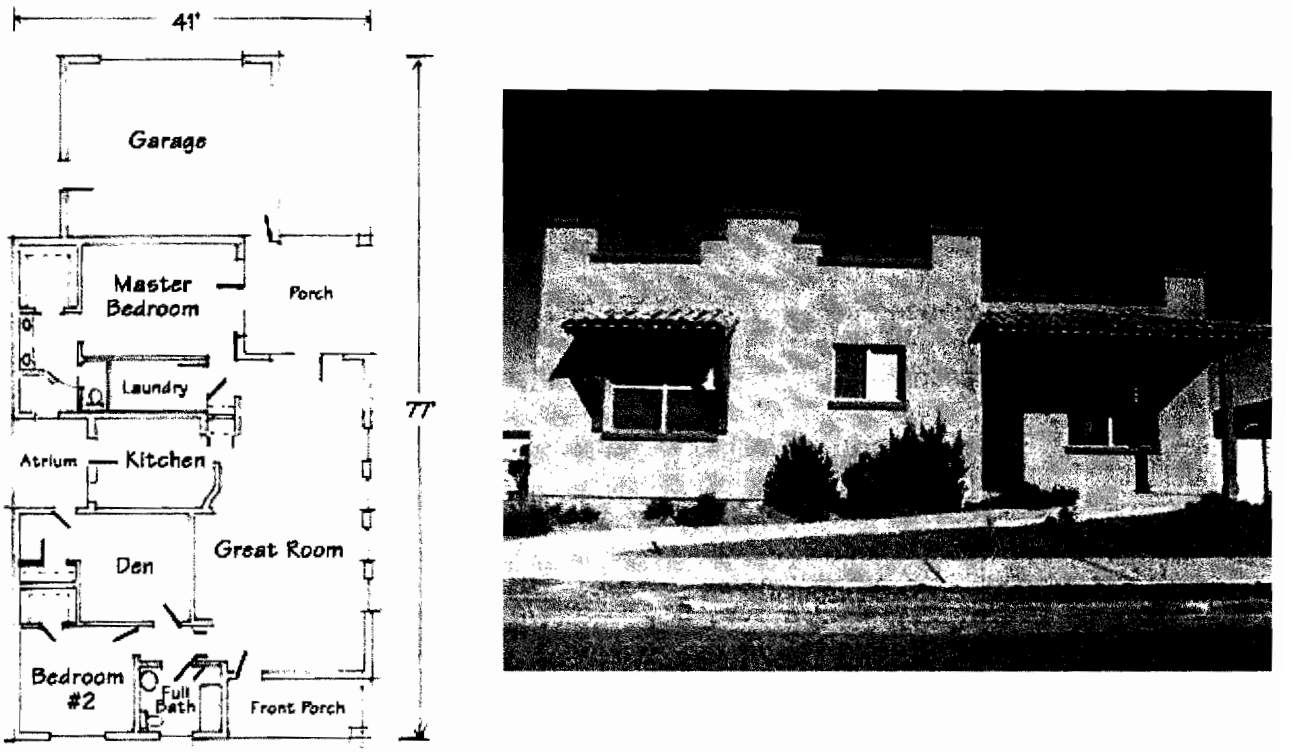


Figure 32. Floor plan (left) of Amory Park del Sol (right)

An Award-Winning Community

As the 2005 EnergyValue Housing Award Builder of the Year, John Wesley Miller (JWM) Companies' mission is energy efficiency. John Wesley Miller Said, "Our mission is to design and build the most energy efficient development in the world by incorporating the latest energy saving technologies…in all of the homes we build." The Armory Park del Sol development (Figure 32) in downtown Tucson combines desert-climate appropriate designs with roof solar energy production to win Sonoran Institute's Livable Community Award (2005), SAHBA Builder of the Year (2003), and City of Tucson's Most Energy Efficient Builder (2003).

Table 12. Energy Simulation of John Wesley Miller Compared to Benchmark

	Tucson Benchmark (kWh)	Armory Park del Sol (kWh)	Energy Savings
Cooling	7,958	2,487	-69%
Heating	2,146	811	-62%
Hot Water	2,410	2,410	-0.0%
Lighting	2,351	1,776	-25%
Appliances	1,969	1,942	-1%
Miscellaneous	3,471	3,471	0.0%
Total (without solar)	**20,305**	**12,897**	**-37%**
Solar Hot Water		920	
Solar PV System		2,491	
Total (with solar)	**20,305**	**9,486**	**-53%**

Measuring Up

An analysis of energy use for the prototype home in comparison to the Benchmark for Tucson shows that the Armory Park del Sol homes were estimated to consume 37% less energy, not including the solar systems savings. The energy continues to reduce to 53% when including the solar hot water and PV systems. Table 12 shows a breakdown of the primary energy uses.

When analyzing utility bills for a number of homes similar to the prototype, an average of 9,730 kWh was shown as being purchased. These data includes the solar hot water and PV system supply to the home – proof that a well-designed and constructed energy-efficient home does live up to its reputation.

A Solar Community Develops

As a builder and developer, John Wesley Miller Companies arranged the lots in the Armory Park del Sol subdivision so that each home could have optimal orientation for a solar PV and hot-water system. The covenants, codes, and restrictions for the development govern the placement and maximum height of trees to avoid shading on the rooftop solar systems. Desert-style parapet walls are ideal in keeping solar hot water and PV panels out of sight.

Solid Construction

In the Tucson climate, Miller feels, masonry construction adds a lot of value to the company's homes. JWM Companies' wall system, which consists of CMUs with solid grout, R-12 exterior rigid foam, and interior steel-framed walls, produces a tight house (2.9 ACH_{50}) with little additional air sealing required. Because plumbing and electrical lines run through the interior steel-framed walls and all ducts are in the conditioned space, no additional air sealing is needed for mechanical penetrations.

Concrete construction provides a thermal mass to temper the extreme heat and cold of the desert climate. Miller explains that the thermal mass property of solid-grout concrete block, combined with exterior insulation, helps temper the indoor environment from the extreme outdoor conditions. In addition, people are willing to pay for the quality of the company's masonry construction. "The resale value is much higher for masonry," Miller says.

Selective about Windows

Spectrally selective coatings on the windows offer protection from the brutal Tucson heat and sun. Having a low U-value of 0.32 prevents conduction of heat indoors and heat loss during the cool nights. The low SHGC of 0.30 helps mitigate direct solar heat gain during the summer months.

Engineering the HVAC System

As part of the design team, a local professional engineer conducts an analysis on all plans for proper sizing of HVAC equipment and location of ductwork. Miller relies on the engineer, who he describes as a "practical guy who grew up in the tin-bending business."

The high ceilings and architectural features, combined with a knowledgeable HVAC engineer, make it possible for the company to bring all the ductwork into a conditioned space. The ducts are enclosed in soffits below the insulation along the central core of the house plan. All ducts are sealed with mastic and tested for leakage. A central return, as well as transfer grilles across interior doorways, helps equalize the pressure throughout the house.

Exploring and Experimenting

JWM Companies is constantly seeking new and interesting building techniques and materials. Consideration is given to the cost of new features. However, according to John Wesley Miller, it isn't always the only consideration. Miller said, "A lot of what we do is trying something to see if it works instead of adopting only what is proven. We don't always look at the cost-benefit analysis. I like to explore and experiment and try things to see what happens. It's research and it's fun." In addition, practicality often factors into Miller's decision to use a new product; products must be locally available and must fit neatly into the construction schedule.

To this end, JWM Companies relies heavily on the subcontractors with which it has loyal and longstanding relationships. The company works closely with the trade contractors to determine the best materials, production, and processes to minimize energy use and take advantage of the abundant solar resource. Periodic meetings with staff and trades are held to review building practices, identify problems, and implement solutions.

Builders as Environmentalists

As John Wesley Miller summarizes, "Builders *are* the environmentalists because we construct the built environment. We have the opportunity to improve that built environment every day and every year, to provide a higher quality of life. We are the ones that can raise the bar to which all of us strive. That's what we, as builders, can do to improve people's quality of life."

Utility Inspiration and Perspiration

Efficiency features make the cost of heating and cooling very low. According to an independent study, the utilities for an average home in the Armory Park del Sol subdivision run about half of what a typical new home in the city costs. Through a synergistic partnership with Tucson Electric Power (TEP), the home's heating and cooling bills are guaranteed not to exceed $0.76 per day for 5 years.

Under the TEP program, periodic quality inspections are performed - at the framing, insulation, and HVAC phases - plus a final inspection. The builder can be assured that the house was constructed as designed; TEP adds a new house to its customer base that sends power to the utility grid at times when TEP needs it most; and the customer's utility bills are guaranteed to fall below a certain amount each month.

Inspections include performance testing to check whole-house air leakage, duct leakage, and pressure in each room with the doors closed. Reducing the pressure difference across interior doorways facilitates air circulation to all rooms and results in a more comfortable home.

A Good Deal

Each home in the subdivision features a solar electric and solar hot-water system. John Wesley Miller Companies has the advantage of working with a progressive utility company that is aggressively encouraging the installation of renewable energy power systems. Currently, the rebate for solar systems is $3 per installed watt. Therefore, all new homes in Armory Park del Sol are getting a $4,500 rebate from the power company, in addition to lower energy bills, for their 1.5-kW photovoltaic system. In turn, Arizona provides a $1,000 tax credit for solar water heating and solar electric systems.

Builder Innovation, Challenges, and Lessons Learned

Though constructing homes for more than 50 years, JWM continues to search for new opportunities to improve his product and process. While most homes constructed in the area have switched to light-frame materials, the Armory Park del Sol homes are constructed of solid grout block, with the insulation attached to the exterior of the block leaving the interior surface to be finished with a skim coat of plaster, and a stable exterior surface that reduces stucco cracks. The comfortable and solid feel to the wall are major selling points that differentiate JWM from the competition. In addition, the homes use a parallel-piping system for the hot-water plumbing, one of the lessons learned from early homes to improve hot water delivery time and reduce water use. And although popular with some customers, the builder has stopped the use of recessed light fixtures because of the energy penalties that are difficult to overcome.

For builders in a sunny desert climate looking to improve energy efficiency, Miller feels that builders should install a solar hot water system. Next, he recommends looking at windows with low U-factors and low SHGC. He suggests that builders should look at the value of thermal mass storage with masonry walls and exterior insulation. Finally, he adds, "Everyone should be insulating concrete slab foundations. A tremendous amount of heat goes out through the slab in the winter."

Snapshot of Energy Features

Floor Area	1,916 ft^2
Construction Cost	\$148 per ft^2
Number of floors	one-story; slab-on-grade
Foundation Insulation	R-12 slab-edge insulation
Wall Construction and Insulation	8-in. solid-grout CMU; R-12 exterior rigid foam
Ceiling/Roof Construction and Insulation	I-joists/flat roof; R-38 fiberglass batt insulation
Windows	Low-E, gas-filled; U = 0.32; SHGC = 0.30
Air Sealing	Foam around rough openings of windows and doors
Blower Door Test	2.9 ACH_{50}
Ducts	100% conditioned space; R-6 insulation
Duct Losses	15 cfm total at 25 Pascals
Ventilation	Passive inlet to return side of air handler
Heating Equipment	HPSF 8.6 heat pump with programmable thermostat
Cooling Equipment	12 SEER heat pump
Hot Water System	Batch-type solar water heating system with tankless back-up
Solar PV System	1.5-kW grid-connected photovoltaic system
Lighting	Combination incandescent and fluorescent
Appliances	ENERGY STAR® refrigerator (643 kWh/yr) and dishwasher (449 kWh/yr)
HERS Score	91.8

Development: **Gamlen House**

Builder: **Artistic Homes**

Location: **Albuquerque, New Mexico**

The home is a 2700-ft^2, four-bedroom, three-bathroom, single-story home with an unvented conditioned crawlspace below (Figures 33, 34, 35). Key features include well-insulated building envelope, low-e windows, ducts and air handler in conditioned space, ENERGY STAR dishwasher, supply ventilation system, and a condensing gas furnace for water and space heating.

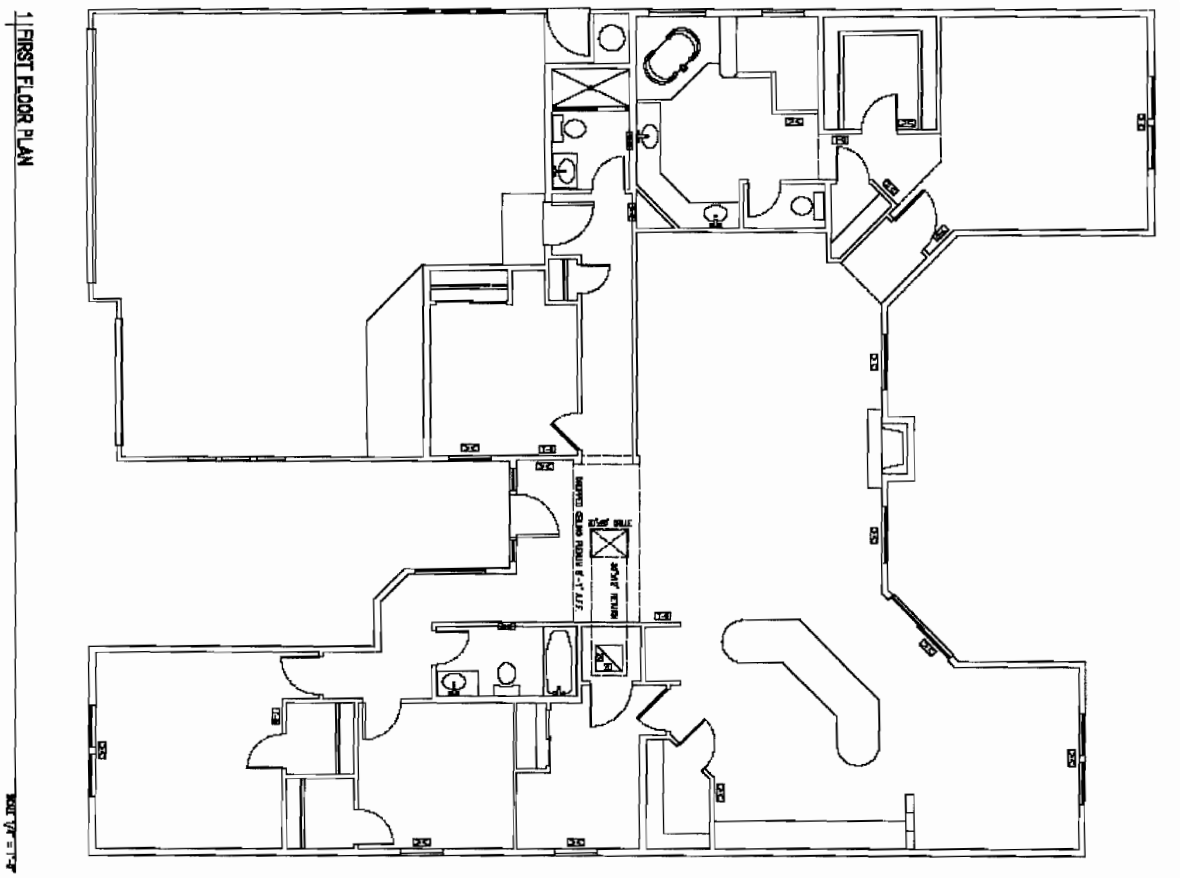


Figure 33. Gamlen House floor plan

Figure 34. Gamlen House front elevation

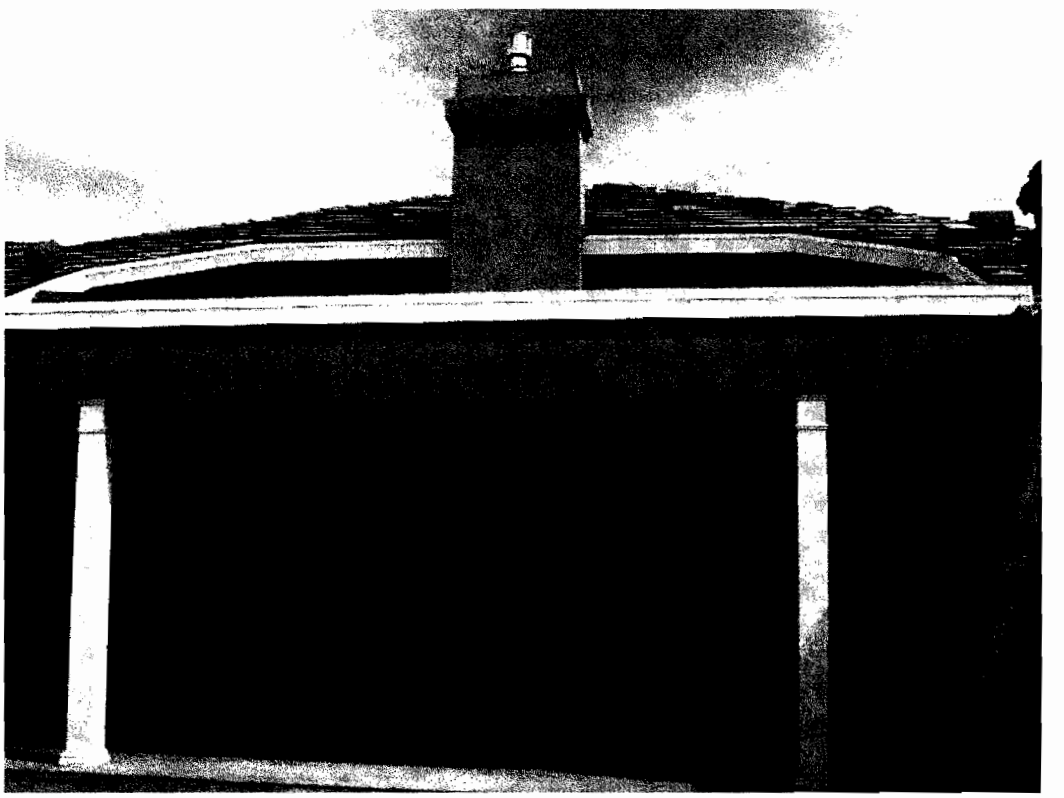


Figure 35. Gamlen House rear elevation

House Specifications

Specifications are provided in Table 13.

Table 13. Specifications for Artistic Homes: Gamlen Residence, Albuquerque, New Mexico

	Benchmark Construction	Building America/EFL™ Platinum	Estimated Cost $
Building envelope			
Ceiling	R-33 on flat vented attic	R-38 attic loose fill fiberglass	$150
Walls	R-11.7 16 oc	R-23 2x6 24 oc + R-1.2 asphalt impregnated	$0*
		sheathing to exterior, OSB on corners	-
		cavity insulation Optima dry-blown fiberglass	-
		R-23 2x6 24 oc	-
Crawl Space Walls	R-13.7 on walls	R-14 2-in. Polyisocyanurate Rigid Insulation	$150
Windows	Single-pane TIM frame	Double-glazed Low-E^2 vinyl	$1,000
	U = 0.44, SHGC = 0.55	vinyl frame; U = 0.35, SHGC = 0.35	-
Infiltration	186 ELA	2.5 in.^{2} leakage area per 100 ft^2 envelope	$0

Table 13 (continued). Specifications for Artistic Homes: Gamlen Residence, Albuquerque, New Mexico

	Benchmark Construction	Building America/EFL™ Platinum	Estimated Cost $
Mechanical systems			
Heat	78% AFUE in vented attic	90%+ AFUE in conditioned floor area	$1,000
Cooling	10 SEER A/C	13 SEER A/C	-
DHW	0.54 naturally aspirating gas water heater in garage	0.86 EF condensing gas furnace in garage	-
Ducts	metal ducts in conditioned crawl	metal ducts in conditioned crawl	$0
Leakage	15% of flow	None (5% or less of nominal flow to outside)	$0
Ventilation	none	Aircycler FR-V with manual damper	$150
		Resulting 2 ton Downsizing	-$1,000
		Total =	$1,450

Specifications

	Building America
Building envelope	
Ceiling	R-38 attic loose fill fiberglass
Walls	R-23 2x6 24 oc + R-1.2 asphalt impregnated sheathing to exterior, OSB on corners cavity insulation Optima dry-blown fiberglass R-23 2x6 24 oc ·
Crawl Space Walls	R-14 2" Polyisocyanurate Rigid Insulation
Windows	Double glazed LoE^2 vinyl vinyl frame; U=0.35, SHGC=0.35
Infiltration	2.5 sq in leakage area per 100 sf envelope
Mechanical systems	
Heat	Lennox CompleteHeat® Combo System AM30Q2/3-70 90% CA_{AFUE} in conditioned space
Cooling	13 SEER A/C (First Air-Lennox)
DHW	Lennox CompleteHeat® Combo System HN30-100 0.86 CA_{EF} 34 gal in garage
Ducts	sheet metal & flex in conditioned crawlspace
Leakage	None (to outside; 5% or less)
Ventilation	AirCycler™ Supply-only system 10 minutes on; 20 minutes off

Innovative Features

Supply Ventilation System

A supply-only ventilation system is specified. An outside air duct is run from the outside (through a gable end) to the return side of the air handler. The running air handler pulls outside air into the return system. A flow regulator or adjustable damper provides fixed outside air supply quantities independent of air-handler blower speed, and the HVAC system provides circulation and tempering. In addition to the flow regulator, an electrically operated damper will be installed to prevent excess ventilation during peak-load usage. This damper will automatically close the fresh-air duct to prevent outside air from diluting the conditioned air too much. This unit should be available through most HVAC contractors.

Continuous running of the air handler in order to draw ventilation air is not recommended. An AirCycler™ FR-V controller is suggested to run air handler periodically; it operates the fan only after a selected amount of time following last operation. Furthermore, this system reduces stagnation in the house by providing mixing of house air and controls the electrically operated damper to prevent over mixing.

Conditioned Crawl Space

This was Artistic Homes' first conditioned crawlspace. The design's intent was to ensure that the home would have the same outside appearance as the slab-on-grade product. This meant that the top of the floor had to be within 8 in. of grade. The detail shown below was the one chosen to accomplish this. The absence of a rim joist contributed to the tightness of the conditioned crawl as noticed in the blower-door tests (Figure 36).

Builder Cost Summary

Builder costs have been individually priced and the associated downsizing savings have been included to show net cost.

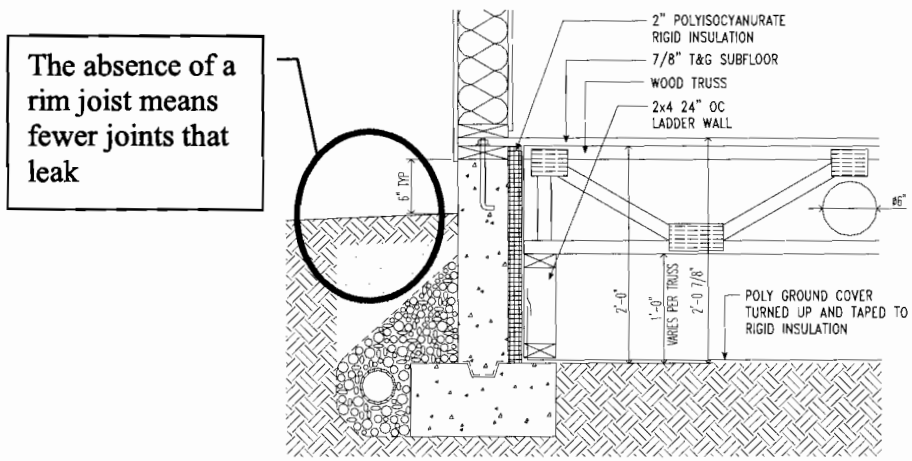


Figure 36. Rim joist

Utility Information

Gas	PNM	$0.4226 per therm + $9.00/month
Electricity	PNM	0-200 = $0.0720 per kWh
		200+ = $0.0843 per kWh + $3.00/month

Source Energy Consumption Summary

The simulations have been updated with a multi-point blower door and single-point duct blaster, as well as a measured outside air intake flow. The savings increased by 5% as a result of the improved tightness and negligible duct leakage to outside. Note that the "Percent of End-Use" column shows how effective the prototype building is at reducing energy use in each end-use category. The "Percent of Total" column shows how the energy reductions in each end-use category contribute to the overall savings (Table 14 and Table 15).

Table 14. Source Energy Consumption Summary

	Estimated Annual Source Energy		Source Energy Savings	
			Percent of End-Use	Percent of Total
End-Use	Benchmark 10^6 BTU/yr	Proto 10^6 BTU/yr	Proto savings	Proto savings
Space Heating	109	58	47%	19%
Space Cooling	29	13	55%	6%
DHW	31	21	33%	4%
Lighting*	27	27	0%	0%
Appliances + Plug	76	76	0%	0%
OA Ventilation**	0	0	0%	0%
Total Usage	274	195	29%	29%
Site Generation	0	0		0%
Net Energy Use	274	195	29%	29%

Table 15. Measured Data

SNAPSHOT© "The Form"			
Lot #: 9	Subdivision:	Address:	Date and time:
Model: Gamlen	Primerose	8609 Royaglo	9/24/03 2:15 PM

INITIALIZATION

	Square feet	2700 ft^2
	Surface area (all outside surfaces, including foundation)	9226 ft^2
	Volume	32997 cu. ft.
	Windspeed (approximate mph)	~ 0 mph
	Outside temperature (estimated)	80 ° F
	Check that all registers and bedroom doors are open	Yes☒ No☐
	Static pressure in Supply and Return	S +5 Pa / R -32 Pa
	Is there a ventilation system?	Yes☒ No☐
	Type of ventilation system (e.g., exhaust-only, HRV, ERV)	Air Cycler Supply Only
	If there is an AirCycler™, enter the off / on times	off 24 on 8
	Enter outside air duct pressure	-35.4 pa
	Type of outside air duct (flex/sheet metal; diameter)	6-in. insulated flex
	Is there an adjustable outside air damper?	Yes☒ No☐
	Is there a fireplace or wood stove?	Yes☒ No☐
	Duct location (approximate % in attic, conditioned space, basement, etc.)	100 % Conditioned Crawl

PRESSURE TESTING

	Stack Pressure (baseline with blower door installed; covers on)			-0.1	pa
	Dominant Duct Leak Effect (baseline with HVAC system running)				pa
	Master Bedroom Door Closure Effect (ΔP from main space to outdoors)				pa
	All Doors Closed Effect (ΔP from main space to outdoors)				pa
	Fireplace/Wood Stove Zone HVAC Test				pa
	Pressure In Each Closed Room. Not available on initial test; no doors were installed.		pa		pa
			pa		pa

Table 15 (continued). Measured Data

BLOWER DOOR TESTING (BDT)

	Blower Door Location and Test Goal	Front Door (Goal = 2310 CFM 50)
	Test 1: Transfer grilles open, hatches closed	CFM50=1217, LR = 0.13, C = 82.6, n = 0.688, R^2 = 0.99965
	Test 2: Transfer grilles open, hatches open	CFM50 = 1214, LR = 0.13, C = 80.0, n = 0.695, R^2 = 0.99953
	Test 3: Transfer grilles closed, hatches closed	CFM50 = 1216, LR = 0.13, C = 87.7, n = 0.672, R^2 = 0.99928

DUCT AIRTIGHTNESS TESTING (DAT)

	DAT CFM25 TOTAL	125 Pa 25 Ring 2	170 CFM 25
	DAT CFM25 OUTSIDE	0 Pa 25 Ring 3	~0 CFM 25

AIR HANDLER FLOW MEASUREMENT (TRUEFLOW located at return)

DG700 Reading	NSOP = ~5.4 Pa, TFSOP = ~4.5 Pa, Cooling Flow = 995 CFM
DG700 Reading	NSOP = ~5.0 Pa, TFSOP = ~4.7 Pa, Heating Flow= 775 CFM

MECHANICALS

	Furnace or air handler	Make: Lennox CompleteHeat©	Model: AM30Q2/3-70
	Air Conditioning	Make: Lennox	Model: HS26-030-4P
	Cooling Coil	Make:	Model: BV 124 36-BPA23 9GL58
	Domestic hot water	Make: Lennox CompleteHeat©	Model: HM61-100-1

Community-Scale Case Studies

Development: **Premier Gardens**

Builder: **Premier Homes**

Location: **Rancho Cordova, California**

Introduction

The Zero Energy Homes (ZEH) in the Premier Homes development – "Premier Gardens" (Figures 37, 38, 39) is located in Rancho Cordova, California. The Sacramento Municipal Utility District (SMUD) is a primary sponsor and research partner with the Building America Program on this project. SMUD cost shared a portion of the incremental costs of the energy efficiency and renewable energy upgrades for the Premier homes. In addition, SMUD has instrumented 19 homes in the ZEH development and a nearby non-ZEH subdivision and is collecting and analyzing performance data on these homes to help evaluate the relative impact of ZEH features on peak and total energy consumption of the homes. A 2.4-kW DC building-integrated photovoltaic system is installed in each ZEH home. With building energy-efficient features, appliances, other appliance/plug loads and fluorescent lighting alone, the homes have achieved around 35% energy savings without PV system and around 60% energy savings with PV system.

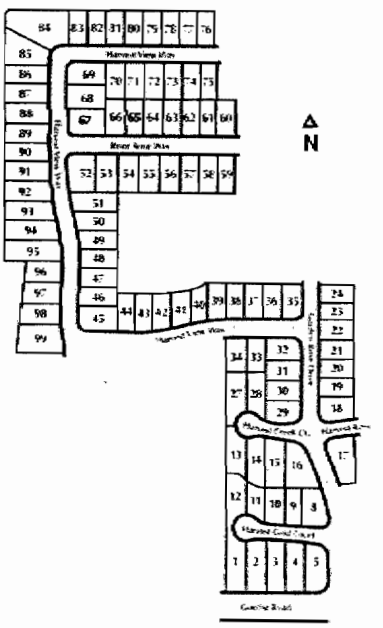


Figure 37. Premier Garden Homes site plan and elevation

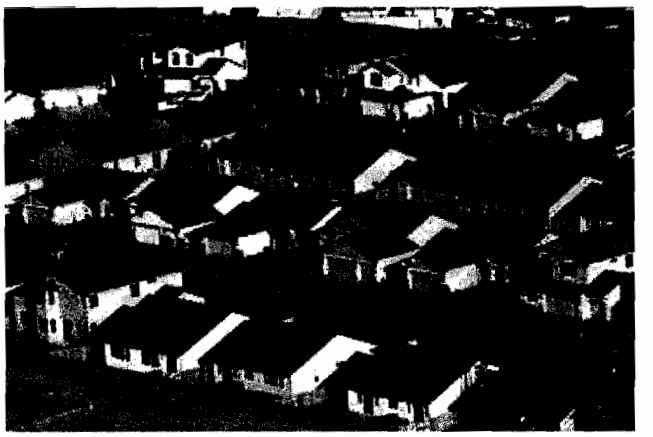


Figure 38. Aerial view of Premier Gardens (Premier Homes photograph courtesy of SMUD)

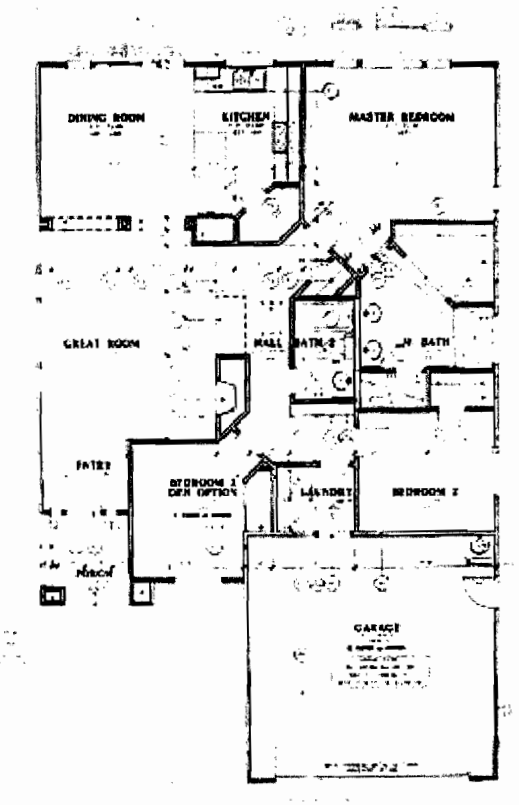


Figure 39. Floor Plan 1503 ft^2 (Lot 68) – (three bedroom, two baths, and one-car garage)

House Specifications

To achieve 60% energy savings below the base case house, the Prototype BAP House requires the following advanced systems:

- R-38 attic insulation (U-value = 0.031). High insulation reduces heat gain in summer and reduces heat loss in winter.
- R-13 fiberglass batts + 1-in. EPS foam (U-value = 0.067). This U-value reflects 25% framing factor.
- 3.5 SLA or low air infiltration rate. Tight building envelope to help minimize outside/inside air from entering/exiting the home. With lower infiltration of unconditioned air and exfiltration of conditioned air, less conditioning is required, making the home more efficient. Homes with low air infiltration/exfiltration are often quieter and cleaner.
- Dual-pane non-metal frame windows with spectrally selective glass with U- factor and SHGC no greater than that listed in Table 16.

These types of glazing help increase the comfort level of the home by reducing solar insolation into the house. In the summer, spectrally selective glass lets in visible sunlight while blocking 80% of both the infrared and ultraviolet solar energy (that drives up cooling costs and degrades curtains, window treatments, carpeting and furnishings). In the winter, these glazing products offer reduced heating costs by reflecting room-side radiant heat back into the room.[57] In hot climates this type of glazing typically enables builders to reduce the size of air conditioners and decrease other building energy related features.

- Engineered System with Heating Ventilating and Air Conditioning (HVAC) efficiencies of 91% AFUE for furnace and 14 SEER for air conditioning with thermal expansion valve (TXV). Licensed mechanical engineers size and select HVAC systems, design duct sizes, and register locations. The final engineered systems will have properly sized and balanced

Table 16. U-values and SHGC values for doors

	U-value	SHGC
Slider	0.36	0.30
Single Hung	0.33	0.32
Fixed	0.30	0.33
Sliding Patio Door	0.34	0.30
French Door	0.33	0.28

[57] Supplemental Catalogue for Cardinal IG: LoE^2 Glass Products "The Choice for Year-Round Energy Savings and Comfort"

HVAC systems with correct duct sizes and placement of registers, this will assure the conditioned air to be evenly distributed throughout the whole house. They will also provide improve efficiency and comfort. The TXV is a metering device for refrigerant flow into the evaporator of an air conditioner. A TXV improves efficiency.

- R-4.2 buried in insulation (R-13 equivalent) with tight duct and ACCA Manual D designed by a licensed mechanical engineer. Duct leakage can have a significant impact on HVAC performance, household infiltration/exfiltration rates, moisture levels in the house, water heater and furnace safety, and overall occupant comfort. A tight duct system is one that does not leak more than 6% of the fan airflow (at 50 Pascal). Excessive air leakages in duct systems make HVAC systems work harder, using more time and energy to cool or heat the home as a result of insufficient air delivery. This results in higher energy bills and less comfort for homeowners/occupants, which often triggers callbacks. Duct leakage typically occurs at these locations:
  - Poorly fitted and improperly sealed joints and seams in the ductwork
  - Disconnected and partially disconnected boot connections
  - Holes in the ducts
  - Use of improperly sealed building cavities for supply and return ducts
  - Poor connections between room registers and register boots
  - Poorly fitted air handler doors, filter doors and air handler cabinets.

Tight duct systems increase forced-air distribution efficiency, resulting in improved comfort and lower utility bills for homeowners. Tight ducts are required to be tested by a third party.

- One tankless water heater with a minimum Energy Factor (EF) of 0.82. R-4 insulation on all trunk lines. This includes any hot water lines located in concrete slabs or underground. A tankless water heater has high efficiencies. Hot water is heated upon demand and has no storage tank.
- All-fluorescent lighting. The wide variety of improved quality, more efficient lighting that are on the market today warrant more careful lighting design. Lighting plans are recommended and fluorescent lamps used wherever possible. Where possible, bayonet-mount fluorescent should be used in compact-fluorescent fixtures. Where this is not possible, medium-base CFLs are permitted. Minimum recommended downlight specifications of fluorescent lamps should be 2700K in cooler temperature, 23-26 watts, and 1300 lumens (used 26 watts). Vanity lighting requirements may vary.
- Gas dryer stub. This is provided to encourage the use of gas dryers, which are less expensive to operate than electric.
- Photovoltaic System. The 2.4-kW DC system by GE Energy produces on average 3420 kWh/year (or 285 kWh/month). The building-integrated PV system not only produces electricity, but is also aesthetically pleasing by blending in with the roof tiles.

Calculated Energy Performance

Table 17 lists the energy savings of the base case house compared to the prototype house.

Table 17. Lot 68 (1503 ft^2) Summary of Energy Savings (Micropas Simulation)

	Base Case House	Prototype House	Energy savings
Heating (from Micropas simulation)	33,863 kBtu/yr	16,849 kBtu/yr	50%
Cooling (from Micropas simulation)	21,252 kBtu/yr	5,095 kBtu/yr	76%
Water Heating (from Micropas simulation)	22,951 kBtu/yr	13,076 kBtu/yr	43%
Lighting	20,550 kBtu/yr	5,345 kBtu/yr	74%
Other Uses/Appliances/Plug Loads	51,009 kBtu/yr	49,659 kBtu/yr	2.5 %
Whole House Energy Savings	***149,624***	***90,023***	***39%***
Site Generation (2.4-kW DC PV system)		*-35,017 kBtu/yr*	
Total	**149,624 kBtu/yr**	**55,006 kBtu/yr**	**63%**

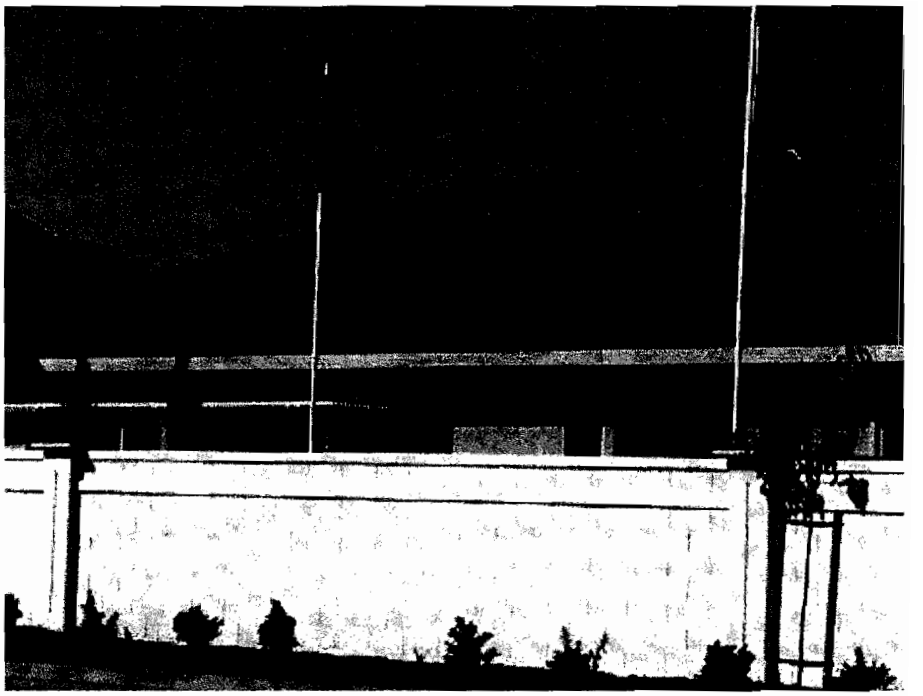
Development: **Lakeside**

Builder: **Morrison Homes**

Location: **Elk Grove, California**

Morrison Homes at Lakeside is located within the master-planned community of Lakeside in the "hometown" of Elk Grove, 25 miles south of Sacramento, California (Figure 40). Lakeside is one of the first homes under the U.S. Department of Energy's Zero Energy Homes (ZEH) initiative, in the Sacramento area. SMUD and ConSol were both invited by Morrison Homes to help them with the Lakeside project. This is a 120-home development with 12 homes being ZEH. Five home plans are available – and all are available with the ZEH package. Floor plans range from 2,126 ft^2 up to 3,672 ft^2. The community was originally designed with ZEH in mind, but no special architectural design was required for the reduced-energy homes. In addition, ZEH is an option available on most of the remainder of the regular homes, with a few exceptions where the roof's solar exposure is not optimal. Monitoring equipment has been installed on the model home. The Sacramento Municipal Utility District (SMUD) installed sensors for determining solar insolation and PV panel temperatures (Figure 41). SMUD provided considerable expertise aiding Morrison with solar features as well as providing hookup fee discounts related to home energy efficiency measures, incentives for efficient lighting and Energy Star home certification as well as PV buydowns. ConSol provided technical expertise to develop the efficiency package that, combined with the solar was agreeable to all to meet DOE, SMUD and Morrison objectives. ConSol and SMUD provided marketing support for the project.

Figure 40. Morrison Homes in Elk Grove, California



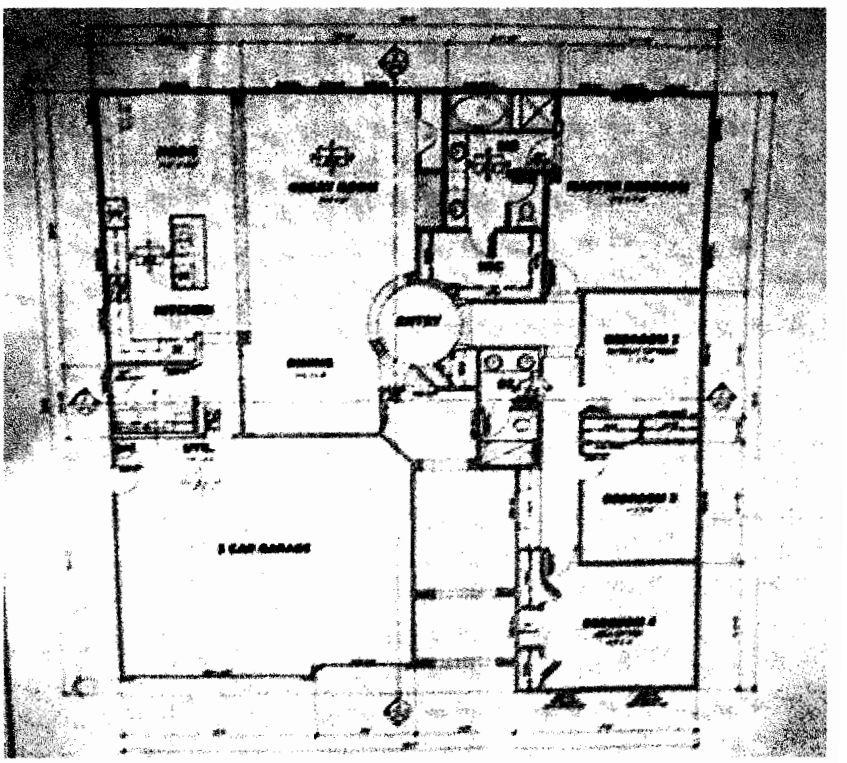


Figure 41. Typical plan floor plan, Lakeside, California

Innovative Energy-Efficient Features

The following is a list of all the energy efficient features deployed in the ZEH home:

Appliances	ENERGY STAR®
Air Sealing	Caulking and sealing measures ensure low air infiltration
Insulation	R-19 wall insulation R-30 second-story floor insulation (two-story plans) R-38 attic insulation R-6 duct insulation - Plans 1 and 4
Windows	Spectrally selective glass, high-performance windows, U-factor: 0.36 for sliders, 0.33 for fixed, 0.35 for patio door; SHGC: 0.33 for sliders, 0.36 for fixed, 0.35 for patio door
Heating/Cooling	0.92 AFUE furnace 14 SEER A/C
Lighting	All fluorescent lighting
Water Heating	Tankless water heater with 0.82 energy rating Hot water pipe insulation
Photovoltaics	2-kW roof-integrated photovoltaic tile system

Energy and Cost Savings

Tables 18 and 19 list the energy and cost savings for Plan 2 with an area of 2513 ft^2.

Table 18. Energy Savings for Base Case and Prototype House

	Base Case / BA Benchmark House (kBtu/yr)	Prototype House - 40% Energy Savings Features (kBtu/yr)	Reduction in Energy Use (kBtu/yr)
Heating	62,951	35,458	
Cooling	34,554	7,665	
Water Heating	27,744	17,516	
Total	**125248**	**60639**	**51.6%**
Lighting	28,823	14,335	
Total (Heat, Cool, WH and Lighting)	**154,071**	**74,973**	**51%**
Other Uses	71,835	70,039	
Total (Heat, Cool, WH, Lighting & Other Uses)	**225,905**	**145,012**	**36%**
Energy Savings	**225,905**	**145,012**	**36%**

Table 19. Energy Savings for Base Case and Building America Benchmark House

	Base Case / BA Benchmark House			**BA Prototype House** - 40% Energy Savings (Upgraded Features, Fluorescent, Gas Dryer Stub and Tankless Hot Water)		
	\		Dollars	Energy Use		Dollars
	Therms	kWh	$	Therms	kWh	$
Energy Code Related						
Space Heating	630		$ 629.51	355		$ 354.58
Space Cooling		3,375	$ 506.21		749	$ 112.29
Water Heating	277		$ 277.44	175		$ 175.16
Other Uses						
cooking	78		$ 78.00	78		$ 78.00
dishwasher		275	$ 41.25		275	$ 41.25
electric or gas dryer		1,113	$ 166.95	96		$ 96.00
refrigerator		669	$ 100.35		669	$ 100.35
Miscellaneous (Appliances + Plug)		4,197	$ 629.51		4,197	$ 629.51
Lighting		2,815	$ 422.25		1,400	$ 210.00
reduce kWh by solar contribution		n/a	n/a		(3,420)	$ (513.00)
Total use	985	12,443	$ 2,851.46	704	3,869	1,284.13

Total Annual Energy Use		225,902	kBtu/yr		109,992	kBtu/yr
Reduction in Energy Use			100%	29%	69%	55%
Total for Column in kBtu/yr	98,494	127,408		70,374	39,618	

Total kBtu/yr for BA Benchmark House	225,902	kBtu/yr
Total kBtu/yr for Prototype House	109,992	kBtu/yr
Percent End Use Energy Savings	**51.3%**	

Estimated Montly Energy Bill		$ 237.62	/mo	$ 107.01	/mo
Reduction in Energy Cost				45%	
price of gas/therm	$1.00				
price of electricity/kWh	$0.15				

Development: **Windemere**

Builder: **Centex Homes, Northern California Division**

Location: **San Ramon, California**

Windemere development contains two neighborhoods that are included in the program; Aventura and Lunaria (Figures 42 and 43). Two energy package options were developed for Centex Homes: basic PowerSave and PowerSave Plus. A model home in each of the neighborhoods was selected to demonstrate the PowerSave Plus option, and a total of 25 homes were pre-plotted with the basic PowerSave features within both neighborhoods. The basic PowerSave option meets the 30% Building America goal and are described in this section. Details of the PowerSave Plus home are not included here because source energy savings exceed 39% on efficiency measures. All of the homes in these two neighborhoods are two stories and range in size from 2,250 ft^2 to 3,800 ft^2. Construction of the models began in September 2003, and all homes will be completed by October 2005. There are two additional neighborhoods, Torello and Montevego, with models in construction that will offer these same options.

Table 20 lists the final group of measures included in the final PowerSave option package. Two measures that were being considered for inclusion in the PowerSave designs were implemented throughout the two communities, leading to spin-off energy savings for all homes. These measures, zero defect insulation and insulated headers, were adopted for both the Aventura and Lunaria communities. Zero defect wall insulation was achieved by employing a blown-in fiberglass insulation product. The small incremental cost compared to fiberglass batts encouraged Centex to use it on all homes.

Insulated headers were initially rejected because the manufacturer did not make headers in the sizes used by Centex. After the manufacturer accommodated Centex by expanding their product line, they were rejected a second time because the recess between the stud face and the header made nailing of siding difficult. The manufacturer then offered to use scrap material to fill in the recess, and Centex adopted the header for universal application. The cost of the insulated headers proved to be less than the cost of linear strand lumber (LSL) wood headers.

Source Energy Consumption Summary

Tables 21 and 22 list source energy use and savings for the Aventura and Lunaria neighborhoods. Savings are relative to the Benchmark. The standard Centex models meet Title 24 and ComfortWise performance requirements. Note that the "Percent of End-Use" column shows how effective the prototype building is at reducing energy use in each end-use category. The "Percent of Total" column shows how the energy reductions in each end-use category contribute to the overall savings.

Table 20. House Specifications Centex – Building America PowerSave Home

Building Envelope	
Ceiling	R-48 blown fiberglass in attic
Walls	Zero defect wall insulation: R-15 blown fiberglass 2X4 16 in. oc. with insulated window and door headers
Floor	Slab-on-grade, uninsulated
Windows	Double-glazed vinyl windows Low-E^2
	U-factor = 0.35 Btu/hr-ft^2-°F, SHGC = 0.37
Infiltration	Tight construction, including draft stops, caulking of top plate penetrations and windows, and bottom plate gaskets. Tested to be less than 3.9 SLA
Mechanical Systems	
Heating	Carrier 80% AFUE variable-speed furnace
Cooling	Carrier 10 SEER condensing unit
Ducts	R-4.2 flex ducts buried in R-49 attic insulation.
	Tested tight ducts < % leakage
Water Heating	Takagi Instantaneous water heater (0.82 EF)
	PEX Home-run piping design
Lighting	CFL's on all permanent fixtures except dining chandelier

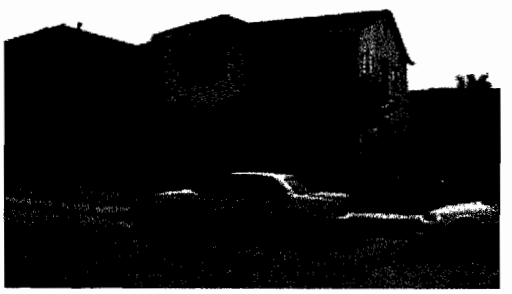


Figure 42. Aventura – front elevation

Figure 43. Lunaria – front elevation

Table 21. Aventura Summary of Estimated End-Use Source Energy

	Estimated Annual Source Energy			Source Energy Savings			
	Benchmark	Centex Standard	Prototype	Percent of End-Use		Percent of Total	
End Use	(MBtu/yr)	(MBtu/yr)	(MBtu/yr)	vs. Benchmark	vs. Standard	vs. Benchmark	vs. Standard
Space Heating	38	27	24	37%	12%	8%	2%
Space Cooling	47	43	38	20%	13%	5%	3%
DHW	32	32	14	54%	54%	9%	10%
Lighting	21	21	7	67%	67%	8%	8%
Appliances+ Plug	42	42	42	0%	0%	0%	0%
OA Ventilation	0	0	0	0%	0%	0%	0%
Total Usage	180	165	125	30%	24%	30%	24%

Table 22. Lunaria Summary of Estimated End-Use Source Energy

	Estimated Annual Source Energy			Source Energy Savings			
	Benchmark	Centex Standard	Prototype	Percent of End-Use		Percent of Total	
End Use	(MBtu/yr)	(MBtu/yr)	(MBtu/yr)	vs. Benchmark	vs. Standard	vs. Benchmark	vs. Standard
Space Heating	72	64	59	19%	8%	5%	2%
Space Cooling	68	46	39	43%	15%	12%	3%
DHW	38		16	58%	58%	9%	10%
Lighting	28	28	9	67%	67%	7%	8%
Appliances+ Plug	44	44	44	0%	0%	0%	0%
OA Ventilation	0	0	0	0%	0%	0%	0%
Total Usage	250		167	33%	24%	33%	24%

Builder Cost Summary

The basic PowerSave package was pre-plotted on 25 lots in the two neighborhoods; six in Aventura and 19 in Lunaria. The package was also offered as an option for the remaining homes. Centex offered the basic PowerSave option for $3,600 for Aventura and $3,850 for the bigger homes in Lunaria. Table 23 summarizes the incremental costs to the builder, and Table 24 summarizes the PowerSave cash-flow analysis for the buyer. Estimated incremental costs in Table 24 were obtained from the builder. Amortized costs are based on a 30-year mortgage at 6% interest. Buyer surveys indicated some interest in the PowerSave package, but it appears that interested parties purchased the pre-plotted homes instead of purchasing a standard home with the PowerSave option.

Table 23. Centex Windemere PowerSave Pricing

	Standard Construction	Building America - PowerSave		Estimated Cost $
Building envelope				
Ceiling	R-38 batt in vented attic	R-49 blown fiberglass		$700-$800
Walls	R-13 2x4 16 in. oc	R-15 blown fiberglass.		$100
Headers	LSL Headers	Insulated headers		$0
Mechanical systems				
DHW	0.54 EF storage gas water heater in garage	0.82 EF instantaneous gas water heater in garage		$1,200
Ducts	R-4.2 suspended from trusses	R-4.2 buried in ceiling insulation		$0
Lighting	Incandescent Lighting	Full CFL Package		$375
		Total	=	**$2,375-$2475**

Table 24. PowerSave Cash Flows

Package	**Aventura**	**Lunaria**
Total Cost	$3,600	$3,850
Annual Amortized Cost	$259	$277
Annual Energy Savings	$452	$598
Net Savings	$193	$321

Appendix A: Passive Solar Design Considerations

There are three primary passive design systems: direct gain, indirect gain, and sunrooms.

Direct Gain. In direct gain (Figure A-1), the sun shines directly into the house through windows, skylights, and clerestories. Depending on the amount and orientation of glazing, thermal mass materials may be needed to be incorporated in walls and floors to absorb the solar radiation and re-release it during the evening. Direct gain can also utilize a strategy called "sun tempering" where glazing is favored on the south side, but limited so that additional thermal mass is not necessary to prevent overheating of south-facing rooms.

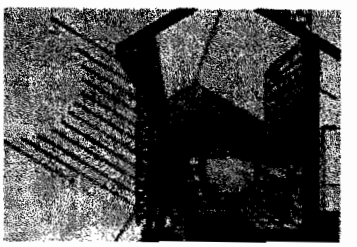


Figure A-1. Direct Solar Gain

Indirect Gain. Indirect gain (Figure A-2), also called thermal storage wall and Trombe Wall, consists of a thermal mass wall, with direct southern exposure. For example, a thermal storage wall could be a poured-in-place concrete wall or a concrete masonry block wall with the cores filled with concrete. One or more panes of glazing are located immediately on the outside of these mass walls. The outside surface of the mass wall is painted a dark color or coated with a selective surface, such as those used in active solar collectors.

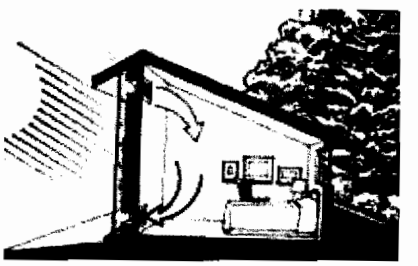


Figure A-2. Indirect Solar Gain

Sunroom. Passive solar sunrooms (Figure A-3) can either be isolated or open to the rest of the home. Because of the large areas of glass, it is usually recommended that they include doors and windows that can be closed to isolate them from the rest of the house. In this configuration, the temperature in the sunroom can be permitted to go higher and lower than would be permitted within the home.

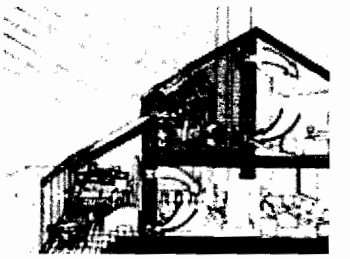


Figure A-3. Passive Solar Gain

To optimize the solar design of the house, which includes size of aperture, glazing performance characteristics (U-value and Solar Heat Gain Coefficient [SHGC]), by orientation, inclusion of mass, and house configuration, it is recommended that detailed energy simulations be undertaken. In general, if passive solar design is to be implemented, the following issues should be addressed, in the following order of importance:

- Site planning to allow for optimizing house orientation
- Orienting the house to optimize solar gains for heating and limiting solar gains during the cooling season. Simply by orienting homes with longer sides with larger glazing areas facing north-south helps to minimize unwanted heat gain in summer and maximize beneficial solar heat gains in winter (Figure A-4).

Builders seeking to optimize individual home and lot orientation can follow these guidelines.

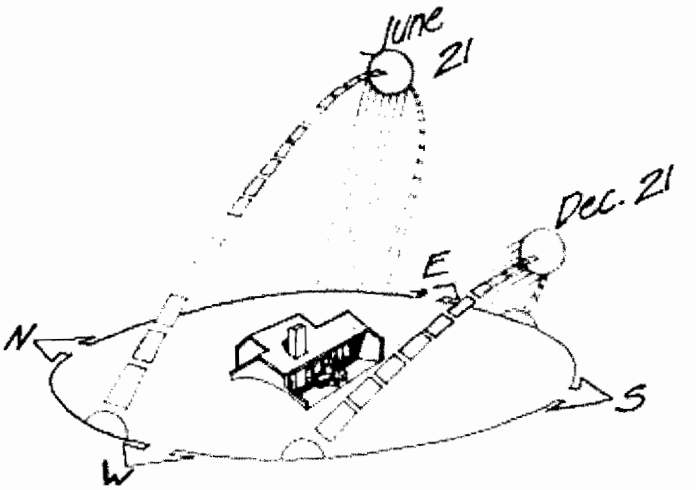


Figure A-4. The paths of the sun in winter and summer over a home with long sides facing north and south

- **Minimize East and West Glazing.** Orienting homes so that the sides with the least glazing face east and west can significantly reduce cooling loads and reduce glare. Typically, afternoon sun shining in west windows is most important to minimize or to shade.
- **North-south Orientation.** Having the longer sides of homes facing north-south is beneficial for reducing both heating and cooling loads. In Cold Climates, having more glazing face south with adequate shading can minimize cooling and heating loads significantly; however, this must be carefully designed to prevent overheating and comfort complaints. South windows can most easily be shaded with overhangs.
- **Architectural Design.** Shape the architectural form and solar apertures of the houses to optimize passive solar heating, including appropriate mass to avoid localized overheating, and summertime shading to mitigate cooling loads. This is best done in conjunction with hourly energy and room temperature modeling to assure energy savings and occupant comfort. Passive designs typically employ increased use of dense materials like concrete slab floors with tile and increased thickness of drywall or interior brick or concrete walls that have high conductivity to heat and high heat capacities. The increased mass can be as simple as replacing carpeted floors with inexpensive tile floors in slab-on-grade construction. If mass materials are warmed by winter sun and cooled with night ventilation systems in summer, they can add to comfort and reduce use of and consumption by conventional heating and cooling systems.
- **Night Cooling:** Locate openings to optimize airflow during temperate conditions and to facilitate "night flushing" of heat built up over the day during the relatively cooler evening hours.

Passive design may have a significant impact on the architectural character of the house and may be viewed in a positive or negative manner by builders and homebuyers. Passive strategies may be pursued as a trade-off for other energy improvements; however, careful consideration of occupant comfort must be taken into account. Effective passive solar heat gain can be very beneficial during the heating season, but it is challenging to design well and requires proper linkage of aperture and thermal storage in order to be useful and to avoid discomfort. Overheating is a significant problem. Passive cooling, both by window shading and glass transmission characteristics, is very beneficial during the cooling season. Window shading can be very effective, but its proper design is critical, and the shading elements may have a strong visual impact on the exterior of the house. Thus, it is not a strategy that is thought to be universally appropriate at the 30% improvement level. For more information on passive design strategies, see the Passive Solar Industries Council's passive solar design guidelines.[58]

Architectural Shading Considerations. Shading, like orientation, is not required to achieve 30% savings, particularly with low-SHGC glazing. However, studies have shown that shading can cut solar heat gain by anywhere from 10% to 50%. Blocking the sun's rays from striking glazing areas and heating up a home is much more efficient than using air conditioning to cool down an already overheated house.

"Architectural shading" is simple, does not need any maintenance, and may reduce costs compared to sophisticated shading devices. Incorporating shading methods into the home during

[58] Sustainable Building Industries Council. *Passive Solar Design Strategies: Guidelines for Home Building.* Sustainable Building Industries Council Website. www.psic.org

the design phase ensures that a home receives the most effective shading. For example, providing properly designed overhangs shading the south glass adequately can reduce the heat gain during the summers while allowing for heat gain during the winters. Shading the west glass can also minimize the unwanted heat gains. A wide range of shading options is available, including the following:

- **Overhangs on South Sides.** Extending the roofline a few feet can create shade for a home's south-facing windows. Because sun angles drop in the winter months, south-facing overhangs will let the warming sun into the home when it is needed. Because of low sun angles in summer mornings and afternoons, overhangs on the east or west have little to no affect. Shades for east- or west-facing windows must have some vertical dimension, such as awnings or shade screens.

Decks and Porches. Adding a covered deck or porch is an excellent way to shade a home and to add living space, too. Porches and covered decks should have enough of an overhang to shield the area from the high sun and still offer a view outside from the interior spaces.

- **Awnings.** Awnings provide excellent shading for south-, east-, and west-facing windows; awnings will block as much as 65% of the summer sun's heat (77% on an east- or west-facing window), but they have the disadvantage of blocking the top half of the view from the window and reducing ventilation when windows are opened. Retractable canvas awnings can overcome this problem to some extent because they can be extended only when they are needed. This is especially helpful in winter months, when occupants want to let the sun in to warm their home.
- **Louvers.** Exterior louvers are attractive because their adjustable slats control the level of sunlight entering the building and, depending on the design, can be manually adjusted from inside or outside. The slats can be vertical or horizontal. Louvers remain fixed and are attached to the exteriors of window frames. Careful attention to the louver angle can allow significant winter sun penetration whilst still excluding all sun in summer.
- **Exterior Shade Screens.** Retractable shade screens are a good choice for windows that receive direct sunlight. They work much like an inside window shade, except that they are attached to the outside of the window. Most shade screen manufacturers offer automatic controls for these products. The screens are installed at the top of the window and can be lowered during sunny days and retracted when not needed. Shade screens are generally custom-made. They are a good choice for a homeowner who wants to retrofit for energy efficiency but still wants to see out of a window that gets lots of sun throughout the day. The downside of shade screens is that they can darken the view when pulled down.

Designing Shading Systems. The following design recommendations generally hold true for properly designed shading devices:

- Use fixed overhangs on south-facing glass to control direct-beam solar radiation. Indirect (diffuse) radiation should be controlled by other measures, such as low-e glazing.
- To the greatest extent possible, limit the amount of east and west glass because it is harder to shade than south glass. Consider the use of landscaping to shade east and west exposures, awnings, exterior shade screens, or interior highly reflective shades.
- Do not worry about shading north-facing glass because it receives very little direct solar gain.

- Shading effects daylighting; consider both simultaneously. For example, a light shelf bounces natural light deeply into a room through high windows while shading lower windows.
- Do not expect interior shading devices such as Venetian blinds or vertical louvers to reduce cooling loads because the solar gain has already been admitted into the work space. However, these interior devices do offer glare control and can contribute to visual acuity and visual comfort.
- An understanding of sun angles is critical to selecting shading devices.
- Carefully consider the durability of shading devices. Over time, operable shading devices can require a considerable amount of maintenance and repair.
- When relying on landscape elements for shading, be sure to consider the cost of landscape maintenance and upkeep on life-cycle cost.
- Shading strategies that work well at one latitude, may be completely inappropriate for other sites at different latitudes. Be careful when applying shading ideas from one project to another.

Appendix B: Detailed *BEopt* Analysis Results

Table B.1. BEopt Option Results for Single-Story Case

CATEGORY	BENCHMARK	35% POINT	NEIGHBOR 1	NEIGHBOR 2	NEIGHBOR 3	NEIGHBOR 4	NEIGHBOR 5	NEXT POINT ON OPT. CURVE	39% POINT
Walls	U = 0.085, 23% FF, R-11 batt, 2x4 16 in. oc + R-2.5 sheathing	R-11, 2x4, 16 in. oc	R-19, 2x6, 24 in. oc	R-19, 2x6, 24 in. oc	R-19, 2x6, 24 in. oc	R-13, 2x4, 6 in. oc	R-19, 2x6, 24 in. oc	R-13, 2x4, 16 in. oc	R-19, 2x6, 24 in. oc
Ceiling	U = 0.042, 11% FF, R-24	R-30 fiberglass	R-30 fiberglass	R-30 fiberglass	R-30 fiberglass	R-30 fiberglass	R-30 fiberglass	R-30 fiberglass	R-30 fiberglass
Thermal Mass	8 lbs/ft^2 - furniture, standard light frame construction	½-in. Ceiling Drywall	½-in. Ceiling Drywall	½-in. Ceiling Drywall	Two 5/8-in. Ceiling Drywall Layers	Two 5/8-in. Ceiling Drywall Layers	Two 5/8-in. Ceiling Drywall Layers	1/2-in. Ceiling Drywall	½-in. Ceiling Drywall
Infiltration	SLA = 0.00057	SLA = 0.0005	SLA = 0.0005	SLA = 0.0005	SLA = 0.0005	SLA = 0.0005	SLA = 0.0005	SLA = 0.0005	SLA = 0.0005
Slab	Uninsulated	Uninsulated	Uninsulated	Uninsulated	Uninsulated	Uninsulated	Uninsulated	Uninsulated	Uninsulated
Glass Type	U = 0.79, SHGC = 0.65	Two-pane Low-e, U = 0.3, SHGC = 0.44 Center of Glass, insulated spacer, Vinyl frame	Two-pane Low-e, U = 0.29, SHGC = 0.29 Center of Glass, insulated spacer, Vinyl frame	Heat Mirror, U = 0.18, SHGC = 0.48 Center of Glass, insulated spacer, Vinyl frame	Two-pane clear, U = 0.49, SHGC = 0.76 Center of Glass, insulated spacer, Vinyl frame	Two-pane Low-e, U = 0.32, SHGC = 0.64 Center of Glass, insulated spacer, Vinyl frame	Two-pane Low-e, U = 0.32, SHGC = 0.64 Center of Glass, insulated spacer, Vinyl frame	Two-pane Low-e, U = 0.3, SHGC = 0.44 Center of Glass, insulated spacer, Vinyl frame	Two-pane Low-e, U = 0.29, SHGC = 0.29 Center of Glass, insulated spacer, Vinyl frame

Table B.1 (continued). BEopt Option Results for Single-Story Case

CATEGORY	BENCHMARK	35% POINT	NEIGHBOR 1	NEIGHBOR 2	NEIGHBOR 3	NEIGHBOR 4	NEIGHBOR 5	NEXT POINT ON OPT. CURVE	39% POINT
Window Area per Wall	270 ft^2, Equal distance on four sides	270 ft^2, 12.5% N&S, 50% W, 25% E	270 ft^2, 2.5% N&S, 50% W, 25% E	270 ft^2, 12.5% N&S, 50% W, 25% E	270 ft^2, 12.5% N&S, 50% W, 25% E	270 ft^2, 12.5% N&S, 50% W, 25% E	270 ft^2, 12.5% N&S, 50% W, 25% E	270 ft^2, 12.5% N&S, 50% W, 25% E	270 ft^2, 12.5% N&S, 50% W, 25% E
Refrigerator	669 kWh/yr	Standard - 671 kWh/yr	Standard - 671 kWh/yr	Standard - 671 kWh/yr	Standard - 671 kWh/yr	Standard - 671 kWh/yr	Standard - 671 kWh/yr	Standard - 671 kWh/yr	Standard - 671 kWh/yr
Cooking Range	45 Therms/yr	45 Therms/yr	45 Therms/yr	45 Therms/yr	45 Therms/yr	45 Therms/yr	45 Therms/yr	45 Therms/yr	45 Therms/yr
Dishwasher	206 kWh/yr, 5-gal DHW/day	Standard, 462 kWh, eight place setting capacity, 131.6 kWh/yr machine energy, 5.39-gal/day DHW	Standard, 462 kWh, eight place setting capacity, 131.6 kWh/yr machine energy, 5.39-gal/day DHW	Standard, 462 kWh, eight place setting capacity, 131.6 kWh/yr machine energy, 5.39-gal/day DHW	Standard, 462 kWh, eight place setting capacity, 131.6 kWh/yr machine energy, 5.39-gal/day DHW	Standard, 462 kWh, eight place setting capacity, 131.6 kWh/yr machine energy, 5.39-gal/day DHW	Standard, 462 kWh, eight place setting capacity, 131.6 kWh/yr machine energy, 5.39-gal/day DHW	Standard, 462 kWh, eight place setting capacity, 131.6 kWh/yr machine energy, 5.39-gal/day DHW	Standard, 462 kWh, eight place setting capacity, 131.6 kWh/yr machine energy, 5.39-gal/day DHW
Clothes Dryer	Gas - 71.6kWh/yr, 31.3 Therms/yr	Gas - 5.7 ft^3, 2.75 EF, 70.1 kWh/yr, 31.8 therms/yr	Gas - 5.7 ft^3, 2.75 EF, 70.1 kWh/yr, 31.8 therms/yr	Gas - 5.7 ft^3, 2.75 EF, 70.1 kWh/yr, 31.8 therms/yr	Gas - 5.7 ft^3, 2.75 EF, 70.1 kWh/yr, 31.8 therms/yr	Gas - 5.7 ft^3, 2.75 EF, 70.1 kWh/yr, 31.8 therms/yr	Gas - 5.7 ft^3, 2.75 EF, 70.1 kWh/yr, 31.8 therms/yr	Gas - 5.7 ft^3, 2.75 EF, 70.1 kWh/yr, 31.8 therms/yr	Gas - 5.7 ft^3, 2.75 EF, 70.1 kWh/yr, 31.8 therms/yr
Clothes Washer	105 kWh/yr, 15 gal/day	Standard, 3.15 ft^3, 533 kWh/yr, 1.16 MEF, 65.6 kWh/yr machine energy, 4.63-gal/day DHW	Standard, 3.15 ft^3, 533 kWh/yr, 1.16 MEF, 65.6 kWh/yr machine energy, 4.63-gal/day DHW	Standard, 3.15 ft^3, 533 kWh/yr, 1.16 MEF, 65.6 kWh/yr machine energy, 4.63-gal/day DHW	Standard, 3.15 ft^3, 533 kWh/yr, 1.16 MEF, 65.6 kWh/yr machine energy, 4.63-gal/day DHW	Standard, 3.15 ft^3, 533 kWh/yr, 1.16 MEF, 65.6 kWh/yr machine energy, 4.63-gal/day DHW	Standard, 3.15 ft^3, 533 kWh/yr, 1.16 MEF, 65.6 kWh/yr machine energy, 4.63-gal/day DHW	Standard, 3.15 ft^3, 533 kWh/yr, 1.16 MEF, 65.6 kWh/yr machine energy, 4.63-gal/day DHW	Standard, 3.15 ft^3, 533 kWh/yr, 1.16 MEF, 65.6 kWh/yr machine energy, 4.63-gal/day DHW

Table B.1 (continued). BEopt Option Results for Single-Story Case

CATEGORY	BENCHMARK	35% POINT	NEIGHBOR 1	NEIGHBOR 2	NEIGHBOR 3	NEIGHBOR 4	NEIGHBOR 5	NEXT POINT ON OPT. CURVE	39% POINT
Interior Lighting	1574 kWh/yr Hardwired, 331 kWh/yr Plug in	14% CFL, 1574 kWh/yr Hardwired, 331 kWh/yr Plug in	76% CFL, 749 kWh/yr Hardwired, 571 kWh/yr Plug in	14% CFL, 1574 kWh/yr Hardwired, 331 kWh/yr Plug in	14% CFL, 1574 kWh/yr Hardwired, 331 kWh/yr Plug in	14% CFL, 1574 kWh/yr Hardwired, 331 kWh/yr Plug in	14% CFL, 1574 kWh/yr Hardwired, 331 kWh/yr Plug in	14% CFL, 1574 kWh/yr Hardwired, 331 kWh/yr Plug in	14% CFL, 1574 kWh/yr Hardwired, 331 kWh/yr Plug in
Air Conditioner	SEER 10, 0.55 W/CFM AH Fan	SEER 10, 2.5 Tons, 0.365 W/CFM AH Fan	SEER 12, 2.5 Tons, 0.365 W/CFM AH Fan	SEER 10, 2.5 Tons, 0.365 W/CFM AH Fan	SEER 12, 3 Tons, 0.365 W/CFM AH Fan	SEER 10, 3 Tons, 0.365 W/CFM AH Fan	SEER 10, 3 Tons, 0.365 W/CFM AH Fan	SEER 10, 2.5 Tons, 0.365 W/CFM AH Fan	SEER 10, 2 Tons, 0.365 W/CFM AH Fan
Furnace	78% AFUE	80% AFUE, 50 kBtu/hr	80% AFUE, 75 kBtu/hr	80% AFUE, 50 kBtu/hr	80% AFUE, 75 kBtu/hr	80% AFUE, 75 kBtu/hr	80% AFUE, 50 kBtu/hr	80% AFUE, 50 kBtu/hr	80% AFUE, 50 kBtu/hr
Ducts	100% Attic, 5% AH fan flow leakage to the outside	Inside Conditioned Space, SA leakage = 1%, OA leakage = 0.23% of fan flow	Typical, SA leakage = 10%, OA leakage = 5% of fan flow	Inside Conditioned Space, SA leakage = 1%, OA leakage = 0.23% of fan flow	Inside Conditioned Space, SA leakage = 1%, OA leakage = 0.23% of fan flow	Inside Conditioned Space, SA leakage = 1%, OA leakage = 0.23% of fan flow	Inside Conditioned Space, SA leakage = 1%, OA leakage = 0.23% of fan flow	Inside Conditioned Space, SA leakage = 1%, OA leakage = 0.23% of fan flow	Inside Conditioned Space, SA leakage = 1%, OA leakage = 0.23% of fan flow
Water Heater	Gas, 40 gal, 0.54EF, 0.76RE	Gas Standard, 40 gallons, 0.55 EF, 0.76 RE	Gas Standard, 40 gallons, 0.55 EF, 0.76 RE	Gas Standard, 40 gallons, 0.55 EF, 0.76 RE	Gas Standard, 40 gallons, 0.55 EF, 0.76 RE	Gas Standard, 40 gallons, 0.55 EF, 0.76 RE	Gas Standard, 40 gallons, 0.55 EF, 0.76 RE	Gas Standard, 40 gallons, 0.55 EF, 0.76 RE	Gas Standard, 40 gallons, 0.55 EF, 0.76 RE

Table B.2. BEopt Energy and Savings Results for Single-Story Case

	BENCHMARK	35% POINT	NEIGHBOR 1	NEIGHBOR 2	NEIGHBOR 3	NEIGHBOR 4	NEIGHBOR 5	NEXT POINT ON OPT. CURVE	39% POINT
	Energy End Use (MBtu/yr)								
Misc. (E)	39.84	38.74	38.74	38.74	38.74	38.74	38.73	38.74	38.74
Lights (E)	16.13	16.13	8.99	16.13	16.13	16.13	16.13	16.13	16.13
Heating Fan (E)	0.95	0.34	0.42	0.20	0.21	0.22	0.17	0.32	0.30
Cooling Fan (E)	22.44	7.21	9.24	7.08	7.86	7.94	7.76	7.17	6.41
Cooling (E)	108.95	54.67	55.46	53.33	51.21	60.49	58.87	54.26	47.95
Heating (G)	14.40	7.60	10.10	4.60	5.00	5.20	4.00	7.30	6.70
Hot Water (G)	16.32	14.54	14.54	14.54	14.54	14.54	14.54	14.54	14.54
Misc. (G)	9.79	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10
Total	228.82	147.33	145.60	142.74	141.79	151.37	148.31	146.56	138.88
				End Use Savings					
Misc. (E)		2.8%	2.8%	2.7%	2.7%	2.8%	2.8%	2.8%	2.8%
Lights (E)		0.0%	44.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Heating Fan (E)		64.1%	55.2%	79.2%	77.5%	76.5%	82.4%	65.8%	68.1%
Cooling Fan (E)		67.8%	58.8%	68.4%	65.0%	64.6%	65.4%	68.1%	71.4%
Cooling (E)		49.8%	49.1%	51.0%	53.0%	44.5%	46.0%	50.2%	56.0%
Heating (G)		47.2%	29.9%	68.1%	65.3%	63.9%	72.2%	49.3%	53.5%
Hot Water (G)		10.9%	10.9%	10.9%	10.9%	10.9%	10.9%	10.9%	10.9%
Misc. (G)		17.2%	17.2%	17.2%	17.2%	17.2%	17.2%	17.2%	17.2%
Total Energy Savings		35.6%	36.4%	37.6%	38.0%	33.8%	35.2%	35.9%	39.3%

Table B.3. BEopt Option Results for Two-Story Case

CATEGORY	BENCHMARK	35% POINT	NEIGHBOR 1	NEIGHBOR 2	NEIGHBOR 3	NEIGHBOR 4	NEIGHBOR 5	NEXT POINT ON OPT. CURVE	39% POINT
Walls	U = 0.085, 23% FF, R11 batt, 2x4 16 in. oc + R2.5 sheathing	R19, 2x6, 24 in. oc	R19, 2x6, 24 in. oc	R19, 2x6, 24 in. oc	R19, 2x6, 24 in. oc	R13, 2x4, 16 in. oc	R13, 2x4, 16 in. oc	R19, 2x6, 24 in. oc	R19, 2x6, 24 in. oc
Ceiling	U = 0.042, 11% FF, R-24	R-30 fiberglass	R-30 fiberglass	R-30 fiberglass	R-30 fiberglass	R-60 fiberglass	R-30 fiberglass	R30 fiberglass	R30 fiberglass
Thermal Mass	8lbs/ft^2 - furniture, standard light frame construction	½-in. Ceiling Drywall	½-in. Ceiling Drywall	½-in. Ceiling Drywall	½-in. Ceiling Drywall	½-in. Ceiling Drywall	½-in. Ceiling Drywall	½-in. Ceiling Drywall	½-in. Ceiling Drywall
Infiltration	SLA = 0.00057	SLA = 0.0005	SLA = 0.0005	SLA = 0.0003	SLA = 0.0005	SLA = 0.0005	SLA = 0.0005	SLA = 0.0005	SLA = 0.0005
Slab	Uninsulated	Uninsulated	Uninsulated	Uninsulated	Uninsulated	Uninsulated	Uninsulated	Uninsulated	Uninsulated
Glass Type	U = 0.79, SHGC = 0.65	Two-pane clear, U = 0.49, SHGC = 0.76 Center of Glass, insulated spacer, Vinyl frame	Two-pane clear, U = 0.49, SHGC = 0.76 Center of Glass, insulated spacer, Vinyl frame	Two-pane clear, U = 0.49, SHGC = 0.76 Center of Glass, insulated spacer, Vinyl frame	Two-pane clear, U = 0.49, SHGC = 0.76 Center of Glass, insulated spacer, Vinyl frame	Two-pane clear, U = 0.49, SHGC = 0.76 Center of Glass, insulated spacer, Vinyl frame	Two-pane Low-e, U = 0.32, SHGC = 0.64 Center of Glass, insulated spacer, Vinyl frame	Two-pane clear, U = 0.49, SHGC = 0.76 Center of Glass, insulated spacer, Vinyl frame	Two-pane clear, U = 0.49, SHGC = 0.76 Center of Glass, insulated spacer, Vinyl frame
Window Area per Wall	540 ft^2, Equal distANCE On four sides	540 ft^2, 12.5% N&S, 50% W, 25% E	540 ft^2, 12.5% N&S, 50% W, 25% E	540 ft^2, 12.5% N&S, 50% W, 25% E	540 ft^2, 12.5% N&S, 50% W, 25% E	540 ft^2, 12.5% N&S, 50% W, 25% E	540 ft^2, 12.5% N&S, 50% W, 25%E	540 ft^2, 12.5% N&S, 50% W, 25% E	540 ft^2, 12.5% N&S, 50% W, 25% E
Refrigerator	669 kWh/yr	671 kWh/yr	671 kWh/yr	671 kWh/yr	671 kWh/yr	671 kWh/yr	671 kWh/yr	671 kWh/yr	671 kWh/yr
Cooking Range	45 Therms/yr	45 Therms/yr	45 Therms/yr	45 Therms/yr	45 Therms/yr	45 Therms/yr	45 Therms/yr	45 Therms/yr	45 Therms/yr

Table B.3 (continued). BEopt Option Results for Two-Story Case

CATEGORY	BENCHMARK	35% POINT	NEIGHBOR 1	NEIGHBOR 2	NEIGHBOR 3	NEIGHBOR 4	NEIGHBOR 5	NEXT POINT ON OPT. CURVE	39% POINT
Dishwasher	206 kWh/yr, 5 gal DHW/day	Standard, 462 kWh, 8 place setting capacity, 131.6 kWh/yr machine energy, 5.39 gal/day DHW	Standard, 462 kWh, eight place setting capacity, 131.6 kWh/yr machine energy, 5.39 gal/day DHW	Standard, 462 kWh, eight place setting capacity, 131.6 kWh/yr machine energy, 5.39 gal/day DHW	ENERGY STAR, 384 kWh, eight place setting capacity, 82.2 kWh/yr machine energy, 3.76 gal/day DHW	Standard, 462 kWh, eight place setting capacity, 131.6 kWh/yr machine energy, 5.39 gal/day DHW	Standard, 462 kWh, eight place setting capacity, 131.6 kWh/yr machine energy, 5.39 gal/day DHW	Standard, 462 kWh, eight place setting capacity, 131.6 kWh/yr machine energy, 5.39 gal/day DHW	Standard, 462 kWh, eight place setting capacity, 131.6 kWh/yr machine energy, 5.39 gal/day DHW
Clothes Dryer	Gas - 71.6 kWh/yr, 31.3 Therms/yr	Gas - 5.7 ft^3, 2.75 EF, 70.1 kWh/yr, 31.8 therms/yr	Gas - 5.7 ft^3, 2.75 EF, 70.1 kWh/yr, 31.8 therms/yr	Gas - 5.7 ft^3, 2.75 EF, 70.1 kWh/yr, 31.8 therms/yr	Gas - 5.7 ft^3, 2.75 EF, 70.1 kWh/yr, 31.8 therms/yr	Gas - 5.7 ft^3, 2.75 EF, 70.1 kWh/yr, 31.8 therms/yr	Gas - 5.7 ft^3, 2.75 EF, 70.1 kWh/yr, 31.8 therms/yr	Gas - 5.7 ft^3, 2.75 EF, 70.1 kWh/yr, 31.8 therms/yr	Gas - 5.7 ft^3, 2.75 EF, 70.1 kWh/yr, 31.8 therms/yr
Clothes Washer	105 kWh/yr, 15 gal/day	Standard, 3.15 ft^2, 533 kWh/yr, 1.16 MEF, 65.6 kWh/yr machine energy, 4.63 gal/day DHW	Standard, 3.15 ft^3, 533 kWh/yr, 1.16 MEF, 65.6 kWh/yr machine energy, 4.63 gal/day DHW	Standard, 3.15 ft^3, 533 kWh/yr, 1.16 MEF, 65.6 kWh/yr machine energy, 4.63 gal/day DHW	Standard, 3.15 ft^3, 533 kWh/yr, 1.16 MEF, 65.6 kWh/yr machine energy, 4.63 gal/day DHW	Standard, 3.15 ft^3, 533 kWh/yr, 1.16 MEF, 65.6 kWh/yr machine energy, 4.63 gal/day DHW	Standard, 3.15 ft^3, 533 kWh/yr, 1.16 MEF, 65.6 kWh/yr machine energy, 4.63 gal/day DHW	Standard, 3.15 ft^3, 533 kWh/yr, 1.16 MEF, 65.6 kWh/yr machine energy, 4.63 gal/day DHW	Standard, 3.15 ft^3, 533 kWh/yr, 1.16 MEF, 65.6 kWh/yr machine energy, 4.63 gal/day DHW
Interior Lighting	14% CFL, 2284 kWh/yr Hardwired, 571 kWh/yr Plug in	14% CFL, 2534 kWh/yr Hardwired, 571 kWh/yr Plug in	14% CFL, 2534 kWh/yr Hardwired, 571 kWh/yr Plug in	14% CFL, 2534 kWh/yr Hardwired, 571 kWh/yr Plug in	14% CFL, 2534 kWh/yr Hardwired, 571 kWh/yr Plug in	14% CFL, 2534 kWh/yr Hardwired, 571 kWh/yr Plug in	14% CFL, 2534 kWh/yr Hardwired, 571 kWh/yr Plug in	14% CFL, 2534 kWh/yr Hardwired, 571 kWh/yr Plug in	14% CFL, 2534 kWh/yr Hardwired, 571 kWh/yr Plug in
Air Conditioner	SEER 10, 0.55 W/CFM AH Fan	SEER 12, 4.00 Tons, 0.365 W/CFM AH Fan	SEER 12, 4.00 Tons, 0.365 W/CFM AH Fan	SEER 12, 4.00 Tons, 0.365 W/CFM AH Fan	SEER 13, 4.00 Tons, 0.365 W/CFM AH Fan	SEER 12, 4.00 Tons, 0.365 W/CFM AH Fan	SEER 12, 4.00 Tons, 0.365 W/CFM AH Fan	SEER 13, 4.00 Tons, 0.365 W/CFM AH Fan	SEER 14, 4.00 Tons, 0.383 W/CFM AH Fan
Furnace	78% AFUE	80% AFUE, 100 kBtu/hr	80% AFUE, 100 kBtu/hr	80% AFUE, 100 kBtu/hr	80% AFUE, 100 kBtu/hr	80% AFUE, 125 kBtu/hr	80% AFUE, 100 kBtu/hr	80% AFUE, 100 kBtu/hr	80% AFUE, 100 kBtu/hr

Table B.3 (continued). BEopt Option Results for Two-Story Case

CATEGORY	BENCHMARK	35% POINT	NEIGHBOR 1	NEIGHBOR 2	NEIGHBOR 3	NEIGHBOR 4	NEIGHBOR 5	NEXT POINT ON OPT. CURVE	39% POINT
Ducts	65% Attic, 35% Conditioned Space, 1.5% AH fan flow leakage to the outside	Inside Conditioned Space, SA leakage = 1%, OA leakage = 0.23% of fan flow	Inside Conditioned Space, SA leakage = 1%, OA leakage = 0.23% of fan flow	Inside Conditioned Space, SA leakage = 1%, OA leakage = 0.23% of fan flow	Inside Conditioned Space, SA leakage = 1%, OA leakage = 0.23% of fan flow	Inside Conditioned Space, SA leakage = 1%, OA leakage = 0.23% of fan flow	Inside Conditioned Space, SA leakage = 1%, OA leakage = 0.23% of fan flow	Inside Conditioned Space, SA leakage = 1%, OA leakage = 0.23% of fan flow	Inside Conditioned Space, SA leakage = 1%, OA leakage = 0.23% of fan flow
Water Heater	Gas, 40 gal, 0.54 EF, 0.76 RE	Gas Standard, 40 gallons, 0.55 EF, 0.76RE	Gas Tankless, 0.84 EF	Gas Standard, 40 gallons, 0.55 EF, 0.76 RE	Gas Standard, 40 gallons, 0.55 EF, 0.76 RE	Gas Standard, 40 gallons, 0.55 EF, 0.76 RE	Gas Standard, 40 gallons, 0.55 EF, 0.76 RE	Gas Standard, 40 gallons, 0.55 EF, 0.76 RE	Gas Standard, 40 gallons, 0.55 EF, 0.76 RE

Table B.4. BEopt Energy and Savings Results for Two-Story Case

CATEGORY	BENCHMARK	35% POINT	NEIGHBOR 1	NEIGHBOR 2	NEIGHBOR 3	NEIGHBOR 4	NEIGHBOR 5	NEXT POINT ON OPT. CURVE	39% POINT
Energy End Use (MBtu/yr)									
Misc. (E)	67.94	66.84	66.84	66.84	66.33	66.84	66.83	66.83	66.84
Lights (E)	25.98	25.98	25.98	25.98	25.98	25.98	25.98	25.98	25.98
Heating Fan (E)	1.55	0.44	0.44	0.26	0.44	0.52	0.46	0.44	0.46
Cooling Fan (E)	36.84	14.43	14.43	13.95	14.12	14.54	13.54	14.12	14.83
Cooling (E)	185.20	97.13	97.13	93.23	90.68	98.17	90.82	90.68	83.76
Heating (G)	24.00	10.30	10.30	6.40	10.30	12.00	10.60	10.30	10.20
Hot Water (G)	16.32	14.54	8.25	14.54	14.24	14.54	14.54	14.54	14.54
Misc. (G)	9.79	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10
Total	367.62	237.76	231.47	229.31	230.19	240.69	230.88	231.00	224.71

Table B.4 (continued). BEopt Energy and Savings Results for Two-Story Case

CATEGORY	BENCHMARK	35% POINT	NEIGHBOR 1	NEIGHBOR 2	NEIGHBOR 3	NEIGHBOR 4	NEIGHBOR 5	NEXT POINT ON OPT. CURVE	39% POINT
End Use Savings									
Misc. (E)		1.6%	1.6%	1.6%	2.4%	1.6%	1.6%	1.6%	1.6%
Lights (E)		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Heating Fan (E)		71.5%	71.5%	83.1%	71.6%	66.7%	70.2%	71.6%	70.1%
Cooling Fan (E)		60.8%	60.8%	62.1%	61.7%	60.5%	63.3%	61.7%	59.7%
Cooling (E)		47.6%	47.6%	49.7%	51.0%	47.0%	51.0%	51.0%	54.8%
Heating (G)		57.1%	57.1%	73.3%	57.1%	50.0%	55.8%	57.1%	57.5%
Hot Water (G)		10.9%	49.5%	10.9%	12.8%	10.9%	10.9%	10.9%	10.9%
Misc. (G)		17.2%	17.2%	17.2%	17.2%	17.2%	17.2%	17.2%	17.2%
Total Energy Savings		35.3%	37.0%	37.6%	37.4%	34.5%	37.2%	37.2%	38.9%

BEopt Cost and Performance Input Assumptions

As with any analysis study, the results of the analysis are subject to the assumptions used during the study. The cost and performance assumptions used in the present study are documented in this Appendix. These assumptions will be updated on a regular basis as new information becomes available from residential field studies. The use of specific manufacturer names in this Appendix does not represent an endorsement or recommendation for use of a specific product. This Appendix is limited to categories that include multiple options specific to the optimizations performed and may not representative of all the possible options currently available within BEopt.

Table B.5. Utility and Onsite Power Inputs

Group	Input Variable	Value	Units
Economics	**Electricity Source/Site Ratio**	**3**	
	Electricity Cost	0.0778	$/kWh
	Natural Gas Cost	0.7986	$/therm
	Discount Rate	0.05	
	Mortgage Interest Rate	0.07	
	Marginal Income Tax Rate	0.28	
	Analysis Period	30	years
	Net Metered Excess Sellback Rate	Local electric rate	$/kWh
	Efficiency Cost Multiplier	1	
Photovoltaics	**Module**	**Sharp NEH120E1**	
	Installed Cost	7.5 (unless noted otherwise)	$/rated W
	Derate Factor	Determined by location	%
	Daily Incident Solar	Determined by location	kWh/m^2
	Average System Efficiency	Determined by location	%

Table B.6. BEopt Cost Assumptions

CATEGORY/OPTION	UNIT COST
Slab	**($/ft)**
Uninsulated	$0.00
2-ft R5 Perimeter, R-5 Gap	$1.38
4-ft R5 Perimeter, R-5 Gap	$2.36
2-ft R10 Perimeter, R-5 Gap	$2.22
4-ft R10 Perimeter, R-5 Gap	$3.92
15-ft R10 Perimeter, R-5 Gap	$8.19
Wall Construction	**($/ft^2)**
R-11 batts, 2x4, 16 in.oc	$3.15
R-13 batts, 2x4, 16 in. oc	$3.17
R-11 batts, 2x4, 16 in. oc + 1-in. foam sheathing	$3.92
R-19 batts, 2x6, 24 in. oc	$3.28
R-19 batts, 2x6, 24 in. oc + 1-in. foam sheathing	$4.05
R-19 batts, 2x6, 24 in. oc + 2-in. foam sheathing	$4.24
Ceiling Insulation	**($/ft^2)**
R-30 Fiberglass	$0.55
R-40 Fiberglass	$0.73
R-50 Fiberglass	$0.92
R-60 Fiberglass	$1.10
Thermal Mass	**($/ft^2)**
Standard ½-in. Ceiling Drywall	$0.19

Table B.6 (continued). BEopt Cost Assumptions

CATEGORY/OPTION	UNIT COST
5/8-in. Ceiling Drywall	$0.27
2 x ½-in. Ceiling Drywall	$0.38
2 x 5/8-in. Ceiling Drywall	$0.54
Infiltration	**($/ft^2)**
Typical (SLA = 0.0005)	$0.00
Tight (SLA = 0.0003)	$0.54
Windows	**($/ft^2)**
Two-pane clear, U = 0.49, SHGC = 0.76 Center of Glass, insulated spacer, Vinyl frame	$21.99
Low-e (e = 0.01), double pane, U = 0.32, SHGC = 0.64 Center of Glass, insulated spacer, Vinyl frame	$24.77
Low-e (e 0.1 w/ tint), double pane, U = 0.31, SHGC = 0.37 Center of Glass, insulated spacer, Vinyl frame	$24.77
Low-e (e = 0.04), double pane, U = 0.3, SHGC = 0.44 Center of Glass, insulated spacer, Vinyl frame	$24.77
Low-e (e = 0.04 w/tint), double pane, U = 0.29, SHGC = 0.29 Center of Glass, insulated spacer, Vinyl frame	$24.77
Heat Mirror (HM22), U = 0.21, SHGC = 0.14 Center of Glass, insulated spacer, Vinyl frame	$30.32
Heat Mirror (HM TC88), U = 0.18, SHGC = 0.48 Center of Glass, insulated spacer, Vinyl frame	$30.32
Refrigerator	**($/unit)**
Standard - 671 kWh/yr	$1,099.99
ENERGY STAR - 572kWh/yr	$1,219.99

Table B.6 (continued). BEopt Cost Assumptions

CATEGORY/OPTION	UNIT COST
Dishwasher	**($/unit)**
Standard, 462 kWh, eight place setting capacity, 131.6 kWh/yr machine energy, 5.39 gal/day DHW	$239.00
ENERGY STAR, 384 kWh, eight place setting capacity, 82.2 kWh/yr machine energy, 3.76 gal/day DHW	$299.00
Clothes Washer	**($/unit)**
Standard, 3.15 ft^3, 533 kWh/yr, 1.16 MEF, 65.6 kWh/yr machine energy, 4.63 gal/day DHW	$419.00
ENERGY STAR, top loader, H-axis, 2.9 ft^3, 273 kWh/yr, 1.68 MEF, 72.9 kWh/yr machine energy, 3.71 gal/day DHW	$799.00
Lighting	**($/bulb)**
Incandescent	$0.25
CFL	$7.99
Air Conditioner SEER value	**Efficiency Cost ($) = 0.817*((186*SEERvalue)-1535)**
10	$265.53
12	$569.45
13	$721.41
14	$873.37
15	$1,025.34
16	$1,177.30
17	$1,329.26
18	$1,481.22

Table B.6 (continued). BEopt Cost Assumptions

CATEGORY/OPTION	UNIT COST
Air Conditioner Capacity (tons)	**Capacity Cost ($) = 0.817*(563*tons)**
0.5	$229.99
1.0	$459.97
1.5	$689.96
2.0	$919.94
2.5	$1,149.93
3.0	$1,379.91
3.5	$1,609.90
4.0	$1,839.88
Furnace Efficiency (% AFUE)	**Efficiency Cost ($) = (23.57*AFUE%*100)-1621**
80%	$264.60
92.5%	$559.23
Furnace Capacity (kBtu/hr)	**Capacity Cost ($) = 2.92*kBtu/hr**
25 kBtu/hr	$73.00
50 kBtu/hr	$146.00
75 kBtu/hr	$219.00
100 kBtu/hr	$292.00
125 kBtu/hr	$365.00
150 kBtu/hr	$438.00
175 kBtu/hr	$511.00
200 kBtu/hr	$584.00

Table B.6 (continued). BEopt Cost Assumptions

CATEGORY/OPTION	UNIT COST
Water Heater	**($/unit, install + equip)**
Gas Standard, 40 gallons, 0.55 EF	$428.00
Gas Premium, 40 gallon , 0.62EF	$624.08
Gas Tankless, 0.84 EF	$1,050.00
Ducts	**($/ft^2 FFA)**
Typical, SA leakage = 10%, OA leakage = 2.3% of fan flow	$0.45
Improved, SA leakage = 2.3%, OA leakage = 0.5% of fan flow	$0.69
Inside Conditioned Space, SA leakage = 1%, OA leakage = 0.23% of fan flow	$0.77

Appendix C: List of Key Trade-based Certifications

Preferred Contractors Program Draft

Below is a preliminary list of the different trade classifications and the sub-specializations that could be associated with a new-home certified-contractors program. The concept is to have a broad range of specialist classifications, to acknowledge the fragmentation and specialization that is inherent in the construction industry. This encourages even those trades who do a very limited scope of work (i.e., just window installation or just duct rough in) to become certified specialists in their field, which requires them to also have a broader understanding of how that piece fits into the bigger house as a system. This concept will need to be discussed with manufacturers and trade contractors to determine its practicality.

1. HVAC
    a. Space-Conditioning System Design Specialist
    b. Duct Design Specialist
    c. Air-Distribution System Installation Specialist
    d. Equipment Installation and Start-up Specialist
        i. Fossil and electric heating
        ii. Refrigeration – AC / Heat Pump
    e. Airflow Balancing Specialist
2. Carpentry
    a. Framing Specialist
3. Thermal envelope
    a. Insulation Specialist
    b. Air-sealing Specialist
4. Above-grade moisture management
    a. Window and Door Installation Specialist
    b. Wall Drainage Plane Specialist
    c. Roof Drainage and Flashing Specialist
5. Below-grade moisture management
    a. Below-Grade Moisture Management Specialist
6. Designers
    a. Architect / Residential Designer
    b. Engineer

Within each of the specializations is a more detailed description of the probable roles and competencies required.

1. HVAC
    a. Space-Conditioning System Design Specialist
        i. Load Calculation, Ventilation, and Equipment-Selection Specialist
            1. Proficiency in ACCA Manual J method for load calculation and how to account for higher performance when calculating heating and cooling loads
            2. Understands relationship between high-performance house (thermal envelope strategies to achieve high-performance homes) and heating and cooling loads to be satisfied by the space-conditioning equipment
            3. Surface area competencies and understanding of thermal envelope assemblies (i.e., framing factors, window properties, etc.)
            4. Understands the types of ventilation systems and their interaction with the heating and cooling equipment
            5. Understands dedicated humidity control options and how to integrate with space-conditioning systems
            6. Understands the internal gains and latent loads associated with people and ventilation
            7. Understands the impact of climate, shading, and other environmental impacts on the building.
        ii. Duct Design Specialist
            1. Understands the impact of duct friction with respect to airflows (equivalent length methods – ACCA Manual D)
            2. Familiarity with structural systems and limitations regarding using running duct systems within structural systems (floor-framing systems, walls, etc.)
            3. Air distribution options in higher performance homes (high sidewall, central return, etc.)
            4. Acoustics of air distribution systems
    b. Air-Distribution System Installation Specialist
        i. Follows layout by Duct-Design Specialist
        ii. Understands duct-sealing techniques
        iii. Understands ventilation system concepts as they relate to ducts and equipment installation issues
        iv. Certified in duct-system leakage testing
        v. Sets furnace and inside AC coils as part of air system

c. Equipment Installation and Start-up Specialists
    i. Installation of equipment and associated refrigeration
    ii. Start-up and commissioning of heating, cooling and ventilation systems
d. Airflow Balancing Specialist
    i. Airflow at the equipment
    ii. Total system duct leakage testing
    iii. Room-by-room airflow balancing and measurement

2. Carpentry
    a. Framing Specialist
        i. Optimum value engineering of wood frame structures
            1. Stack framing
            2. Wall layout and value engineering wall-framing techniques
            3. Floor framing and interaction with HVAC system and plumbing system
            4. Structural and code limitations
        ii. Air-sealing techniques incorporated during framing (i.e., band joist gluing and sealing, mud sill sealing, cantilevers, floors over garages, chases, etc.)

3. Thermal envelope
    a. Insulation Specialist
        i. Insulation basics
            1. How insulation works
            2. Encapsulation requirements
            3. Types of insulation products, limitations, and applications
            4. Insulation and flame spread issues
        ii. Blown-in wall techniques (new and retrofit)
            1. Damp spray
            2. Net and fill cavity
            3. Two-hole method
            4. Hole and tube (dense pack)
        iii. Blown attic and horizontal cavity (floor, cantilever, etc.)
        iv. Batt installation
        v. Below-grade insulation systems (interior)
        vi. Crawlspace vapor barrier installation
        vii. Sub-Specialist designation

b. Air-Sealing Specialist
    viii. Envelope air-tightening techniques
    ix. Window and door rough openings
    x. Framing intersections
    xi. Bypasses / chases / soffits
    xii. Cantilevers, floors over unconditioned spaces
    xiii. Fire codes and safety
    xiv. Diagnostics
    xv. Blower door
        1. Pre- and post-testing
        2. Blower door directed air-sealing techniques
    xvi. Infrared imaging
    xvii. Pressure diagnostics

4. Above-grade moisture management
    a. Window and Door Installation Specialist
        i. Flashings
        ii. Integration to drainage plane
    b. Wall Drainage Plane Specialist
        i. Drainage plane installation
        ii. Integration with windows and doors
        iii. Integration with roof flashing systems
        iv. Roof-flashing systems at wall intersections
    c. Roof Drainage and Flashing Specialist
        i. Roof-penetration flashings
        ii. Roof wallflashing systems
        iii. Integration to wall systems
        iv. Gutter and downspouts
5. Below-grade moisture management
    a. Below-Grade Moisture Management Specialist
        i. Perimeter drainage systems
        ii. Sub-slab capillary break and vapor diffusion control
        iii. Capillary break at footing
        iv. Vapor barrier at crawlspaces
        v. Foundation damp-proofing systems
        vi. Foundation waterproofing systems

6. Designers
    a. Architect / Residential Designer
    b. Engineer

Appendix D: National Housing Quality Rating Table

Table D.1. Leadership

Leaders align everyone in the organization with a common purpose, values, and priorities.

	Level 1	Level 2	Level 3	IBACOS Level 3	Level 4	*IBACOS Level 4*	Level 5	*IBACOS Level 5*
1.1 Company Mission, Vision, and Values	Company's main quality goal is to avoid customer disappointment and complaints.	Quality and customer satisfaction is important to the company but not included in a written mission statement.	Written company mission statement includes a commitment to quality and customer satisfaction.	Quality is defined in the five key performance metrics (Health, Safety, Durability, Efficiency & Comfort) with measurable attributes associated with the definition.	In addition to level 3, values or principles important to the company are included in a written statement.	Performance metrics of competition is Benchmarked and three of five area exceed Benchmark industry standards	In addition to level 4, there is a compelling future vision of what the company can become.	Vision is created with stretch goals for all five performance metrics
1.2 Senior Management Involvement	Senior managers get involved with quality to handle customer complaints.	Senior managers like the idea of quality but are not involved in improvement activities.	Senior managers demonstrate personal commitment to the company's quality mission and are often involved in quality-related activities	Performance attributes are given equal weight to other quality criteria. Quality Management is a cross-cutting management function	Senior managers constantly communicate the company's quality mission to customers, employees, and trade contractors.	One point of contact for managing the performance attributes of the home from pre-design through warrantee. Goals of all Senior managers tied to achieving performance metrics	In addition to level 4, managers and supervisors at all levels are actively engaged in reinforcing the company mission, vision, and values.	All team members are reinforcing performance attributes at all phases and stages of product
1.3 Leadership Feedback and Improvement	Senior management uses their experience to guide the company toward their vision for the future.	Senior managers actively seek employee feedback to gauge the organization's alignment toward the company mission, vision, and values.	In addition to level 2, surveys measure the alignment of employee values and beliefs toward those of the organization.	Performance metrics are included in survey	In addition to level 3, senior managers plan initiatives to reinforce the company mission, vision, and values.	Performance metrics are included in initiatives	In addition to level 4, the leadership function is managed as a process that is continuously improved through evaluation, adjustment, and verification of results.	Performance achievements in homes is used as one measure of leadership success

Table D.1. Leadership (continued)

	Level 1	Level 2	Level 3	IBACOS Level 3	Level 4	IBACOS Level 4	Level 5	IBACOS Level 5
1.4 Living the Mission	Employees may have different priorities but there is a general understanding of what the company is trying to accomplish.	Most employees know key elements of the company mission, values, and vision for the future and could explain how it relates to their job.	Most employees recognize and support organizational mission, values, and vision, and use them to guide their decision making.	Performance metrics are instilled as one component that is used in decision making	In addition to level 3, survey data shows that most employees embrace the company mission, vision, and values. There is a strong feeling that everyone is working toward common goals.	Survey includes performance metrics and evaluates employee understanding and implementation of performance attributes	In addition to level 4, employees actively reinforce the company mission, vision, and values among themselves during the course of everyday work.	Employees are empowered and rewarded for achieving performance metrics.
1.5 Public Responsibility	Some people at the company are personally involved in activities that benefit the community, the public, or the housing industry.	When asked, the company supports activities to benefit the community, the public, or the housing industry.	Being a responsible corporate citizen is regarded as good for the company. The company is actively involved in activities to benefit the community, the public, or the housing industry.	Company involvement is related to performance metrics	In addition to level 3, the company creates opportunities to be actively involved in activities to benefit the community, the public, or the housing industry.	Company initiatives action that related to performance metrics	For its size, the company is one of the area's leading business supporters of activities to benefit the community, the public, or the housing industry.	Company is a regional or national leader in supporting initiatives related to performance metrics

Note: Yellow denotes minimum level for considering adopting a 30% whole-house energy-savings solution set.

Table D.2. Strategic Planning

Achieving a future vision of what the company can become requires creating and executing a strategic plan for getting there.

	Level 1	Level 2	Level 3	*IBACOS Level 3*	Level 4	*IBACOS Level 4*	Level 5	*IBACOS Level 5*
2.1 Company-wide Success Drivers and Performance Measures.	Measures of company performance are limited to sales and profit.	In addition to level 1, customer satisfaction is important, but performance data is not tracked.	The current customer satisfaction rating is one of the company's monthly performance measures communicated to all employees.	Customer satisfaction measurements include consumer feedback on performance metrics, and limited testing to verify performance metrics are being achieved	In addition to level 3, company-wide performance measures link directly to key success drivers for achieving the company mission and vision.	Level 3 is supplemented with statistically valid sampling plan is in place to test performance metrics	In addition to level 4, operational performance measures through all levels of the company fully support company-wide performance measures.	100% testing and commissioning strategy
2.2 Strategic Plans	Company improvement strategy is to increase sales and reduce costs, but specific action plans are not in place.	The company's competitive business strategy includes improving customer satisfaction and products that enhance homeowner value.	In addition to level 2, written improvement plans are in place with measurable goals. Plans explain how performance improvement goals will be achieved.	Written improvement plans include performance standards and testing requirements. Plan outlines cross functional leader for performance-based quality initiative	In addition to level 3, strategic plans link directly to improvement of company-wide performance measures and fully support the company's mission and values.	Performance measures are based in integrated design and construction approach.	In addition to level 4, a systematic approach is in place for using factual information and data to plan improvements to organizational performance and competitive position.	Measured data form preplanning through warrantee costs are tracked to evaluate total system design strategies and implementation results
2.3 Plan Deployment	The senior managers who make the strategic plans also carry out the improvement initiatives. Employees are involved on an as-needed basis.	Senior managers develop the strategic plan with some employee input. The plan is used to set departmental objectives.	In addition to level 2, senior managers organize employee teams to carry out improvement projects that may involve multiple departments.		A systematic process is in place for involving most employees in the development of strategic objectives, carrying out action plans to achieve them, and monitoring progress.	Most employees are involved in the performance standards setting process, and understand the role these standards play within the context of a larger quality initiative	In addition to level 4, trade contractors, product suppliers, and business partners are involved in the company's strategic improvement process.	Outside partners are an integrated part of the performance standard setting and execution process, particularly in the design process and construction phase.
2.4 Monitoring Progress to Plan	Progress is monitored on an as-needed basis.	Quarterly review meetings monitor improvement progress.	Monthly review meetings monitor actual versus planned improvement activities. Adjustments to plans are made to accommodate current status.	Measurements of key performance attributes are made to judge achievement of goals	In addition to level 3, measurement data is used to monitor performance toward strategic objectives.	Track data as a function of design effectiveness and construction improvements	In addition to level 4, root causes of plan variances are systematically analyzed, understood, and used to prevent future problems and project future performance.	Data is used to feedback into design process and records are kept of unsuccessful designs and reasons for failure.

Note: Yellow denotes minimum level for considering adopting a 30% whole-house energy-savings solution set.

Table D.3. Customer Satisfaction

Sustaining high levels of customer satisfaction requires performing well from the customer's point of view.

	Level 1	Level 2	Level 3	*IBACOS Level 3*	Level 4	*IBACOS Level 4*	Level 5	*IBACOS Level 5*
3.1a Market Research	Market requirements are learned mainly from customer requests.	In addition to level 1, market trends are learned from tours of other builders' products and builder magazines.	In addition to level 2, detailed price and feature comparisons with other builders are used to analyze competitive position and uncover unfilled market niches. Feedback from lost customers is used to analyze unfilled needs.	Product is Benchmarked compared to national and local standards. Feedback strategies also capture data regarding performance attributes	In addition to level 3, markets are analyzed by demographic groups. Surveys or focus groups identify customer preferences for features and services.	Focus groups also include exploration of key performance features in housing according to company 5-year stretch performance goals	In addition to level 4, the design of products and services anticipate market trends. They are planned through analysis of changing demographics, economic forecasts, emerging technologies, style trends, and other leading indicators.	Predictive analysis of trends in building performance, world energy, and builder litigation inform market trends
3.1b Product Design Processes	A company expert or consultants create new home designs.	In addition to level 1, select employees provide some input into the design process.	A new home design team includes construction and sales personnel.		In addition to level 3, homeowners, employees, and trade contractors are systematically included in the home design process.	Pre-design and schematic design phase activities are used to incorporate a integrated design process that embraces a systems approach to performance	In addition to level 4, a process is in place to regularly review existing designs and feedback from customers to make design improvements.	Existing product is redesigned over time to include more cost effective implementation of performance metrics
3.2 Customer Satisfaction Drivers	Avoiding homeowner disappointment with the constructed product is the main customer satisfaction priority.	Completing the home on time with a short punch list at final inspection is the company's main focus for satisfying customers.	In addition to level 2, the customer experience and relationship with the builder are important customer satisfaction drivers. Meeting customer expectations is recognized as the key to reliably satisfying customers.	Builder monitors expectation set by other builders, and seeks to set similar consumer expectations through sales process	Exceeding customer expectations is an important company priority. Employees understand how their team and department performance contributes to overall customer satisfaction.	Builder sets higher customer expectations than competition in sales process, by making performance attributes explicit.	In addition to level 4, anticipating individual needs is recognized as the means to achieve the highest levels of customer satisfaction.	Builders guarantee certain key success drivers that are related to the performance standards and attributes of the home (i.e., energy costs and supply, comfort, durability, etc.)

Table D.3. Customer Satisfaction (continued)

	Level 1	Level 2	Level 3	*IBACOS Level 3*	Level 4	*IBACOS Level 4*	Level 5	*IBACOS Level 5*
3.3 Customer Relationship Management	Maintaining good customer relationships through final inspection is the main priority. Everyone has his or her own way of working with customers, with varying degrees of effectiveness.	Maintaining good customer relationships through the end of the warranty period is the main priority. Policies for dealing with customers are in place for the sales process.	Relationships with customers are recognized as a key customer satisfaction driver. A process is in place for creating positive customer relationships in sales, construction, and service phases.		In addition to level 3, customer expectations for key customer satisfaction drivers are systematically managed throughout the customer relationship. Customers are viewed as customers for life.	Key Satisfaction Divers include Performance standards	In addition to level 4, the customer relationship process is designed to systematically exceed customer expectations. Customer satisfaction data on each customer contact point is used to set standards and improve the relationship process.	Performance Standards are designed to set a higher level of customer expectation, and process is in place to exceed those expectations
3.4a Customer Satisfaction Measurement	Customer satisfaction feedback data consists of final inspection punch lists and warranty callbacks.	Customer satisfaction is measured occasionally by surveys or by asking customers. Some questions ask customers to rate employee performance.	All customers are surveyed on their satisfaction with the home and the customer experience during the sales, construction, and warranty service periods. Questions focus on process performance rather than employee ratings.	Survey links expectations of housing performance compared to actual experience of living in home (i.e., comfort, energy performance, durability, noise, etc.)	In addition to level 3, customer satisfaction survey questions are directly linked to known customer satisfaction drivers.	Measurements for customer satisfaction include questions on key performance drivers.	In addition to level 4, feedback from customers and employees is used to refine survey questions and improve the survey process.	New metrics for satisfaction are developed for the industry
3.4b Sharing of Customer Satisfaction Feedback	Customer complaints are shared with the persons responsible.	Customer letters and surveys are routinely circulated among employees.	In addition to level 2, Summary customer satisfaction data is available to all employees. Trends are tracked and posted for all to see. Senior managers frequently discuss customer feedback with employees.		Customer satisfaction ratings are routinely communicated to the organization as one of the company-wide performance measures. Relevant customer satisfaction data is shared with suppliers and trade contractors.	Performance data is included in these survey results	Customer satisfaction is one of the company's vital few key success measures that are tracked monthly by the company's performance management system.	Customer satisfaction is linked to performance of housing, not just buying and construction process

Table D.3. Customer Satisfaction (continued)

	Level 1	Level 2	Level 3	IBACOS Level 3	Level 4	IBACOS Level 4	Level 5	IBACOS Level 5
3.5 Customer Satisfaction Results	Percentage of customers who would recommend the company to a friend is not measured.	More than 75% of customers surveyed would recommend the company to a friend. Customer satisfaction seems to be improving.	More than 85% of customers surveyed would recommend the company to a friend. There are measured improvements in customer satisfaction.	More than 85% of customers surveyed feel home meets the company standard of performance	More than 90% of customers surveyed would recommend the company to a friend. Customer satisfaction shows measured improvements in most products and services.	More than 90% of customers surveyed feel home meets the company standard of performance	More than 95% of customers surveyed would recommend the company to a friend. Customer satisfaction shows strong improvements in most products and services.	More than 95% of customers surveyed feel home meets the company standard of performance

Note: Yellow denotes minimum level for considering adopting a 30% whole-house energy-savings solution set.

Table D.4. Performance Management

	Level 1	Level 2	Level 3	IBACOS Level 3	Level 4	IBACOS Level 4	Level 5	IBACOS Level 5
4.1a Creating High-Performance Work Processes	Meeting minimum performance expectations is an important priority for most employees.	Most employees have well-defined responsibilities. Finding ways to reduce costs is the main focus of work improvement activities.	Key work processes are well defined. Customer satisfaction and cost are important work improvement priorities.	"Building performance quality management" has been identified as a key work process, and has been assigned within the organization	Customer needs drive work systems design and improvements. Some work systems are modeled on industry best practices.	The integrated design process has been mapped and assigned	Key processes have high-performance approaches and goals based upon world-class Benchmarks. Key performance metrics are tracked and used for the control and improvement of processes.	All processes associated with key building-performance standards have been identified and documented
4.1b Bench-Marking Business Processes	Information on how other builders do things is obtained mostly from publications and seminars.	Occasional visits to other builders are made to get some good ideas.	Regular visits to other builders are made to compare performance results and set improvement objectives.	Those builders visited include others who are improving building performance at Level 3 and at least one at Level 4	In addition to level 3, detailed studies of other builders' operations are used to design operational improvements.	Those builders visited include others who are improving building performance at Level 4 and at least one at Level 5	In addition to level 4, a systematic approach is used to study organizations outside the construction industry, make improvements, and set long-range goals.	Outside organizations studied reflect similar core values of performance in the product developed
4.2 Performance Management	Performance is managed by monitoring the productivity of individual employees.	In addition to level 1, conformance to department budgets is used to manage financial performance.	Performance management focuses on the productivity of key business processes. Results are tracked and reviewed monthly.	Building to a predefined performance standard is identified as a key business process	In addition to level 3, key work processes have performance measures that link directly to company-wide key success measures. Results are shared with all employees.	Performance attributes are measured and used in this process	In addition to level 4, employees, teams, and trade contractors have performance measures for their own processes that support company-wide key success measures.	Trades perform performance measurements during work
4.3 Process Improvement	Problems are handled as they occur to avoid customer complaints.	Changes to company processes are made occasionally to prevent recurring problems. Some employees are involved in improvement projects.	Improving company processes is an important part of everyone's job. There are many improvements made throughout the company. The company uses a systematic method to make improvements.	Process of designing and building for performance is identified as a key process improvement area	An effective strategy and goals are in place for involving the entire workforce in problem solving and quality improvement. Most employees have been trained in the company's process improvement methods.	Quality Process management involves workforce to continually improve performance	In addition to level 4, all major trade contractors participate in the company's problem-solving and quality improvement system.	Performance measures are part of trade feedback and design process involving trades

Table D.4. Performance Management (continued)

	Level 1	Level 2	Level 3	IBACOS Level 3	Level 4	IBACOS Level 4	Level 5	IBACOS Level 5
4.4 Improvement Results	Some company work processes seem to be improving, but there are no measures of progress.	Some company work processes show measured quality improvements.	*Most* company work processes show measured quality improvements.		Most company work processes show measured quality improvements and excellent quality results.	Performance metrics are included in this measurement	Most measures of organizational effectiveness are considered Benchmarks for the industry.	Performance standards are considered Benchmarks as well
4.5 Financial Improvement Results	Some improvements have resulted in cost reductions.	Substantial cost reductions have been made but have not yet helped improve home sales.	Home sales and company profitability show improvement.	Profitability is in some way attributable to performance standards (reduction in callbacks, improved value, etc.)	Company's share of home sales is increasing. Company profitability shows excellent results with positive trends.	Metric is developed to measure overall cross cutting impact of performance on Value, cycle, and operations to measure overall profitability	In addition to level 4, company profitability is consistently among the best among builders in the area.	

Note: Yellow denotes minimum level for considering adopting a 30% whole-house energy-savings solution set.

Table D.5. Human Resources

The human resources system must develop the full potential of employees and drive the right behaviors in support of company performance and learning objectives.

	Level 1	Level 2	Level 3	*IBACOS Level 3*	Level 4	*IBACOS Level 4*	Level 5	*IBACOS Level 5*
5.1a Employee Satisfaction	The company shows a general concern for employee well-being and morale.	Company shows that employee well-being and morale are priorities in making business decisions. There are occasional morale-building activities.	In addition to level 2, employee satisfaction is recognized as important for the company's success. Senior managers take initiatives to do what they think will improve the work environment.		The company understands which factors drive employee satisfaction. Employee surveys measure employee satisfaction and the information is used to improve the work environment.	Relationship to performance standards and end product is measured as a component of employee satisfaction	In addition to level 4, employee satisfaction is integrated into the company's strategic planning process with long-range goals and action plans.	Performance is one metric used in the strategic planning process
5.1b Jobsite Safety	There are occasional safety-related training activities.	Health and safety training is provided to all field employees.	Company shows that employee health and safety are priorities in making business decisions.		In addition to level 3, there is an organized approach to analyzing causes of injuries and preventing accidents.		In addition to level 4, trade contractors are involved in an organized approach to prevent injuries.	
5.1c Job Responsibilities	Employees learn job responsibilities from on-the-job experience.	Job descriptions define job responsibilities.	In addition to level 2, most employees clearly understand their job responsibilities and how their job contributes to company performance.	Job Responsibilities are also tied to Building Performance	In addition to level 3, employees feel responsible for performing their job to meet the needs of other employees who depend on them.	One measure is in relation to building performance by internal survey of employees and trades	In addition to level 4, employees are expected to take initiatives that exceed customer expectations or solve their problems.	
5.1d Teamwork	Individual effort is the main way things get done.	Some natural work groups are formed into operating teams with shared responsibilities.	Most employees are part of an operating team with a well-understood purpose. Teams are the main way that day-to-day work gets done.	Performance attributes and standards are part of the purpose within a team	In addition to level 3, teamwork is the primary mechanism for solving problems and making performance improvements.	Problem solving and improvements include building performance standards related issues	In addition to level 4, employees are actively engaged in teams that perform key management functions for the company.	Integrated design process brings team members in from all levels of the organization and trade partners

Table D.5. Human Resources (continued)

	Level 1	Level 2	Level 3	IBACOS Level 3	Level 4	IBACOS Level 4	Level 5	IBACOS Level 5
5.2 Workforce Development	Skills are learned on the job.	Work-related training is delivered as needed when time and budget allows.	There is a company training budget. Most employees receive some training. Most employees have personal training and development plans.	Key general training on issues related to building-performance standards is provided and specifically related to company performance standards	In addition to level 3, the company's training and hiring plan is aimed at developing the skills necessary for achieving the long-range company vision.	Training for building performance is specialized by employee and function,	In addition to level 4, the company has a systematic skills-development program for key job positions.	Key positions are targeted for more in-depth building-science training
5.3 Employee Evaluation and Compensation Systems	Most employees receive an annual performance review.	Annual employee performance reviews have well-defined evaluation criteria. Bonuses and recognition reward individual efforts.	In addition to level 2, employee performance evaluation criteria are linked to job descriptions. Bonuses focus on *team* efforts.	Evaluation criteria include measurement of achievement of building-performance standards	Employee performance evaluation criteria are based on fulfillment of personal development plans and key elements of the company mission, vision, and values.	Building Performance standards are one of the Key elements	In addition to level 4, employee bonuses are linked directly to performance of the company's key success measures.	Building performance is one Key success measure

Note: Yellow denotes minimum level for considering adopting a 30% whole-house energy-savings solution set.

Table D.6. Quality Construction Processes

Systematic quality management approaches are necessary to ensure high performing, trouble-free products and services.

	Level 1	Level 2	Level 3	*IBACOS Level 3*	Level 4	*IBACOS Level 4*	Level 5	*IBACOS Level 5*
6.1 Setting Quality Expectations	Informal standards exist. "We know if it's OK when we see it."	Construction details and workmanship specifications control known problem areas.	In addition to level 2, the builder, contractor, and other trades collaborate to set quality requirements. Contract scopes of work reference specific construction standards and workmanship tolerances.	Performance standards are selected and adopted by builders to meet or exceed Benchmark levels in region	In addition to level 3, requirements analysis of building codes, construction standards, product installation instructions, and industry guidelines are used to set quality specifications.	Building standards exceed Benchmark levels, and are based on a whole-house building-science approach	In addition to level 4, construction detail drawings are provided for nearly every aspect of the home.	Design documentation includes performance aspects and integrates a significant amount of means and methods descriptions to assist trades in implementation, including detailed scopes of work
6.2 Assuring Quality Results	The company fixes any defects the homeowner may find at final walk-through or during the warranty process.	Construction personnel use their experience to catch defects.	There are inspection checklists for most trades. Formal inspections are performed for each phase of construction by the builder.	Performance standards are included on checklists, some performance testing is included	In addition to level 3, trade contractors use checklists to perform quality self-inspections. The main function of builder inspections is to monitor quality performance rather than screen out defects from trade contractors.	Performance standards are included on checklists, a higher level of performance testing is included	Key trades have ISO 9000-based quality assurance systems. Conformance to specifications is a well-documented process. Company generally needs only to spot check trade contractor or product quality.	Performance standards are included on checklists, a higher level (up to 100%) of performance testing is included, but may be done as part of the trade contractors work.
6.3 Quality Problem Prevention	Quality problems are corrected as needed.	In addition to level 1, actions are taken to prevent chronic problems.	Defect data is recorded, trends monitored, and improvement objectives are set. Actions to solve defect problems occur regularly.	Troubleshooting activities use building science basis for performance based defect analysis	In addition to level 3, systematic analysis of root causes are routinely used to prevent defects. Defect prevention focuses on improving processes.	Mechanisms in place to integrate root cause prevention into design process	In addition to level 4, employees and trade contractors are actively engaged to continually refine processes toward zero defect goals.	Zero defect goals include performance attributes of buildings. Zero Defect is well defined relative to performance standards

Table D.6. Quality Construction Processes (continued)

	Level 1	Level 2	Level 3	IBACOS Level 3	Level 4	IBACOS Level 4	*Level 5*	IBACOS Level 5
6.4 Warranty Service	Service callbacks are handled but not tracked.	Systems are in place to track warranty complaints and their completion.	In addition to level 2, warranty service data is used to set priorities for solving quality problems.	Warrantee service data is broken down to capture root causes	In addition to level 3, response time and customer satisfaction with each service call are important performance measures.	Key performance drivers are identified, tracked and fed back to reduce warrantee calls and improve customer satisfaction	Warranty service excellence is among the best of builders in the area and a competitive advantage of the company.	Warranty specialist are trained in building science approach and use diagnostic skills to improve product
6.5 Product and Service Quality Results	Product and service quality seems to be improving, but there are no measures of progress.	Problems found at final inspection are decreasing. There are fewer callbacks.	Data shows that constructed quality is improving.	Quality is defined according to building science based performance metrics	Most product and service quality performance indicators show excellent results with positive trends. Zero defect final inspections are commonplace.	Defects are also measured by building science performance measurements, and are measured by testing	*All* major product and service quality performance indicators show positive improvement *trends* and *excellent* results. Most homes have zero defect final inspections.	Defects are also measured by building-science performance measurements and are measured by higher levels (up to 100%) testing

Note: Yellow denotes minimum level for considering adopting a 30% whole-house energy-savings solution set.

Table D.7. Supplier Partnerships

Partnering approaches are essential for high performance relationships with trade contractors and product manufacturers.

	Level 1	Level 2	Level 3	*IBACOS Level 3*	Level 4	*IBACOS Level 4*	Level 5	*IBACOS Level 5*
7.1 Trade Contractor and Supplier Relationships	Difficult quality problems are usually solved by changing contractors or suppliers.	A systematic process is in place for the selection of trade contractors. Trades and suppliers participate in solving problems.	Key trade contractors and suppliers are considered partners. Company helps them improve quality and reduce costs.	Performance standards are a metric of quality, testing measures improvement	In addition to level 3, most major trade contractors and suppliers participate in a systematic approach to problem-solving and quality improvement.	Company has integrated design process for contractors to participate in new construction and building-science-based solution / redesign process for existing product	In addition to level 4, trade contractors and suppliers participate in planning and implementing long-term quality improvements.	Trades are actively involved in identifying proper scopes of work, sequencing, and even-flow scheduling with builder
7.2 Trade Development	There are no formal initiatives to develop the capabilities of trade contractors.	Improving trades is focused on solving problems.	A general strategy is in place to develop the capabilities and performance of trade contractors.	Builder provides general training on Performance standards and trades relation to standards	The company's trade development plans are linked directly to achieving the company's long-range vision.	Trades are trained to understand building science approach and integrated designs, and interrelationship of their work to the overall performance standards and company goals	In addition to level 4, Key trades have their own development plans that support the company vision. The builder provides incentives for trades participating in training improvement programs.	Builder required certified trades in all key performance standards areas
7.3 Trade Contractor Performance Management	Trade performance is evaluated when problems arise or when contracts are renewed.	Trade performance data consists of inspection punch lists and callbacks, but trend data is not tracked.	Trade performance trend data is tracked and reviewed regularly with the key trades and used to improve quality and prevent defects.	Primary use is checklists, some performance test data used to gauge trade against performance standards	Customer satisfaction survey data on construction workmanship is used as a trade performance indicator.	Performance testing is used as another metric for trade performance	Trades use builder performance data to monitor and improve performance. Trades are recognized and rewarded for outstanding performance.	Performance testing is used as another metric for trade performance
7.4 Trade Contractor and Supplier Results	Trade contractor quality seems to be improving, but there are no measures of progress.	Some trade contractors show *measured* quality improvements.	*All* major trade contractors show measured quality improvements.	Measurement system includes key performance attributes	All major contractors show *excellent quality results.* Most trade contractors routinely meet quality standards.	Quality standards include Performance standards	In addition to level 4, all major trade contractors show positive quality improvement *trends.*	Performance testing shows improvement trends.

Appendix E. National Housing Quality Survey

NHQ Survey information	Information Champion
Company Mission, Vision and Values	
• What are the company mission statement, core values, and vision for the future? How is this documented and communicated amongst the staff?	
• How do senior managers demonstrate a commitment to the company mission, values, and vision, and to what extent does this translate to the actions of others throughout the organization?	
• What feedback mechanisms exist from field to management relating to company's ability to deliver to the company mission, values, and progress towards vision?	
• How does the company understand if employees are in alignment with the company mission, values, and vision, and are there activities that specifically encourage and reinforce that alignment?	
• Does the company facilitate and coordinate opportunities to benefit the local community in alignment with the mission, values, and vision?	
Strategic Planning	
• What measurement mechanisms exist to evaluate if the company is achieving the mission, progressing towards the vision, and achieving customer satisfaction and operational performance metrics?	
• Is there a written strategic plan that documents the improvement process in different operational areas, the tools and systems used to identify areas of weakness and measure company-wide operational improvements, a detailed strategic plan for improvements in key areas, and who is involved in developing specific strategic improvement plans?	
• What process is in place to implement the plan, and how far throughout the organization does implementation reach?	
• What mechanisms are used and how often is review performed to monitor how well the organization is improving relative to the strategic plan? How often is the strategic plan updated?	

NHQ Survey information	Information Champion
Customer Satisfaction	
• What market research mechanisms are in place to understand customers, position relative to local competition, and forward positioning of products based on leading indicators (e.g., demographics, economic, style, etc.)	
• What is the design process? Who is involved? What feedback mechanisms exist?	
• What importance is placed on customer satisfaction, and how is that expressed in the company mission, values, and vision?	
• What process is in place to guide the customer through the sales and construction process?	
• How is customer satisfaction measured and used throughout the company to improve the customer relationship process?	
Performance Management	
• How does the organization set up work processes, identify work process improvements, and Benchmark against other industry and non-industry top performers?	
• How are work processes measured, and do they support key company wide success measures?	
• How are work-processes evaluated and improved?	
• How are work-processes tied to the quality of the house?	
• How are company financial results measured, and tied to work processes?	
Human Resources	
• Are employees are surveyed on job satisfaction and have input on improving employee satisfaction?	
• What is the company safety plan, and how far into the organization does it reach?	
• How empowered are employees with respect to their job and achieving key success metric?	
• How are teams utilized to perform management functions within the organization?	
• What kind of the training and employee development program exists in the company?	

NHQ Survey information	Information Champion
• How are employees and teams evaluated, compensated, and given incentive toward key success measures for the company	
Quality Construction Process	
• What are the company's quality standards, and how are these communicated throughout the organization and to trades?	
• How do management, field, and trades monitor consistency and delivery of product that meets quality standards?	
• How do the company and the trades monitor and evaluate quality problems and develop process improvements to eliminate problems?	
• How is warranty service used to identify and fix root causes of quality problems?	
• How have these improvements contributed to zero defect at final inspection, and show positive trends in quality improvement and excellent results	
Supplier Partnerships	
• How are trade contractors and suppliers engaged in the company's quality initiatives?	
• What strategies are in place to align trade contractors with the company mission, values, and vision; develop the trades to achieve quality standards; and provide financial rewards for achieving quality goals?	
• How is trade contractor performance tracked, and how is that data used to continually improve the trade contractor's performance?	
• What are the results associated with the trade contractor initiatives?	

Appendix F. SNAPSHOT Form

SNAPSHOT© "The Form"			
Lot #:	Subdivision:	Address:	Date and time:
Model:			

INITIALIZATION

	Square feet	sq. ft.
	Surface area (all outside surfaces, including foundation)	sq. ft.
	Volume	cu. ft.
	Windspeed (approximate mph)	mph
	Outside temperature (estimated)	° F
	Check that all registers and bedroom doors are open.	Yes☐ No☐
	Measure static pressure in return between fan & filter.	pa
	Static pressure in Supply and Return	S Pa / R Pa
	Is there a ventilation system?	Yes☐ No☐
	Type of ventilation system (e.g., exhaust-only, HRV, ERV)	
	If there is an AirCycler™, enter the off / on times.	off on
	Enter outside air duct pressure.	pa
	Type of outside air duct (flex/sheet metal; diameter)	
	Is there an adjustable outside air damper?	Yes☐ No☐
	Is there a fireplace or wood stove?	Yes☐ No☐
	Duct location (approximate % in attic, conditioned space, basement, etc.)	

PRESSURE TESTING

	Stack Pressure (baseline with blower door installed; covers on)				pa
	Dominant Duct Leak Effect (baseline with HVAC system running)				pa
	Master Bedroom Door Closure Effect (ΔP from main space to outdoors)				pa
	All Doors Closed Effect (ΔP from main space to outdoors)				pa
	Fireplace/Wood Stove Zone HVAC Test				pa
	Pressure In Each Closed Room (room label and pressure)		pa		pa
			pa		pa
			pa		pa
			pa		pa
			pa		pa

BLOWER DOOR TESTING (BDT)

	Blower Door Location	
	Total CFM50 (add C & n values if available on multipoint test)	CFM50= C= n=

DUCT AIRTIGHTNESS TESTING (DAT)

	DAT CFM25 TOTAL	
	DAT CFM25 OUTSIDE	

MECHANICALS

	Furnace or air handler	Make:	Model:
	Air Conditioning	Make:	Model:
	Domestic hot water	Make:	Model:

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Executive Services and Communications Directorate (0704-0188). Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ORGANIZATION.

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
January 2006	Subcontract Report	January 2005 – November 2005

4. TITLE AND SUBTITLE
Building America Residential System Research Results: Achieving 30% Whole House Energy Savings Level in Hot-Dry and Mixed-Dry Climates

5a. CONTRACT NUMBER
DE-AC36-99-GO10337

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Building Industry Research Alliance (BIRA); Building Science Consortium (BSC); Consortium for Advanced Residential Buildings (CARB); Davis Energy Group (DEG); Florida Solar Energy Center (FSEC); IBACOS; National Association of Home Builders Research Center (NAHBRC); National Renewable Energy Laboratory (NREL)

5d. PROJECT NUMBER
NREL/SR-550-38201

5e. TASK NUMBER
BET6.8004

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

8. PERFORMING ORGANIZATION REPORT NUMBER
NREL/SR-550-38201

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)
NREL

11. SPONSORING/MONITORING AGENCY REPORT NUMBER

12. DISTRIBUTION AVAILABILITY STATEMENT
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

13. SUPPLEMENTARY NOTES

14. ABSTRACT *(Maximum 200 Words)*
The Building America program conducts the system research required to reduce risks associated with the design and construction of homes that use an average of 30% to 90% less total energy for all residential energy uses than the Building America Research Benchmark, including research on homes that will use zero net energy on annual basis. To measure the program's progress, annual research milestones have been established for five major climate regions in the United States. The system research activities required to reach each milestone take from 3 to 5 years to complete and include research in individual test houses, studies in pre-production prototypes, and research studies with lead builders that provide early examples that the specified energy savings level can be successfully achieved on a production basis. This report summarizes research results for the 30% energy savings level and demonstrates that lead builders can successfully provide 30% homes in the Hot-Dry / Mixed-Dry Climate Region on a cost neutral basis.

15. SUBJECT TERMS
Building America; U.S. Department of Energy; systems research; Hot-Dry Mixed-Dry Climates; 30% energy savings level; energy efficient housing

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER *(Include area code)*
Unclassified	Unclassified	Unclassified	UL		

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

A Strong Energy Portfolio for a Strong America

Energy efficiency and clean, renewable energy will mean a stronger economy, a cleaner environment, and greater energy independence for America. Working with a wide array of state, community, industry, and university partners, the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy invests in a diverse portfolio of energy technologies.

Research and Development of Buildings

Our nation's buildings consume more energy than any other sector of the U.S. economy, including transportation and industry. Fortunately, the opportunities to reduce building energy use—and the associated environmental impacts—are significant.

DOE's Building Technologies Program works to improve the energy efficiency of our nation's buildings through innovative new technologies and better building practices. The program focuses on two key areas:

- **Emerging Technologies**
  Research and development of the next generation of energy-efficient components, materials, and equipment
- **Technology Integration**
  Integration of new technologies with innovative building methods to optimize building performance and savings

For more information contact:
EERE Information Center
1-877-EERE-INF (1-877-337-3463)
www.eere.energy.gov

U.S. Department of Energy
Energy Efficiency and Renewable Energy

An electronic copy of this publication is available on the Building America Web site at **www.buildingamerica.gov**

Visit our Web sites at:

www.buildingamerica.gov | www.pathnet.org | www.energystar.gov

Building America℠ U.S. Department of Energy

PATH Partnership for Advancing Technology in Housing

ENERGY STAR

Building America Program
George S. James • New Construction • 202-586-9472 • fax: 202-586-8134 • e-mail: George.James@ee.doe.gov
Terry Logee • Existing Homes • 202-586-1689 • fax: 202-586-4617 • e-mail: terry.logee@ee.doe.gov
Lew Pratsch • Integrated Onsite Power • 202-586-1512 • fax: 202-586-8185 • e-mail: Lew.Pratsch@hq.doe.gov
Building America Program • Office of Building Technologies, EE-2J • U.S. Department of Energy • 1000 Independence Avenue, S.W. • Washington, D.C. 20585-0121 • **www.buildingamerica.gov**

Building Industry Research Alliance (BIRA)
Robert Hammon • ConSol • 7407 Tam O'Shanter Drive #200 • Stockton, CA 95210-3370 • 209-473-5000 • fax: 209-474-0817 • e-mail: Rob@consol.ws • **www.bira.ws**

Building Science Consortium (BSC)
Betsy Pettit • Building Science Consortium (BSC) • 70 Main Street • Westford, MA 01886 • 978-589-5100 • fax: 978-589-5103 • e-mail: Betsy@buildingscience.com • **www.buildingscience.com**

Consortium for Advanced Residential Buildings (CARB)
Steven Winter • Steven Winter Associates, Inc. • 50 Washington Street • Norwalk, CT 06854 • 203-857-0200 • fax: 203-852-0741 • e-mail: swinter@swinter.com • **www.carb-swa.com**

Davis Energy Group
David Springer • Davis Energy Group • 123 C Street • Davis, CA 95616 • 530-753-1100 • fax: 530-753-4125 • e-mail: springer@davisenergy.com • deg@davisenergy.com • **www.davisenergy.com/index.html**

IBACOS Consortium
Brad Oberg • IBACOS Consortium • 2214 Liberty Avenue • Pittsburgh, PA 15222 • 412-765-3664 • fax: 412-765-3738 • e-mail: boberg@ibacos.com • **www.ibacos.com**

Industrialized Housing Partnership (IHP)
Subrato Chandra • Florida Solar Energy Center • 1679 Clearlake Road • Cocoa, FL 32922 • 321-638-1412 • fax: 321-638-1439 • e-mail: subrato@fsec.ucf.edu • **www.baihp.org**

National Association of Home Builders (NAHB) Research Center
Tom Kenney • National Association of Home Builders (NAHB) Research Center • 400 Prince George's Boulevard • Upper Marlboro, MD 20774 • 301-430-6246 • fax: 301-430-6180 • toll-free: 800-638-8556 • **www.nahbrc.org/**

National Renewable Energy Laboratory
Ren Anderson • 1617 Cole Boulevard, MS-2722 • Golden, CO 80401 • 303-384-7433 • fax: 303-384-7540 • e-mail: ren_anderson@nrel.gov • **www.nrel.gov**

Tim Merrigan • 1617 Cole Boulevard, MS-2722 • Golden, CO 80401 • 303-384-7349 • fax: 303-384-7540 • e-mail: tim_merrigan@nrel.gov • **www.nrel.gov**

Oak Ridge National Laboratory
Pat M. Love • P.O. Box 2008 • One Bethel Valley Road • Oak Ridge, TN 37831 • 865-574-4346 • fax: 865-574-9331 • e-mail: lovepm@ornl.gov • **www.ornl.gov**

Produced for the U.S. Department of Energy (DOE) by the National Renewable Energy Laboratory, a DOE national laboratory.

January 2006 • NREL/SR-550-38201

Printed with a renewable-source ink on paper containing at least 50% wastepaper, including 10% postconsumer waste.

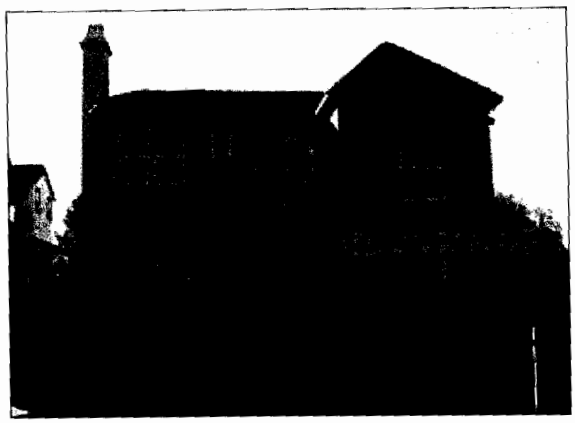
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

SUMMERHILL HOMES

San Francisco Bay Area

Every Home an Energy-Efficient Home

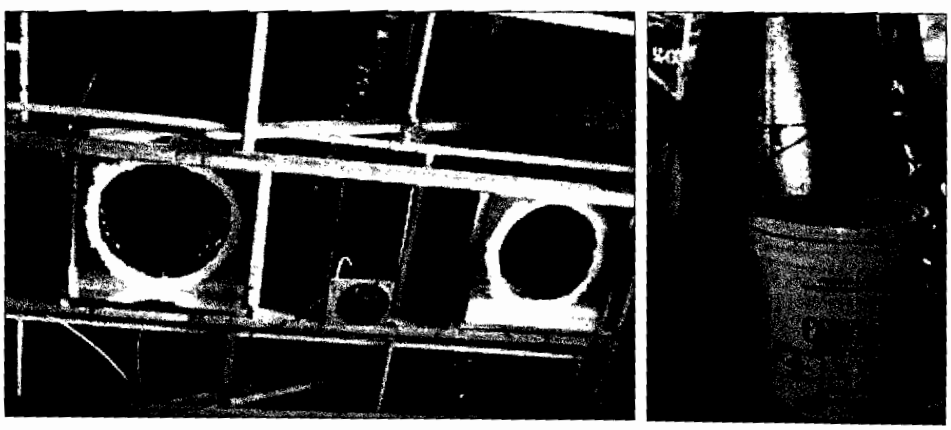
SummerHill Homes, based in California's San Francisco Bay area, doesn't offer energy efficiency as an upgrade option, it's a standard feature of every home they build. "We just think it's the right thing to do," said Santos Alvarez, SummerHill's vice president of operations.



According to Alvarez, SummerHill builds about 250 homes per year and the homes typically exceed California's energy code by 18% to 22%. "Our goal is 20%" said Alvarez. They achieve that savings through better insulation, a higher efficiency furnace, an engineered duct system, and more attention to details like caulking and sealing.

Alvarez also attributes the savings to training and on-site inspections. Building America team leader ConSol is one of the inspectors SummerHill works with, using ConSol's ComfortWise version of ENERGY STAR®. "Their field inspectors are sometimes on our job every day. Teaching, training, keeping us up to date—these are some of the things they do for us. They provide formal classroom training and on the job training, including classes for assistants and supervisors, to make sure we are meeting requirements and installing things correctly. They'll also do walk-throughs with our supervisors at the site, pointing out what needs to be paid attention to," said Alvarez.

SummerHill moved to a consistent policy of energy-efficient construction shortly after Alvarez joined the company four and a half years ago. Alvarez had known about ConSol from previous jobs. "Every where I've worked I've pursued energy efficiency," said Alvarez.



Careful duct sealing with mastic helps improve comfort and energy efficiency at low cost.

INTRODUCTION
Taking action in your community

HOMEOWNERS
Shopping for value, comfort, and quality

MANAGERS
Putting building science to work for your bottom line

MARKETERS
Energy efficiency delivers the value that customers demand

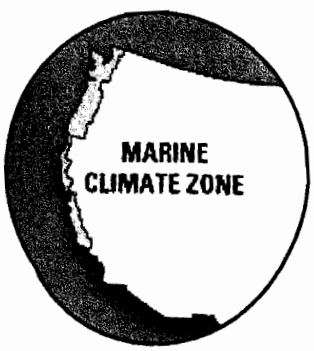
SITE PLANNERS & DEVELOPERS
Properly situated houses pay big dividends

DESIGNERS
Well-crafted designs capture benefits for builders, buyers, and business

SITE SUPERVISORS
Tools to help with project management

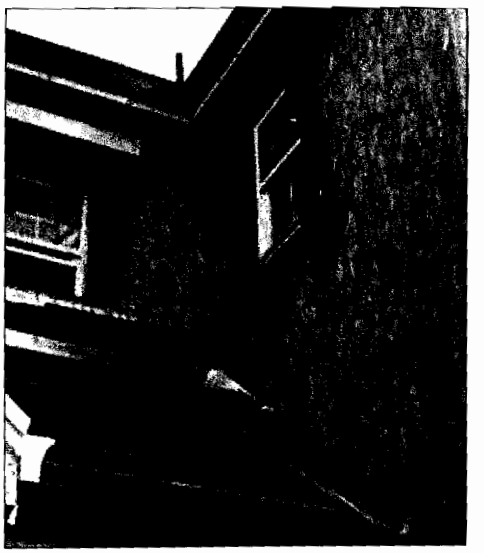
TRADES
Professional tips for fast and easy installation

CASE STUDIES
Bringing it all together



The policy seems to be a winner for the company as well as the environment. "The sales associates love it," said Alvarez "they look forward to talking to home buyers about it."

Alvarez also noted that callbacks have gone down since they started building to ComfortWise standards. "I would attribute this to the additional third-party inspections and training," said Alvarez.



Installing window and roof flashing is critical for long-term durability and must happen at correct stages of construction.

Housewrap provides a drainage plain behind stucco and other finishes.

Key Features:

Field certification with two inspections of each model and each floor plan per release using diagnostics: blower door test, duct blaster test, air flow measurements at each register, insulation density measurements; visual inspection that specified components are installed correctly.

Caulking and sealing of all joints and penetrations

Engineered HVAC system and duct layout

Sealed ducts with duct blaster testing

Correct sizing of air conditioning equipment

Dual-paned vinyl windows with Low-E glass for improved energy savings

All exterior doors feature full weather stripping

Dual-zone high-efficiency forced air gas furnace with electronic ignition and energy efficient electronic set-back thermostat

Energy saving 100-gallon gas water heater with recirculation pump to all fixtures

BUILDER PROFILE

SummerHill Homes, a division of Marcus & Millichap

Where:
San Francisco Bay Area, California

Founded:
1976

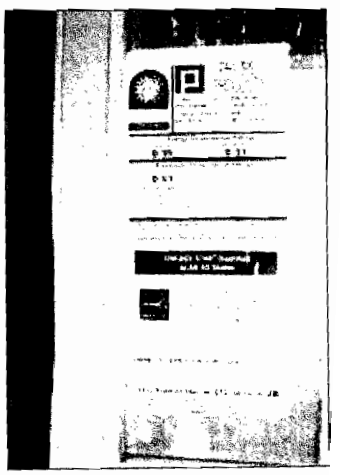
Employees:
120

Development:
Villa Savona Homes in Fremont, California

Number of Homes:
26

Square Footage:
3,545 - 3,889 sq. ft.
3 - 5 bedrooms
3.5 - 4.5 baths

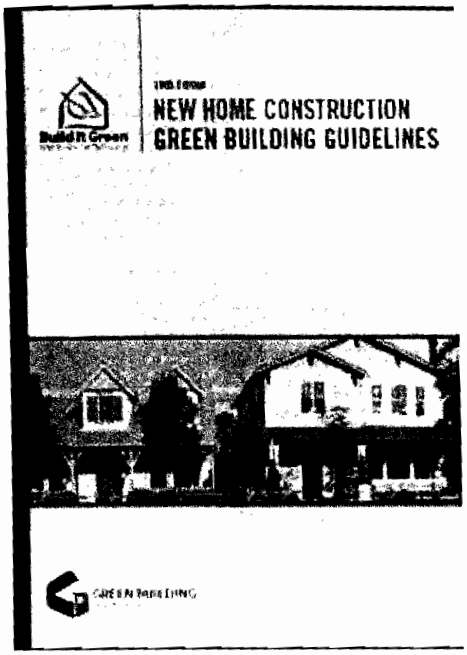
Price Range:
from the mid $1,500,000's



High efficiency windows improve comfort and help protect furnishings from solar radiation. This National Fenestration Rating Council label shows a U-factor of 0.35 and solar heat gain coefficient of 0.31. The window also qualifies as an ENERGY STAR product.

Innovations

SummerHill has gone beyond the ENERGY STAR standards to incorporate green building practices in their homes as well. Alvarez said this started about two years ago with their Sycamore Heights development located in Alameda County. They implemented several green building features including using recycled materials, protecting native soil, minimizing disruption of existing plants and trees, recycling at the construction site, using formaldehyde-free insulation, and installing gas water heaters with a recirculation pump to all fixtures. Several of these features were required by Alameda County as part of the county's Green Building Guidelines. Sycamore Heights achieved the county's Gold Level Status for green construction. Now SummerHill incorporates these features in all of its new construction.



"When we looked at what was required to achieve Gold Level Status, 90% of it we were already doing," said Alvarez.

SummerHill's efforts have been recognized by the building community. SummerHill developments have received several coveted Best In American Living Awards from the National Association of Home Builders, and SummerHill was the winner of two Golden Nugget Grand Awards and five Gold Nugget Merit Awards at the 2005 Pacific Coast Builders Conference.

Don't Duck Duct Details:

ConSol contends that sealing HVAC ducts is a key to improving a home's energy efficiency. ConSol aims for a duct leakage goal of less than 6% leakage. "The biggest source of leakage in duct systems is from not sealing the can that holds the AC duct to the register. The can should be sealed to the drywall with caulk. We estimate that 40% of duct leakage is due to that omission alone," said Doug Dryer, ConSol's national marketing director. To ensure that ducts are tight, ConSol performs field inspections and diagnostics including duct blaster tests and measurements of air flow at each register in the home. ConSol's mechanical engineers design the HVAC system for each floor plan to determine the correct size for the heating and air conditioning equipment and to optimize the duct layout. "The ideal is a perfectly balanced house, pressure wise, with a correctly sized HVAC system and adequate air flow into each room," said Dryer.

Green Features

In addition to energy efficiency, SummerHill Homes's Sycamore Heights development meets the requirements of Alameda County's Green Building Program. These include:

Materials & Products

- 15% fly ash in concrete
- Engineered lumber for floors, structural beams and headers
- Wood I-joists for floors and ceilings
- OSB for subfloors and sheathing
- Finger-jointed trim
- Non-chromium/arsenic treated wood
- Fiber-cement exterior siding (James Hardie Hardiplank and Hardishingle)
- Durable concrete r[redacted] (Monier Lifetile)

Other Green Features

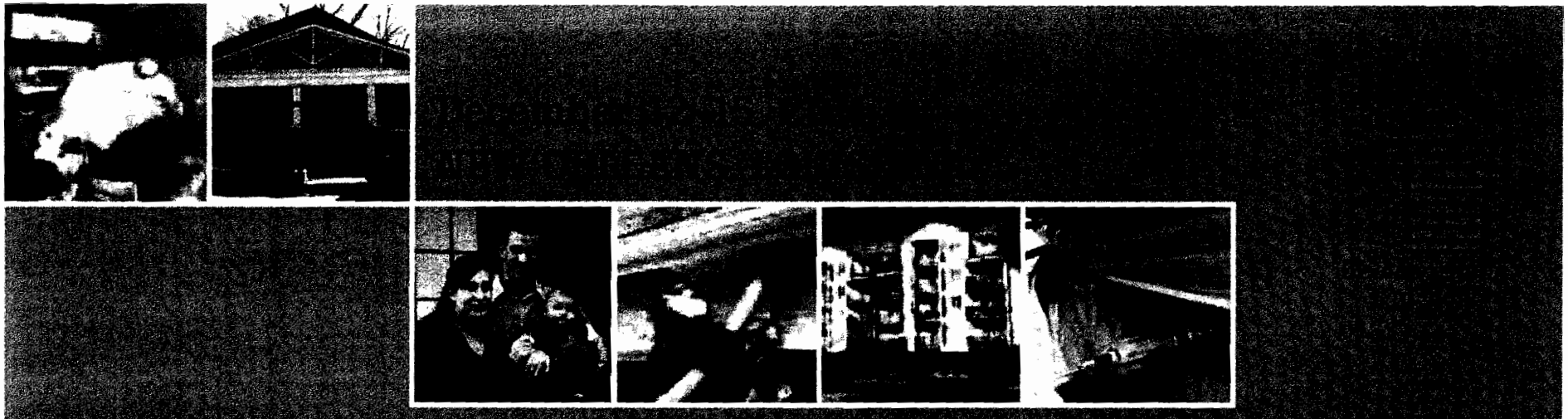
- 75% recycling of construction waste
- Reused form boards
- Built-in recycling center
- Stormwater management and soil protection during construction
- High-efficiency irrigation system and resource-efficient landscapes
- Range hoods vented to outside
- Low-VOC* interior paint *(*volatile organic compunds)*

ConSol's ComfortWise ENERGY STAR promotes Building America's Common Sense Building Science Principles

ConSol is the team lead for the Building Industry Research Alliance, one of Building America's research consortia. ConSol's ComfortWise ENERGY STAR program is based on the common sense building science principles that Building America has developed and promotes. By following this whole house systems approach, builders can build high-quality durable homes that use at least 30% less energy for space heating and cooling than homes built to meet the National Model Energy Code or 15% savings over homes built to the California Energy Code. ConSol provides builders with an HVAC layout and design as well as full energy code and lender documentation. ConSol specifies spectrally selective low-emissivity windows and tight ducts and provides on-site third-party inspections and diagnostic testing including duct blaster, blower door, insulation density, air flow, and other measurements. ConSol also provides marketing support and materials, sales staff and contractor training, and information on energy-efficient mortgages to help builders implement energy efficiency practices and use them to expand markets and increase profitability.

The Bottom Line

According to Alvarez: "Cost is not a big issue. It's not hard and it's not expensive. It's just a little more work. It takes a little more attention. And you've got to allow the time for testing and inspection."



2011 National Weatherization Training Conference

Advanced Diagnostics: Duct Leakage Testing

Adam Harris, Dale Sherman – NYSWDA

Michael Stahl – Environmental Management Consultants

Marquam George - UAS

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Why Duct Leakage Testing?

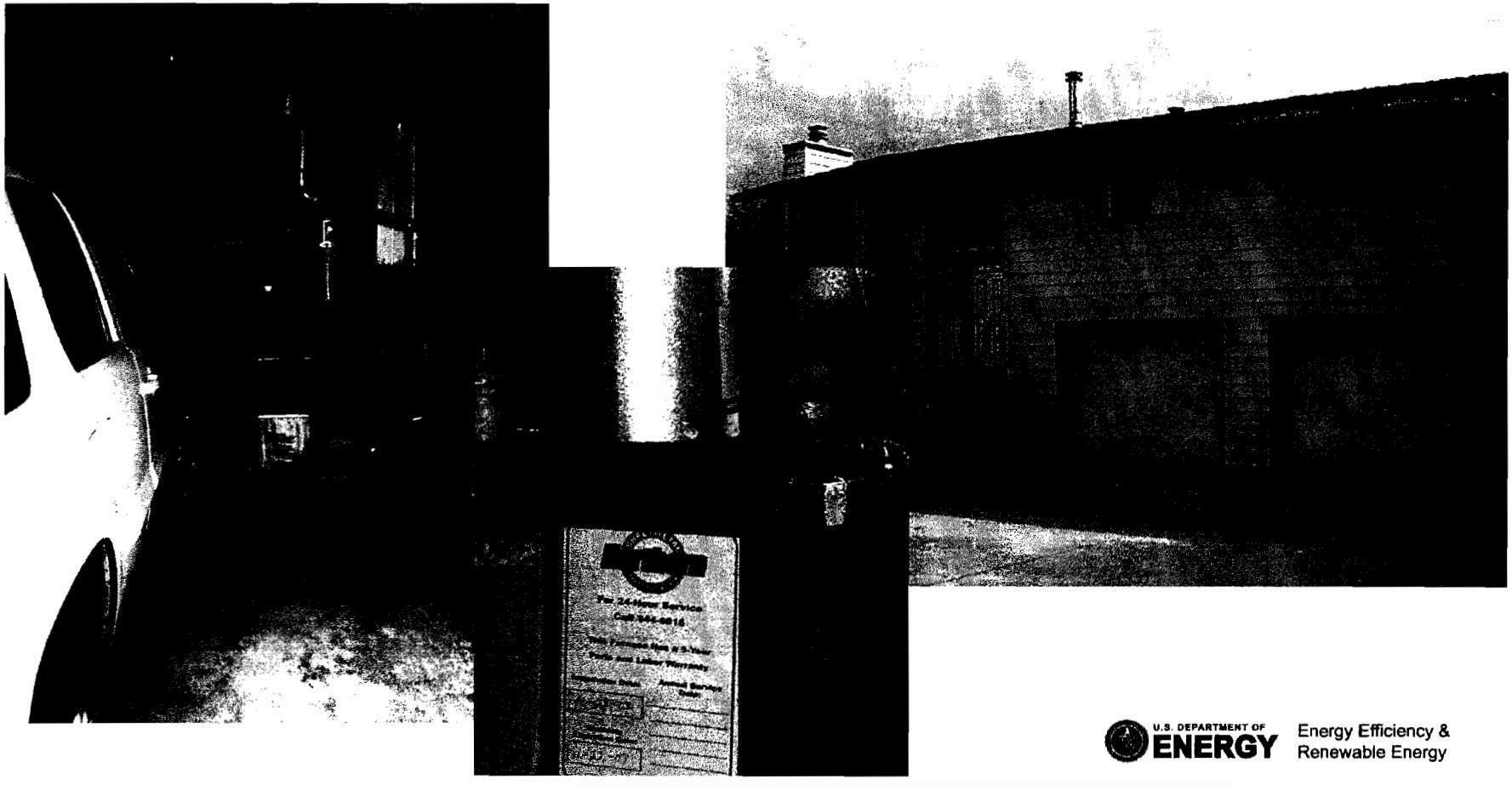
- Studies indicate that duct leakage can account for as much as 25% of total house energy loss

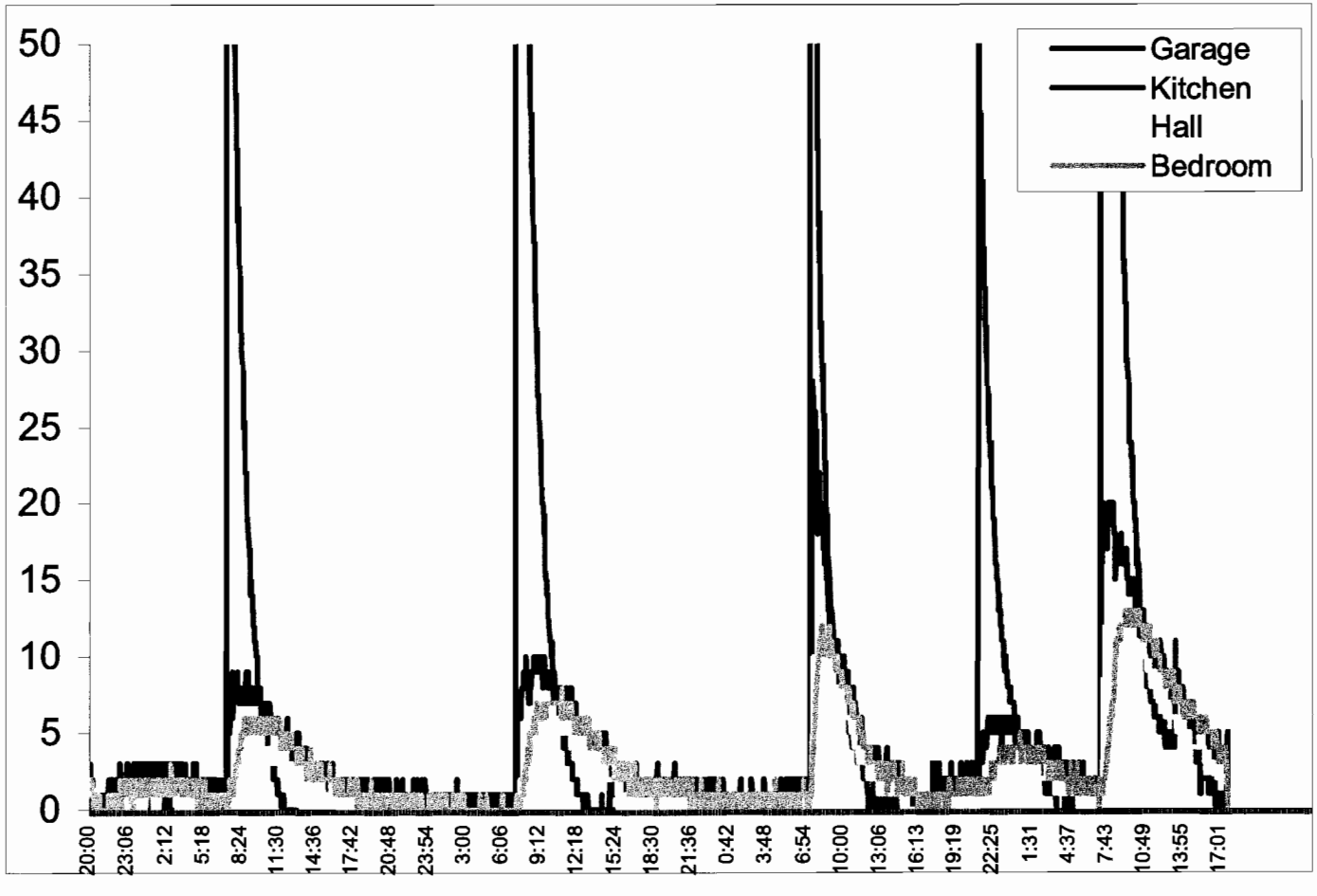
Why Test & Utilize Diagnostics?

- Troubleshooting comfort and performance complaints
- Measure effectiveness of duct sealing
- Estimate annual HVAC system losses from duct leakage
- Certifying compliance

Why? Building Durability

Why? Compliance



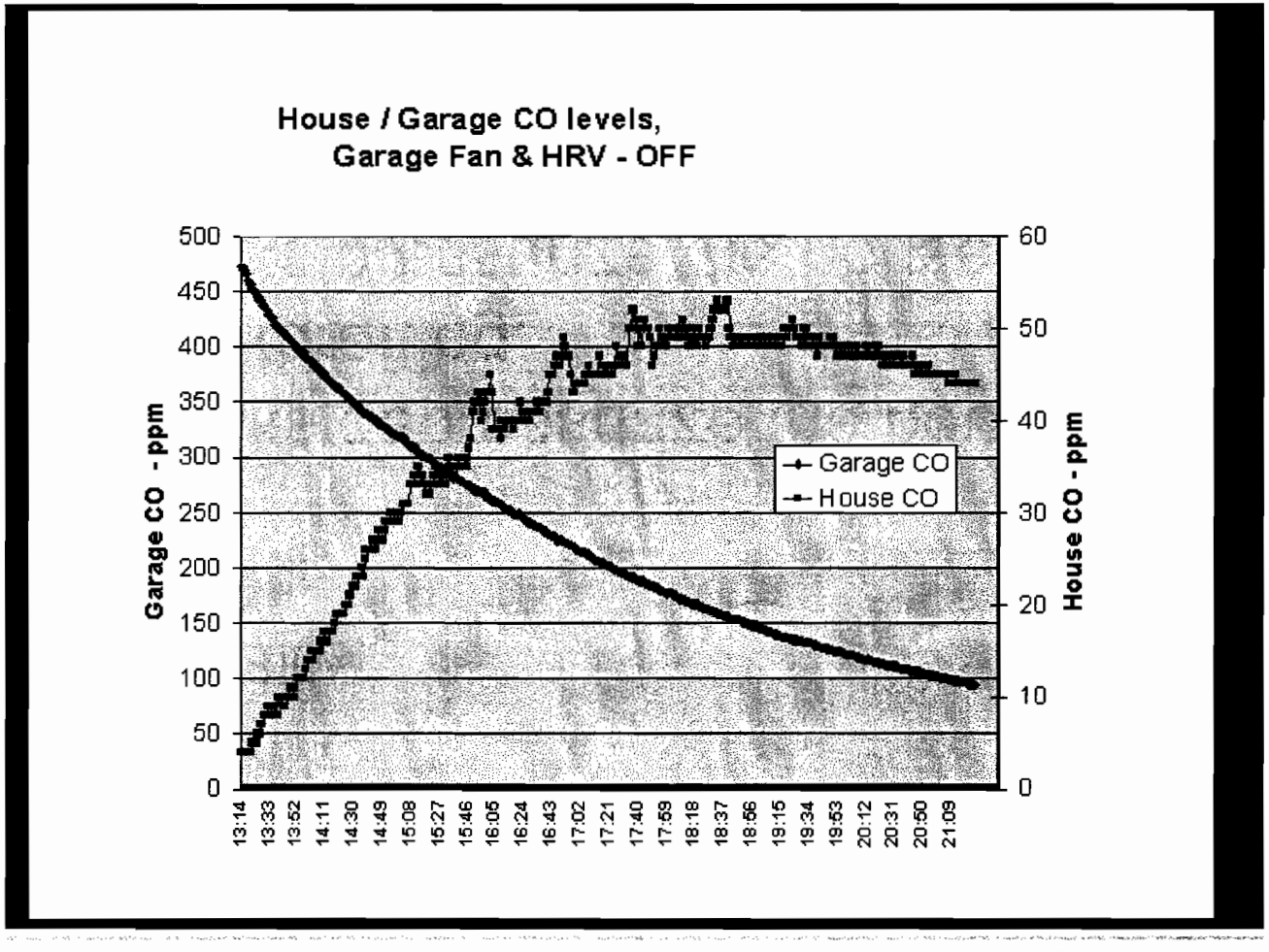

50
45
40
35
30
25
20
15
10
5
0
Garage
Kitchen
Hall
Bedroom
20:00
23:06
2:12
5:18
8:24
11:30
14:36
17:42
20:48
23:54
3:00
6:06
9:12
12:18
15:24
18:30
21:36
0:42
3:48
6:54
10:00
13:06
16:13
19:19
22:25
1:31
4:37
7:43
10:49
13:55
17:01

Why? Unplanned Airflows

ASHRAE 62.2-2007 - 6.5 Garages

When an occupiable space adjoins a garage, the design must prevent migration of contaminants to the adjoining space.

HVAC systems that include air handlers or return ducts located in garages shall have return or total air leakage of no more than 6% of total fan flow when measured at 0.1 in. w.c. (25 Pa) using California Title 24 or equivalent.


House / Garage CO levels,
Garage Fan & HRV - OFF
Garage CO - ppm
House CO - ppm
Garage CO
House CO
500
450
400
350
300
250
200
150
100
50
0
60
50
40
30
20
10
0
13:14
13:33
13:52
14:11
14:30
14:49
15:08
15:27
15:46
16:05
16:24
16:43
17:02
17:21
17:40
17:59
18:18
18:37
18:56
19:15
19:34
19:53
20:12
20:31
20:50
21:09

Air Quality Penalty

Supply leaks depressurize the house and can cause backdrafting.
Return leaks pressurize the house, where is this leaky duct air coming from?

Common Leak Locations

- Plenum connections to air handler
- Filter slots
- Duct connections in wall cavities
- Branch lines off main supply and return lines

Supply Duct Leakage

Leaks in your supply ducts cause expensive conditioned air to be dumped into basements, attics, crawlspaces and garages instead of where it is intended.

INTO CONDITIONED LIVING AREA

Supply leaks into unconditioned space also cause moisture issues because of temperature differences

RETURN DUCT LEAKS

Return duct leaks in unconditioned space pull outside air

- Hot in summer
- Cold in winter

Into your duct system forcing the system to run longer and harder to keep you comfortable

Return Leak Hazards

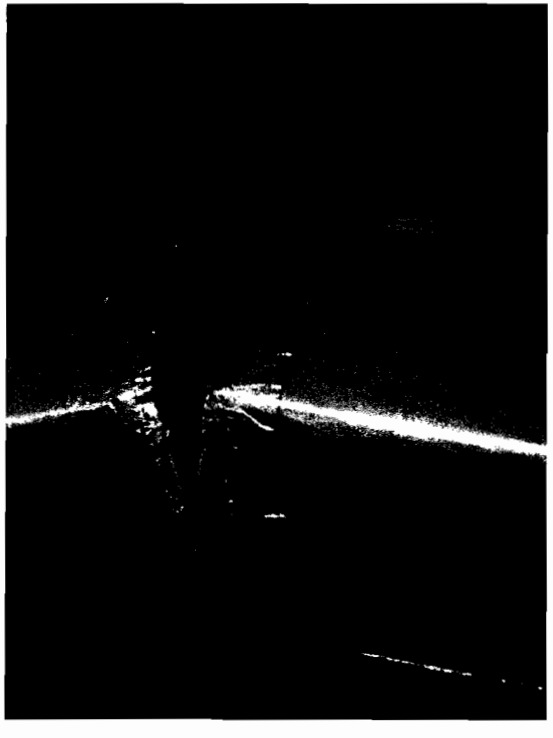
Return air leaks in unconditioned space can pull pollutants and irritants into conditioned space

- Mold
- Pollen
- Dust
- Insulation fibers

Energy Penalty

Supply ducts from a furnace deliver heated air to the house at between 110 and 140 degrees.
If we leak that air to the outside that's an energy penalty

2017 National Weatherization Training Conference



U.S. DEPARTMENT OF ENERGY
Energy Efficiency & Renewable Energy

Pressure pan testing

- Depressurize house with blower door, usually to -50pa
- Place pressure pan over each supply or return register and measure the pressure difference across the pan.
- Large readings indicate significant leaks

2011 National Weatherization Training Conference

December 12-15, 2011
NEW ORLEANS, LOUISIANA

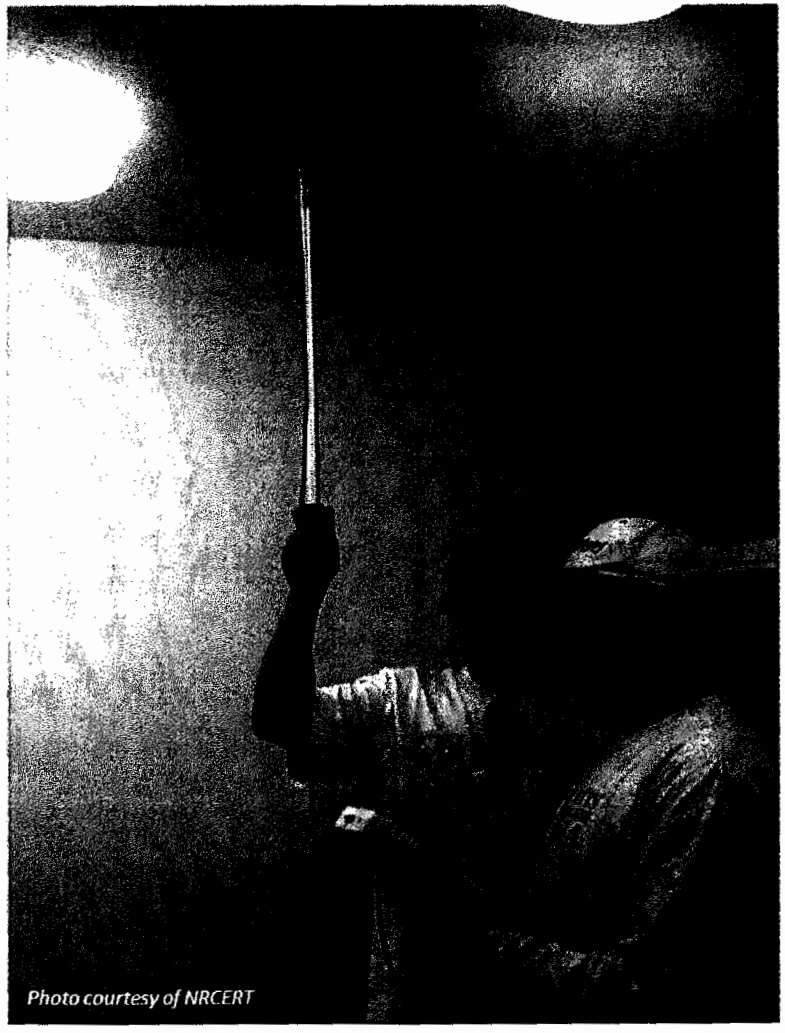
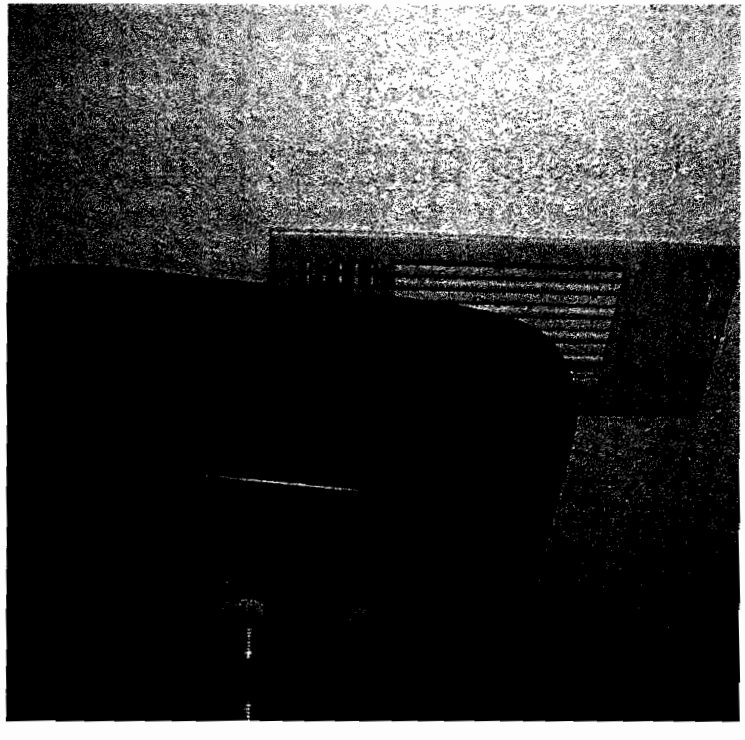
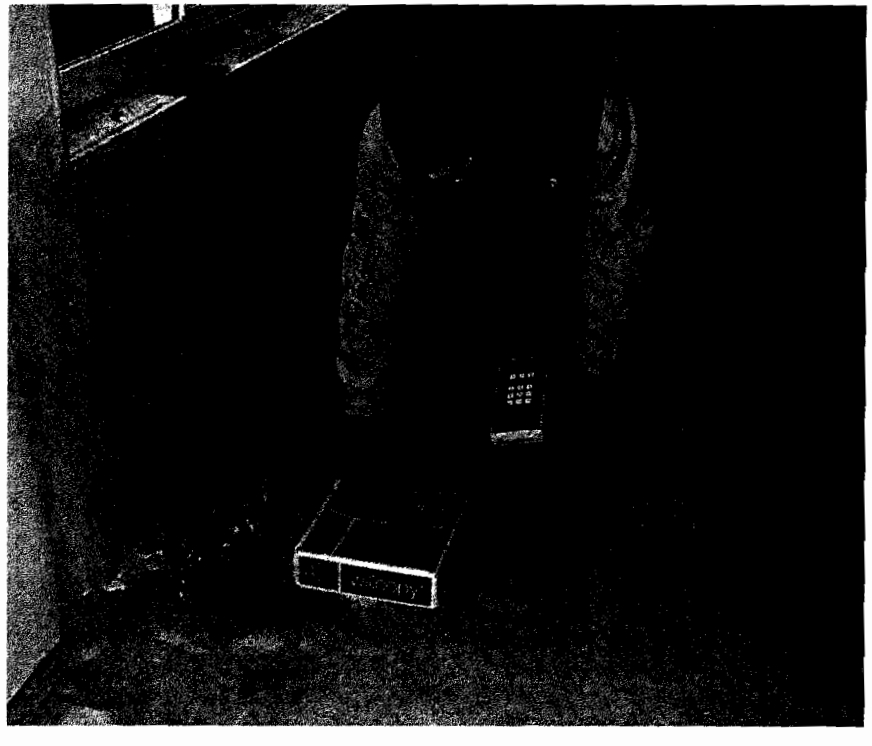


Photo courtesy of NRCERT

U.S. DEPARTMENT OF ENERGY
Energy Efficiency & Renewable Energy

Pressure Pan





Pressure pan testing downfalls

- It does not quantify leakage in CFM
- Have to access each register
- Small reading at multiple registers may indicate large leak further away

Pressure pan testing downfalls

- It does not quantify leakage in CFM
- Have to access each register
- Small reading at multiple registers may indicate large leak further away

Duct Pressurization Device " Duct Blaster"

- Duct pressurization is used to measure total duct system leakage
- Measuring total duct system leakage involves sealing all registers and pressurizing the duct system with a calibrated fan typically to 25 Pa, while reading air flow through the fan
- Good test for determining supply from return leakage

Duct Pressurization Device " Duct Blaster"

-Setup-

- Seal off all registers
- Hook up fan to either air handler cabinet or large central return grill
- Reference duct work pressure to manometer input
- Attach Fan to manometer input
- Pressurize duct to 25pa
- Record air flow through fan

"Duct Blaster" downfalls

- Have to access all register
- If working with toekicks, must seal off at boot if not ducted to register
- Fan connection can be tricky
- Measurements are taking at a simulated pressure rather than normal operating pressures

Measuring Total Duct Leakage

- Includes unknown proportion of indoor and outdoor leaks
- Pressurization or depressurize
- Measure air flow in cfm at 25 Pa

Common Leak Locations

- Plenum connections to air handler
- Filter slots
- Duct connections in wall cavities
- Branch lines off main supply and return lines

Supply Duct Leakage

Leaks in your supply ducts cause expensive conditioned air to be dumped into basements, attics, crawlspaces and garages instead of where it is intended.

INTO CONDITIONED LIVING AREA

Supply leaks into unconditioned space also cause moisture issues because of temperature differences

RETURN DUCT LEAKS

Return duct leaks in unconditioned space pull outside air

- Hot in summer
- Cold in winter

Into your duct system forcing the system to run longer and harder to keep you comfortable

Return Leak Hazards

Return air leaks in unconditioned space can pull pollutants and irritants into conditioned space

- Mold
- Pollen
- Dust
- Insulation fibers

Total Duct Leakage Procedure

- Turn off air handler so that it does not come on during test as well as all exhaust fans and dryers etc.
- Remove all filters from the duct system
- Open a window or exterior door and all interior doors should be open.
- Tape off all supply and return diffusers so that they are air tight

Total Duct Leakage Procedure

- Pressurize ducts to 25pa by connecting Duct blaster fan to the largest centralized return vent or fan compartment on air handler
- Leakage or flow rate should be measured at a supply register closest to the air handler
- In zoned systems, all zone dampers must be open, or each supply run must be tested separately

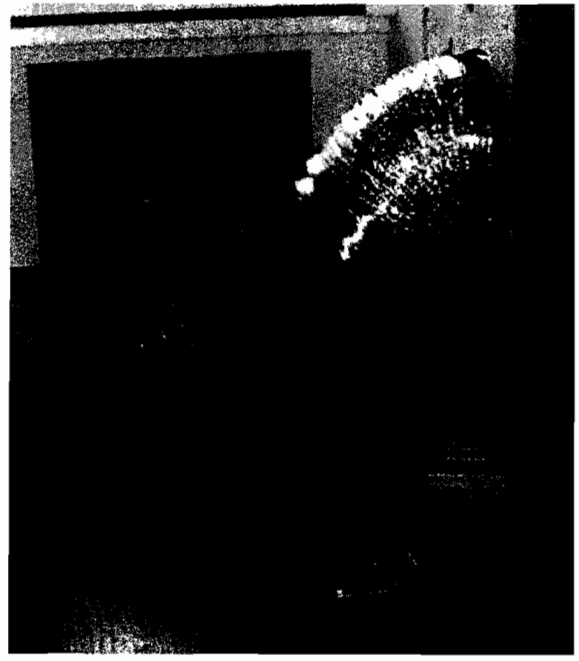
Total Duct Leakage Procedure

- The flow reading that is taken in the supply duct is the amount of total leakage in that system
- This test will measure the leakage in the ducts located in conditioned space and outside conditioned space

Duct Leakage To the Outside

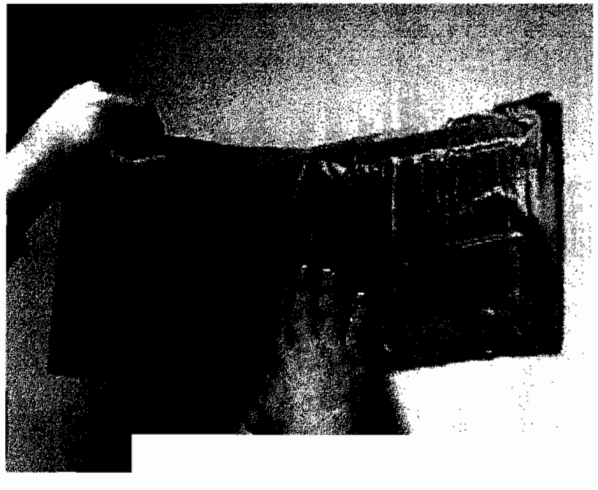
- Testing for duct leakage to the outside will determine the amount of conditioned air that is leaking outside the intended cooling or heated area of the home
- In most cases duct leakage in condition space is not a concern , but leakage to the outside is wasted dollars and can cause many issues as stated previously

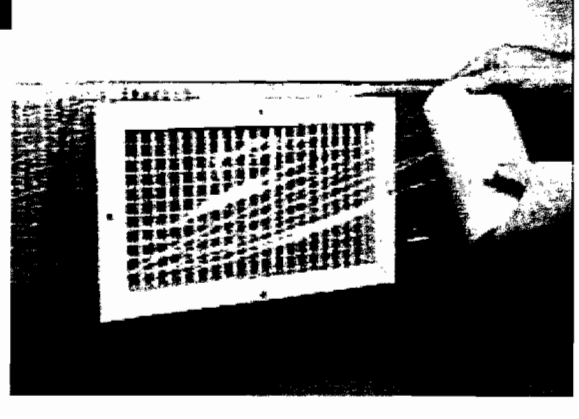
Equipment



Prepare ducts and house

Sealing Ducts



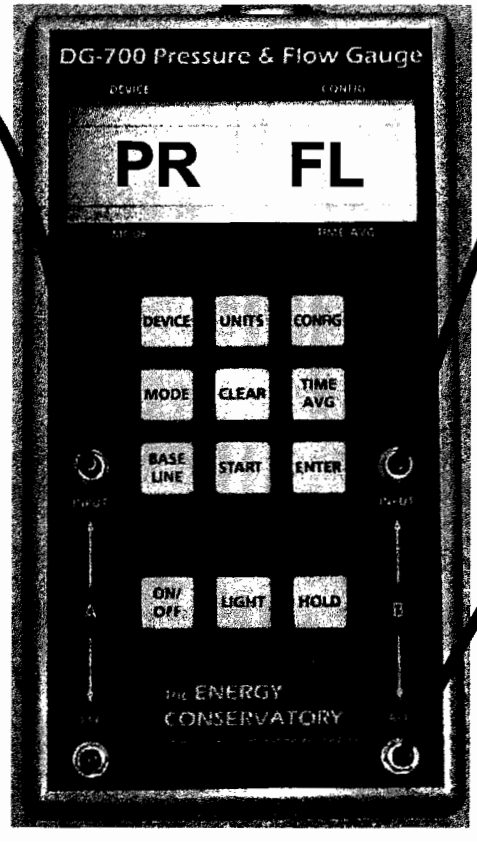


Depressurization Testing

- Fan must be connected to the flexible extension duct.
- The flow conditioner and one flow ring must be installed.

Courtesy: The Energy Conservatory

Duct Blasting - Depressurization



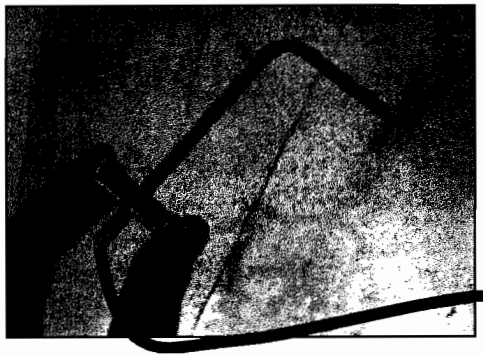
Connect to the pressure probe installed in the duct system

Connect to the Brass tap on duct blaster fan

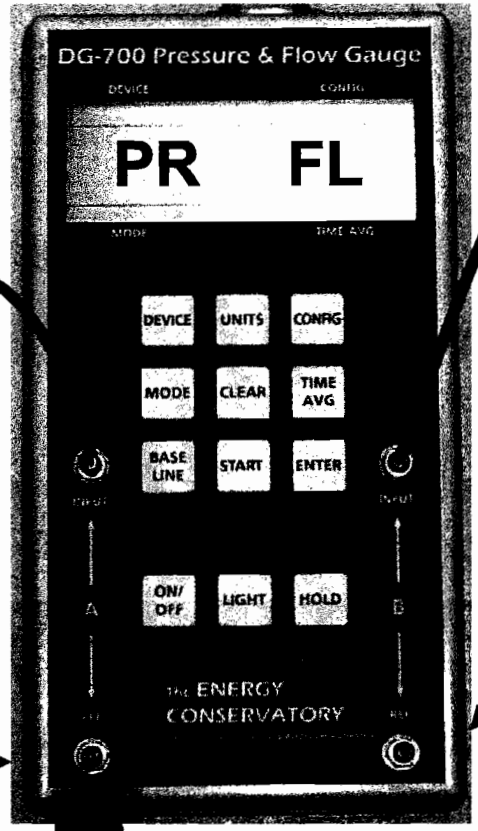
Connect to the plastic tap on the round transition piece

Should be open to inside of building

Duct Blasting - Pressurization



Connect pressure probe to the duct system



Connect to the Brass tap on duct blaster fan

Should be open to inside of building if duct blaster is installed In the building

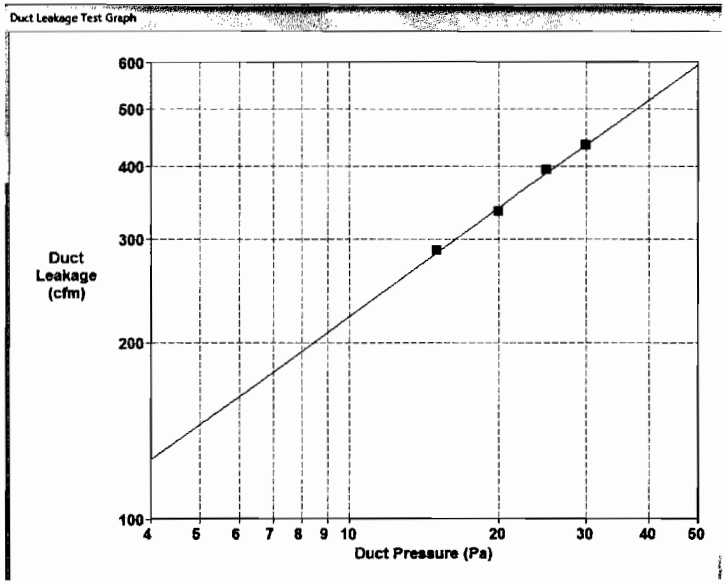
Should be connected to Space where the duct blaster fan is installed

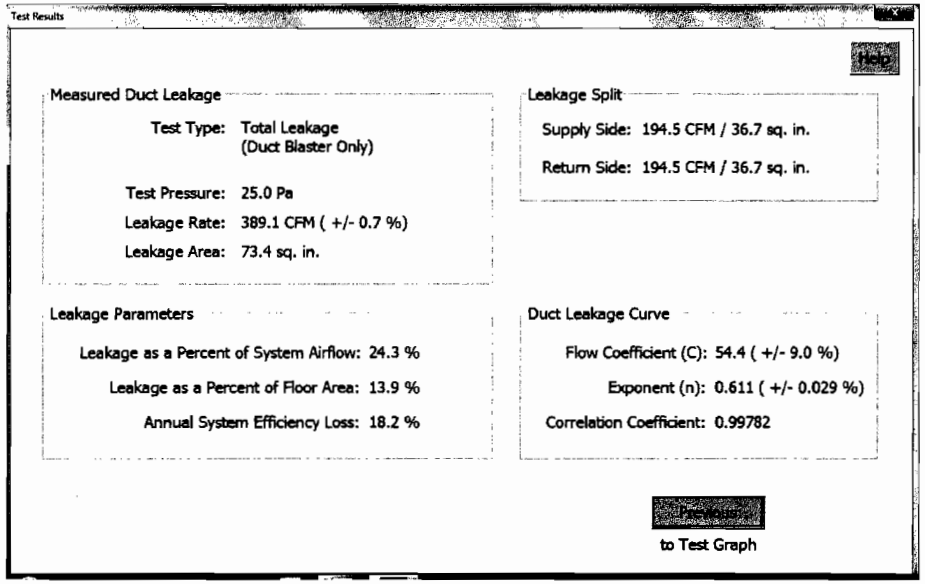
U.S. DEPARTMENT OF ENERGY Energy Efficiency & Renewable Energy

Troubleshooting

- Not able to reach target pressure
  - Check covers on all registers
  - Tape may be being blown off during pressurization
  - Duct system just too leaky to test accurately
  - Change reference tube location (closer to air handler)

Software


Duct Leakage Test Graph
Duct Leakage (cfm)
600
500
400
300
200
100
4
5
6
7
8
9
10
20
30
40
50
Duct Pressure (Pa)


Test Results
Measured Duct Leakage
Test Type: Total Leakage (Duct Blaster Only)
Test Pressure: 25.0 Pa
Leakage Rate: 389.1 CFM (+/- 0.7 %)
Leakage Area: 73.4 sq. in.
Leakage Split
Supply Side: 194.5 CFM / 36.7 sq. in.
Return Side: 194.5 CFM / 36.7 sq. in.
Leakage Parameters
Leakage as a Percent of System Airflow: 24.3 %
Leakage as a Percent of Floor Area: 13.9 %
Annual System Efficiency Loss: 18.2 %
Duct Leakage Curve
Flow Coefficient (C): 54.4 (+/- 9.0 %)
Exponent (n): 0.611 (+/- 0.029 %)
Correlation Coefficient: 0.99782
to Test Graph

"Duct Blaster" downfalls

- Have to access all register
- If working with toekicks, must seal off at boot if not ducted to register
- Fan connection can be tricky
- Measurements are taking at a simulated pressure rather than normal operating pressures

Acceptable Duct leakage

Energy Star

- 6 CFM leakage to the outside per 100 sq.ft. of floor area

Example

- Home is 1800 sq.ft.
- 18 x 6= 108
- 108 CFM @25 acceptable leakage to the outside

Maximum Allowable Duct Leakage

BPI Standards

- System Airflow : 1200 CFM

Formula

System Air flow X 0.10= Allowable Duct Leakage

Example

1200 X 0.10 = 120 CFM @25

Acceptable Duct leakage

Old Construction Standards

- 12 CFM leakage to the outside per 100 Sq.Ft. of floor area

Example

- Home is 2400 Sq.Ft.
- 24 x 12 = 288
- 288 CFM @25 acceptable leakage to the outside

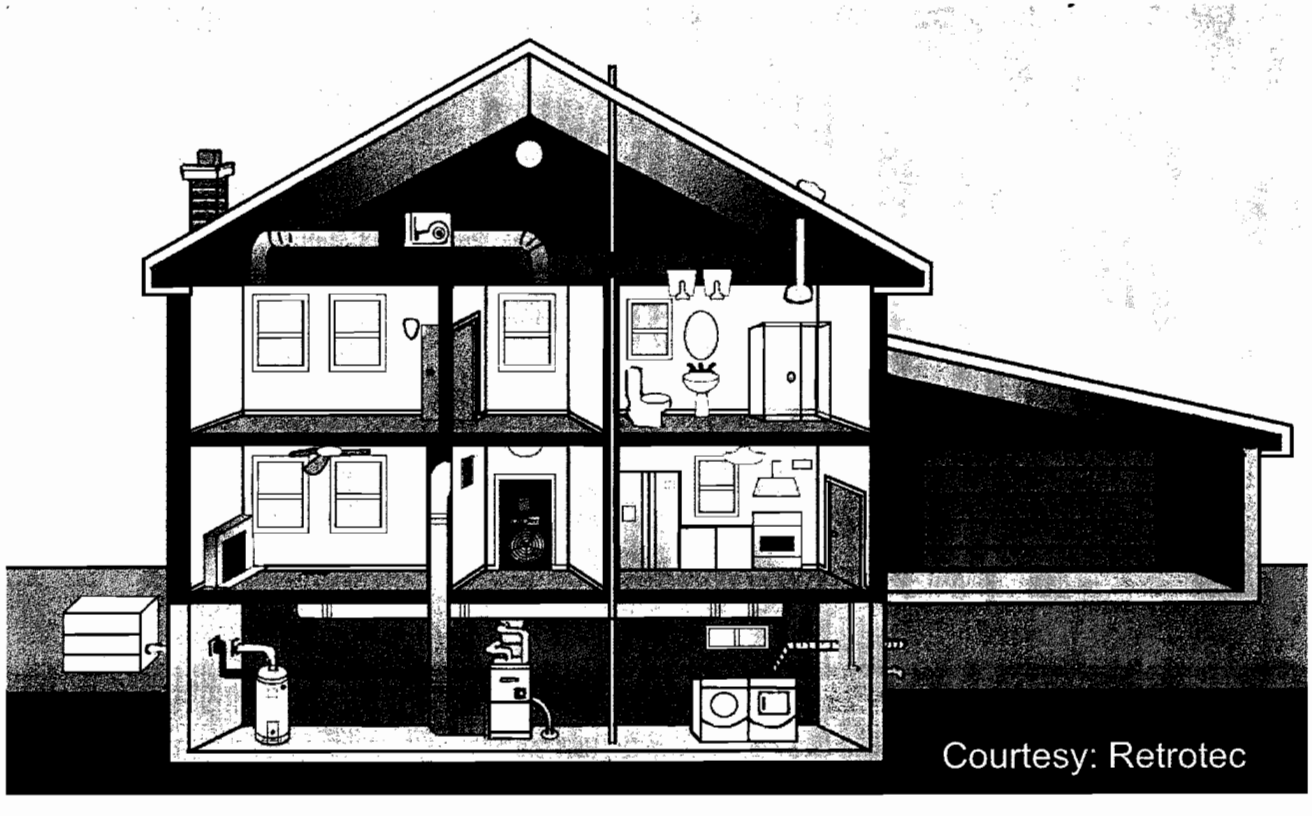
Delta-Q Testing

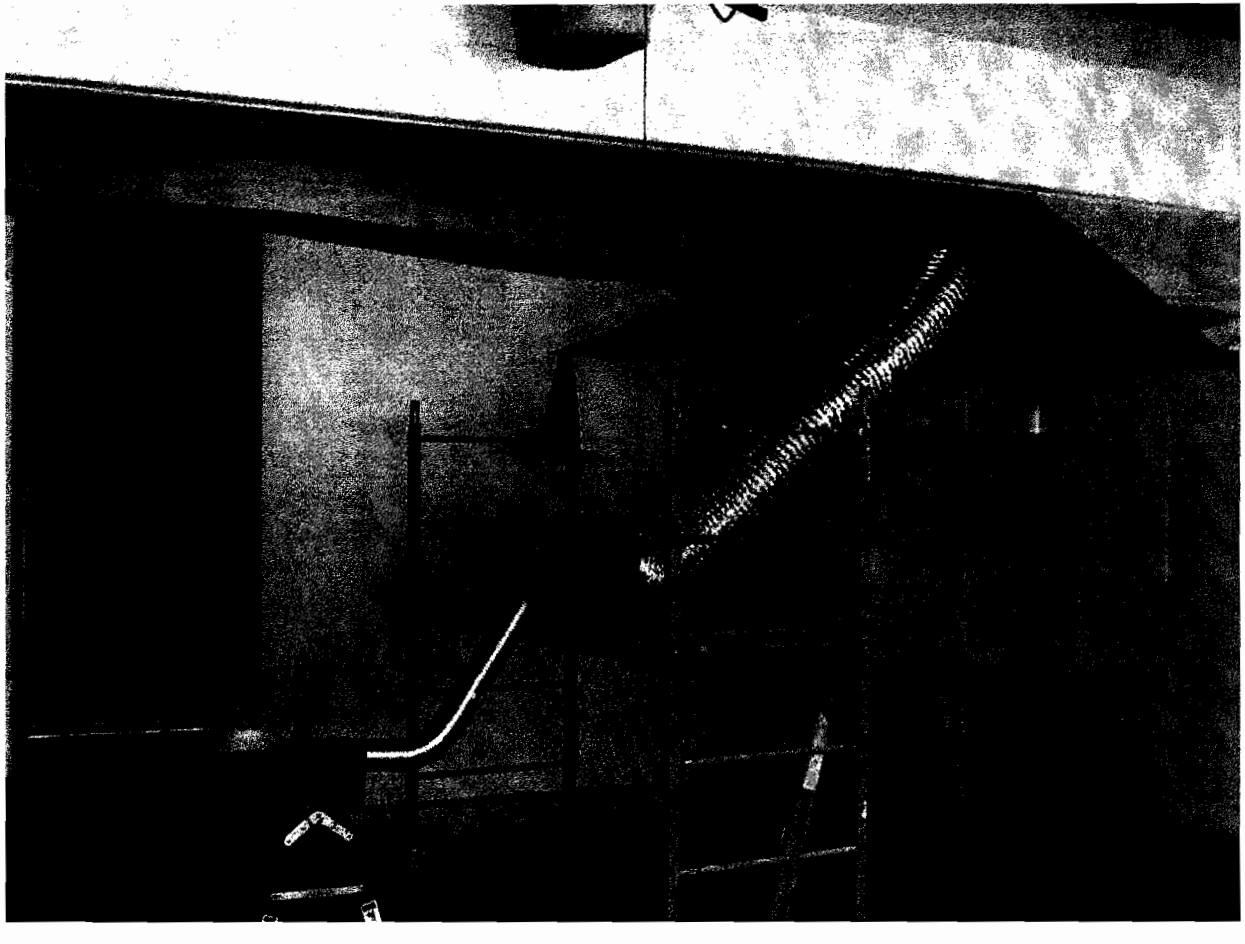
- The Delta-Q test measures blower door flow across a wide range of house-to-outside pressures, both with the air handler operating and without it operating
- The process has been greatly advanced by automated software
- Delta-Q measurements are meant to reflect leakage under normal operating conditions

Delta-Q Testing

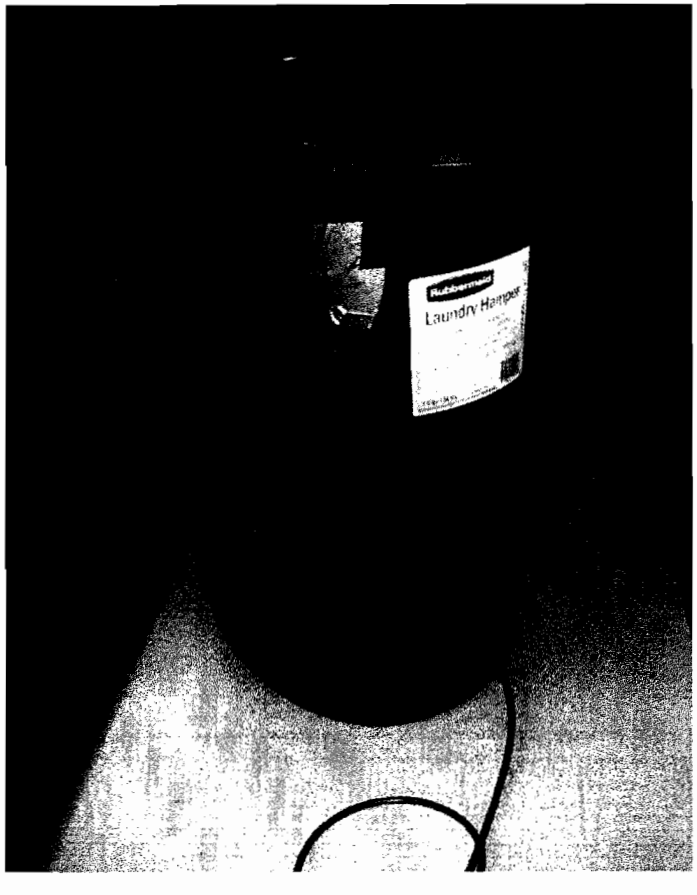
- Depressurize the envelope to -5pa, record leakage
- Continue on a scale of 5pa increments all the way up to -50pa, recording leakage at every point
- Repeat previous tests with air handler on
- Now pressurize the envelope to +5pa, record leakage
- Continue on a scale of 5pa increments all the way up to +50pa, recording leakage at every point
- Repeat previous tests with air handler on

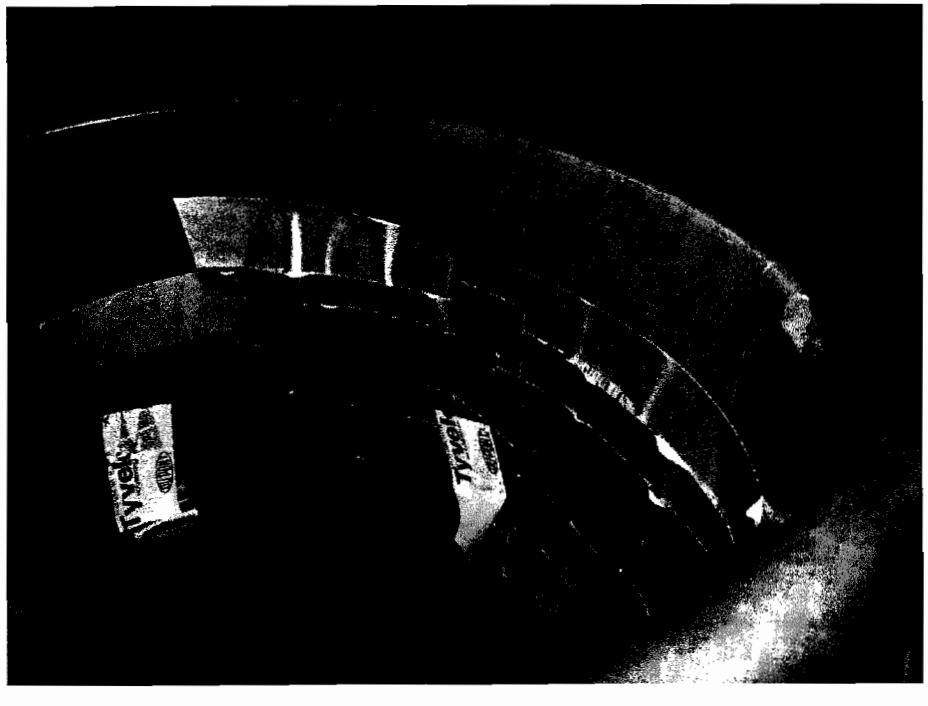
Leakage to Outdoors





2011 Material Weatherization Training Conference





U.S. DEPARTMENT OF ENERGY
Energy Efficiency & Renewable Energy

Basic Energy Auditing & House Assessment

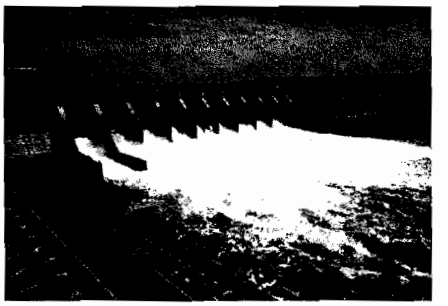
Presenters: Rod Burk & Ken Robinette
South Central Community Action Partnership
Twin Falls, Idaho

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

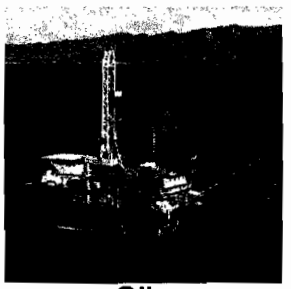
Forms of Ene

Coal

Wind



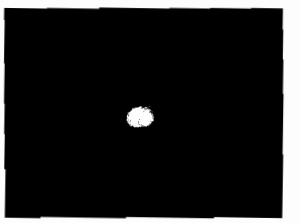
Hydro



Oil

Natural Gas

Fire



Solar

U.S. DEPARTMENT OF ENERGY Energy Efficiency & Renewable Energy

Laws of Thermodynamics

- Governing heat's behavior in the universe
- Energy is never created or destroyed – it just moves from place to place
- Heat moves from a higher temperature region to a lower temperature region

Heat Energy

- A British thermal unit is approximately equal to the heat produced by a kitchen match
- Common fuel source energy measurements:
  - **Electricity** **3,413 BTU/KWH**
  - **Propane** **92,000 BTU/Gal.**
  - **Natural Gas** **100,000 BTU/Therms**
  - **Fuel Oil** **138,000 BTU/Gal.**

U.S. DEPARTMENT OF ENERGY Energy Efficiency & Renewable Energy

Three Types of Heat Flow

- **Conduction**

  Heat transport molecule to molecule in a solid

- **Convection**

  Heat transport by movement in a fluid

- **Radiation**

  Heat waves traveling through space

Conduction Heat Flow

- Conduction is heat flow though solids such as wood and masonry
- Examples:
  - Rapid heat flow through an un-insulated foundation
  - Rapid heat flow through aluminum window frames
  - Walking on a hot sidewalk with bare feet

Convection Heat Flow

- Convection is heat flow in fluids such as air or water
- Common examples:
  - Downdrafts at windows during the winter
  - Operation of a gas water heater
  - Convection currents between primary window and storm window

Radiant Heat Flow

Two types of radiation heat flow:

- Solar heat radiation

  High-energy radiation from the sun

- Thermal heat radiation

  Lower temperature radiation from objects on earth

Radiation flows from higher temperature bodies to lower temperature bodies

Heat Flow in Buildings

- **Transmission heat flow**
  - Ceiling transmission
  - Wall transmission
  - Floor/foundation transmission
  - Window/door transmission
- **Air Flow**
  - Mechanical ventilation
  - Air leakage

How Does This Science Apply to The Work We Do in Weatherization?

U.S. DEPARTMENT OF ENERGY Energy Efficiency & Renewable Energy

Making it work

- With the combination of building science and the physics of energy transfer, energy auditors can evaluate houses and determine cost effective energy improvements.
- A successful energy analysis can be achieved by following these 7 easy steps.

7 Easy Audit Step Process

- Prepare
- Home Visit
- Client Concerns
- Visual Inspection
- Measurement/DataCollection
- Putting it All Together
- Calculate Energy Savings/ Computerized Energy Audit

Step 1 – Preparation

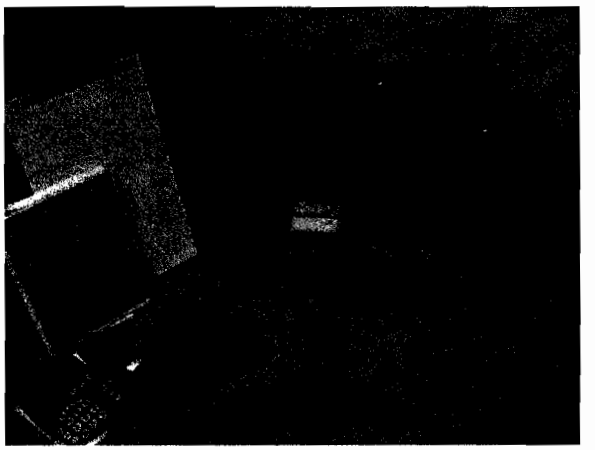
- Gather information about Client
  - Determine location/address
    Use Map Quest/GPS if not familiar with area
  - Job Work Order Sheet
  - Forms to be signed by Client (i.e. owner/renter agreement)
  - EPA Forms and pamphlets
  - Client Education handouts
  - Other necessary Agency forms

Preparation

Preparation: Gather Necessary Equipment to include:

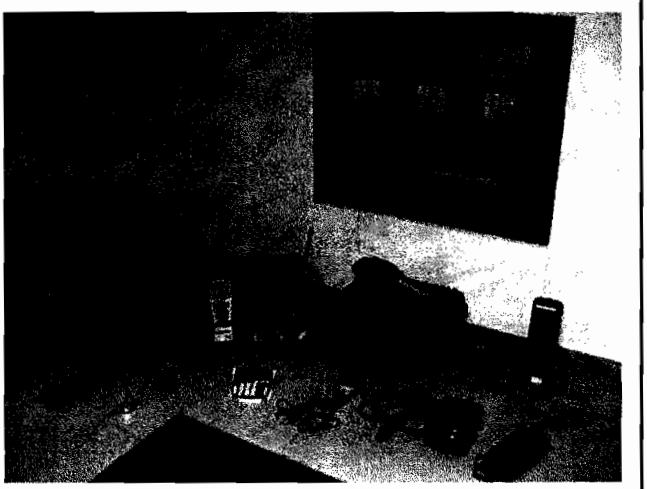
- Step & Extension Ladders
- Tape Measure
- Blower Door/Duct Blaster (Optional)
- Furnace Diagnostic Testing Equipment
- Digital camera /Infra red camera (if available)
- Multi-Volt Meter/Data Logger
- Flash Light
- Cooking Thermometer
- Drill (Cordless Preferred)
- Misc. Hand Tools (Hammer, Awl, Screwdrivers Mirror)
- Personal Protective Equipment (Mask, Coveralls, Kneepads)
- Field Manual/ Clipboard & Cell Phone

U.S. DEPARTMENT OF ENERGY Energy Efficiency & Renewable Energy

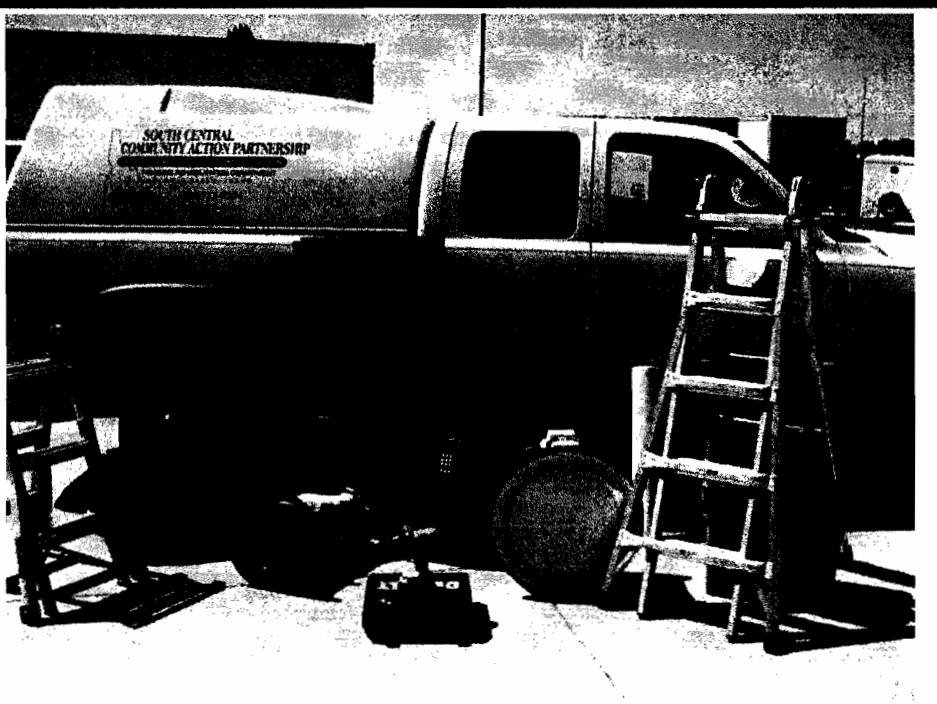


Hand Tools & misc Supplies

Diagnostic Testing Equipment



U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



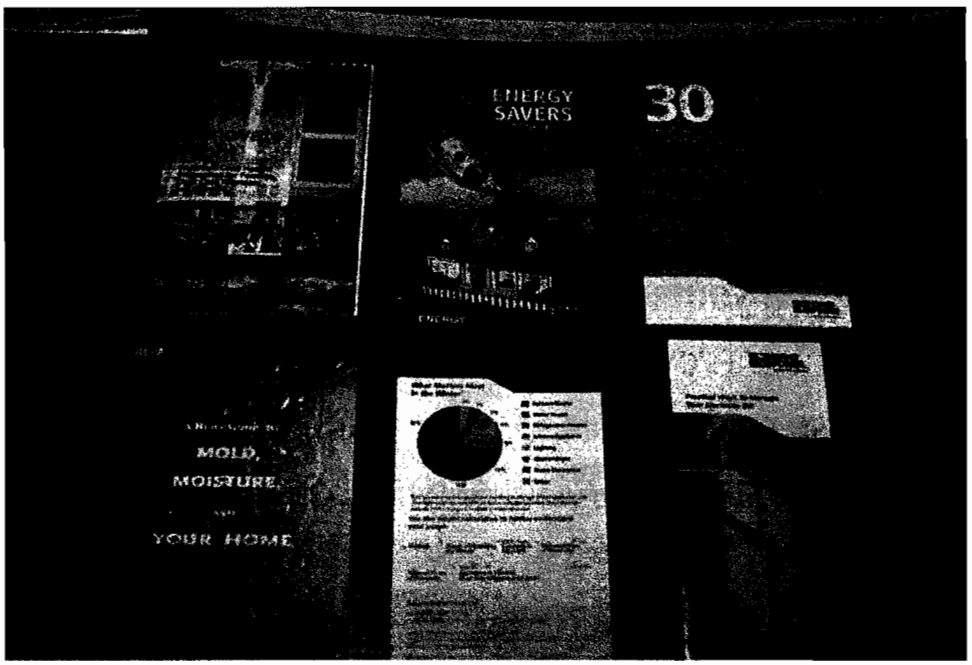
U.S. DEPARTMENT OF ENERGY Energy Efficiency & Renewable Energy

U.S. DEPARTMENT OF ENERGY Energy Efficiency & Renewable Energy

U.S. DEPARTMENT OF ENERGY Energy Efficiency & Renewable Energy

Step 2 – Home Visit

- Introduction
  - Introduce yourself and provide client with audit plan
  - Present energy educational pamphlets to client
  - Discuss risks from lead base paint, mold and moisture
  - Give Client an overview of what will be done with Lead Safe Work Practices to assure their safety



U.S. DEPARTMENT OF ENERGY Energy Efficiency & Renewable Energy

Step 3 – Client Concerns

- Ask Client if there specific problems or concerns relating to their home.

Try to keep concerns to house directed to energy related issues only.

In some cases you will hear their life story.~ Be patient

Step 4 – Visual Inspection

- Perform a visual inspection of the inside and outside of the home and collect measurements.
- Begin at the front door and move to the right or left, but stay consistent.
- Look for possible hazards that could effect the *Health and Safety* of your crews or contractors

  Mold, evidence of drug use, dogs, nasty stuff in crawlspaces, spiders, bare wiring, open sewage, skeletons, etc. (deferral/walk-away policy)
- Measure the house and draw a picture showing dimensions.

House Information & Measurements

- Collect information on the following:
  - Windows
    - Type? Condition? U-Value?
    - With or Without Storm Windows?
    - Measure Each Window
  - Doors
    - Type? Condition? U-Value?
    - With or Without Storm Door?
    - Measure Each Door

Collect Information

- Walls
  - Type of Siding?
  - Condition?
  - With or Without Insulation?
  - If Insulation – What Type?
  - How Much?
  - R-Value?
  - Wiring? (Knob & Tube, Romex)
  - Other Possible Problems/Issues

Collect Information

- Inspect Roof
  - Condition?
  - Ventilation?
  - Type?
  - Size?
  - How Many?
- Inspect Attic
  - Type of Insulation?
  - How Much?
  - Heat Producing Devices? (Flues, Recess Lights, Fans)
  - Bypasses?
  - Other Possible Problems/Issues

Collect Information

- Inspect Foundation (If Applicable)
  - Condition?
  - Venting – Type, Size, How Many?
  - Clearance?
  - Type of Floor Joist (2"x6", 2"x10" Etc.)
  - Type of Insulation (If Any) How Much?
  - Ground Barrier?
  - Water Pipes?
  - Heat Ducts? (If Applicable)
  - Other Possible Problems/Issues

Heating System

- Type?
- Condition?
- Check T-Stat for Heat Anticipator Setting
- Fire Up Furnace
- Complete Diagnostic Testing
  - Combustion Fired Units– CO Analyzer, Draft Test (Coal, Oil, Gas, Wood, Propane)
  - Oil – Perform Smoke Test First
  - Electric – Volt/Amp Meter

Water Heater, Blower Door & Duct Blaster

- Test
  - Type?
  - Condition?
  - If Electric – Test Elements / T-Stat
  - If Gas – Test for Draft and CO
- Run Blower Door Test
- Run Duct Blaster Test (if Applicable)

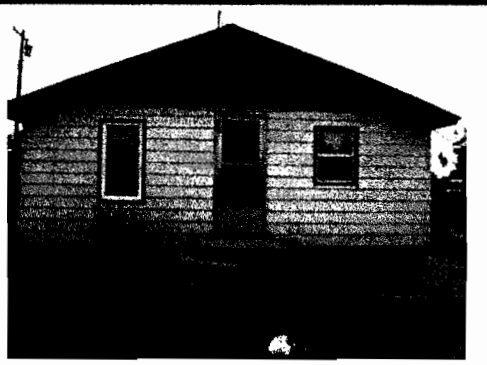
Wrap Up

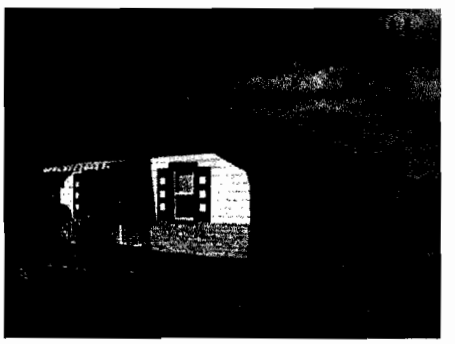
- Inform Client of your findings and what you project to do to make their home more energy efficient.
- Return to office and…

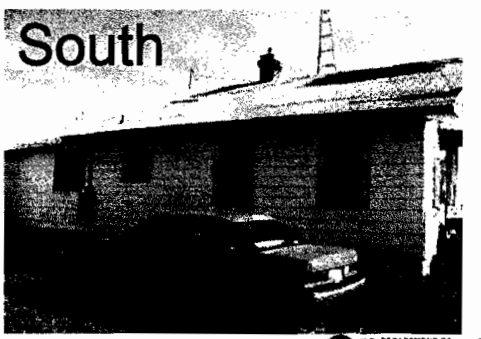
put it all together

Exercise

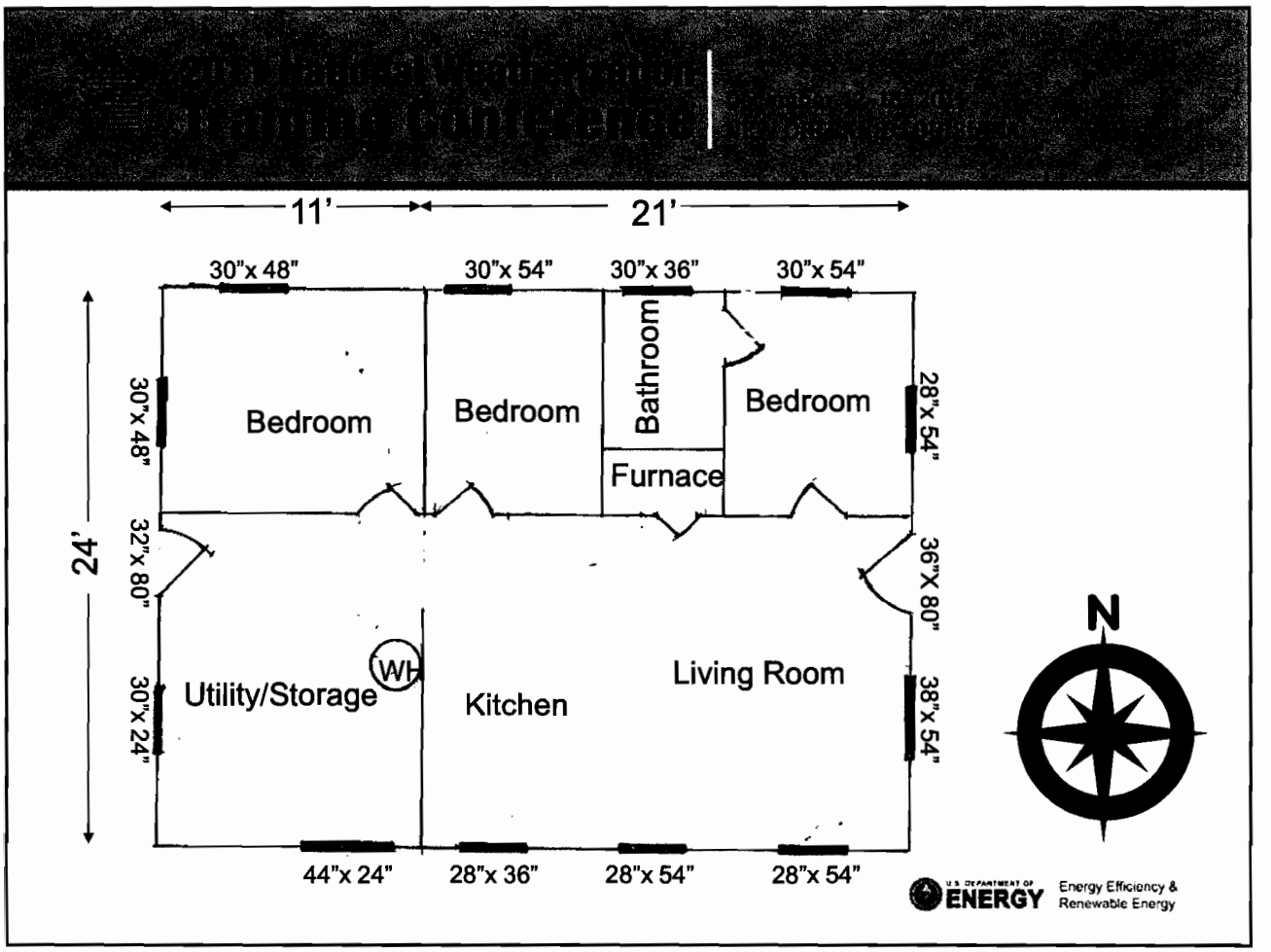
- Fill out Audit with information from house on Job Work Order Sheet.
  - Complete Square Footage
  - Calculate Window Area
  - Calculate Door area
  - Calculate Attic Area
  - Calculate Walls Area
  - Calculate Floor Area







U.S. DEPARTMENT OF ENERGY
Energy Efficiency & Renewable Energy


11'
21'
24'
30"x 48"
30"x 54"
30"x 36"
30"x 54"
30"x 48"
28"x 54"
32"x 80"
36"X 80"
30"x 24"
38"x 54"
44"x 24"
28"x 36"
28"x 54"
28"x 54"
Bedroom
Bedroom
Bathroom
Bedroom
Furnace
Utility/Storage
WH
Kitchen
Living Room
N
U.S. DEPARTMENT OF ENERGY
Energy Efficiency & Renewable Energy

House Characteristics

- Ranch Style w/crawlspace, Twin Falls, ID
  - Built in 1951
  - Siding Metal No Insulation (Nothing Between Steel and Wood)
  - Walls 11'x24'x7' 2"x4" Studs
    21'x24'x8' 2"x4" Studs
  - Attic 3" Redwood Shavings R-4
    3" Blown fiberglass R-7
  - Venting 3-12"x24" Gable Vents
    3-9" Roof Vents
  - Foundation - 6" Concrete Foundation with 4-8"x10" Foundation Vents
  - Floor – 3' High Crawlspace – 2"x6" Joist – 24" OC – 0 Insulation and no Ground Barrier
  - Sub-Floor – Single Layer with Carpet

House Characteristics

- Water Heater – 19" x 46" (50 Gal. Tank)
  - Water Temperature 120°
  - Upper Element 18 amps
  - Lower Element 18 amps
- Water Pipes – 120 L/F in Crawlspace
- Windows – Wood Sash Single Glaze/Single Hung
- Doors – 1-36"x 80" 1 3/4" Metal Insulated Door w/Storm Door
  1-32"x 80" 1 3/8" Panel Door w/ Storm Door
- Heating System – Natural Gas Forced Air with Standing Pilot Light, Located in Center of Home
  - 80% Steady State
- Heat Ducts – 140'-6" un-insulated Rigid Ducts in Crawlspace

Price List

• **Materials Price List**	
Cellulose Insulation	$4.95 per 30# Bag
R-19 Fiberglass	$15.00 per Roll (49 sq ft Roll)
R-11 Vinyl Duct Wrap Insulation	$60.00 per Roll (4'x50' Roll)
Tie Straps	$ .27 per Strap
Duct Mastic	$19.00 per Gallon
R-4 Tubular Pipe Insulation	$ .61 per L/F (6' Lengths)
6 mil Visqueen (Black)	$41.00 (10'x100' Roll)
Wood Lath	$11.00 per bundle (50 Pcs)
1 ¾" Metal Insulated Pre-Hung Door	$127.00 (36"x80")
1 ¾" Metal Insulated Pre-Hung Door	$127.00 (32"x80")
Keyed Entrance	$8.75 ea
Vinyl Insulated Window	$9.88 per sq ft
• **Labor Cost**	$18.00 per Hour
• **Overhead**	$85.00 per Job

U.S. DEPARTMENT OF ENERGY Energy Efficiency & Renewable Energy

Simple Heat Savings Calculation
&
Simple Payback

Basic Heat Savings Calculations

CONDUCTIVE HEAT SAVINGS SYMBOLS

Δ	=	DIFFERENCE (DELTA)
A	=	AREA
U	=	U-VALUE
HDD	=	HEATING DEGREE DAYS
C	=	CORRECTION FACTOR
P	=	PRICE OF FUEL
S	=	SEASONAL EFFICIENCY (HEATING SOURCE)
V	=	VALUE OF FUEL

FORMULA FOR CONDUCTIVE HEAT SAVINGS

$$\$ = \frac{\Delta U \times A \times HDD \times C \times P}{S \times V}$$

FUEL PRICES (IDAHO)	Electric	. 058	Gas RS-1 1.25	Oil 2.50

U.S. DEPARTMENT OF ENERGY Energy Efficiency & Renewable Energy

Basic Heat Savings Calculation

Attic – Existing R-11 = U-Value .091

Proposed R-38 = U-Value .026

$$\$ = \frac{\Delta U \times A \times HDD \times C \times P}{S \times V}$$

1 Divided by R-Value = U-Value

ΔU = .065 **S = .61**
Area = 768 **V = 100,000**
HDD = 6324 **P = 1.25**
C = 17

$$\$ = \frac{0.065 \times 786 \times 6324 \times 17 \times 1.25}{0.61 \times 100{,}000} = \frac{6{,}865{,}730}{61{,}000}$$

= $112.55 = 1st Yr Savings

U.S. DEPARTMENT OF ENERGY Energy Efficiency & Renewable Energy

Simple Payback Calculation

C = Cost of Measure (includes Labor Costs)
S = 1ST year Savings (Calculated from Conductive Heat Savings Formula)
P = Payback in Years

C/S =P

Material – 24 Bags @ $4.95 = $118.80
Labor – 3 hrs x $18 x 2 Techs. = $108 + $85 Overhead = $193.00
Total Cost - $311.80

$311.80 / $112.55 = 2.8 Year Payback

Basic Heat Savings Calculation

Walls – Existing No insulation = U-Value 0.189

Proposed R-13 = U-Value 0.077

$$\$ = \frac{\Delta U \times A \times HDD \times C \times P}{S \times V}$$

Total Walls	**= 850 sq ft**		
Less Windows	- 115 sq ft	**ΔU = .112**	**S = .61**
Less Doors	- 38 sq ft	**Area = 592**	**V = 100,000**
Less Studs	- 105 sq ft .	**HDD = 6324**	**P = 1.25**
		C = 17	
Total Area	**592 sq ft**		

$$\$ = \frac{.112 \times 592 \times 6324 \times 17 \times 1.25}{0.61 \times 100{,}000} = \frac{8{,}910{,}263}{61{,}000}$$

= $146.07 = 1st Yr Savings

U.S. DEPARTMENT OF ENERGY Energy Efficiency & Renewable Energy

Simple Payback Calculation

C = Cost of Measure (includes Labor Costs)

S = 1ST year Savings (Calculated from Conductive Heat Savings Formula)

P = Payback in Years

C/S =P

Material – 17 Bags @ $4.95 = $84.15

Labor – 8 hrs x $18 x 2 Techs. = $288 + $85 Overhead = $373.00

Total Cost - $457.15

$457.15 / $146.07 = 3.13 Year Payback

U.S. DEPARTMENT OF ENERGY Energy Efficiency & Renewable Energy

Basic Heat Savings Calculation

Kitchen Window – Existing U-Value 1.02

Proposed U-Value .34

New Window is a Vinyl ¾in. insulated, Low E window

Window – 28in x 36in / 144 = 7 sq ft

$$\$ = \frac{\Delta U \times A \times HDD \times C \times P}{S \times V}$$

ΔU = .68 **S = .61**
Area = 7 **V = 100,000**
HDD = 6324 **P = 1.25**
C = 17

$$\$ = \frac{0.68 \times 7 \times 6324 \times 17 \times 1.25}{0.61 \times 100{,}000} = \frac{639{,}673}{61{,}000}$$

= $10.49 = 1st Yr Savings

U.S. DEPARTMENT OF ENERGY Energy Efficiency & Renewable Energy

Simple Payback Calculation

C = Cost of Measure (includes Labor Costs)
S = 1ST year Savings (Calculated from Conductive Heat Savings Formula)
P = Payback in Years

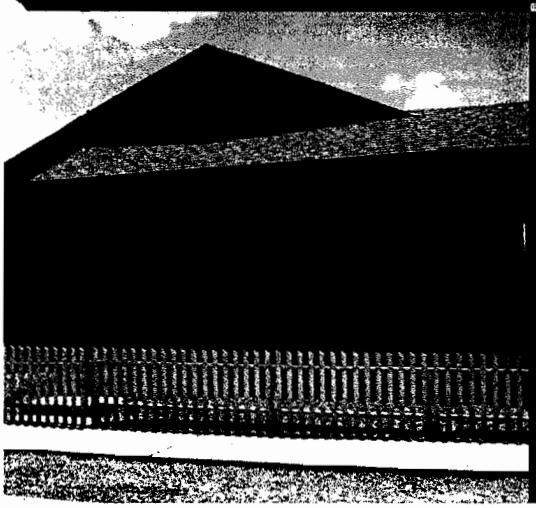
C/S =P

Material – $9.50 x 7 sq ft = $66.50
Labor – 1 ½ hrs x $18 x 1 Tech. = $27 + $85 Overhead = $112.00
Total Cost - $178.50

$178.50 / $10.49 = 17 Year Payback

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

BUILDING TECHNOLOGIES PROGRAM



Builders Challenge

Recognizing Energy Leadership in Homebuilding

High Performance Builder Spotlight

Artistic Homes

Albuquerque, New Mexico

Every Artistic Home sold in 2010 qualified for DOE's Builders Challenge certification. Artistic has been a Building America partner for 11 years, working with Building America teams Building Science Consortium and Building Industry Research Alliance (BIRA).

HOT-DRY & MIXED-DRY CLIMATES

BUILDER PROFILE

Artistic Homes

Tom Wade, Co-owner
www.artistichomes.com
(505) 247-8400

1986

8, not counting subs

1,305-2,905 sq. ft.

$160,000 to $300,000

Building AMERICA® U.S. Department of Energy
Research Toward Zero Energy Homes

In a very slow real estate year, Artistic Homes of Albuquerque was able to raise prices 15% and still sell houses because buyers are seeing the value of its Builders Challenge-certified zero-energy homes. "2010 was the worst housing economy on record. We increased our prices and were still able to sell homes," said Tom Wade, co-owner of Artistic Homes of Albuquerque. "If we can sell in this market, I can't wait until tomorrow," adds Wade.

Artistic Homes is the first production home builder in the United States to offer a true net-zero upgrade option on all of its homes. According to Wade, in Albuquerque in 2010, 45% of its homes sold were built to near or true zero energy (with HERS scores of under 5). "Our largest demographic is people nearing retirement who are shoring up their finances and see the value in an energy-efficient home," said Wade. Artistic's standard home averages a low HERS score of 51.

Every one of the 100 homes Artistic sold in 2010 qualified for the U.S. Department of Energy's Builders Challenge, ENERGY STAR's Indoor airPLUS criteria, and LEED's silver to platinum level.

> "Zero energy was not much harder than what we are already doing. When we sat down with our subs and told them our goals, they got excited about hitting that zero too."
>
> **TOM WADE**, *co-owner Artistic Homes*

Standard features include advanced framed 2x6 24-inch on-center walls, R-21 blown insulation in the walls, high-efficiency windows, slab-on-grade foundations with R-10 rigid foam insulation under the slab and R-5 rigid foam slab edge insulation. Ducts are located in conditioned space in a dropped ceiling in the hallway and the airhandler is located inside in the utility room. In 2009, Artistic added R-50 blown fiberglass attic insulation (up from R-32) to its list.

To improve air quality, every home has a heat recovery ventilator with a HEPA filter, radon mitigation with a passive pipe venting from below the slab to the roof, and a garage venting system that uses a motion sensor to switch on a garage fan mounted to an outside wall.

Air sealing details include gasketing the sill plate and caulking or foam sealing all wiring and piping holes. Every home is tested for whole house and duct leakage. Whole house air leakage ranges from 500 to 800 cfm: a code-built house would

typically be about 2,700 cfm, according to Wade, who said Artistic's goal is to get every home below 500 cfm in 2011.

In markets outside of Albuquerque, where Artistic is competing primarily with local builders, their 1,300-2,900 square-foot homes often sell for less, sometimes several thousand dollars less, than competitors' homes. In Albuquerque, where they are sometimes underpriced by national builders selling code-typical homes, they hold their own by marketing energy efficiency. "At least half of the buyers coming in are looking for energy efficiency," said Wade.

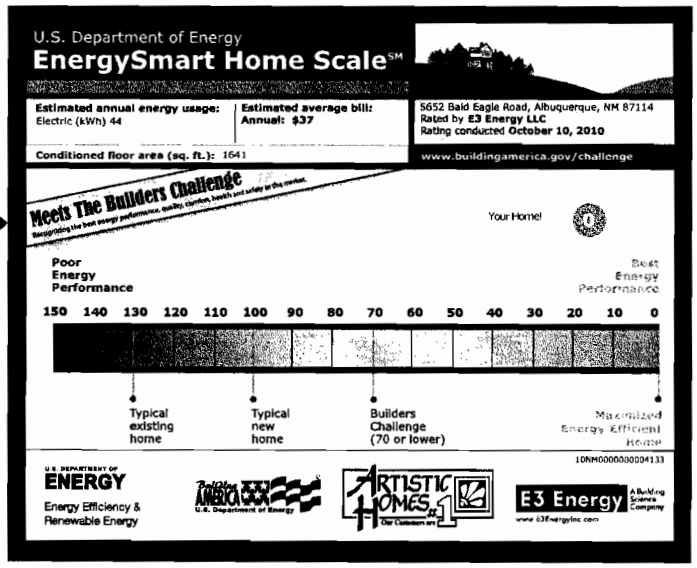
The zero-energy package includes roof-mounted solar photovoltaic panels ranging in size from 4.2 to 7.0 kWh at added costs of $32,000 to $42,000. The zero-energy homes also have a roof-mounted solar thermal water heater and 80-gallon storage tank. Artistic's "Solar 30" package includes a 1.3 to 2.0 kW system and costs about $11,000 to $16,000. Rebates, incentives, net metering, or renewable energy certificates (currently 11 cents per produced kW paid by the Public Utility of New Mexico) make the solar systems much more affordable.

Artistic Homes offers homeowners web-based data collectors for hour-by-hour monitoring of their energy loads. The systems are free for homeowners participating in a 2-year study to help Artistic find ways to make its homes even more energy efficient.

Artistic installs high-efficiency furnaces and ducts in conditioned space and provides a fresh air intake and heat recovery ventilator with HEPA filter for greater efficiency, air quality, and comfort.

U.S. Department of Energy Builders Challenge

DOE seeks to give every consumer the opportunity to buy a cost-neutral, net-zero energy home anywhere in the U.S. by 2030. Homes that qualify for this Builders Challenge must achieve a 70 or less on the EnergySmart Home Scale (E-Scale) which is based on the Home Energy Rating System (HERS) index (www.natresnet.org). The E-Scale allows homebuyers to understand—at a glance—how the energy performance of a particular home compares with others.



To learn more about the Builders Challenge and find tools to help market your homes, visit www.buildingamerica.gov/challenge.

Energy-Efficient Features

- Air handler in sealed utility closet
- Ducts in conditioned space
- R-21 blown insulation in walls, R-50 blown insulation with wind baffles at soffit vents in attics
- Advanced framing techniques
- Heat recovery ventilator with HEPA filter
- Gasketing, foam sealing, and caulking of all envelope penetrations
- Fresh air inlet; jump ducts
- 3rd party HERS rater blower door and duct blaster testing of every house
- 15 SEER AC and 9.0 HSPF electric furnace
- Heating and cooling energy usage and comfort are guaranteed
- Low-e, dual-pane, Fibrex® windows
- Borate treatment of studs and bottom plate
- Low and no VOC products
- Job-site recycling

True net-zero upgrade package includes:

- Roof-mounted photovoltaic power system (4.2 to 7.0 kWh)
- Solar thermal hot water heating

U.S. DEPARTMENT OF ENERGY
Energy Efficiency & Renewable Energy

EERE Information Center
1-877-EERE-INF (1-877-337-3463)
www.eere.energy.gov/informationcenter

PNNL-SA-76880 January 2011 - 1

For information on **Building America** visit **www.buildingamerica.gov**. The website contains expanded case studies, technical reports, and best practices guides.

DOE Tribal Multi-County Weatherization Program

October 2010

Brief Summary of Tribe

The Scotts Valley Band of Pomo Indians is located in Northern California with tribal offices located in Lakeport, Lake County and the City of Richmond, Contra Costa in California. The current Tribal membership consist of 227 members. Scotts Valley is a landless Tribe and currently has 23 acres in fee simple status in Lake County.

Project Overview

The program promotes Tribal energy self-sufficiency, social & economic development, employment opportunities, and training for Tribal communities on the creation of energy efficiency and renewable energy.

As building knowledge and skills is essential to developing, implementing, and sustaining energy efficiency and renewable energy development projects, the program also offers energy education.

Project Overview

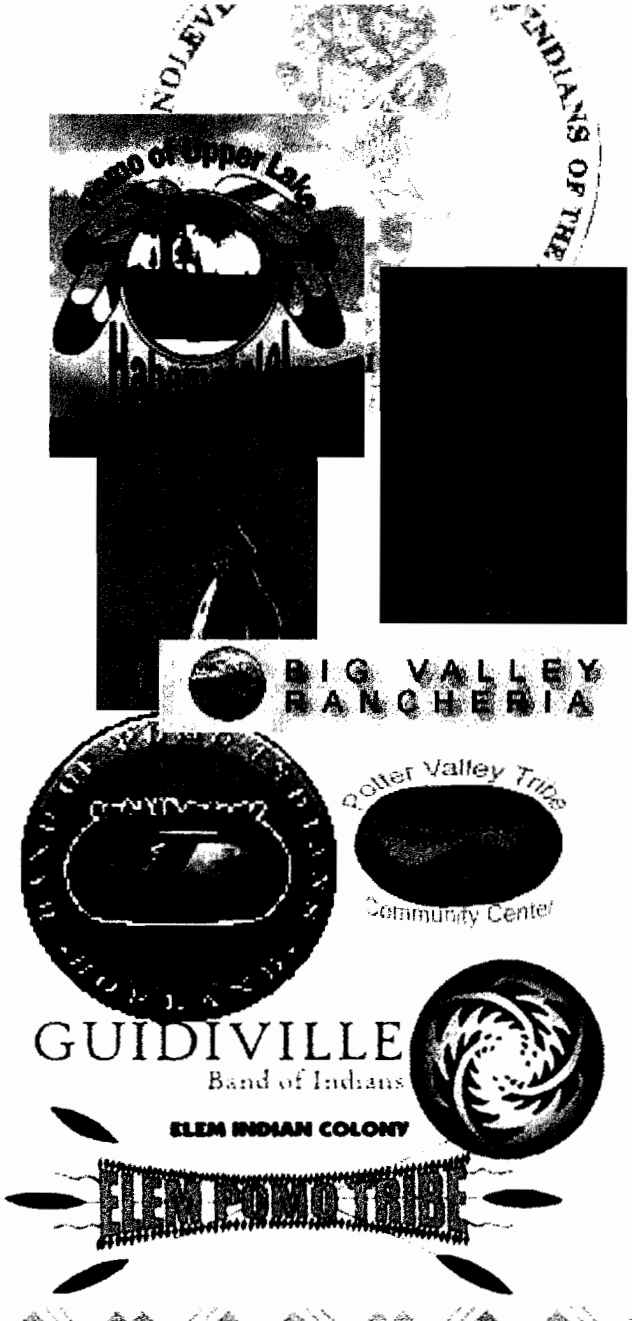
The goals of the proposed project are:

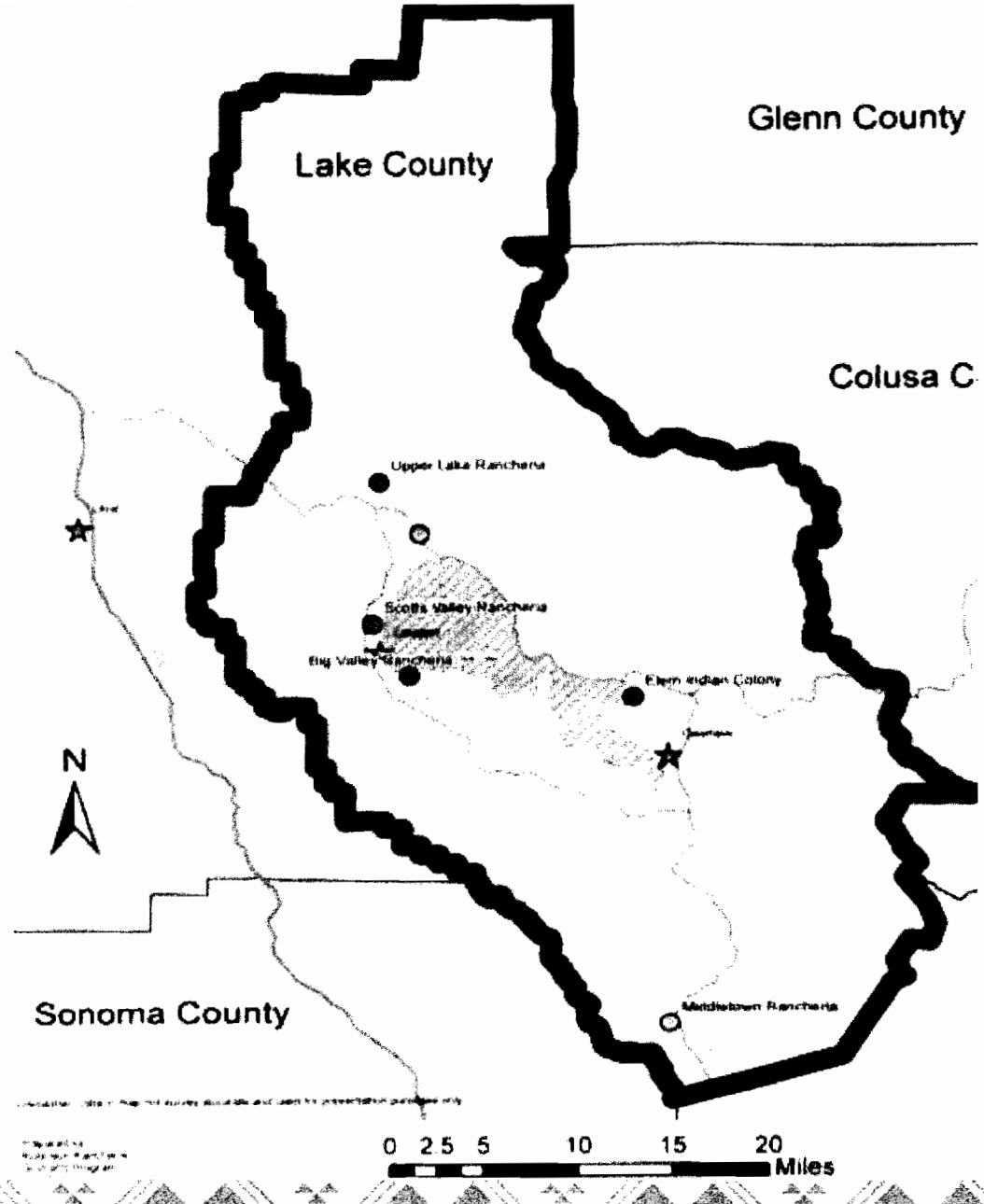
- Training to bring renewable energy and energy efficiency jobs to Indian Country
- Enhance Tribal capacity through energy education and training
- Improve local Tribal economics and the environment
- Make a difference in the quality of life of California Indians

Project Participants

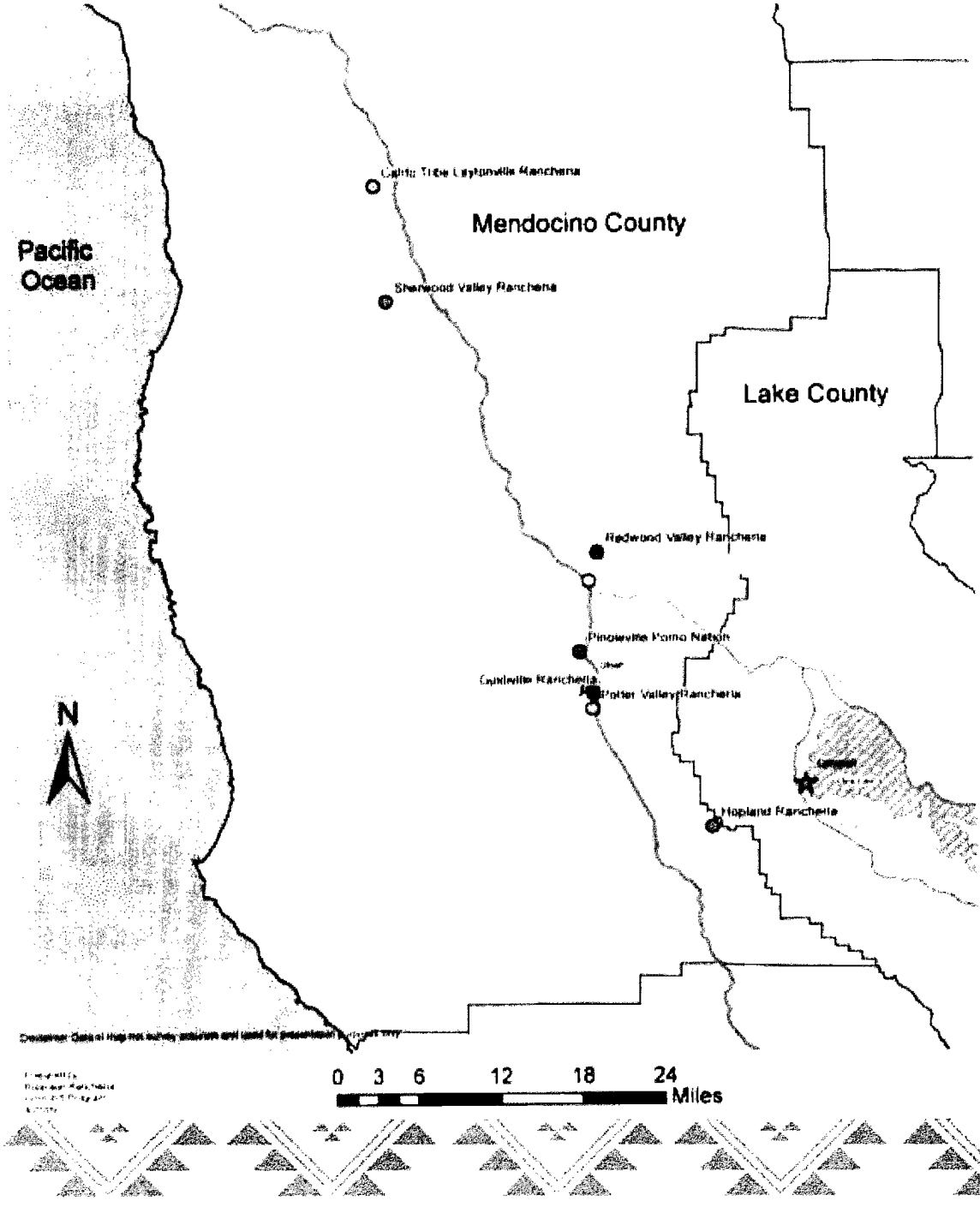
Scotts Valley will partner with the following twelve Tribes located in Lake and Mendocino counties:

- Scotts Valley Band of Pomo Indians
- Big Valley Rancheria
- Elem Indian Colony
- Habematolel Pomo of Upper Lake
- Middletown Rancheria of Pomo Indians
- Cahto Tribe of Laytonville Rancheria
- Guidiville Rancheria
- Potter Valley Rancheria
- Redwood Valley Little River Band of Pomo Indians
- Sherwood Valley Band of Pomo Indians
- Hopland Band of Pomo Indians
- Pinoleville Pomo Nation





Project Location: Tribes of Lake County



Project Location: Tribes of Mendocino County

Other Supporting Partners

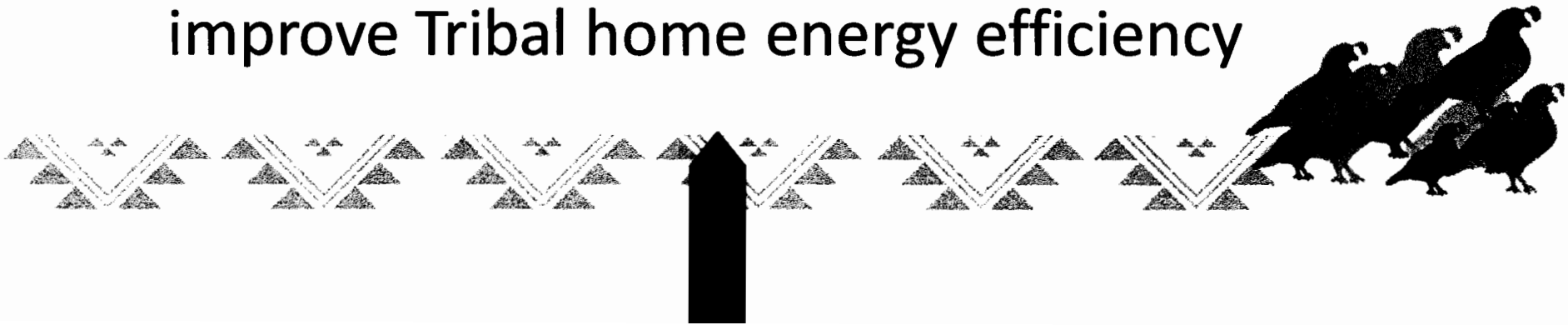
- North Coast Energy Services
- Pinoleville Pomo Nation Vocational Rehabilitation Program
- County of Lake, Board of Supervisors
- Pacific Gas and Energy Company- Utility Provider
- Energy Efficiency Training Academy of Northern California (EETA)

Project Accomplishments

23 Tribal members received Weatherization Training. Courses included classroom instruction and hands on training:

- Basic Weatherization
- Combustion Appliance Safety
- Duct Blaster and Blower Door

From this training three Tribal members have been hired by Tribes to do weatherization to improve Tribal home energy efficiency



Scotts Valley EPA and Natural Resources Office

ENERGY EFFICENCY PROGRAMS

Is presenting a "Energy 101" class for all interested Tribal community members and Tribal Energy Programs.

When: Friday, October 15, 2010
Time: 1:00—3:00 p.m.
Place: Consolidated Tribal Health Project Inc.
6991 N State St.
Redwood Valley, CA 95470

Topics Presented:

- Introduction to Energy Audits
- Energy Efficiency and Conservation Measures
- Language of Energy
- Renewable Energy
- How energy applies in today's funding for jobs in the energy sector, energy efficiency employment opportunities and promoting advance energy training

Please contact us at the Scotts Valley EPA for more information:
Gabriel Ray, Project Energy Coordinator, gray@svpomo.org Cell no.:(707) 350-6508 OR
Irenia Quitiquit, Environmental Director, iquitiquit@svpomo.org Cell no.:(707) 350-6507 OR
Main Office (707) 263 4220.

No registration required, but please call to reserve your seat

Funded by Department of Energy Tribal Weatherization Program Grant 2010

Community Outreach

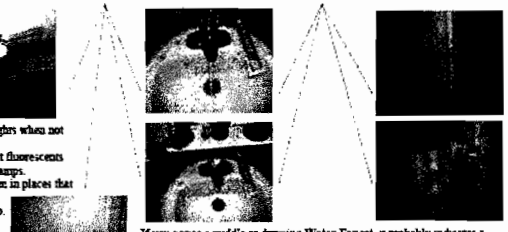
Scotts Valley Band of Pomo Indians

"Weatherization Shines in California"

Weatherization Works! It creates significant benefits for California Tribes by providing long-term solutions for energy problems. Weatherization measures decrease energy use in the tribal home, while increasing the comfort level. These cost-effective measures create energy savings for low-income families and economic and environmental benefits for the community. It can work on your Rancheria!

HERE ARE FEW HOME ENERGY SAVING TIPS

Turn off your lights when not using.
DO use compact fluorescents in fixtures and lamps.
DON'T use them in places that are only lit for an hour of so.
DO use them in hard-to-reach fixtures
DON'T use them in fixtures and lamps that are turned off frequently.



If you notice a puddle or dripping **Water Faucet**, it probably indicates a leak and will need to be fixed. The sooner it's fixed the more likely your water bill will save money and energy costs.

Watch your **Refrigerator**, they cost $5 to $8 per month to operate and consume 3-5% of your home's total energy use. To keep out warm room air, keep the door closed as much as possible. If you have more that one refrigerator or freezer and one doesn't get much use, unplug it and save energy costs.

More TIPS To Save $$$.....

Lower your water temperature. Your hot water is probably hotter than necessary. Most are set at 140 degrees, turn it down to 120 degrees

Insulate your water heater by wrapping the tank in a blanket of fiberglass insulation will reduce heat loss by 25-40% . This means a saving of 4-9% on your water-heating bill.

Replace your showerhead, replace it with a quality low-flow showerhead that will allow to use only 1-2 gal of water a minute instead of 5 gal a minute.

Plug those leaks. On a cold windy day, do you feel those breezes blowing through your house? On windows and doors use weather stripping, caulk around wall outlets, use door sweep on bottom of doors and seal around baseboards, gaps around pipes and small holes. Remember every hole plug means fewer drafts, a corner home and lower heating bills.

Produced by the Scotts Valley Tribal Natural Resources Office (707) 263-

Community Outreach

- Created the Scotts Valley EPA Energy Efficiency Programs Brochure
- Energy Efficiency Articles for the Monthly Tribal Newsletter
- Promoted Energy Efficiency at Environmental Meetings (Tribal and County) by reporting trainings and progress
- Participated in Outreach Booth at annual Lake County Fair

Community Outreach

- Hosted “Energy 101”course for Multi-county Tribal communities
- Created Scotts Valley Tribal Energy Packet with Information and Resource Material
- Educational booth activities at Tribal Events including annual Tule Boat Festival
- Report Energy Programs progress at Scotts Valley Tribal Council and staff meetings

Collaboration

The program success depends on working collaboratively with other organizations

- Developed MOU for weatherization apprenticeship program (EETA vs. NCES)
- Working closely with the California State unemployment office to identify green job opportunities for newly trained Tribal members
- Developed relationship with the Pinoleville Tribal Voc-Rehab Program for trainees to receive vocational benefits
- Work closely with internal Tribal Housing Dept. on buy-in for weatherization services

Collaboration

- GRIDS Alternative: Working closely with GRIDS Alternative (a subcontractor through CPUC/PG&E) to promote and recruit Mendocino and Lake County Tribes to participate in the Single-Family Affordable Solar Homes (SASH) program. The SASH program is for low-income homeowners that qualify for solar systems on their homes. So far, two homes have received solar systems and 10-15 are in the approval process.

Project Expectations

The following tasks are now in progress:

- Building Performance Institute Training
- More advanced Energy Efficiency Training
- Weatherization Apprenticeships
- Outreach to Tribes
- Economic Development Opportunities
- Green Job Opportunities
- Research Green Grant Opportunities
- Integrate Grant Tasks to enhance program objectives

Future Plans

- To access state or federal funding to start up a Tribal Weatherization Assistance Program (WAP)
- To qualify tribal homeowners for weatherization services from energy assistance providers and available solar technology, such as solar panels, solar water panels, and geothermal

Future Plans

- Promote and encourage entrepreneurs to start up energy efficiency businesses
- Create a local in-house energy efficiency resource library
- Utilize trained Tribal members to have job placements within their Tribes (housing)
- Encourage Tribes to attend free energy efficiency classes provided by PG&E (CA utility provider) to maintain skills

Scotts Valley Band of Pomo Indians
EPA & Natural Resource Department
301 Industrial Avenue
Lakeport, California 95453
(707) 263-4220
Irenia Quitiquit, Envir. Dir. & and Gabriel Ray, Proj. Energy Coord.

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Strategy Guideline: Transitioning HVAC Companies to Whole House Performance Contractors

Arlan Burdick
IBACOS

May 2012

Building AMERICA SM
U.S. Department of Energy

NOTICE

This report was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor any agency thereof, nor any of their employees, subcontractors, or affiliated partners makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or any agency thereof.

Available electronically at http://www.osti.gov/bridge

Available for a processing fee to U.S. Department of Energy
and its contractors, in paper, from:
U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
phone: 865.576.8401
fax: 865.576.5728
email: mailto:reports@adonis.osti.gov

Available for sale to the public, in paper, from:
U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
phone: 800.553.6847
fax: 703.605.6900
email: orders@ntis.fedworld.gov
online ordering: http://www.ntis.gov/ordering.htm

Printed on paper containing at least 50% wastepaper, including 20% postconsumer waste

Strategy Guideline: Transitioning HVAC Companies to Whole House Performance Contractors

Prepared for:

Building America

Building Technologies Program

Office of Energy Efficiency and Renewable Energy

U.S. Department of Energy

Prepared by:

Arlan Burdick

IBACOS, Inc.

2214 Liberty Avenue

Pittsburgh, Pennsylvania 15222

NREL Technical Monitor: Michael Gestwick

Prepared under Subcontract No. KNDJ-0-40341-02

May 2012

Contents

List of Tables vi
Definitions vii
Executive Summary viii
1 Introduction 1
2 Research Approach 1
3 Findings 2
3.1 Literature Search Results 2
3.2 Comparative Activities of HVAC to WHPC 2
4 Expert Meeting Findings 11
5 Fact Sheets 13
6 Conclusions and Next Steps 14
7 References 15
Appendix A – Literature Search Results 16
Appendix B – Training 32
Appendix C – Equipment 33
Appendix D – Customer Education 34
Appendix E – Community Engagement 35
Appendix F – On-Site Customer Interview 36
Appendix G – Whole House Performance Assessment 37
Appendix H – Customer Presentation Process 38
Appendix I – Subcontractor and Vendor Relations 39
Appendix J – Full Value Ratings of Work Activities 40

List of Tables

Table 1. Typical High-Level Business Operations Profile of a WHPC 3
Table 2. Business Planning/Processes. 4
Table 3. Marketing/Customer Contact 5
Table 4. Assessment 6
Table 5. Sales 7
Table 6. Contract Administration 8
Table 7. Production 9
Table 8. Customer Service 10
Table 9. Value Ratings for 15 Transition Points. 12

**Unless otherwise noted, all tables were created by IBACOS.*

Definitions

ACCA	Air Conditioning Contractors of America
HVAC	heating, ventilation, and air conditioning
WHPC	whole house performance contracting

Executive Summary

This Strategy Guideline describes the findings from research that the U.S. Department of Energy's Building America team IBACOS conducted related to heating, ventilation, and air conditioning (HVAC) companies that have made the decision to transition to whole house performance contracting (WHPC). By utilizing a house-as-a-system approach, the WHPC contractor can evaluate the total energy performance of the entire house and make upgrades on a prioritized basis, according to the energy benefit.

IBACOS believes that an HVAC contractor is well suited to take on the tasks of whole house energy upgrades and to advance large-scale energy efficiency in the residential market. Because the HVAC contractor already works on one of the most technically complex systems in the house, they have already overcome the barrier of training to the complex HVAC system and can reduce the time required to transition to delivering whole house energy upgrades on a wide scale. Providing contractors with new technical skills and a revised business approach is one way to achieve change on a large scale and to help the United States meet its goals regarding job creation and energy independence. However, HVAC companies need guidance on how to transition successfully from their traditional business approach to one that includes WHPC.

Research for this Strategy Guideline included a literature search of periodicals, industry trade publications, and reports available to the general public on the topic of WHPC. IBACOS created an outline of a successfully integrated HVAC company with a WHPC business and presented the outline to a group of experts currently working in the industry. The feedback received from the experts was used to identify the key areas in which guidance would be most useful to WHPC contractors, and eight of these areas were expanded for guidance.

The appendices included with this Strategy Guideline present information a transitioning contractor may find useful and were collected from published periodicals, along with short and concise Fact Sheets.

1 Introduction

This Strategy Guideline describes the findings from research IBACOS conducted related to heating, ventilation, and air conditioning (HVAC) companies who have made the decision to transition to whole house performance contracting (WHPC). Home performance is the energy-related services offered by a contractor who uses testing and building science to diagnose and repair issues of comfort, safety, durability, and energy efficiency in a house. Whole house performance contracting brings control of the home performance tasks of improving the insulation, HVAC, air sealing, windows, and appliances in a house under one company. Integrating the necessary energy upgrades allows for the analysis of the comfort, energy efficiency, and cost of the upgrades so the highest-value energy upgrades can be completed first.

IBACOS believes that an HVAC contractor is well suited to take on the tasks of whole house energy upgrades and to advance large-scale energy efficiency in the residential market. HVAC companies were the focus of this study, based on their market position of typically having an existing and ongoing relationship with homeowners through service and maintenance contracts. This ongoing relationship places the HVAC contractor in an ideal position to deliver energy upgrades to whole communities or sections of communities. The HVAC contractor already works on one of the most technically complex systems in the house, eliminating the barrier of training to the complex HVAC system and reducing the time required to transition to delivering whole house energy upgrades on a wide scale. Energy upgrades may be supplemental to an HVAC contractor's core business, a new guiding strategy for their company, or a sales tool to enable up-selling to a larger project in partnership with other qualified trade contractors. Providing contractors with new technical skills and a revised business approach is one way to achieve change on a large scale and to help the United States meet its goals regarding job creation and energy independence.

There are two primary ways to define the routes of transition for HVAC companies taking on WHPC: (1) subcontracting out the shell repair and upgrade work or (2) integrating the shell repair and upgrade work into their existing businesses.

The appendices included with this Strategy Guideline present the information a transitioning contractor may find useful from published periodicals, along with short and concise Fact Sheets.

2 Research Approach

IBACOS defined the following research questions relative to this area of study:

- What are the business best practices associated with well-run WHPC companies?
- What are the business profiles for HVAC companies to offer WHPC?
- What are the transition strategies for HVAC companies who want to become home performance contractors?

This research was not intended to identify motivation for HVAC companies to make the transition to WHPC, but rather to identify the topics where HVAC companies will need guidance on how to successfully transition from their traditional business to one that includes WHPC.

Research began with a literature search of periodicals, industry trade publications, and reports available to the general public on the topic of WHPC. Individuals currently involved in home performance work and HVAC companies who have brought WHPC into their service offerings were interviewed. From the information gained through the literature search and individual interviews, IBACOS created an outline of a successfully integrated HVAC and WHPC business. Work activities that represent areas of transition for the HVAC companies were identified. An Expert Meeting (IBACOS 2011) was held, where industry participants were asked to validate completeness of the outline and to rate the identified transition points. The highest rated transition points from the Expert Meeting have been extracted for further study and comment in the appendices of this Strategy Guideline.

3 Findings

3.1 Literature Search Results

The literature search spanned back across 10 years to the late 1990s, not because the search was limited to that time frame, but because home performance began to emerge as an industry during that time. As a tool for the transitioning contractor, a categorized bibliography of pertinent articles from that literature search is included as Appendix A in this Strategy Guideline.

Home Energy magazine, published by Energy Auditor & Retrofitter, Inc., was an obvious place to begin the search because the mission of that publication is to disseminate objective and practical information on residential energy efficiency, performance, comfort, and affordability. A Hanley Wood LLC publication, *The Journal of Light Construction*, written for residential and light commercial contractors, also included articles on energy upgrade topics. From the perspective of the HVAC industry, home performance has been the topic of an annual special edition of the Air Conditioning Contractors of America (ACCA) monthly periodical, *Contractor Excellence,* since 2004. Periodicals offer a continuing resource of current information to the transitioning contractor because they tend to track recent developments within the industry.

Reports from previous studies found in the search included a Bevilacqua Knight report titled "PIER Whole House Contracting Study and Charting the Home Performance Contractors Territory" (Bevilacqua Knight November 2003). A conclusion in that study stated that, based on their survey results at that time, "Surprisingly, HVAC contractors, who typically have greater technical expertise, appeared much less likely to embrace whole house approaches that integrate shell with HVAC disciplines."

3.2 Comparative Activities of HVAC to WHPC

Table 1 shows a high-level outline of how an integrated WHPC company could be divided into seven Operational Areas, based on the information gained from the literature search of periodicals, industry trade publications, reports, and interviews performed by IBACOS with industry experts. Shaded cells in the Business Functions rows identify areas where noted differences exist between the HVAC contractor's typical Business Function and the WHPC Business Function.

Table 1. Typical High-Level Business Operations Profile of a WHPC*

Operational Area	Business Planning/ Processes	Marketing/ Customer Contact	Assessment	Sales	Contract Administration	[illegible]	Customer Service
Business Functions	Training	PR Strategies	Customer Interaction	Proposal	Contract Processing	Project Planning and Scheduling	Customer Relations
	Employee Relations	Advertising Strategies	Whole House Performance Assessment	Sales Presentation to Customer	Customer Financing	Project Implementation	Warranty Requests Resolution
	Procurement	Customer Referral Strategies		Closing	Rebates and Incentives	Quality Assurance	
	Subcontracts	Call Management			Accounts Receivable/ Payable		
	Strategic Planning	Lead Management					

* Based on research, an integrated WHPC company could be divided into these seven Operational Areas. Shaded cells in the Business Functions rows identify areas where noted differences exist between the HVAC contractor's typical Business Function and the WHPC Business Function.

Tables 2 through 8 further break down the Business Functions into Work Activities. The Work Activities where a transitioning HVAC contractor is anticipated to need guidance are shaded in yellow in these tables and are referred to as Transition Points in the remainder of this guideline.

Table 2. Business Planning/Processes*

Operational Area	**Business Planning/Processes**				
Business Function	**Training**	**Employee Relations**	**Procurement**	**Subcontracts**	**Strategic Planning**
Work Activities	Technical	Job Progression/ Growth	Manufacturer Relations	Vendor Relations	Company Mission/Vision
	Safety	Retention	Material Inventory	Pricing	Five-Year Strategic Plan
	Management	Compensation	New Equipment		One-Year Operational Plan
	Sales	Referral Bonus	Equipment Maintenance/ Repair/ Calibration		Management Objectives
		Quality Management	Pricing		Quality Management
Internal Lead	Leadership Team	Leadership Team	Leadership Team	Leadership Team	Leadership Team
External Resources	Training/ Certification Providers	HR/Quality Management Consultants	Manufacturers	Subcontractors, Manufacturers	Management Consultants

* Highlighted cells indicate Work Activities that are Transition Points.

In Table 2, the highlighted cells indicate Work Activities that are Transition Points. The Work Activities identified as Transition Points for the Business Planning/Processes area are as follows:

- Technical Training
- Manufacturer Relations
- New Equipment
- Equipment Maintenance/Repair/Calibration
- Vendor Relations
- Company Vision/Mission
- Five-Year Strategic Plan
- One-Year Operational Plan

The areas of Technical Training and Equipment Maintenance/Repair/Calibration requirements are expanded further in Appendix B and Appendix C, respectively, in this Strategy Guideline.

Table 3. Marketing/Customer Contact*

Operational Area	Marketing/Customer Contact				
Business Function	**PR Strategies**	**Advertising Strategies**	**Customer Referral Strategies**	**Call Management**	**Lead Management**
Work Activities	Newspaper	Newspaper	Community Engagement	Call Scripting	Sales Coordination
	Local TV/Radio	Local TV/Radio	Social Media	Inbound Call Process	Lead Database and Tracking
	Local Expert	Billboards	Direct Referral Programs	Recurring Call Schedule	Lead Qualification
	Customer Education	Neighborhood Blitz	Newsletter (E– or Paper)		Scheduling
	Home Shows	Web Site	Service Tech Referrals		Appointment Verification
		Search Engine Optimization			
Internal Lead	Marketing	Marketing	Marketing	Operations	Sales/ Operations
External Resources	PR Agency	Ad Agency/ Designer	Ad Agency/ Designer/ Community Groups	Sales Consultant	Sales Consultant

* Highlighted cells indicate Work Activities that are Transition Points.

In Table 3, the highlighted cells indicate Work Activities that are Transition Points. The Work Activities identified as Transition Points for the Marketing/Customer Contact area are as follows:

- Customer Education
- Community Engagement
- Social Media
- Direct Referral Programs
- Newsletter
- Service Tech Referrals
- Call Scripting
- Inbound Call Process
- Recurring Call Schedule

The areas of Customer Education and Community Engagement are expanded further in Appendix D and Appendix E, respectively, in this Strategy Guideline.

Table 4. Assessment*

Operational Area	Assessment	
Business Function	**Customer Interaction**	**Whole House Performance Assessment**
Work Activities	Pre-Assessment Preparation Call	Exterior Architectural Features Assessment
	Arrival Process	Interior Building Features Assessment
	On-Site Customer Interview	Thermal Enclosure Components
		Space Conditioning System Assessment
		Plumbing System Assessment
		Electrical System Assessment
		Moisture Assessment
		System Testing
		Home Energy Upgrade Modeling
Internal Lead	Operations	Operations
External Resources		

* Highlighted cells indicate Work Activities that are Transition Points.

In Table 4, the highlighted cells indicate Work Activities that are Transition Points. The Work Activities identified as Transition Points for the Assessment area are as follows:

- Pre-Assessment Preparation
- Arrival Process
- On-Site Customer Interview
- Whole House Performance Assessment

Whole House Performance Assessment was identified as the area with many new facets of the service offering for the HVAC contractor transitioning to WHPC. The areas of On-Site Customer Interview and Whole House Performance Assessment are expanded further in Appendix F and Appendix G, respectively, in this Strategy Guideline.

Table 5. Sales*

Operational Area	Sales		
Business Function	**Proposal**	**Sales Presentation to Customer**	**Closing**
Work Activities	Work Scope Development and Approval	Close at Audit Process	Contracting
	Customer Presentation Process	Follow-Up Sales Process	Identify Financing Needs
	Anticipated Objections	Phased Implementation Sales Process	Rebates and Incentives
	Assessment Report	Overcoming Objections	
	Pricing		
	Subcontracts		
Internal Lead	Sales	Sales	Sales/Operations
External Resources	Subcontractors		Finance Partners

* Highlighted cells indicate Work Activities that are Transition Points.

In Table 5, the highlighted cells indicate Work Activities that are Transition Points. The Work Activities identified as Transition Points for the Sales area are as follows:

- Customer Presentation Process
- Assessment Report
- Phased Implementation Sales Process
- Rebates and Incentives

The area of Customer Presentation Process is expanded further in Appendix H in this Strategy Guideline.

Table 6. Contract Administration*

Operational Area	Contract Administration			
Business Function	**Contract Processing**	**Customer Financing**	**Rebates and Incentives**	**Accounts Receivable/ Payable**
Work Activities	Contract Review and Approval	Financing Mechanisms	Utility Reporting	Create Account
	Create Work Order	Loan Processing	State or Local Program Reporting	Deposit Payments
	Inventory and Production Management		Tax Credit Reporting	Billing
	Subcontracts			Payment Terms
Internal Lead	Operations	Operations	Operations	Operations
External Resources	Subcontractors	Financial Partners	Program Staff	

* Highlighted cells indicate Work Activities that are Transition Points.

In Table 6, the highlighted cells indicate Work Activities that are Transition Points. The Work Activities identified as Transition Points for the Contract Administration area are as follows:

- Financing Mechanisms
- Loan Processing
- Utility Reporting
- State or Local Program Reporting

Although these are all important Work Activities, they are not expanded further in this Strategy Guideline due to the lack of available technical material related to these Transition Points.

Table 7. Production*

Operational Area	Production		
Business Function	**Project Planning and Scheduling**	**Project Implementation**	**Quality Assurance**
Work Activities	Scheduling	Work Scope Procedures	Job Completion Verification
	Inventory/Material Preparation	Job Safety	Post-Installation Field Verification Sample
	Crew Lead Work Scope Review	Customer Interaction Procedures	Customer Satisfaction Scores
		Job Completion/Test Out	
		Change Orders	Sponsoring Program Quality Assurance
		Subcontractor and Vendor Relations	
Internal Lead	Operations/Production	Production	Operations/Production
External Resources			

* Highlighted cells indicate Work Activities that are Transition Points.

In Table 7, the highlighted cells indicate Work Activities that are Transition Points. The Work Activities identified as Transition Points for the Production area are as follows:

- Work Scope Procedures
- Customer Interaction Procedures
- Job Completion/Test Out
- Job Completion Verification
- Post-Installation Field Verification Sample
- Sponsoring Program Quality Assurance
- Subcontractor and Vendor Relations

The area of Subcontractor and Vendor Relations is expanded further in Appendix I in this Strategy Guideline.

Table 8. Customer Service*

Operational Area	Customer Service	
Business Function	**Customer Relations**	**Warranty Requests Resolution**
Work Activities	Customer Appreciation	Customer Care Intake
	Certificate	Scheduling
	Rating Score	Customer Visit Process
	Guarantee	Utility Bill Review
	Homeowner Manual	Service Call Diagnostics
	Referral Cards/Lead Generation	Warrantable Item Repair/Replacement
	Billing and Collections	Manufacturer Relations
	Utility/Local Program Documentation	Subcontractor Management
Internal Lead	Operations	Production
External Resources		

* Highlighted cells indicate Work Activities that are Transition Points.

In Table 8, the highlighted cells indicate Work Activities that are Transition Points. The Work Activities identified as Transition Points for the Customer Service area are as follows:

- Utility Bill Review
- Service Call Diagnostics
- Warrantable Item Repair/Replacement

Although these are all important Work Activities, they are not expanded further in this Strategy Guideline due to the lack of available technical material related to these Transition Points.

4 Expert Meeting Findings

The outline of a successfully integrated HVAC and WHPC business was presented to a group of industry experts at an Expert Meeting. Details of this Expert Meeting have been published in the Building America report, "Final Expert Meeting Report: Transitioning Traditional HVAC Contractors to Whole House Performance Contractors" (IBACOS 2011).

At this Expert Meeting, the panel was asked to validate the accuracy and the comprehensiveness of the outline in capturing the business activities. The expert panel praised the level of detail to which the outline was broken out and validated its accuracy. Transition Points were validated and carefully rated for their value of guidance and difficulty to implement. The ratings of the Transition Points were valued where "1" is a low value to the transitioning contractor through "4" being the highest value to the transitioning contractor, as well as "1" being the easiest to execute through "4" being the most difficult to execute. The combined score of value and ease of execution was used to rank the importance for further study.

There were 15 Transition Points that rose to the top as being rated "4" (highest) for value to the transitioning contractor. Table 9 shows the scores for each of these 15 Transition Points. The entire matrix of value to a transitioning contractor and difficulty to implement, as determined by the expert panel, can be found in Appendix J of this Strategy Guideline.

- Technical Training
- Equipment Requirements
- Vendor Relations
- Strategic Planning
- Customer Education Process
- Community Engagement
- Assessment Arrival Process
- On-Site Customer Interview
- Whole House Performance Assessment
- Customer Presentation Process
- Assessment Report
- State or Local Program Reporting
- Work Scope/Procedures
- Job Completion Verification
- Subcontractor Relations

Table 9. Value Ratings for 15 Transition Points

Operational Area	Work Activity	Value of Guidance to Contractor	Difficulty	Sum
Business Planning/ Process	Training	4	2	6
Business Planning/ Process	Equipment	4	3	7
Business Planning/ Process	Vendor Relations	4	4	8
Business Planning/ Process	Strategic Planning	4	4	8
Marketing/ Customer Contact	Customer Education	4	4	8
Marketing/ Customer Contact	Community Engagement	4	4	8
Assessment	Arrival Process	4	3	7
Assessment	On-Site Customer Interview	4	4	8
Assessment	Whole House Performance Assessment	4	4	8
Sales	Customer Presentation Process	4	3	7
Sales	Assessment Report	4	3	7
Contract Administration	State or Local Program Reporting	4	4	8
Production	Work Scope Procedures	4	4	8
Production	Job Completion Verification	4	1	5
Production	Subcontractors	4	3	7

The value of guidance in the form of a white paper was called into question by the expert panel as well as the value of webinars if they are too extensive in length. To that end, the guidance from this Strategy Guideline has been distilled into easy-to-read Fact Sheets in Appendix B through Appendix I, with links to additional information included.

5 Fact Sheets

From the 15 highest rated Transition Points, eight were identified by IBACOS for expansion. Fact Sheets were created for these Transition Points in this Strategy Guideline. The use of the Fact Sheets to deliver information in small chunks was highly reccomended by the industry experts consulted. Fact Sheets are included as Appendix B through Appendix I of this Strategy Guideline, as follows:

- Training
- Equipment
- Customer Education
- Community Engagement
- On-Site Customer Interview
- Whole House Performance Assessment
- Customer Presentation Process
- Subcontractor and Vendor Relations

While not strictly technical in nature, Customer Education and Community Engagement were chosen as topics for the Fact Sheets based on their importance for early stages of the transition process. On-Site Customer Interview and Customer Presentation Process were chosen for their importance in developing a successful sales team.

The final four topics for the Fact Sheets—Whole House Performance Assessment, Equipment, Training, and Subcontractor and Vendor Relations—represent a solid base for the delivery of the whole house energy upgrade.

6 Conclusions and Next Steps

HVAC companies need guidance on how to successfully transition from their traditional business strategy to one that includes WHPC. Although eight of the 15 highest-rated Transition Points are discussed in the appendices of this Strategy Guideline, contractors will need guidance in all aspects of their transition. The guidance offered in Building America reports is typically focused more on the technical aspects, with less emphasis on the business aspects. However, the two are not easily separated and must be considered together by the transitioning contractor as well as those developing further industry guidance.

Further development of the information contained in the Fact Sheets or the development of Fact Sheets for the remaining Transition Points would be the logical next steps to deliver the guidance needed.

7 References

Bevilacqua Knight, Inc. (November 2003). 500-02-011, PIER Whole House Contracting Study. Oakland, CA: Bevilacqua Knight, Inc.

Contractor Excellence. Arlington, VA: Air Conditioning Contractors of America. www.contractorexcellence.com.

Home Energy. Berkeley, CA: Energy Auditor & Retrofitter, Inc. www.homeenergy.org.

IBACOS, Inc. (2011). Final Expert Meeting Report: Transitioning Traditional HVAC Contractors to Whole House Performance Contractors, Building America Report. http://www.nrel.gov/docs/fy12osti/52665.pdf.

The Journal of Light Construction. Washington, D.C.: Hanley Wood LLC. http://www.jlconline.com.

Appendix A – Literature Search Results

I. Technical Training

1) *Energy Modeling Versus Reality* — Home Energy Magazine

   ci. Mann, Steve. *Energy Modeling Versus Reality,* Home Energy Magazine, January/February 2010.

2) *ENERGY STAR for Homes 3.0* — Home Energy Magazine

   ci. Mann, Steve. *ENERGY STAR for Homes 3.0,* Home Energy Magazine, January/February 2011.

3) *Best Construction Details for Deep-Energy Retrofits* — Green Building Advisor

   ci. Martin, Holladay. *Best Construction Details for Deep-Energy Retrofits,* Green Building Advisor. http://www.greenbuildingadvisor.com/blogs/dept/musings/best-construction-details-deep-energy-retrofits, May 7, 2010.

4) *How Do I...?* — Home Energy Magazine

   ci. Zimmerman, Allen. *How Do I...?* Home Energy Magazine, September/October 2007.

5) *Keeping Educated in a Rapidly Changing Environment* — Home Energy Magazine

   ci. Murphy, Casey. *Keeping Educated in a Rapidly Changing Environment*, Home Energy Magazine, September/October 2009.

6) *Computer-Based Energy Analyst Training* — Home Energy Magazine

   ci. Murphy, Casey. *Keeping Educated in a Rapidly Changing Environment*, Home Energy Magazine, September/October 2009.

7) *From HVAC to Home Performance Contracting* — Home Energy Magazine

   ci. Plympton, Patricia; Dagher, Leila. *From HVAC to Home Performance Contracting,* Home Energy Magazine, March/April 2007.

8) *Guide to Training Programs for HPC (2005)* — Home Energy Magazine

   ci. Home Energy. *Guide to Training Programs for Home Performance Professionals,* Home Energy Magazine, July/August 2005.

9) *Guide to Training Programs for HPC (2009)* — Home Energy Magazine

   ci. Home Energy. *Guide to Training Programs for Home Performance Professionals,* Home Energy Magazine, July/August 2009.

10) *The 411 on Home Performance Contracting* — ACCA Contractor Excellence

   ci. Contractor Excellence Magazine Staff. *The 411 on Home Performance Contracting,* ACCA Contractor Excellence. http://www.contractorexcellence.com/326, September 1, 2009.

11) *How to Properly Seal Ducts* — Contracting Business

   ci. Richardson, David. *How to Properly Seal Ducts,* Contracting Business. http://contractingbusiness.com/indoor_air_quality/content/, June 1, 2010.

12) *Quality Capacitors = Quality Service* Contracting Business

ci. Parisi, Jim. *Quality Capacitors = Quality Service,* Contracting Business. http://contractingbusiness.com/service/content/quality-capacitors-0411/, April 1, 2011.

13) *Saving Energy with Manual J and Manual D* Green Building Advisor

ci. Holladay, Martin. *Saving Energy with Manual J and Manual D,* Green Building Advisor. http://www.greenbuildingadvisor.com/blogs/dept/musings/saving-energy-manual-j-and-manual-d, August 13, 2010.

14) *Sealing Ducts: What's Better, Tape or Mastic?* Green Building Advisor

ci. Holladay, Martin. *Sealing Ducts: What's Better, Tape or Mastic?* Green Building Advisor. http://www.greenbuildingadvisor.com/blogs/dept/musings/sealing-ducts-what-s-better-tape-or-mastic, August 6, 2010.

15) *When It's Time to Replace a Duct* Contracting Business

ci. Falke, Rob. *When It's Time to Replace a Duct,* Contracting Business. http://contractingbusiness.com/service/content/replacing_duct0918/, September 18, 2009.

16) *4 Pitfalls of Spray Foam Insulation* Energy Vanguard

ci. Bailes, Allison. *4 Pitfalls of Spray Foam Insulation,* Energy Vanguard. http://www.energyvanguard.com/blog-building-science-HERS-BPI/bid/25546/4-Pitfalls-of-Spray-Foam-Insulation, June 29, 2010.

17) *Air Sealing Tapes and Gaskets* Green Building Advisor

ci. Holladay, Martin. *Air Sealing Tapes and Gaskets,* Green Building Advisor. http://www.greenbuildingadvisor.com/blogs/dept/musings/air-sealing-tapes-and-gaskets, July 30, 2010.

18) *Does It Make Sense to Move the Building Envelope...* Energy Vanguard

ci. Bailes, Allison. *Does It Make Sense to Move the Building Envelope to the Roofline?* Energy Vanguard. http://www.energyvanguard.com/blog-building-science-HERS-BPI/bid/38272/Does-It-Make-Sense-to-Move-the-Building-Envelope-to-the-Roofline, May 23, 2011.

19) *Creating a Conditioned Attic* Green Building Advisor

ci. Holladay, Martin. *Creating a Conditioned Attic,* Green Building Advisor. http://www.greenbuildingadvisor.com/blogs/dept/musings/creating-conditioned-attic, December 31, 2010.

20) *A Do-It-Yourself Guide to Sealing and Insulating with...* ENERGY STAR

ci. U.S. Environmental Protection Agency. *A Do-It-Yourself Guide to Sealing and Insulating with ENERGY STAR,* ENERGY STAR, August 2007.

21) *Flash and Batt* Builder Online

ci. Binsacca, Rich. *Flash and Batt,* Builder Online, http://www.builderonline.com/construction/flash-and-batt.aspx, February 10, 2011.

22) *How to Insulate a Low-Slope Roof* Green Building Advisor

ci. Gibson, Scott, *How to Insulate a Low-Slope Roof*, Green Building Advisor. http://www.greenbuildingadvisor.com/blogs/dept/green-building-blog/how-insulate-low-slope-roof, June 20, 2011.

23) *Tighten Up Your Advice About Air Sealing* Home Energy Magazine

ci. Newey, Mark. *Tighten Up Your Advice About Air Sealing,* Home Energy Magazine Special Issue 2005.

24) *Comparing Open- and Closed-Cell Foams* Home Energy Magazine

ci. Wyatt, Ed. *Comparing Open- and Closed-Cell Foams,* Home Energy Magazine, November/December 2010.

25) *Homeowner's Guide to Insulating* Owens Corning

ci. Owens Corning. *Homeowner's Guide to Insulating,* Pub. No. 10001528, September 2006. THE PINK PANTHER™.

26) *What is Pressure?—Understanding Air Leakage* Energy Vanguard

ci. Bailes, Allison. *What Is Pressure?—Understanding Air Leakage,* Energy Vanguard. http://www.energyvanguard.com/blog-building-science-HERS-BPI/bid/35339/What-Is-Pressure-Understanding-Air-Leakage, January 24, 2011.

27) *Are Dew-Point Calculations Really Necessary?* Green Building Advisor

ci. Holladay, Martin. *Are Dew-Point Calculations Really Necessary?* Green Building Advisor. http://www.greenbuildingadvisor.com/blogs/dept/musings/are-dew-point-calculations-really-necessary, September 2010.

28) *Controlling Humidity* Green Building Advisor

ci. Wilson, Alex. *Controlling Humidity,* Green Building Advisor. http://www.greenbuildingadvisor.com/blogs/dept/energy-solutions/controlling-humidity, June 13, 2010.

29) *Moisture Control Techniques for Wood-framed Homes* Professional Builder

ci. Peavey, John. *Moisture Control Techniques for Wood-framed Homes,* Professional Builder, April 17, 2011.

30) *Preventing Moisture Problems* Green Building Advisor

ci. Wilson, Alex. *Preventing Moisture Problems,* Green Building Advisor. http://www.greenbuildingadvisor.com/blogs/dept/energy-solutions/preventing-moisture-problems, September 30, 2008.

31) *Seal & Supply Solves Bathroom Mold Strife* Contracting Business

ci. O'Neil, Kevin. *Seal & Supply Solves Bathroom Mold Strife,* Contracting Business. http://contractingbusiness.com/indoor_air_quality/content/seal-supply-bathroom-mold-0411/. April 1, 2011.

32) *Radiant Barriers: A Solution in Search of Problem* Green Building Advisor

ci. Holladay, Martin. *Radiant Barriers: A Solution in Search of a Problem,* Green Building Advisor. http://www.greenbuildingadvisor.com/blogs/dept/musings/radiant-barriers-solution-search-problem, September 24, 2010.

33) *Crawl Space Building Science* Energy Vanguard

ci. Bailes, Allison. *Crawl Space Building Science,* Energy Vanguard. http://www.energyvanguard.com/crawl-space-building-science/, 2011.

34) *Designing a Good Ventilation System* Green Building Advisor

ci. Holladay, Martin. *Designing a Good Ventilation System,* Green Building Advisor. http://www.greenbuildingadvisor.com/blogs/dept/musings/designing-good-ventilation-system, June 15, 2010.

35) *Don't Let Your Attic Suck—Power Attic Ventilators...* Energy Vanguard

ci. Bailes, Allison. *Don't Let Your Attic Suck—Power Attic Ventilators Are a Bad Idea,* Energy Vanguard Blog. http://www.energyvanguard.com/blog-building-science-HERS-BPI/bid/38676/Don-t-Let-Your-Attic-Suck-Power-Attic-Ventilators-Are-a-Bad-Idea?source=Blog_Email_%5bDon%e2%80%99t+Let+Your+Attic%5d, June 08, 2011.

36) *Mechanical Ventilation: Breathe* Energy Circle

ci. Energy Circle Staff. *Mechanical Ventilation: Breathe,* Energy Circle. http://www.energycircle.com/learn/air-quality/mechanical-ventilation, August 18, 2009.

37) *Reexamining Roof Ventilation* Home Energy Magazine

ci. Woods, Tony. *Reexamining Roof Ventilation,* Home Energy Magazine, November/December 2000.

38) *Nailing Window Flanges Through Foam* Green Building Advisor

ci. Holladay, Martin. *Nailing Window Flanges Through Foam,* Green Building Advisor. http://www.greenbuildingadvisor.com/blogs/dept/musings/nailing-window-flanges-through-foam, May 20, 2011.

39) *'Superwindows' To the Rescue?* Green Building Advisor

ci. Roberts, Tristan. *'Superwindows' To the Rescue?* Green Building Advisor. http://www.greenbuildingadvisor.com/blogs/dept/energy-solutions/superwindows-rescue, June 7, 2011.

40) *Understanding What Makes High-Performance Windows...* Green Building Advisor

ci. Roberts, Tristan. *Understanding What Makes High-Performance Windows Perform,* Green Building Advisor. http://www.greenbuildingadvisor.com/blogs/dept/energy-solutions/understanding-what-makes-high-performance-windows-perform, May 23, 2011.

41) *Using Window Stickers to Get What's Right for You* Green Building Advisor

ci. Roberts, Tristan. *Using Window Stickers to Get What's Right for Your Climate,* Green Building Advisor. http://www.greenbuildingadvisor.com/blogs/dept/energy-solutions/using-window-stickers-get-whats-right-your-climate, May 31, 2011.

II. Equipment Requirements

1) *Products List* ACCA Contractor Excellence

ci. Contractor Excellence Magazine Staff. *Products List,* ACCA Contractor Excellence. http://www.contractorexcellence.com/category/sections/products, last updated April 5, 2011.

2) *Minneapolis Blower Door* The Energy Conservatory

ci. Brochure: *Minneapolis Blower Door*, The Energy Conservatory, 2010.

3) *testo 317-3* Testo Inc.

ci. Brochure: *testo 317-3*, Testo, Inc., 35 Ironia Rd., Flanders, NJ 07836.

4) *Leakator 10 Combustible Gas Leak Detector* Bacharach

ci. Brochure: Bacharach, *Leakator 10 Combustible Gas Leak Detector,* August 2002. www.bacharach-inc.com.

5) *CD200 Combustible Gas Leak Detector* UEi

ci. Brochure: UEi, *CD200 Combustible Gas Leak Detector,* UEi 2007. www.ueitest.com.

6) *Combustible-Gas Leak Detectors* Home Energy Magazine

ci. Raymer, Paul. *Combustible-Gas Leak Detectors,* Home Energy Magazine, May/June 2011.

7) *Minneapolis Duct Blaster* The Energy Conservatory

ci. Brochure: *Minneapolis Duct Blaster*, The Energy Conservatory, 2010.

8) *REM/Rate* Architectural Energy

ci. Architectural Energy. *REM/Rate,* Architectural Energy Corporation. http://www.archenergy.com/products/remrate, 2010.

9) *Right-J* Wright Soft

ci. Wright Soft. *Right-J.* http://www.wrightsoft.com/products/right-j.aspx 2011.

10) *Fluke TiS Building Diagnostic Thermal Imaging Scanner* Fluke

ci. Brochure: *Fluke TiS Building Diagnostic Thermal Imaging Scanner,* ©2010 Fluke Corporation. Printed in U.S.A., 6/2010, 3804542A D-EN-N.

11) *IR-Worth a Thousand Words* Home Energy Magazine

ci. Collins, Maureen. *IR-Worth a Thousand Words*, Home Energy Magazine, September/October 2008.

12) *Dispatching Software: The Wind Beneath Your Wheels* Contracting Business

ci. McIver, Terry. *Dispatching Software: The Wind Beneath Your Wheels,* Contracting Business. http://contractingbusiness.com/service/dispatching-software-0411/index.html, April 1, 2010.

13) *The Right Tools For the Job* ACCA Contractor Excellence

ci. Contractor Excellence Magazine Staff. *The Right Tools for the Job,* ACCA Contractor Excellence. http://www.contractorexcellence.com/4595, March 31, 2011.

14) *Bacharach Equipment Manuals* Bacharach

15) *MN Equipment Manuals* The Energy Conservatory

16) *Retrotec Equipment Manuals* Retrotec

17) *Combustible-Gas Leak Detectors* Home Energy Magazine

ci. Raymer, Paul. *Combustible-Gas Leak Detectors,* Home Energy Magazine, May/June 2011.

III. Vendor Relations

1) *A Way to Build Great and Lasting Vendor Relationships* R.B. Lewis & Associates

ci. Lewis, Ron. *A Way to Build Great and Lasting Vendor Relationships—Vendors Measuring Your Performance,* R.B. Lewis & Associates. www.rblewisassociates.com, 12/2010.

IV. Strategic Planning

1) *Building a Multifamily Home Performance Program* Home Energy Magazine

ci. Summerford, Julieann. *Building a Multifamily Home Performance Program,* Home Energy Magazine, May/June 2011.

2) *The Business Case for 'Smaller is Better'* Green Building Advisor

ci. Strong, Michael. *The Business Case for 'Smaller Is Better,'* Green Building Advisor. http://www.greenbuildingadvisor.com/blogs/dept/business-advisor/business-case-smaller-better, December 20, 2010.

3) *Contractor Takes Holistic Approach* ACCA Contractor Excellence

ci. Contractor Excellence Magazine Staff. *Contractor Takes Holistic Approach,* ACCA Contractor Excellence. http://www.contractorexcellence.com/2817, September 20, 2010.

4) *Remodeling a Business* Home Energy Magazine

ci. James, Mary. *Remodeling a Business,* Home Energy Magazine, September/October 2004.

5) *Learning and Working Our Way to Success* Home Energy Magazine

ci. Rogers, Mike. *Learning and Working Our Way to Success*, Home Energy Magazine Special Issue 2005.

6) *My 8th Commandment: Never Let the Client...* Green Building Advisor

ci. Strong, Michael. *My 8th Commandment: Never Let the Client....* Green Building Advisor. http://www.greenbuildingadvisor.com/blogs/dept/business-advisor/my-8th-commandment-never-let-client, October 11, 2010.

7) *Practical Lessons from a Home Performance Contract* Home Energy Magazine

ci. Knight, Bob; Locke, Time. *Practical Lessons from a Home Performance Contractors Association*, Home Energy Magazine.

8) *The Making of a Small Business Owner* Home Energy Magazine

ci. Lupberger, David. *The Making of a Small Business Owner,* Home Energy Magazine HPC-A Business Development Guide.

9) *So You Want to Be a Home Performance Contractor* Home Energy Magazine

ci. Thomas, Greg. *So You Want to Be a Home Performance Contractor,* Home Energy Magazine HPC-A Business Development Guide.

10) *Guaranteed to Succeed* Home Energy Magazine

ci. James, Mary. *Guaranteed to Succeed,* Home Energy Magazine, March/April 2005.

11) *A Whirlwind Startup* Home Energy Magazine

ci. James, Mary. *A Whirlwind Startup,* Home Energy Magazine, November/December 2004.

12) *Greening of a Home Performance Contractor* Home Energy Magazine

ci. Thomas, Greg. *Greening of a Home Performance Contractor*, Home Energy Magazine, May/June 2005.

13) *Internet Marketing* ACCA Contractor Excellence

ci. Hudson, Adams. *Internet Marketing.* ACCA Contractor Excellence. http://www.contractorexcellence.com/5254, May 9, 2011.

14) *Marketing Essentials* Home Energy Magazine

ci. Home Energy. *Marketing Essentials,* Home Energy Magazine HPC-A Business Development Guide.

15) *Help Customers Choose High Efficiency* ACCA Contractor Excellence

ci. Turpin, Joanna. *Help Customers Choose High Efficiency,* ACCA Contractor Excellence. http://www.contractorexcellence.com/1940, July 6, 2010.

16) *How to Sell Comfort in a Green World* C ontracting Business

ci. Givens, Alan. *How to Sell Comfort in a Green World,* Contracting Business. http://contractingbusiness.com/indoor_air_quality/content/sell-comfort-green-0609/index.html, June 1, 2009.

17) *How to Win the Job* Home Energy Magazine

ci. Gorman, Mike. *How to Win the Job,* Home Energy Magazine, September/October 2009.

18) *Sales Strategies* Home Energy Magazine

ci. Kornbluth, Dick; Taylor, Larry; Hughes, Darin; Seville, Carl. *Sales Strategies,* Home Energy Magazine HPC-A Business Development Guide.

19) *Selling High-Performance Audits* Home Energy Magazine

ci. Cooke, Gord. *Selling High-Performance Audits,* Home Energy Magazine, September/October 2009.

20) *The Five Ingredients in a Sale* ACCA Contractor Excellence

ci. Rees, Michael. *The Five Ingredients in a Sale,* ACCA Contractor Excellence. http://www.contractorexcellence.com/5142, April 25, 2011.

21) *Tips for Selling Green* ACCA Contractor Excellence

ci. Contractor Excellence Magazine Staff. *Tips for Selling Green,* ACCA Contractor Excellence. http://www.contractorexcellence.com/3911, January 3, 2011.

22) *Two Ears, One Mouth: Listen Your Way to Increased...* Contracting Business

ci. Greer, Charlie. *Two Ears, One Mouth: Listen Your Way to Increased Sales,* Contracting Business. http://contractingbusiness.com/columnists/greer/two-ears-one-mouth-0411/, April 1, 2011.

V. Customer Education Process

1) *Use Your Customers as Part of Your Sales Force* Building Performance Institute

ci. Building Performance Institute. *Use Your Customers as Part of Your Sales Force.* http://www.bpi.org/news_pm_july_09.aspx, Building Performance Institute 2010.

2) *Winter Relief Assistance Program* APPRISE

ci. APPRISE. *Winter Relief Assistance Program.* http://www.appriseinc.org/reports/Final%20PPL%20WRAP%20Evaluation%20Report.pdf, APPRISE, April 2006.

3) *What Every Consumer Really Wants to Know* Contracting Business

ci. Falke, Rob. *What Every Consumer Really Wants to Know,* Contracting Business, February 3, 2010.

4) *Maine Home Performance Technical Standards* ENERGY STAR

ci. Boothby, Tom; Karg, Rick. *Maine Home Performance Technical Standards.* http://www.karg.com/pdf/MHP%20Standards%20Book%20Final%200908%20v2.pdf, Maine Home Performance with ENERGY STAR Standards, September 2008, v2.

5) *Energy Efficient Mortgages* Home Energy Magazine

ci. Mann, Steve. *Energy Efficient Mortgages,* Home Energy Magazine, March/April 2009.

6) *Best-Kept Secret in the Mortgage Industry* Home Energy Magazine

ci. Baden, Steve. *Best-Kept Secret in the Mortgage Industry,* Home Energy Magazine, January/February 2007.

7) *A Wisconsin Usonian Home: 37 Years of Energy History* Home Energy Magazine

ci. Foell, Wesley K. *A Wisconsin Usonian Home: 37 Years of Energy History,* Home Energy Magazine, July/August 2009.

VI. Community Engagement

1) *Community Energy Efficiency Program Best Practices...* Clean Energy Solution

ci. Clean Energy Solution. *Community Energy Efficiency Program Best Practices Marketing Strategies.* http://www.cleanenergysol.com/news/news_confrences.html, September 2010.

2) *Inform Homeowner Participation in California Energy...* Action Research

ci. Action Research. *Inform Homeowner Participation in California Energy-Efficiency Home Improvement Programs.* http://www.takeactionresearch.com, 7/26/2010.

3) *The DC Project* WeatherizeDC

ci. WeatherizeDC. *The DC Project.* http://www.WeatherizeDC.org, 2010 Annual Report.

VII. Assessment Arrival Process

1) *Combustion Appliance Testing: Why, How, When?* Home Energy Magazine

ci. Sterner, A. Tamasin. *Combustion Appliance Testing: Why, How, When?* Home Energy Magazine, November/December 2010.

2) *Combustible-Gas Leak Detectors* Home Energy Magazine

ci. Raymer, Paul. *Combustible-Gas Leak Detectors,* Home Energy Magazine, May/June 2011.

3) *Letters* Home Energy Magazine

ci. Sterner, Tamasin; Stratton, Chris. *Letters,* Home Energy Magazine, May/June 2011.

VIII. On-Site Customer Interview

1) *Be a Detective* — Contracting Business

ci. Coop, Tina. *Be a Detective, and 'Investigate' During Service Calls,* Contracting Business. http://contractingbusiness.com/service/content/be-detective-investigate-0311/, March 1, 2011.

2) *IAQ for Homes* — Contracting Business

ci. Esch, Bill. *IAQ for Homes,* Contracting Business. http://contractingbusiness.com/indoor_air_quality/content/iaq-homes-0909/, September 1, 2009.

IX. Whole House Assessment

1) *Kick the Can! No Recessed Lights in the Building Envelope* — Energy Vanguard

ci. Bailes, Allison. *Kick the Can! No Recessed Lights in the Building Envelope,* Energy Vanguard. http://www.energyvanguard.com/blog-building-science-HERS-BPI/bid/37246/Kick-the-Can-No-Recessed-Lights-in-the-Building-Envelope, April 4, 2005.

2) *Multifamily Assessment* — Home Energy Magazine

ci. Genge, Colin. *Measuring Leakage in Multifamily Buildings*, Home Energy Magazine, September/October 2007.

3) *Sealed Attics?* — Home Energy Magazine

ci. Coble, Brian. *Sealed Attics?* Home Energy Magazine, January/February 2010.

4) *The Telltale Sign of Infiltration* — Energy Vanguard

ci. Bailes, Allison. *The Telltale Sign of Infiltration,* Energy Vanguard. http://www.energyvanguard.com/blog-building-science-HERS-BPI/bid/30707/The-Telltale-Sign-of-Infiltration, September 20, 2010.

5) *Plan Your Attack* — Energy Circle

ci. Energy Circle Staff. *Plan Your Attack,* Energy Circle. http://www.energycircle.com/learn/air-sealing/plan-your-attack, August 18, 2009.

6) *An Easier Way to Measure Duct Leaks* — Home Energy Magazine

ci. Sherman, Max; Walker, Iain. *An Easier Way to Measure Duct Leaks*, Home Energy Magazine, September/October 2002.

7) *Grupe Homes Enters the Whole-House Retrofit Market* — Home Energy Magazine

ci. Gilbride, Therease; Hefty, Marye. *Grupe Homes Enters the Whole-House Retrofit Market*, Home Energy Magazine, March/April 2010.

8) *Baseline Standard Practices Survey: Task Report* — Team IBTS

ci. Team IBTS. *Baseline Standard Practices Survey: Task Report.* www.huduser.org, January 30, 2006.

9) *New Construction Report Card II* — Home Energy Magazine

ci. Chitwood, Rick; Hoeschele Marc. *New Construction Report Card, Part II*, Home Energy Magazine, March/April 2003.

10) *Testing Duct Leakage* — Home Energy Magazine

ci. Francisco, Paul; Pigg, Scott. *Testing Duct Leakage,* Home Energy Magazine, March/April 2009.

11) *Formicary Corrosion—A Primer* — ACCA

ci. Prather, Donald. *Formicary Corrosion—A Primer,* Air Conditioning Contractors of America, 2009.

12) *Passive Solar Heating* — Green Building Advisor

ci. Wilson, Alex. *Passive Solar Heating,* Green Building Advisor. http://www.greenbuildingadvisor.com/blogs/dept/energy-solutions/passive-solar-heating, November 4, 2008.

13) *Temperature Differentials in Residential Applications* — ACCA

ci. Prather, Donald. *Temperature Differentials in Residential Applications,* Air Conditioning Contractors of America, 2009.

14) *Why You Need HVAC Load Calculations* — Energy Vanguard

ci. Bailes, Allison. *Why You Need HVAC Load Calculations,* Energy Vanguard. http://www.energyvanguard.com/hvac-design/, 2011.

15) *An Introduction to Indoor Air Quality* — EPA

ci. U.S. Environmental Protection Agency. *An Introduction to Indoor Air Quality,* U.S. Environmental Protection Agency. http://www.epa.gov/iaq/voc.html, March 22, 2011.

16) *Roof Topography & Ice Damming* — Home Energy Magazine

ci. Labbé, Greg. *Roof Topography & Ice Damming*, Home Energy Magazine, January/February 2010.

17) *Indoor Environmental Quality Daydreams and Night...* — Home Energy Magazine

ci. Shaw, Kirsten. *Indoor Environmental Quality Daydreams and Nightmares,* Home Energy Magazine, May/June 2011.

18) *Attic Stairs—A Mind-Blowing Hole in Your Building...* — Energy Vanguard

ci. Bailes, Allison. *Attic Stairs—A Mind-Blowing Hole in Your Building Envelope,* Energy Vanguard. http://www.energyvanguard.com/blog-building-science-HERS-BPI/bid/34932/Attic-Stairs-A-Mind-Blowing-Hole-in-Your-Building-Envelope, January 7, 2011.

19) *Does It Make Sense to Move the Building Envelope to...* Energy Vanguard

ci. Bailes, Allison. *Does It Make Sense to Move the Building Envelope to the Roofline?* Energy Vanguard Blog. http://www.energyvanguard.com/blog-building-science-HERS-BPI/bid/38272/Does-It-Make-Sense-to-Move-the-Building-Envelope-to-the-Roofline?source=Blog_Email_%5bDoes+It+Make+Sense+t%5d, posted May 23, 2011.

20) *Cold Interior Walls, Useless Insulation, and Building Science* Energy Vanguard

ci. Bailes, Allison. *Cold Interior Walls, Useless Insulation, and Building Science,* Energy Vanguard. http://www.energyvanguard.com/blog-building-science-HERS-BPI/bid/33564/Cold-Interior-Walls-Useless-Insulation-and-Building-Science, December 3, 2010.

21) *Flat or Lumpy—How Would You Like Your Insulation?* Energy Vanguard

ci. Bailes, Allison. *Flat or Lumpy—How Would You Like Your Insulation?* Energy Vanguard. http://www.energyvanguard.com/blog-building-science-HERS-BPI/bid/25547/Flat-or-Lumpy-How-Would-You-Like-Your-Insulation, June 28, 2010.

22) *Infrared Thermography: (Nearly) A Daily Tool* Home Energy Magazine

ci. Snell, John. *Infrared Thermography: (Nearly) A Daily Tool,* Home Energy Magazine, March/April 2008.

23) *RESNET & Infrared Thermography* Home Energy Magazine

ci. Snell, John. *RESNET & Infrared Thermography*, Home Energy Magazine, January/February 2010.

24) *Successful Warm-Weather Infrared Inspections* Home Energy Magazine

ci. Schwoegler, Matt. *Successful Warm-Weather Infrared Inspections,* Home Energy Magazine, May/June 2011.

25) *Check Your Showerhead!* Home Energy Magazine

ci. Hain, Lexie; Harrod Jon. *Check Your Showerhead!* Home Energy Magazine, November/December 2007.

X. Customer Presentation Package

1) *Energy Monitoring; Product Review* Energy Circle

ci. Energy Circle Staff; Harrison, Tom. *Energy Monitoring; Product Review*, Energy Circle. http://www.energycircle.com/learn/energy-monitoring, Energy Monitoring: December 18, 2009; Product Reviews: September 13, 2010.

2) *How to Sell Green Upgrades* Green Building Advisor

ci. Strong, Michael. *How to Sell Green Upgrades...*, Green Building Advisor. http://www.greenbuildingadvisor.com/blogs/dept/business-advisor/how-sell-green-upgrades-radiant-barrier-paints, January 25, February 8, March 9, June 9, 2011.

3) *Making Your Home Safer with a Sealed Combustion...* Energy Vanguard

ci. Bailes, Allison. *Making Your Home Safer with a Sealed Combustion Closet,* Energy Vanguard. http://www.energyvanguard.com/blog-building-science-HERS-BPI/bid/35938/Making-Your-Home-Safer-with-a-Sealed-Combustion-Closet, February 11, 2011.

4) *The Ductless Mini-Split Heat Pump's Big Brother* Energy Vanguard

ci. Laumer-Giddens Chris. *The Ductless Mini-Split Heat Pump's Big Brother—CITY MULTI,* Energy Vanguard. http://www.energyvanguard.com/blog-building-science-HERS-BPI/bid/38008/The-Ductless-Mini-Split-Heat-Pump-s-Big-Brother-CITY-MULTI, May 11, 2011.

5) *Retrofit Your Existing Building with High Performance...* Quad-Lock Building Systems

ci. Quad-Lock Building Systems. *Retrofit Your Existing Building with High Performance Insulation,* Quad-Lock Building Systems version 1.4, 01/2010.

6) *10 Things You Should Put in Your House* Builder Online

ci. Maynard, Nigel. *10 Things You Should Put in Your House in 2010,* Builder Online. http://www.builderonline.com/products/10-things-you-should-put-in-your-house-in-2010.aspx, December 1, 2009.

7) *Products Guide* ACCA Contractor Excellence

ci. Contractor Excellence Magazine Staff. *Products Guide,* ACCA Contractor Excellence. http://www.contractorexcellence.com/category/sections/products, last updated April 5, 2011.

8) *Residential: Ducted/Non-ducted Air Conditioning, Geo...* Contracting Business

ci. Kelly, Kate. *Residential: Ducted/Non-ducted Air Conditioning, Geothermal Systems; Commercial: Chillers, VRF Systems, and Applied Equipment,* Contracting Business. http://contractingbusiness.com/residential/content/residential-ducted-nonducted-air-conditioning-0310/index.html, March 1, 2010.

9) *2009/2010 Guide to High Efficiency Gas Furnaces* Contracting Business

ci. Contracting Business.com. *2009/2010 Guide to High Efficiency Gas Furnaces.* http://contractingbusiness.com/images/0909HeatingGuide.pdf, September, 2009.

10) *2011 Guide to High Efficiency Air Conditioning* Contracting Business

ci. Contracting Business.com. *2011 Guide to High Efficiency Air Conditioning.* http://contractingbusiness.com/CB0411-2011-AC-guide.pdf, April 4, 2011.

11) *New Green Building Products* Green Building Advisor

ci. Holladay, Martin. *New Green Building Products,* Green Building Advisor. http://www.greenbuildingadvisor.com/blogs/dept/musings/new-green-building-products, September 10, 2010.

12) *Martin's Useless Products List* Green Building Advisor

ci. Holladay, Martin. *Martin's Useless Products List,* Green Building Advisor. http://www.greenbuildingadvisor.com/blogs/dept/musings/martin-s-useless-products-list, September 25, 2010.

13) *A Roundup of New Green Building Products* Green Building Advisor

ci. Holladay, Martin. *A Roundup of New Green Building Products,* Green Building Advisor. http://www.greenbuildingadvisor.com/blogs/dept/musings/roundup-new-green-building-products, March 25, 2010.

14) *Energy Savers: Thermostats and Control Systems* U.S. DOE

ci. U. S. Department of Energy. *Energy Savers: Thermostats and Control Systems*, U.S. Department of Energy. http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12720, 02/09/2011.

15) *Using Thermostats* Green Building Advisor

ci. Wilson, Alex. *Using Thermostats,* Building Green Advisor. http://www.greenbuildingadvisor.com/blogs/dept/energy-solutions/using-thermostats, March 24, 2009.

16) *Reduce Hot Water Use for Energy Savings* U.S. DOE

ci. Energy Savers. *Reduce Hot Water Use for Energy Savings.* http://www.energysavers.gov/your_home/water_heating/index.cfm/mytopic=13050, U.S. Department of Energy, 2/9/2011.

17) *Tankless Water Heaters Getting More Efficient* Professional Builder

ci. Corey, Jason. *Tankless Water Heaters Getting More Efficient,* Professional Builder, May 31, 2011.

18) *Affordable Window Retrofits* Green Building Advisor

ci. Yost, Peter. *Affordable Window Retrofits,* Green Building Advisor. http://www.greenbuildingadvisor.com/blogs/dept/green-communities/affordable-window-retrofits, June 21, 2011.

19) *The Pros and Cons of Window Films* Builder Online

ci. Royer, Evelyn. *The Pros and Cons of Window Films,* Builder Online. http://www.builderonline.com/green-products/the-pros-and-cons-of-window-films.aspx, May 4, 2011.

XI. Assessment Report

1) *Converting Between CFM 50 and Natural Airflow* Building Performance Institute

ci. Building Performance Institute. *Converting Between CFM 50 and Natural Airflow,* Building Performance Institute, 4/07.

2) *Distribution Efficiency Look-Up Table* Building Performance Institute

ci. Building Performance Institute. *Distribution Efficiency Look-Up Table,* Building Performance Institute, 4/07.

3) *Ensuring ASHRAE 62.2—2010 Ventilation Compliance...* ACCA

ci. Prather, Donald. *Ensuring ASHRAE 62.2-2010 Ventilation Compliance for Residential Structures,* Air Conditioning Contractors of America, 2010.

4) *Sick Building Syndrome* Building Performance Institute

ci. Building Performance Institute. *Sick Building Syndrome,* U.S. Environmental Protection Agency, February 1991.

5) *R-Value Calculations* Building Performance Institute

ci. Building Performance Institute. *R-Value Calculations,* Building Performance Institute, 4/07.

XII. State or Local Program Reporting

1) *Home Performance with ENERGY STAR Customer Incent* ENERGY STAR

ci. Consumers Energy. *Home Performance with ENERGY STAR Customer Incentives,* ENERGY STAR, 1/12/11.

2) *Want Energy-Saving Improvements in Your Home?...* San Francisco Chronicle

ci. Hibble, Anna Marie. *Want Energy-Saving Improvements In Your Home? The Feds May Help...,* San Francisco Chronicle, 4/21/2011.

3) *Clean Up Your Ecological Footprint* Home Energy Magazine

ci. Gunshinan, Jim. *Clean Up Your Ecological Footprint,* Home Energy Magazine, May/June 2005.

4) *Incentives and Rebates for Energy Efficient Windows...* Efficient Windows Collaborative

ci. Efficient Windows Collaborative. http://www.efficientwindows.org, January 2011.

XIII. Work Scope/Procedures

1) *Combustion Safety Test* Building Performance Institute

ci. Saturn Resource Management, *BPI Combustion Test Instructions,* SRMI. http://www.srmi.biz.

2) *Combustion Safety Test (2)* Building Performance Institute

ci. Building Performance Institute. *Combustion Safety Test Procedure for Vented Appliances,* Building Performance Institute, 4/07.

3) *Guide to Performance Test* Building Performance Institute

ci. Building Performance Institute. *Building Analyst-Guide to Performance Test,* Building Performance Institute, 1/26/07.

4) *Sick Building Syndrome* EPA

ci. U.S. Environmental Protection Agency. *Sick Building Syndrome,* Environmental Protection Agency—Research and Development, February 1991.

XIV. Job Completion Verification

1) *Improving Your Home Performance Contracting Bus...* Home Energy Magazine

   ci. Abrey, David. *Improving Your Home Performance Contracting Business Through Quality Management,* Home Energy Magazine, September/October 2009.

2) *Baseline Standard Practices Survey: Task Report* Team IBTS

   ci. Team IBTS. *Baseline Standard Practices Survey: Task Report.* www.huduser.org, January 30, 2006.

3) *RESNET Quality Assurance* Home Energy Magazine

   ci. Gunshinan, Jim. *RESNET Quality Assurance,* Home Energy Magazine, July/August 2005.

Appendix B – Training

HVAC Transition Guide for Building Performance Contractors

Operational Area: **Business Planning/Process**

Work Activity: **Training**

Issue

Transitioning into home performance contracting requires training in the basics of building science, as well as a comprehensive understanding of the various aspects of home performance. Home performance contractors should be able to identify problems not just with a single residential system but anywhere in the home using a "house as a system" approach. Certified training providers can teach these concepts through courses that present building performance standards such as the Building Performance Institute (BPI)'s Building Analyst standards and RESNET's Home Energy Rating System (HERS) Rater standards. Conferences also can be an excellent source of training.

(National Renewable Energy Laboratory/PIX 11712 http://www.nrel.gov/data/pix/Jpegs/11712.jpg)

Building Science

A strong and comprehensive home performance training course should be built on a foundation of building science concepts. Key themes should include principles of energy conservation and efficiency; building shell construction and diagnostics; insulation and heat transfer; air pressure and airflow; humidity and moisture; HVAC and water heating essentials; lighting and appliances; and occupant health and safety. Thoroughly understanding how these principles operate and interact will help you evaluate the myriad of situations you may come across in actual homes and will allow you to devise the best possible solutions on a case-by-case basis.

Topics Covered

Beyond the basics, training in home performance should cover a wide range of specific topics. A good course will focus on not only energy efficiency and building science but also health, safety, and comfort. A full curriculum will generally include all of the following topic areas:

- Heat transfer and heat flow: types of heat flow (conduction, convection, and radiation); energy transformation into heat; heat loss.
- Air pressure and air flow: air pressure evaluation; leakage diagnostics; air sealing; duct leakage; blower door testing.
- Building envelope: thermal boundary; insulation; solar gain; external air infiltration.
- Moisture management: infiltration of humid air; internally generated moisture; rainwater infiltration; vapor diffusion.
- Indoor air quality: indoor pollutants; pollutant distribution; thermal comfort; ventilation.

Learning these concepts fully also requires some hands-on training in the field, which in some cases may be combined with classroom instruction, including the following:

- Blower door setup and operation
- Use of a smoke pencil to detect air leaks
- Analyzing pressure differentials with a digital manometer
- Diagnosing duct leakage with a duct blaster
- Assessing air distribution balance with a flow hood
- Installing and using carbon monoxide detectors and gas sniffers
- Conducting a thorough combustion test

Beyond training in the fundamental concepts listed above, a successful home performance contractor should become educated in areas such as building codes and regulations, as well as available incentive programs. To be competitive, the contractor should stay on top of best practices from a business perspective as well.

Building America
U.S. Department of Energy

Certifications

There are many different certifications available, depending on your needs, clients, market, and programs in which you may want to work. These range from professional certifications within a particular slice of the energy efficiency industry (e.g., renewables, building operations, commissioning, auditing) to certifications in associated industries, such as green building. The two building performance certifications most recognized by state and federal programs today are those issued by BPI and RESNET (the Residential Energy Service Network). Historically, BPI focused primarily on existing buildings, while RESNET's HERS certification focused more on new construction. However, more recently that line has been blurred.

There are still some differences between the two programs, although they are more subtle. Both certifications now include a combustion safety requirement to identify unsafe space heating and water heating systems. BPI also includes identifying natural gas leaks and monitoring ambient carbon monoxide, while HERS Rater training emphasizes duct testing with the use of a duct blaster. In addition, HERS Raters are trained to use software that will provide a house with an overall efficiency rating. RESNET operates a quality assurance system for all HERS Raters.

Nonetheless, because the fundamental concepts in both types of training are mostly the same, it is worth examining the curriculum of whichever course you choose to make sure it includes the items you wish to learn. One reason to choose a particular certification may also be that it is required by a particular incentive program that you can tap into when marketing your services to potential customers.

Training and preparing for a professional certification usually takes at least a week of time at a cost of about $1,500, not including time away from your business. Qualifying for the certification is another $1,000 or so.

Note that both standards programs also carry continuing education requirements. HERS Raters must complete 12 hours of classroom instruction every year, while BPI Building Analysts must recertify every three years with 10 to 30 hours of classroom instruction and an option for written examination.

Conferences

Local, regional, and national conferences are an excellent training resource. While some provide pre- or post-training toward certification, most are useful primarily for continuing education, networking with others in the field, and keeping abreast of the latest developments in the building performance world. Some of the more popular building science conferences include the following:

- ACEEE Hot Water Forum
- ACEEE Summer Study in Buildings
- Affordable Comfort Conference
- Better Buildings By Design (EVT)
- Building Energy (NESEA)
- Energy and Environmental Building Assoc.
- GreenBuild (USGBC)
- National Green Building Conference (NAHB)
- RESNET Conference

Article Snippets

Home Energy Magazine:

Keeping Educated in a Rapidly Changing Environment

"Home performance contracting addresses a multitude of issues that affect homeowners, including their home's energy use, moisture movement, indoor air quality (IAQ), comfort, and durability. It is not sufficient for a contractor to be a jack-of-all-building-trades. He or she must be a master of most, and must know where to look when searching for answers to difficult questions." 9/4/2009
http://www.homeenergy.org/show/article/nav/homeperformance/id/657

From HVAC to Home Performance Contracting

Matthew Holtkamp, founder of Holtkamp Heating and Air Conditioning (HHVAC) in Atlanta, Georgia, obtained home performance training to serve his customers better.

"With the new testing equipment and procedures, Holtkamp could pin down the source of any HVAC problem and find a solution based on the condition of the whole house. Before the training, for example, if the client complained of high energy bills and dust, he would install a new high-efficiency furnace and recommend a new furnace filter for dust. After the training, he and his employees would diagnose the problem as duct leakage using a blower door assessment, and seal the ducts before installing the new furnace." 10/3/2007
http://www.homeenergy.org/show/article/nav//id/373

(Lawrence Berkeley National Laboratory, http://homeenergypros.lbl.gov/photo/q32-ductester-system/prev?context=user)

Resources

BPI Training:
http://www.bpi.org/schedules_training.aspx

RESNET HERS Rater Training:
http://www.resnet.us/programs/training

"House Simulator Tent."
http://homeenergypros.lbl.gov/photo/q32-ductester-system/prev?context=user

Appendix C – Equipment

HVAC Transition Guide for Building Performance Contractors

Operational Area: **Business Planning/Process**

Work Activity: **Equipment**

Issue

Transitioning into home performance contracting will require some investment in the tools necessary to diagnose and complete a comprehensive home performance job. The advantage of acquiring and learning how to use these devices is that you will be much better equipped to identify any issues in a customer's home and then upgrade them effectively and safely. From air leakage to excess moisture to health and safety problems, having the right tools in your kit will enable you to conduct a thorough assessment, avoid missing any issues, and repair the home's deficiencies.

Blower Door

(Arizona Department of Energy, http://www.azenergy.gov/)

Purpose: Tests for air leakage between the interior and exterior of a home, which can lead to significant heating and cooling energy losses and unwanted moisture.

Basic Concept: A powerful calibrated fan in an external doorway sucks air out of the house, which creates a pressure differential that draws external air back in through any cracks in the exterior. Using your hands or a smoke pencil, you can detect where air is coming in to identify leakage spots in need of repair. With gauges, you can also quantify the amount of air leakage as a reference to standards or before/after results of work done on a home.

How It Works: Learning how to use a blower door and all other equipment requires hands-on training. The basic steps include:

- Prepare house according to standard conditions;
- Set up the frame and curtain;
- Install the fan and connect it to a digital manometer (which measures pressures);
- Take a baseline reading with the fan cover on, and
- Take a second reading with the fan cover off to determine the extent of air leakage. When the cover is off, you can use a smoke pencil to locate the source of air leaks.

Standards: RESNET's "Mortgage Industry National Home Energy Rating Systems Standards" require blower door testing in compliance with ASHRAE Standard 119, Section 5.1, which lays out procedures for measuring air leakage area. The RESNET Standards also specify physical conditions that should be in place prior to testing. The Building Performance Institute's (BPI) Building Analyst Professional Standards require blower door testing under many common scenarios in compliance with ASHRAE Standard 62-89, which provides minimum ventilation requirements. The BPI Standards also require certain physical conditions prior to testing and prohibit depressurization tests when airborne asbestos is a risk.

Cost: A typical system will cost $2,500–$3,000, not including cases and major replacement parts. Digital manometers are sold separately for about $700 to $800.

Duct Blaster

(National Renewable Energy Laboratory/PIX 04913, http://www.nrel.gov/data/pix/Jpegs/04913.jpg)

Purpose: Tests for air leakage through a home's duct system.

Basic Concept: Whereas a blower door pressurizes an entire home, a duct blaster pressurizes only the home's duct system. Measuring the amount of airflow needed to bring the duct system up to a standard level tells you the amount of air leaking out of the system.

How It Works: Two tests are typically performed with duct blasters: a "total leakage" test that reveals the extent of air leakage throughout the whole system, and an "outdoor test" that measures only leakage to the outside and unconditioned space (which causes energy loss). The basic steps in a total leakage test are as follows:

- The duct blaster is connected to the duct system either at the air handler or a return grille. The duct system is isolated from the house by taping off all registers and grilles.
- Indoor and outdoor pressures are equalized by opening an exterior door or window.
- The duct blaster is run, and the airflow required to achieve standard pressurization is measured to determine total leakage.

An "outdoor" test uses the following modified procedure:

- When possible, any unconditioned space in the house is equalized with the outdoors by opening a window or door (if available), and interior access to this space is closed off.
- A blower door and a duct blaster are used simultaneously to equalize the pressure inside the home's conditioned space and inside the duct system.
- The airflow is measured. At this point the only duct system leakage that will occur will be to the outdoors or to unconditioned space because there is no pressure differential within the conditioned space.

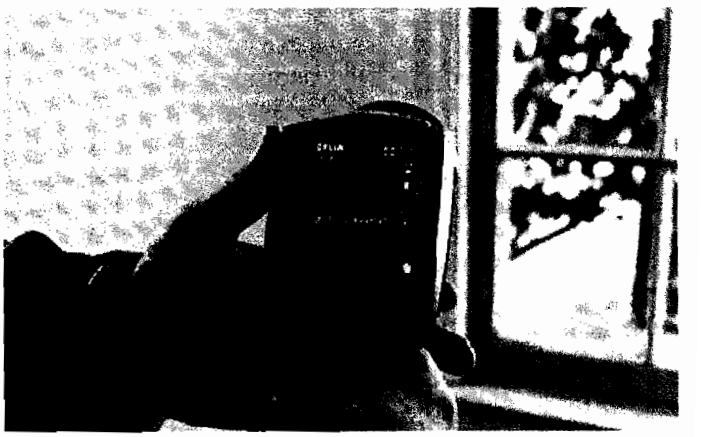
Standards: The RESNET Mortgage Industry Standards require that duct leakage testing comply with ASHRAE Standard 152, which establishes procedures for measuring both outside and total duct system leakage. The RESNET Standards include just a few modifications (e.g., supply and return leakage can be measured together). BPI Building Analyst Standards require "before and after" duct leakage testing whenever duct sealing is conducted, but the Standards do not call for specific testing procedures.

Cost: Typically about $2,000, plus a digital manometer for about $700 to $800.

Infrared Camera

Purpose: Tests for missing insulation and air leakage in the building envelope.

Basic Concept: The amount of infrared radiation emitted at different points along the building envelope varies with differences in surface temperature, which can be affected by missing insulation or air leaks. The camera translates the pattern of infrared radiation emitted into a visible image on a screen, using different shades or colors to depict where temperatures diverge.



(ENERGY STAR, http://www.energystar.gov/index.cfm?c= behind_the_walls.btw_inspection)

How It Works: Actual operation of an infrared camera is relatively simple, yet interpreting the images displayed can be fairly complex. The most difficult aspects of the process are ensuring that the right physical conditions are in place so that temperature variations will show up properly, as well as being aware of any structural issues that may obscure or impact surface temperature readings.

The temperature difference between the interior and exterior surfaces must be great enough that the variation is apparent in places where there are insulation gaps. Surface temperature can be affected by all of the following factors:

- Air temperature (both inside and outside)
- Sunlight
- Moisture
- Wind

Keep in mind that temperature changes throughout the day, so it is best to conduct the analysis at a time when the temperature is relatively constant. In addition, the effects of solar gain can affect both exterior and interior surfaces and may take several hours to wear off, so if possible it can help to test late at night or early in the morning (or perhaps on a heavily overcast day).

Testing for missing insulation can be done by analyzing either the interior or exterior of the home. Temperature variation is sometimes easier to detect indoors, but indoor testing brings its own challenges. Furniture and wall hangings can cause obstructions and should be moved if possible. Other construction elements such as ductwork, radiant heating components in the walls, or internal air cavities may also obscure readings, so knowledge of the building design can be essential. In addition, certain interior spaces may be inaccessible, in which case additional outdoor imaging may be helpful.

When testing for air leakage, it is best to use a blower door to depressurize the home and draw in external air, which will show up as thermal variation if the indoor surface temperature is different. The blower door should be run long enough to change the surface temperature at the point of the leak. Note, however, that running the blower door for too long can eventually minimize the temperature difference of the whole surface with the outdoors. In addition, be aware that if the air passes first through an internal cavity, its temperature may change before it reaches the wall surface, meaning the leak may not show up.

Standards: RESNET recently adopted standards for thermographic testing with an infrared camera to detect both insulation defects and air leakage. The Standards establish a list of required camera specifications, including standards for thermal sensitivity, spectral range, field of view, and image recording. When testing for insulation gaps, the RESNET Standards require an indoor/outdoor temperature differential of 10°C (18°F) for four hours prior to testing, as well as removal of furniture and other obstructions. The temperature differential can be less for air leakage inspections, but blower door usage is required. The RESNET Standards are based on several previously established standards adopted by various organizations in the United States and abroad. BPI has not adopted thermographic inspection standards at this point.

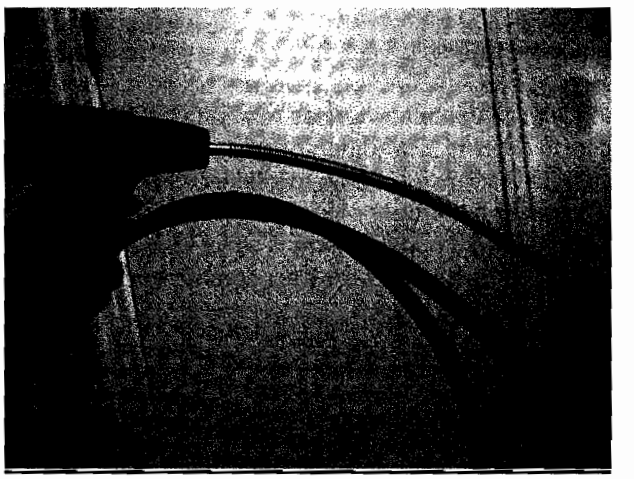
Cost: Prices can vary widely, but cameras that meet the RESNET specifications are available for less than $10,000.

Combustion Analyzer

Purpose: Tests the gas concentrations, temperature, and draft pressure in appliances that burn fuel to determine efficiency, safety, and emissions levels.

Basic Concept: Higher levels of CO_2 and lower levels of CO are safer and indicate efficient fuel combustion with oxygen in the supply air, although too much supply air can cool the combustion system and reduce efficient heat transfer. The analyzer tests for these concentrations along with levels of regulated emissions gases.

Temperature is measured because excess heat leaving through the exhaust flue amounts to inefficient energy loss. Draft is regulated since low draft pressure can cause combustion gas buildup and venting into the home, while high draft pressure can draw too much heat, damaging flames, and explosive gas into the flue.



(Lawrence Berkeley National Laboratory, http://homeenergypros.lbl.gov/photo/flexible-probe-for-our-testo?context=user)

How It Works: The analyzer determines gas concentrations by measuring electrochemical reactions in a gas sample drawn from the appliance with a probe and pump. Temperature is measured using thermocouples that produce a certain voltage, depending on the temperature difference between two ends of the conductor. Draft pressure is gauged with a manometer or transducer that emits a given signal, depending on the amount of pressure exerted on it.

It is extremely important to receive proper training before conducting any combustion analysis test. The basic procedures that should be covered are as follows:

- Take a gas sample by inserting as close to the base of the flue as possible and below any draft damper, hood, or diverter.
- Measure temperature by placing a thermocouple where the exhaust is hottest, generally at the flue base or just downstream of a heat economizer. Supply air temperature (measured outside the equipment or in the duct system) is subtracted from exhaust temperature to determine the net exhaust temperature.
- Gauge draft pressure with a manometer or transducer, generally at the same point at which the temperature was measured. An additional

measurement should be taken downstream of any draft damper, hood, or diverter.

The measurements are displayed as readings on a portable electronic screen.

An important aspect of combustion testing is the "worst case" combustion appliance zone (CAZ) test, which gauges potential back-drafting of toxic or explosive gases into the home. Back-drafting is caused by anything that depressurizes the home, such as bathroom fans, kitchen range hoods, clothes dryers, and even unintended duct leaks. A worst-case CAZ test involves taking a pressure reading with all these appliances running (including the air handler) to determine whether the pressure exceeds minimum safety limits. During this test, gas spillage is also detected using a mirror or smoke pencil to determine whether the length of time that gas spills from the appliance after startup is below acceptable limits.

Standards: BPI Standards include very specific requirements regarding combustion analysis testing. The Standards call for CO measurement, draft measurement, and spillage evaluation, as well as worst-case CAZ testing. Acceptable limits are spelled out for all of these tests, and specific actions are required at certain levels or when the equipment fails to meet specifications. In addition, a clear step-by-step procedure is laid out for combustion safety testing. RESNET Standards on combustion analysis testing were recently adopted and cover gas leakage, worst-case CAZ depressurization, and CO testing, although BPI procedures may be substituted by BPI-certified professionals under the RESNET Standards.

Cost: A combustion analyzer can be purchased for $300 to $900, depending on features.

More Assessment Tools

To round out your home performance assessment and work scope, some additional equipment may be needed, such as the following:

- A flow hood to gauge the amount of air moving through forced air or ventilation vents, which can create airflow and conditioning problems in particular rooms.
- A CO detector to install in the home, which will monitor carbon monoxide levels on an ongoing basis.
- A gas sniffer, which checks for natural gas or propane leakage.
- A hygrometer or psychrometer to measure relative humidity, which is key to preventing mold and avoiding moisture damage.
- Appliance meters to determine how much energy is being drawn by major appliances during a sampling period, which can be extrapolated over a year with additional information from the homeowner.
- A digital camera to display what you have found in the attic, crawlspace or other hard-to-reach areas to the homeowner.

Software

Energy and building software serves as the foundation for the house model, analysis, and recommendations. By inputting your actual measurements and comparing potential efficiency measures, you can recommend a cost-effective scope of work to the homeowner.

(National Renewable Energy Laboratory/PIX 04866, http://www.nrel.gov/data/pix/Jpegs/04866.jpg)

Strive for the highest level of accuracy of predictions you can afford to ensure credibility. True up with the homeowners' past utility bills. Some new tools achieve impressive levels of accuracy with minimal inputs.

Good software should produce results in a graphic-rich, customer-friendly format. Spend the time necessary to educate the customer on the report so that they understand the scope of work you have proposed. Print out and leave a report behind, if possible.

Software should also allow you to provide a rating or label for the home, both as is and after recommended improvements. This simplified quantification can serve as a powerful means of boiling down lots of detail into a single understandable metric that the homeowner can digest.

Installation: Cellulose Blower

Purpose: Fills wall cavities, attics, and other spaces with cellulose insulation, increasing the R-value and reducing air leakage.

Basic Concept: Cellulose insulation is made from recycled paper products such as old newspapers and is treated with fire retardant. It is "loose fill" in the sense that it is separated into small chunks by agitators in the cellulose blower drum, which makes it a great option for filling up insulation gaps. Using the right filling technique, it can be densely packed into wall cavities when blown in with a tube, which maximizes the R-value and air sealing effectiveness.

How It Works: Insulation works best when air is not moving through or around it. So it is very important to seal air leaks before installing insulation to ensure the best performance from the insulation.

When installing blown cellulose, particularly in exterior walls, it is essential to be aware of safety concerns such as the location and type of electrical wiring and the potential presence of lead or asbestos. It is also important to understand details of construction such as the integrity of the wall framing, especially when dense packing.

(National Renewable Energy Laboratory/PIX 17964, http://www.nrel.gov/data/pix/Jpegs/17964.jpg)

Be sure to receive proper training before attempting to blow cellulose. The steps that should be covered include the following:

- When insulating existing exterior walls, holes must be drilled in each stud bay (the cavity marked off by the wall studs). If insulating from the outdoors, a portion of the siding or other materials such as shingles must first be removed before the hole can be drilled. Angling the hole can make it easier to slide the tube in a particular direction.
- Cellulose is emptied from its packaging into the blower drum, where it will be broken up by agitators when the blower is turned on. A slide gate controls the rate at which the cellulose is blown in, while another control may regulate the amount of air that flows in simultaneously.
- A tube connected to the blower drum is inserted into the drilled hole. Dense packing can be achieved by sliding the tube first all the way to the top of the cavity and then pulling it back down slightly to leave room for the cellulose to blow in easily. Running only air through the tube first will straighten it out.
- The cellulose blower is switched on manually or with a remote control. To dense pack, the cavity is filled gradually from the top down, removing the tube slowly down toward the drilled hole as it becomes snug along the way.
- The process is completed by clearing the tube and knifing it downward from the hole to the bottom of the cavity, then blowing and gradually removing the tube back up toward the hole.
- The process is repeated for each cavity. When the blowing is complete, the holes are sealed off and any siding or shingles are replaced.

The process for blowing cellulose into the attic is relatively simpler. The key is to measure the floor space so you will know how much insulation is needed and then mark the desired depth on the attic framing. Cellulose bags will typically indicate how many are required to reach a certain R-value. Before blowing any insulation into an attic, first complete all air-sealing work and isolate potential fire hazards, such as recessed lights and bathroom fans. The cellulose can then be blown in directly onto the attic floor, taking care not to cover soffit vents, which can be protected with paneling. Placing a barrier around the attic opening and any other vertical breaches will ensure the cellulose builds up in these areas to the desired depth. After blowing is complete, check with a measuring stick to ensure that depth has been reached. Raking may be required to achieve an even spread.

Standards: BPI's Building Envelope Professional Standard calls for a thorough pre-inspection to identify unsafe or unsound areas for installing insulation, such as areas with knob and tube wiring, recessed light fixtures that have not been rated for direct contact with insulation, areas with moisture problems, and areas that are structurally unsound. At the same time, the Standards actually require installation of dense-packed or foam insulation to block air leakage paths in enclosed cavities,

with the specification that cellulose must be installed at 3.5 pounds per cubic feet or greater. Refer to this Standard for additional requirements.

RESNET's Contractor Work Scope Reference Standards cite ASTM Standard C1015-06, "Standard Practice for Installation of Cellulosic and Mineral Fiber Loose-Fill Thermal Insulation." This Standard also requires a pre-inspection to locate and block off certain areas, and it prohibits installation around metal flues, chimneys, or fireplaces. Reviewing the full details of this Standard carefully is strongly recommended.

Cost: Several blowers are available in the range of $2,500 to $5,000, although more expensive models can be purchased with additional features and higher capacities.

Spray Foam

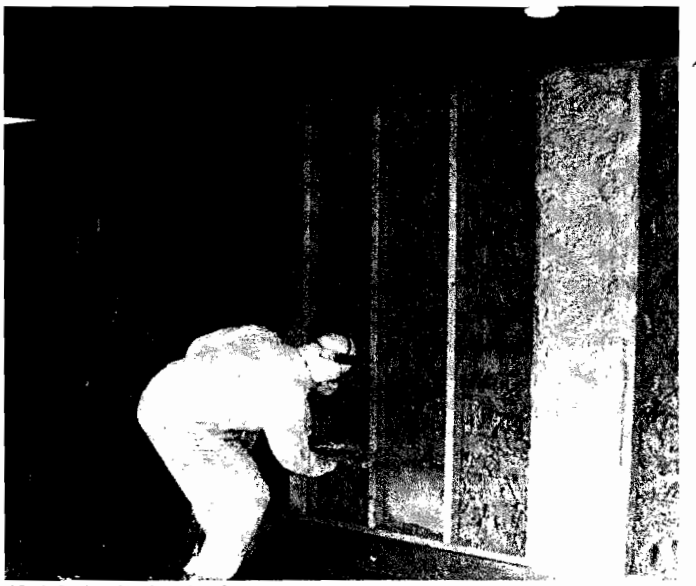
Purpose: Spray foam insulation is typically used to insulate walls and prevent air leakage. Dense spray foam known as "closed-cell" insulation also acts as a moisture barrier.

Basic Concept: Two components, a base and a foaming agent, are mixed and sprayed into open wall cavities, or into enclosed spaces using "slow rise" foam. The foam expands when it is sprayed on, filling in any gaps and crevices to create an airtight seal.

How It Works: Two types of sprayed foam are available on the market, known as "open cell" and "closed cell" foam. This refers to the density of the foam: open cell is about 0.5 pounds per cubic foot, while closed-cell is about 2 pounds per cubic foot. Closed-cell foam has a higher R-value and may be a better choice if moisture is a concern, although it is typically more expensive.

Depending on which product is used, the closed cell or open cell foaming agent is mixed with the base by a machine that controls mixing rates, pressure, and temperature. Mixing correctly is important because poor mixing has been reported to cause foam to contract over time. This can leave gaps between the foam and the framing that can lead to significant energy loss and can compromise the value of the insulation.

Before applying foam to open cavities such as basement walls with open stud bays, certain areas may need to be protected. These may include any electrical outlets, as well as nearby HVAC equipment, windows or doors, and flooring, as the foam tends to overspread and stick. When filling open cavities, you should wear protective gear such as a polyethylene suit to prevent skin exposure and a respiratory mask with an organic vapor cartridge and particulate filters.



(Oak Ridge National Laboratory, http://www.ornl.gov/sci/roofs+walls/AWT/HotboxTest/WoodFrame/SoyBean/index.htm)

When spraying in an open cavity, the foam should be applied evenly between gaps. The foam will expand significantly, so a conservative application should be enough to achieve the desired depth. After the foam has set, a long handsaw blade can be used to shave off the excess foam and make it even with the studs.

With existing walls, installing spray foam requires many of the same considerations as blowing cellulose, including knowing the wall's structural integrity and investigating the location of any electrical outlets, wiring, or obstructions in the wall. To install the foam, holes should be drilled in the wall cavities and a tube inserted into the hole. Multiple tubes may be required for the job because the foam may "cure" (expand) inside the tubing. Drilling multiple holes and filling from the bottom up can help to ensure an airtight seal with no gaps. Once the holes are drilled, foam should be sprayed slowly into the enclosed cavity and given a few minutes to expand. If excess foam emerges from the holes, it can be shaved and sanded down prior to patching the holes.

Standards: Many of the same requirements that apply to cellulose blowing under the BPI Envelope Professional Standard are also applicable to spray foam insulation. In addition, the Standard requires that spray foam be installed at or above the manufacturer's recommended density to limit airflow. The RESNET Standards do not specifically cite any reference standards for installing spray foam. ASTM Standards dictate certain manufacturer specifications, as do certain national and international code organizations.

Cost: Prices are highly variable, as a full professional system may require multiple components that are often sold separately.

Resources

DOE Building Energy Software Tools Directory.
http://apps1.eere.energy.gov/buildings/tools_directory/subjects_sub.cfm

Home Energy Magazine: "So You Want to Be a Home Performance Contractor" (4/16/2006).
http://www.homeenergy.org/show/article/page/7/id/199

RESNET Mortgage Industry National Standards.
http://www.resnet.us/standards/RESNET_Mortgage_Industry_National_HERS_Standards.pdf

RESNET Guidelines for Thermographic Inspections of Buildings.
http://www.resnet.us/standards/RESNET_IR_interim_guidelines.pdf

Building Performance Institute Standards.
http://www.bpi.org/standards.aspx

ASTM Standards.
http://www.astm.org/Standard/index.shtml

"Air Seal and Insulate with ENERGY STAR."
(http://www.energystar.gov/index.cfm?c=home_sealing.hm_improvement_sealing)

"Independent Testing and Inspection to Ensure Quality Construction," ENERGY STAR.
http://www.energystar.gov/index.cfm?c=behind_the_walls.btw_inspection

"Flexible Probe for Our Test 327 Combustion Analyzer."
http://homeenergypros.lbl.gov/photo/flexible-probe-for-our-testo?context=user

"Advanced Wall Systems: Hotbox Test R-value Database."
http://www.ornl.gov/sci/roofs+walls/AWT/HotboxTest/WoodFrame/SoyBean/index.htm

Appendix D – Customer Education

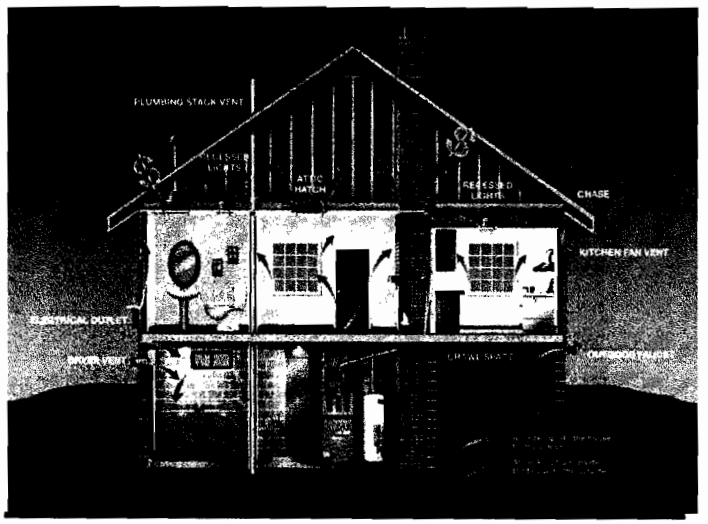
HVAC Transition Guide for Building Performance Contractors

Operational Area: **Marketing and Customer Contact**

Work Activity: **Customer Education**

Issue

Customer education is essential to generating business as a home performance contractor. Crafting a clear and concise message about the benefits of your services and spreading that message effectively will greatly increase your potential customer base.



(ENERGY STAR, http://www.energystar.gov/index.cfm?c=behind_the_walls.btw_airsealing)

Best Practices

There are many ways to educate customers about the benefits of your services. The key is to frame the message in a way that grabs customers' attention and then to follow through with additional information on your comprehensive offerings. Consider the following "best practices" when devising your own customer education strategy:

- Describe yourself as a problem solver. The best way to get in the door is to offer a solution to a problem that many potential customers are having, such as comfort issues, mold and mildew, or high energy bills. Once you've been invited inside, you can explain more about the value of a whole-house assessment.
- When using media to attract customers, remember that the most important thing is to "break through the clutter" of too much advertising. Short, attention-grabbing headlines can be at least as important as the rest of the message. You should also display in ads and marketing materials any certifications you have acquired to enhance your professional credibility.
- Sometimes the best way to deliver your message is through others. Referrals are especially powerful because customers learn about your business from someone they already trust. A good way to get referred is to go out of your way to satisfy your existing customers. Word of mouth can spread quickly in a neighborhood when one customer is happy.
- You can generate additional referrals by making presentations. Start by presenting to relevant groups such as home inspectors and real estate agents, who may be asked by their own customers for contractor recommendations. Business groups and professional associations may also be interested in learning more about the services you provide.
- Presenting to licensed or certified housing professionals who require regular continuing education unit (CEU) credits can be an effective means of spreading the word about you and your business. Real estate agents, architects, appraisers, and others are always looking for new CEU topics and presenters. With a little investment in development of a curriculum and completion of an application, many state licensing boards and associations will welcome a new home performance class.
- Home shows tend to draw a lot of homeowners looking for new ideas, products, and services. Purchase a booth in a prominent location, display your diagnostic tools, including your blower door and infrared camera, as conversation props, and talk to a lot of consumers. Spread the word on your business and its benefits.
- Don't overlook existing customers. Now that you offer a wider range of services, customers who already know you may be open to learning more about the benefits of your expanded business because they will already have a general understanding of what you do. Plus, customer retention typically costs far less than new customer generation.

Tools

A number of different tools can be used to educate customers (or those who might provide referrals) about the benefits of your business, including the following:

- Direct Mail: Make sure to craft a well-thought-out list of customers to target. Current customers and potential customers in a similar demographic or neighborhood are a good place to start.
- Internet: Building a website is no longer enough. Work with your web designer to make sure it's built so that it will show up in search results. Consider creating Facebook and Twitter accounts and perhaps a weekly blog with home performance tips.
- Email: Use your website to collect "email sign-ups." Then send out newsletters or helpful tips that potential customers will actually want to read.
- Traditional media continues to be an effective way of reaching customers, including the following:
    - Print media, such as
        - Newspapers
        - Magazines
        - Trade publications
    - Radio/Television: Consider both advertising and being interviewed on talk shows (or even creating a talk show of your own related to home performance)
- Handouts and Specialty Items: Items that provide your web address and contact information can be sent or handed to potential and existing customers, encouraging them to learn more about the solutions you offer when a relevant problem arises. The best items are those that are likely to stick around and be seen often or when it matters most (e.g., refrigerator magnets, thermostat stickers, and valve tags).
- Customer testimonials are an effective way of backing up your own statements about your business. Video testimonials on your website can be especially powerful.

Article Snippets

Home Energy Magazine:
Marketing Essentials

Five leaders in the home performance field—Greg Thomas, Dick Kornbluth, Larry Taylor, Darin Hughes, and Carl Seville—reveal how they get their phones to ring.

- *"If you offer multiple services, market all of those services in the same venues that you have always marketed your individual services, but tweak your message. For example, if you have traditionally advertised in a local newspaper's special fall home issue, then continue to do so; just make sure to* ***mention specific benefits that you can provide that homeowners need****. If there are specific climate-related problems in your area, such as ice dams in the winter or cooling comfort problems in the summer, market your ability to provide solutions to those problems."*
- *"Work hard to generate* ***referrals*** *by taking good care of your customers. You can also get leverage in educating customers through delivering* ***presentations****. We once did a presentation that only one person attended. But he was a home inspector. And we got a steady stream of referrals from that inspector for years after."* 4/16/2006
http://www.homeenergy.org/show/article/nav/salesandmarketing/page/2/id/200

A Whirlwind Startup

Mike Woodson and Jerold Sit, principals of Practically Free Energy:

- *"They bought some advertising airtime on a local radio station and talked their way into a monthly show with one of the station's regular hosts…. 'It can be like giving a haircut over the phone,' says Woodson. When discussing building science principles on air, Woodson sticks to* ***easy-to-understand metaphors****. 'We don't talk about CFM and convection,' he says. 'We talk about filling up a house with basketballs. We talk about heat transfer in terms of hair dryers and frying pans.'"* 3/3/2006
http://www.homeenergy.org/show/article/nav//id/148

Contractor Excellence:

Solid Marketing Strategies for a Struggling Economy

"You need to ***educate [customers] as you go*** *or they won't understand the justification. It's like when you see a chugging, un-tuned old car rumble past and think, 'Wow, for the gas they're wasting every few miles, they could have their car tuned up.' In other words, the service would pay them a profit, but they've not been taught. That's your job." ("Solid Marketing Strategies for a Struggling Economy")* 7/1/2008
http://www.contractorexcellence.com/967

Resources

Home Energy Magazine Archive:
http://www.homeenergy.org/

ACCA Contractor Excellence Marketing Column:
http://www.contractorexcellence.com/author/ahudson

Air Sealing and Insulation That Works, ENERGY STAR,
http://www.energystar.gov/index.cfm?c=behind_the_walls.btw_airsealing

Appendix E – Community Engagement

HVAC Transition Guide for Building Performance Contractors

Operational Area: **Marketing and Customer Contact**

Work Activity: **Community Engagement**

Issue

Engaging the community in efforts to save energy carries not only public awareness of this important issue but can also increase demand for your home performance business. As a contractor, you can reach out to community members on your own or by partnering with public agencies and community groups. Either way, a good outreach strategy will put you at the top of customers' minds when they decide to make efficiency improvements to their living environment.

(Photo courtesy of National Renewable Energy Laboratory/PIX 10520, http://www.nrel.gov/data/pix/Jpegs/10520.jpg).

Best Practices

Effective community engagement strategies can vary widely. The focus of any strategy, however, should first be on getting people's attention, then delivering your message through effective channels, and finally following through to turn heightened awareness into action. The following tips will h`elp you implement your strategy:

- Focus on what really motivates people. Reducing greenhouse gas emissions is good, but often individuals have other motivations such as saving money or fixing home performance problems. Lead with whatever message causes people to pay attention.
- Advertise your services at community events, and arrange speaking engagements in front of groups of people. Events such as home shows, community fairs, and home-improvement workshops are useful for reaching people who may already want to do something in their home. Speaking at neighborhood venues will give people a chance to discuss the information you present with people they trust.
- Establish partnerships with public programs and community organizations that are running energy efficiency campaigns. Often these programs will have lists of qualified home performance contractors who are able to carry out energy efficiency work. Sometimes they will also provide subsidies for home performance assessments and contracting work, lowering the cost of your services to community members.
- Reach out to neighbors in the areas where you are working. Even before you contact them, they may have seen the work going on and may be curious to learn more. You can provide information using flyers and mailings or go door-to-door in the project area, but be aware that some neighbors may view an unsolicited knock as an intrusion.
- Rate and label the homes you upgrade with before and after scores so that the homeowner is left with a simple quantification of the energy improvements made to the home. This will help demonstrate the impact of your work and will allow the homeowner to boast to their neighbors.
- Be sure to follow up with additional communication after conducting initial outreach. Collect contact information from all your community interactions, and reach out by email, telephone, or regular mail to provide additional information. Getting community members to commit to something as complex and capital intensive as home performance improvement requires continued engagement over a period of time.

Tools

Some of the best tools for community engagement can be the simplest, such as the following:

- Before you start working on a customer's house, place door hangers on the doors of your customer's neighbors. The hangers can provide information about all the benefits your customer is receiving from your services, which may encourage the neighbors to make similar improvements to their own homes.

- After you have completed a job, give your customer several "Pass It On" cards to share with neighbors and friends. That way, when your satisfied customers are asked about their experience, they can do your advertising for you.
- Direct mail can also be a very effective tool, but make sure to create a targeted list. Direct mailing a whole community can be costly and tends to yield low response rates.

While these methods can be very effective, higher tech community engagement tools can sometimes be more versatile. For example:

- Through your website, you can provide basic information about your services and can engage people actively with frequent updates. Consider posting home performance tips and creating a forum so users can share their own tips and experience.
- Blogging and social networking are great ways to get community members involved as well. You can ask customers to describe their experience on your blog, and you and your customers can share performance tips through your Facebook or other social networking site.

Article Snippets

Action Research:

- *"Our review of the most successful projects indicated that word-of-mouth (friends, neighbors, and community leaders) serves an important means for learning about and encouraging program participation.... Importantly, industry leader interviews offered an important caveat pertaining to word-of-mouth approaches. Specifically, they warned that word-of-mouth does not begin until the first contractor is paid and the homeowner is happy with the work."*
- *"[Focus group] participants were positive about the potential community-level benefits of utilizing a whole house approach and were less motivated by individual "green" labels or ratings.... Participants described the normative effects of such improvements, stating the potential "domino effect." They commented that such changes would ultimately improve their whole neighborhood."*
- *"Participants consistently mentioned wanting to talk to real homeowners who had been through a home performance experience, as well as being able to see the results. Neighbors were considered to be a highly reliable source of information not only because they were trustworthy and not profiting, but because presumably their home is similar in size."*
  http://www.builditgreen.org/_files/DevCom/Greenpost/CBSM_Report.pdf

Lawrence Berkeley National Laboratory:

Driving Demand for Home Energy Improvements

- *Houston's Residential Energy Efficiency Program (REEP) weatherization program has found that using contractors to market the program while they are working in a neighborhood is a very effective outreach technique. When the contractors weatherize a home, they visit neighboring homes and talk to residents or leave door hangers. These residents can then reach out to talk to their neighbor who just got her home weatherized to confirm that they had a positive experience.*
  http://drivingdemand.lbl.gov/

Clean Energy Solutions:

- *Make use of traditional community organizing tools... and social marketing through neighborhood networks. In the residential and small commercial sector, door-to-door canvassing is an incredibly effective recruitment and educational tool.*
  http://cleanenergysol.com/news/BPs%20Marketing%20Strategies%209-3-10.pdf

Resources

Action Research, "Community Based Social Marketing to Inform Homeowner Participation in California Energy-Efficiency Home Improvement Programs," prepared for Build It Green, July 2010.
http://www.builditgreen.org/_files/DevCom/Greenpost/CBSM_Report.pdf

Lawrence Berkeley National Laboratory, "Driving Demand for Home Energy Improvements," September 2010.
http://drivingdemand.lbl.gov/

Clean Energy Solutions, "Best Practices in Community Energy Efficiency Programs," September 2010.
http://cleanenergysol.com/news/news_EAFrame.html

Department of Energy's "Home Energy Score" rating.
http://www1.eere.energy.gov/buildings/homeenergyscore/methodology.html

EnergySavvy is a simple, free, online home rating tool.
http://www.energysavvy.com/estimate/

Appendix F – On-Site Customer Interview

HVAC Transition Guide for Building Performance Contractors

Operational Area: **Assessment**

Work Activity: **Onsite Customer Interview**

Issue

Conducting an onsite customer interview is the first step in diagnosing a home's performance issues. Even without technical expertise, customers often know when something is wrong in their home simply by virtue of spending so much time in it. Listening to the customer attentively can provide invaluable clues that point toward particular problems, which in turn will shorten the time it takes to find solutions.

(National Renewable Energy Laboratory, http://www.nrel.gov/data/pix/Jpegs/09664.jpg)

Best Practices

The onsite interview is the customer's first real chance to get to know you, so it is important to maintain a professional demeanor and to focus on establishing the customer's trust. In addition, you should listen to the customer with open ears so that you will not miss anything later during the whole house assessment that the customer might point out as an issue. Some tips to keep in mind when conducting an onsite interview include the following:

- Make sure the homeowner is aware of your certifications (BPI, NATE, RESNET, etc.) and understands enough about what they mean to feel comfortable with your level of competency.
- Come prepared. Show up with handouts, fact sheets, and other educational materials relevant to the customer's house. If you have received their utility data already, pre-load it into your energy analysis software to enable you to show them results, costs, and savings before you leave.
- Present yourself as a professional. Show up on time, communicate regularly, manage expectations, take off your shoes, clean up afterward, fulfill your promises, and, generally, leave a positive impression that your work will follow suit.
- Make eye contact, and pay attention when the customer is talking. Avoid jumping in to disagree or debate with the customer, even if you can think of an alternate explanation for a problem. Give the customer a chance to explain any issues fully from their perspective.
- Gather as much information as possible in the interview, and listen for clues that might reveal potential problems.
- Ask follow-up questions to make sure you understand what the customer has told you, and delve more deeply into any potential issues that you flag.
- Refrain from forming conclusions too early about the customer's home performance issues, and avoid guesswork. Keep an open mind until you have finished the interview and have had a chance to conduct a full assessment.

Key Questions

Asking the customer some basic questions will provide a starting point for a whole house assessment. Identifying problem areas, usage patterns, and the customer's own objectives will streamline the assessment process before it begins and will give you a sense of what to focus on. The following set of essential questions should be asked of most homeowners during onsite interviews:

- Problem Areas:
    - Do any rooms in the house feel too hot or too cold?
    - Are any rooms or areas of the house especially drafty?
    - Are there any signs of excess moisture, mold, or mildew inside the house?

- Are any mechanical systems (HVAC, water heating, etc.) or appliances not working properly? If so, what seems to be the problem, and how long has it gone on?
- Does anything else regarding the house's performance look or feel "wrong"?

- Usage Patterns
  - How many people live in the house?
  - How much time do people spend in the home?
  - How many showers are taken daily and for how long?
  - Which rooms in the home are used frequently/infrequently?
  - What are the typical thermostat settings?
  - When were the mechanical systems and major appliances in the home installed or replaced? How frequently are they maintained, and when did they last receive maintenance? Are there any maintenance records?
  - Are there any unusual energy-using products in the house (waterbed, aquarium, kiln, manufacturing facilities, welding equipment, engine block heaters, etc.)?
  - Are there any future plans for the home (additions, renovation/remodeling, more/less time spent in the home, planning to sell, etc.)?

- Client's Objectives
  - Increased comfort?
  - Lower utility bills?
  - Increased safety?
  - Improved environmental footprint?
  - Other?

In addition, if you have not yet received them, you should ask the customer for at least a year's worth of previous utility bills in order to establish how much fuel of various types the customer is using and at what cost.

Article Snippets

Contracting Business:

Be a Detective, and 'Investigate' During Service Calls
Tina Coop, service and installation manager, CroppMetcalfe, Rockville, Maryland:

- *"A good investigation starts with listening and asking questions. Unfortunately, this is an area in which I believe many technicians are lacking. You must arrive at each home and **view it as a blank slate**. Listen to the homeowner. Gather every piece of information that you can. Don't form opinions or decide on a course of action until you have all the facts."*

- *"The trouble is, many technicians aren't paying attention when customers are talking. They think they are the experts and are afraid that asking questions may make them look unknowledgeable in their customers' eyes. Nothing could be further from the truth. **Homeowners know their homes**. They live there every day, and they know when something's wrong or different. We're only there for a few hours."*
- *"Another technician and I went to a customer's home, and as we talked about the comfort problems she was experiencing, she mentioned that she never needed to change her air filter: it never got dirty. If we hadn't talked with her, we might have seen a clean filter and assumed she had just changed it. But the filter that never got dirty provided **the clue we needed** to diagnose a return air duct problem. We fixed the line, cleaned out all the dirt in it that never made it to that nice clean filter, and created a happy customer."*
  3/1/2011

http://contractingbusiness.com/service/be-detective-investigate-0311/

Running Service Step 2: Your First 60 Seconds

Charlie Greer, creator of Tec Daddy's Service Technician Survival School on DVD:

*"While customers are explaining their problems, try not to be walking or doing anything. It's best if you're facing each other, giving the customer your undivided attention, and making eye contact. After you've listened to their response, repeat back to them what they just said. This is called being an '**active listener**.'"* 11/1/2009
http://contractingbusiness.com/columnists/greer/running-service-step-2-1109/

Two Ears, One Mouth: Listen Your Way to Increased Sales

Charlie Greer, creator of Tec Daddy's Service Technician Survival School on DVD:

- *"You can't think and listen at the same time, so thinking about your opinions on what's being said instead of concentrating on what is actually being said will interfere with listening. **You can't speak and listen at the same time**, so interrupting and talking over others is a problem. Deciding what people are going to say and starting to compose your response before they finish speaking is undoubtedly what's happening when people*

complain that we didn't exactly answer the question they asked."

- ***You were given two ears and one mouth. Use them in that proportion***. 4/1/2011

http://contractingbusiness.com/columnists/greer/two-ears-one-mouth-0411/

Resources

Contracting Business:
http://contractingbusiness.com

Home Energy Magazine:
http://www.homeenergy.org/list/archive

ACCA Contractor Excellence:
http://www.contractorexcellence.com/

Appendix G – Whole House Performance Assessment

HVAC Transition Guide for Building Performance Contractors

Operational Area: **Assessment**

Work Activity: **Whole House Performance Assessment**

Issue

The purpose of a whole house performance assessment is to identify for the homeowner the amount of energy currently being consumed, pinpoint the largest sources of energy use and unnecessary energy loss, and identify a prioritized list of potential energy saving measures, while also considering health and safety. Once identified, these measures should be presented to the homeowner as part of a report that analyzes their cost effectiveness. In addition, the report should focus on the recommended measures' impact in terms of health, safety and comfort, as well as their potential to raise the value of the home.

(ENERGY STAR, http://www.energystar.gov/index.cfm?c=behind_the_walls.btw_airsealing)

Air Leakage

Air leakage can account for up to 40 percent of the cost of conditioning a home. Finding and sealing air leaks is a top priority in any whole house performance assessment. The most common techniques used for identifying air leaks are as follows:

- Blower door testing. Using a fan and a frame installed in an exterior doorway, the blower door creates a pressure differential with the outdoors so that air leaks can be identified. Feeling with your hands or using a smoke pencil during a blower door test will help you locate the source of any air leaks. A digital manometer hooked up to the blower door can also give you a pressure reading to help you quantify the extent of the home's leakiness.
- Duct leakage testing. Similar in concept to a blower door, a "duct blaster" pressurizes just the duct system of a home to make it easier to identify conditioned air leaks. A "total leakage test" will tell you how much air is leaking out of the system overall. Since only the air leaked into unconditioned space or outdoors causes energy loss, a second "outside test" is run with the duct and conditioned space equally pressurized using a blower door and duct blaster simultaneously. The resulting leakage indicates how much conditioned air is leaving the conditioned space.
- Infrared camera analysis. Often used in conjunction with a blower door, an infrared camera can make it easier to spot the sources of air leaks. Particularly on cold days, outside air that is drawn in will cool surfaces near the leaks, changing the amount of radiation emitted in that spot and showing up on the camera.

In addition to running these tests, it is important to understand how the structural design of the home may increase the chances of air leakage. Ceiling construction, wall and floor cavities and chase-ways, and other structural elements can create built-in air leaks that need to be sealed. Be prepared to recommend sealing strategies such as installing rigid air barriers, dense-pack insulation, foam sealants and weather stripping to prevent further leaks.

Insulation

Insulation protects the thermal boundary of the home by slowing the rate of heat transfer between the conditioned space and the exterior. While many types of insulation exist, generally they all work by reducing air convection within the insulated space and slowing heat conduction across the boundary. Gaps in the insulation, however, can lead to "thermal bridging," or rapid heat transfer across uninsulated building materials. Finding and filling those gaps is thus an important part of the home performance assessment process.

One of the best ways to find insulation gaps is with the use of an infrared camera, which can detect varying amounts

of radiation at the surface of the building envelope. Radiation levels tend to vary with temperature, so anomalies that show up as different colors or shades may indicate insulation gaps. Many factors can affect infrared readings, however, so it is important to learn to conduct these tests and interpret the results properly.

HVAC

HVAC contractors are typically well aware of the procedures necessary for checking and tuning up heating and cooling. These checks are an important part of a whole house performance assessment because so much of a home's efficiency level depends on the performance of these systems.

Homes with combustion heating systems should undergo a thorough combustion analysis, not only to assess whether the system presents any safety concerns, but also to determine the level of combustion efficiency. Often heat is lost in the combustion process as a result of excess combustion air, which can be assessed and adjusted through the use of a combustion analyzer. Testing for spillage and backdrafting should also be done simultaneously.

While the steady-state efficiency of the heating system can be noted, the more important measure of the heating system performance is the overall seasonal efficiency, or the Annual Fuel Utilization Efficiency (AFUE). Additionally, the distribution system (typically ductwork or hydronic piping) plays an important role in overall system efficiency. Total system efficiency rating information is included as part of the Residential Energy Service Network (RESNET) "Mortgage Industry National Home Energy Rating Standards".

The efficiency of other heating types should be assessed and reported, as well. For example, in homes with air source heat pumps, the Heating Seasonal Performance Factor (HSPF) should be noted.

Cooling assessments often involve more than simply checking the existing air conditioning system. Many options may exist to reduce the need for air conditioning usage, such as increasing shading and ventilation and applying a reflective roof coating. In terms of the system itself, the Seasonal Energy Efficiency Ratio (SEER) should be noted for central air conditioners and the Energy Efficiency Ratio (EER) for room air conditioners, and these should be compared with the efficiency ratings of newer systems currently on the market.

Installing programmable thermostats can also reduce wasted energy quickly.

Water Heating

Water heating uses as much as 15 percent of all electricity and 25 percent of all natural gas in the residential sector. The efficiency of water heaters varies significantly by design and capacity. Water heaters are rated for efficiency with an "energy factor", (EF) which is a ratio between zero and one describing the amount of heat input that remains in the water when it leaves the storage tank.

Several efficiency measures can help to improve the efficiency of an existing water heater. These measures should be checked and may be recommended if they have not already been installed. They can include items such as low-flow shower heads, tank and pipe insulation, and automatic temperature controls that adjust to typical demand schedules. Since most water heaters rarely last more than 15 years, replacing an older model with a new more efficient one can both head off a potential future problem when it dies and save energy in the mean time.

Lighting and Appliances

Lighting and appliances make up a significant portion of a home's total energy consumption, particularly in homes located in milder climates. Lighting itself typically accounts for between five and ten percent of a home's energy costs. A home performance assessment should take note of current lighting usage, including the number of lights in a home, the wattage, and the length of time they are typically left on. Recommendations to improve efficiency may include replacing existing bulbs with more efficiency ones such as compact fluorescents lights (CFLs), as well as installing lighting controls like timers, photo sensors, and occupancy sensors that turn lights off when they are not needed.

Appliances may also require considerable energy consumption, depending on their age, size, type and design. Refrigerators and freezers tend to draw the most energy, followed by clothes dryers, clothes washers, and dishwashers. A whole-house performance assessment should note whether the home's appliances have energy efficiency labels such as ENERGY STAR® and should compare current consumption to theoretical consumption with efficient replacements. The report to the homeowner should also discuss behavioral factors that can impact energy consumption.

Health, Safety and Comfort

In addition to the systems discussed above, several additional elements of the home can affect the health, safety and comfort of its occupants. These items should

all be incorporated into a whole-house performance assessment. They may include:

- Indoor air quality: checking for air pollutants, carbon monoxide and radon levels, and biological organisms that can create health problems such as asthma.
- Moisture management: looking for air leaks and condensation and measuring relative humidity with a hygrometer or psychrometer. Moisture problems and excess humidity can damage systems and materials in the home, cause mold, and create occupant discomfort.
- Ventilation: determining whether the home is tight enough to warrant installing a mechanical ventilation system. This can be a simple as recommending the installation of an efficient bathroom fan on a 24-hour timer.

A fully comprehensive home-performance assessment will also assess the occupants' thermal comfort, noise levels, and other related issues that can potentially be corrected to enhance the living experience in the home.

Home Performance Modeling

Once you have completed your walk-through assessment, you can input the information you have gathered into an energy modeling software program. These programs will allow you to compare the home's current energy consumption and costs with the energy and cost required to operate a theoretical home with your recommended measures installed. You will also be able to rank the measures by cost effectiveness.

A good practice is to bring a laptop with you so that you can input the information onsite and give the homeowner a chance to interactively engage with the software. This will give them a better sense of the value of your recommendations. The best software programs are easily interpreted and present results in a customer-friendly format. You may even want to bring a printer with you so you can leave a copy of the report behind when you depart.

Professional Standards

Conducting your home performance assessment according to a set of professional standards will ensure that you engage in your work thoroughly and comprehensively, and it will give the homeowner confidence that they are receiving quality service. You should receive training and certification in whatever set of standards you choose prior to advertising your ability to conduct an assessment according to these guidelines.

The two building performance certifications most recognized by state and federal programs today are those issued by the Building Performance Institute (BPI) and RESNET. Historically, BPI focused primarily on existing buildings, while RESNET's HERS certification focused more on new construction. However, more recently that line has been blurred.

There are still some differences between the two programs, although they are more subtle. For example, BPI places strong emphasis on combustion analysis, while RESNET has recently focused on adopting standards for infrared analysis. In addition, HERS Raters are trained to use software that will provide a house with an overall efficiency rating. RESNET operates a quality assurance system for all HERS Raters.

Nonetheless, because the fundamental concepts in both types of training are mostly the same, it is worth examining the curriculum of whichever course you choose to make sure it includes the items you wish to learn. One reason to choose a particular certification may also be that it is required by a particular incentive program that you can tap into when marketing your services to potential customers.

Article Snippets

Home Energy Magazine:

So You Want to Be a Home Performance Contractor?

"Treating a home from a whole-house perspective means taking control of the home's flows of energy, heat, air, and moisture, and producing an indoor environment that will truly satisfy customers and turn them into the best advertising any contractor could have: happy customers who are excited to tell others what you did to their homes." 4/16/2006.

http://www.homeenergy.org/show/article/nav/archive/page/7/id/199

Adding Home Performance Contracting to an Existing HVAC Business

"We at AirRite Air Conditioning Company, Incorporated, were no different from other contractors! We attended manufacturers' training seminars, trying to stay up-to-date on load calculations, duct designs, infiltration testing, house sealing, and values and types of insulation. Even with this new knowledge, though, we found that customers still had problems with uneven temperatures, poor air quality, dusty homes, and combustion safety. We kept wondering why...

Home performance contracting has since opened our eyes and minds to new sources of revenue for our company.

We started to see that sealing recessed can lights, sealing ducts, and sealing thermal bypasses were all possible new revenue streams, as were installing dehumidifiers, heat recovery ventilators, humidifiers, attic ventilation, and attic insulation. Many other possibilities were available if we just opened our eyes." 4/16/2006

http://www.homeenergy.org/show/article/nav//id/206

Resources

Home Energy Magazine Archive:
http://www.homeenergy.org/

BPI Training:
http://www.bpi.org/schedules_training.aspx

RESNET HERS Rater Training:
http://www.resnet.us/programs/training

RESNET Mortgage Industry National Home Energy Rating Standards:
http://www.resnet.us/standards/mortgage

"Air Sealing and Insulation That Works, ENERGY STAR.
http://www.energystar.gov/index.cfm?c=behind_the_walls.btw_airsealing

Appendix H – Customer Presentation Process

HVAC Transition Guide for Building Performance Contractors

Operational Area: **Sales**

Work Activity: **Customer Presentation Process**

Issue

The customer presentation process is key to selling home performance improvements. The more the customer understands about how their house works, what is wrong with it, what you can do to fix it, and the potential benefits, the greater the likelihood that you will sell the job.

(National Renewable Energy Laboratory/PIX 04895, http://www.nrel.gov/data/pix/Jpegs/04895.jpg)

Best Practices

The presentation process is all about gaining the customer's trust so they will believe your results and buy into your recommendations for installation. Letting the customer get involved can be an effective way of getting them on board. Short of that, you should make your presentation as clear as possible and back it up with pictures and graphics that are easy to interpret. Some additional customer presentation tips include the following:

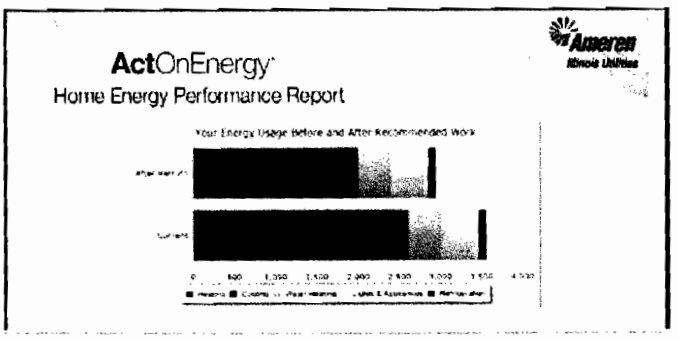
- Invite the homeowner to tag along and assist when you are conducting the home assessment and diagnostic tests. Letting the customer see what you are doing will give them more confidence in the assessment results you present to them.
- Take lots of pictures of deficiencies and retrofit opportunities in the house, and show the owner as part of your presentation process. This way the customer can actually see where there are problems and will not simply have to "take your word for it."
- Present pros and cons and good-better-best options every time while clearly explaining the differences. Make sure the customer understands their home performance issues and the possible solutions. Encourage them to ask questions.
- Consider using a laptop to show the customer your results in an interactive way using modeling software after you have performed your assessment. Let the customer participate in the process of evaluating the status quo versus potential installation option. A customer who has become involved in this way is more likely to be committed to the improvements because they know where the projected benefits come from.
- Explain the full range of benefits of your proposed improvements. Present cost savings in terms of "rate of return," comparing the results to what a customer's 401(k) or other investments might be getting. Highlight the health, safety, and environmental benefits that the measures will create as well.
- Bring a portable printer with you, and print out the results of your assessment, as well as the installation plan. This way there will be no questions later about the work to be done.

Modeling Software

Once you have conducted your whole house assessment, your results will become the inputs in your energy modeling software, which in turn serves as the basis for the customer presentation. There is a wide range of software programs on the market, so it is worth exploring different options. The key is to make sure the software you choose is not only accurate but also presents results in a way that can be easily interpreted. Follow these tips for optimal use of modeling software:

- Strive for the highest level of accuracy of predictions you can afford to ensure believability. Consider software that can adjust these predictions based on the customers' actual utility bills. Some new tools achieve impressive levels of accuracy with minimal inputs.
- Ensure that the presentation of the results is in a graphic-rich, customer-friendly format. Print out the results, and leave them with the customer if possible. Spend the time necessary to educate the customer on the report so that they can explain it to their spouse.
- Provide a rating or label for the home, both as is and after recommended improvements. This simplified quantification can serve as a powerful means of boiling down lots of details into a single understandable metric.

The cost of energy analysis software ranges widely from a few hundred dollars to thousands. If you are fortunate enough to operate in an area that offers a Home Performance Program through your local utility, many times the software is made available at little or no charge.



(Ameren Illinois Utilities, http://www.ameren.com/sites/aiu/Pages/Home.aspx)

Article Snippets

ACCA Contractor Excellence:

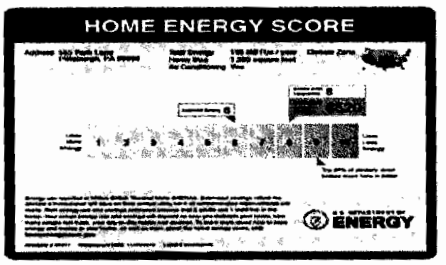
Contractor Takes Holistic Approach

*So the TAG team [TAG Mechanical, Syracuse, New York] attempts to educate their clients, effectively laying out the pros and cons of system alterations and installs. "**We want our clients to be informed**," [Ellis] Guiles, [vice president of TAG] said. "No matter what the decision of a client is, they will have everything laid in front of them, so they can make the best decision for them personally at that time."* 9/20/2010.
http://www.contractorexcellence.com/2817

Help Customers Choose High Efficiency

Greg Gill, president and CEO, Action Air Conditioning, Heating, and Solar, San Marcos, California:

- *"Sell customers whatever they want, but give everyone the same **best-better-good** presentation. Give everyone the same treatment the same way every time. Never assume someone can't afford a high-end system."*



(U.S. Department of Energy, http://www1.eere.energy.gov/buildings/homeenergyscore/index.html)

- *"Take the time to show them the benefits of high-efficiency equipment, including the **return on investment**."*
- *"Customers are often amazed by what they see in the **pictures** – crushed ductwork, holes in the plenum. They've never seen this before because most contractors don't bother going into the attic or crawl space to look at the whole system. When we take the time to look everywhere and show them what's wrong with their system, we find **they are much more willing to spend the money with our company**, even though we may be $3,000 or $4,000 higher than someone else."* 7/6/2010
http://www.contractorexcellence.com/1940

Tips for Selling Green

Larry Taylor, president, AirRite Air Conditioning Co., Fort Worth, Texas:

- *"We explain that **the whole house is a puzzle**, and if you leave a piece out, you end up with a hole in the middle of the picture. We actually use a picture of a puzzle with a piece missing when we talk with customers."*
- *"The main thing is to show the customer **the results of the audit in a consumer-friendly way** and then detail the process for completion of the project. After going through the reports with the customer and explaining the technical data, most will say, 'What is it going to take to fix my problems, and **can you do it for me**?'*

Wow, I hate those high-pressure sales calls!" 1/3/2011
http://www.contractorexcellence.com/3911

Contracting Business

What Every Consumer Really Wants to Know

Rob "Doc" Falke, president of National Comfort Institute:

*"'Nothing happens 'til somebody sells something.' That's a common phrase that rings through sheet metal shops across the country, but in recent years our industry has learned that sales don't happen until we have '**taught the customer something.**'"*
2/3/2010http://contractingbusiness.com/service/content/sales_techniques0203/

Resources

Energy Star Financial Evaluation Calculators:
http://www.energystar.gov/index.cfm?c=assess_value.financial_tools

U.S. Department of Energy's Building Energy Software Tools Directory:
http://apps1.eere.energy.gov/buildings/tools_directory/subjects_sub.cfm

Home Energy Magazine:
http://www.homeenergy.org/list/archive

ACCA Contractor Excellence:
http://www.contractorexcellence.com/

Ameren Illinois Utilities:
http://www.ameren.com/sites/aiu/Pages/Home.aspx

U.S. Department of Energy, Home Energy Score
http://www1.eere.energy.gov/buildings/homeenergyscore/index.html

Appendix I – Subcontractor and Vendor Relations

HVAC Transition Guide for Building Performance Contractors

Operational Area: **Business Planning/Process and Production**

Work Activity: **Vendor Relations and Subcontractor Relations**

Issue

Home performance contractors are dependent on a large network of partnerships that contribute in important ways to the completion of comprehensive home improvements. Vendors are essential in providing the necessary systems, appliances, and materials that will need to be installed, while subcontractors will often perform the actual installations. Establishing strong relationships on both sides of this supply chain will help you complete quality work in a timely and cost-effective manner, which in turn will contribute to your good reputation.

(U.S. Environmental Protection Agency, http://www.epa.gov/region9/mediacenter/richmond/rb-hires.html)

Vendors – Best Practices

There are a number of factors to look for when choosing vendors to supply the materials for your home performance jobs. Cost is one factor, but other considerations are important as well. Keep in mind the following issues when evaluating which vendors to work with:

- Price versus quality. While a low price will help you make competitive bids, in the long run your reputation can be more impacted by the vendor's service, reliability, and quality. Find vendors who balance all of these factors well.
- Technical support. For complex systems, you may need vendors with the technical expertise and quality of service to provide guidance both during and after installation.
- Find vendors--or work to get your preferred vendor--to stock the best products for your home performance jobs. Don't necessarily trust that what they have always carried will suffice. Research the best home performance products (e.g., spray foam kits, duct mastic, caulking, HVAC equipment), and make sure your vendors keep these in stock.
- Loyalty versus shopping around. Sticking with one or just a few vendors can increase your quality of service and sometimes bring volume discounts. On the other hand, spreading out your orders allows you to search for lower prices and more easily meet designer, program, or customer specifications. Choose the option that works best for your business.

Once you have chosen your vendors, follow these guidelines to help you build and maintain productive relationships that will keep your interactions flowing smoothly:

- With every transaction, fill out a clearly written purchase order that specifies exactly what you expect to have delivered and when.
- Before completing your supply order, make sure you have established delivery and invoicing procedures that both parties agree upon.
- Try to avoid last-minute/expedited orders and frequent order changes to increase the chances of getting the correct supplies on time and on budget.
- Consider signing written agreements with key vendors that clarify the basic processes of your interactions and make them routine.

Subcontractors – Best Practices

Given the wide range of measures that often need to be installed as part of comprehensive home performance improvements, you may find yourself lacking certain types of expertise. This raises the question of whether you should try to develop the required knowledge in-house or partner with subcontractors for some of the work. Factors to consider when making this decision include the following:

- Work flow. Hiring subcontractors may make sense for jobs that tend to be intermittent and unpredictable. Keeping employees on hand for this type of work may not be worth the cost.
- Quality control. Keeping your work in-house gives you direct oversight of all work that is done and can cut down on conflicts and complications. On the other hand, the benefits may not be worth it if a subcontractor with a good reputation can provide greater technical expertise.
- Timeliness. Subcontractors maintain their own schedules and may run into scheduling conflicts or be unavailable for a particular job. However, the flexibility of hiring subcontractors only when needed can still be cost effective.

Assuming you do choose to use subcontractors in at least some cases, the following tips will help you build and maintain productive relationships with them:

- Require contractors to demonstrate proper licensing and other credentials and provide references that establish their capacity to perform competent, quality work.
- Be sure that all subcontractors carry proper insurance and workers' compensation policies. Your own provider can advise you on whether a subcontractor's policies should name you as an additional insured for a given job.
- Set a timeline for job completion, and establish clear milestones that will keep everyone on schedule.
- Perform regular inspections of your subcontractors' work to correct any problems before they become too large.
- Set clear expectations about the level of quality you require, including conditions for termination based on underperformance and incentives for exceptional work.
- Be sure to follow federal guidelines that define a subcontractor versus an employee. Consult with your legal advisor to be sure you do not cross this line unintentionally.

Article Snippets

RB Lewis Associates:

A Way to Build Great and Lasting Vendor Relationships

- *"**Plumbing the depths for the low cost vendor when motivated solely by greed often ends up badly**. Is your strategy based on how much money you can save by attracting the cheapest seller? How would you like it if your customer admitted they hired you only because you were the cheapest and your value proposition or quality reputation had no bearing on the buyer's decision – that they were hiring you solely to maximize their margin?"*
- *"Look first internally when you are finally ready to implement your vendor relations strategy. Create the right conditions for strong supplier performance. Collaborate with your suppliers, and develop their scope of services consistent with each other's identified needs. **Articulate clearly defined responsibilities, yours and theirs**. Perform to high standards, and demand they do, too." 12/2010*

http://rblewisassociates.com/wp-content/uploads/2011/01/vendor-relations-strategy.pdf

Home Energy Magazine:

So You Want to Be a Home Performance Contractor

*"General contracting works if you can keep down your cost of subs and if jobs are intermittent and you don't want to try to carry employees over the slow periods. But **one of the basic tenets of home performance contracting is doing quality work**. Getting quality insulation and HVAC subcontractors to work for you for below-market rates may not be easy. This can work if you have the marketing skills that the subcontractors lack and can keep them busy and happy."* 4/16/2006

http://www.homeenergy.org/show/article/nav/archive/page/7/id/199

Lowe's Commercial Services:

Subcontractors vs. Full-Time Employees: What's Best for Your Company?

*"If you stock your contacts list with quality subs, you'll have the flexibility of inserting them on a project without the year-round financial burden of a full-time staffer. Many contractors use subs in order to save money, because they can pre-determine the cost of a project regardless of how many hours it will take. Keep in mind that someone who is **juggling multiple jobs** may not always be available when you need him. Therefore, if you plan to use the same subs on a regular basis, try to put the same consideration into who you hire as you would with an employee."* 3/2011

http://www.lowesforpros.com/subcontractors-vs-full-time-employees-whats-best-for-your-company

Deep-Energy Retrofits for Existing Homes

*"[Don Ferrier, president of Ferrier Custom Homes and Ferrier Builders, Inc. in Fort Worth, Texas] recommends setting up **full screenings** of your subcontractors where the conversation is thorough and outlines exactly what a retrofit will entail and what is expected of the subcontractor, including questions of how they plan to implement and perform their work. Then, you can determine whether or not the subcontractor is right for the job."* 5/2010
http://www.lowesforpros.com/deep-energy-retrofits-for-existing-homes

Resources

RB Lewis Associates:
http://rblewisassociates.com

Home Energy Magazine:
http://www.homeenergy.org/list/archive

Lowe's Commercial Services:
http://www.lowesforpros.com

"Federal Stimulus Dollars Help Train Disadvantaged Richmond Residents for Jobs in Renewable, Clean Energy," U.S. Environmental Protection Agency.
http://www.epa.gov/region9/mediacenter/richmond/rb-hires.html

Appendix J – Full Value Ratings of Work Activities

Appendix J – Full Value Ratings of Work Activities

Operational Area	Work Activity	Value of Guidance to Contractor	Difficulty	Sum
Business Planning/ Process	Training	4	2	6
Business Planning/ Process	Manufacturer Relations	1	1	2
Business Planning/ Process	Equipment	4	3	7
Business Planning/ Process	Equipment Maintenance/Calibration	2	2	4
Business Planning/ Process	Vendor Relations	4	4	8
Business Planning/ Process	Strategic Planning	4	4	8
Marketing/ Customer Contact	Customer Education	4	4	8
Marketing/ Customer Contact	Community Engagement	4	4	8
Marketing/ Customer Contact	Social Media	1	1	2
Marketing/ Customer Contact	Direct Referral Programs	2	1	3
Marketing/ Customer Contact	Newsletter	1	1	2
Marketing/ Customer Contact	Service Tech Referrals	2	1	3
Marketing/ Customer Contact	Call Scripting	2	1	3
Marketing/ Customer Contact	Inbound Call Process	2	1	3
Marketing/ Customer Contact	Recurring Call Schedule	0	0	0
Assessment	Pre-Assessment Preparation	3	1	4
Assessment	Arrival Process	4	3	7
Assessment	On-Site Customer Interview	4	4	8
Assessment	Whole House Performance Assessment	4	4	8
Sales	Customer Presentation Process	4	3	7
Sales	Assessment Report	4	3	7
Sales	Phased Implementation Sales Process	3	3	6

Operational Area	Work Activity	Value of Guidance to Contractor	Difficulty	Sum
Sales	Rebates and Incentives	1	1	2
Contract Administration	Financing Mechanisms	1	3	4
Contract Administration	Loan Processing	1	1	2
Contract Administration	State or Local Program Reporting	4	4	8
Production	Work Scope Procedures	4	4	8
Production	Customer Interaction Procedure	3	2	5
Production	Job Completion/Test-Out	3	3	6
Production	Job Completion Verification	4	1	5
Production	Post-Installation Verification Sample	1	1	2
Production	Sponsoring Program Quality Assurance	1	1	2
Production	Subcontractors	4	3	7
Customer Service	Diagnostics	2	3	5
Customer Service	Repair/Replacement	2	3	5

buildingamerica.gov

U.S. DEPARTMENT OF ENERGY
Energy Efficiency & Renewable Energy

DOE/GO-102012-3555 • May 2012

Printed with a renewable-source ink on paper containing at least 50% wastepaper, including 10% post-consumer waste.

Ducts: How the System Works

Tom Brodbeck, Universal Energy

Jack Martin, Bucks County Community College

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

HVAC and Duct Systems

- HVAC systems should provide thermal comfort, acceptable indoor air quality, ventilation, and maintain consistent pressures relationships between conditioned spaces
- Ducts supply the conditioned air through out the conditioned spaces building.
- Ducts should be designed to meet the Standards listed in the ACCA Manual D Residential Duct Systems

Bad Duct Design and Installation

U.S. DEPARTMENT OF ENERGY Energy Efficiency & Renewable Energy

Duct Systems Should Be Designed to meet the Following Requirements:

- Deliver and *RETURN* the right amount of air from each room to provide comfort year-round
  - Implies room by room heat loss and heat gain calculations
  - System should be dampered, either automatically or manually
  - Ducts are Sealed, Tested for Tightness and Insulated to the R-value Recommended in Your Area

U.S. DEPARTMENT OF ENERGY Energy Efficiency & Renewable Energy

Benefits of Properly Designed & Installed Duct System

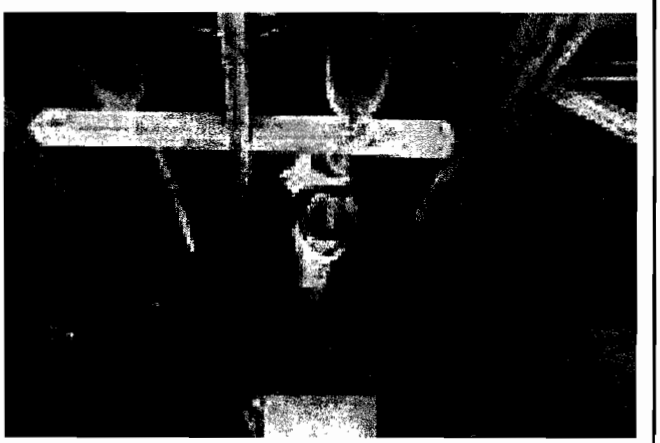
- Adequate air flow
- Less conditioned air leakage
- Higher energy efficiency
- Smaller, less expensive equipment
- Longer equipment service life
- Healthier, safer indoor air quality
- Greater comfort for occupants
- Reduced house air leakage
- Fewer call backs
- No Potential for Backdrafting Appliances

U.S. DEPARTMENT OF ENERGY Energy Efficiency & Renewable Energy

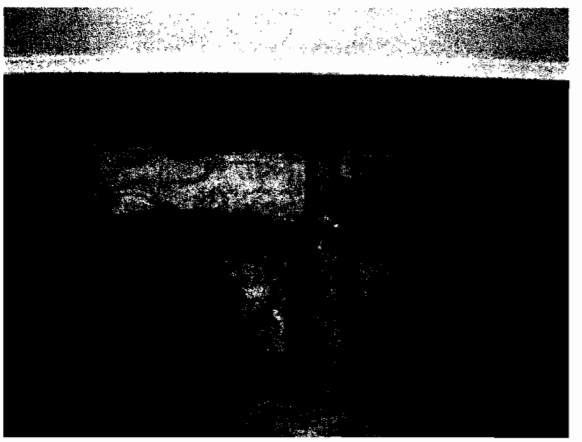
It Can Be a Bit Confusing? Yes

Do Not Use Unlined (Sheet Metal) Building Cavities

- Some builders have used joist bays or other building cavities as supplies or returns. Since these areas are very difficult to seal properly, the use of panned joist bays in supply and return air systems is no longer allowed by building codes.

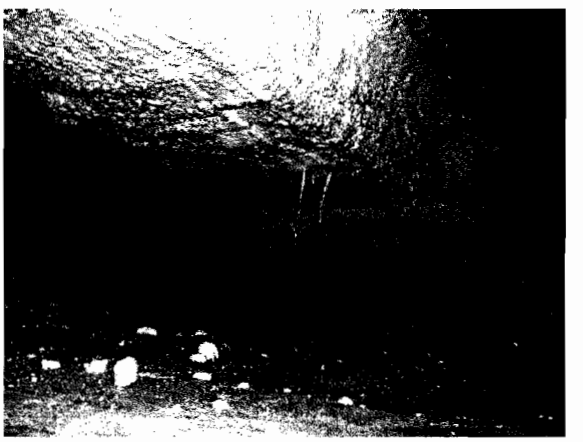


Pan Over Joist Cold Air Return



Pan Joist Return Sealed w/2 Part Foam

Sealing Pan Over Joist Returns with 2 Part Foam



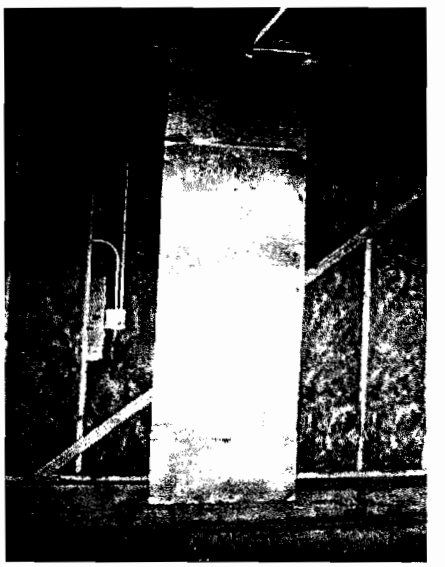
Design Recommendations

- System and duct work designed and installed according to ACCA and ASHRAE handbooks. Four steps should be followed to ensure energy efficiency and comfort.
- 1. Determine room-by-room loads and air-flows by using ACCA Manual J and Manual D calculation procedures.
- 2. Layout Duct System on Floor Plan, account for Potential Obstructions and determine register locations and types locations and types, duct lengths and connections required

Design Recommendations

- 3.Size the Ducts using ACCA Manual D calculations (or equivalent).
- 4. Size HVAC equipment to sensible load and to house characteristics using ACCA Manual S (or equivalent).
- Design Considerations use air tight fittings if available and Provide return air paths in all bedrooms.
- Ensure the System is Balanced: the air in the Supply Ducts is flowing back through the Cold Air Return

Air Tight Take Offs and Wall Cavity as a Supply Duct



U.S. DEPARTMENT OF ENERGY Energy Efficiency & Renewable Energy

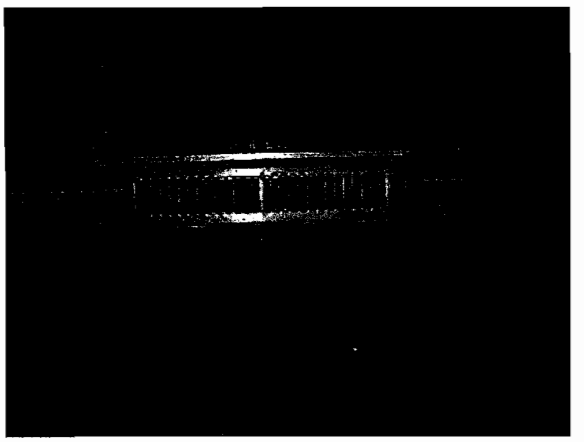
Heating and Cooling Load and Sizing Ducts

- Guides published by the Air Conditioning Contractors of America (ACCA) should be the foundation for sizing ducts. No contractor should specify a system without using the ACCA's Manual J, which calculates heating and cooling loads, and Manual D, which tells the contractor how to size the ducts.

Design Considerations Don't's

- Avoid toe kick supplies, use pans if installed
- Never use stud cavities as a duct
- Do not use tape to seal ducts
- Do not kink ducts
- Do not allow ducts to touch the ground
- Do not use air filter 'slots'
- No turns greater than 90 degrees in ducts

Toe Kicks Bad Design and Hard to Seal



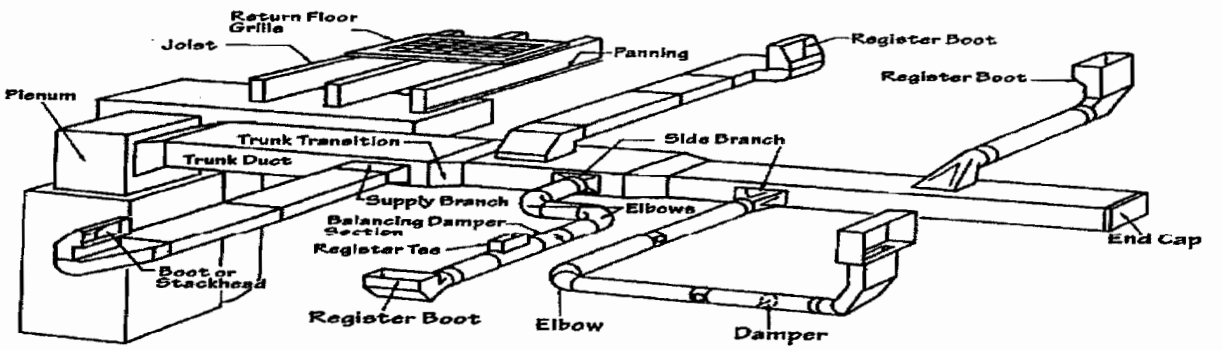
Duct on the Ground and Restricted Flex Duct

Restricted Flex Duct and Disconnected Flex Duct

U.S. DEPARTMENT OF ENERGY Energy Efficiency & Renewable Energy

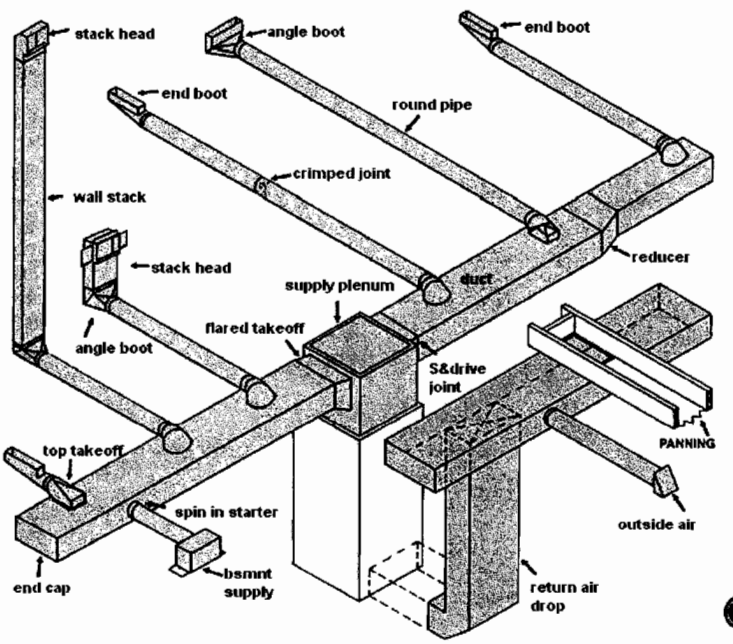
The Parts of a Duct System

Duct Fittings and Air Handler



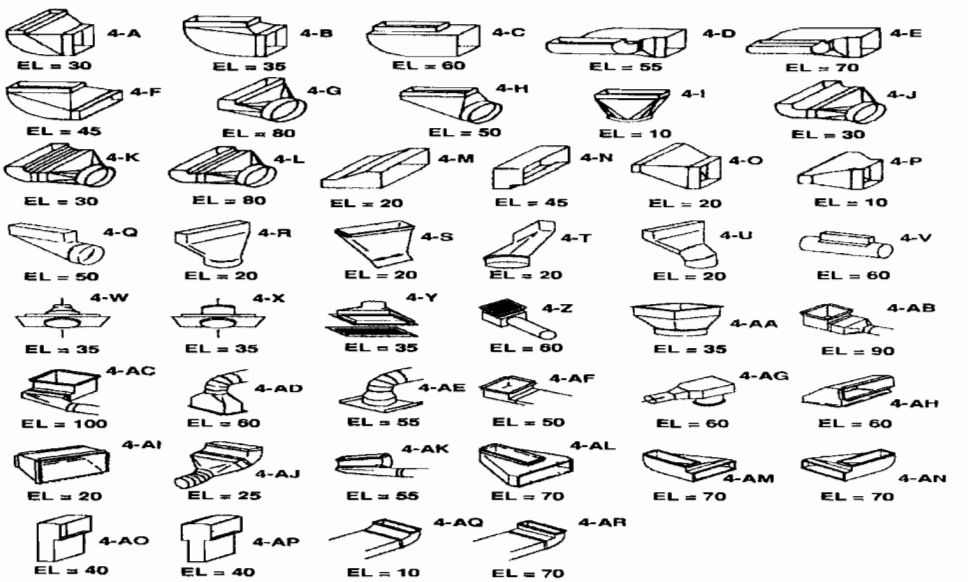
U.S. DEPARTMENT OF ENERGY Energy Efficiency & Renewable Energy

The Parts of a Duct System



U.S. DEPARTMENT OF ENERGY Energy Efficiency & Renewable Energy

Group 4
Supply Air Boot and Stack Head Fittings
Reference Velocity = 900 FPM
Reference Friction Rate = 0.08 in.Wg. per 100 Feet



Sizing Return for AC and Heat Pump

- A general rule is one net square foot of return grille per ton

A 20 x 20 inch grill = 400 sq in

400 x .75=300 sq in NFA

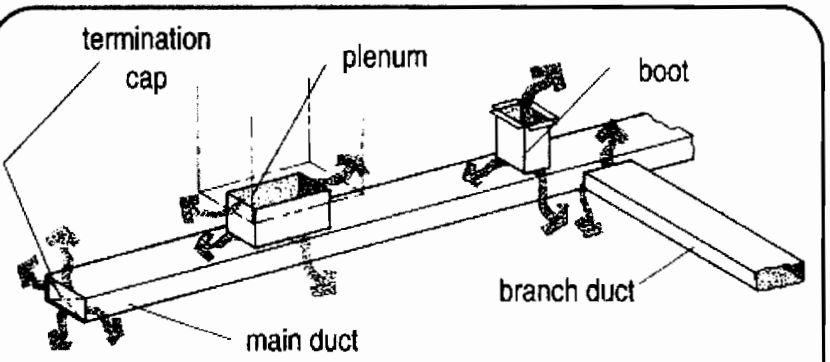
300 sq in / 144 sq in = 2.08 sq ft

Just enough for a two ton system

Returns can not be Oversized

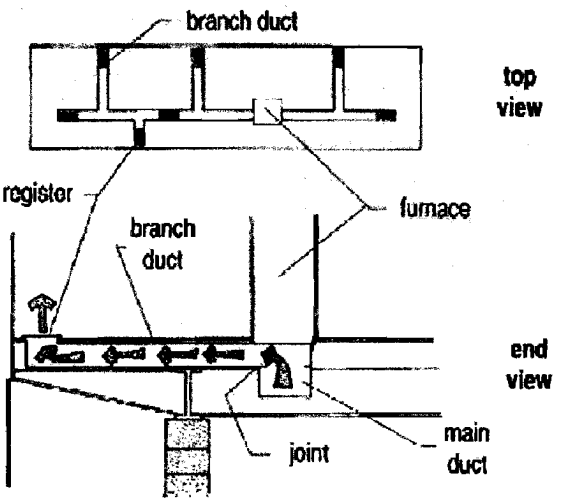
U.S. DEPARTMENT OF ENERGY Energy Efficiency & Renewable Energy

Mobile Home Duct Systems



Duct Leaks *- Joints in the mobile home duct system are a major source of air leakage.*

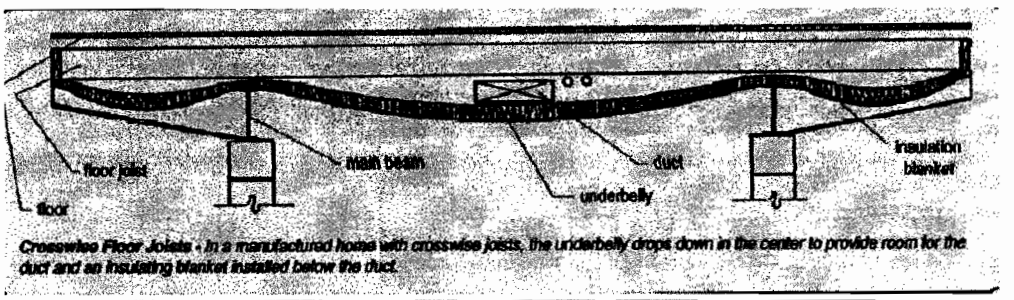
Branch Ducts in Mobile Homes Needs Sealing



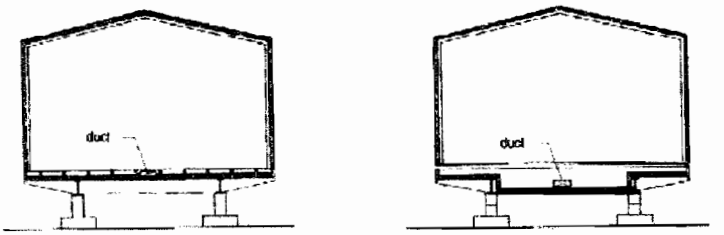
Branch Ducts *- Some homes have branch ducts. Joints between these branch ducts and the main duct should be inspected for air*

U.S. DEPARTMENT OF ENERGY Energy Efficiency & Renewable Energy

Location of Mobile Home Ducts



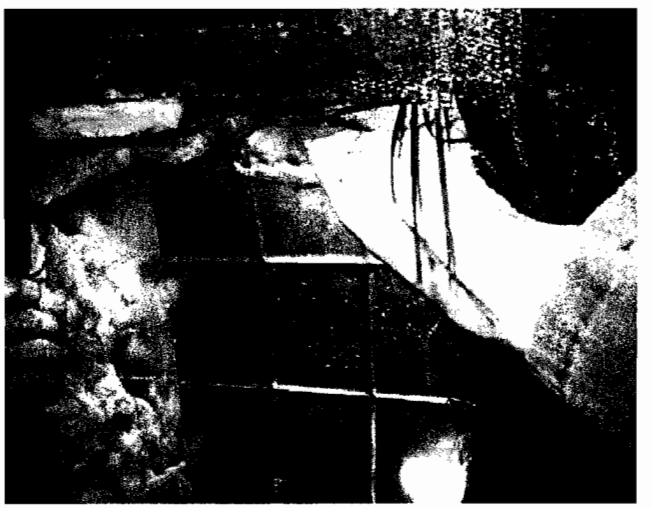
Crosswise Floor Joists - In a manufactured home with crosswise joists, the underbelly drops down in the center to provide room for the duct and an insulating blanket installed below the duct.



Duct Location - In homes with lengthwise joists, the main duct is installed between the floor joists, touching the flooring material. In homes with crosswise joists, the main duct is installed below the floor joists.

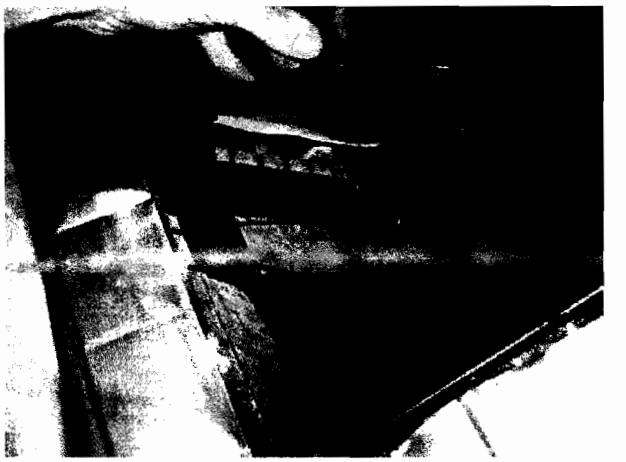
U.S. DEPARTMENT OF ENERGY Energy Efficiency & Renewable Energy

Cut Belly Board & Cut Duct Under Plenum

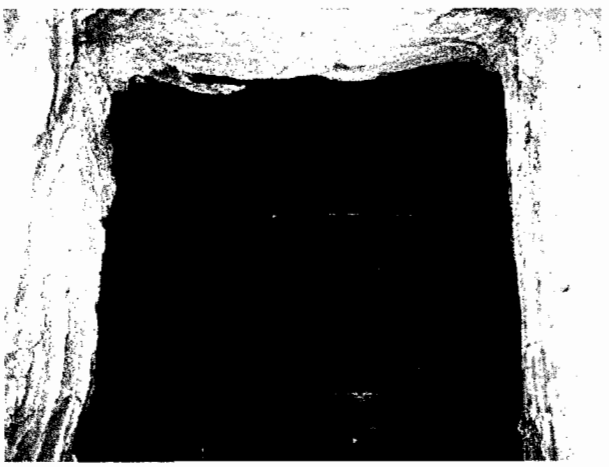


U.S. DEPARTMENT OF ENERGY Energy Efficiency & Renewable Energy

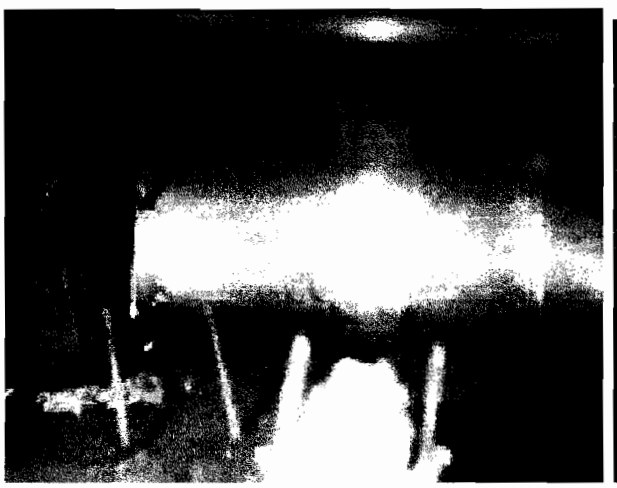
Sealing and Inspecting the Plenum

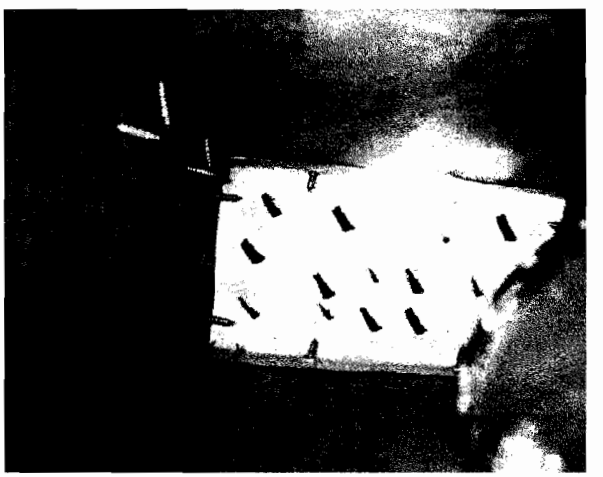


Plenum Connection Sealed New Sheet Metal & Fiberglass Tape & Mastic



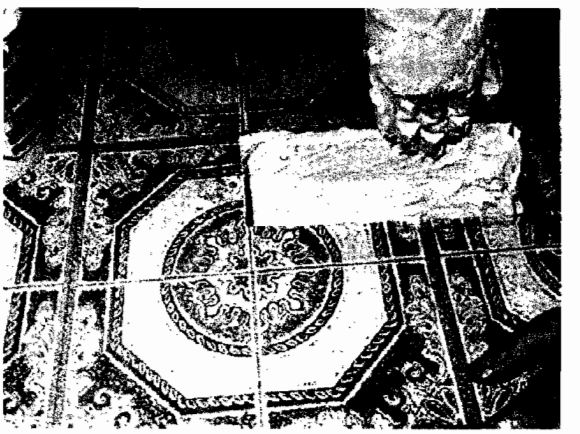
Mobile Home Ducts Bad Design





U.S. DEPARTMENT OF ENERGY Energy Efficiency & Renewable Energy

End Sweeps w/ Sheet Metal, Screws, Mastic



Duct Leakage Testing

The main purpose of an air tightness test of a duct system to is to measure and document the amount of leakage in the system at a specified reference duct pressure.

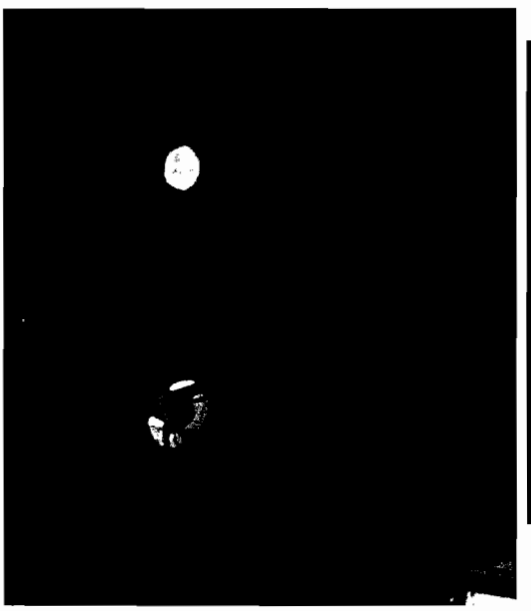
Duct leakage testing is preformed to determine the amount of leakage in a duct. Different methods of duct leakage testing can produce very different results. Any type of duct leakage testing is better than no testing

Methods of Measuring Duct Leakage

- Blower Door Subtraction Method

The test is is simple to understand, relying on two blower door tests, one with the house as found and the other with the supply and return air registers taped off. If ducts or air handler is located in the garage then open the garage door to the outside. The blower door test with all the registers taped off is subtracted from the blower door test with the house as found. The difference is the duct leakage. Depressurize the house to –50 pascals (or test pressure) with the blower door. The test requires the blower door can't reach 50 (or test pressure) multiplier are averaged for the zones in which the ducts are located.

Blower Door Subtraction Method

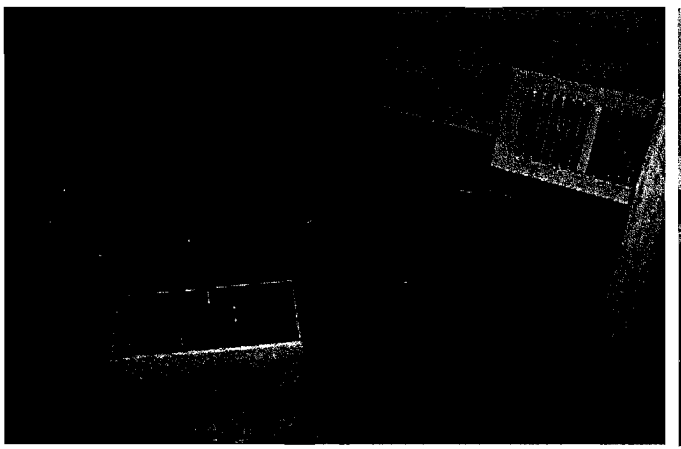


Pressure Pan Method

Blower Door and Pressure Pan

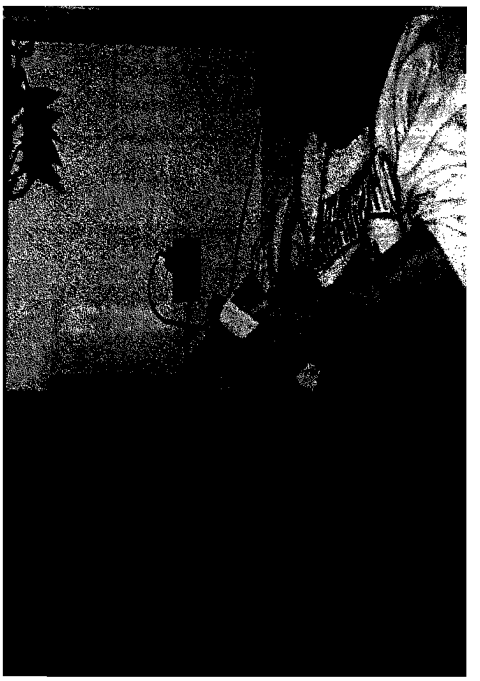
Locate supply and return registers and ensure they are open. Remove all the filters in the air handler system. If ducts or air handler is located in the garage then open the garage door to the outside. Depressurize the house to 50 pascals (or test pressure) with the blower door. Connect a small hose to the pressure pan and the digtial manometer or magnehelic gauge. Record the pressure pan numbers. Multiply the pressure pan reading by the appropriate can't reach 50 number.

Zone Pressure Testing



Can't Reach 50 Multiplier

Zone Pressure	Can't Reach 50 Multiplier
1	50
1.1	45
1.25	40
1.42	35
1.66	30
2	25
2.5	20
3.5	15
5	10
10	5



Duct Blaster

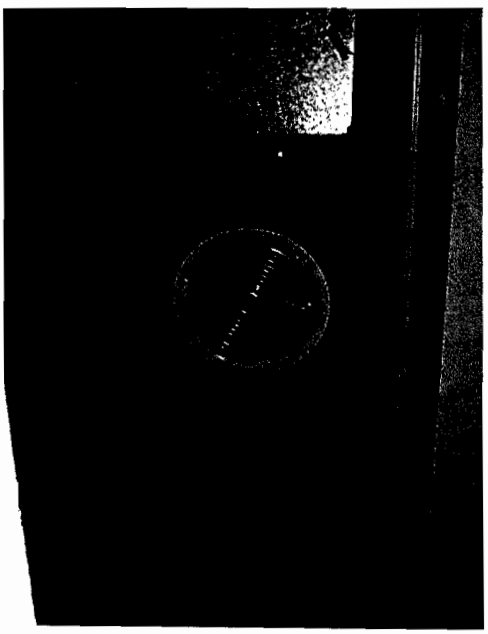
- Is a calibrated air flow measurement system used to test and document the Air tightness of forced air distribution system. The duct blaster can measure total leakage of a duct system (inside and outside) and with the use of a blower door can measure outside leakage. Outside leakage is important to weatherization programs, unless inside leakage is causing safety or durability issues.

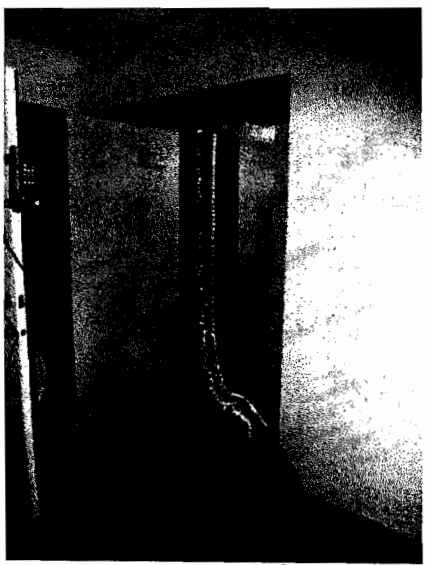
U.S. DEPARTMENT OF ENERGY Energy Efficiency & Renewable Energy

Can't Reach Pressure Factors (-25 Pa Target)

Duct Pressure	CRP	Duct Pressure	CRP
24	1.02	14	1.42
23	1.05	13	1.48
22	1.08	12	1.55
21	1.11	11	1.64
20	1.14	10	1.73
19	1.18	9	1.85
18	1.22	8	1.98
17	1.26	7	2.15
16	1.31	6	2.35
15	1.36	5	2.63

Duct Leakage Testing with the Duct Blaster, Installed at the Furnace and CAR



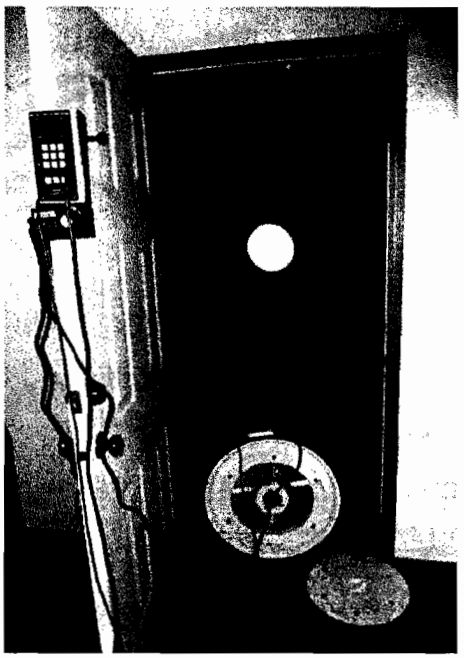


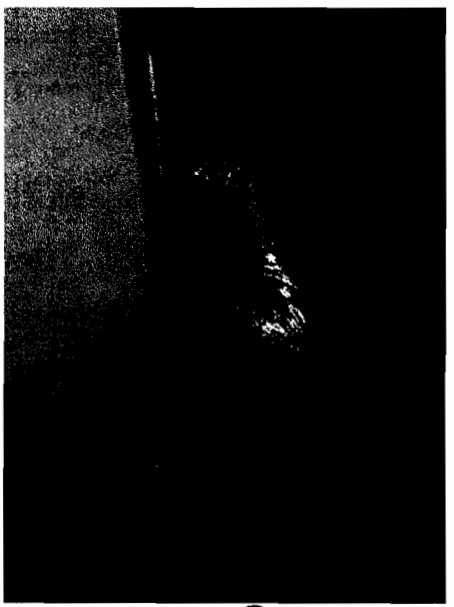
U.S. DEPARTMENT OF ENERGY Energy Efficiency & Renewable Energy

Total Duct Leakage Test

- The Total Leakage Pressurization Test is used to measure the duct leakage rate in the entire duct system (including leaks in the air handler cabinet), when the duct system is subjected to a uniform test pressure.
- The Total Leakage Pressurization Test measures both duct leakage to the outside of the building (e.g. leaks to attics, crawlspaces, garages and other zones that are open to the outside), and duct leakage to the inside of the building.
- This test procedure requires use of a Duct Blaster system only.
- There must be an opening to the outside: open window or Blower Door Ring open
- Test pressure typically at 25pa or 50pa

Leakage to the Outside, Uses Blower Door & Duct Blaster





U.S. DEPARTMENT OF ENERGY Energy Efficiency & Renewable Energy

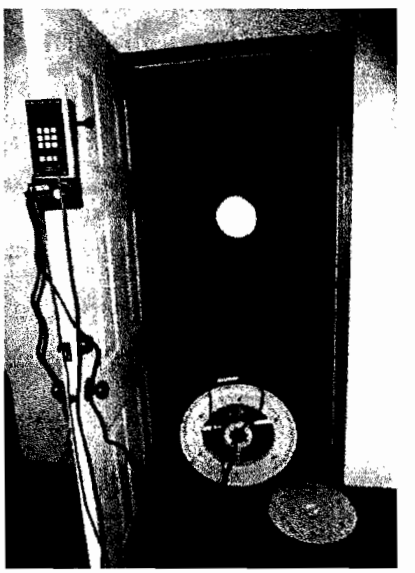
The Leakage to Outside Test w Blower Door & Duct Blaster

- The Leakage to Outside Test is used to measure the duct leakage rate to the outside of the building only, when the duct system is subjected to a uniform test pressure.
- This test procedure requires simultaneous use of both a Duct
- Blaster and Blower Door system.
- During this procedure, a Blower Door fan will be used to pressurize the building to the test pressure, while the Duct Blaster system is used to pressurize the duct system to the same pressure as the building.
- Because the duct system and the building are at the same pressure, there will be little or no leakage between the ducts and the
- building during the leakage rate measurement.

U.S. DEPARTMENT OF ENERGY Energy Efficiency & Renewable Energy

Setting up the Blower Door for an Outside Leakage Test

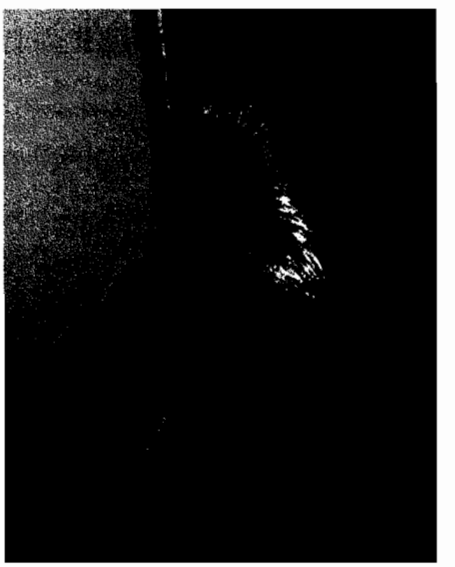
- The Blower Door fan should be set up to pressurize (or blow air into) the building. Importantly, we will not be measuring air flow through the Blower Door fan during this test procedure.
- Blower Door Pressurized at 25 pa



U.S. DEPARTMENT OF ENERGY Energy Efficiency & Renewable Energy

Digital Manometer is put into the PR/FL Mode

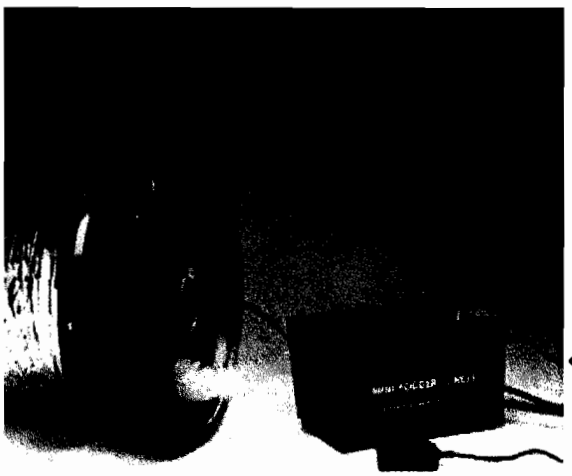
- This mode is a multi-purpose mode used to measure a test pressure on Channel A while simultaneously measuring air flow from the Duct Blaster fan on Channel B.
- Increase the fan speed until the pressure between the duct system and the building (displayed on Channel A) reads zero.
- Channel B on the DG-700 will now display the CFM25 leakage to outside estimate



U.S. DEPARTMENT OF ENERGY Energy Efficiency & Renewable Energy

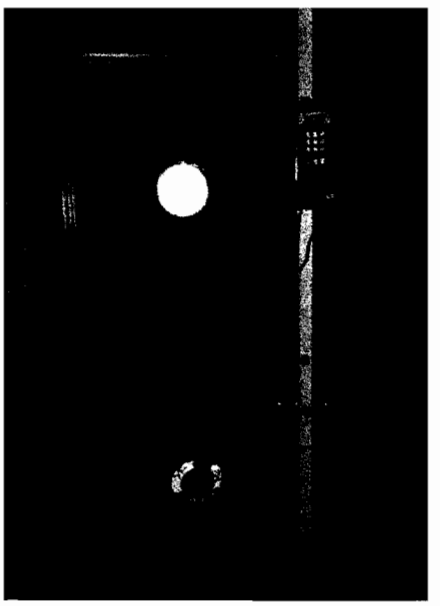
Finding Duct Leaks w Theatrical Fog Machine

- One way to find leaks in a duct system is to use a theatrical fog machine while **pressurizing the duct system**
- With the registers and grilles temporarily sealed off, the fog machine is used to inject a nontoxic theatrical fog through the Ducts Blaster and into the duct work.
- The theatrical fog is pushed out of the leakage sites.



U.S. DEPARTMENT OF ENERGY Energy Efficiency & Renewable Energy

Delta Q Duct Leakage Test

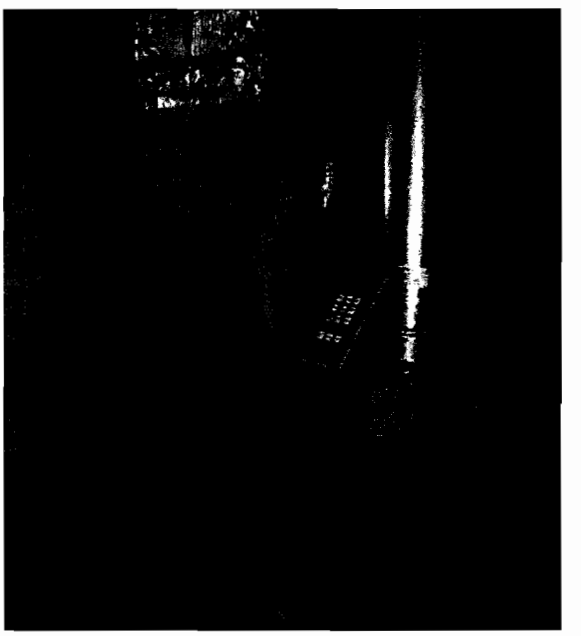


- Done with a blower door tests with air handler on and off
- Fairly quick and easy screening too
- Requires more equipoment and a laptop
- Complicated, but holds promise to predicting true operating duct leakage
- Very sensitive to wind
- Not ready for field use

Testing Static Pressure

- Typical Fan Curve

ESP	CFM
.3	900
.4	850
.5	800
.7	675



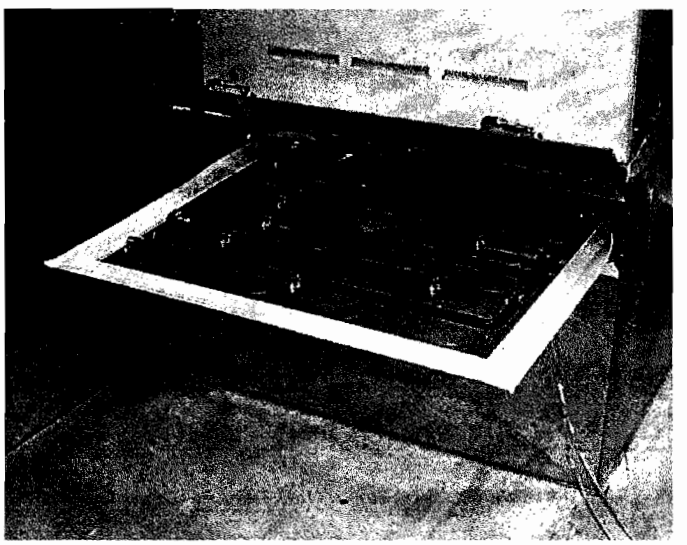
U.S. DEPARTMENT OF ENERGY Energy Efficiency & Renewable Energy

Correct Airflow Across the Evaporator Coil is Important

- 74% of residential systems installed today have improper airflow according to a recent EPA study pertaining to Energy Star.
- Airflow across the evaporator is one of the most overlooked yet the most important parts of verifying proper operation of air conditioning or heat pump systems.
- Air conditioners are designed for a nominal 400 CFM (450 for heat pumps) of airflow per ton depending upon air density.

U.S. DEPARTMENT OF ENERGY Energy Efficiency & Renewable Energy

TrueFlow Air Handler Flow Meter



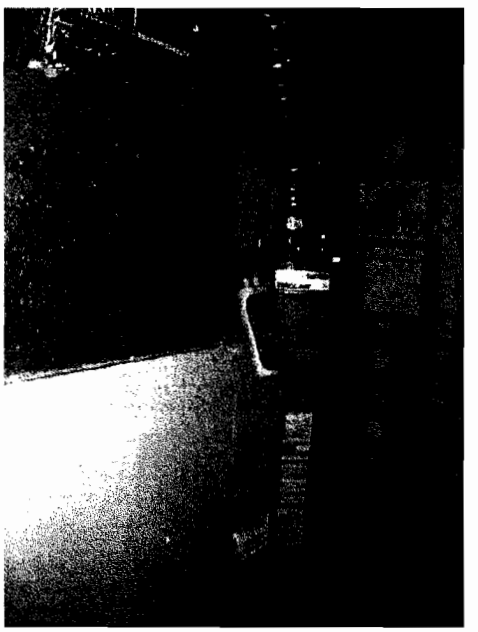
U.S. DEPARTMENT OF ENERGY Energy Efficiency & Renewable Energy

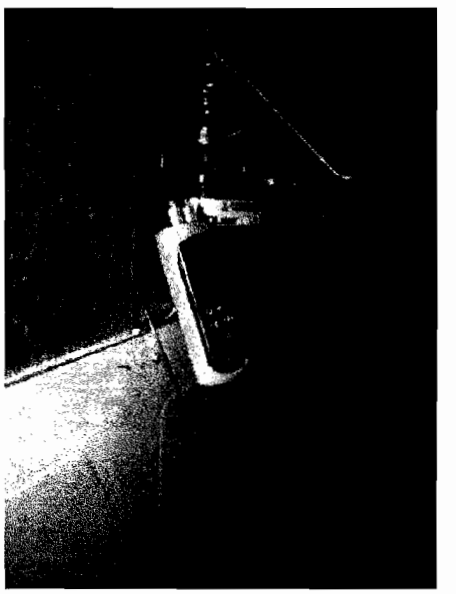
Temperature Rise

- Temperature rise is an important operating parameter for heating equipment. It provides a measure of the sensible heat gain to the air flowing over the heat exchanger and allows specifying technicians to match heating equipment to the comfort level desired in the conditioned space.

  Checking the Temperature Rise and Static Pressure on a Furnace is an important test after Duct Sealing

Testing Heat Rise



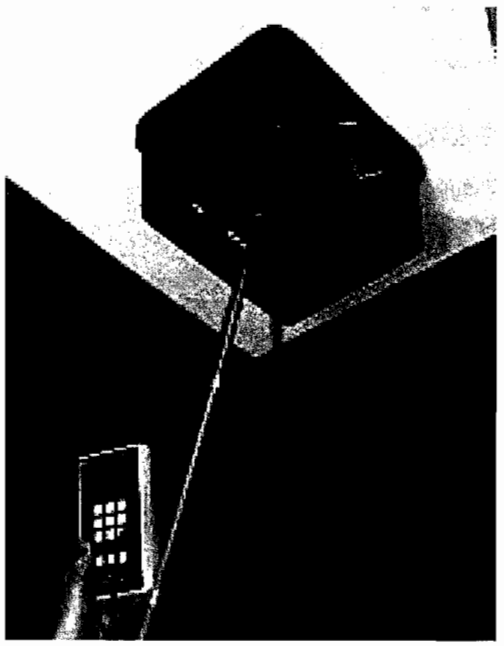


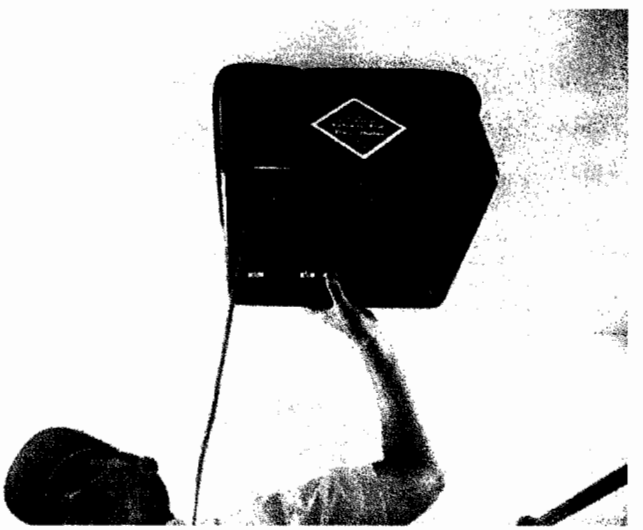
U.S. DEPARTMENT OF ENERGY Energy Efficiency & Renewable Energy

Exhaust Fan Flow Meter

- ***This is designed too make a quick and accurate measurements of air flow through residential exhaust fans. The effective air flow measurement range is 10 to 124 cubic feet per minute (CFM). The device needs to be connected to a digital manometer to obtain accurate readings.***

The Exhaust Fan Flow Meter





U.S. DEPARTMENT OF ENERGY Energy Efficiency & Renewable Energy

Duct Systems

Thank You

Questions and Answers

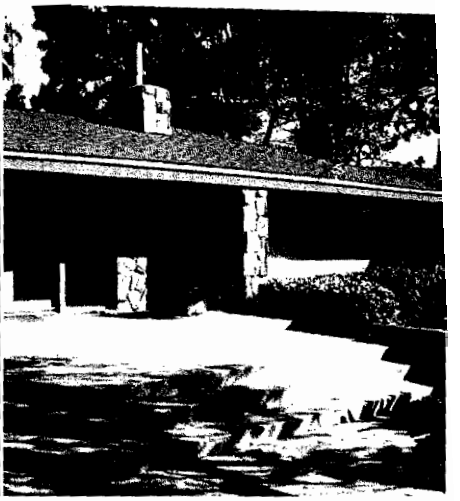
Efficient Solutions for Existing Homes

Building America
U.S. Department of Energy
Research Toward Zero Energy Homes

HOME PERFORMANCE WITH ENERGY STAR

Case Study:

HartmanBaldwin Design/Build
Pasadena, CA



Building shell leakage was cut by 45% and duct leakage was cut by 91% in this Home Performance with ENERGY STAR retrofit by HartmanBaldwin in Pasadena, California

High-End Architect and Construction Company's Questions lead to Building Science

Since 1979 HartmanBaldwin Design/Build, a fully integrated architecture and construction company, has been remodeling for high-end clientele and has earned more than 40 local and national awards for design/build excellence. Through all these projects, founding partners Bill Baldwin and Devon Hartman have been driven by the same question: How do we know that the beautiful buildings we create are durable, sustainable, and energy efficient?

Building science, which is the foundation for Home Performance with ENERGY STAR, provided the answer.

"A few years ago when we discovered building science, it was like Christmas for us," said Hartman. "We found out about the science of building through the CBPCA [California Building Performance Contractors Association] in California. We took some classes by Rick Chitwood, a wonderful friend and mentor, and we discovered the answers we had been looking for over 30 years."

The CBPCA is currently the only organization in California providing contractor training for Home Performance with ENERGY STAR. The training is funded primarily by Pacific Gas and Electric, Southern California Edison, and Sacramento Municipal Utility District according to Pat Colburn, director of CBPCA's Support Services.

Home Performance with ENERGY STAR, a national program from the EPA and DOE, promotes a comprehensive, whole-house approach to making energy-efficiency improvements. The program is available in cities where a local sponsor (typically a utility company, state agency, or local association promoting energy efficiency) has agreed to partner with ENERGY STAR. The local sponsor recruits home improvement contractors and trains them to perform comprehensive home assessments and best-practice improvements based on whole-house building science.

Unlike typical home energy audit programs, a goal of Home Performance with ENERGY STAR is to turn recommendations into improved homes. Participating contractors complete the needed renovations or team with other participating contractors who can. Upon project completion, the contractor assesses the home's performance again to document that improvements were properly installed to achieve the promised energy savings. All participating contractors are subject to quality assurance reviews by the third-party sponsor.

BUILDER PROFILE

HartmanBaldwin Design/Build

100 W. Foothill Blvd.
Claremont, CA 91711
(909) 621-6296
info@hartmanbaldwin.com

Founded: 1979

Employees: 45

Featured Project: Three bedroom, two and a quarter baths

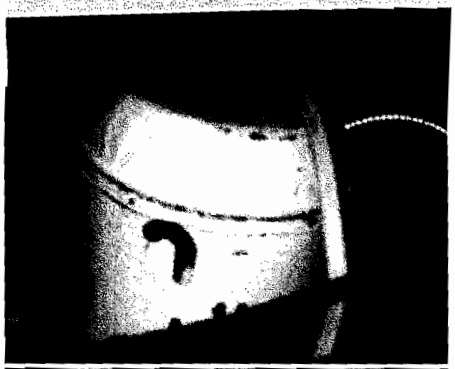
Home Built: 1959

Square Footage: 2,402 sq. ft.

Awards: HartmanBaldwin has been the recipient of more than 40 local and national awards for design/build excellence. These include the Gold Nugget award from the Pacific Coast Building Conference and the Grand Prize Design award from Remodeling Magazine.

"Once we discovered building science, we [HartmanBaldwin staff] became as knowledgeable as possible, got as many certifications as possible, took every class we could find. We are now certified or accredited by BPI, CHEERS, LEED, and Build It Green."

Devon Hartman, president and co-founder of HartmanBaldwin



(top) Holes in 52 can (recessed) lights caused significant air leakage.

(bottom) Batt insulation above the office had been moved and not repositioned to provide adequate ceiling coverage.

What makes Home Performance with ENERGY STAR Contractors different?

Knowing what energy-efficiency improvements to make to a home and how they can work together requires special expertise. Home Performance contractors are equipped with specialized training and diagnostic tools to determine how your home is performing, and can assist you in achieving your goals, whether it's improving comfort, cutting energy costs, or protecting the environment.

For information about Home Performance with ENERGY STAR training in California, visit www.cbpca.org

"Our signature training is called the Green Home Energy Upgrade. It is a 9-day course divided into three 3-day segments or levels. At the end of the third level, our participants can take the written test from the Building Performance Institute (BPI)," said Coburn. All four BPI specialty written tests are offered on the third day of level three. Participants can be certified in one or all of these specialty areas: Building Analyst Professional, Envelope Professional, Heating Professional, and Air Conditioning/Heat Pump Professional.

The Process—A Home Performance with ENERGY STAR Retrofit from Start to Finish

Homeowner Jamie McCoy is not only thrilled by the results of her Home Performance with ENERGY STAR retrofit, which was completed over a year ago, but she is thrilled by the process HartmanBaldwin followed. "Everything in remodeling or construction seemed so imperfect and immeasurable to me...[HartmanBaldwin] did a duct blaster test and other tests, and then used numbers and measurements. [The results] were so verifiable. I thought, 'this is great.'"

Although McCoy originally contacted HartmanBaldwin to remodel her kitchen, she changed her mind and signed up for a whole-house energy retrofit. "After learning about home performance, I decided to do this first and do my kitchen later," says McCoy. "It feels good to know I can make my home more energy efficient."

McCoy's 2,402-square-foot home in Pasadena, California, was custom built by a previous owner in 1959. This single-story three-bedroom, two-bath home uses all-electric heating and cooling.

Conducting a Comprehensive Energy Audit

HartmanBaldwin charges on average $700 for a complete test, and this test follows Home Performance with ENERGY STAR guidelines. Andrew Durben, a senior building analyst at HartmanBaldwin, led the team that conducted blower door tests to determine air leakage; used infrared cameras to show heat and air infiltration areas; checked for insulation levels and gaps in the attic/ceiling, walls, and floor; studied the types and conditions of the windows; studied details of the mechanical heating and cooling systems; checked for signs of moisture infiltration; measured moisture levels; and documented ventilation needs.

One test result proved particularly interesting. "I did the duct blaster test a couple of times," said Durben. "I thought I must be doing something wrong because I wasn't getting any reading. Finally, I crawled under the house to see. The bottom of the return plenum had completely rusted out."

McCoy adds, "I have had repairmen here countless times for things, and no one ever mentioned to me that the ducts were rusted through and sitting in the dirt."

Making Recommendations

With the energy audit complete, Durben reviewed the results with McCoy and provided a detailed proposal with specific prices. McCoy agreed to most of the recommendations. "It was not an inexpensive project, but it feels good to know it was money well spent," said McCoy.

Although McCoy did not investigate federal, state, and local rebates and financial incentives for her Home Performance with ENERGY STAR retrofit, these do exist. The Database of State Incentives for Renewables and Efficiency (DSIRE) can be accessed at www.dsireusa.org. This site provides a comprehensive source of information on state, local, utility, and federal incentives and policies that promote renewable energy and energy efficiency. Established in 1995, DSIRE is an ongoing project of the North Carolina Solar Center and the Interstate Renewable Energy Council funded by the U.S. Department of Energy.

Doing the Home Performance with ENERGY STAR Retrofit

The HartmanBaldwin team organized the retrofit into two areas: completely sealing the building shell and installing a new HVAC system.

Initial tests and visual inspections showed the building shell had major air leakage. "We conducted a blower door test," explains Durben, "The recommended ventilation for her house based on BPI [Building Performance Institute] standards is 159 square inches; her house tested at 13,523 cfm_{50}, that is equivalent to a 742-square-inch hole in the building shell."

To address this leakage problem, the team started with sealing the attic. They removed the existing R-13 batt insulation from the attic's floor, which was performing at an R-5 due to its poor installation and condition. Then, they sealed the interior wall cavities that were open to the attic. "These cavities allow hot or cold air from the attic to come down inside the interior wall cavities," says Durben.

Through an electrical safety check, the team discovered numerous electrical code violations, which were subsequently fixed in order to then properly seal the attic's surface area. A significant air leakage problem came from the 52 non-insulated, non-airtight recessed (can) lights that allowed for conditioned air to escape up to the attic. They built air-tight boxes over each light with adequate space for fire safety, and then buried these in new blown-in cellulose at 10 to 12 inches in height for a new R-38 value.

To determine the appropriate loading order for retrofit work, many variables are taken into consideration. In this case, a poorly insulated attic in southern California reaches average temperatures of 140°F in the summer. The temperature differential between the 75°F interior house temperature and the 140°F attic causes the cooler air of the house to be sucked up into a leaky attic. Therefore, since the temperature differential between the walls at 75°F and the outside temperature at 100°F is not as significant, replacing windows and wall insulation wasn't as high in priority as properly insulating the attic when determining the most cost-effective improvements.

As Durben explains: "When you look at an old home, everyone assumes that the windows are the first thing to address, but if you have 300 square feet of glass and you replace it, you go from R-1 to R-3 [which is the typical R value for new windows]. For a fraction of the cost, you can take the 2,000-square-feet of ceiling surface area and increase it from R-6 or R-10 to R-38 at the place where it really matters—in the attic."

The team did replace several jalousie (louvered) windows that showed significant leakage.

After completing the air sealing in the attic, the team tackled the crawlspace. They removed the rusted-through ducts and debris; inspected and repaired electrical, plumbing, and gas issues; installed a vapor barrier and ventilation fan, and sealed all the vents. They also sealed all major floor penetrations, including electrical, plumbing water, waste pipes, and tub and shower access areas.

Two SEER 14, HSPF 8.0 1½-ton heat pumps were installed. Two were installed because the house is long, and they wanted to use smaller units and keep the duct runs as short as possible. "It is more energy efficient to do two small systems and also more comfortable because we are heating and cooling the air at a slower rate," say Durben. "SEER 13 is the lowest you can buy in California. What we have discovered is that adding high-efficiency equipment alone is not cost effective. It is easy to sell your customers more expensive high-SEER equipment. It is harder to make sure you get the duct system installed just right, that it is tight, and that you keep the duct runs as short as possible."

(top) The bottom of the furnace's return plenum was completely rusted out.

(bottom) Unidentified debris covered the duct insulation in the crawlspace.

More than half of the over 66 million single-family homes in the United States were constructed before modern energy codes existed. Many of these homes have no wall insulation, high levels of air infiltration, inefficient heating and air conditioning, and inefficient water heaters and appliances. In fact, over 40% of households report at least some winter drafts, and 62% complain of a room that is too warm in the summer.

Home Performance with ENERGY STAR website

Through 2008 more than 50,000 existing homes have been improved through Home Performance with ENERGY STAR, with 12,000 homes improved in 2008 alone. There are more than 25 program sponsors and 750 participating contractors.

Jonathan Passe, EPA Communications Coordinator for ENERGY STAR Residential Programs

High moisture content was found in the soil of the crawlspace which had no vapor barrier covering.

Key Energy-Saving Features

Duct blaster showed duct leakage cut from 800 cfm to 62/70 cfm

Blower door test showed whole house air leakage cut from 13,523 cfm_{50} to 7400 cfm_{50}

Air conditioning reduced from 8 to 3 tons

Electric bills cut in half

Laid mylar vapor barrier over the crawlspace dirt floor and added a ventilation fan; all floor penetrations sealed

Increased attic insulation from sloppy R-5 batt to R-38 blown cellulose

Built air-tight boxes around 52 noninsulated, non air-tight recessed can lights in ceiling

Extensive attic air sealing

Replaced leaking windows

Installed two new SEER 14, HSPF 8.0 1½-ton heat pumps

Replaced rusted out metal ducts with R-8 insulated plastic flex duct configured for short duct runs

For additional information, contact:
Theresa Gilbride
theresa.gilbride@pnl.gov

PNNL-SA-68405

The team installed plastic flex duct with R-8 insulation and lined the crawlspace floor with a Mylar vapor barrier. In the new design, each supply duct run is a home run to the supply plenum to ensure the correct amount of air could be delivered at the right speed to each room. This is important explains Durben because "Too much air or too little air in the room is going to be uncomfortable, and you need the air delivered at the right speed."

Conducting Follow-up Testing

The original blower door testing showed significant leakage at an interpolated reading of 13,523 cfm_{50}, which is 742 square inches. After sealing the home, leakage was reduced to 7,400 cfm_{50} or 406 square inches.

The first system's duct leakage measured 800 cfm, and the second was too leaky to test. The post-test numbers started at about 100 cfm. They conducted smoke tests and did additional sealing and ended up with post-retrofit duct leakage of 70 cfm at 25 pascals of pressure in the living area and 62 cfm 25 Pa in the bedrooms.

"This home originally had eight tons of air conditioning equipment, and today it has 3 tons. In the traditional home, an HVAC system is designed so that one ton of capacity will cool or heat about 400 square feet. In this home, we were able to cool 800 square feet with every ton of air conditioning," says Durben.

The homeowner's reduced energy bills and increased comfort may be the real follow-up test. "I just recently got the real apples to apples bill for July. It was exactly half what I paid the year before in July," says McCoy. She is as enthusiastic about how the house feels. "I am like a commercial for them. I so believe in what they did. I had my niece visiting here two weeks ago from New York. I hadn't told her anything about the retrofit. It was a very hot day, and we had been out outside. We came in and were sitting in the dining room and she said to me, 'You know it is so comfortable in here.' And she meant the temperature. That is how this house is. It is comfortable now, and before it was hot."

The Bottom Line

For Devon Hartman and his staff, building science makes the difference. "We can now, with existing technology and off-the-shelf materials, assess a person's home, retrofit it, and reduce energy, reduce greenhouse gases, and attack some of the most important problems in sustainable building today. Right now. That's what's exciting.... Now we have the testing equipment to identify issues, fix the problem, retest to prove that we fixed the problem, and move on with a great feeling of satisfaction."

To find your state sponsor for Home Performance with ENERGY STAR, go to **www.energystar.gov** Then, click on *Home Performance with ENERGY STAR*. From here, click on the link labeled "contractors participating in a locally sponsored Home Performance with ENERGY STAR Program." Or, Google: *Home Performance with ENERGY STAR Locations.*

For more information about Home Performance with ENERGY STAR, visit **www.energystar.gov/homeperformance**

Clark Howard Does His Homework

By: Sydney G. Roberts, Ph.D.

Planning home improvements can be a daunting task, even for the savviest homeowner. There is so much information, and misinformation, available in the marketplace that it can be difficult to determine the right solutions.

We all want to get the most bang for the buck and consumer advocate Clark Howard is certainly no exception. Those who know Clark Howard from radio, television, or the newspaper know that he is always searching for the best value. So when Clark wanted advice on the most cost effective improvements for lowering his energy bills last winter, he called Southface to first identify the problems.

Clark, wife Lane, and their children live in a comfortable and well-maintained 18-year-old home in Atlanta. They have invested in home improvements and maintenance to increase the comfort, health and energy efficiency of their home during their eight years in the house. Specifically, Clark and Lane have installed high efficiency air conditioners and high efficiency air filters for their heating and cooling systems, which are regularly serviced. Despite these efforts, their energy bills were quite high, and some family members experience asthma and allergy symptoms in the home.

Southface developed and administers a program called Home Performance with ENERGY STAR®. Under the program, Southface trains contractors to use the whole-house approach to inspect homes, diagnose problems, and offer solutions. The homeowner receives a list of recommended improvements prioritized by cost effectiveness that the contractor can perform, with Southface monitoring for quality control on a percentage of projects. Additional information is available at southfacehomeperformance.com.

Southface residential staff Sydney Roberts and Howard Katzman performed a Southface Home Assessment following the Home Performance with ENERGY STAR criteria. The home was visually inspected from the basement to the attic, inside and out, and diagnostic tests were performed to quantify both building envelope and duct leakage. The results of Clark Howard's initial inspection are summarized in the second and third columns of Table 1. After the inspection, the Howards received prioritized suggestions for improvement, with "A" being the highest priority.

Figure 1a. BEFORE: Missing insulation on the sloped ceiling. Note that some of it is discolored, indicating an air leakage pathway.

Studies show that ductwork leaks are the biggest source of energy loss in most Southern homes, accounting for up to 30 percent of total heating and cooling costs. For the average home, this amounts to hundreds of dollars each year. Additionally, comfort and indoor air quality are significantly compromised by leaky ducts.

A duct blaster test was performed to measure duct leakage of two HVAC systems. In this test, the ducts are pressurized with a calibrated fan and air leakage out of the ducts is measured. The systems showed leakage of 29 percent and 27 percent. Unfortunately, this large amount of leakage is not unusual. A significant portion of conditioned air was being lost to the attic, and unconditioned and unfiltered air was being drawn into the system through leaks in the return side of the ductwork. In this case, the leaks were hidden behind the insulation that was wrapping the ducts (Figrue 1a). Clark and Lane were surprised to learn that their home and duct systems had significant air leakage.

As a solution, the Howards chose to have the metal ductwork sealed and insulated (Figure 1b). In doing this, the improvement contractor found and replaced a duct that had been crushed by previous workers in the attic. The boot connections through the drywall were sealed with caulk. By taking these steps, duct leakage was reduced to 13%. That is a 55% improvement!

Ductwork can be sealed from either the outside or the inside. The choice of approach depends on the home. If the ductwork is all accessible like in Clark Howard's home, for instance in an attic or unfinished basement, it is often possible to seal the ducts from the outside. Whether the ducts are constructed of hard metal or flexible runs, the insulation layer should be peeled back and all joints and seams should be sealed at the pressure boundary. The most durable sealant is duct mastic. Ducts must be reinsulated once sealing is complete. A duct system fact sheet is available at www.southface.org.

The other option is to air seal ductwork from the inside with a system such as AeroSeal®. This procedure involves computer controlled pumping of an aerosol sealant into the duct system to seal holes up to ½ inch in size. Sealing from the inside may be the best option if ducts are inaccessible or if metal ducts are already insulated. Additional information on AeroSeal is available at www.aeroseal.com.

Like the ductwork, the entire house was tested for air tightness with a blower door. Prior to making improvements, the house was experiencing 0.51 air changes per hour under normal conditions (ACHnat). To provide context, EarthCraft House standards require homes to have 0.35 ACHnat or less; smaller is tighter. These leaks were coming from many different spots in the home including through attic access doors, unsealed recessed lights, plumbing and electrical penetrations, chimneys, and around windows and doors. These leaks are directly related to energy, and money loss. The Howards took a multi-pronged strategy for sealing the leaks. Chases were covered with foam board and the edges sealed with spray foam (Figure 1b). Plumbing, electrical and other penetrations were sealed with spray foam (Figure 2). Insulated, airtight boxes were built over leaky recessed can

Table 1. Quantitative Home Performance with ENERGY STAR improvements.

Improvement Type	Priority Level	Pre-Improvement	Post-Improvement	Improvement Achieved
Ductwork air tightness	A	29% leakage	13% leakage	55%
House air tightness	B	0.51 ACHnat	0.35 ACHnat	31%
Kneewall insulation	B	Loose batts	Spray foam insulation	Permanent, complete coverage
Attic insulation	C	R-24	R-40	Plenty, for Atlanta climate

Southface
Responsible Solutions for Environmental Living
bryant
Carrier
Turn to the Experts.

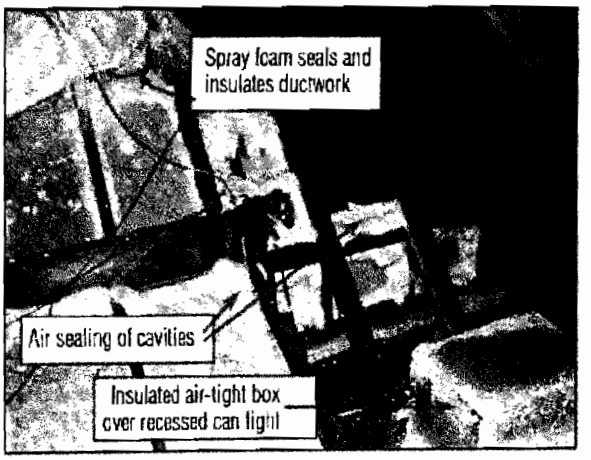


Figure 1b. AFTER: Cavities are air sealed; air-tight boxes built over recessed can lights; spray foam insulation is used to seal and insulate metal ductwork. Cellulous insulation was added later.

lights. The attic kneewall door was weather-stripped and a threshold was installed. On the attic side of the pull-down stair, an Attic Tent™ was installed. Additional weather stripping was installed on some exterior doors. All of these improvements added up to a 31% improvement in air tightness, bringing the value to 0.35 ACHnat.

Attic kneewall insulation and air sealing and attic floor insulation were also high priorities for improvement. For the attic kneewall, the vertical wall separating attic space from living space, the solution was to replace the batt insulation on the kneewall with spray foam and to block off joist cavities under kneewalls with foam board using spray foam to seal the joints. Spray foam is ideal for vertical applications because it provides air sealing and insulation in one application.

Blown cellulous insulation was added to the attic floor, increasing the effective R-value from 24 to 40. While a lower priority than the other improvements in this case, adding attic insulation is relatively simple and affordable. For all homes, the effective R-value of attic insulation should be at least R-30. It is critical to ensure that all penetrations through the attic floor are air sealed prior to adding insulation.

Exhausts for two bathroom fans were emptying into the attic instead of being ducted to the outside. This situation had caused visible moisture damage and mold growth on the underside of the roof deck. Bath fans, as well as kitchen fans and laundry dryer vents, should be ducted to the outside. Controlling moisture at the source reduces the work that the air conditioner must do to decrease humidity.

Outside the house some downspouts terminate only a foot from the building. This tends to soak the foundation walls, increasing the likelihood of high humidity or water penetration into the basement. Downspouts should be connected to piping that carries the water to a spot that is downhill and at least 5 feet from the house.

Clark has been diligent in replacing incandescent light bulbs with more efficient compact fiorescent lights (CFLs). Not only do CFLs use only 25 percent of the energy of incandescent bulbs, they last 10 times longer. For an average bulb, this will save $50 over the life of the CFL.

An important part of taking the whole-house approach to improvement work is to maintain the health and safety of the occupants. At the final inspection, Southface performed a combustion safety test to ensure that gas water heaters would not back draft under worst-case conditions. The Howard's home passed the test. In homes that do not pass, carbon monoxide, moisture and other combustion gases can be drawn into the home with potentially catastrophic consequences.

In all homes with combustion equipment (e.g., gas appliances and fireplaces), carbon monoxide detectors should be installed outside of each sleeping area and in each room with a fireplace or other combustion equipment.

Clark Howard and his family have experienced incredible comfort benefits as a result of these improvements. Lane reports, "I love it. The house is so much more comfortable. I mean, a real change." Now, all rooms in the house are the same, comfortable temperature; there are no longer certain rooms that are hotter or colder than the rest of the house. The drafty feeling is gone. Additionally, it is very easy to maintain a constant temperature throughout the house all day and night. The family no longer adjusts the thermostat, relying instead on the programmable thermostat to keep the house comfortable while still setting the temperature back at night for greater energy efficiency.

A surprise benefit has been the reduced noise of the heating and cooling system. In the past, it was not uncommon for the noise to wake up their young daughter in the middle of the night. She, in turn, would wake up her parents. Since the improvements were made, everyone is sleeping through the night.

Further, respiratory system symptoms have lessened for affected family members. Lane no longer awakened on mornings this past winter to a scratchy throat. Clark suffers from asthma but reports that his symptoms have lessened.

Following the Home Performance with ENERGY STAR protocol provided a quantitatively-based road map for making whole-house improvements for Clark Howard and his family. The Howard's were empowered to make smart decisions regarding their home improvements that have resulted in increased comfort in the home. Lane Howard paid the process and the improvements the highest compliment, saying, "I love it. I would do it again."■

Figure 2: Plumbing, electrical, and other penetrations through the attic floor were sealed with spray foam prior to adding blown cellulous insulation. Old insulation was removed to reveal these holes.

HOME PERFORMANCE WITH ENERGY STAR

Home Performance with ENERGY STAR – A business opportunity for HVAC contractors.

Why should HVAC contractors be interested in the home performance approach? Here are some of the many reasons:

· Market differentiation. Taking a whole house approach allows you to offer more comprehensive solutions. HVAC solutions alone don't always solve customers' problems. For example, bonus rooms often have building envelope issues that need to be addressed. One contractor stated that he joined the program because he couldn't solve all his customers' problems with HVAC alone.

· Reduce competition. When homeowners see you as just any other HVAC contractor you have hundreds of competitors. If you transform your company to become a home performance contractor, you'll have only a handful of companies competing for the business.

· Increase sales and profits. When you offer to fix other areas and issues in the home your sales per job increase. Most home performance contractors report that profits increase as well. Homeowners want the one-stop shop; they are too busy to deal with multiple contractors. When you offer solutions that make sense they'll want you to handle all of it.

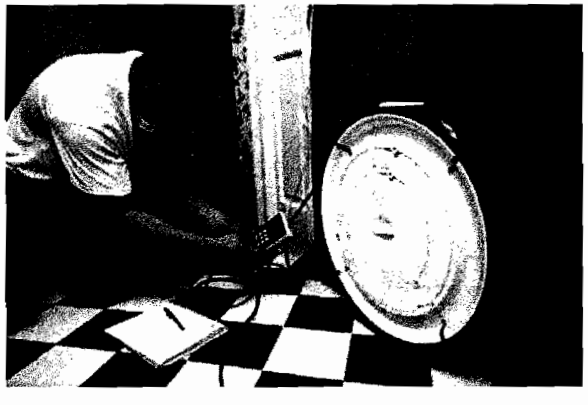
· Even out workflow. Most HVAC contractors in Atlanta report significant drop offs in calls and work orders for one or two periods per year. When you sell comprehensive home assessments and solutions you create work during the "slow" seasons.

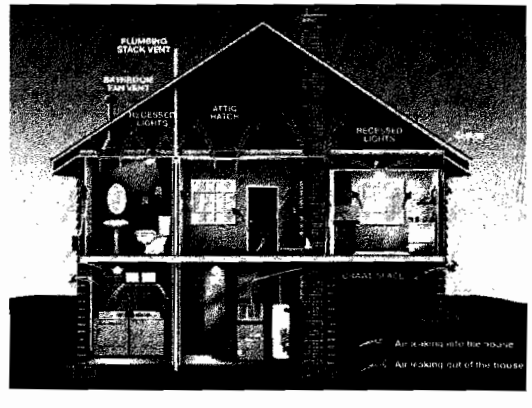
· Increase credibility. When you join the Home Performance with ENERGY STAR program you are joining a program recognized by the public. The ENERGY STAR logo enjoys 60% recognition. Southface, a local energy non-profit with 28 years of experience helping homeowners and builders in greater Atlanta, provides training, technical assistance and quality assurance. As the ENERGY STAR sponsor, Southface checks a percentage of the contractors' paperwork and projects to ensure program quality and consistency.

The next training for contractors who want to join the program is November 8th, 15th, and 16th. For more information, go to www.southfacehomeperformance.com/contractors/training.html.■

Home Performance with ENERGY STAR

Existing Homes Efficiency – If You Want BetterBuildings – Go with HPwES





August 5, 2010
Chandler von Schrader, EPA
Casey Murphy, ICF Int'l
Matthew Phillips, Austin Energy

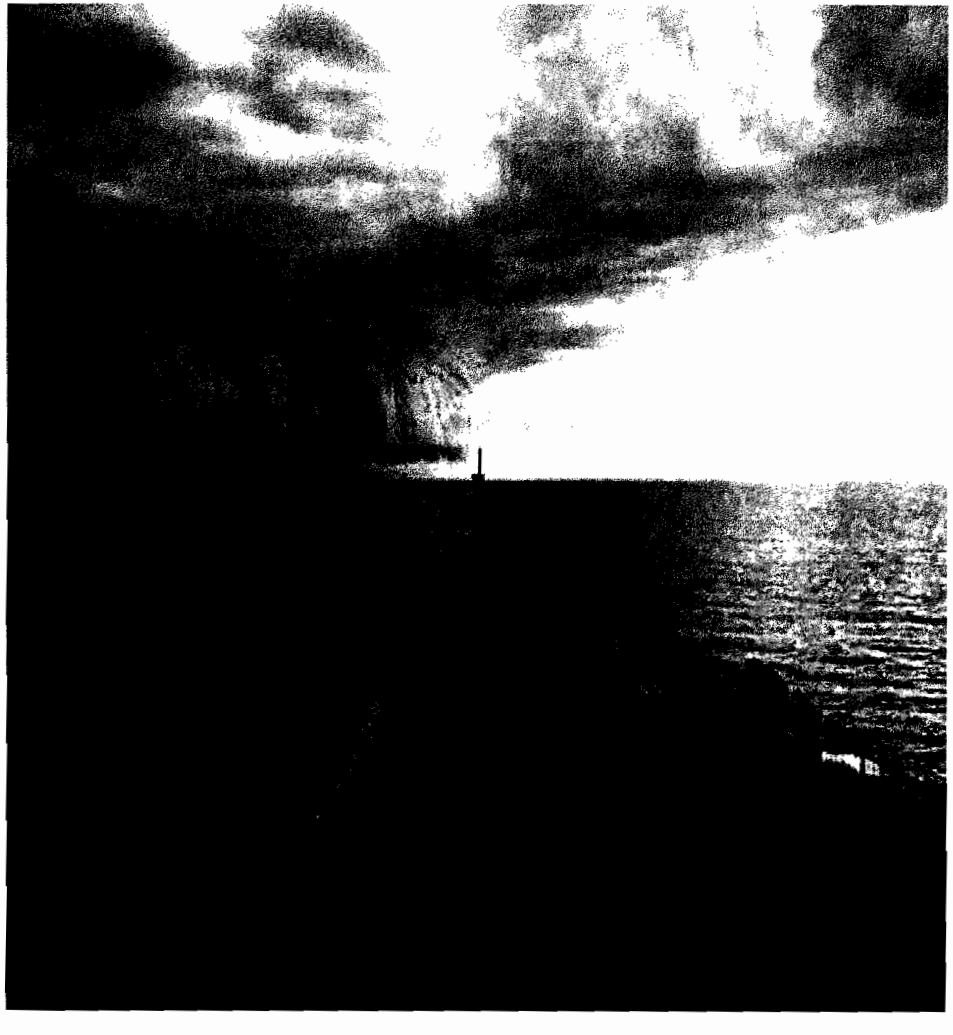
EPA

Agenda

- Inside the Home of Home Performance delivery
- Connecting your program to HPwES – don't reinvent – piggyback!
- Requirements of a HPwES Sponsor & Contractor
- Take a look at Austin Energy's HPwES program
- Keeping HPwES alive post DOE funding
- Next steps and questions

Perfect Energy/Environment Storm is Brewing

- Huge national WX goals
- Infrastructure will be hard pressed
- Utilities stepping up or being pushed
- Energy costs are rising
- Climate change is here
- DOE funding stimulus
- Media is spinning green
- New generation plants tough to pass



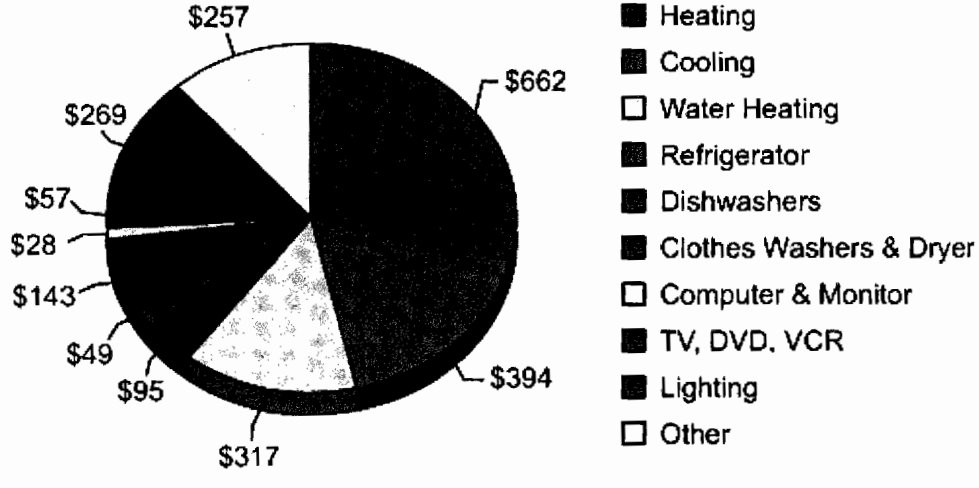
EPA

Residential Energy Use

- 114 million households[1]
  - 69% built before 1980[1]
  - 68% or 76 million owner occupied[1]
  - 59% single-family owner occupied[1]

- Average energy cost $2200/year

Typical House's Annual Utility Bill



- Heating and Cooling almost 50%
  - 56% heat with natural gas[2]
  - 26% heat with electricity[2]
  - 64% cool with central AC[2]

[1]2007 Building energy Data Book, DOE
[2]2005 RECS, Single-Family Homes Table US14, HC2.4 and HC2.6 EIA/DOE

EPA

100 Million Existing Homes Today *(And They Ain't Going Away)*

- One-third of owner-occupied homes are at least 45-years-old
- Another one-third are between 25 and 45-years-old
- 70% of the homes in 2050 are standing today
- Majority of homes are in increasing need of remodeling and repair…AND upgrade of the home's performance.
- Opportunity rich environment - Who are they going to call?

EECBG Competitive Grants

- $390 Million "Retrofit Ramp-Up" program
- $64 Million for cities, counties, and Indian tribes

http://www.eecbg.energy.gov/Downloads/EECBGCompetitiveFOA148MON.pdf

DOE issued this FOA in conjunction with the Recovery through Retrofit Report issued by White House Middle Class Task Force and the Council on Environmental Quality. Applicants were encouraged to be aware of guidance and other information in this report.

http://www1.eere.energy.gov/wip/eecbg_grants.html

Recovery Through Retrofit Report

BARRIERS

Access to Information:
Consumers do not have access to straightforward and reliable information.

Access to Financing:
Homeowners face high upfront costs and are often unable to recoup the value of their investment.

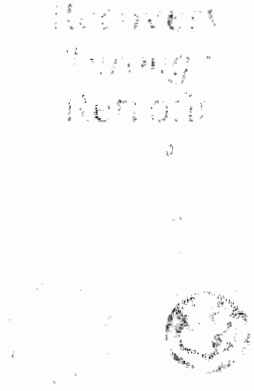
Access to Skilled Workforce:
There is an insufficient amount of skilled workers to expand energy retrofit programs on a national level.

Program Elements

QA/QC

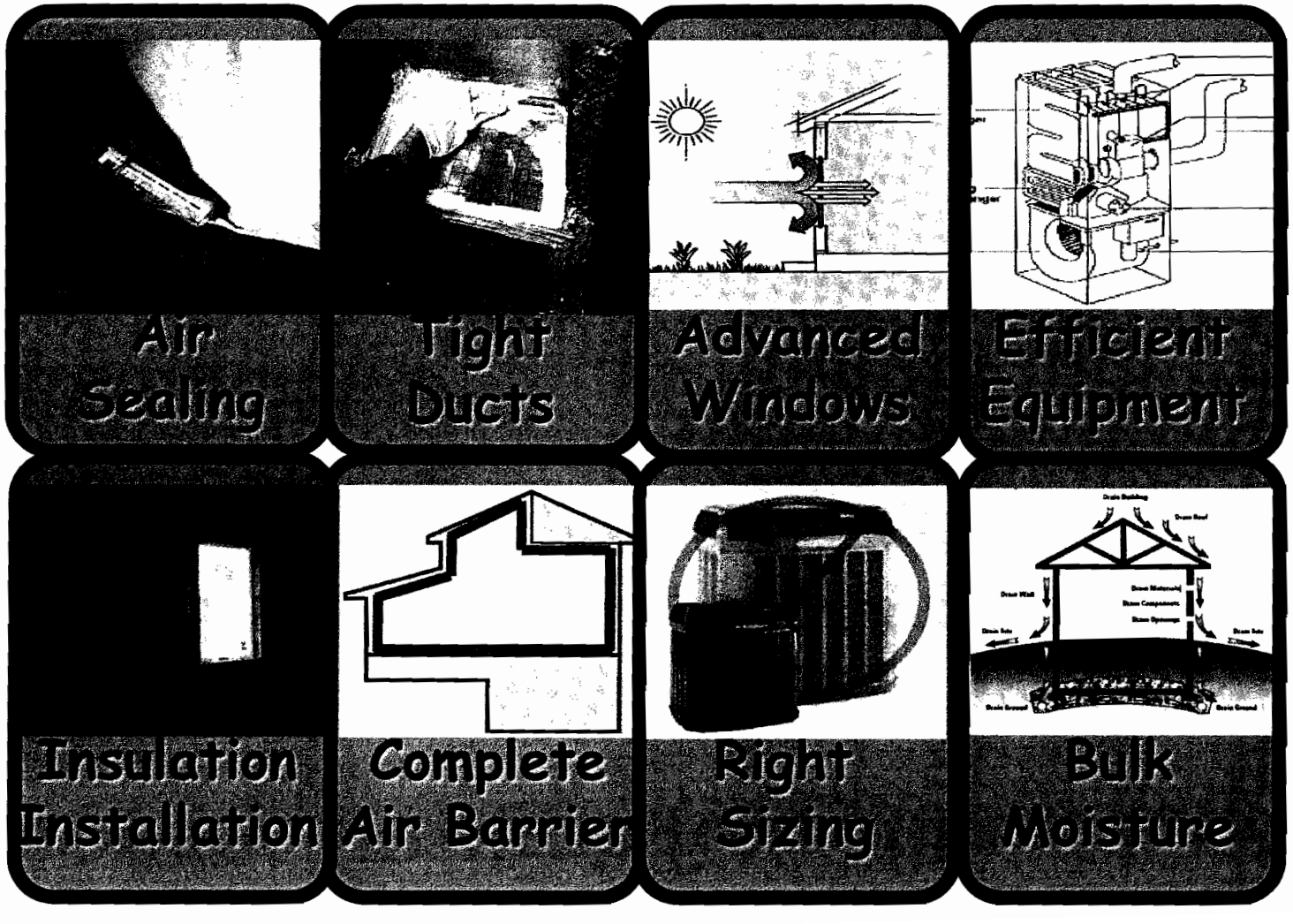
Demand

Supply



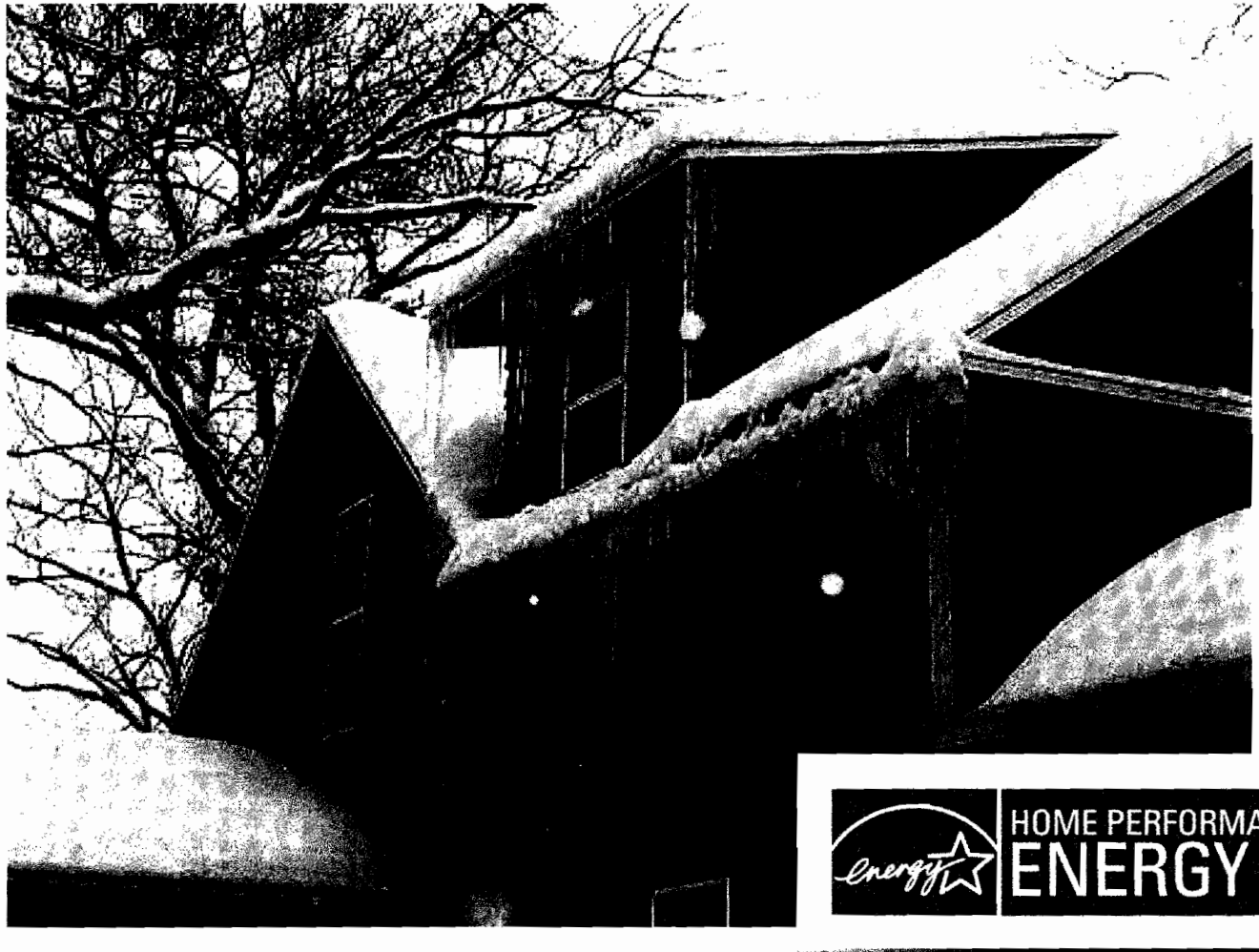
EPA

Controlling Air, Thermal and Moisture Flow are Key to Home Performance



EPA

Can Roofers Fix This?



HOME PERFORMANCE WITH ENERGY STAR

EPA

Energy Savings

- Whole-house energy saving of 20% and more is achievable

Table 1 Potential per Home Energy Savings by Climate Zone

	NORTHEAST	MIDWEST	SOUTH	WEST
Electricity (kWh)	1400	1700	4600	1400
Natural Gas (Therms)	400	400	200	200
Typical Improvements	Increasing attic insulation; insulating crawl spaces or rim joists; duct sealing, repair and insulation; air sealing; and installing programmable thermostat, energy-efficient replacement water heater, heat pump, air conditioner, furnace, boiler, lighting or windows.			

- Estimated peak electricity demand savings
  - 1.6 kW per home in summer
  - 0.9 kW per home in winter
- Estimated levelized cost of conserved energy (CCE) of 0.05 $/kWh*

*Based on information from Austin Energy

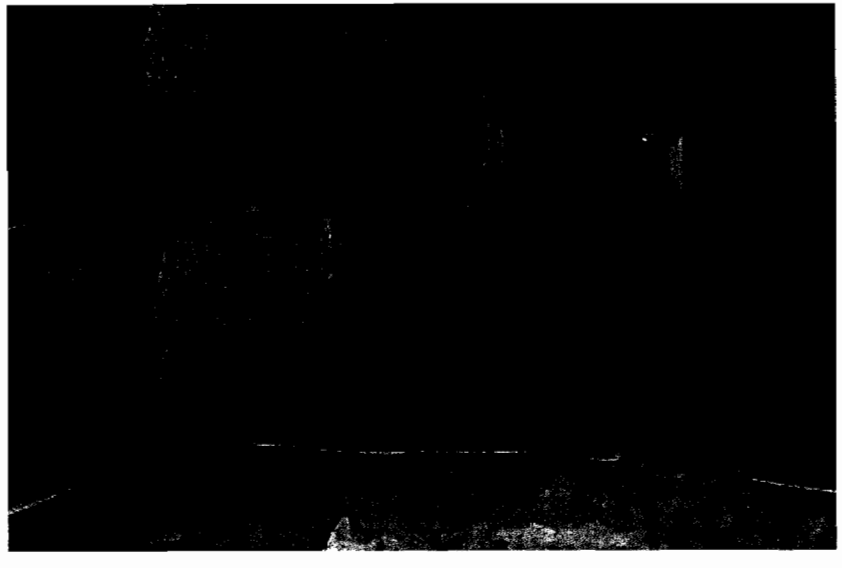
Tier One – Nuts and Bolts

Program Tasks:

- Recruitment, training & certification of auditors and **installers/contractors**
- Well defined in-home process – with savings report software
- Promote through web portal and utility marketing
- Clear incentives – fee or free
- Define & deliver QA and EM&V
- Referral to HPwES program if in place

Can Insulators Fix This?

Insulators see this as Good Work

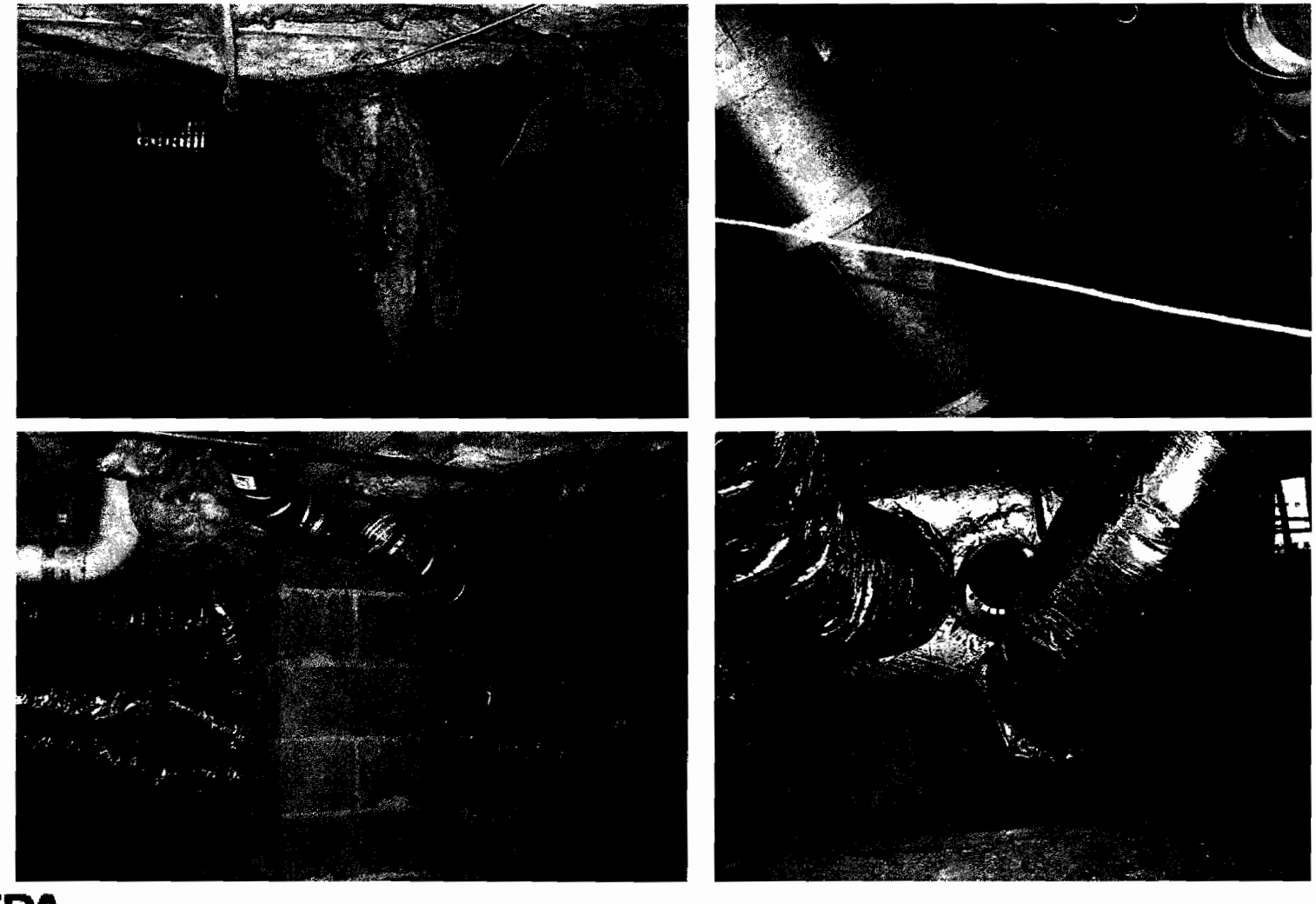


Air Sealing? Maybe….

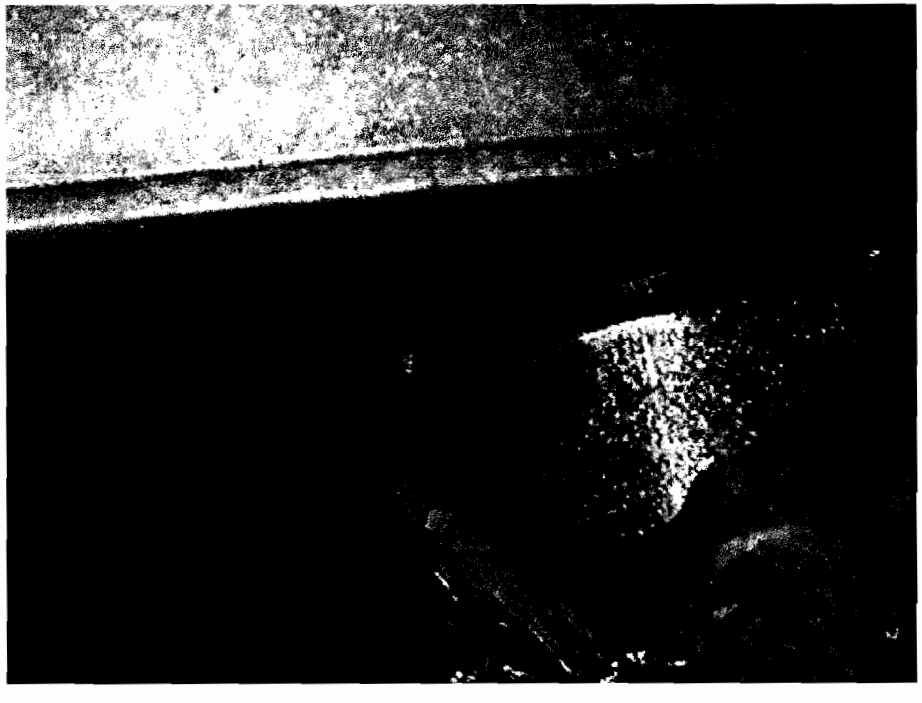
Who Fixes This?

EPA

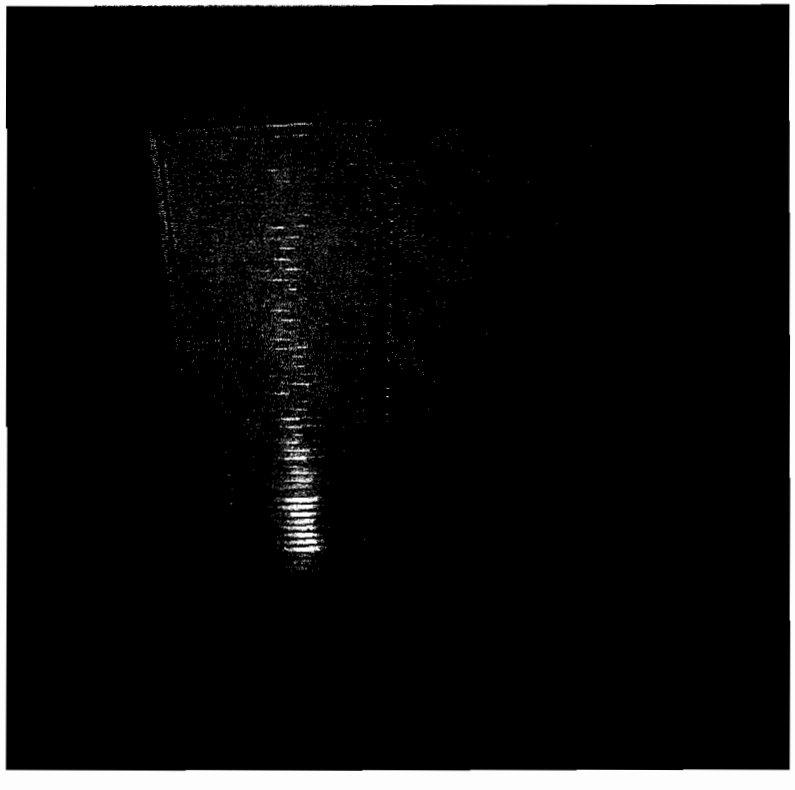
How Comfortable is this House?

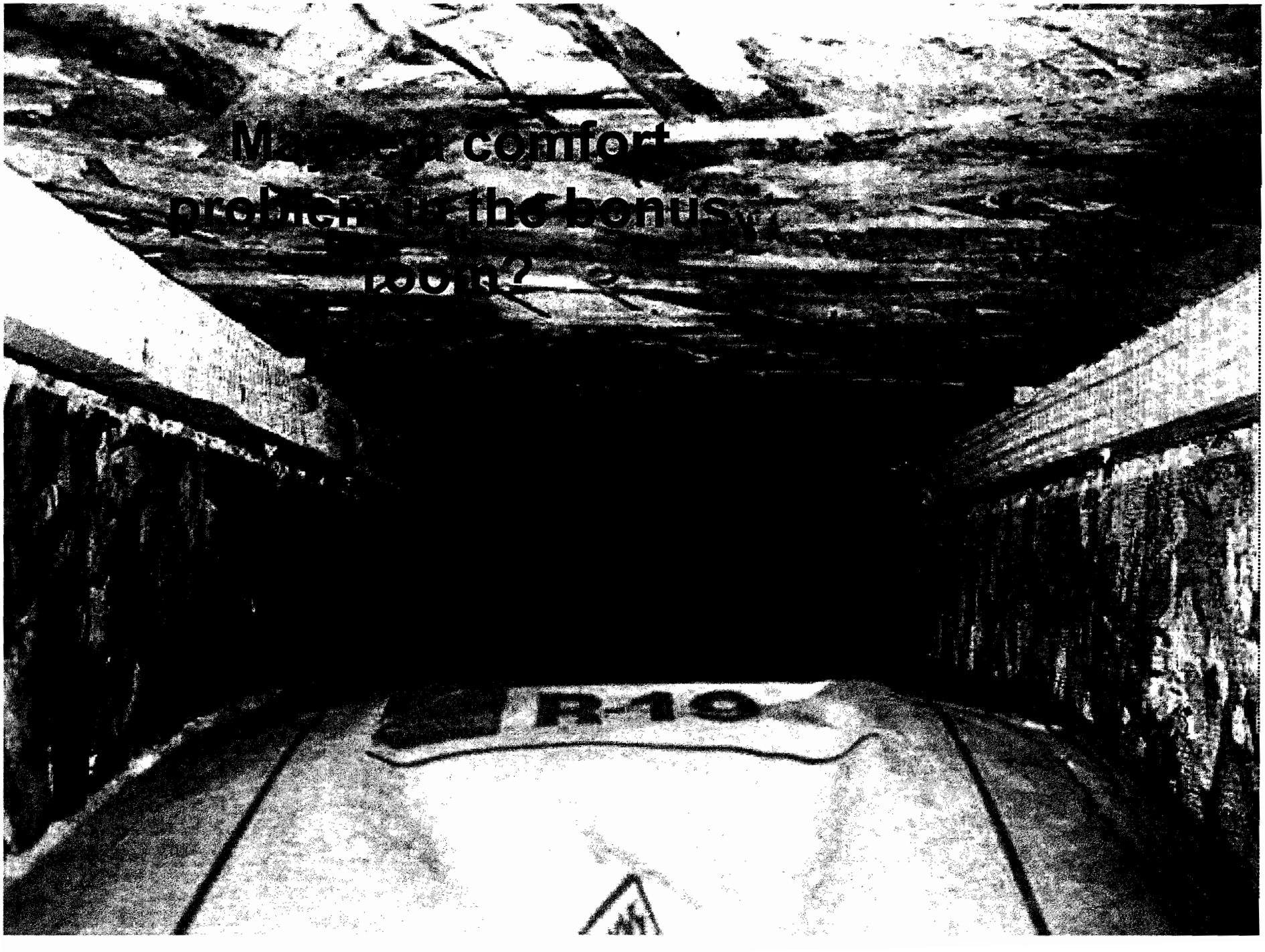


Maybe a Comprehensive Audit?

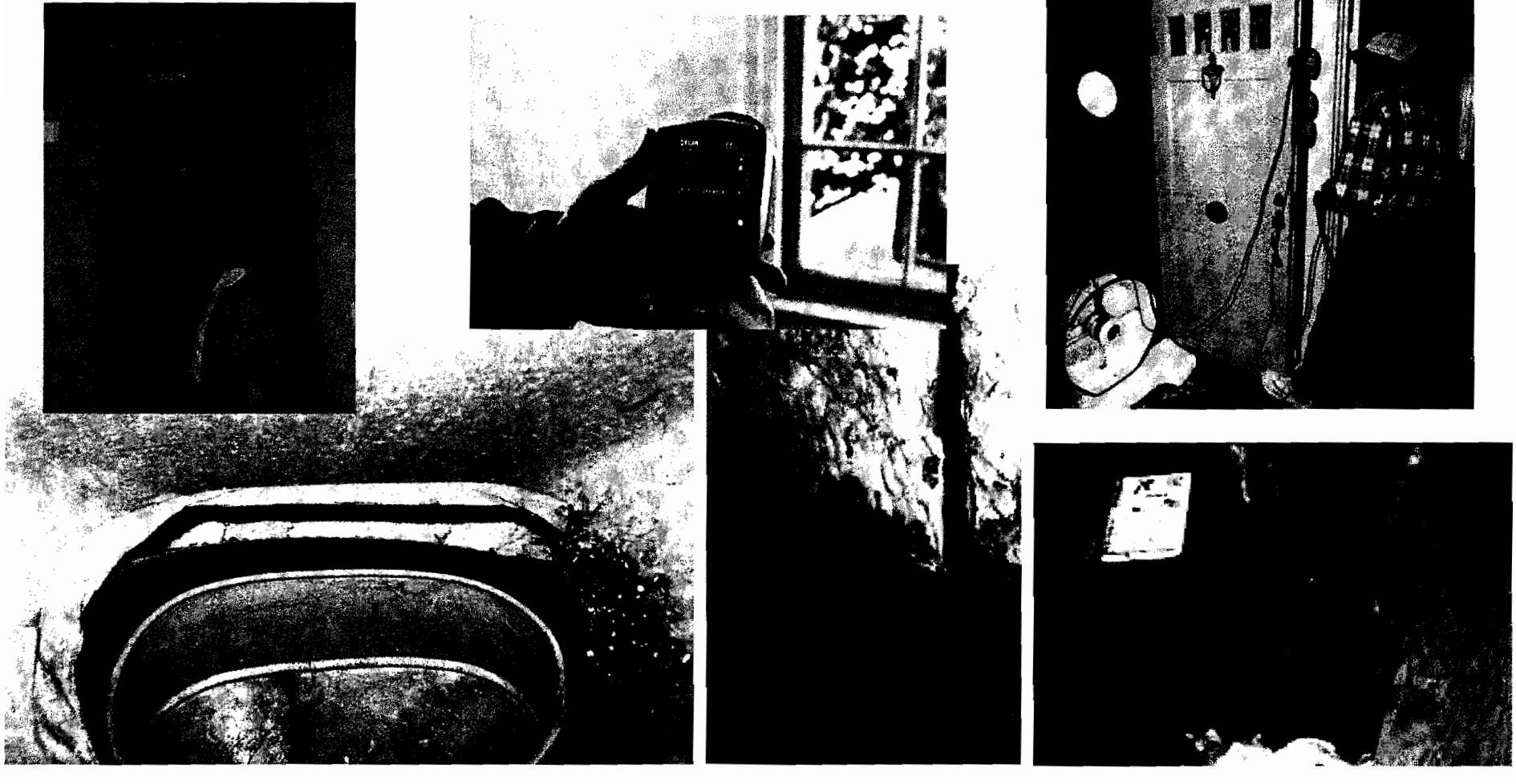


Would a HVAC Contractor Look Here?

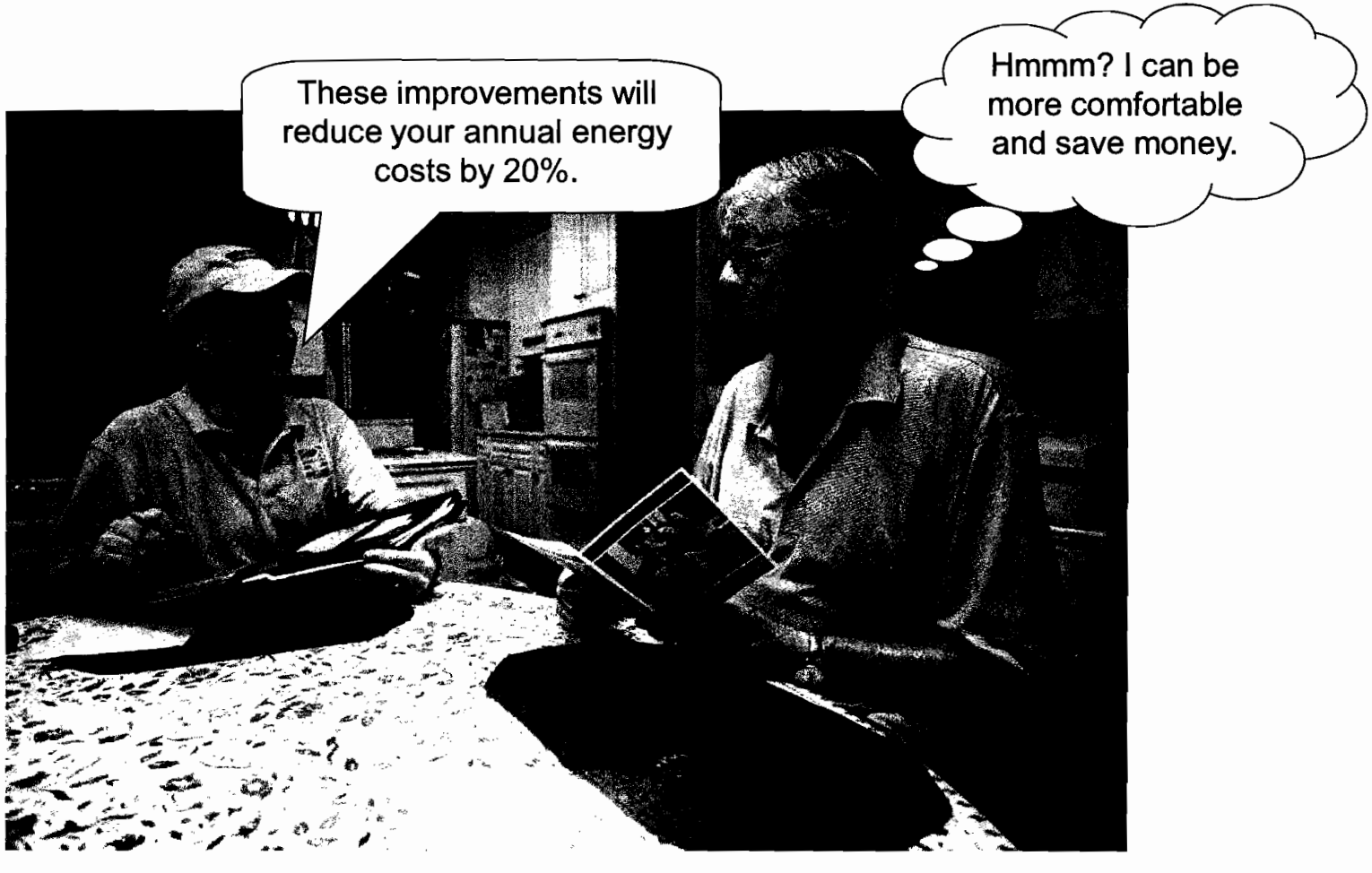



R-10

HPwES to the Rescue!



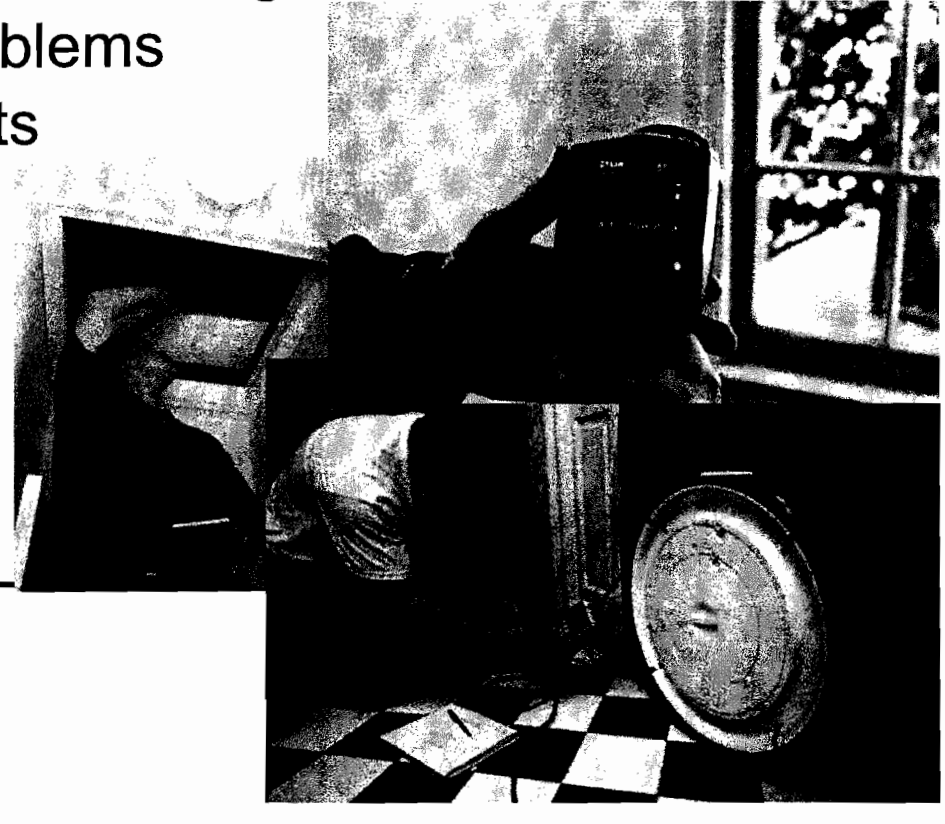
Present Results and Proposal



Selling is EVERYTHING!!

HPwES Comprehensive Job

- Whole-house energy inspection
  - Energy specialist trained in building science
  - Using tools figure out problems
  - Connect performance dots
- Summary report
  - Findings
  - Recommendations
  - Estimated costs and savings



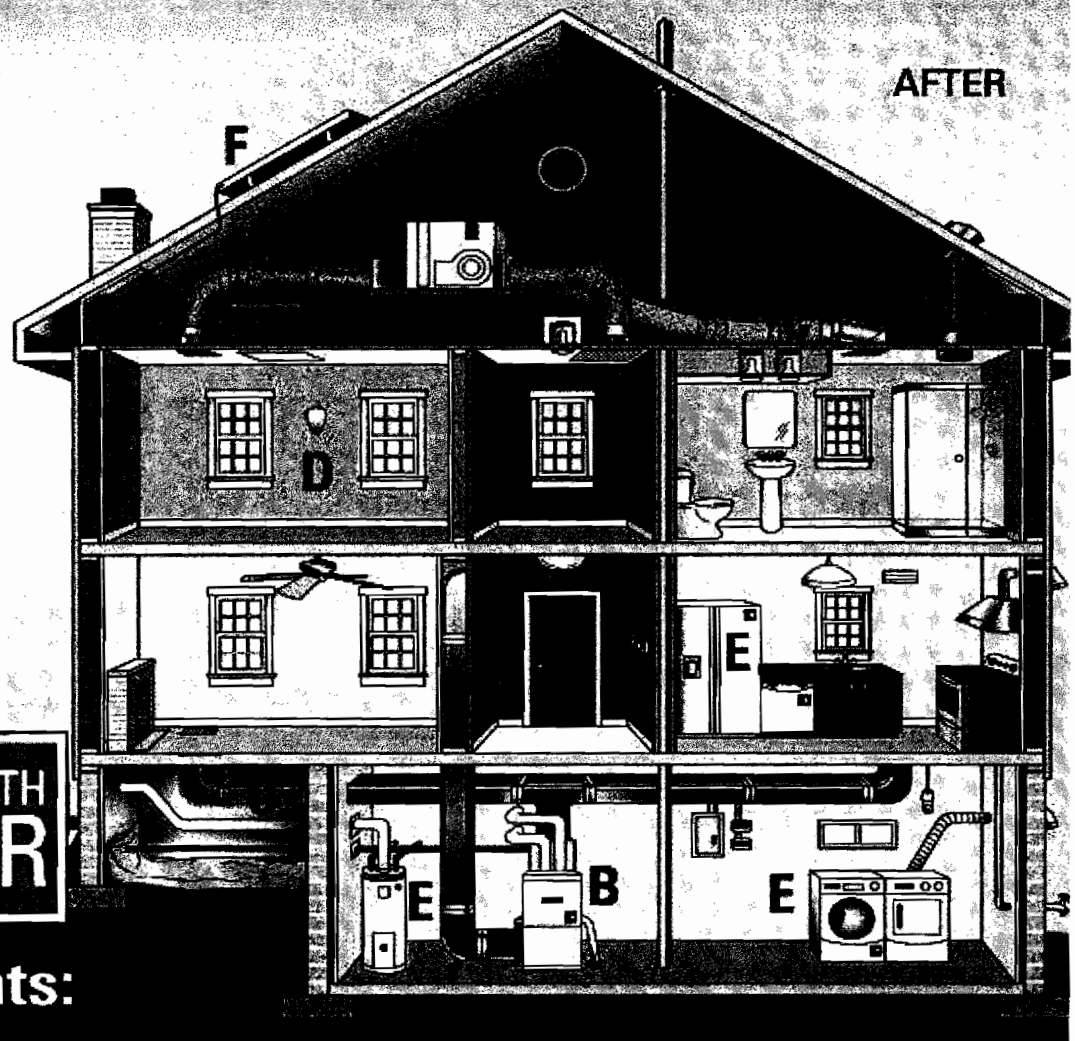
➢ DO WORK – TEST OUT

➢ Report work!

EPA

BEFORE

AFTER



HOME PERFORMANCE WITH ENERGY STAR

Typical Home Improvements:

- [A] Sealing Air Leaks and Adding Insulation
- [B] Improving Heating and Cooling Systems
- [C] Sealing Ductwork
- [D] Replacing Windows
- [E] Upgrading Lighting, Appliances, and Water Heating Equipment
- [F] Installing Renewable Energy Systems

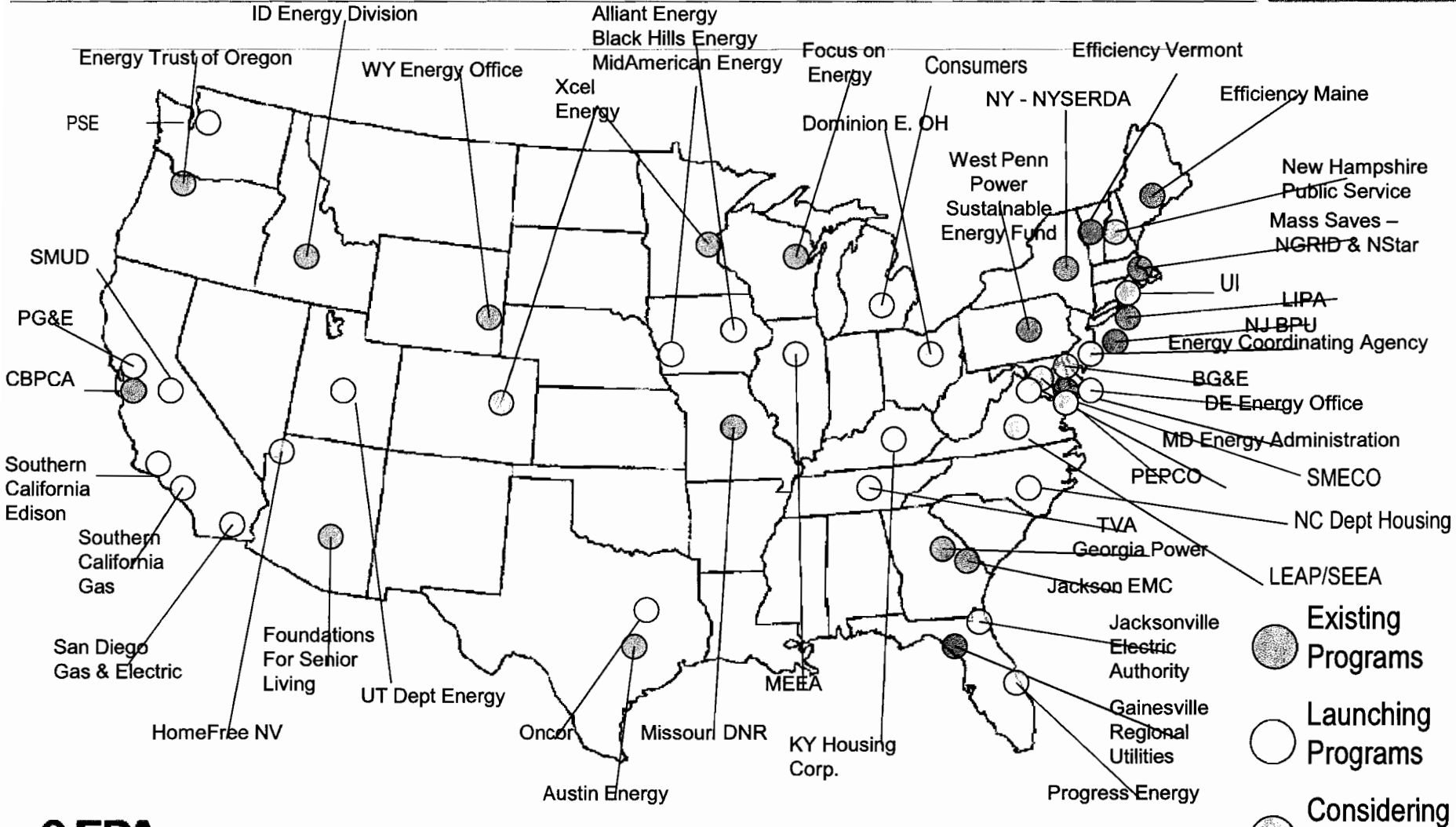
Home Performance with ENERGY STAR

- Sponsored by a utility, state or local gov't
- A network of specialty trained contractors
  - Comprehensive audit with diagnostic tools
  - Recommend a package of improvements that typically save 20% of total energy use
  - Ready to complete work – or provide contacts
  - Homeowner chooses and pays for work
  - Post-work performance test
- Sponsored delivered quality assurance

Components for a Successful HPwES Program

- Committed & trained contractors – without this, nada
- Program marketing – using multiple channels that are sustained, must raise awareness and make phone ring
- Incentives – both big and understandable, must drive comprehensive work
- Financing – both attractive and easy, ratchet to promote comprehensive work
- Job reporting – without this, nada
- Quality Assurance – protects everyone and ES logo

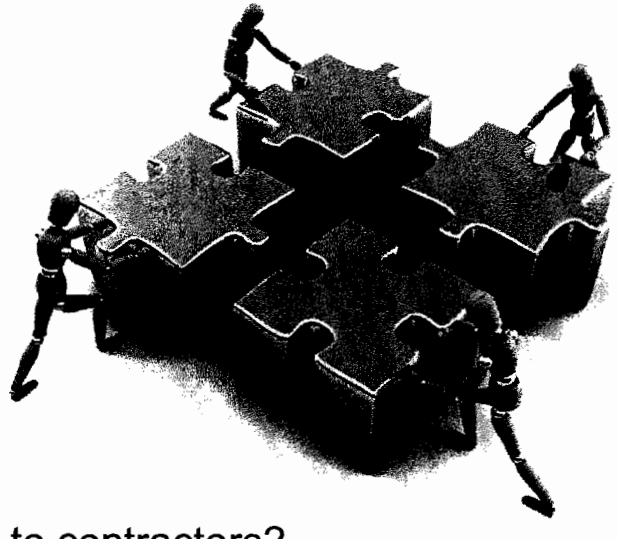
HPwES 2010 - Getting Busy



80,000+ homes improved!

Home Retrofit Program Elements

- **Goals, Budget, Stakeholders**
  - What do we want to accomplish? How will it be funded?
  - Who will lead? Who will compliment?
- **Standards**
  - Home Performance Assessment
  - Work quality
  - Test-out
- **Contractor Recruitment**
  - Who is qualified to do this work?
  - Training and certification



- **Quality Assurance**
  - How can I, in good faith, refer citizens to contractors?
  - Verifying work meets standards
- **Increasing Consumer Demand**
  - What is your message and how will homeowners hear it?
- **Financing**
  - How will homeowners afford these improvements?
- **Program Evaluation**

EPA

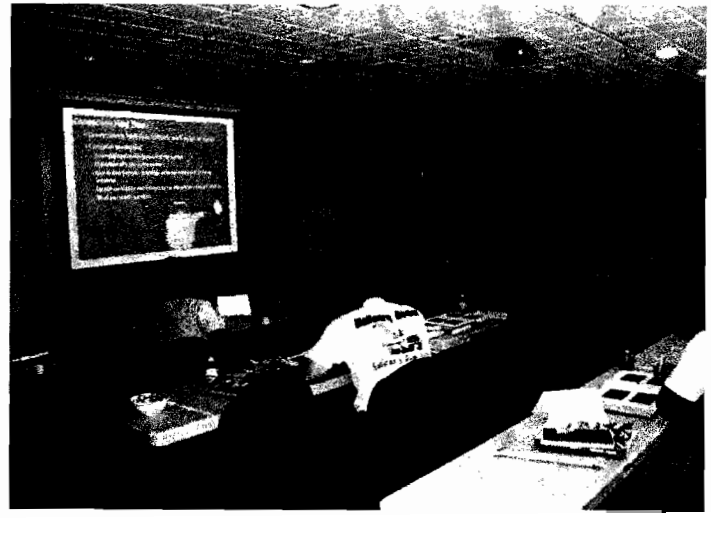
Sponsor Requirements

- Submit a plan (we have templates) – demonstrate capacity
  - Contractor competency / building
  - Savings estimating tools / data mgmt
  - Marketing plan / demand building
  - Budget and production goals

- Sign a Partnership Agreement
  - Agree to Reporting & QA requirements

Sponsor Must Build It

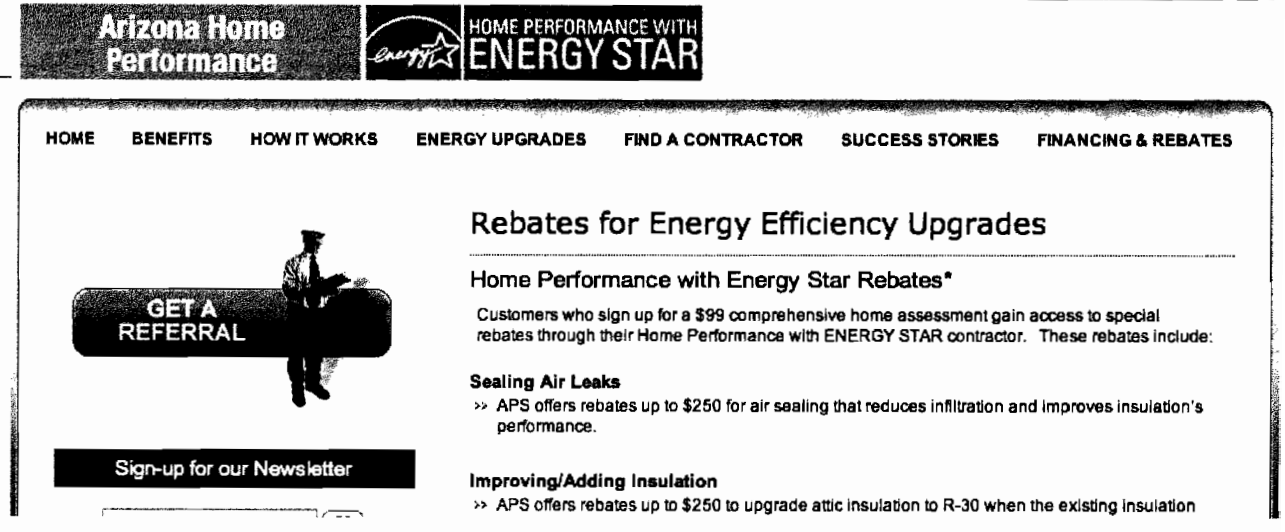
- Supply
  - Identify, recruit, train, certify, mentor participants
  - Reference training standards / define qualifications for program participation
  - Enable companies to differentiate themselves in the marketplace
  - Give them tools and resources to be profitable



EPA

Sponsor Must Build It

- **Demand**



  - **Educate homeowners – about energy usage, the program, and the process – leverage ENERGY STAR brand**
  - **Identify and overcome barriers to purchase**
    - **Cost of initial audit**
    - **Lower total costs via rebates**
    - **Enable homeowners to finance cost-effective solutions**

EPA

QA Sponsor Rigors

- Starts with trained workforce – understands program rules of engagement via signed Participation Agreement with sponsor
  - ENERGY STAR logo use guidelines policed

- Mentor contractors early – helps all parties

Sponsor Reporting Requirements

- Quarterly reports – jobs done, site inspections
  - Key is getting right carrot for contractors to submit jobs! Make reporting easy…
- Year-end summary – will serve as application for national ENERGY STAR award recognition

EPA

Quality Assurance

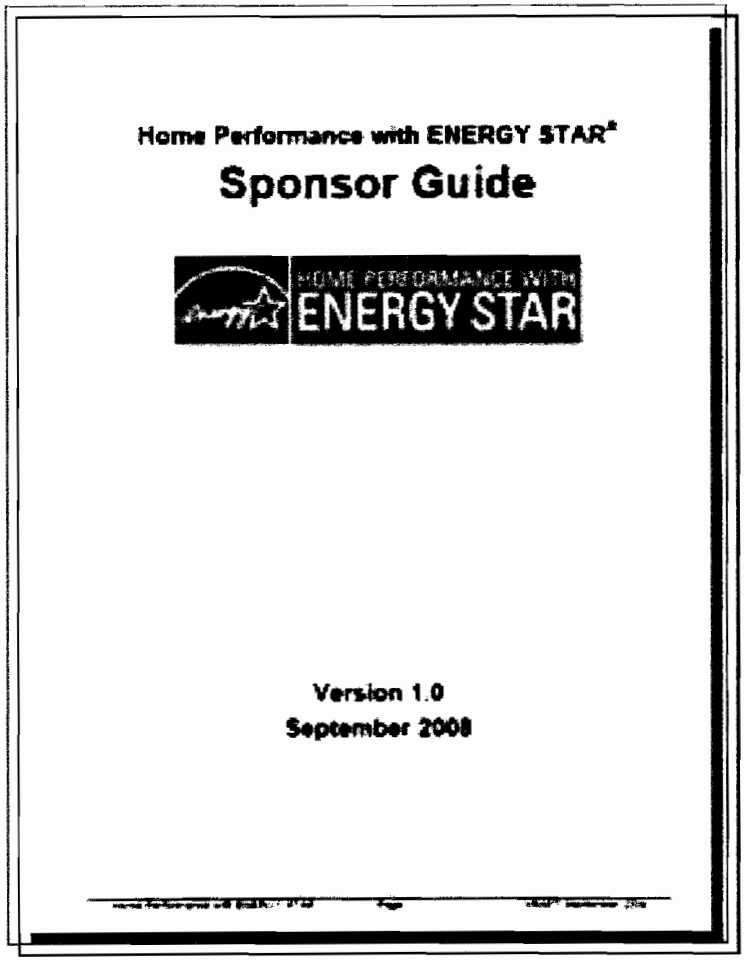
- Essential to achieve program success
  - Energy savings - software
  - Credibility/reputation
- Requirements
  - Contractor participation agreement
  - 100% job reporting (electronic encouraged)
  - 100% job report review
  - 5% onsite inspection (1 in every 20 jobs)
    - Tier 1 – 3 of first 5 jobs will be inspected or mentored
    - Tier 2 – 20% of next 20 jobs inspected
    - Tier 3 – 5% of all jobs inspected
  - Customer satisfaction survey

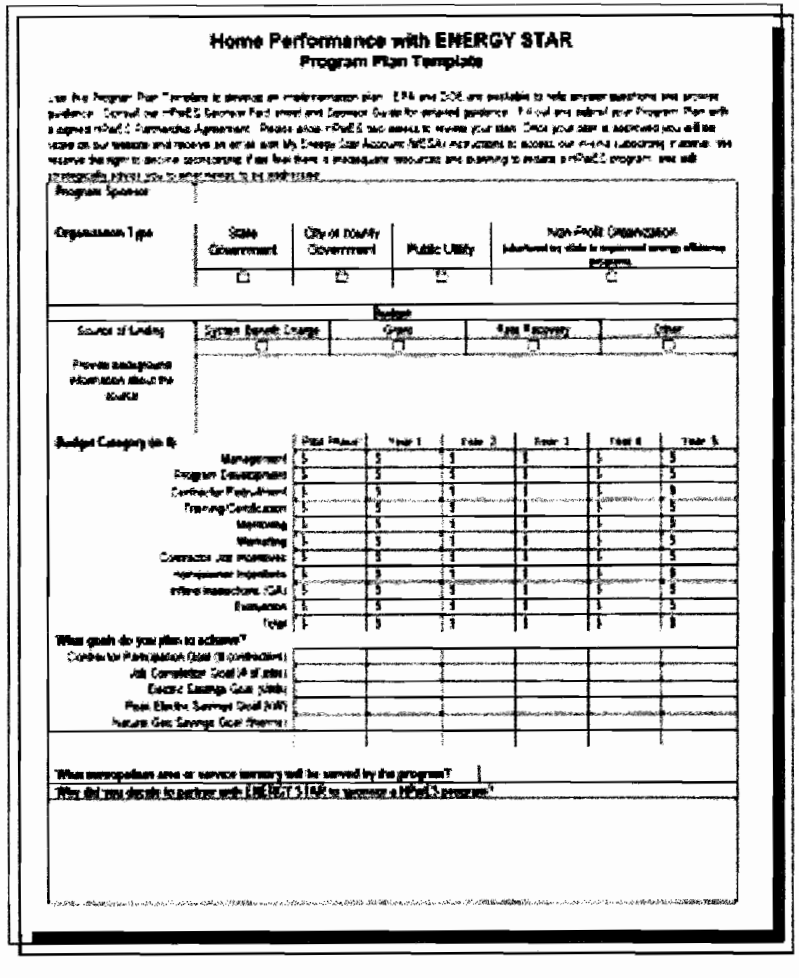
Contractor Tests After Improvements to Verify Results

- Diagnostic testing (after work)
  i.e. Air infiltration, HVAC air flow, duct leakage, combustion safety testing
- Feedback to
  - the contractor
  - the homeowner
  - the program administrator
- Verified improvements and persistent energy savings

EPA

Planning -- We can Help

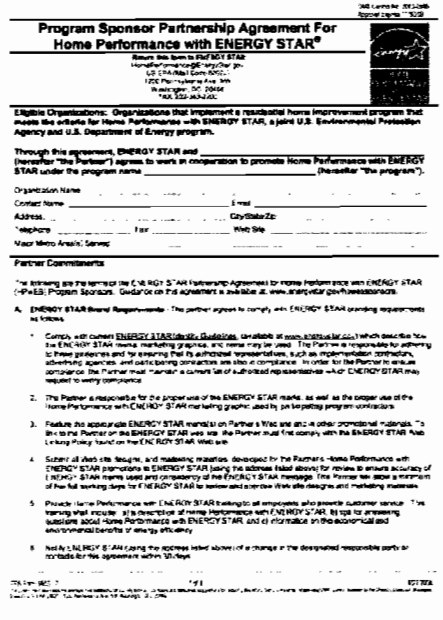




Download Sponsor Guide and Program Plan Template from web site to help with planning

Program Elements

- Planning (goals, budget, stakeholders)
- Standards
  - Comprehensive Home Assessment
  - Work quality
  - Test-out
- Contractor Recruitment, Training & Certification
  - Who is qualified to do this work?
- Quality Assurance
  - Verifying work meets standards
- Increasing Consumer Demand
- Program Evaluation



Program Sponsor Partnership Agreement For Home Performance with ENERGY STAR®

Download
Sponsor Guide and
Program Plan Template
from web site to help with planning

Funding – Beyond Grants

- Leverage short-term funding to build long-term relationships
- Establish long-term funding infrastructure

  Resources

  – *Advancing State Clean Energy Funds*

  http://www.epa.gov/RDEE/documents/clean_energy_fund_manual.pdf

  – *Who Should Pay for Raterpayer Funded Energy Efficiency Programs*

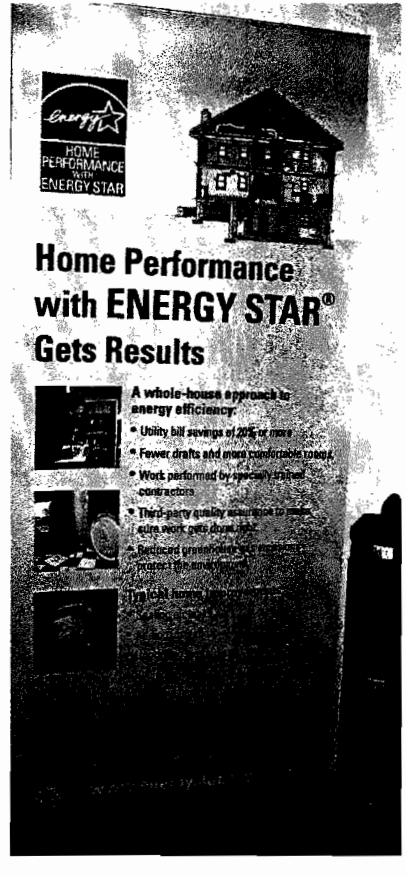
  http://www.raponline.org/Pubs/RatePayerFundedEE/RatePayerFundedEEPartI.pdf

  - Build utility connections as future funding source – demonstrate savings are real and substantial

I hope they realize how important this is.

Don't "reinvent the wheel" Partner with ENERGY STAR

- Program Development
  - One-on-one Assistance
  - Sponsor Guide
  - RFP Sample Language
- Promotional Video
- Website Templates
- Consumer Brochure
- Promotional Banner Stands
- Online Marketing Toolkit
  - Advertising templates
- Contractor Business Development Guide
- Contractor Recruitment Workshops
- Contractor Sales Workshop
  - Sales Book Template
  - Bill Analysis Tool



Home Performance with ENERGY STAR:
Marketing Tools for Sponsors and Contractors

EPA and DOE provide a variety of materials to help program sponsors and participating contractors educate homeowners about making their homes more energy efficient, reducing high energy bills, improving comfort, and protecting the environment through Home Performance with ENERGY STAR (HPwES). Take advantage of these available tool and resources:

HOME PERFORMANCE WITH ENERGY STAR MARKETING GRAPHIC. Use this logo in advertising, signage, and promotional materials to associate your program or services with the nationally-recognized and trusted ENERGY STAR program.

MARKETING TOOLKIT. Use this online tool to create highly-customized marketing materials that promote the value of HPwES to consumers. Available templates include print advertisements, direct mail postcards, val-pak inserts, fact sheets, yellow page ads, and web buttons and banners.

PROMOTIONAL VIDEO. Use this 7-minute video to explain the value of HPwES to homeowners. Consider showing the video on house calls, at local home shows, and on your web site.

HOME PERFORMANCE HOUSE GRAPHICS. These detailed graphics demonstrate the common problems found in many homes, and how HPwES can help to solve them.

PROMOTIONAL BANNERS. Use at trade shows, home shows, and other events. They are available for loan to sponsors and contractors; and graphics files are available to allow you to create versions with your own logo, web site, or other contact information.

BROCHURES. Provide homeowners with ENERGY STAR publications that reinforce the value of making energy-efficient home improvements, including the HPwES consumer brochure, Guide to Energy Efficient Heating & Cooling, Seal & Insulate with ENERGY STAR, Duct Sealing, and other brochures about ENERGY STAR qualified lighting, appliances, and home electronics.

HOME ENERGY YARDSTICK. Host this tool on your web site to help homeowners compare their energy use to others across the country and help decide if they should take action to improve the efficiency of their home. The Yardstick can be a powerful tool for lead generation and customer screening.

Instructions for hosting online tools are available on the ENERGY STAR Web site www.energystar.gov; and hard copies of guides and brochures can be ordered free-of-charge at www.energystar.gov/publications.

Homeowner Education Through the Web

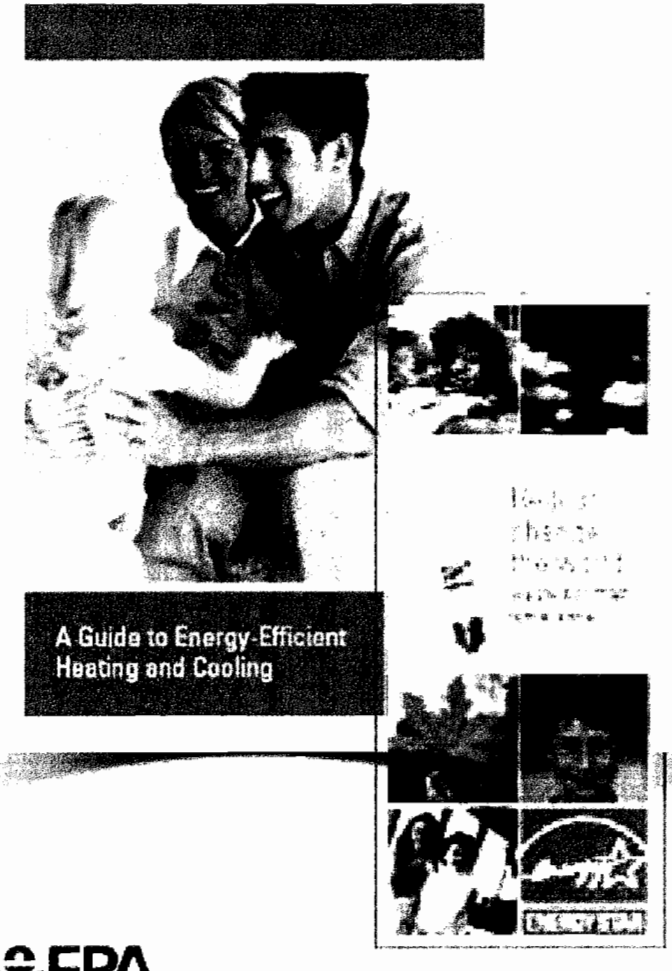
- ENERGY STAR @ Home
  Go room-by-room
  www.energystar.gov/home
  Can be hosted on your site

- Home Energy Advisor
  Make a plan
  www.energystar.gov/homeadvisor

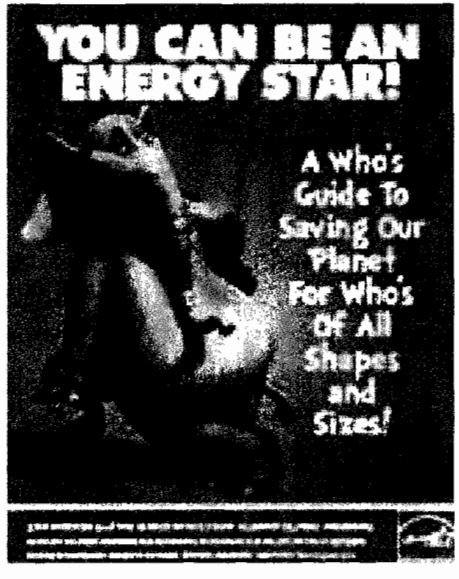
- Home Energy Yardstick
  Track your progress
  www.energystar.gov/yardstick
  Can be hosted on your site

ENERGY STAR Publications

Residential Resources



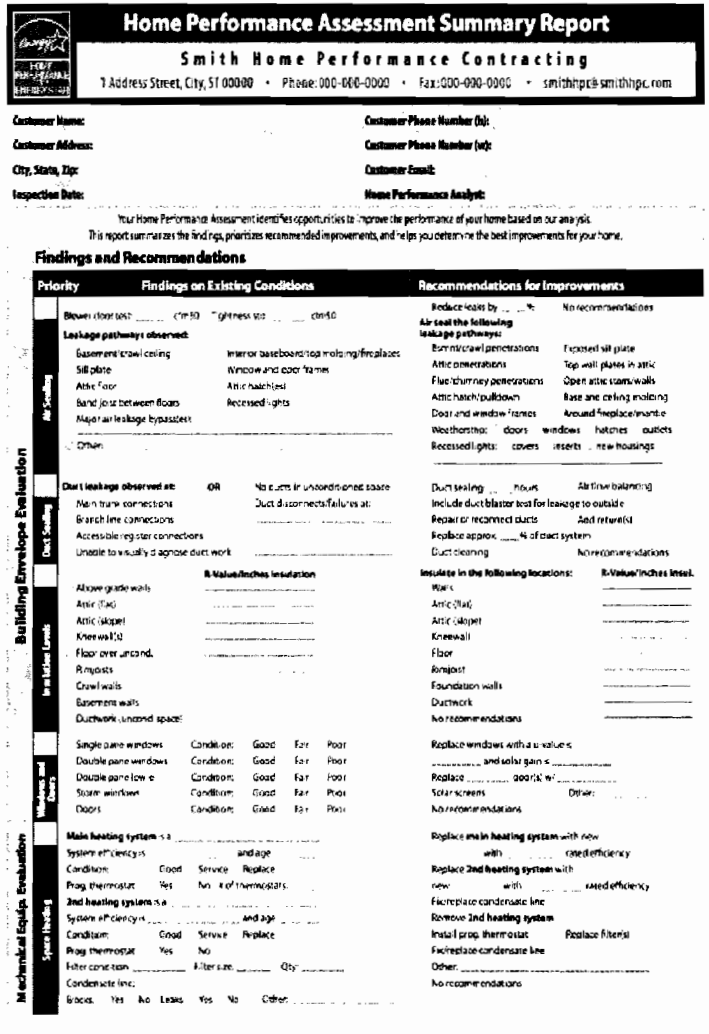
Educational Resources



www.energystar.gov/publications

EPA

Form Templates Available



Home Performance Assessment Summary Report

Smith Home Performance Contracting

1 Address Street, City, ST 00000 • Phone: 000-000-0000 • Fax: 000-000-0000 • smithhpc@smithhpc.com

Customer Name: **Customer Phone Number (h):**

Customer Address: **Customer Phone Number (w):**

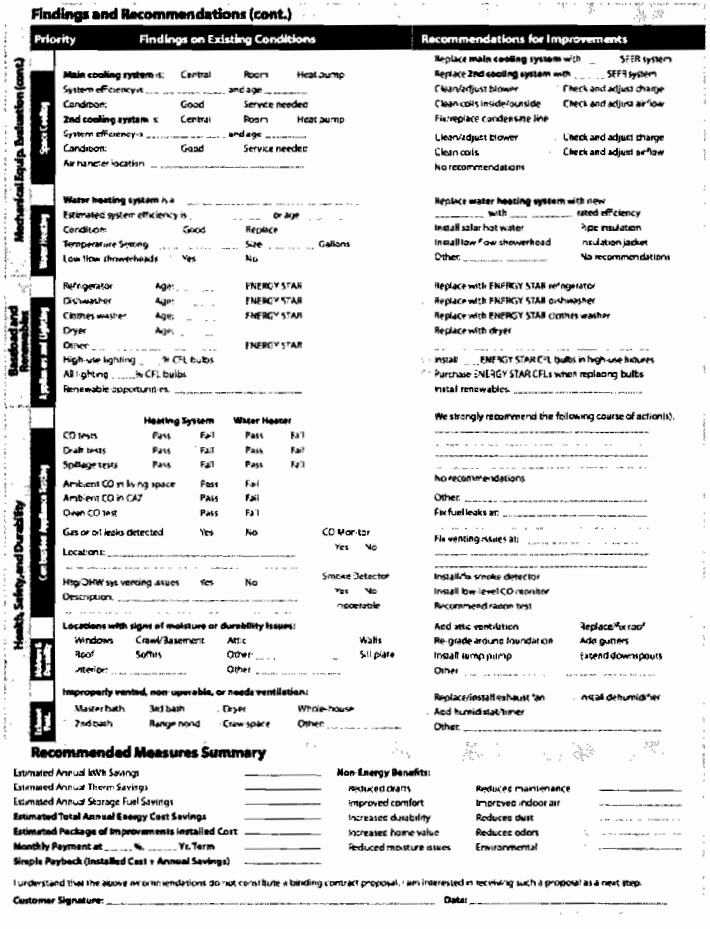
City, State, Zip: **Customer Email:**

Inspection Date: **Home Performance Analyst:**

Your Home Performance Assessment identifies opportunities to improve the performance of your home based on our analysis.
This report summarizes the findings, prioritizes recommended improvements, and helps you determine the best improvements for your home.

Findings and Recommendations

Priority	Findings on Existing Conditions	Recommendations for Improvements
Building Envelope Evaluation — Air Sealing	Blower door test ____ CFM50 Tightness ach ____ cfm50 **Leakage pathways observed:** Basement/crawl ceiling; Interior baseboard/top molding/fireplaces Sill plate; Window and door frames Attic floor; Attic hatch(es) Band joist between floors; Recessed lights Major air leakage bypasses:	Reduce leaks by ____%; No recommendations **Air seal the following leakage pathways:** Bsmt/crawl penetrations; Exposed sill plate Attic penetrations; Top wall plates in attic Flue/chimney penetrations; Open attic stairs/walls Attic hatch/pulldown; Base and ceiling molding Door and window frames; Around fireplace/mantle Weatherstrip: doors windows hatches outlets Recessed lights: covers inserts new housings
Duct Sealing	**Duct leakage observed at:** OR No ducts in unconditioned space Main trunk connections; Duct disconnects/failures at: Branch line connections Accessible register connections Unable to visually diagnose duct work	Duct sealing ____ hours; Air flow balancing Include duct blaster test for leakage to outside Repair or reconnect ducts; Add return(s) Replace approx. ____% of duct system Duct cleaning; No recommendations
Insulation Levels	**R-Value/inches insul.** Above grade walls Attic (flat) Attic (slope) Knee wall(s) Floor over uncond.	**Insulate in the following locations:** **R-Value/inches insul.** Walls Attic (flat) Attic (slope) Kneewall Floor
	Rim joists Crawl walls Basement walls Ductwork (uncond. space):	Rim joist Foundation walls Ductwork No recommendations
Windows and Doors	Single pane windows Condition: Good Fair Poor Double pane windows Condition: Good Fair Poor Double pane low-e Condition: Good Fair Poor Storm windows Condition: Good Fair Poor Doors Condition: Good Fair Poor	Replace windows with u-values ____ and solar gain ≤ ____ Replace ____ sq. ft. w/ ____ Solar screens Other: No recommendations
Mechanical Equip. Evaluation — Space Heating	**Main heating system** is a ____ System efficiency is ____ and age ____ Condition: Good Service Replace Prog. thermostat: Yes No # of thermostats: ____ **2nd heating system** is a ____ System efficiency is ____ and age ____ Condition: Good Service Replace Prog. thermostat: Yes No Filter condition: ____ Filter size: ____ Qty: ____ Condensate line: Ducts: Yes No Leaks: Yes No Other:	Replace **main heating system** with new ____ with ____ rated efficiency Replace **2nd heating system** with new ____ with ____ rated efficiency Fix/replace condensate line Remove **2nd heating system** Install prog. thermostat; Replace filter(s) Fix/replace condensate line Other: ____ No recommendations



Findings and Recommendations (cont.)

Priority	Findings on Existing Conditions	Recommendations for Improvements
Mechanical Equip. Evaluation (cont.) — Space Cooling	**Main cooling system** is: Central Room Heat pump System efficiency is ____ and age ____ Condition: Good Service needed **2nd cooling system** is: Central Room Heat pump System efficiency is ____ and age ____ Condition: Good Service needed Air handler location: ____	Replace **main cooling system** with ____ SEER system Replace **2nd cooling system** with ____ SEER system Clean/adjust blower; Check and adjust charge Clean coils inside/outside; Check and adjust airflow Fix/replace condensate line Clean/adjust blower; Check and adjust charge Clean coils; Check and adjust airflow No recommendations
Water Heating	**Water heating system** is a ____ Estimated system efficiency is ____ or age ____ Condition: Good Replace Temperature Setting ____ Size ____ Gallons Low flow showerheads: Yes No	Replace **water heating system** with new ____ with ____ rated efficiency Install solar hot water; Pipe insulation Install low flow showerhead; Insulation jacket Other: ____; No recommendations
Appliances and Lighting — Refrigerator	Age: ____ ENERGY STAR	Replace with ENERGY STAR refrigerator
Dishwasher	Age: ____ ENERGY STAR	Replace with ENERGY STAR dishwasher
Clothes washer	Age: ____ ENERGY STAR	Replace with ENERGY STAR clothes washer
Dryer	Age: ____	Replace with dryer
Other: ____	ENERGY STAR	____
High-use lighting ____% CFL bulbs		Install ____ ENERGY STAR CFL bulbs in high-use fixtures
All lighting ____% CFL bulbs		Purchase ENERGY STAR CFLs when replacing bulbs
Renewable opportunities: ____		Install renewables: ____
Combustion Appliance Safety	**Heating System** Pass Fail **Water Heater** Pass Fail CO tests Pass Fail Pass Fail Draft tests Pass Fail Pass Fail Spillage tests Pass Fail Pass Fail Ambient CO in living space Pass Fail Ambient CO in CAZ Pass Fail Oven CO test Pass Fail Gas or oil leaks detected: Yes No CO Monitor Yes No Location: ____ Htg/DHW sys venting issues: Yes No Smoke Detector Yes No recordable Description: ____	We strongly recommend the following course of action(s): ____ No recommendations Other: ____ Fix fuel leaks at: ____ Fix venting issues at: ____
Health, Safety, and Durability — Moisture Issues	**Locations with signs of moisture or durability issues:** Windows Crawl/Basement Attic Walls Roof Soffits Other: ____ Sill plate Interior: ____ Other: ____	Add attic ventilation; Replace/fix roof Re-grade around foundation; Add gutters Install sump pump; Extend downspouts Other: ____
Other Tests	**Improperly vented, non-operable, or needs ventilation:** Master bath 3rd bath Dryer Whole-house 2nd bath Range hood Crawl space Other: ____	Install/fix smoke detector Install low-level CO monitor Recommend radon test Replace/install exhaust fan; Install dehumidifier Add humidistat/timer Other: ____

Recommended Measures Summary

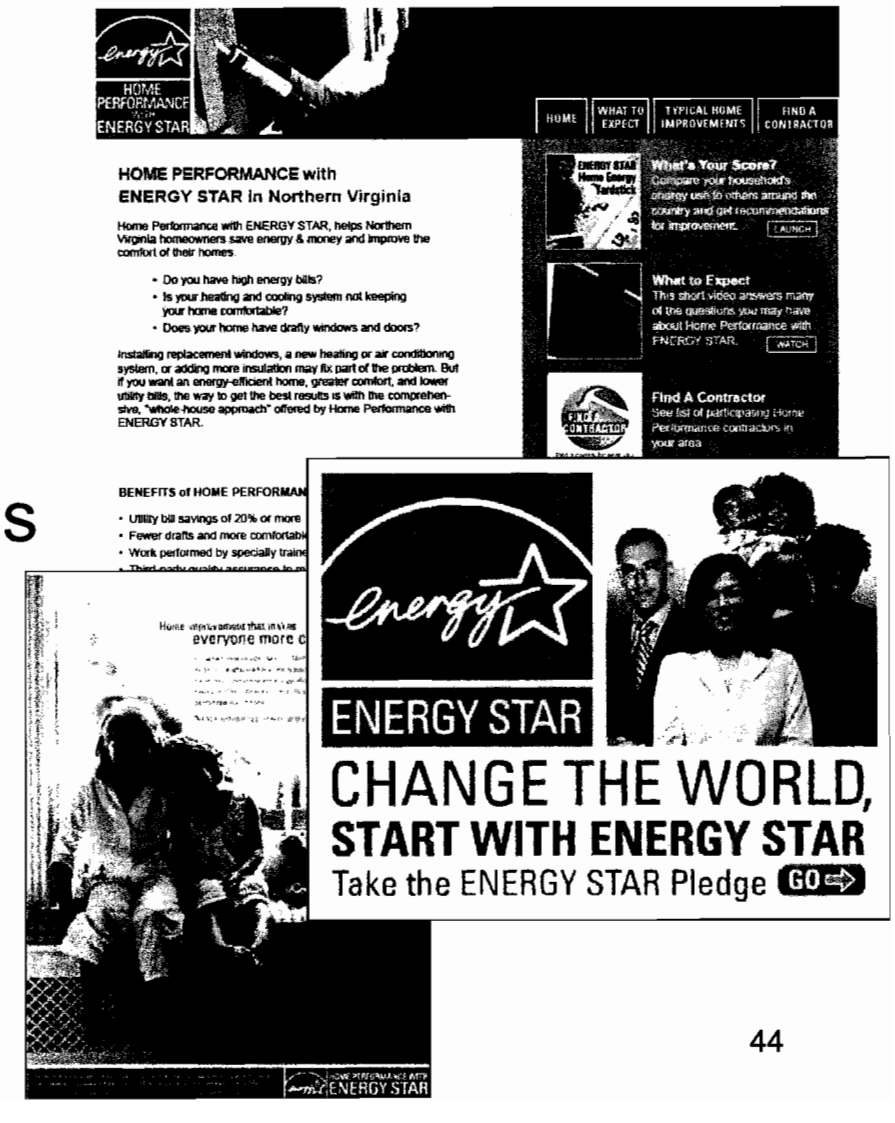
Estimated Annual kWh Savings	____	**Non-Energy Benefits:**	
Estimated Annual Therm Savings	____	Reduced drafts	Reduced maintenance ____
Estimated Annual Storage Fuel Savings	____	Improved comfort	Improved indoor air ____
Estimated Total Annual Energy Cost Savings	____	Increased durability	Reduced dust ____
Estimated Package of Improvements Installed Cost	____	Increased home value	Reduced odors ____
Monthly Payment at ____%, ____ Yr. Term	____	Reduced moisture issues	Environmental ____
Simple Payback (Installed Cost ÷ Annual Savings)	____		

I understand that the above recommendations do not constitute a binding contract proposal. I am interested in receiving such a proposal as a next step.

Customer Signature: ____ **Date:** ____

Increasing Consumer Demand

- Marketing
  - Website
  - Consumer education
  - Advertising
  - Grass-roots campaigns
- Public Relations
- Incentives



MO Example - Efficiency Investment Substantial

- 1,364 jobs reported by MO DNR for 2009
- $7,000 average job
- $9,500,000 invested improvements by MO homeowners by MO based firms
- At 20% savings – approximately $400 yr per home served, total MO homeowners saved over $500,000 – and these savings will continue

Home Performance with ENERGY STAR : ENERGY STAR

YOUR HOME CONTRIBUTES TO
THE QUALITY OF OUR ENVIRONMENT
U.S. Environmental Protection Agency U.S. Department of Energy

About ENERGY STAR News Room FAQs Search Go

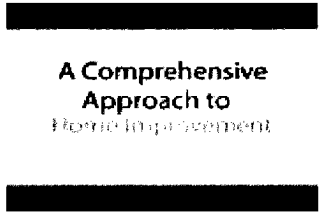
Products | Home Improvement | New Homes | Buildings & Plants | Partner Resources

- Home Improvement
- Common Home Problems
- Home Energy Yardstick
- Home Energy Audits
- Air Seal & Insulate
- Heat & Cool Efficiently
- Home Performance with ENERGY STAR
  - Locations
  - For Sponsors
- Home Improvement FAQs
- For Contractors
- For Insulation Manufacturers

Join ENERGY STAR

Home > Home Improvement > Home Performance with ENERGY STAR

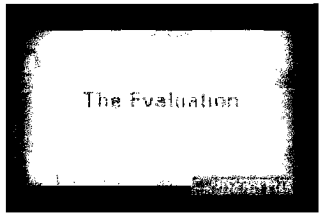
Home Performance with ENERGY STAR Video: A Comprehensive Approach to Home Improvement



Chapter 1: A Comprehensive Approach to Home Improvement

Length: 1:09

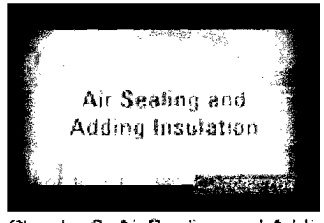
Captioned Version

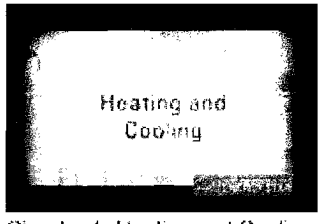


Chapter 2: The Evaluation

Length: 1:05

Captioned Version

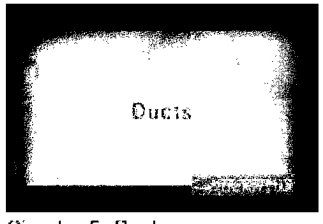




Chapter 4: Heating and Cooling

Length: 0:39

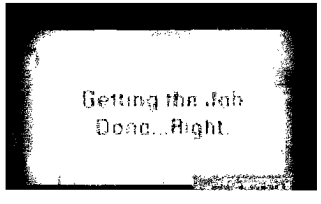
Captioned Version



Chapter 5: Ducts

Length: 0:41

Captioned Version



Residential Programs

Austin Energy awarded:

PARTNER OF THE YEAR

&

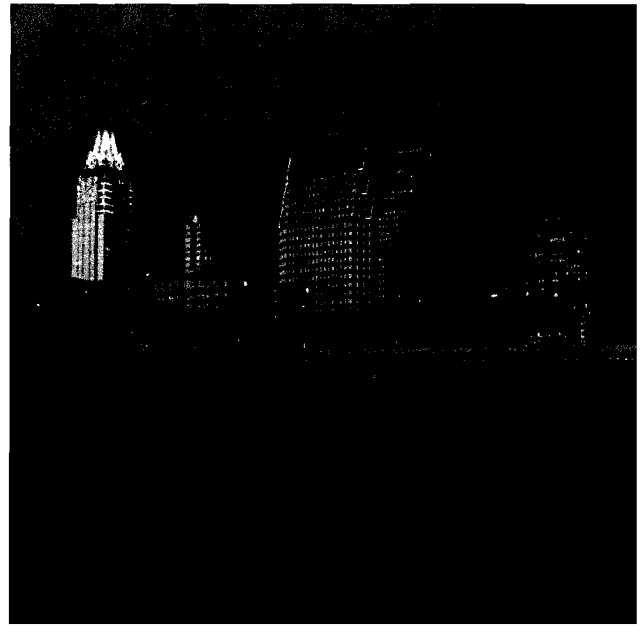
Sustained Excellence Award
2007-2010

EPA

Overview

Austin Energy – Austin, Texas

- Municipal-Owned Electric Utility
  - *10th Largest Municipal Utility*
- Serves > 888,000 Population
  - *320,000 Residential*
  - *40,000 Commercial*
- Generation – 3,170 MWs
  - *Coal 35%, Nuclear 28%, Gas 28%, Purchase Power 5%, Renewable 4%*



Residential Program

Program Offerings

- – Home Performance with ENERGY STAR ®
- • Rebates
- • Loans
- – Solar Shading
- – Attic Insulation
- – Radiant Barrier
- – Duct Sealing, Replacement & Testing

Residential Program

Program Offerings (cont.)

– Air Infiltration
- Comprehensive
- System Performance

– HVAC Replacement
- Package Units
- Central Split Systems

Residential Programs

Home Performance with ENERGY STAR®

System Replacement: (Package & Split)
14.0 SEER-11.5 EER or Greater
Air Conditioning/Heat Pumps
Rebates from $300 up to $600

Attic Insulation-R Value of 38
Add R Value x attic sq. ft. x $0.0035 x $45= Rebate

Radiant Barrier: $0.10 per sq. ft.

Solar Screens, Film, Low E Glass ($1.00 per square ft.)
South, West, East 1 hour or more-40% of window

EPA

Residential Programs

Comprehensive

Duct Replacement 50% or less of duct work

$1.75 per linear ft.

Duct Insulation

$1.25 per linear ft.

Duct Sealing

$0.12 per sq. ft.

Test out: Blower door, back draft and duct blaster is required

System Performance

- Duct Replacement 50% or more of duct work & Window A/C units are converted to a central A/C system
  - $1.75 per linear ft.
- Duct Insulation:
  - $1.25 per linear ft. (wrap)
  - $0.30 per linear ft (drape or bury)
  - $200 Each System
  - $50 per New Return Air Improvement

Residential Program

Loan Options

- Velocity Credit Union
- 0%-6.0% APR Unsecured Loans
- 3-10 Year Term Options
- Single Family-Duplex Properties Eligible
- Up to $11,000

Participation & Energy Savings 2005-2009

Year	2005	06	07	08	09
Participants	1,399	1,731	1,960	2,436	2,654
MW	2.4	2.5	3.1	4.02	4.43
MWh	2,810	3,610	3,382	4,390	4,864

Questions ?

Matthew Phillips

matthew.phillips@austinenergy.com

Phone # 512-482-5326

Financing – Making It Affordable

- Recent Innovations in Financing Clean Energy - SWEEP
  - http://www.swenergy.org/pubs/Recent_Innovations_in_Financing_for_Clean_Energy.pdf
- Guide to Energy Efficiency and Renewable Energy Financing Districts
  - http://www.ci.berkeley.ca.us/ContentDisplay.aspx?id=44262
- Financing Guidebook for Energy Efficient Program Sponsors
  - http://www.energystar.gov/ia/home_improvement/downloads/FinancingGuidebook.pdf
- ENERGY STAR Mortgage and Financing
  - http://www.energyprograms.org/energystar/lenders/lender_faq.html
- State-Sponsored Energy Efficiency Grant, Loan and Tax Credit Programs – EPC Issues Brief
  - http://www.energyprograms.org/briefs/0701-GrantLoanPrograms.pdf

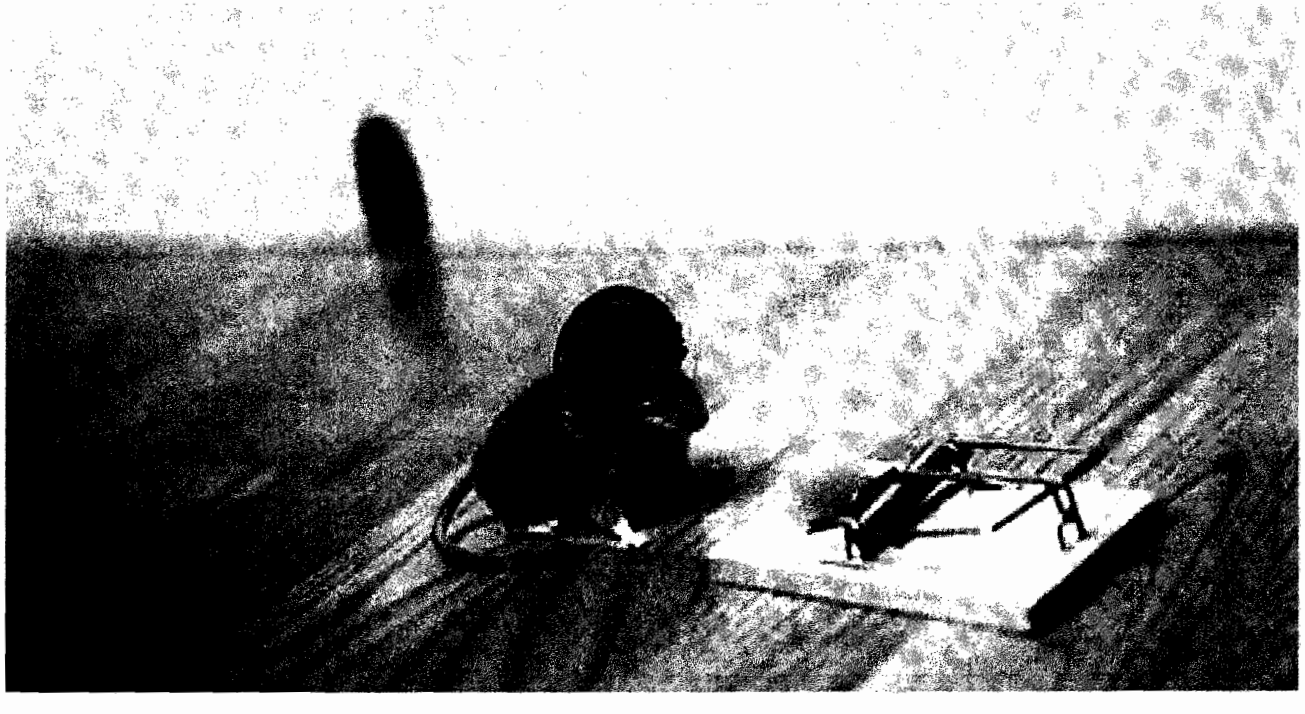
In Conclusion

- Home Performance is **the** right delivery – yet needs trained workforce, attractive incentives and a motivated sponsor
- Don't re-invent the wheel on existing home's efficiency programs – dial in
- Look to build infrastructure toward sustainability – leverage training resources and utilities
- Don't under-estimate marketing and consumer education needs

www.energystar.gov/hpwessponsors

EPA

Brave New World of Efficiency!



vonschrader.chandler@epa.gov

caseymurphy@icfi.com

LEARN MORE AT energystar.gov

ENERGY STAR®, a U.S. Environmental Protection Agency program, helps us all save money and protect our environment through energy efficient products and practices. For more information, visit www.energystar.gov.

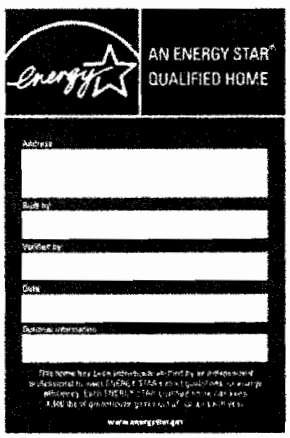
Independent Inspection and Testing

Helps Make Sure a Home is Energy Efficient

All new homes look great from the outside. But to make sure that your next new home is truly energy efficient, it's important to look "behind the walls." How can home buyers really be sure? Look for homes that have earned the ENERGY STAR—these homes have been inspected and tested by an independent Home Energy Rater. These professionals advise builders how to select the most appropriate energy-efficient features for a home; Raters inspect and test the home during and after construction to verify that the home meets EPA's strict guidelines for energy efficiency.

BENEFITS OF INDEPENDENT INSPECTION AND TESTING

- **Peace-of-Mind for Making a Smart Purchase.** Before buying a used car, consumers often take the car to a trusted mechanic not affiliated with the seller to have an expert verify its performance. This helps ensure they are making a smart purchase. Homebuyers can have similar peace-of-mind by looking for the ENERGY STAR label—typically located on a home's circuit breaker box. This label assures homebuyers that the home has been verified by an independent Home Energy Rater to be truly energy efficient. In addition to lowering monthly utility bills, the energy efficiency features typically found in ENERGY STAR qualified homes can also contribute to improved home durability and homeowner comfort.

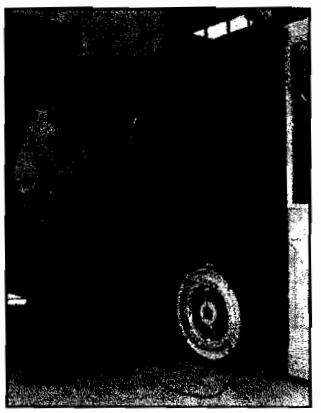


Look for the ENERGY STAR on the breaker box of your next home.

- **Climate-Specific Recommendations.** An energy-efficient home built in Florida would not necessarily be energy efficient if it were built in Michigan. For a home to be energy efficient, it must be designed for regional weather characteristics. Home Energy Raters are trained in climate-effective energy saving techniques, and their knowledge and field experience helps ENERGY STAR builder partners construct high-quality, energy-efficient homes.

- **Additional Inspections for Quality.** Homes that earn the ENERGY STAR typically undergo more inspections and testing than code-built homes. The ENERGY STAR verification process helps identify and correct mistakes before they are hidden behind the walls and holds builders constructing ENERGY STAR qualified homes to a higher standard. As a result, independent inspection and testing can help improve the quality and energy efficiency of a home.

HOW INSPECTION AND TESTING WORKS



Home Energy Rater performs a blower door test.

Home Energy Raters are trained to evaluate construction techniques, take key measurements, and perform inspections and testing procedures to verify a home's efficient performance. Here's how the process works:

Selection of Energy-Efficient Features. Raters help builders choose energy-efficient features for their ENERGY STAR qualified homes in two ways:

- With a **traditional Home Energy Rating**, a Rater simulates a home's energy use with specialized computer software. The results of this analysis allow the Rater to identify the most effective upgrades to meet ENERGY STAR performance guidelines.
- With a **Builder Option Package,** a Rater does not calculate the home's energy use. Instead, the builder and Rater use a set of climate-specific construction specifications developed by EPA called a Builder Option Package (BOP). Based on extensive analyses, the BOP specifications have been determined to result in homes that consistently meet ENERGY STAR guidelines.

Completion of Field Verification. Regardless of how the energy efficiency features are selected, Home Energy Raters must also conduct on-site inspections and testing of a home. This field verification ensures that energy-saving measures are consistent with ENERGY STAR guidelines. The process usually includes a blower door test (to test the leakiness of the house), a duct blaster test (to test the leakiness of the duct system), and completion of a thermal bypass checklist (a visual inspection of common construction areas where air can flow through or around insulation).

The standards for Home Energy Ratings, inspection protocols, and testing guidelines are maintained by the Residential Energy Services Network (RESNET). For more information, visit the RESNET Web site at www.resnet.us.

A BETTER FUTURE

ENERGY STAR is a voluntary partnership between the government and more than 9,000 organizations, including more than 3,500 of the nation's home builders. Together with home buyers and their families, we are working to achieve a common goal—protecting the environment for future generations by changing to more energy-efficient practices and products today.

ENERGY STAR is the government-backed symbol for energy efficiency. It identifies new homes, buildings, and more than 50 types of products that are energy efficient and offer the features, quality, and performance that today's consumers expect. Products that can earn the ENERGY STAR include windows, heating and cooling equipment, lighting, and appliances. To learn more about ENERGY STAR, visit www.energystar.gov.

EPA
United States
Environmental Protection
Agency

Financing Guidebook for Energy Efficiency Program Sponsors

December 2007

ENERGY STAR

TABLE OF CONTENTS

Executive Summary..... 1

Introduction..... 3

Home Improvement Spending in the United States..... 4

A. National Trends..... 4
B. Homeowner Investments in Energy Efficiency..... 6
C. Paying for Home Improvements..... 7

Energy-Efficiency Home Improvement Programs..... 9

A. Common Elements of Successful Programs..... 9

1. Comprehensive Home Assessments..... 9
2. Contractor Networks..... 10
3. Consumer Financing and Incentives..... 10
4. Marketing and Outreach..... 11
5. Post Installation Inspections and Quality Assurance..... 11

B. Setting Up a Financing Option..... 13

Energy Efficiency Program Summaries..... 14

A. MassSAVE HEAT Loan Program..... 14
B. Wisconsin Energy Conservation Corporation..... 15
C. New York State Energy Research and Development Authority..... 16
D. Austin Energy..... 17
E. Pennsylvania's Keystone Home Energy Loan Progam*..... 18
F. Southern California Gas Company and San Diego Gas & Electric*..... 19

Conclusions and Recommendations..... 20

Appendix A - Home Improvement Loan and Mortgage Products..... 21

*New program summaries added July 2008.

Executive Summary

American homeowners have spent record sums to upgrade their living space and increase the value of their prized asset. This guidebook provides an overview of the market trends and financial issues that affect homeowner expenditures on home improvements, and outlines the role efficiency programs and special financing can play in encouraging greater investment in energy efficiency. It is intended for program sponsors who may be considering the development of a new home improvement program, or are considering ways to improve an existing one. Key findings are outlined below.

American homeowners spend significant funds to improve their homes. U.S. home improvement spending grew five percent per year between 2000 and 2005.[1] In 2005, the latest year for which data are available, American homeowners spent an estimated $188 billion improving their homes.[2] This growth is being driven by several demographic and economic factors, including a steady rise in homeownership rates (especially among minorities); the continued aging of the U.S. housing stock; a growing preference for larger and more luxurious living spaces; and a trend among older baby boomers to upgrade their homes prior to retirement so they can age in place. Rising income levels and home prices, especially at the higher-end of the market, have provided the financial means for homeowners to pay for the desired improvements.[3]

Recent homebuyers are likely to make home improvements. Though homeowners make home improvement decisions in response to a number of different factors—such as equipment failure or the birth of a new child—one event known to spur significant expenditures is a home purchase. These improvements are usually made within the first two years of home ownership.

Energy-related improvements account for about 14% of home improvement spending. The most popular improvement projects include kitchen and bath remodels and room additions. However, in 2005 approximately 14% of expenditures ($23 billion) were directed toward improvements that affect energy use, such as HVAC replacements, new windows, and insulation.[4] Owners of older homes tended to spend more on these types of upgrades, on average, than owners of newer homes. Energy-related spending will likely increase as the U.S. housing stock ages and energy prices continue to climb.

Homeowners use a variety of options to pay for desired home improvements. Homeowners have demonstrated that they will spend money to improve their homes, both to enhance their quality of life and to increase the re-sale price of their home. The three most common sources of funds are the following:[5]

- Cash (63% of Expenditures). Over 85% of homeowners report using available cash to pay for at least some of their home improvement costs. The typical sources include savings or a sudden windfall such as a tax refund, bonus, or gift. Because no interest costs are incurred, cash is typically the least expensive method for financing a home improvement project.
- Home Equity (18% of Expenditures). As home prices have risen, many Americans have found themselves with significant equity in their homes. Homeowners can tap into this equity in a number of ways and use the proceeds to finance home improvements. This includes home equity loans, a home equity line of credit, or a cash-out refinance. Because such loans are secured by the home, interest rates tend to be lower than other types of loans. Any interest paid is also tax deductible, further reducing the net costs of these loans.
- Personal or Unsecured Debt (12% of Expenditures). Homeowners without cash or available home equity can borrow money using unsecured debt instruments. These include personal loans from a credit union, bank, or other lending institution, as well as credit cards. Unsecured financing has interest rates that are higher than home equity loans (because they are not secured), and the interest costs are not tax deductible.

[1] Joint Center for Housing Studies of Harvard University (JCHS), *Improving America's Housing 2007: Foundations for Future Growth in the Remodeling Industry* (2007).

[2] Ibid, Total U.S. remodeling spending in 2005 was approximately $280 billion; $188 billion of that was spent by homeowners on remodeling single and multi-family housing. The remainder was spent on general maintenance of and improvements to rental housing (p. 2, and Table A-1).

[3] For more information on these and other trends affecting home improvement spending, see the JCHS remodeling reports published in 2007 and 2005.

[4] JCHS, Harvard University (2007).

[5] JCHS, Harvard University. *Home Improvement Finance: Evidence from the 2001 Consumer Practices Survey* (October, 2003).

Sponsor-provided financing gives homeowners another option.
Some homeowners lack sufficient cash or home equity, to pay for desired upgrades. Faced with using credit cards or taking out a personal loan, some may decide to delay or downsize a project. Many energy-efficiency program sponsors work with lenders to offer special financing to homeowners who participate in their home improvement programs. This financing is typically structured as unsecured debt, with limits of up to $20,000, repayment periods up to 10 years, and starting interest rates similar to a personal loan (currently about 13%), though some program sponsors choose to reduce the effective interest rate offered to the homeowner by "buying down" the rate via a lump sum payment to the lender. This special energy-efficiency financing can be attractive to homeowners if the interest rate is lower than other options, or the borrowing process involves less hassle.

In addition, program-sponsored financing can make the difference for lower-income homeowners who may not have access to cash, home equity, or market-rate financing. Mainstream lenders typically will not issue them loans without special assurances from the program sponsor. Program sponsors can help address these barriers by offering special incentives or financing options targeted to these households. This could involve partnering with local community organizations, working with lenders approved by the Federal Housing Administration (FHA) to offer discounted FHA home improvement loans or streamlined 203(k) rehabilitation mortgages, or providing loan guarantees for select homeowners. Program sponsors can also form alliances with state energy-efficiency finance programs and housing finance programs to leverage resources to finance the incremental cost of efficiency improvements for lower income households.

Program sponsors can use special financing to improve overall program effectiveness.
Many homeowners do not *need* special program-provided financing to pay for energy improvements as they have accumulated savings and/or have access to attractive equity-based loan products. However, including special financing in an energy-efficiency program provides three important benefits for the program sponsor. First, when low interest rates are offered, special financing can be a promotional hook to attract homeowners' attention. By promoting a special deal, the program sponsor can interest homeowners in its efficiency program, and then begin to recruit their participation. Second, when structured as a simple transaction with limited paperwork or time delays, special financing can help contractors close deals and encourage greater homeowner follow through. Third, program financing can be used to create a key financial connection among the program sponsor, the contractor, and the homeowner. It provides a mechanism for the program sponsor to achieve important program goals, such as requiring a comprehensive assessment, using only pre-screened and trained contractors, and installing recommended efficiency measures. Financing also provides a valid link for the program sponsor to conduct appropriate post-installation quality assurance and gather information for use in program evaluation.

Introduction

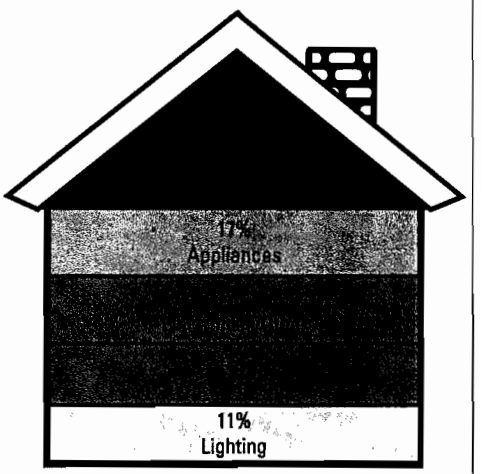
U.S. households typically use up to 30 percent more energy than necessary to achieve the desired level of performance and comfort.[6] This waste costs consumers money, stresses our energy supply systems, and unnecessarily creates air pollution from fossil fuels used to produce electricity. The impacts are local, national, and global, and the U.S. Government has increasingly recognized the need to improve the efficiency of existing housing in the United States.

The largest portion of household energy consumption—over 40 percent—goes toward warming the inside environment in the winter and cooling it in the summer.[7] Homeowners can dramatically reduce this seasonal energy consumption by installing new heating and cooling equipment; sealing and insulating heating, ventilating, and air conditioning (HVAC) duct work; and improving the building envelope with air sealing, insulation, and upgraded windows. These efficiency measures are proven, cost-effective, and provide numerous benefits for homeowners, including increased comfort and improved durability. Yet many homeowners have not embraced these measures and significant energy-savings potential remains to be captured.

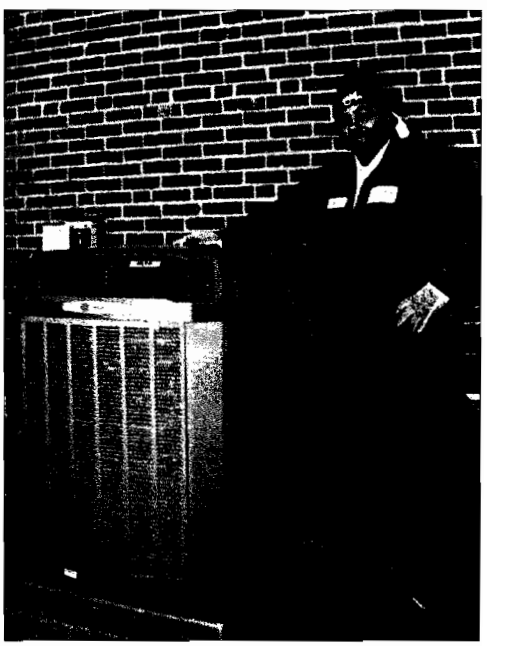
Nearly 100 utilities, states, and regional organizations—referred to here as energy-efficiency program sponsors—offer programs to spur consumer investment in heating- and cooling-related energy-efficiency improvements. Their home improvement programs range from simple to complex, and can include such elements as consumer education and outreach, technical assessments, contractor training, post-installation inspections, and financial incentives (often special energy-efficiency financing). Many homeowners have access to cash or market based financing and really do not need financial assistance from program sponsors to afford the efficiency upgrades. However, program sponsors have found that offering financing enhances the success of their programs by providing a marketing hook for consumers, serving as a platform for building a qualified contractor network, and providing a mechanism for gathering program evaluation data.

The purpose of this report is to help program sponsors understand how homeowners typically pay for home improvements, and the role special program financing can play in improving energy-efficiency programs. It provides background information on U.S. home improvement spending, identifies key sources of funds used to pay for improvements, outlines best practices in energy-efficiency home improvement program design, describes options for setting up a financing program, and provides summaries of six successful efficiency programs that have used financing in slightly different ways. Appendix A includes a more detailed overview of the various market-based loan products available to homeowners for financing home improvements.

MAJOR HOME ENERGY END USES



Source: *Building Energy Data Book*, U.S. DOE, 2007



[6] The U.S. Environmental Protection Agency (EPA) estimates that by using ENERGY STAR qualified products and services, U.S. households can reduce energy use up to 30 percent and save $600 a year on their utility bills without sacrificing comfort or performance.

[7] The U.S. Department of Energy, 2007 Building Energy Databook.

Home Improvement Spending in the United States

NATIONAL TRENDS

In 2005, over 20 million U.S. homeowners implemented over 50 million home improvement projects, spending an average of $9,080 per household.[8] The total spending of $188 billion was 36% more than in 2003. While growth slowed slightly in 2006, housing experts predict that the slowdown will be temporary.[9] This significant growth is being driven by a number of social and economic factors.

First, the U.S. housing stock is aging (average age is 31 years), and homeowners must invest continually to maintain their homes. This leads to a steady stream of spending on roof replacements, electrical upgrades, and plumbing repairs. Second, homeowners have increased wealth—either from increased income or rising home equity—and many are choosing to spend some of that wealth on their home. In fact, the largest share of home improvement spending, and the area of the biggest growth, is discretionary projects designed to enhance aesthetics or quality of life, such as kitchen and bath remodels and room additions (See Table 1 for more details). Changes in cultural attitudes, such as a preference for larger living spaces and an increased focus on the home as a place to entertain friends and family, have also fueled the volume of remodeling and expansion projects.

Americans of all types take on home improvement projects, but two groups are responsible for the greatest spending: wealthy homeowners and baby boomers. Wealthier households are more likely to implement high-end projects, and they thus spend more per household than other homeowners. Owners of higher-end homes (valued over $400,000) made up 17% of all homeowners, but were responsible for 41% of home improvement expenditures in 2005 (see Table 2). Baby boomers are investing heavily due to increased wealth and a desire to upgrade their homes for retirement. In 2005, baby boomers represented 45% of all homeowners but accounted for 54% of all expenditures. They are the wealthiest generation ever, and many are upgrading their homes with a desire to age in place. Even as the oldest baby boomers settle into retirement, spending by younger boomers (born 1955–1964) is expected to remain strong for years. A third group worth noting is recent homebuyers, who make up 18% of homeowners but account for 36% of home improvement projects. Homebuyers often make major improvements within a year or two of moving into a house. Recent research indicates that about 75% of homebuyers identify a list of desired projects at the time of purchase, and almost 90% work on these improvements within a year of moving in.[10] Buyers who trade up are more likely to undertake larger, more expensive projects than first-time buyers.

TABLE 1. HOME IMPROVEMENT EXPENDITURES BY U.S. HOMEOWNERS (2005)

TYPE OF IMPROVEMENT	NUMBER OF PROJECTS	EXPENDITURES
Remodeling (kitchen, bath, room additions)	7.2 million	$69.8 billion
Interior and exterior replacements (roofing, siding, window/doors, insulation, flooring)	17.6 million	$51.4 billion
Property improvement (garage, driveway, retaining walls, etc.)	6.5 million	$30.9 billion
Systems and equipment replacement (plumbing, electric, HVAC, appliances)	17.8 million	$19.5 billion
Other improvements (porch/deck addition, disaster repair, other)	2.6 million	$16.7 billion
TOTAL	51.7 million	$188.3 billion

Source: *Foundations for Future Growth in the Remodeling Industry*, JCHS, Harvard University, 2007. Table A-1.

[8] JCHS, Harvard University, 2007. Figures include single-family and multifamily owner-occupied housing.
[9] Ibid.
[10] JCHS, Harvard University. *Measuring the Benefits of Home Remodeling*. 2003. p.10, referring to a survey conducted by Hanley-Wood.

TABLE 2. DEMOGRAPHICS OF HOME IMPROVEMENT EXPENDITURES (2005)

	TOTAL HOMEOWNERS		HOMEOWNERS REPORTING PROJECTS		TOTAL EXPENDITURES		AVG. SPENDING PER HOUSEHOLD
	(000s)	(%)	(000s)	(%)	($ Millions)	(%)	($)
TOTAL	**74,293**	**100%**	**20,742**	**100%**	**188,345**	**100%**	**$9,080**
Annual Income							
Under $40,000	26,315	35%	6,242	30%	$38,425	20%	$6,156
$40-80,000	24,894	34%	7,209	35%	$49,069	26%	$6,807
$80-120,000	13,043	18%	4,047	20%	$41,234	22%	$10,189
$120,000 and Over	10,010	13%	3,236	16%	$29,605	16%	$9,149
Home Value							
Under $100,000	21,581	29%	5,543	27%	$27,223	14%	$4,911
$100-150,000	12,339	17%	3,418	16%	$18,386	10%	$5,379
$150-200,000	9,657	13%	2,800	13%	$17,579	9%	$6,278
$200-250,000	6,611	9%	1,929	9%	$15,791	8%	$8,186
$250-400,000	11,698	16%	3,434	17%	$31,368	17%	$9,135
$400,000 and Over	12,406	17%	3,617	17%	$77,999	41%	$21,565
Age of Household Head							
Under 35	9,621	13%	2,778	13%	$19,369	10%	$6,972
35-44	15,339	21%	4,577	22%	$51,763	27%	$11,309
45-54	17,631	24%	5,201	25%	$58,104	31%	$11,172
55-64	13,962	19%	3,935	19%	$34,816	18%	$8,848
65 and Over	17,740	24%	4,251	20%	$24,294	13%	$5,715
Race							
White	59,159	80%	16,757	81%	$153,758	82%	$9,176
Black	5,953	8%	1,447	7%	$13,164	7%	$9,097
Hispanic	5,651	8%	1,610	8%	$10,606	6%	$6,588
Asian and Other	3,530	5%	927	4%	$10,817	6%	$11,669
Generation							
Echo (1975 and later)	5,398	7%	1,518	7%	$8,895	5%	$5,860
Gen X (1965-74)	12,769	17%	3,798	18%	$42,208	22%	$11,113
Younger Baby Boom (1955-64)	17,659	24%	5,212	25%	$56,939	30%	$10,925
Older Baby Boom (1945-54)	15,779	21%	4,590	22%	$45,000	24%	$9,804
Matures (1935-44)	10,822	15%	2,892	14%	$21,482	11%	$7,428
Pre-Depression (Before 1935)	11,865	16%	2,732	13%	$13,820	7%	$5,059

Data include single-and multi-family owner occupied housing.

Source: JCHS, Harvard University, *Foundations for Future Growth in the Remodeling Industry*, 2007.Table A-3

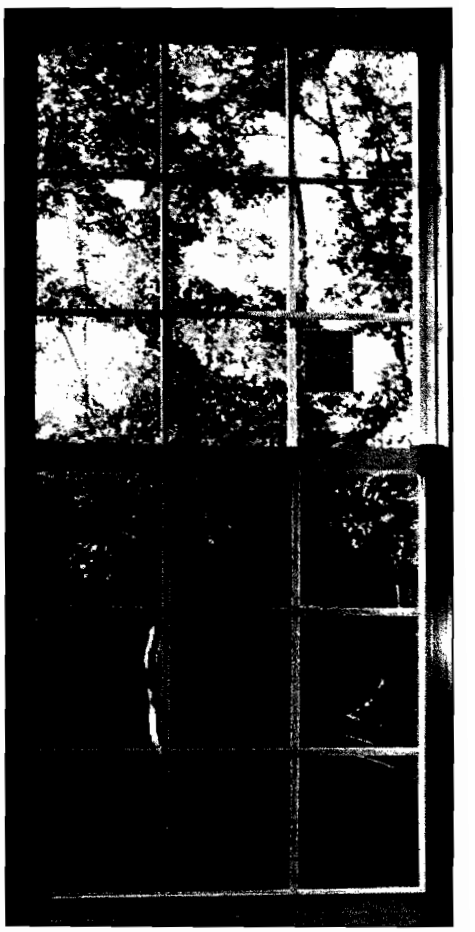
HOMEOWNER INVESTMENTS IN ENERGY EFFICIENCY

Every year U.S. homeowners replace aging heating and cooling systems and upgrade building shell components such as windows or insulation. In 2005, Americans spent $23 billion on these energy-related projects, up from about $15 billion in 1995.[11] While virtually all HVAC and window retrofits will increase efficiency compared to the old models they are replacing, market share data for ENERGY STAR qualified HVAC and windows indicate that many homeowners do not opt for the most energy-efficient choices when making replacement decisions. Program planners and policy makers tend to attribute this behavior to three commonly identified market barriers:

- Limited awareness or motivation. The majority of U.S. homeowners are unaware of the relative efficiency of their homes, what type of efficiency upgrades should be made, or how they would benefit. Even when aware, many consumers encounter conflicting priorities when determining which home improvement projects to address. Some homeowners choose to invest in aesthetic projects unrelated to energy efficiency (e.g., kitchen and bathroom remodeling, siding replacement, and wood flooring installation) over more mundane projects such as HVAC replacement or new insulation.

- Limited access to knowledgeable and qualified contractors. While there are many contractors who can install HVAC equipment or replace windows, relatively few are trained in the most energy-efficient design and installation practices. For example, many HVAC contractors neglect to perform an equipment sizing calculation before selecting a new air conditioner or furnace, and insulation contractors may not seal air leaks in the attic before laying down new insulation. Thus, when homeowners are making equipment replacement decisions, they may not be counseled effectively on the most energy-efficient options.

- Limited financial resources to pay for upgrades. Some homeowners lack cash and are unable or unwilling to take on additional debt. Others are restricted by low credit scores that hinder their ability to qualify for desirable financing. Approximately 27% of Americans have a credit score below 650, which puts them in a range less attractive to lenders and likely to limit their loan options or raise their interest rates.[12]



Future opportunities for energy efficiency investment are large. Two-thirds of the nation's housing stock is at least 25 years old, and the need for upgrading of systems and structures will provide opportunities to change out old HVAC systems and add insulation. Rising energy prices and growing concerns about climate change have made homwowners more aware of their energy consumption and more interested in finding ways to cut monthly utility bills. Consumer tax credits included in the 2005 Energy Policy Act have contributed to increased interest and encouraged actual investment. A survey conducted by a building products manufacturer found that 39% of homeowners planned to take advantage of the energy-efficient products tax credits in 2007—a significant increase from the 23% who reported that they took advantage of the tax credits in 2006.[13]

[11] JCHS, Harvard University. *Foundations for Future Growth in the Remodeling Industry.* 2007. Table A-10.

[12] MyFICO.com, the online consumer site of the Fair Isaac Company. FICO credit scores can range from 350 to 850, and the median score is 723.

[13] The 2006 Energy Efficiency Tax Credit survey of 1,040 American adults conducted for building products manufacturer Johns Manville by Opinion Research Corporation.

PAYING FOR HOME IMPROVEMENTS

Homeowners can pay for desired home improvements in a number of ways. The most commonly used source of funds is savings, followed by home equity and unsecured credit (see Table 3). The various funding options for homeowners, along with their particular advantages and disadvantages, are outlined below (see Appendix A for more details):

- Savings. Many homeowners withdraw funds from their savings accounts or mutual funds, or apply a tax refund, bonus, or gift to pay for home improvements. Using cash or savings is typically the least expensive way to pay for a project—since no interest costs are involved—and it tends to be the preferred choice for homeowners who have funds available.
- Home equity loan. For homeowners with equity in their homes, borrowing on that equity can be an easy and relatively low-cost way to finance improvements. Formerly called a second mortgage, home equity loans commonly carry fixed interest rates over 5, 10 or 15-year terms. Approvals are usually quick and fees minimal. For more flexibility and even faster access to funds, homeowners can use a home equity line of credit (HELOC). The interest rate for a HELOC is variable, but borrowers can pay off the balance whenever they want as long as they continue to make regular interest payments. The interest on home equity loans and HELOCs is tax deductible, and this helps reduce the net interest cost paid by the homeowner. Home equity loans and HELOCs have been growing in popularity, with total borrowing in 2005 estimated to be over $300 billion, compared to only $30 billion in 1995.[14] Experts estimate that anywhere from a quarter to a third of money borrowed through home equity loans or HELOCs is spent on home improvements.[15]

TABLE 3. HOMEOWNER EXPENDITURES ON REMODELING-BY SOURCE (2001)

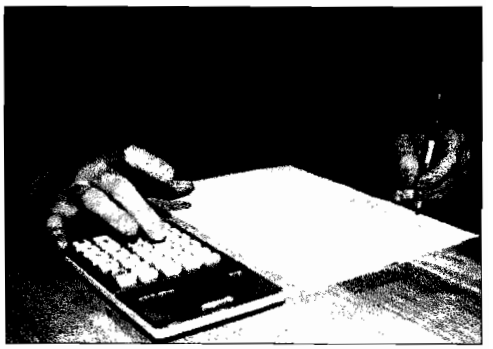
FUNDING SOURCE	SHARE OF HOMEOWNERS[16]	SHARE OF EXPENDITURES
AVAILABLE CASH (SAVINGS, TAX REFUNDS, GIFTS)	85.5%	63.4%
TOTAL HOME SECURED CREDIT	7.0%	17.7%
Home Equity Loan	2.9%	7.4%
Home Equity Line of Credit	2.2%	4.7%
Cash out Refinance	2.0%	5.5%
TOTAL UNSECURED CREDIT	22.1%	12.3%
Credit Card	20.2%	8.3%
Personal Loan	2.3%	4.1%
INSURANCE	5.1%	4.2%
OTHER	2.7%	2.5%
TOTAL	122.9%	100.0%

Source: JCHS, Harvard University. *Home Improvement Finance: Evidence from the 2001 Consumer Practices Survey* (October, 2003).

[14] Greenspan, A and James Kennedy. *Sources and Use of Equity Extracted from Homes* (2007).

[15] Ibid.

[16] Share of homeowners adds to more than 100% because some homeowners reported more than one source of funds for their projects.



- Mortgage refinance with cash out. Homeowners can also extract the equity in their homes and refinance at the same time. The interest rates can be the same as or slightly higher than regular mortgages, and are typically lower than home equity loans. However, there are often fees, or points, associated with a refinance, and many experts recommend this option only if a homeowner can take advantage of lower interest rates. Many homeowners have utilized this option, and Freddie Mac estimates that in 2006 homeowners extracted $318 billion in equity as part of a refinancing transaction - almost 3 times more than was extracted in 2002.[17] As with home equity loans, about one-third of the funds generated via cash-out refinances are spent on home improvements.[18]

- Rehabilitation Mortgage. Rehabilitation mortgages allow buyers of homes in need of repair to combine the home purchase and renovation costs in a single fixed-rate mortgage. These special loans can also be used for refinancing. One type of rehabilitation mortgage is the Federal Housing Administration's (FHA) streamline 203(k). This mortgage, offered only through FHA-approved lenders, can benefit cash-strapped homebuyers as it requires only a 3% down-payment.

- Energy Improvement Mortgage (EIM). The EIM allows borrowers to include the cost of energy-efficiency improvements in the mortgage at the time of sale or refinancing, without increasing the down-payment. EIMs are sometimes confused with EEMs, or energy efficiency mortgages, which are available to buyers of new homes that already meet specified energy-efficiency levels. EIMs are sponsored by federally insured mortgage programs (FHA and Veterans Administration) and the conventional secondary mortgage market (Fannie Mae and Freddie Mac). They can be beneficial for buyers of older homes in need of significant efficiency upgrades, but EIMs have not been widely used. Lenders familiar with EIMs cite several reasons for the low demand, including lack of lender and consumer awareness, the requirement to conduct a home energy assessment before obtaining the mortgage, and the need to establish a separate escrow account for the renovation funds.

- Personal unsecured loan. For homeowners without equity in their homes, taking out a personal loan can be a practical option. These loans can be originated through a bank, credit, union, or other type of financial institution. They are usually limited to no more than $35,000, and must be paid back within 10 years. Interest rates are typically higher than on secured home equity loans or lines of credit. Some lenders offer FHA Home Improvement Loans, which are backed with a federal loan guarantee and tend to have lower interest rates similar to a secured home equity loan.

- Credit card. Credit card debt is often subject to high compounding interest rates and is not usually a good way to finance major retrofits. Absent other alternatives, however, credit cards can be useful for smaller purchases or ones that the homeowner can pay off quickly.

- Contractor-originated lien contracts. Some contractors have arrangements with lending institutions that allow the contractor to offer loans called "lien contracts." Lien contracts involve placing a lien or deed of trust against a home, and if loan payments are not made the lender can foreclose on the property and sell it at public auction. If this happens, the homeowner rarely receives anything from the sale no matter how small the original debt. Because of numerous scams that have been perpetrated on unsuspecting homeowners, experts typically discourage consumers from using lien contracts.

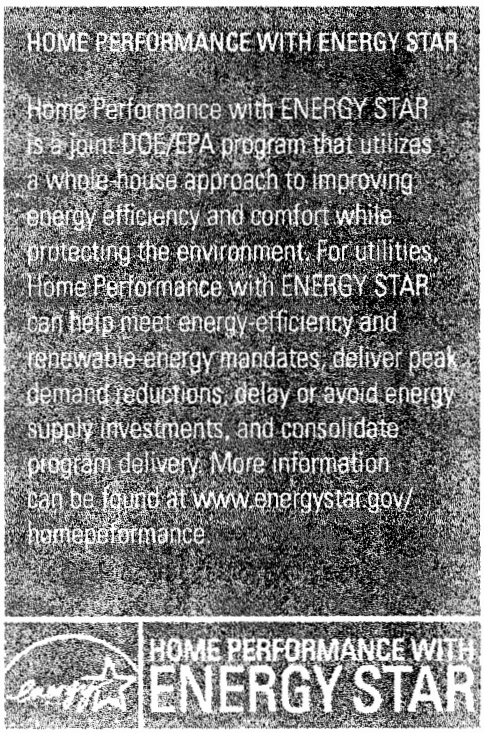
[17] Freddie Mac, Office of the Chief Economist. *Cash-out Refinance Report: 3Q2007* (2007).

[18] Greenspan, A and James Kennedy, *Sources and Use of Equity Extracted from Homes* (2007).

Energy-Efficiency Home Improvement Programs

COMMON ELEMENTS OF SUCCESSFUL PROGRAMS

Program sponsors around the country offer a wide variety of home improvement programs for their customers or constituents. The simplest may include a basic outreach campaign combined with a low-interest loan to attract homeowners. The most sophisticated programs may provide one-stop shopping, offering homeowners education, multiple financing options, and direct access to qualified contractors. Common elements of the most successful programs are outlined below.



COMPREHENSIVE HOME ASSESSMENTS

Energy-efficiency program sponsors began offering what were often called "energy audits" in the 1970s after rising energy costs increased consumer interest in energy consumption. The purpose of these audits was usually consumer education, and consisted of a simple survey of the home, recommendations for no- or low-cost improvements, and identification of more extensive upgrades that the homeowner could implement if desired. Sometimes the auditor provided educational materials and free energy-saving products, such as weather-stripping.

In recent years, these audits—or home energy assessments—have become much more comprehensive. Many program sponsors use them in their residential efficiency programs, both as a mechanism to attract participation, and as a means to enhance program cost-effectiveness by customizing the recommendations and incentives for each homeowner. Some program sponsors have a team of consultants that perform baseline checkups and then refer homeowners to qualified contractors. In other programs, participating contractors conduct the home energy assessment, allowing the homeowner to get the analysis and installation performed by a single entity.

The most well-known and nationally recognized home energy assessors are Home Energy Rating System (HERS) raters. HERS raters undergo training and are qualified under the Mortgage Industry National Home Energy Rating System Accreditation Standards, which set the national procedures for home energy ratings. HERS raters are trained and certified by training providers accredited by the Residential Energy Services Network (RESNET). A comprehensive HERS assessment will typically include a top-to-bottom walk-through of the home, use of a blower door to measure air leakage, use of a duct blaster to measure duct leakage, and the use of an infrared camera to detect cold and hot spots and air movement in the walls. The last step is to recommend cost-effective upgrades for the homeowner. This type of assessment can take two to three hours to complete and cost a few hundred dollars.

Some program sponsors will provide free assessments to homeowners to get their foot in the door. Unfortunately, there is mounting evidence that few homeowners actually make improvements after a free assessment. As a result, some program sponsors ask homeowners to contribute at least part of the cost for the assessment, which helps ensure that homeowners are more vested in the process and less likely to back out after the assessment is complete.

CONTRACTOR NETWORK

Many programs include a network of participating or eligible contractors who have undergone some level of training and/or pre-screening. Having an established contractor network helps program sponsors ensure that homeowners are satisfied with equipment installations, and that projected energy savings are achieved. It can take several years to develop and cultivate a good contractor network.

In addition to recruiting and signing up contractors, it is necessary to develop a training and certification system. Training can include both classroom and field sessions and should focus on building science principles, diagnostic testing, and proper installation techniques. Some program sponsors also offer training on sales techniques to help contractors promote energy-efficiency upgrades more effectively to homeowners.

To make sure training is effective, and to ensure contractors are performing adequately, programs can include written exams and field oversight. Some program sponsors set up a system for spot-checking a proportion of each contractor's jobs, and will remove from the program contractors who do not meet the established standards. Increasingly, large program sponsors are turning to outside organizations to assist with contractor certification and oversight. One such organization is the Building Performance Institute (BPI), which offers support for program sponsors who want to create a contractor network. BPI and RESNET are joining forces to create a certification that both BPI technicians and RESNET raters can qualify for—the Home Performance Analyst. Another option is to employ non-profit consumer advocate organizations to perform contractor screening. These organizations typically charge contractors to perform an independent screening of their licenses, bonding, insurance, financial integrity, and references. They can also provide complaint resolution services.

BUILDING PERFORMANCE INSTITUTE (BPI)

BPI is a non-profit organization formed in 1993 to provide third-party certifications of weatherization contractors. It now operates an integrated certification, accreditation, and quality assurance program for building industry professionals. BPI establishes technical standards and administers certification tests for technicians. It also accredits contracting firms that meet several criteria, including the employment of BPI certified technicians. Some program sponsors require that contractors be accredited by BPI to participate in their program. For more information on BPI, visit www.bpi.org.

HOMEOWNER FINANCING AND INCENTIVES

As mentioned previously, program sponsor financing is not essential in helping homeowners pay for improvements—many homeowners can access cash or various market-based financing—but it is an important element of good program design. Program sponsors who include financing and/or rebates in their programs can attract interest from homeowners at all income levels and reduce the upfront cost of investing in efficiency measures. Financing is a beneficial mechanism for defining what measures the homeowner installs and who they hire to do the installation, thereby helping program sponsors improve energy savings and cost effectiveness of their programs. Program sponsors typically require that homeowners who take advantage of their energy-efficiency financing or rebates use participating contractors to do the installation work. In addition, many require that only efficiency measures identified during a home energy assessment are eligible for rebates or inclusion in a loan package.

There are three general types of financial incentives offered by program sponsors:

1. A special loan (either market rate or at a reduced interest rate)
2. A lump-sum rebate based on the total upgrade cost
3. Product-specific rebates (e.g., $300 toward a high-efficiency furnace)

Some program sponsors only offer one of these incentives, while others offer homeowners a choice. For example, a program sponsor may offer a loan with a discounted interest rate, or a cash rebate of equivalent value for homeowners who decide to finance the upgrade themselves. Many programs include special incentives for lower-income households, including higher rebates or lower interest rates on the loan. Rebate payments and loan disbursements are generally made after installation work is complete, with loan disbursements almost always routed straight to the contractor.

Energy-efficiency financing offered by program sponsors is typically structured as unsecured debt (no home equity required), with repayment terms of up to 10 years, low or no fees, and quick approvals. Lenders offer these loans at market rates of interest. To secure a lower rate for consumers the program sponsor can "buy down" the rate by making a payment to the lender at the time the loan is originated. While consumers sometimes have the option to include non-efficiency-related products in the special loan, they typically must install one or more eligible measures to qualify.[19] Contractors can actively promote loans to homeowners during their marketing and in-home sales efforts. In some programs, the contractor manages the loan paperwork for the customer, working with customers to fill out the forms and then obtaining lender approval. This system benefits both the customer (streamlined service) and the contractor (closing more deals).

REBATES VERSUS LOANS: WHAT DO CONSUMERS PREFER?

Many program sponsors offer both low-interest loans and product rebates. Their programs have shown that customers will tend to select one incentive over the other, based on their financial situation. Homeowners with cash on hand or access to cheap funds on their own are more inclined to take the cash rebate. Homeowners with less available cash or no available equity in their home tend to opt for the low-interest loans through the program sponsor. Offering both types of financial incentives allows program sponsors to meet the needs of a wider consumer audience.

MARKETING AND OUTREACH

An essential element of any efficiency program is outreach to inform customers about the opportunity to save energy, reduce utility expenses, and help the environment. Program sponsors spread the word in a variety of ways, including utility bill inserts, Web site content, press releases, newspaper story placement, and radio and newspaper advertisements. If the program also includes participating contractors, they conduct marketing efforts as well. Program sponsors can also work with local real estate agents and lenders. Real estate agents develop a close relationship with homebuyers and have the ability to provide information about energy-efficiency programs and funding before financing is set and the home is purchased.

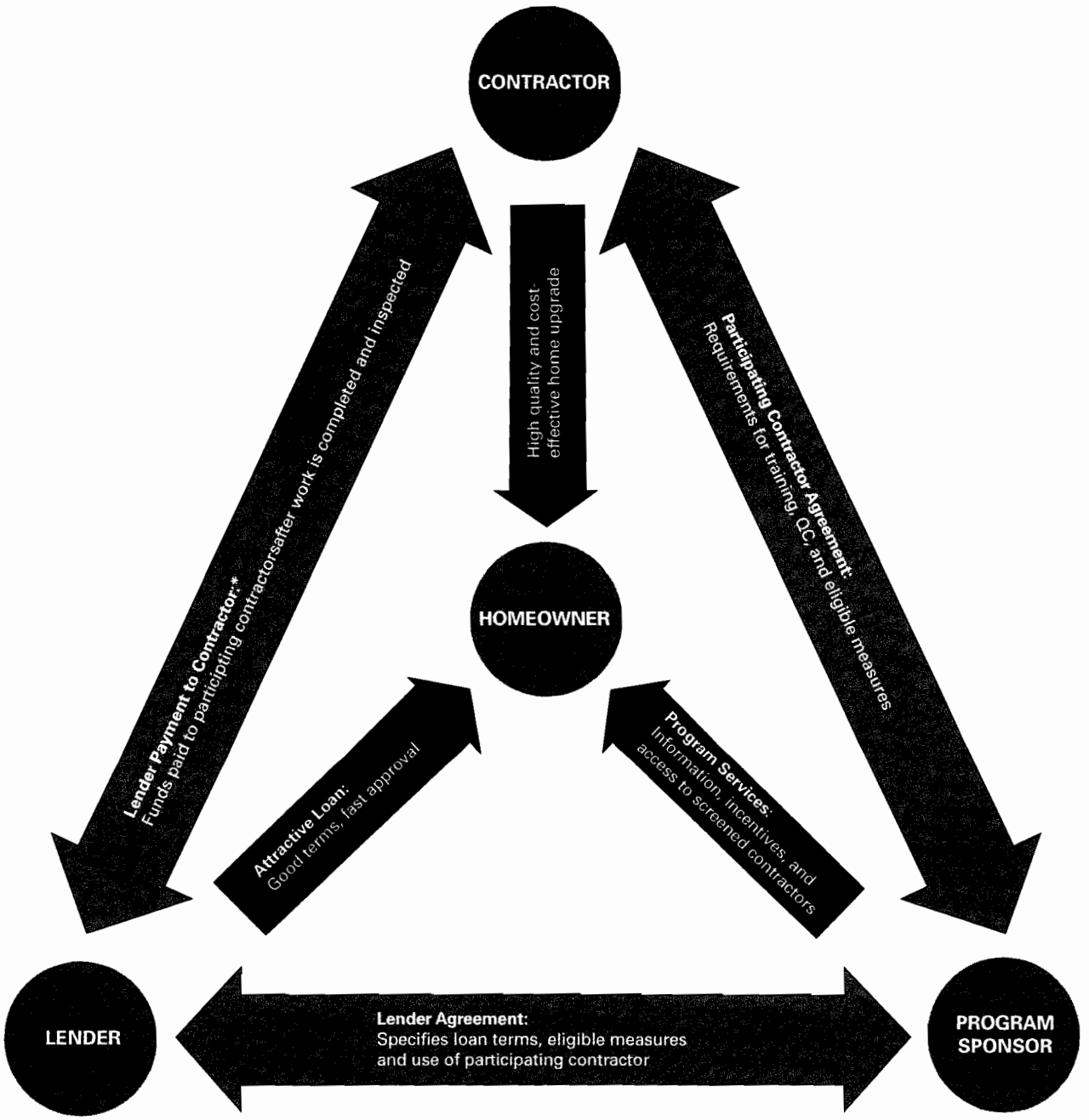
Another method for motivating homeowners is to provide them with a historical energy usage profile and a list of recommended improvements. This can be informative for both existing and new homeowners. Some utilities include historical energy usage on monthly bills. The ENERGY STAR program offers the Home Energy Yardstick online tool (www.energystar.gov/yardstick), which helps homeowners compare their home's energy use to similar homes across the country, and recommends energy-saving home improvements. ENERGY STAR also offers the Home Energy Advisor that provides homeowners with recommended improvements for typical homes in their area (www.energystar.gov/homeadvisor).

POST INSTALLATION INSPECTIONS AND QUALITY ASSURANCE

To ensure work is done properly and the equipment is actually installed, many program sponsors inspect completed jobs. Some will inspect all jobs, while others randomly inspect only a portion of jobs completed by each participating contractor. Quality assurance inspections can be performed by in-house personnel or contracted out to a third party. Inspections serve a critical role in reassuring homeowners that participating contractors will be held accountable for their work, and helps build trust in the program sponsor.

[19] Some eligible measures commonly included in energy-efficiency programs include high-efficiency heating and cooling systems; solar and high-efficiency domestic hot water systems; attic, wall, and crawl space insulation; air sealing; duct sealing and insulation; programmable thermostats; photovoltaic systems; and high-efficiency windows. (For more information on products and specific rebate amounts for individual home improvement programs, consult www.dsireusa.org, or www.energystar.gov/rebatefinder.)

USING FINANCING TO PROMOTE QUALITY ENERGY-EFFICENCY IMPROVEMENTS



* Note: For programs using retail installment contracts, contractors execute an agreement with the lender allowing them to offer loans directly to homeowners. The homeowner would still make monthly payments to the lender.

SETTING UP A FINANCING OPTION

In the past, some program sponsors used their own funds to operate a loan program, but negative experiences with bad debt led most to abandon this approach. Now most work with outside lending organizations to establish energy-efficiency financing for homeowners. There are two basic methods: 1) work with a local bank to set up a customized version of a regular unsecured consumer loan; or 2) hire a loan program administrator to offer a turn-key service using a retail installment contract. Each is described below.

A number of program sponsors form partnerships with one or more local banks or credit unions, and then refer eligible homeowners to the participating lenders. The lender screens potential recipients, determines creditworthiness, issues the loan, and handles ongoing collection of loan payments. The financing is typically unsecured consumer loans. No home equity is required, but the homeowner must be deemed creditworthy by the lender to qualify. Starting interest rates for such loans can be high, though program sponsors can provide a lump-sum payment to the lender to "buy-down" the interest rate to a lower level. To be eligible for the reduced interest rate, homeowners must follow certain rules outlined by the program sponsors, such as the inclusion of eligible measures and the use of participating contractors to do the work. Austin Energy and MassSave are two program sponsors that use this approach. They are featured in program summaries below.

Program sponsors that want more control over loan terms, or greater ability to leverage contractors in the sales process, can work with an outside loan program administrator to develop a special financing product called a retail installment contract (RIC). A RIC is a financial arrangement that allows a consumer to purchase goods or services from a contractor on credit, using a special contract that fixes the finance charge and number of payments or "installments." RICs are unsecured debt with simple interest and no origination fees or pre-payment penalties. Consumers may be familiar with RICs as they are a common way to finance the purchase of a new car. Unlike a loan, the RIC can be originated by the contractor at the time of sale, according to rules established by the lender. This allows contractors to take the financing paperwork on sales calls, and to execute it with the customer in the convenience of their own home. In addition to being a valuable sales tool for contractors, RICs provide extra benefits to borrowers by enabling them to assert a future claim against the lender if there is a problem with the installation. This provision makes lenders very motivated to oversee the quality of the contractors participating in their RIC program. Wisconsin Energy Conservation Corporation and NYSERDA are two program sponsors that have contracted with loan program administrators to operate a RIC-based program.

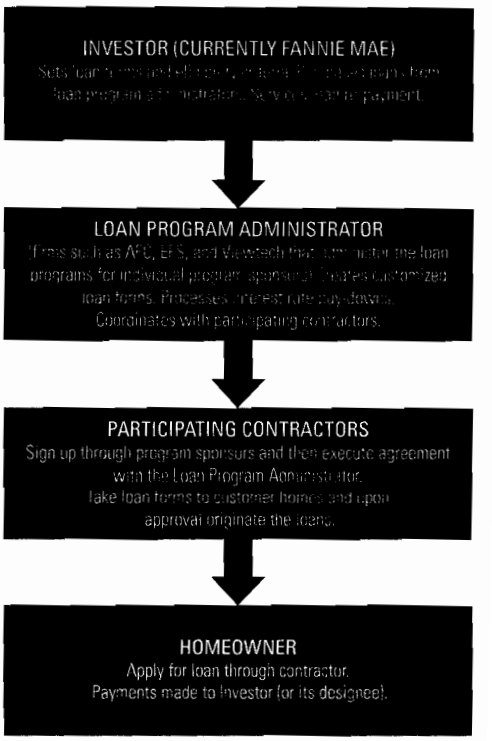
LOAN PROGRAM ADMINISTRATORS THAT WORK WITH PROGRAM SPONSORS

AFC First Financial
1005 Brookside Road
Allentown, PA 18106
Phone: (610) 433-7486

Energy Finance Solutions
431 Charmany Drive
Madison, Wisconsin 53719
Phone: (800) 569-9327

Viewtech Financial Services
5109-D East La Palma Ave.
Anaheim, CA 92807
Phone: (714) 695-3375

HOW RICS WORK FOR PROGRAM SPONSORS



A number of loan program administrators specialize in developing RICs for energy efficiency program sponsors (see sidebar above). The funds for these RIC loan programs are provided by Fannie Mae, a government-backed lending institution best known for consolidating home mortgages. Several program sponsors have successfully utilized RIC-based financing, and information about their programs is included in the following section.

Energy Efficiency Program Summaries

MASSSAVE HEAT LOAN PROGRAM

MassSAVE is the new name for the Massachusetts Residential Conservation Services Program, which has been available since 1980 as a residential rating service. It underwent a massive redesign in 2001 and now provides energy information and services to all Massachusetts residential energy users. It is sponsored by the state's investor-owned utilities, as well as the Cape Light Compact, and is funded via the public good charge.

Financing Options

For National Grid, NSTAR Electric, and Berkshire Gas, the program is provided as a Home Performance with ENERGY STAR branded service. MassSAVE has arrangements with a number of local lenders to provide unsecured consumer loans. The sponsoring organizations subsidize the interest rates to make the loans attractive to homeowners (3% for regular homeowners and 0% for low-income households). Homeowners can borrow up to $15,000 with repayment over five or seven years. The sponsors have found that centralized financing approved by phone is an extremely customer-friendly mechanism. Many of the sponsoring utilities also provide product rebates for certain measures, which can be combined with the HEAT loan to further reduce the costs of an upgrade.

Program Process

The homeowner begins by requesting a home energy assessment through MassSAVE. The energy advisor will identify energy-efficiency needs and determine what improvements are eligible for financing. The homeowner must then secure written contractor price proposal(s) for installation of the improvements. Some measures can be provided directly by program-supervised contractors as well. The price proposals are submitted to MassSAVE for review and approval. Once approved, the homeowner receives a HEAT Loan Authorization Form from MassSAVE and must then apply for a loan from a participating lender. After all improvements are installed, MassSAVE conducts a post-installation inspection.

Eligible Measures

- High-efficiency heating systems
- Oil, natural gas, or propane hot water boilers, furnaces, and steam boilers
- High-efficiency heat pumps
- Solar and high-efficiency domestic hot water systems
- Attic, wall, and basement insulation
- Air sealing measures
- Duct insulation and duct sealing
- ENERGY STAR qualified windows (replacements for single-pane windows only)
- ENERGY STAR qualified thermostats

Results

National Grid, one of the MassSAVE sponsors, reported that for its service territory (1.3 million customers) there were over 4,900 energy assessments completed and approximately 600 MassSAVE HEAT Loans issued in 2006, totaling $4 million. Nearly 200 of the projects financed used 0% five-year loans (currently discontinued), and the remaining used 3% seven-year loans. The average loan was around $6,800. The majority of loans were used for replacement heating systems (468 projects); the rest were for air sealing and insulation (200), domestic hot water upgrades (210), and window replacements (114).

WISCONSIN ENERGY CONSERVATION CORPORATION (WECC)

The Wisconsin Focus on Energy program is managed by the Wisconsin Public Service Commission, and is implemented by WECC, with assistance from the Energy Center of Wisconsin and other marketing and evaluation subcontractors. It is funded with public benefits charges; program services are available to customers of the utilities that contribute funds.

WECC
wisconsin energy
conservation corporation

WECC oversees the Home Performance with ENERGY STAR Program, which includes an in-home assessment and rating, assistance with contractors, cash-back rewards, and a post-installation inspection. The cash-back rewards vary by program year. The program also offers financing options.

Financing Options

WECC offers homeowners financing through Energy Finance Solutions (EFS). The financing is an unsecured retail installment contract (RIC), and is available to homeowners with FICO scores of 620 or above. Prepayment of the loan, either in full or in part, is allowed at any time without penalty. There are no fees or charges for loan application or origination, and no points at closing. The minimum loan amount is $1,000 and the maximum is $10,000. To qualify for the subsidized financing, homeowners must install at least two of the eligible efficiency measures and use a program-approved contractor to perform the installation.

Starting on October 1, 2007, the Home Performance with ENERGY STAR Program made financing available at a subsidized interest rate of 9.99%. (Prior to that date market interest rates of 13.49% to 14.25% were available.) Homeowners who take advantage of the subsidized financing cannot receive cash-back rebates, which are available on some measures.

Program Process

Homeowners begin by scheduling an in-home assessment with a program consultant. The consultant provides an objective, third-party report of recommended solutions, and leaves behind a list of participating contractors for the homeowner.

The homeowner then selects a contractor and determines the efficiency measures they would like installed. Homeowners who desire financing can contact EFS directly to obtain an application, or they may be pre-approved by phone or online. The contractor will forward to EFS a copy of the signed contract for work, and upon approval EFS will draft a loan agreement for the homeowner to sign.

Once the homeowner has had all work completed, the consultant follows up with a post-installation inspection. Results are submitted to the Home Performance with ENERGY STAR Program and, upon approval from the program and receipt of the EFS certificate of completion (executed by the customer and contractor), EFS will submit payment to the contractor for the work performed.

Eligible Measures

- Natural gas or liquid propane water heaters
- Insulation (attic, wall, floor, sill box, interior and exterior foundation, sidewall)
- Air sealing
- Chimney liner (for poor drafting units only)

Results

Since 2001, nearly 10,000 homes have been evaluated under the Home Performance with ENERGY STAR Program, including 1,900 in the past year. WECC estimates that during the two-year period of July 2005 through June 2007, the program has secured gross energy savings of 1.26 million kWh/year and 800,000 therms/year. Peak load reductions are estimated to be 600 kW. Most of the savings are attributed to attic and wall insulation, and air sealing.

NEW YORK STATE ENERGY RESEARCH AND DEVELOPMENT AUTHORITY (NYSERDA)

NYSERDA's Home Performance with ENERGY STAR program is a comprehensive and coordinated program for guiding homeowners through a whole-house upgrade. Participating contractors conduct in-home assessments, install eligible measures, and can help homeowners secure financing. Only contractors who are fully accredited by the BPI are eligible to participate in the program.

Financing Options

NYSERDA provides several choices to help homeowners pay for upgrades. ENERGY STAR financing is offered by participating contractors, and processed by EFS. These RICs have a limit of $15,000 or $20,000, depending on the homeowner's credit score and desired loan term. The current interest rate is 5.99%. To help homeowners who can't qualify for the EFS financing product, NYSERDA also offers a loan in partnership with EFS and American General Finance (AGF) which is available to homeowners with credit scores as low as 550. It has a maximum loan term of five years and a maximum loan amount of $10,000. It was launched in 2006 with a special introductory annual percentage rate (APR) of 4.99%. Energy Smart Loans are offered through a number of participating New York state financial institutions. These loans can be either secured or unsecured. The interest rate is bought down by NYSERDA by 4 percentage points for up to 10 years. Homeowners who choose to forgo program financing may be eligible to receive a rebate equal to 10% of the cost of certain energy-efficiency improvements, up to a maximum of $3,000.

NYSERDA offers additional subsidies to low-income homeowners under its Assisted Home Performance with ENERGY STAR program. NYSERDA will pay up to 50% of the costs associated with the energy-efficiency improvements, up to a maximum of $5,000 per household or $10,000 for a two- to four-family building. The subsidy may be combined with other financing options or other low-income programs.

Program Process

Homeowners receive an in-home assessment from a participating contractor. They can then hire that contractor, or another participating contractor, to do the recommended work. Homeowners can work through the contractor to secure financing, apply for an ENERGY SMART Loan, or decide to finance the improvements themselves and receive a rebate equivalent to the interest rate subsidy provided to other program participants. Once the energy upgrades are complete and NYSERDA signs off on the work scope, payment is made directly to the contractor.

Eligible Measures

- Insulation upgrades
- Air sealing
- Duct sealing
- Heating system repair or replacement
- Domestic hot water heating upgrades
- ENERGY STAR appliances and lighting
- Other cost-effective energy saving measures

Results

In 2006 there were over 4,000 projects completed, representing $31.8 million of work. About $12.3 million (1,507 homeowners) was covered by the Assisted Home Performance with ENERGY STAR subsidy and $15 million (2,283 homeowners) was financed with the 10% homeowner incentive. Additionally, NYSERDA expended $4.4 million (592 homeowners) on ENERGY STAR loans; $1.1 million on the Energy $mart Loan Fund; and $455,442 (50 homeowners) on AGF loans. The average ENERGY STAR loan was $7,512 and the average 10% homeowner financing incentive was $6,589.

AUSTIN ENERGY

Austin Energy's efficiency programs date back to 1982 and are some of the most comprehensive in the country. Austin Energy is a community-owned electric utility and a department of the City of Austin.

Financing Options

Austin Energy works with a local lender, Velocity Credit Union, to offer loans with fixed interest rates of between 0% and 6.5%, depending on the duration of the loan. The maximum loan amount ranges from $8,500 to $11,000 and is based on the specific home improvement(s) the customer is undertaking. Homeowners can select a three-, five-, seven-, or ten-year term. Loans with higher maximums are available to owners of homes and duplexes that require more substantial efficiency improvements.

Program Process

The first step in this program is for a homeowner to request a home energy analysis and have a participating contractor provide recommendations and bids for cost-effective energy improvements. The homeowner then elects or waives an on-site bid approval by Austin Energy. Regardless, Austin Energy is responsible for submitting the bid to the lender for loan closing, allowing the contractor to begin work immediately thereafter. After the upgrades are completed, Austin Energy provides a quality installation inspection. In addition to the inspection, all contractors are previously trained in home performance improvements and duct air blasting techniques. Austin Energy ensures that all contractors follow strict installation standards, resulting in lower callbacks after the final inspection. Upon verification and completion the customer must sign a Completion Certificate, which is sent to the lender. The contractor is then paid directly by the lender.

Eligible Measures

- Duct sealing
- Duct replacement
- Air conditioning system replacement
- Window to central air conditioning system conversion
- Other cost-effective measures

Results

During 2007, 248 homeowners received loans under the program, producing estimated energy savings of 493,024 kWh. Rebates were paid to 1,712 homeowners, saving an estimated 3,403,456 kWh.

KEYSTONE HOME ENERGY LOAN PROGRAM

The Keystone Home Energy Loan Program–or Keystone HELP™–is a public-private partnership in which two Pennsylvania agencies are cooperating to offer energy loans under a single private-sector marketing umbrella. The program was launched by AFC First Financial (AFC) in January 2006, and offers financing for both energy-efficiency and renewable-energy improvements. AFC is responsible for marketing, contractor recruitment, training and management, and loan processing. Funding for the loans is provided by the Pennsylvania Treasury Department and the Pennsylvania Housing Finance Agency. Keystone HELP is endorsed and promoted by all of the state's regulated utilities

Financing Options

Keystone HELP offers both secured and unsecured loans to all credit-qualified Pennsylvania homeowners regardless of income level. The unsecured loan is a fixed-rate loan of $1,000 to $10,000 with terms up to 10 years. Because the Pennsylvania Treasury Department provides the funds for these loans the interest rates and repayment terms are significantly better than what homeowners can typically obtain from traditional financing sources. Keystone HELP employs a "sustainable" financing model that recycles re-paid funds to support new loans. Keystone HELP/AFC is also the statewide energy lender for the Pennsylvania Housing Finance Agency's secured home renovation program, which makes loans up to $35,000. These larger loans, secured by home equity, can be for terms of up to 20 years.

Program Process

To be eligible for the Keystone HELP loans, homeowners must have the work done by an approved Keystone HELP contractor/dealer. Over 650 contractor/dealers in the heating, cooling, remodeling, and renewable energy specialties are participating in the program. The loan process is simple and customer friendly. Consumers can apply on-line or by calling the Keystone HELP call center. The contractor submits his estimate showing the qualifying improvements, the customer completes the simple loan paperwork, and the contractor is paid in full immediately upon satisfactory completion of the work. On the secured loan program independent energy audits are conducted.

Eligible Measures

A wide variety of home upgrades can be financed through Keystone HELP, so long as at least 65% of the costs are attributable to eligible ENERGY STAR or other efficiency and renewable-energy improvements, including:

- ENERGY STAR qualified HVAC systems and related work
- ENERGY STAR qualified windows, doors, and roofing
- Insulation
- Solar water heaters, Solar PV systems, and small wind systems
- Other efficiency upgrades identified via a "whole house" energy assessment

Results

In the first two years of the program over 2,400 Pennsylvania homeowners have used Keystone HELP financing to complete over $14 million in energy-efficiency improvements. With the expansion of the program into larger secured loans this volume is expected to more than double. Borrower approval rates have been running at approximately 70% with exceptional credit performance at lower than 1% delinquency.

SOUTHERN CALIFORNIA GAS COMPANY AND SAN DIEGO GAS & ELECTRIC

Southern California Gas Company and San Diego Gas & Electric promote the Fannie Mae Energy Loan to their customers, and have retained Viewtech Financial Services to market and administer these loans in their territory.

Financing Options

The program offers a simple interest, no-fee RIC financing option, in amounts from $2,000 - $25,000. Contractors participating in the program can carry the finance applications, which are completed by customers in their homes. The two utilities do not currently provide any additional buy-down of the interest rate, but separate rebates are available on some measures. After Viewtech approves a loan, the company takes assignment of the RIC from the contractor and then "sells" the RIC to Fannie Mae.

Program Process

Interested homeowners contact Viewtech to request a list of participating contractors. To be included in the program, contractors must undergo a background check by the non-profit League of California Homeowners (LCH). Contractors pay LCH for the initial screening as well as annual "re-certification." LCH confirms licenses and bonding with State agencies, checks customer references, and verifies financial integrity using business credit agencies and vendor inquiries.[20]

Participating contractors bring financing paperwork to the homeowner, and then submit it to Viewtech for processing. Once the loan is approved (usually within 24 hours), the homeowner can schedule the work. Contractors must secure a signed Completion Certificate from the homeowner prior to receiving their funds. Viewtech conducts random on-site verifications of projects to ensure jobs were completed.

Contractors are subject to a formal complaint resolution process undertaken by Viewtech and LCH. Contractors must also adhere to a "Code of Conduct" established by LCH and comply with a Blanket Purchase Agreement ("BPA") signed with Viewtech. This creates a "two-pronged" quality control process and maintains an "arm's length" relationship between participating contractors and the utilities.

Eligible Measures

Customers are permitted to finance a wide range of home improvement upgrades, based on the rules established by Fannie Mae. Water conservation improvements are also eligible.

Results

Since 1998, 18,392 loans, totaling approximately $161 million, have been processed through Fannie Mae. 1,320 of these loans, totaling approximately $11 million, received interest rate buy-downs to 9.9%, funded by Southern California Gas Company to target certain ENERGY STAR measures.

[20] For more information on LCH, visit www.homeowners.org.

Conclusions and Recommendations

Although many homeowners can access cash and/or market-rate financing for home improvement projects, program sponsor-provided financing can be an effective tool for encouraging and facilitating action by homeowners to make energy-efficiency home improvements. It can also act as the "glue" that connects key program components, making them work together in achieving the program's energy savings goals while also building positive relationships between the program, its customers, and participating contractors and lenders. Based on information gathered from program sponsors, implementers, and lenders, financing can be used to strengthen residential energy-efficiency programs in the following ways:

- Generate homeowner interest. Special loans with low interest rates can attract homeowners' attention and entice them to learn more about an energy-efficiency program. National Grid, an electric utility in New England, found that offering energy efficiency loans at a 3% interest rate was very effective at generating interest in their program. Special financing can also attract the interest of local home improvement contractors, encouraging them to get involved in the program or promote it to their customers.

- Promote comprehensive whole-house improvements. To ensure that an entire home's energy use is evaluated, some program sponsors require that customers receive a comprehensive home energy assessment prior to undertaking any work. This identifies all possible efficiency measures that make sense for a given home. To maintain program cost-effectiveness, financing is offered only for the measures that are deemed cost effective in the assessment. To encourage customers to install as many recommended measures as possible, program sponsors can offer loans with longer repayment periods, and use tiered incentives that reward greater levels of investment (e.g., a lower interest rate for installing more of the measures recommended in the energy assessment).

- Encourage customer follow-through. Many program sponsors offer home energy assessments, but a common problem has been encouraging customers to follow-through with the recommendations. Financing can address this challenge by providing fast loan approvals and low fees to make the funding process as easy and affordable as possible for the homeowner NYSERDA has found that allowing participating contractors to execute loan paperwork in the customer's home at the time of sale is a very effective way to increase closure rates. A retail installment contract or RIC allows contractors to originate loans directly for homeowners rather than referring them to lenders.

- Enhance contractor quality oversight. To encourage higher-quality installations and more reliable energy savings, many program sponsors require homeowners to use pre-screened contractors for all installation work as a condition of obtaining special financing. It is then possible to use the leverage of possible customer referrals to encourage local contractors to become active participants in the program, such as by attending training classes on home energy efficiency and distributing education and outreach materials to homeowners. Over time, this can create a valuable contractor network and stimulate improved installation practices. An additional tactic for enforcing the performance of contractors is to have the lender issue loans (and pay contractors) only after a post-installation inspection.

- Provide assistance for lower-income homeowners. While program sponsors can work with loan program administrators to offer special financing, this financing is usually limited to homeowners with sufficient income and credit scores. To ensure program services and the benefits of those services are accessible to all customers, program sponsors may wish to consider developing financing options tailored for lower-income homeowners. This could include partnering with local community organizations, working with an FHA-approved lender, or providing loan guarantees. Sponsors could also look to partner with affordable housing stakeholders such as state energy offices and state housing finance agencies to leverage resources and maximize incentives that can offset the incremental cost of efficiency upgrades.

Appendix A-Home Improvement Loan and Mortgage Products

LOAN PRODUCTS

HOME EQUITY LOANS (SECURED)

Home equity loans are the most common mechanism for funding major home improvements. Homeowners tap into the equity they have built up in their homes, and the loan is secured by a deed of trust against the home. These loans are sometimes referred to as second mortgages. The interest rates are typically the lowest available and the interest payments are tax deductible, making them very attractive to homeowners. Homeowners can borrow on the equity of their home in two general ways.

- Home equity loan, which entails receiving a lump sum from a lender, a set repayment schedule, and a fixed interest rate.
- Home equity line of credit (HELOC) allows the homeowner to withdraw funding as needed, often by just writing a check or using a credit card. Only a minimum payment is due every month. HELOCs generally offer variable interest rates and changing monthly payments.

Current home equity loans have rates around the prime lending rate, such as "prime + 0" or even "prime -1%"). Home equity loans are originated by banks, credit unions, and mortgage lenders.

ELIGIBILITY	INTEREST RATE	FEES	LOAN LIMITS	PROCESSING TIME
Must have equity in home (appraised value greater than loan balance)	Approximately 8%	2-5%; often waived or eliminated since loan is small.	Generally limited to 100% of equity.	30-90 days, but can be much faster.

PERSONAL OR HOME IMPROVEMENT LOANS (UNSECURED)

Homeowners who are unable or unwilling to leverage their home equity can apply for an unsecured loan at a credit union, bank, or other lending institution. Some are marketed specifically as "home improvement loans." Customers qualify based on their credit score and perceived ability to repay the loan. Interest rates are fixed and tend to be higher than home equity loans (since they are not secured), but lower than most credit cards. Interest rates are often on a sliding scale linked to the borrower's credit score. Loan terms of up to 10 years are possible.

ELIGIBILITY	INTEREST RATE	FEES	LOAN LIMITS	PROCESSING TIME
Must be Creditworthy	Two-year bank personal loans averaging above 11.8%. Credit unions are lower than banks.	Vary but are negligible compared to other financing.	Usually $1,000 to $35,000.	1-3 days

FHA HOME IMPROVEMENT LOAN	Any homeowner can take advantage of FHA Title 1 Home Improvement loans to pay for home upgrades, including energy-efficiency improvements. The loans are unsecured and no home equity is required. They are offered only through FHA-approved lenders, but there is a large base of participating organizations. Because of a HUD guarantee, the loans are offered at market rates similar to home equity loans. This makes them more desirable in some cases than a regular home improvement loan. For loans over $7,500, a lien is applied to the home's deed. This requires slightly longer to process and includes origination fees.			
ELIGIBILITY	**INTEREST RATE**	**FEES**	**LOAN LIMITS**	**PROCESSING TIME**
Must be creditworthy, but eligibility rules are more flexible. No income limits.	Market rate similar to home equity loans.	Typically 1% or $150 above $15,000	Up to $25,000	2-3 hours
CONTRACTOR-ORIGINATED LIEN CONTRACTS	Consumers can often access financing directly from contractors installing measures in their home. Many contractors have arrangements with lending institutions, sometimes through the supplying dealer or manufacturer, to offer home improvement loans called "lien contracts." With a lien contract, a bank, credit union, or financial institution agrees to purchase a remodeling or home improvement loan contract from an approved contractor. Similar to a mortgage, there is a lien on the property and if the homeowner defaults on payments, the home is foreclosed to pay back the lender.			
ELIGIBILITY	**INTEREST RATE**	**FEES**	**LOAN LIMITS**	**PROCESSING TIME**
Creditworthy.	Above market rates.	No closing costs.	Up to $20,000 or more, depending on credit score.	Approved at point of sale. Contractor is paid directly by lender.
CREDIT CARDS	Consumers can pay for improvements via credit card, and then pay the investment off over time. Typically the most expensive way to finance an improvement, unless the credit card company offers a promotional rate and the homeowner pays the expense off within the time period of the promotion.			
CRITERIA	**INTEREST RATE**	**FEES**	**LOAN LIMITS**	**PROCESSING TIME**
Clean or decent credit history.	Average 13.44% - 14.56% but can be much higher. Sometimes lower rates offered for 6-12 months.	Varies. Usually negligible, but late fees can be high.	Based on credit score and history.	(N/A)

MORTGAGE PRODUCTS

REHABILITATION MORTGAGE

Allows homebuyers to combine the home purchase and estimated renovation costs into a single mortgage at the time of purchase. Loan amount is limited to 90% of the estimated value of the home after the renovations are completed. Offered by many lenders, and usually has an interest rate slightly higher than for a regular mortgage. Can be used for new sale or a refinance.

ELIGIBILITY	INTEREST RATE	FEES	LOAN LIMITS	PROCESSING TIME
Creditworthy buyer of existing home. Can cover all types of home repair and improvements, including energy efficiency.	Market rates typically higher than regular mortgages.	Regular + charges for appraisal and inspections.	90% of the estimated value of the home after the renovations are completed.	30–90 days

FHA STREAMLINE 203(K) REHABILITATION MORTGAGE

Similar to regular rehabilitation mortgage. Allows consumers to combine purchase price and up to $35k of renovation costs into a single mortgage at one fixed interest rate. The loans can only be originated by FHA-approved lenders, and the homeowner must meet a variety of requirements. Mortgages only require a 3% down payment and interest rates are lower than for regular rehab mortgages. Can be used for new sale or a refinance.

ELIGIBILITY	INTEREST RATE	FEES	LOAN LIMITS	PROCESSING TIME
Creditworthy. No income caps. Can cover all types of home repair and improvements, including energy efficiency.	Market rates.	Up to 1% origination fee + supplemental fees and appraisals as determined by lender.	Maximum loan amount set by FHA; varies by county. Add up to $35,000 to mortgage for improvements.	60–90 days for processing. All improvements must be completed within 6 months.

ENERGY IMPROVEMENT MORTGAGE (EIM)	EIMs allow the inclusion of additional funds in the mortgage to cover cost-effective energy-efficiency improvements, without requiring additional down payment. Can be issued at time of sale or refinance. EIMs can be attractive to homebuyers who put all of their available cash into a down payment for a fixer-upper that will require some immediate improvements to be habitable. Allows the homeowner to make the needed improvements right away without any up-front costs, and to finance the payments over the term of their mortgage (up to 30 years). If current interest rates are the same or lower than rates on older mortgages, some homeowners can benefit by refinancing their current loan with an EIM. Doing this would enable them take out a larger loan to cover energy-efficiency costs associated with a major remodel/ addition, HVAC replacement, or major building shell improvement.			
CRITERIA	INTEREST RATE	FEES	LOAN LIMITS	PROCESSING TIME
Creditworthy. Must have a HERS rating done. Only cost-effective energy upgrades can be included.	Market rates.	Standard + HERS rating.	Fannie Mae allows up to 115% of home value; generally depends on utility savings; up to $417,000.	30-180 days (home purchase in 30 days; improvements and released escrow within 90 days).

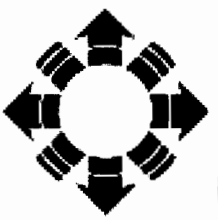
August 2002 • NREL/TP-550-30270

Technical Report

Building America System Performance Test Practices: Part 2, Air-Exchange Measurements

Ed Hancock
Mountain Energy Partnership

Paul Norton and Bob Hendron
National Renewable Energy Laboratory
Center for Buildings and Thermal Systems



National Renewable Energy Laboratory

1617 Cole Boulevard
Golden, Colorado 80401-3393

NREL is a U.S. Department of Energy Laboratory
Operated by Midwest Research Institute • Battelle • Bechtel

Contract No. DE-AC36-99-GO10337

August 2002 • NREL/TP-550-30270

Building America System Performance Test Practices: Part 2, Air-Exchange Measurements

Ed Hancock
Mountain Energy Partnership

Paul Norton and Bob Hendron
National Renewable Energy Laboratory
Center for Buildings and Thermal Systems

Prepared under Task No. BET1.8004

National Renewable Energy Laboratory

1617 Cole Boulevard
Golden, Colorado 80401-3393

NREL is a U.S. Department of Energy Laboratory
Operated by Midwest Research Institute • Battelle • Bechtel

Contract No. DE-AC36-99-GO10337

NOTICE

This report was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or any agency thereof.

Available electronically at http://www.osti.gov/bridge

Available for a processing fee to U.S. Department of Energy
and its contractors, in paper, from:

U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
phone: 865.576.8401
fax: 865.576.5728
email: reports@adonis.osti.gov

Available for sale to the public, in paper, from:

U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
phone: 800.553.6847
fax: 703.605.6900
email: orders@ntis.fedworld.gov
online ordering: http://www.ntis.gov/ordering.htm

Printed on paper containing at least 50% wastepaper, including 20% postconsumer waste

TABLE OF CONTENTS

1. Introduction 1

2. Available Tools and Test Methods 2

2.1 Blower Door 2

2.2 Duct Blaster 3

2.3 Flow Hood 3

2.4 Tracer Gas Measurements 3

3. Calculating Energy Use Due To Infiltration and Ventilation 5

4. Complicating Factors 6

4.1 Interaction Effects 6

4.2 Infiltration Heat Recovery 6

5. Example of Air-Exchange Measurement: Medallion Homes, San Antonio, August 2000 7

5.1 Field Test Objectives 7

5.2 Test Conditions 9

5.3 Airflow Measurements 9

5.4 Blower door and Duct Blaster Measurements 11

5.5 Tracer Gas Measurements 12

5.6 Field Test Conclusions 15

6. References 16

List of Figures

Figure 1. Example decay of SF_6 concentration in a test home 4

Figure 2. Measured air-exchange rates for prototypes and standard practice houses. (Zero is midnight; day of week label is noon.) The figure includes the results for a two-story home not discussed in this report. 13

Figure 3. Measured wind speed during the tracer gas measurement period 14

Figure 4. Average air temperatures during the tracer gas measurement period 14

List of Tables

Table 1. Medallion Homes Test House Descriptions (Expected) 8

Table 2. Supply Airflow Summary 10

Table 3. Airflow Summary 10

Table 4. Blower Door and Duct Blaster Measurements 11

Acknowledgments

Many thanks to Ren Anderson and Sara Farrar-Nagy of NREL for their long-time commitment to quality technical research in the Building America Program; to Greg Barker of Mountain Energy Partnership, Paul Reeves of the Partnership for Resource Conservation, and Dennis Barley and Ron Judkoff of NREL for their thoughtful reviews and comments; and to Bill Cobban, Lauren Poole, and Nancy Wells of NREL for their technical editing and document preparation work support.

We thank the staff of Integrated Building and Construction Solutions (IBACOS) Consortium of the Building America Program who partnered with NREL on the field-test example contained in this report. We also express our gratitude to George James, Department of Energy Program Manager for Building America, for the leadership and resources needed to complete this work.

1. Introduction

This document outlines the current test practices used by NREL staff and contractors to quantify the air-exchange characteristics of homes built within the Building America Program. It is not intended to be a standard protocol for these measurements. Instead, it documents the test methods currently being used to increase understanding of their advantages and limitations and to promote discussion of the approach used.

The Building America Program is an industry-driven program sponsored by the U.S. Department of Energy (DOE) that uses systems engineering approaches to accelerate the development and adoption of advanced building energy technologies in production housing. Building America partners with residential building industry teams to produce advanced residential buildings on a community scale. The Building America Teams work directly with production builders to develop methods to increase the quality and reduce the energy consumption of the homes that they build. Residential building systems are evaluated by conducting successive design, build, test, redesign, build, and retest iterations until cost and performance trade-offs yield innovations that can be implemented in production-scale housing. Building

The Building America program is responsible for evaluating features of new construction that affect the energy efficiency and quality of the home. One of the specific tasks in this effort is to quantify the envelope and air-distribution-system airtightness. Substantial energy savings may be available if current practice does not already produce tight houses. On the other hand, a minimum amount of outside air is required for acceptable indoor air quality, so continuing to expend efforts on further tightening when standard practice already achieves tight houses may not be beneficial. The amount of air exchange that actually occurs is not apparent to homebuilders or owners. This places an emphasis on testing to evaluate the success of air-infiltration reduction strategies.

It is important to initially test the airtightness of the builder's current standard practice to evaluate the need for envelope improvements and ventilation requirements. Many houses built using current standard practice result in air-exchange rates that are already low compared to minimum requirements. These houses may need mechanical ventilation for indoor air quality and may not benefit from additional efforts to improve airtightness, unless heat recovery ventilation (HRV) is used. Testing the current standard practice can indicate whether or not infiltration should even be included for consideration in the Building America energy efficiency package for a given builder. The relative importance of envelope leakage and duct leakage must also be evaluated to understand the effects of operating the distribution fan on the overall performance of the house.

The following is a basic question for evaluating Building America prototype houses:

> *What are the air exchange characteristics of the envelope and ducts of Building America homes?*

The general approach in addressing this question is to characterize the shell leakage, duct leakage, and intentional ventilation for both the prototype and base case. These characteristics

are compared to leakage goals set by the builder and specified in standards such as ASHRAE 62.2P: *Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings.*

Several specific questions are usually important in our evaluation of airtightness in Building America houses, including the following:

- How does the airtightness characteristic (effective leakage area, ELA) of the envelope in the Building America prototype compare to the builder's standard practice?
- How does the natural infiltration rate (air changes per hour, ACH) in the Building America prototype compare to the builder's standard practice?
- How does the duct system airtightness characteristic of the Building America prototype compare to the builder's standard practice?
- How does the duct air leakage during normal operation of the air handler in the Building America prototype compare to the builder's standard practice?
- Does operation of the air handler cause additional air leakage through the shell of the building?
- Is the performance of the ventilation system adequate to supply the minimum required ventilation in all seasons?
- Is the air handler distributing air appropriately to all parts of the house?

2. Available Tools and Test Methods

2.1 Blower Door

A blower door is a device used to pressurize or depressurize a house to determine the leakage characteristics of the building envelope. A variable-speed fan is temporarily mounted in a doorway or other opening to pressurize (or depressurize) the house by specified amounts. The flow rate through a calibrated orifice is measured at the different house pressures. The relationship between flow rate and pressure difference is an indication of shell airtightness. Weatherization contractors often use blower door testing, and some builders and mechanical contractors also have equipment in-house for doing blower door tests. For full details on blower door operating procedures, see reference [1]. The blower door method is also documented in standards ASTM E779 [2], ASTM E1827 [3], ANSI/ASHRAE 136 [4], and ANSI/ASHRAE 119 [5].

The results of the blower door tests can be expressed as one of several figures of merit. One simple expression of the envelope tightness is the blower door flow rate at a pressure difference of 50 Pascals (Pa) or "CFM50." This test is the simplest and easiest to perform because it requires the blower door operator to determine only one pressure (50 Pa) and one flow rate. The 50-Pa pressure is the highest used in a typical blower door test and is the least sensitive to the influence of wind variation during the test. It, therefore, tends to be more repeatable than parameters that require measurements at lower pressures, but does not provide adequate information to use in algorithms for calculating actual air-exchange rates [6]. ACH50 is the air changes per hour at 50 Pa (equal to the CFM50 multiplied by 60 minutes per hour and divided by the house volume). ACH50 can be a useful metric for comparing houses of different sizes.

The Equivalent Leakage Area (ELA) is defined as the area of a calibrated orifice that would have the same air flow rate the house does at a pressure of 4 Pa. The ELA, therefore, is an estimate of

the aggregate size of all the leaks in the building. An ELA can be calculated from the results of a multipoint blower door test. NREL uses a laptop computer with TECTITE software [7] to automatically control the blower door during multipoint tests. We usually take 100 data points at each of 8 different pressures between 15 and 50 Pa to determine the relationship between pressure and leakage rate for the test home. The ELA is based on the leakage rate at a 4-Pa pressure difference, which is determined by a curve fit to the blower door test data at various pressures. The ELA can then be used in conjunction with weather conditions at the home site to model the natural ACH at particular times and to estimate long-term or annual infiltration rates [1, 6, 8].

2.2 Duct Blaster

A Duct Blaster, a device similar to a blower door, is used to pressurize only the air-distribution system, including the ducts and air handler cabinet. During the test, all supply and return registers are taped closed, and the duct blaster fan is temporarily mounted to pressurize the taped-off duct system. A multipoint test could be performed to infer a leakage area, but it is more common to pressurize to a reference pressure of 25 Pa. NREL typically performs a single point test at 25 Pa. The flow rate at this pressure is an indication of the leakage characteristic of the air-distribution system. The supply and return sections of the air-distribution system can be separately tested by inserting a blocking section in the air handler. An inference can be made as to the proportion of leakage to the outside under test conditions by pressurizing the house to reference pressure using a blower door during the duct blaster test. Because the ducts and house are then at the same pressure, any leakage from the ducts is assumed to be to the outside rather than to the house. The results of this test provide a useful benchmark for evaluating the general quality of the air-distribution system, but the test results do not directly indicate duct air leakage during normal operation of the system. For full details on duct blaster operating procedures, see reference [9] and ASTM E1554 [10]. NREL has also begun experimenting with the Nulling Test, proposed by Francisco and Palmiter [11] for estimating duct leakage.

2.3 Flow Hood

A flow hood is a device that measures the airflow rate into or out of a register while the air handler is operating. The flow hood channels the air through a short fabric duct containing thermal anemometers to measure the flow of air entering or exiting the register. The NREL field test team uses an Alnor Low-Flow Balometer with a range of 10 to 500 cubic feet per minute (cfm) and a rated accuracy of ±3% of reading +2 cfm. During normal air handler operation, the flow hood is held over each supply and return register and the flow rate for that register is recorded. These measurements are used to check the total air flow for the house and room-to-room air flow balance.

2.4 Tracer Gas Measurements

Blower door and duct blaster tests provide measurements of the leakage characteristics of the envelope and air-distribution systems, but may not be accurate for predicting how much outside air actually enters a particular house under particular driving forces. Tracer gas measurements can provide such direct measurements. The test method typically used for Building America evaluation is the tracer decay using sulfur hexafluoride (SF_6) as the tracer gas. In this test, a small amount of SF_6 is initially injected into the house and mixed to achieve a uniform concentration. As infiltration or intentional ventilation brings outside air into the house, the concentration of SF_6 is diluted. The rate of change (decay) of SF_6 concentration indicates the air-exchange rate of the house expressed as air changes per unit time. This method is documented in ASTM E741 [12]. An example of this decay rate is shown in Figure 1.

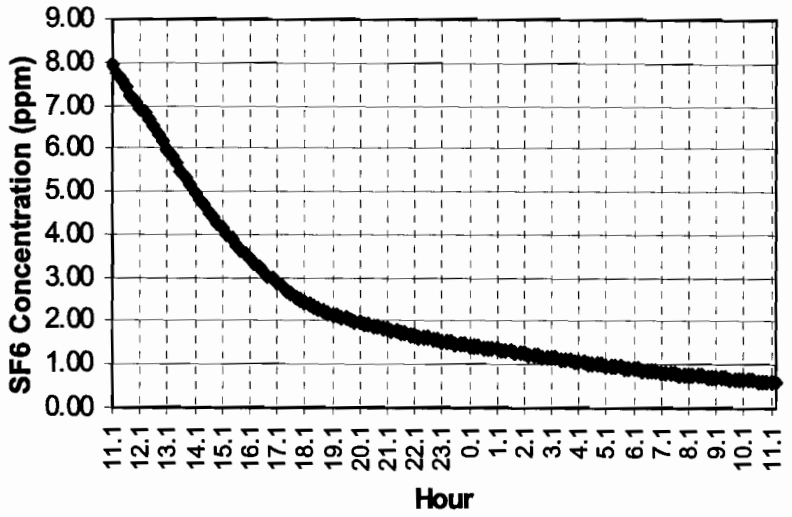


Figure 1. Example decay of SF_6 concentration in a test home

The air-exchange rate measured with tracer gas can be compared to that calculated using blower door measurements. Many studies have indicated that, in general, this comparison can show large differences between the two methods [13, 14, 18]. The tracer gas test results can be used to improve the choice of difficult-to-know inputs for the blower-door model and produce an improved comparison between tracer gas measurement and blower door model estimation.

Duct blaster tests are intended to quantify the duct leakage under standard conditions, they do not capture the nuances of actual operating conditions. Because we are interested in duct leakage due to air handler operation under actual operating conditions, we use tracer gas tests. In this test, an SF_6 decay test is initiated with the air handler turned off and the inside temperature maintained with electric heaters without use of the normal heating system. During this period, the natural infiltration of the building envelope is measured without any influence of duct leakage. The air handler is then turned on to operate continuously for several hours. The step-change in air-exchange rate at the time of turning on the air handler is attributed to duct leakage. A similar indication can be observed in the step-change in air-exchange rate when the air handler is turned off.

3. Calculating Energy Use Due To Infiltration and Ventilation

In most cases, we measure the infiltration and ventilation characteristics to compare them with standards and the builder's goals. Our objective, therefore, is to accurately measure the air exchange characteristics of the homes and report them back to the builder through the Building America teams. This is the case for the example given later in this report.

On occasion we have also evaluated the energy use due to air exchange in prototype and base-case homes. The net air-exchange rate of the house results from the combined effects of infiltration, duct leakage, and intentional ventilation. The combined effect of these flow rates is specified as an input to an hourly energy simulation model (such as DOE2), which is used to calculate the annual heating and cooling energy required to maintain the temperature and humidity conditions for the building. We can then compare this rate of energy use to the energy use in a base-case home with different air-exchange characteristics to determine the energy impacts of the air-exchange characteristics.

When the house is not equipped with a mechanical ventilation system, we use the ELA from a blower door test and have the model calculate envelope infiltration using the Lawrence Berkeley Laboratory (LBL) model [15]. This is superimposed with the induced ventilation due to duct leakage to calculate the net air-exchange rate.

For houses with mechanical ventilation systems, several weeks of tracer gas testing data are collected on the net air-exchange rate of the house with air handler on and off, with ventilation system on and off and under various temperature and wind conditions. A linear regression model is then used to relate the measured air-exchange rate to the monitored air-infiltration drivers of: central heating/cooling mechanical system operation, separate ventilation system operation, wind speed and temperature difference between indoor and outdoor. The coefficients associated with the wind speed and temperature difference are used in an annual model for natural infiltration, while the coefficients of the system operation drivers are used to characterize the performance of those systems.

4. Complicating Factors

Some factors that influence actual air exchange and resulting heat exchange are difficult to characterize in one-time tests and can result in significant uncertainty in evaluating energy savings from airtightening.

4.1 Interaction Effects

The airflows caused by infiltration, duct leakage, and intentional ventilation are not independent. Duct leakage and intentional ventilation can change the pressure distribution within the building, which in turn, changes the infiltration rate due to wind and stack effect. A ventilation fan flow rate of 50 cfm may not result in a 50 cfm net change of the building air-exchange rate because the ventilation fan also changes the pressure distribution that causes infiltration. The interaction of these effects is a potential future research project for the Building America Program

4.2 Infiltration Heat Recovery

The infiltration heat recovery factor has been described and measured by several investigators [16, 17, 18]. In this phenomenon, air that flows through the materials of the building envelope exchanges heat with the building materials as it passes between inside and outside. A portion of the heat loss that would be attributed to air infiltration is thus "recovered," and heating or cooling loads are reduced accordingly. The magnitude of the infiltration heat recovery effect is difficult to predict in advance or measure in place for a particular building and has been reported to range from near zero to more than 50 percent with most studies averaging about 20 percent. For the purposes of evaluation with simulations, we currently assume that no infiltration heat recovery takes place. If it does occur to about the same extent in the prototype and base-case houses, the actual energy use (and savings) would be reduced. We are not aware that any Building America measures actually attempt to enhance the infiltration heat-recovery effect.

The air-exchange rates estimated in our analyses for evaluating energy savings assume that natural driving forces and mechanical system operation determine air exchange. In occupied houses, the behavior of the occupants can have a significant influence on actual air-exchange rates and energy savings. Occupants exercise a wide range of behaviors with respect to opening and closing windows and exterior and interior doors. In some cases, the operation of the ventilation system is at the discretion of the occupants. In building energy simulations, we make reasonable assumptions for opening and closing of windows and operation of ventilation equipment [19].

5. Example of Air-Exchange Measurement: Medallion Homes, San Antonio, August 2000

This section contains the description and results of a field test of the air-exchange characteristics of two homes in San Antonio, Texas. During the field-testing, we also measured the energy consumption of the homes. However, only the air-exchange tests are described here. This is given as an example of the test practices outlined earlier. In this example, no energy simulation was performed. The results and discussion of the air-exchange tests were supplied to Integrated Building and Construction Solutions (IBACOS), the Building America Team involved in the project. This information was used in their work with Medallion Homes to improve the energy efficiency of Medallion's building practices.

5.1 Field Test Objectives

The objective of these short-term tests was to evaluate and compare the air-exchange characteristics of a Medallion Homes pilot house and a base-case house, both of which were one-story homes in San Antonio, Texas. The pilot house was originally tested in January 2000 and was located in the Mainland Square residential development. The base-case house had a similar floor plan as the pilot home and was located at the Finesilver Ranch community. The tests were conducted during the cooling season, which is the dominant season in San Antonio. The primary differences between the two houses were fan-controlled return air ventilation versus no controlled ventilation, air handler and supply ducts in conditioned space versus in the attic, and high interior wall supply registers versus perimeter ceiling supply registers. Specifications for the prototype and base-case houses are summarized in Table 1.

A combination of tests incorporating blower door, duct blaster, flow hood, and tracer gas was conducted to answer the following questions:

1. What is the natural infiltration rate (ACH) of each house as measured by a tracer gas under the following conditions?
   a. Air handler unit (AHU) and ventilation system inlets blocked (envelope only)
   b. With AHU operating, but ventilation system inlets blocked (ducts and envelope)
   c. Normal operation of AHU and ventilation system (ventilation system effectiveness)
2. What are the blower door results (ACH50, CFM50, ELA, and estimated natural ACH) for each house?
3. What is the duct leakage (CFM50) for each house (supply to inside, supply to outside, return to inside, and return to outside)?
4. What the register flow rate at each supply register?

Table 1. Medallion Homes Test House Descriptions (Expected)

	Pilot Home	One-Story Base Case
Location	Mainland Square Subd. 8646 Sunny Oaks San Antonio, TX 78250	Finesilver Ranch Subd. Lot #2 Ferris Branch Road San Antonio, TX
Model	Haskellas Model 1537 1-story, slab-on-grade 3 bedrooms	Augusta Model 1-story, slab-on-grade 4 bedrooms
Size (sq. ft.)	1,537	1,752
Front orientation	North	West
Garage	Detached	Attached
Insul: - Walls	R-13 blown-in cellulose, 2x4 framing, building paper	Same
- Roof	R-38 loose-fill fiberglass, truss framing, vented	Same
- Slab	None	Same
Windows	Double-pane, low-e spectrally selective coating, vinyl frame U=0.24, SHGC=0.41	Same
Shading	No shading on south, east, or west sides	Moderate shading on south and east sides; no shading on west
Ventilation	Outside air duct with fan to return of air handler, backdraft damper & AirCycler control (10 min. on, 15 min. off), design airflow rate 120 cfm	Continuous exhaust ventilation in laundry room
Ducts	Air handler in interior closet Supply ducts in dropped ceiling within conditioned space, 2 return ducts in attic	Air handler in attic Supply & return ducts in attic, 2 returns
	High interior wall supply registers	Ceiling perimeter supply registers
Heating	Gas furnace in interior closet with combustion air duct, 80% AFUE, 40 kBtuh	Gas furnace in attic, 80% AFUE, 40 kBtuh
Cooling	12-SEER, 2 tons	12-SEER, 2 tons
Water Heating	50 gallons, 40 kBtuh,	40 gallons, power vented, 0.62 EF

5.2 Test Conditions

Some of the house specifications deviated from what was expected. Ceiling insulation in all houses was sprayed-in cellulose instead of loose-fill fiberglass. The insulation depth was mostly 5 to 7 in. in the pilot home, which was consistent with an R-value in the range of 20–26 instead of R-38 as expected. A certificate from the installing company stated that the intended R-value was R-30 for the pilot home. There was a radiant barrier on the underside of the roof deck in the pilot home. The ventilation fan in the pilot home did not operate whenever the air handler operated, which was the case during the January 2000 test. The AirCycler controller counted down from 15 minutes even when the air handler was running, but the ventilation fan did not turn on unless the air handler was off. In the base case, the air conditioner capacity was 3 tons, not 2 tons as expected.

The weather conditions for the test period were severely hot and humid. The outside temperature ranged from 90–111°F during the daytime and 72– 86°F at night. The winds were mild during the day and very still at night, relative humidity was high, and daytime skies were fairly clear every day. Thermostats were set for 75°F during all testing. However, the base-case house had been allowed to soak at a significantly higher temperature for an extended period before the test. As a result, there may have been some residual heat stored in the thermal mass for the first 1–2 days of the test. The air conditioners were turned off during the airflow and blower door measurements and for about 8 hours before the return from set-up test.

5.3 Airflow Measurements

Flow hood measurements were performed using an Alnor Low-Flow Balometer on each register with the air handler operating. These measurements are summarized in Tables 2 and 3. The results indicated that with the exception of low flow to the master bathroom in the pilot house, supply air was distributed in reasonable quantities through each register. The low flow rate in the master bedroom was likely caused by obstructions or kinks in the corresponding air duct. The total supply flow rate for each model tracked the air conditioner capacity fairly well. As shown in Table 3, all exhaust fans in the bathrooms were functional. The laundry room exhaust fan was designed to serve as a source of continuous ventilation for the base case. However, this fan did not exhaust a sufficient amount of air to draw significant amounts of outside air into the house. Because of this issue, the exhaust fan in the master bathroom was used as the alternate ventilation system during the tracer gas testing of the base case.

Table 2. Supply Airflow Summary

Pilot Home (One-story)	Supply Flow Rate, (scfm*)	Base Case (One-story)	Supply Flow Rate, (scfm)
Kitchen 1	108	Laundry	86
Kitchen 2	117	Kitchen 1	48
Living 1	128	Kitchen 2	125
Living 2	155	Living 1	90
NBR	155	Living 2	116
WBR	64	Dining	175
Bath	58	Bath	66
Laundry	32	WBR	60
MBR	112	NBR	63
Mbath	8	MBR 1	92
Mcloset	38	MBR 2	87
		MBath	118
		MToilet	22
		MCloset	72
Total Supply scfm	975	Total Supply scfm	1,220

* Standard cubic feet per minute.

Table 3. Airflow Summary

	One-Story Pilot Home	One-Story Base Case
Total Supply cfm	975	1,220
Exhaust cfm		
Bath	24	25
Mbath	33	
Mtoilet		34
Laundry	28	0
2 Bath		
Nominal tons	2	3
CFM per ton	488	407

5.4 Blower Door and Duct Blaster Measurements

Blower door measurements were conducted in accordance with ASTM Standard Test Method E-779 [2]. The results are summarized in Table 4. Blower door data for the pilot home are based on earlier tests conducted by IBACOS on January 5, 2000. The combustion air duct in the mechanical room of the pilot home was taped closed during the blower door test, and the results represent the average of two separate tests. Using the Minneapolis Blower Door software developed by the Energy Conservatory, the ELA was calculated to be approximately 48 $in.^2$ for the pilot home. This is a relatively tight house, but not significantly tighter than the base-case houses when exterior surface area is factored in. Natural air-exchange rates for the test houses were estimated using a blower door program developed by Ron Judkoff, which is based on the Sherman-Grimsrud infiltration model, and actual weather conditions during the test period.

Minneapolis duct blaster testing was performed on the base-case house. Again, duct blaster measurements conducted by IBACOS in January 2000 were used for the pilot home in lieu of repeating the test. The results indicate that both total air leakage (7% of total flow) and leakage to the outside (1% of total flow) were smaller for the prototype than for the standard practice house (10% and 5% of total flow). By locating the air handler in a conditioned mechanical room and the supply ducts in a dropped ceiling, it appears that the builder significantly reduced the loss of conditioned air to the outside.

Table 4. Blower Door and Duct Blaster Measurements

	One-Story Pilot Home	One-Story Base Case
Blower Door		
CFM50	1,004	1,212
ELA @ 4 Pa, $in.^2$	48	60
ELA/100 ft^2 surface area	1.53	1.84
C	64.0	80.9
N	0.704	0.692
r^2	0.9999	0.999
ACH_{nat}	0.10	0.11
Duct Blaster		
CFM at 25 Pa		
Total	70	118
to outside	10	64
Supply	45	*71*
to outside	0	*44*
Return	*25**	47
to outside	*10*	20

* Duct blaster results in italics indicate calculated values.

5.5 Tracer Gas Measurements

Bruel and Kjer 1302/1303 tracer gas-monitoring systems were installed in the pilot and base-case homes on Monday, August 28, 2000. Tubing was run to six sample points throughout each house, including one point without an extension tube. Sulfur Hexafluoride (SF_6) was periodically injected in all areas of each house and mixed to a uniform concentration using the air handlers. The air-exchange rate, stated as ACH, was calculated based on the measured rate of decay in the concentration of SF_6. Uniform concentration was not necessarily maintained during the decay period because the air handlers periodically cycled off under their own control programs. It is assumed that the average ACH values in multiple zones are generally representative of typical air-exchange rates, even though the concentration within the volume of the house is not perfectly uniform at all times.

Figure 2 shows the measured ACH for each test house during the period of Monday, August 28, until Wednesday, September 6, 2000. The air conditioners operated normally from the beginning of the test until 8:00 a.m. on Sunday, when the return from set-up test began. The ventilation system in the pilot home operated normally until Tuesday morning at 9:00 a.m., at which time the ventilation system was disabled by disconnecting the AirCycler and taping over the outside air intake. Exhaust ventilation systems in both houses were activated on Thursday morning (utility room in the pilot home, master bath in the base-case home). The ventilation systems were again turned off on Friday morning. On Saturday morning, heaters were operated in both homes to evaluate the capacity of the air-conditioning equipment. The return from set-up test began Sunday morning. On Monday morning, both houses returned to normal operation with their primary ventilation systems enabled. The air infiltration tests ended for the base-case house on Tuesday morning, but the pilot home was operated until Wednesday with the outside air duct open and the AirCycler disabled to evaluate the effect of the ventilation fan.

Both houses were very tight when the ventilation systems were disabled, with air-exchange rates ranging between 0.05 ACH at night and 0.15 ACH during the afternoon. These measurements were consistent with estimates based on the blower door tests. In general, the supply ventilation system in the pilot home raised the average air-change rate to nearly 0.35 ACH, the level recommended in ASHRAE Standard 62. It appeared that the AirCycler-controlled ventilation fan met the design intent of the system. The air-exchange rate dropped significantly when the ventilation fan was turned off while the outside air duct was left open, especially at night when the air handler operated less frequently. However, the air-exchange rate only increased by about 0.05 ACH for the base case when the master bathroom exhaust ventilation fan was turned on. The increase in air-exchange rate was even smaller in the pilot home when the exhaust fan in the laundry room was used to provide ventilation. The primary reason for the observed ineffectiveness of the exhaust ventilation systems in both houses seems to be undersized exhaust fans.

The air-exchange rate of the prototype was lower during this test than it had been during the earlier test in January 2000 when the average air-change rate during coheating was about 0.17 ACH. Possible explanations include larger stack effect during the colder months, higher average wind speeds, and leakage through the combustion air duct in the utility closet, which did not yet have a door during the earlier test.

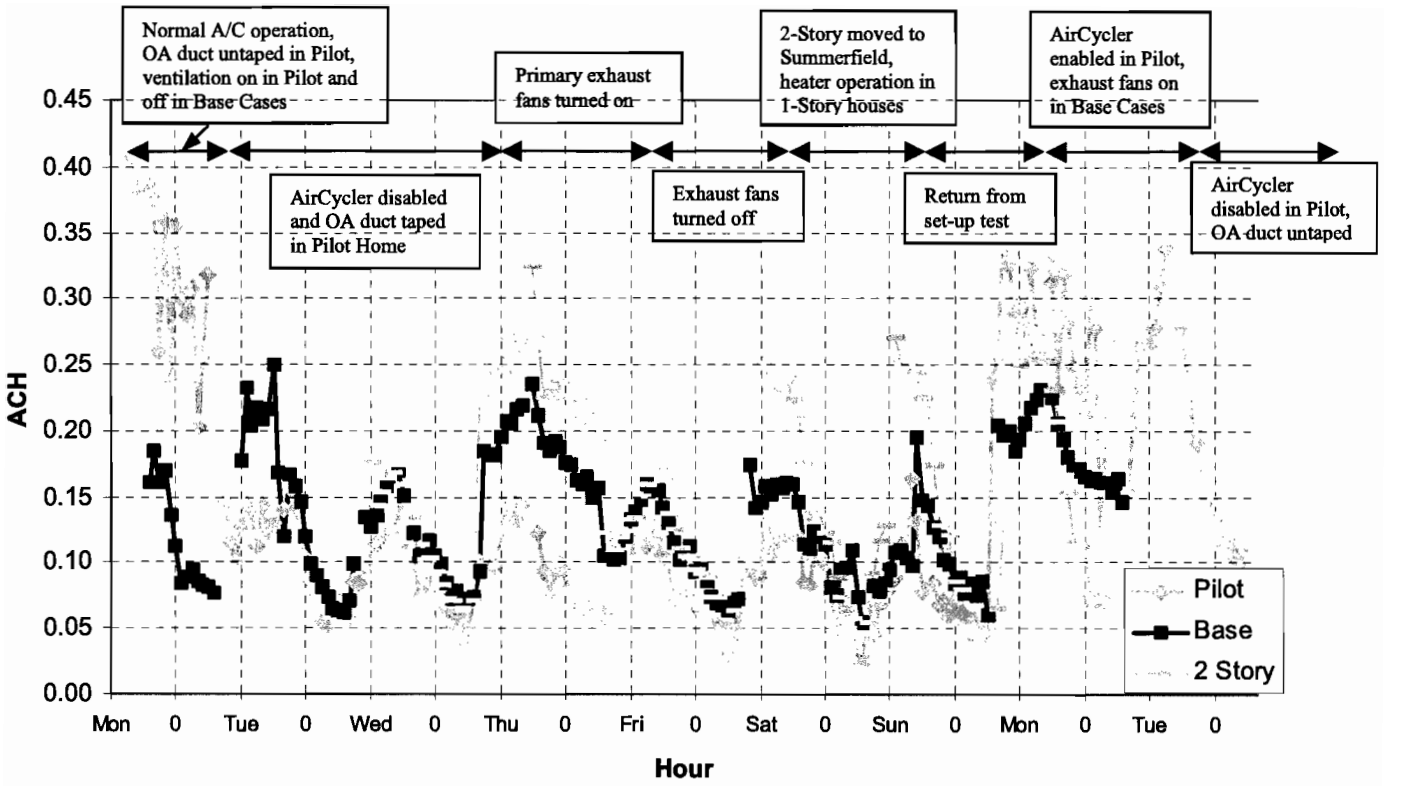


Figure 2. Measured air-exchange rates for prototypes and standard practice houses. (Zero is midnight; day of week label is noon.) The figure includes the results for a two-story home not discussed in this report.

Figures 3 and 4 show the wind speed and inside and outside temperatures during the tracer gas test period. The wind speed was very low throughout the test period, although it was not measured during the first day of testing. The inside-outside temperature difference ranged between 0 degrees at night and almost 20°C (68°F) during the hottest afternoon. Air infiltration showed a tendency to increase with wind speed and temperature difference, peaking in the afternoon, but this also was the time when peak usage of the air conditioners occurred. Average interior temperature was well controlled in both homes, except for a couple of mild excursions in the base case and during the return from set-up test on Sunday night.

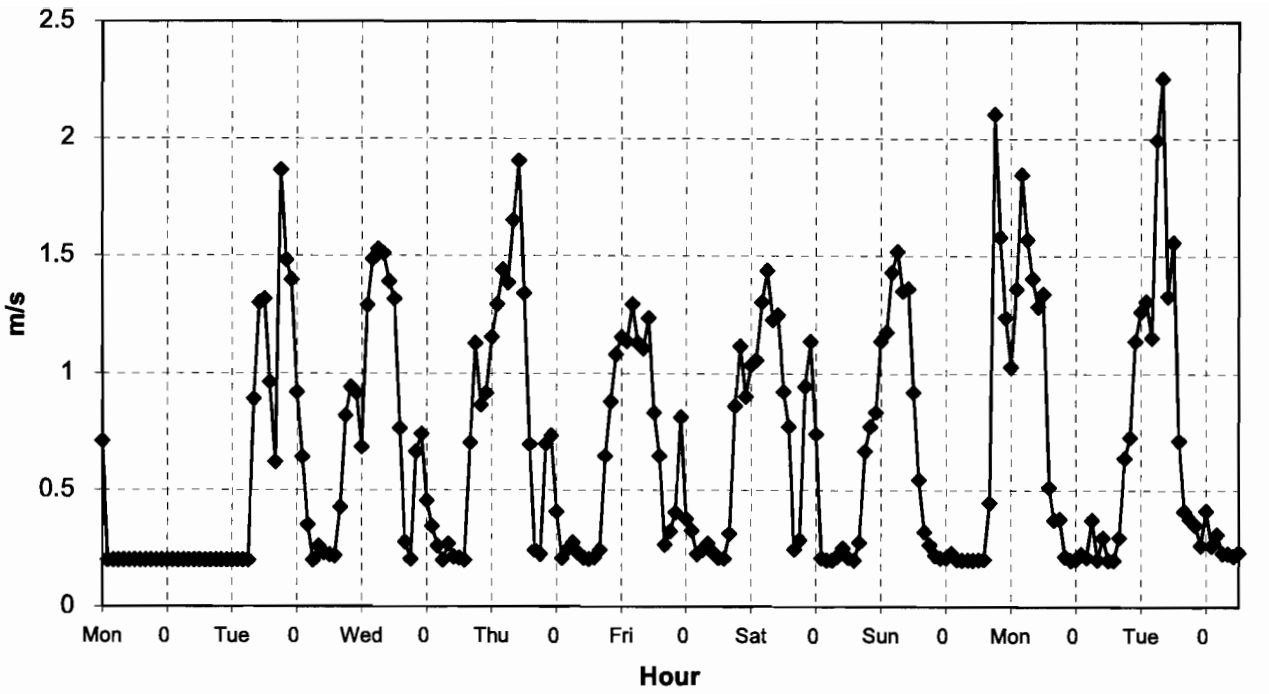


Figure 3. Measured wind speed during the tracer gas measurement period

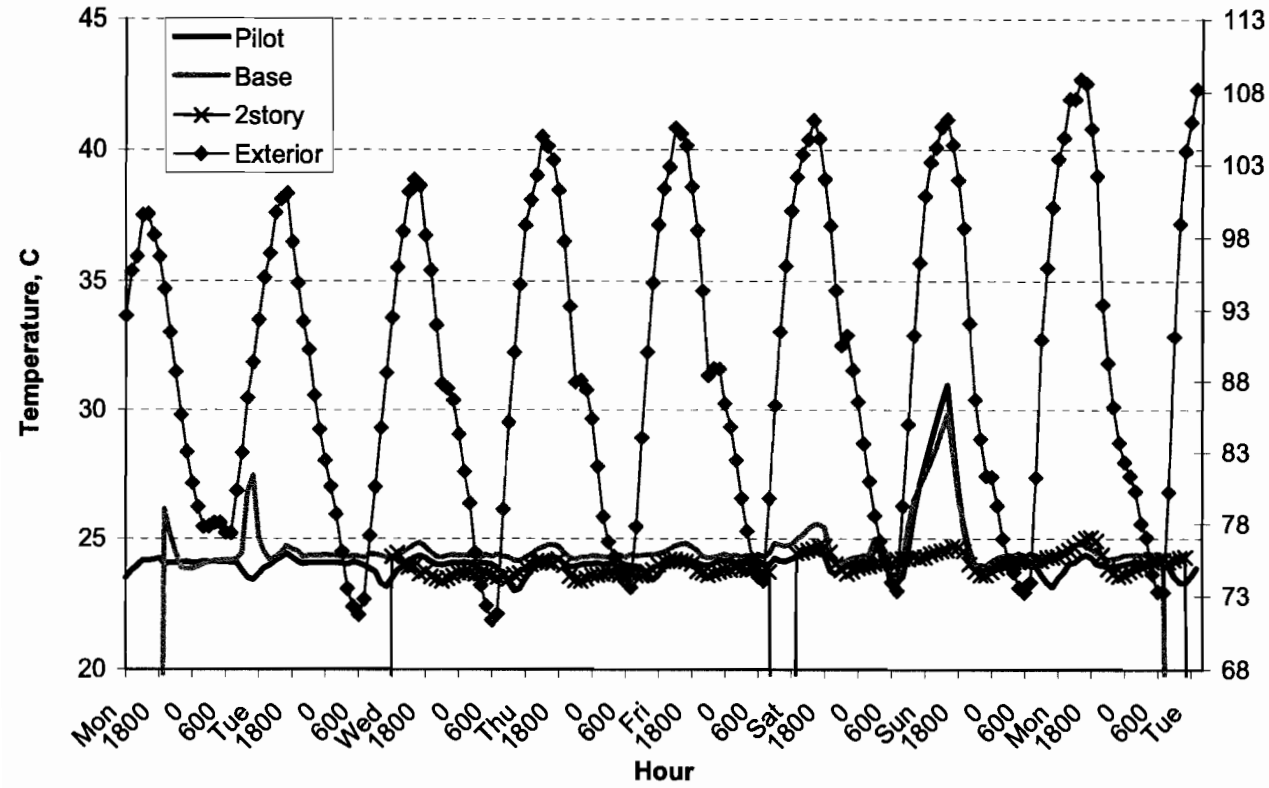


Figure 4. Average air temperatures during the tracer gas measurement period

5.6 Field Test Conclusions

The following observations based on the preceding test results are noteworthy:

- Both test houses had very tight building envelopes
- Several exhaust fans did not provide adequate airflow, including the primary ventilation fan in the one-story base case
- Duct leakage to the outside was significantly smaller in the pilot home, most likely a result of locating the air handler and supply ducts inside the conditioned envelope
- The supply ventilation system in the pilot house raised the air-exchange rate more effectively than the exhaust fans in the base-case houses, none of which exceeded 0.35 ACH at any point during the test period.

6. References

1. The Energy Conservatory. *Minneapolis Blower Door Operation Manual.* Minneapolis, Minnesota: The Energy Conservatory, January 2001. (See www.energyconservatory.com).

2. American Society for Testing and Materials. ASTM E779, *Standard Test Method for Determining Leakage Rate by Fan Pressurization.* West Conshohocken, Pennsylvania: American Society for Testing and Materials, 1992.

3. _____. ASTM E1827, *Standard Test Methods for Determining Airtightness of Buildings Using an Orifice Blower Door Test Method.* West Conshohocken, Pennsylvania: American Society for Testing and Materials, 1996.

4. American Society of Heating, Refrigerating, and Air Conditioning Engineers. ANSI/ASHRAE 136, *A Method of Determining Air Change Rates in Detached Dwellings.* Atlanta, Georgia: American Society of Heating, Refrigerating, and Air Conditioning Engineers, 1993.

5. _____. ANSI/ASHRAE 119, *Air Leakage Performance for Detached Single-Family Residential Buildings.* Atlanta, Georgia: American Society of Heating, Refrigerating, and Air Conditioning Engineers, 1994.

6. Judkoff, R. *A Computer Program to Calculate Effective Leakage Area from Blower Door Data, and to Calculate Natural Infiltration Rate as a Function of Building and Weather Specific Variables*, Solar Energy Research Institute (now the National Renewable Energy Laboratory), November 1986.

7. The Energy Conservatory. TECTITE Version 2. Minneapolis, Minnesota: The Energy Conservatory, 1999. (See www.energyconservatory.com).

8. Sherman, M. and Modera, M. ASTM STP904, *Comparison of Measured and Predicted Infiltration using the LBL Infiltration Model*, West Conshohocken, Pennsylvania: American Society for Testing and Materials, April 1984.

9. _____. *Minneapolis Duct Blaster Operation Manual.* 8th edition. Minneapolis, Minnesota: The Energy Conservatory, April 1996. (See www.energyconservatory.com).

10. American Society for Testing and Materials. ASTM E1554, *Standard Test Methods for Determining External Air Leakage of Air Distribution Systems by Fan Pressurization.* West Conshohocken, Pennsylvania: American Society for Testing and Materials, 1994.

11. Francisco, P.W., and Palmiter, L.S. The Nulling Test: A New Measurement Technique for Estimating Duct Leakage in Residential Homes. *ASHRAE Transactions*, V. 107, Pt. 1, 2001.

12. _____. ASTM E741, *Standard Test Method for Determining Air Change in a Single Zone by Means of a Tracer Gas Dilution.* Conshohocken, Pennsylvania: American Society for Testing and Materials, 2000.

13. Palmiter, L.S., Brown, I.A., and Bond, T.C. Measured Infiltration and Ventilation in 472 All-Electric Homes. *ASHRAE Transactions* 97(2): 979-987, 1991.

14. Parker, G.B., McSorley, M., and Harris, J. The Northwest Residential Infiltration Survey: A Field Study of Ventilation in New Homes in the Pacific Northwest. *ASTM Symposium: Air Change Rate and Airtightness in Buildings.* Atlanta, Georgia: April 1989.

15. Sherman, M. H. *The Use of Blower Door Data.* LBL 35173. Berkeley, California: Lawrence Berkeley Laboratory, March 1998.

16. Liu, M. and Claridge, D.E. Is the Actual Heat Loss Factor Substantially Smaller Than You Calculated? *ASHRAE Transactions* 101(2): 3 – 13, 1995.

17. Palmiter, L., Brown, I., and Bond, T. Infiltration and Ventilation in New Electrically Heated Homes in the Pacific Northwest. *Proceedings of the ACEEE 1990 Summer Study on Energy Efficiency in Buildings*, pages 979 – 987. American Council for an Energy-Efficient Economy, 1990.

18. Judkoff, R., Balcomb, J.D., Hancock, C.E., Barker, G., and Subarro, K. *Side-by-Side Thermal Tests of Modular Offices: A Validation Study of the STEM Method.* National Renewable Energy Laboratory, Golden, Colorado, NREL/TP-550-23940, December 2000.

19. Hendron, B., Farrar-Nagy, S., Anderson, R., Judkoff, R., Hancock, E., and Reeves, P. *Building America House Performance Analysis Procedure.* National Renewable Energy Laboratory, Golden, Colorado, NREL/TP-550-27754, August 2001.

REPORT DOCUMENTATION PAGE

Form Approved
OMB NO. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	August 2002	Technical Paper

4. TITLE AND SUBTITLE
Building America System Performance Test Practices: Part 2, Air-Exchange Measurements

5. FUNDING NUMBERS
BET1.8004

6. AUTHOR(S)
E. Hancock, P. Norton, and B. Hendron

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NREL/TP-550-30270

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
Staff at the National Renewable Energy's Laboratory's Center for Buildings and Thermal Systems and associated contractors perform experiments to quantify the air-exchange characteristics of homes built with the Building America program. This report documents the test practices used. The document was prepared to increase understanding of the advantages and limitations of the approach described. This document is not intended to be a standard protocol for these test measurements.

14. SUBJECT TERMS
house testing; blower door; duct blaster; tracer gas; infiltration; duct leakage; ventilation

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABS[illegible]
Unclassified	Unclassified	Unclassified	UL

NREL National Renewable Energy Laboratory
Innovation for Our Energy Future

A national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy

Field Evaluation of a Near Zero Energy Home in Oklahoma

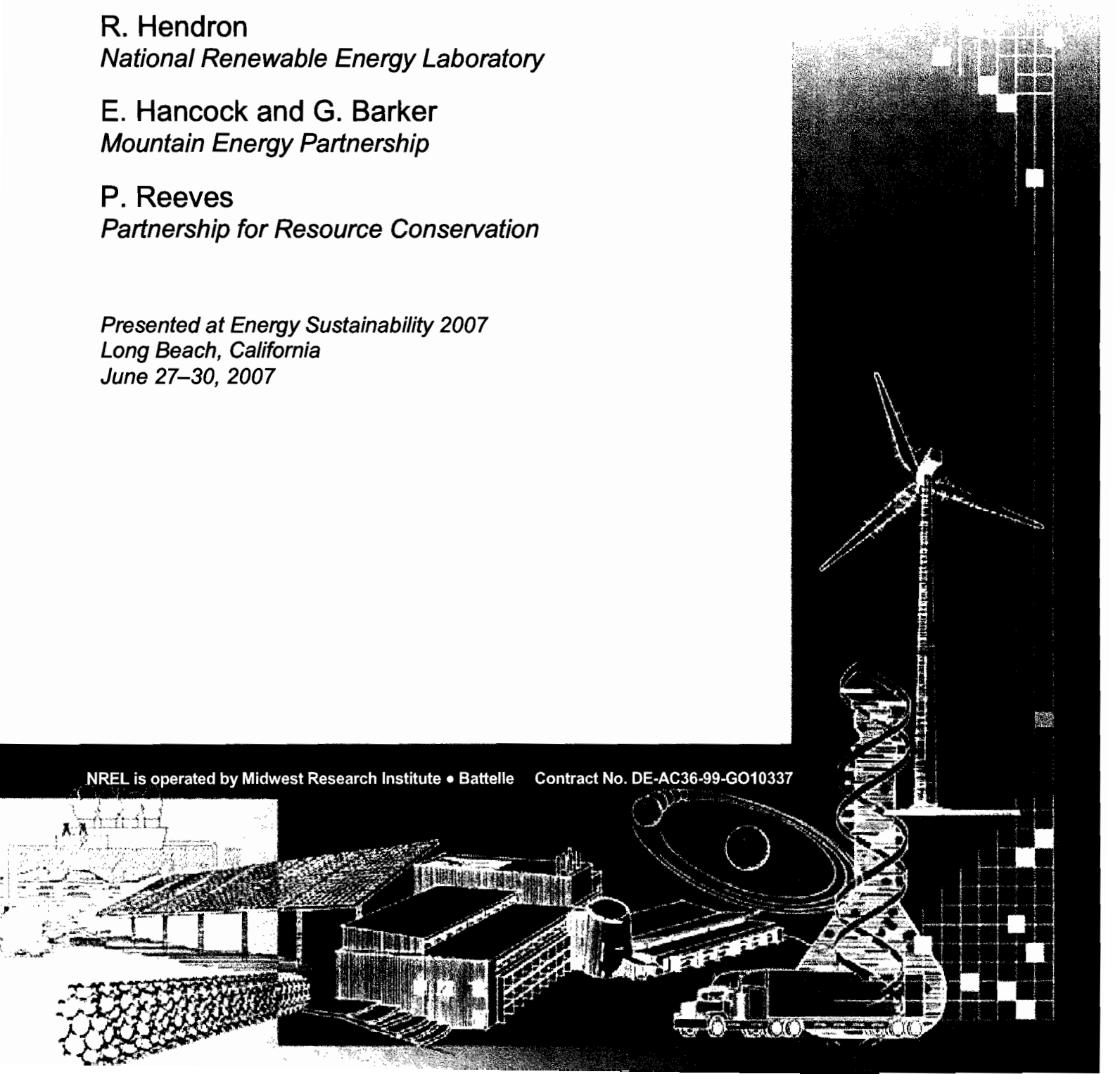
Conference Paper
NREL/CP-550-40875
August 2008

R. Hendron
National Renewable Energy Laboratory

E. Hancock and G. Barker
Mountain Energy Partnership

P. Reeves
Partnership for Resource Conservation

Presented at Energy Sustainability 2007
Long Beach, California
June 27–30, 2007



NREL is operated by Midwest Research Institute • Battelle Contract No. DE-AC36-99-GO10337

NOTICE

The submitted manuscript has been offered by an employee of the Midwest Research Institute (MRI), a contractor of the US Government under Contract No. DE-AC36-99GO10337. Accordingly, the US Government and MRI retain a nonexclusive royalty-free license to publish or reproduce the published form of this contribution, or allow others to do so, for US Government purposes.

This report was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or any agency thereof.

Available electronically at http://www.osti.gov/bridge

Available for a processing fee to U.S. Department of Energy and its contractors, in paper, from:

U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
phone: 865.576.8401
fax: 865.576.5728
email: mailto:reports@adonis.osti.gov

Available for sale to the public, in paper, from:

U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
phone: 800.553.6847
fax: 703.605.6900
email: orders@ntis.fedworld.gov
online ordering: http://www.ntis.gov/ordering.htm

Printed on paper containing at least 50% wastepaper, including 20% postconsumer waste

FIELD EVALUATION OF A NEAR ZERO ENERGY HOME IN OKLAHOMA

Robert Hendron
National Renewable Energy Laboratory
Golden, CO

Ed Hancock
Mountain Energy Partnership
Boulder, CO

Greg Barker
Mountain Energy Partnership
Boulder, CO

Paul Reeves
Partnership for Resource Conservation
Boulder, CO

ABSTRACT

The authors evaluated a Zero Energy Home (ZEH) built by Ideal Homes in Edmond, Oklahoma, that included an extensive package of energy-efficient technologies and a photovoltaic (PV) array for site electricity generation. The ZEH was part of a Building America (BA) research project in partnership with the Building Science Consortium to exhibit high efficiency technologies while keeping costs within the reach of average home buyers, and was a modified version of a production 1584-ft^2, three-bedroom, single-story, slab-on-grade design with attached garage. The home included a tight, well-insulated envelope, an energy recovery ventilator, high-performance windows, tankless gas water heater, efficient lights and appliances, and a ground source heat pump (GSHP). We conducted a series of short-term tests beginning in August 2005, and have collected long-term data under occupied conditions since February 2006. The GSHP performance was disappointing until the outdoor unit was replaced, after which time the efficiency began to meet expectations. However, the electricity use of the replacement unit was higher than expected because of an unusually low cooling setpoint. Based on the measured test results, the predicted whole-house energy savings compared to the BA Benchmark was 96%, with savings of 55% for efficiency measures alone.

NOMENCLATURE

h_{conv}	convection heat transfer coefficient (W/m^2-K)
h_r	linearized radiation heat transfer coefficient = $\sigma\varepsilon(T_m+T_{sky})(T_m^2+T_{sky}^2)$ (W/m^2-K)
I_c	incident solar radiation (W/m^2)
i_{mp}	current at maximum power point (A)
i_{sc}	short circuit current (A)
P_{mp}	power at maximum power point (W)
P_{pv}	DC power produced by PV (W)
P_{ac}	AC power out of the inverter (W)
T_{amb}	ambient air temperature (K).
T_{db}	dry-bulb air temperature (°C)
T_m	module temperature (K)
T_{sky}	black-body sky temperature (K)
V_{mp}	voltage at maximum power point (V)
V_{oc}	open circuit voltage (V)
ε	emissivity of glazing
η_0	efficiency at Standard Test Conditions
η_{mp}	efficiency at maximum power point
σ	Stefan-Boltzmann constant (W/m^2-K^4)
$\tau\alpha$	transmittance-absorptance product of glazing and cells

INTRODUCTION

Ideal Homes built a Zero Energy Home (ZEH) in Edmond, Oklahoma, (a suburb of Oklahoma City) using a comprehensive package of energy efficiency measures and a photovoltaic array to generate electricity on-site. The ZEH was a research project designed to showcase high efficiency technologies, while trying to keep costs reasonable, with the objective of helping to put Zero Energy Homes within the reach of average home buyers. Designed in partnership with Building Science Consortium (BSC), one of seven Building America (BA) industry teams, the ZEH was a modified version of Ideal Homes Plan 1644, and was a 1584-ft^2, three-bedroom, single-story, slab-on-grade design with attached garage. The home was designed to have a tight, well-insulated envelope, and included an energy recovery ventilator (ERV), high-performance windows, tankless gas water heater, efficient lights and appliances, and a closed-loop ground source heat pump (GSHP) for space conditioning. A photo of the ZEH is shown in Fig. 1. Key design specifications are listed in Table 1. The overall reduction in energy use was initially expected to be 88% compared to the BA Benchmark [1] based on preliminary analysis conducted by BSC.

This report summarizes the results of short-term and long-term testing and analysis of the ZEH. The National Renewable Energy Laboratory (NREL) and BSC performed the initial field testing in August 2005, and NREL visited the site three additional times (November 2005, January 2006, and September 2006) to evaluate subsequent modifications to the house, many of which addressed problems identified during the initial test.

Fig. 1 Ideal Homes ZEH (view from northeast)

Table 1 Key Specifications for Ideal Homes ZEH

	Ideal Zero Energy Home
Building envelope	
Orientation	North
Ceiling	R-38 blown cellulose at ceiling
Walls	R-19 blown cellulose + R-3 insulating sheathing
Foundation	Slab, R-4 perimeter insulation
Windows	Double-glazed vinyl-frame LowE^2 U = 0.39, SHGC = 0.31 Mostly south-facing with overhang
Infiltration	2.5-in^2 leakage area per 100 ft^2 envelope area
Mechanical systems	
Space heating	4.3 COP GSHP, 2-3 ton capacity (original) 3.5 COP GSHP, 2-ton capacity (final)
Cooling	20 EER GSHP, 2-3 ton capacity (original), 16.6 EER GSHP, 2-ton capacity (final)
Domestic hot water (DHW)	Rinnai tankless gas water heater, 0.82 Energy Factor
Air-handler location	In conditioned space (utility room)
Ducts	In vented attic, R-6 insulation, 5% or less leakage to the outside
Ventilation	ERV with 70% sensible recovery, 92 cfm @ 50 % duty cycle, AirCycler for mixing only (17% duty cycle)
Lighting	90% compact fluorescent lighting
Appliances and miscellaneous electric loads	ENERGY STAR refrigerator, clothes washer, dishwasher
PV System	5.3-kW DC maximum under standard test conditions, 5.1-kW inverter

SHORT-TERM FIELD-TEST RESULTS

Blower Door, Duct Blaster, and Airflow Measurements

All envelope and duct leakage targets were met (Table 2). Even though the ducts were located in an unconditioned attic, air leakage to the outside was only about 3% of total flow. The measurements indicated that none of the return-air leakage was to the outside, suggesting that the leakage points were either around the perimeter of the registers or near the air handler, which was located in an interior closet.

The overall supply volume (>1200 cfm) was very high for such an energy efficient house. The air handler fan was sized for 3-ton operation of the GSHP in anticipation of large heat loads during the local Parade of Homes. A new fan with an electronically commutated motor (ECM) was installed in September 2005, and the total flow rate was reduced to 800 cfm while the GSHP was operating at 2-ton capacity, which was the vast majority of the time. The ERV and all exhaust fan airflows met design expectations.

Table 2 Blower Door and Duct Blaster Measurements

		Target	Measured
Blower Door	cfm@50Pascal	1230	1071
	Effective leakage area (in^2)	67.5	44.1
Duct Blaster	cfm@25Pa, total	-	120
	cfm@25Pa, outside	60	40
	cfm@25Pa, total, supply	-	87
	cfm@25Pa, outside, supply	-	40

Tracer-Gas Testing

The NREL tracer-gas monitoring system was installed in the ZEH for two nights of testing beginning Friday, August 26. This system monitors the decrease in concentration of sulfur hexafluoride (SF_6) over time and calculates the overall air-exchange rate of the house in units of air changes per hour (ACH). Six sampling points were used during the test, and small fans were used to maintain uniform mixing throughout the house. Peak temperatures during the afternoon were about 93°F (34°C), with overnight lows of about 66°F (19°C). Although it was quite breezy on Saturday afternoon, the wind died down substantially at night. The results of the tracer-gas test are plotted in Fig. 2.

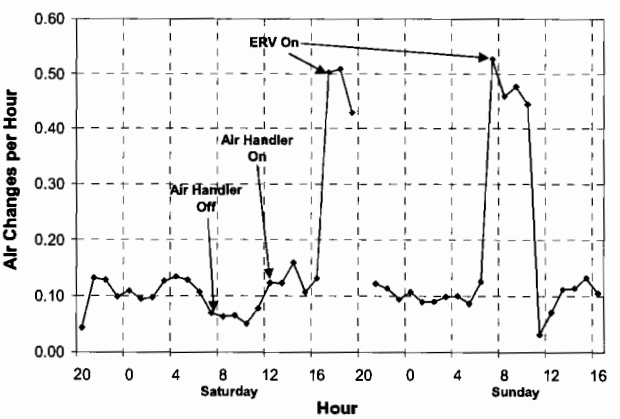


Fig. 2 Tracer-gas results for Ideal Homes ZEH

Under normal operation, the air infiltration for the ZEH was approximately 0.10-0.15 ACH. When the air handler was turned off in the ZEH early Saturday morning (known as a "bump test"), the air-exchange rate decreased by about 0.04 ACH, corresponding to a net effect of approximately 10 cfm caused by duct leakage or room pressurization. Because there was a significant increase in wind speed coincident with the second bump test at noon on Saturday, the result of that test was not meaningful. Each of the two ERV bump tests caused an increase in air-exchange rate of about 0.38 ACH (94 cfm). Because a ventilation rate of 46 cfm was recommended by ASHRAE Standard 62.2, the builder programmed the ERV to operate at a duty cycle of 50%.

Supplemental Duct-Leakage Testing

A series of alternative duct-leakage tests were conducted as part of an effort to identify appropriate test procedures for evaluating ducts in unconditioned space. The following discussion provides a basic description of the methodology for each test, identifies some of the practical issues encountered during the execution of the test, and analyzes the measured results (Table 3).

Table 3 Results of Alternative Duct-Leakage Test Procedures

	Tracer-Gas Bump	Duct Pressurization @ 25 Pa	Sum of Register Flows	DeltaQ	Nulling	Blower Door Subtraction @ 25 Pa
Total Leakage (cfm)		120				
Total Supply Leakage (cfm)		87	50			
Total Return Leakage (cfm)		28				
Total Leakage to Outside (cfm)		40				-14
Supply Leakage to Outside (cfm)		40		-11	14	
Return Leakage to Outside (cfm)		0		-18	0	
Net Impact on Infiltration (cfm)	10					

Tracer-Gas Bump Test. A tracer-gas bump test involves the measurement of whole-house air-change rate immediately before and after a building system is turned on or off. Bump tests are used most frequently to evaluate the whole-house effect of either air-handler or ventilation system operation (or both at once). In order to minimize the complication of wind effects, the test is usually conducted very early in the morning (4 a.m. to 5 a.m.) when winds tend to be the calmest.

A tracer-gas bump test measures the combined effect of duct leakage to the outside and induced infiltration through the building envelope caused by unbalanced duct leakage or room pressurization. It does not measure the actual air leakage through the ducts, and does not provide any information about the split between supply- and return-duct leakage. When ducts are located in a buffer space, such as an attic or crawlspace, the bump test accounts for the supply-duct leakage that re-enters the house through return-duct leaks (usually a very small fraction in a well-vented space), but does not provide information about the temperature change of that air.

For the ZEH, the bump test produced a change in infiltration of approximately 0.04 ACH or 10 cfm. Because ventilation in the ZEH was provided by a separate system and the air handler was in conditioned space, this measurement included only the effects of duct leakage to the outside and room pressurization. Although the signal was small, the noise was also small because the envelope was extremely tight, allowing us to estimate the change in ACH with an uncertainty of about ±25%. If this house would have been as leaky as a more typical house (~0.35 ACH), a small change of 0.04 ACH would have been much more difficult to observe.

Duct Pressurization. A duct-pressurization test typically involves the use of a duct blaster to measure the flow rate of air necessary to pressurize the air-distribution system to 25 Pa. The test is usually performed once with the house depressurized and again with the house pressurized. The latter test allows the isolation of duct leakage lost to the outside. During these tests, the supply and return registers are taped off, and a barrier may be placed in the filter slot to isolate the supply ducts from the return ducts and air handler. This is by far the most common duct-leakage test and is a standard procedure for many residential energy efficiency programs.

Duct-pressurization testing measures the air leakage under uniform pressure conditions, which may be significantly different from the actual pressure conditions when the air handler is operating. The pressure drop across a leak can have a very large effect on the flow rate through that leak. This makes the duct-pressurization test useful as a quality control tool, but not meaningful from the standpoint of quantifying actual duct leakage and associated energy losses under normal operation (unless the measured leakage is zero).

For the ZEH, the supply-duct leakage to the outside at 25 Pa was 40 cfm, and there was no measurable return-duct leakage to the outside. Duct leakage to the inside was about 80 cfm, of which about 47 cfm was on the supply side.

Sum of Register Flows. This method for calculating duct leakage compares the sum of the individual supply-register flows to the total air-handler flow. A similar test is performed by summing the return-register flows. For a house with no duct leakage, these three values should be identical. If the sum of the supply-register flows and the total air-handler flow are not the same, the difference is equal to the total supply-duct leakage. Similarly, the difference between the sum of return air flows and the air-handler flow is equal to the return-duct leakage. Unfortunately, it is not possible to differentiate between leakage to the inside and leakage to the outside using this approach.

The supply-register flow measurements for the ZEH summed to 1250 cfm. Because there was no filter slot located at the air handler, the total air-handler flow rate was measured using the duct blaster instead of a calibrated orifice plate. The total flow rate was estimated to be about 1300±50 cfm,

because the duct blaster reached its maximum capacity at 1250 cfm, and we were just shy of the flow rate necessary to match the pressure in the supply plenum under normal operation. Taking the difference between total flow rate and the sum of supply-register flows, we estimated a supply-duct leakage of approximately 50 cfm using this test approach. Return-duct leakage could be estimated in a similar manner, but the return registers were too large for our flow hood to accommodate. Fortunately, we already knew from the duct-blaster test that the return leakage to the outside was near zero.

One of the concerns with this approach is the accuracy and bias of the flow-hood measurements. Tests conducted by Lawrence Berkeley National Laboratory (LBNL) have suggested that standard flow hoods, such as the one used in this test, have root mean square (RMS) errors in the range of 20%-30% for individual measurements [2]. When summing multiple registers, the errors may not average out because of possible bias in the measurements. Combining these potential errors with the difficulties we encountered when measuring total air-handler flow, we expect that our estimate of 50 cfm supply duct leakage is highly uncertain.

DeltaQ. The DeltaQ test is a technique developed by LBNL that examines the change in whole-house ACH caused by operation of the air-handler fan with the house at different levels of pressurization and de-pressurization [3]. The DeltaQ equation includes four unknown values, including supply- and return-duct leakage and the effective leakage pressures in the supply and return ducts. If the DeltaQ test is run at enough pressures, these unknowns can be calculated with reasonable accuracy using statistical techniques. This approach has several appealing features: (1) The test can be conducted using a standard blower-door set-up; (2) supply and return leakage are calculated separately; and (3) the results represent leakage under normal operating conditions.

NREL conducted a DeltaQ test at the ZEH on Saturday, August 27. The process was straightforward, but relatively time consuming (taking approximately an hour to complete the test). Our understanding is that LBNL is working with the Energy Conservatory to develop an automated system that performs the DeltaQ test at hundreds of pressures in a very short period of time.

The results were difficult to interpret because the leakage values calculated by the DeltaQ spreadsheet were negative, which of course is physically impossible. This was likely a result of the combination of small duct leakage and relatively high winds that caused fluctuations in our outside pressure readings (which were actually measured in the garage with the garage door open slightly).

Nulling Test. The nulling test procedure was developed by Ecotope [4] and uses a blower door to counteract the change in house pressure caused by air handler operation, while measuring the flow rate necessary to offset that pressure change. The blower-door flow rate should be approximately equal to the unbalanced duct leakage, with a net inflow of air from the blower door representing supply-dominated duct leakage and a net outflow indicating return-dominated leakage. The test can be repeated with the return ducts isolated from the air-distribution system (using a barrier in the filter slot and a duct blaster to provide a leak-free return path) in order to measure supply leakage only.

The nulling test is relatively quick and simple to perform and provides a measurement of duct leakage to the outside under normal operating conditions. One limitation with this procedure is caused by the need to isolate a small quantity (duct leakage to the outside) from a much larger effect (envelope leakage).

The nulling test was performed at the ZEH on August 27. Because we already knew that return leakage was negligible, we assumed that the measurement of unbalanced duct leakage would be the same as the supply leakage to the outside. Unfortunately, the interior and exterior pressures fluctuated greatly because of wind effects during the test period (even after the outside pressure tap was moved to the garage), making it very difficult to quantify the change in pressure caused by the operation of the air handler. Using extended time averages, we were eventually able to estimate a reduction in pressure of about 0.1 Pa when the air handler was turned on, and that a blower door flow rate of 14 cfm seemed to offset that pressure change. This value was fairly consistent with the 10 cfm net leakage measured with the tracer gas.

Blower-Door Subtraction. This is a simple test where a blower-door test is performed at 25 Pa with and without the supply and return registers taped off. It measures an effect similar to a duct blaster, but with the added complication that duct leakage must be separated from envelope leakage. This test was performed on the ZEH, and the blower-door flow rate measured at 25 Pa actually decreased from 614 cfm to 600 cfm when the registers were untaped. Similar to our experience with the DeltaQ test on the ZEH, the blower-door subtraction test was complicated by strong wind effects, ultimately yielding meaningless results.

Ground Source Heat Pump (GSHP)

The GSHP at the ZEH was a customized split-system design with three 200-ft ground wells, somewhat different from the more common packaged systems for which published performance data were available. We conducted field measurements on August 29, 2005, to determine if the GSHP was performing as expected under hot summer conditions. The test data was collected when the outside air and ground loop temperatures were each about 90°F. We did not measure the ground temperature itself, but we estimate that it was about 73°F during the test period at a depth of 4 ft, approaching 60°F at greater depths. Of course, heat dissipation caused by the operation of the GSHP would have introduced localized short-term and long-term increases in ground temperature. The field measurements indicated that the energy efficiency ratio (EER) of the GSHP was 8.9 during the test period, significantly lower than the catalog value of about 13 EER with 90°F entering water temperature, and much lower than the rated value of about 17 EER under standard test conditions. The heat load for this calculation was approximated using air temperature measurements on each side of the cooling coil, along with an assumed latent heat load equal to 15% of the sensible heat load.

In the months after learning of these results, engineers from the GSHP manufacturer met with NREL and made some

changes to the system in an effort to improve the performance. The ground loop was emptied and re-charged to 60 psi when it was observed that the loop was not properly pressurized and there was some debris in the loop. One of the refrigerant filters was removed, and the refrigerant loop was re-charged. In addition, the 1200-cfm air-handler fan was replaced with a blower with an electronically commutated motor (ECM) that operated between 450 and 1200 cfm.

There were some concerns raised by the manufacturer regarding the electricity uses that should be included in the calculation of EER and Coefficient of Performance (COP). According to ASHRAE/ISO 13256-1 (the test standard governing the calculation of COP for water-source heat pumps), the "effective power input" used in the calculation of COP should include the compressor, the water pump, the air-handler fan, and all associated controls. However, fan power used in the calculation of COP/EER does not include flow resistance from ducts, and pump power does not include the resistance of the ground loop, because the ultimate designs of these external flow paths would be unknown to the manufacturer. Except for the ISO rating, pump power is generally not included in catalog data for the GSHP industry. As a result, we need to separately evaluate whether the GSHP is performing as designed (published COP without pump power), and as expected by the builder and potential homebuyers (COP including actual pump and fan power, under actual operating conditions).

In January 2006, we measured the air flow rates and power draws corresponding to different fan speeds for the new ECM air handler. The resulting heating COP based on air-side measurements of heat load calculated at 1-hour intervals over a 5-day period beginning in late January 2006 is shown in Fig. 3. A variety of outdoor conditions were encountered during this time period: the outdoor temperature ranged from 36-68°F, the indoor temperature was about 72°F, and the ground loop return temperature was in the range of 54-64°F while the GSHP was operating.

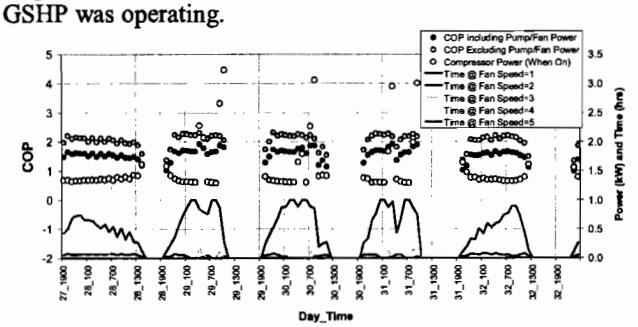


Fig. 3 GSHP coefficient of performance (COP), fan speed, and compressor power following the third site visit in January 2006

The COP is plotted in two ways, both including and excluding the pump power (240 W) and air handler fan power (146 W for fan speed #2). Regardless of whether pump and fan power were included, the heating COP continued to be much closer to 2.0 than the value of 4.0 under rated conditions that was published in the manufacturer's catalog.

The outdoor unit, including the compressor, pump, and controls, was replaced by the manufacturer in July 2006 with a unit that was tested in the laboratory under conditions similar to those encountered in the ZEH. In addition, the multi-speed ECM blower was replaced with a single-speed, 700 cfm blower. The replacement GSHP had a more efficient pump (179 W), and a rated COP of 4.9 in cooling mode. The new outdoor unit and air handler produced a marked improvement in COP. A malfunctioning compressor in the original outdoor unit was later identified by the manufacturer as the reason for the poor performance.

The installed COP of the new GSHP system was evaluated using three different types of sensors to calculate the heating and cooling load. Two types of sensors were installed in the ground water loop: resistance temperature detectors (RTDs) and thermopiles. Additionally, a pair of thermocouples measured the air temperatures in the supply and return plenums. The measured compressor and pump power were subtracted from the heat transfer rate to the ground-water when calculating the useful cooling load and added when calculating the heating load.

The GSHP efficiency as a function of duty cycle is plotted in Fig. 4, with positive COP in cooling mode and negative in heating mode. The values are actually quite different using the different sensors, but on balance we have the highest confidence in the water-side RTD because the installed locations of the thermopiles are sub-optimal, and the air-side readings are complicated by greater measurement uncertainties. However, there are certain system losses accounted for by the air-side measurements that are not captured by the water-side measurements, such as energy losses from the refrigerant lines to the unconditioned attic, an effect estimated to be less than 5% by the GSHP manufacturer. Duct leakage to the attic is also not reflected in the water-side calculations, though we estimate this effect to be less than 1%.

It is evident from Fig. 4 that larger differences between air-side and water-side COP calculations were present in heating mode compared to cooling mode. The data doesn't provide a clear explanation, but the cause of this trend may be either inaccurate average air temperature measurements caused by temperature non-uniformity over the cross-section of the ducts, or inaccurate flow rates caused by a change to system operation over time. We also examined the effects of heat losses from the pump and compressor to the outside, and thermodynamic differences in density and velocity before and after the air handler, and we feel confident that neither effect can explain the larger discrepancy between the air-side and water-side COP in heating mode compared to cooling mode.

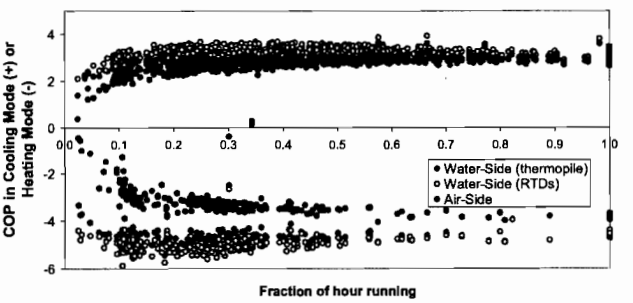


Fig. 4 Installed COP (including pump and fan energy) of the GSHP using alternative temperature measurements to calculate useful heat load

Figs. 5 and 6 compare the COP of the replacement GSHP (not including pump power) in both heating and cooling mode with laboratory data measured by the manufacturer using various ground-water and conditioned-air temperatures (T_{db}). The results match very well, indicating that the GSHP performance is now consistent with the manufacturer's expectations.

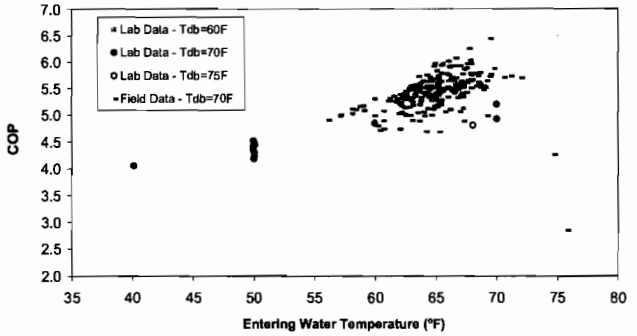


Fig. 5 Installed vs laboratory COP of the GSHP in heating mode following replacement of the outdoor unit in July 2006

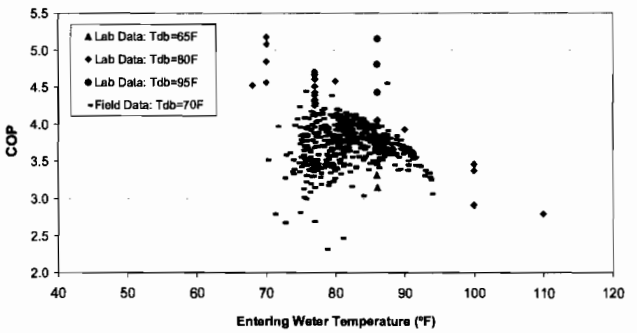


Fig. 6 Installed vs laboratory COP of the GSHP in cooling mode following replacement of the outdoor unit in July 2006

Photovoltaic System

On August 28-29, 2005, NREL recorded 10-min averaged measurements of the PV system installed on the roof of the ZEH. During the 2-day test, measurements were made of the alternating current (AC) power delivered by the inverter, the solar radiation in the plane of the array, and the back-of-module temperature (T_{pv}). Using T_{pv} as a surrogate for cell temperature, the manufacturer's performance parameters and model were used to calculate the "expected" DC power output of the array under the actual weather conditions. The measured efficiency was about 22% lower than expected. During the second site-visit in late November 2005, NREL noted that one of the seven photovoltaic strings was not connected to the inverter, which explained most of the 22% difference. The problem was corrected by the PV installer in mid-December 2005.

NREL conducted a total of 328 i-V (current-voltage) curve measurements [5] over a range of solar and temperature conditions during the third visit to the site in January 2006. These short-term measurements were used to calibrate a TRaNsient SYstems Simulation (TRNSYS) [6] model for predicting long-term performance of the PV system.

Parameters at Standard Test Conditions (STC) calculated for the calibrated model are compared in Table 4 to those provided by the manufacturer. The measured currents and voltages were all within 5.5% of the values specified by the manufacturer. It is important to remember that the manufacturer's specifications are for a uniform cell temperature of 25°C, whereas the measured parameters are for a back-of-module temperature of 25°C. We attempted to place our sensor in an "average" location, but the effective average cell temperature over time may have been higher or lower than our point measurement.

Table 4 Comparison of parameters in January 2006: manufacturer-supplied to measured

Description	Rated	Measured (Curve Traces)	Units	Ratio: Measured/ Rated
i_{sc} @STC, Array	26.25	26.09	amps	0.994
V_{oc} @STC, Array	270.00	268.42	volts	0.994
i_{mp} @STC, Array	24.29	25.63	amps	1.055
V_{mp} @STC, Array	219.20	212.51	volts	0.969
P_{mp} @STC, Array	5324	5446	watts	1.023
η_{mp} @STC, Array	16.1	16.5	%	1.023

ANNUAL ENERGY SIMULATIONS

Photovoltaic System

Developing an accurate model for predicting the effective average module temperature of a PV array is perhaps the most difficult task in modeling its annual performance. Fortunately, a single temperature, which may be offset from the average but follows the average temperature, was deemed to be sufficient for our approach. As long as the point temperature measured during the short-term test (i-V traces) can be modeled accurately, the TRNSYS model simply uses this temperature in predicting PV performance. Equation 1 gives the model we employed in this study:

$$T_m = 1/(h_r+h_{conv})*\{[(\tau\alpha)-\eta_0)]*I_c+[h_r]*T_{sky}+ h_{conv}*T_{amb}\} \quad (1)$$

Equation 1 takes into account convection heat transfer from the module to the ambient air, as well as radiative heat transfer to the sky. It is assumed that radiation from the back of the module to the roof surface (which is only a few inches away) is negligible. We did not have a measurement of wind speed at the site, so for this study we assumed a constant convection heat transfer coefficient (h_{conv}). For our data set, a best-fit to Equation 1 yielded a value of h_{conv} = 21.5 W/m^2-K with an RMS error of 4.2°C for the hours where the incident solar radiation was greater than 50 W/m^2.

Figures 7 and 8 illustrate some of the accuracies and deficiencies of the model described by Equation 1. Both days were cloudless days with mid-day ambient air temperatures of between 9°C and 13°C. The model matched the measured array-center temperature quite well for March 13 (Fig. 7) but not very well for March 14 (Fig. 8). The bad fit on March 14 may be a result of different wind conditions (speed and/or direction) or may be caused by an inadequate description of the heat transfer geometry assumed in Equation 1. The reader should also note the light-blue line (square symbols), which

represents the measured temperature difference between the center module and the corner module. The fact that this difference is not constant illustrates the weakness of assuming that the average module temperature linearly follows any single point temperature measurement of the array. A methodology for accurately predicting the temperature behavior of PV arrays, including the possible application of infrared scanning, is an important topic for further research.

In Fig. 9 we compare the measured direct-current (DC) output of the PV array to several different simulation results on a monthly basis. In all cases, the simulations were driven by measured weather data, but the module temperature was handled in three different ways: (1) using the measured-module temperature, (2) using the temperature predicted by Equation 1 fit to 5 months of data, and (3) using the temperature predicted by Equation 1 fit to the 2 days of data during the short-term tests. In addition we show the results based on our TRNSYS model derived from the curve traces, as well as the model based on the manufacturer's specifications and the measured module temperature. The seventh bar is similar to the model used after the initial short-term test in August 2005. In general, the two advantages of using a model based on measured data are (1) that the model relies on an actual measured module temperature, even if does not represent the average module temperature, and (2) it takes into account the effects of wiring losses and connection resistances, which are difficult to ascertain any other way. In this case, because all of the models predict the PV output fairly well for the 3-month period, it appears that the errors are not very large, or cancel out over an extended time period.

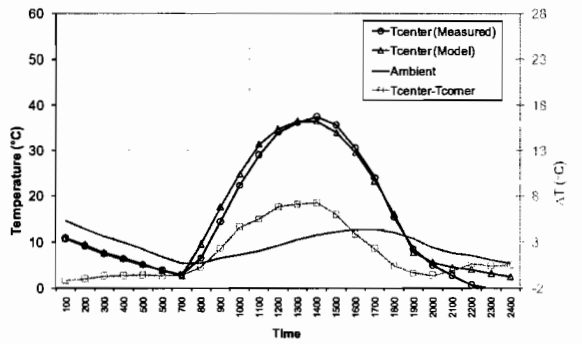


Fig. 7 Measured and predicted center-of-array module temperature, showing a good comparison of measured to modeled.

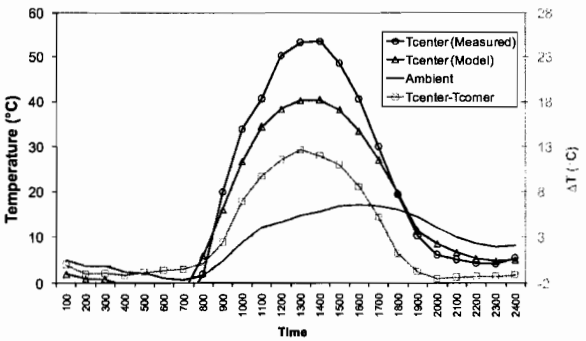


Fig. 8 Measured and predicted center-of-array module temperature, showing a poor comparison of measured to modeled.

TRNSYS was used to simulate the performance of the PV system under TMY2 (Typical Meteorological Year) conditions using the curve fit of module temperature to long-term data (the fourth bar in Fig. 9). The results are summarized in Table 5. The predicted annual site AC electricity generation based on this calibrated model was 9288 kWh/year.

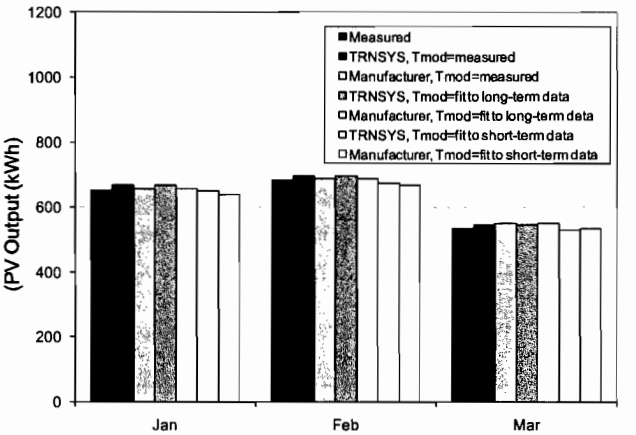


Fig. 9 Monthly DC energy production by the PV array using various modeling approaches

Table 5 Predicted Monthly Performance of the PV System Using TRNSYS and Measured Data

Month	Ambient Temp	Wind Speed	Insolation	P_{pv}	P_{ac}	System Efficiency (AC)
	(°C)	(m/s)	(kWh/m^2)	(kWh)	(kWh)	
Jan	-0.3	6.2	122	676	621	15.5%
Feb	3.3	4.8	130	711	657	15.3%
Mar	10.4	6.7	165	872	807	14.8%
Apr	14.8	6.9	182	941	871	14.5%
May	20.6	5.9	183	929	853	14.2%
Jun	23.7	5.3	188	945	868	14.0%
Jul	26.3	5.3	201	998	915	13.8%
Aug	27.9	4.6	198	976	896	13.7%
Sep	22.1	3.9	168	854	785	14.1%
Oct	16.9	4.8	164	855	789	14.6%
Nov	9.8	4.7	124	667	612	14.9%
Dec	5.1	5.2	122	670	614	15.2%
YEAR	**15.0**	**5.3**	**1946**	**10096**	**9288**	**14.4%**

Whole-House Simulations

An hourly energy analysis of the ZEH was performed using the DOE-2.2 building-simulation software. The measured performance characteristics of the ZEH in its final configuration were used as inputs to the model whenever possible. Such inputs included duct leakage, envelope leakage, GSHP efficiency, ventilation rate, fan energy (ERV and air handler), and ERV sensible heat recovery.

In accordance with the Building America Performance Analysis Procedures [7], the ZEH was compared to the BA Benchmark and Builder Standard Practice (BSP). The BSP specifications for Ideal Homes were based on the Eagle Cliff community built to ENERGY STAR standards in Norman,

Oklahoma, along with information provided by Ideal Homes. Key features of the BSP house include a condensing gas furnace, SEER 14 air conditioner, clear double-pane windows, perimeter slab insulation, tight building envelope and ducts, and a standard gas water heater.

The predicted annual source energy use for the Benchmark and the ZEH are shown in Fig. 10. Source energy, also known as primary energy, is assumed to be 3.16 times site energy for electricity [1], and includes the effects of generation and transmission losses. The corresponding site-to-source energy multiplier for natural gas is 1.06. Space-heating and cooling energy are both dramatically reduced for the ZEH, and significant improvements are made to the DHW and lighting loads. The largest remaining end-use category is "Appliances/MELs," which is the most difficult category for a builder to influence because these loads are primarily under the control of the occupants.

A breakdown of the change in cumulative energy savings associated with individual energy efficiency measures is shown in Table 6. Site energy, source energy (which includes generation and distribution losses for electricity), and energy cost savings are shown for each measure. Total annual source energy savings is projected to be 96%, with 55% for efficiency measures alone, and the rest attributable to the PV system. Other than the PV system and measures that are already part of Ideal Homes standard practice (which is 35% more efficient than the Benchmark), the improvements that made the greatest impact were the efficient lighting and appliances, the tankless water heater, improved insulation, and the GSHP. Because Ideal Homes standard practice for space heating is a condensing gas furnace, and natural gas prices are high in Oklahoma, the GSHP measure appears more beneficial on a local energy cost basis (20% savings) than it does on a source energy basis (4% savings) when compared to BSP.

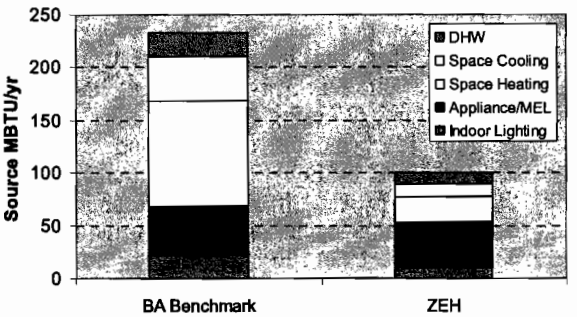


Fig. 10 Predicted annual energy use for the ZEH and Benchmark

Table 6 Predicted Savings for Individual Energy Efficiency Measures in the Ideal Homes ZEH

	Site Energy		Source Energy		National Average Energy Cost		Builder Standard (Local Costs) Energy Cost		Measure	Package
Increment	kWh	therms	MBTU	Savings %	$/yr	Savings %	$/yr	Savings %	value ($/yr)	savings $/yr
Building America Benchmark	20018	292	234.9		$2,028		$1,393			
Benchmark with SEER10 AC & 78% AFUE Furnace	9348	1000	197.8	16%	$1,769	13%	$1,879			
Ideal Homes Standard Practice (BSP)	8040	691	152.9	35%	$1,361	33%	$1,423			
Ideal Std + Improved Ceiling/Wall Insulation	7916	641	146.5	38%	$1,302	36%	$1,352	5%	$71	$71
Ideal Std ++ LowE Windows	7657	701	150.0	36%	$1,337	34%	$1,419	0%	$(67)	$4
Ideal Std ++ Reduced Infiltration	7571	662	145.1	38%	$1,292	36%	$1,364	4%	$55	$59
Ideal Std ++ ERV Ventilation	7784	612	142.2	39%	$1,263	38%	$1,312	8%	$52	$111
Ideal Std ++ Tankless DHW	7784	530	133.8	43%	$1,185	42%	$1,205	15%	$107	$217
Ideal Std ++ Improved Ducts	7682	501	129.8	45%	$1,148	43%	$1,163	18%	$42	$259
Ideal Std ++ Imp. HVAC (GSHP)	9956	212	123.6	47%	$1,072	47%	$886	38%	$277	$537
Ideal Std ++ CFL Lig and E-Star Appl.	8565	175	105.6	55%	$915	55%	$776	45%	$110	$646
Ideal Std ++ PV (ZEH As-Built)	**-724**	**175**	**10.4**	**96%**	**$103**	**95%**	**$177**	**88%**	**$599**	**$1,246**

National Average Electric Cost:	0.0874	$/kWh	
National Average Gas Cost:	0.952	$/therm	
Local Average Electric Cost:	0.070	$/kWh	first 600 kWh/month
	0.040	$/kWh	remaining kWh/month
Local Average Gas Cost:	1.300	$/therm	

The high-performance windows (low emissivity, low solar heat gain) actually had a negative effect on energy savings compared to the BSP windows (clear double-pane, U = 0.46, SHGC = 0.57), primarily because the reduction in radiative heat losses associated with the low-emissivity coating (U = 0.39) was outweighed by the reduction in free heating energy associated with low solar heat gain (SHGC = 0.31). Because most of the windows were already located on the south façade, and significant summertime shading was already provided by the roof overhang, there was no energy benefit to the use of low-SHGC glass. However, certain

comfort-related benefits are associated with low-SHGC glass that must also be considered.

Another somewhat surprising result is the small apparent benefit of the energy recovery ventilator (ERV). However, at that step of the analysis the heating system was an efficient gas furnace consistent with BSP. As a result, the ERV is trading natural gas against electricity on a source-energy basis, making it appear about 33% less beneficial than it would in conjunction with an electric heat pump. This illustrates the significant impact of alternate sequencing on the predicted energy savings for an individual measure. It should also be noted that the ERV has a larger effect on energy cost, because the local gas rate is very high ($1.30/therm) near Oklahoma City and the electricity rate is very low (7¢/kWh), especially when a household uses more than 600 kWh/month (4¢/kWh).

NREL examined the effect on energy and cost savings for several different space-conditioning systems, including the GSHP system used in the ZEH. We compared this system to the Ideal Homes standard practice (90% AFUE furnace and SEER 14 air conditioner), along with a SEER 13 air-source heat pump, which was the National Appliance Energy Conservation Act (NAECA) minimum efficiency for 2006. The source energy use for each system, assuming the Benchmark thermostat settings of 71°F for heating and 76°F for cooling, is shown in Fig. 11. It appears that the GSHP system uses significantly less source energy than the other options considered. Because the cost of electricity is exceptionally low in Oklahoma compared to natural gas, the energy cost for the GSHP would also be the lowest. However, first cost must also be considered when evaluating cost-effectiveness.

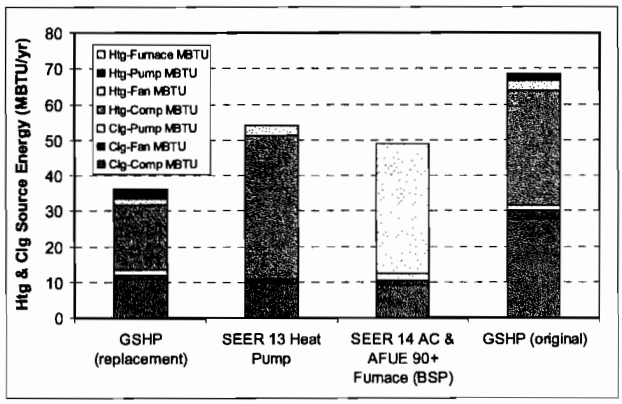


Fig. 11 Heating and cooling source energy with alternative HVAC systems

LONG-TERM MONITORING

NREL installed long-term monitoring equipment in the ZEH in late November 2005 and began recording the energy use of key building systems under occupied conditions in February 2006. One issue we observed was the diminished COP of the GSHP caused by the very low cooling setpoint of 70°F that was being used in the occupied home. The GSHP operated at lower efficiency because the heat transfer rate at the cooling coil was diminished. At the same time, the cooling load was larger because the temperature difference between the inside and outside conditions was larger than usual. Fig. 12 shows the estimated effect of various cooling setpoints on annual cooling energy for the ZEH. By cooling their home to 70°F, we estimate that the occupants were using 2.5 times more cooling energy than they would have if they had used a more typical setpoint of 76°F.

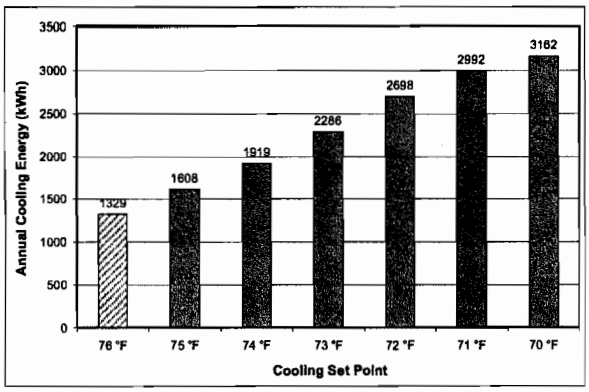


Fig. 12 Impact of cooling thermostat setting on GSHP electricity use

The measured electricity use and PV generation for the first 10 months of occupancy are shown in Fig. 13. Until July, the actual electricity use was much higher than predicted because of the unexpectedly poor performance of the GSHP. After the outdoor unit was replaced in July, there was generally closer similarity between predicted and measured electricity use. PV generation was consistent with expectations, but has met only 64% of the electricity use for the ZEH, instead of the 100% predicted. It must be noted that the predicted values for both the GSHP and the PV system were based on typical weather conditions and occupant behavior, so a good correlation is not to be expected until the model is adjusted to match actual operating conditions, which will happen after 1 year of data are collected for the new GSHP system.

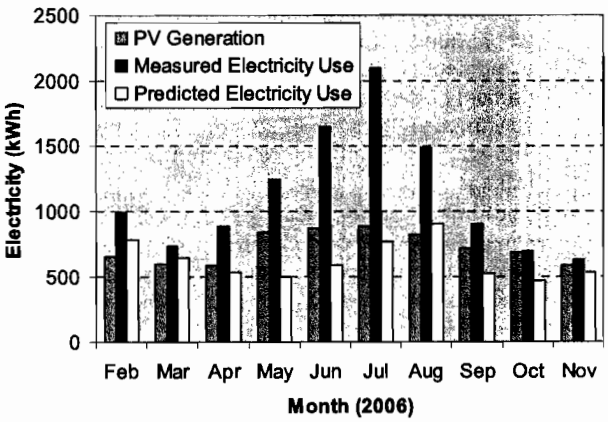


Fig. 13 Measured PV output compared to electricity consumption during first 10 months of occupancy

Natural gas usage for DHW for the first 10 months of occupancy is shown in Fig. 14. Actual monthly gas consumption was less than predicted, at least partly because

the daily volume of hot water was less than expected (29 gal/day compared to 56 gal/day in June and July).

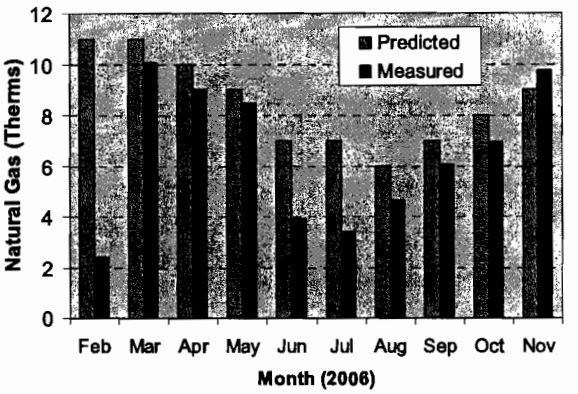


Fig. 14 Measured gas usage for DHW compared to simulation during first 10 months of occupancy

CONCLUSIONS

The following conclusions summarize the key findings of the field testing and analysis of the Ideal Homes ZEH:

- The envelope and duct leakage targets established by BSC were met for the ZEH, as measured using a blower door and duct blaster.
- Tracer-gas testing verified the tightness of the building envelope. During the test period, the natural infiltration rate was typically less than 0.10 ACH. We would expect a somewhat higher natural ACH during the winter when driving forces tend to be larger.
- Tracer-gas bump tests in the ZEH indicated that the increase in whole-house air-exchange rate caused by air handler operation was only about 10 cfm even though the ducts were in an unconditioned attic.
- Each of the six duct-leakage test methods we attempted had different strengths and weaknesses. Based on our results, none of the methods seem to be both simple and accurate. The tracer-gas bump test provides the most accurate information for use in a whole-house simulation tool, but the necessary equipment is quite expensive. The duct-blaster test is probably the best quality control tool in new construction because of its simplicity and ability to disaggregate supply vs. return and outside vs. inside leakage.
- The initial performance of the GSHP was poor compared to the manufacturer's rating because of a defective compressor. Once the outdoor unit was replaced with a new unit that was tested in the laboratory under the same operating conditions as the ZEH, the installed COP matched design expectations.
- The power output of the PV system was initially 22% less than its rated value, but the system began performing as expected once we discovered that one of seven strings was not connected to the inverter and a repair was made.
- Predicting the average PV array temperature with accuracy was problematic for this project. However, the errors appear to be small enough that our model has predicted overall monthly PV output very well.
- The predicted whole-house energy savings for the ZEH compared to the Building America Benchmark is 96%, exceeding the goal of 88% established by BSC and Ideal Homes. For efficiency measures alone, the predicted energy savings is 55%. The largest contributors to the energy savings (over and above Ideal Homes standard practice) are the PV system, compact fluorescent lights and ENERGY STAR appliances, improved envelope insulation, the GSHP, and the tankless gas water heater.
- The low solar heat gain windows installed in the ZEH (U = 0.39, SHGC = 0.31) are not expected to save energy compared to the Ideal Homes standard practice windows (U = 0.46, SHGC = 0.57) given the climate and the architectural design of the house.

ACKNOWLEDGMENTS

The authors express our appreciation to Vernon McKown, Todd Booze, and Tim Sullivan of Ideal Homes for providing NREL with extensive field support, including generous access to the ZEH during the test period. We would also like to acknowledge the assistance of Mark Sevier and the rest of the BSC team for their help in testing the ZEH and for offering their insights throughout the project. The engineering team at ClimateMaster provided valuable feedback on the GSHP testing and analysis. Finally, we want to thank Ed Pollock and George James of DOE for the leadership and resources necessary to perform this work.

REFERENCES

[1] R. Hendron, 2005, "Building America Research Benchmark Definition, Updated December 29, 2004," NREL Report No. 37529, Golden, CO.

[2] C.P. Wray, I.S. Walker, and M.H. Sherman, 2002, "Accuracy of flow hoods in residential applications," Proceedings of the ACEEE Summer Study on Energy Efficiency in Buildings, Pacific Grove, California, Volume 1, Pages 339-350, LBNL-49697, Washington, DC.

[3] D.J. Dickerhoff, I.S. Walker, and M.H Sherman, 2005, "Validating and Improving the DeltaQ Duct Leakage Test," LBNL 53959, Berkeley, CA.

[4] P.W. Francisco, and L.S. Palmiter, 2001, "The Nulling Test: A New Measurement Technique for Estimating Duct Leakage in Residential Homes," ASHRAE Transactions vol. 107, pt 1, Atlanta, GA.

[5] G. Barker, P. Norton, 2003, "Building America System Performance Test Practices: Part 1 – Photovoltaic Systems," NREL Report No. TP-550-30301, Golden, CO.

[6] S. Klein., et al., 2000, TRNSYS: A Transient System Simulation Program - Reference Manual, Solar Energy Laboratory, University of Wisconsin, Madison, WI.

[7] R. Hendron, R. Anderson, R. Judkoff, C. Christensen, M. Eastment, P. Norton, P. Reeves, and E. Hancock, 2004, "Building America Performance Analysis Procedures: Revision 1," NREL Report No. TP-550-35567, Golden, CO.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Executive Services and Communications Directorate (0704-0188). Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ORGANIZATION.

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
August 2008	Conference Paper	

4. TITLE AND SUBTITLE
Field Evaluation of a Near Zero Energy Home in Oklahoma

5a. CONTRACT NUMBER
DE-AC36-99-GO10337

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
R. Hendron, E. Hancock, G. Barker, and P. Reeves

5d. PROJECT NUMBER
NREL/CP-550-40875

5e. TASK NUMBER
BET88004

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

8. PERFORMING ORGANIZATION REPORT NUMBER
NREL/CP-550-40875

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)
NREL

11. SPONSORING/MONITORING AGENCY REPORT NUMBER

12. DISTRIBUTION AVAILABILITY STATEMENT
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

13. SUPPLEMENTARY NOTES

14. ABSTRACT *(Maximum 200 Words)*
The authors evaluated a zero energy home built by Ideal Homes in Edmond, Oklahoma, that included an extensive package of energy-efficient technologies and a photovoltaic array for site electricity generation. The home was part of a Building America research project in partnership with the Building Science Consortium to exhibit high efficiency technologies while keeping costs within the reach of average home buyers.

15. SUBJECT TERMS
photovoltaics; pv; zero energy home; building america

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER *(Include area code)*
Unclassified	Unclassified	Unclassified	UL		

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

DOE/GO-102000-1072
FS114
September 2000

ENERGY EFFICIENCY AND RENEWABLE ENERGY

FACT SHEET

Financing an Energy-Efficient Home

The average homeowner spends close to $1,300 a year on utility bills. But an energy-efficient home—with such features as proper insulation, high efficiency heating and cooling systems, and energy-efficient windows—can lower your utility bills by 10 to 50 percent.

It's easier than you may think to enjoy the savings and comfort of an energy-efficient home. Since an energy-efficient home is cost-effective, there are financing programs available from mortgages to home improvement loans, which allow more people the opportunity to live in such a home.

You can benefit from energy-efficient financing whether you're buying, selling, refinancing, or remodeling a home. If you're looking to buy an energy-efficient home, you can qualify for a better, more comfortable home because with lower utility costs, you can afford a slightly larger mortgage payment. You can also obtain financing to make energy-efficient improvements to an older home before moving in or to your existing home. And if you put your home on the market, you can use its energy efficiency as an attractive selling point.

Terry Schuyler, NREL/PIX07679

A homeowner in Colorado refinanced his home (above) through an energy-efficient mortgage to pay for the solar electric back-up system installed on the roof.

This document was produced for the U.S. Department of Energy (DOE) by the National Renewable Energy Laboratory (NREL), a DOE national laboratory. The document was produced by the Information and Outreach Program at NREL for the DOE Office of Energy Efficiency and Renewable Energy. The Energy Efficiency and Renewable Energy Clearinghouse (EREC) is operated by NCI Information Systems, Inc., for NREL / DOE. The statements contained herein are based on information known to EREC and NREL at the time of printing. No recommendation or endorsement of any product or service is implied if mentioned by EREC.

Printed with a renewable-source ink on paper containing at least 50% wastepaper, including 20% postconsumer waste

An energy rater will inspect the energy-related features of a home.

Home Energy Rating

Most energy-efficient financing programs will encourage you to have an energy rating for your new or existing home, which will tell you and the lender how energy-efficient it is. A rating typically involves an inspection by a professional energy rater who is certified under a nationally or state accredited home energy rating system (HERS). There are several options regarding HERS, so the type of HERS used will depend on where you live. Some states even have more than one HERS. Some of the organizations listed at the end of this fact sheet may be able to provide you with more information regarding HERS in your state.

For the most part, an energy rater will inspect the energy-related features of a home, such as insulation levels, window efficiency, heating and cooling systems, and air leakage. After the inspection, the energy rater will probably give you a report that includes the home's energy rating along with an estimation of annual energy use and costs. The report also may include recommended energy-efficient improvements, if needed, and their costs, as well as the potential annual savings and eventual payback of the improvements.

To help qualify for most energy-efficient financing, the report usually must show that the home is energy-efficient or that recommended improvements are cost-effective and will save you more money than you'd be borrowing to install them. While calculating whether a borrower qualifies for a mortgage, a lender can recognize these savings and add the cost of the improvements into the mortgage. Or, if the home is already energy-efficient, the lender can stretch the debt-to-income qualifying ratio, which is expressed as a percentage (the ratio is calculated by dividing a borrower's monthly payment obligation on long-term debts by the borrower's net effective income or gross monthly income).

The cost of a home energy rating and how it can be paid—by the borrower, the seller, the lender, the real estate agent, or financed as part of the mortgage—as well as the availability of certified energy raters, can vary from state to state and from one energy-efficient financing program to another.

Warren Gretz, NREL/PIX04869

A home energy rating inspection sometimes involves a duct blaster test, which measures air leakage in the ductwork.

An Example of a HERS and Its Reports

HERS Scale

Points	Stars	Energy Consumption
0-39	✪	More than 3 x the reference home
40-59	✪✪	More than 2 x and up to 3 x the reference home
60-79	✪✪✪	More than 1 x and up to 2 x the reference home
80-85	✪✪✪✪	Reference home level and up to 30% less than reference home
86-91	✪✪✪✪✪	30% less and up to 60% less than reference home
92-100	✪✪✪✪✪+	60% less and up to 100% less than reference home

Table 1. This scale, developed by the National Home Energy Rating Systems Council, is based on the U.S. Department of Energy's national voluntary guidelines for HERS uniformity. For rating purposes, a subject home is compared to a "reference home," which scores 80 points on a 100-point scale with a rating of four stars. Every 5% decrease in the annual energy costs between the subject home and the reference home increases the subject's home score by 1 point from 80 points. Meanwhile, every 5% increase reduces the score by 1 point from 80 points. Note: your state may use a different HERS and scale.

HERS Reports

An Energy-Efficient Home
Estimated Annual Energy Use & Costs

Description		Energy Use*	Energy Cost
Space Heating	23.9%	21.90 Mbtu	$110.33
Space Cooling	33.2%	30.41 Mbtu	$588.61
Water Heating	16.6%	15.23 Mbtu	$76.14
Other Energy Uses	26.3%	24.12 Mbtu	$272.36
Total	**100%**	**91.66 Mbtu**	**$1,047.44**

Source: National Home Energy & Resources Organization, Inc.
**Mbtu= 1,000,000 Btu*

Table 2. Based on the HERS scale in Table 1, this brand new, energy-efficient, 3,585 square-foot home in Houston, Texas, received a score of 89 points and five stars. The home features double-glazed windows, a 40-gallon natural gas water heater, a natural gas central air furnace, and an electric central air conditioner. A programmable thermostat controls the furnace and air conditioner.

A Home in Need of Energy-Efficient Improvements
Annual Energy Use & Costs without Improvements

Description		Energy Use*	Energy Cost
Space Heating	78.5%	223.44 Mbtu	$1,141.43
Space Cooling	10.5%	29.79 Mbtu	$645.77
Water Heating	6.2%	17.60 Mbtu	$88.02
Other Energy Uses	4.9%	13.92 Mbtu	$265.04
Total	**100%**	**284.79 Mbtu**	**$2,140.26**

Source: National Home Energy & Resources Organization, Inc.
**Mbtu= 1,000,000 Btu*

Table 3. Based on the HERS scale in Table 1, this 1,475 square-foot home in Tulsa, Oklahoma, received a score of only 21 points and one star. The home has single-paned windows, a 40-gallon natural gas water heater, natural gas central furnace, and an electric central air conditioner. A manual thermostat controls the furnace and the air conditioner. Equivalent carbon-dioxide emissions of 31.01 tons per year.

Estimated Annual Energy Use & Costs with Improvements

Description		Energy Use*	Energy Cost
Space Heating	58.7%	63.99 Mbtu	$326.90
Space Cooling	12.4%	13.46 Mbtu	$291.73
Water Heating	16.2%	17.60 Mbtu	$88.02
Other Energy Uses	12.8%	13.92 Mbtu	$265.04
Total	**100%**	**108.97 Mbtu**	**$971.69**

Source: National Home Energy & Resources Organization, Inc.
**Mbtu= 1,000,000 Btu*

Table 4. The homeowner will save more than 50% annually in energy costs if recommended energy-effiecient improvements are made to the house in Table 3. These improvements include sealing heating and cooling ducts, caulking, weatherstripping, installing a more energy-efficient central cooling system (10 SEER), installing more insulation in the crawlspace/basement and in the ceiling, and insulating hot water pipes. Payback for the improvements is estimated at a little more than 4 years. Equivalent carbon-dioxide emissions of 10.88 tons per year.

Energy-Efficient Financing Programs

You can apply for energy-efficient financing through a government-insured or conventional loan program. Some states even have programs for their residents, so it's a good idea to contact your state energy office to find out if your state does.

There are two types of energy-efficient mortgages (EEMs): one for a new home and one for an existing home. With an EEM, you can purchase or refinance a home that is already energy-efficient. Or you can purchase or refinance a home that will become energy-efficient after energy saving improvements are made. Most energy-efficient financing programs offer both types of EEMs, as well as home improvement loans for making energy efficiency upgrades to your existing home.

There are two types of energy-efficient mortgages: one for a new home and one for an existing home.

Here's an overview of some of the energy-efficient financing programs available. Each program is subject to change; therefore, you should contact a program directly for the most current, detailed information.

Government-Insured

U.S. Department of Housing and Urban Development

Under the U.S. Department of Housing and Urban Development (HUD), the Federal Housing Authority (FHA) insures mortgage and home improvement loans, through its approved lenders, for borrowers who would not otherwise qualify for conventional loans on affordable terms, such as some first-time home buyers and some residents of disadvantaged neighborhoods.

FHA Energy-Efficient Mortgage
FHA allows borrowers to finance the cost of adding energy-efficient improvements to new or existing homes as part of their FHA-insured purchase or refinancing mortgage.

- Energy-efficient improvement costs of $4,000 or 5 percent of the property value (up to $8,000), whichever is greater, can be financed.
- The FHA maximum mortgage limit for an area may be exceeded by the cost of the improvements.
- No additional down payment is required.
- No requalifying is necessary.
- No new appraisal is needed.
- Up to $200 of the cost of a home energy rating may be included in the mortgage.

This EEM can be used in conjunction with several other FHA-insured mortgages, including the 203(k) rehabilitation mortgage insurance described below.

FHA Section 203(k) Rehabilitation Mortgage Insurance
FHA Section 203(k) rehabilitation mortgage insurance provides a borrower with a single loan that covers both the purchase or refinancing and the cost of major home improvements, including those that save energy. The program allows borrowers to complete improvements after the loan closes. The funds are placed in an escrow account and released as improvements are made.

- Total cost of improvements must exceed $5,000.
- The total property value must still fall within the FHA mortgage limit for the area. (The property value is determined by whichever is less: the value before the rehabilitation plus the cost of the rehabilitation or 110 percent of the appraised value after rehabilitation.)

How an EEM Can Save You Money

Borrower finances 100% of energy improvements (7.25%*—30 year term)

	Standard Mortgage	New EEM
Energy Improvement Costs		$ 3,000
Appraised Value	$100,000 (add cost of improvements)	$103,000
Down Payment	$ 10,000	$ 10,000
Mortgage Amount	$ 90,000	$ 93,000
P&I	$ 614	$ 634
Energy Savings (monthly)	$ —	$ (50)
Total Monthly Payment	$ 614	$ 584

*Source: Fannie Mae *interest rates subject to change*

Richmond Times Dispatch, NREL/PIX07641

This single mother (left) used an energy-efficient mortgage to purchase and upgrade her home in Richmond, Virginia.

You can apply for energy-efficient financing through a goverment-insured or conventional loan program.

FHA Energy-Efficient Home Mortgage
When purchasing an energy-efficient home, an FHA-approved lender can stretch the borrower's debt-to-income ratio by 2 percent.

FHA Mortgage Increase for Solar Thermal Systems
The maximum loan limit under FHA's standard 203(b) or 203(k) property rehabilitation mortgage insurance can be exceeded by 20 percent if the home has or will have a passive or active solar heating system. The home must also have a 100 percent operational, conventional backup system.

FHA Title I Property Improvement Loan Insurance
FHA also insures home improvement loans, including those that will make a home more energy-efficient, for homeowners with FHA-insured mortgages. It features:

- Loans up to $25,000 for a single-family home
- Loans insured up to 20 years
- No required home energy rating reports.

U.S. Department of Veterans Affairs

The U.S. Department of Veterans Affairs (VA) guarantees mortgage loans for veterans with active duty service and qualified reservists. Its EEM can be used to purchase or refinance a home along with the cost of making energy-efficient improvements. To cover the cost of the improvements, the loan amount can be increased:

- Up to $3,000 based solely on documented costs
- Up to $6,000 if the increase in the mortgage payment is offset by the expected reduction in utility costs.
- More than $6,000 based on a value determination by VA.

A VA refinancing loan may not exceed 90 percent of the home's appraised value plus the costs of the improvements.

Conventional

Most of the national lenders who offer energy-efficient financing operate through one of the following programs.

ENERGY STAR® Mortgage

The ENERGY STAR® Homes program—sponsored jointly by the U.S. Department of Energy and the U.S. Environmental Protection Agency—promotes voluntary partnerships with home builders to construct new homes that are 30 percent more efficient than the guidelines established by the Model Energy Code—a "model" national standard for residential energy efficiency.

The program also encourages lenders to provide EEMs for certified ENERGY STAR® homes. An ENERGY STAR® mortgage offers a minimum 2 percent stretch on a borrower's debt-to-income ratio, plus at least one additional incentive for borrowers. Incentives may include:

- A lower interest rate
- A discount on closing costs and/or origination fees

Some national lenders offer conventional energy-efficient financing through various programs.

Whether you're buying or selling an energy-efficient home, it's best to use a realtor that is familiar with energy ratings and energy-efficient financing in your state.

- Up to a 4 percent extension of the debt-to-income ratio stretch
- Paying for the cost of the home energy rating.

Fannie Mae

Fannie Mae—a private, shareholder-owned corporation—operates under a congressional charter that directs it to channel efforts into increasing the availability and affordability of homeownership. It doesn't lend money directly to home buyers; it purchases mortgages from lenders, ensuring that funds are available.

Energy-Efficient Mortgage

Fannie Mae encourages lenders to offer its EEM by providing incentives and specific criteria for those that it's willing to purchase from lenders. Both existing and new homes fall under this EEM.

- Several approved home energy rating methods and programs, not just a HERS, are allowed to evaluate a home's energy efficiency.
- For existing homes, the cost of improvements is limited to 15 percent of its total cost. There is no limit imposed on the cost of improvements for new construction.
- A home buyer can finance 100 percent of the energy efficiency improvements without increasing the down payment.

Residential Energy Efficiency Improvement Loan

Fannie Mae is partnering with utility companies to provide loans to utility customers for the installation of energy-efficient home improvements. The loans feature:

- A below-market interest rate
- An unsecured financing option
- Up to $15,000
- A term of up to 10 years
- A "whole-house" or bundled approach to efficiency improvements.

Freddie Mac

Freddie Mac is a stockholder-owned, congressionally chartered corporation that works to create a continuous flow of funds to mortgage lenders in support of homeownership and rental housing. It purchases mortgages from lenders and packages them into securities that are sold to investors, providing homeowners and renters with lower housing costs and better access to home financing.

It's always a good idea to ask lenders, energy raters, and realtors for references.

Energy-Efficient Mortgage
Like Fannie Mae, Freddie Mac provides incentives and criteria, as well as flexible guidelines, for EEMs that it's willing to buy, which encourage lenders to offer them. However, the EEMs are limited to purchasing existing energy-efficient homes or those to be retrofitted or renovated for energy efficiency.

- Several home energy rating methods and/or documentation, not just a HERS report, are acceptable.
- Lenders can exceed the standard 2 percent debt-to-income stretch at their own discretion.
- It allows a broader range of energy-efficient improvements than most EEM programs.

E Seal

E Seal, an Edison Electric Institute program, provides energy-efficient solutions for home buyers, residential energy customers, small business customers, and home builders.

Energy Efficiency Mortgage
This EEM is available through utilities with E Seal certified programs. It can be used to finance the purchase of a new home with energy efficiency upgrades or to refinance an existing home while adding these improvements. It features:

- 100 percent financing of energy efficiency upgrades
- No additional down payment, mortgage insurance obligation, or requalification
- Maximum qualifying ratios that are 5 percent better than standard ratios and 3 percent better than regular EEMs
- Lower than prevailing market interest rates and closing costs.

Residential Financing Program
For energy-efficient home improvement loans, E Seal's program participates with Fannie Mae's Residential Energy Efficiency Improvement Loan program (see page 6).

When it comes to energy-efficient financing—whether you want to purchase, refinance, or remodel a home—it's best to work with lenders and/or real estate agents who are familiar with home energy ratings and program requirements. If you'd like a home energy rating report, it's also best to work with a certified energy rater. In all instances, it's always a good idea to ask for references and check companies with your local better business bureau.

Resources

The following are sources of additional information on energy-efficient financing.

The Energy Efficiency and Renewable Energy Clearinghouse (EREC)
P.O. Box 3048
Merrifield, VA 22116
Phone: 1-800-DOE-EREC (1-800-363-3732)
E-mail: doe.erec@nciinc.com
Web site: http://www.eren.doe.gov/consumerinfo/

EREC provides free general and technical information to the public on many topics and technologies pertaining to energy efficiency and renewable energy.

You can also contact your state and local government energy offices for region-specific information on energy-efficient financing.

Organizations

E Seal
Edison Electric Institute
701 Pennsylvania Ave., NW
Washington, DC 20004-2696
Phone: (202) 508-5557
Web site: http://www.eei.org/esg/e_seal/

ENERGY STAR® Homes
Phone: 1-888-STAR-YES (1-888-782-7937)
E-mail: info@energystar.gov
Web site: http://yosemite.epa.gov/appd/eshomes/eshaware.nsf

(Continued on page 8)

(Continued from page 7)

Fannie Mae
3900 Wisconsin Avenue, NW
Washington, DC 20016-2892
Phone: 1-800-7FANNIE (1-800-732-6643)
Web site: http://www.fanniemae.com/
Consumer Web site: http://www.homepath.com/

Federal Housing Authority (FHA)
U.S. Department of Housing and Urban Development (HUD)
451 7th Street SW
Washington, DC 20410
Web site: http://www.hud.gov/
EEM program Web site:
http://www.hud.gov/progdesc/energy-r.html

FHA can be contacted through your local HUD office, which can be found in the phone book or on HUD's Web site.

Freddie Mac
8200 Jones Branch Drive
McLean, VA 22102-3107
Phone: 1-800-FREDDIE (1-800-373-3343)
Web site: http://www.freddiemac.com/

National Home Energy & Resources Organization (HERO)
4005 Poplar Grove Road
Midlothian VA 23112
Phone: 1-800-373-2416
Fax: (804) 560-9139
E-mail: n-hero@ix.netcom.com
Web site: http://www.national-hero.com/

Provides state-by-state listings of the energy raters it trains and certifies.

Residential Energy Services Network (RESNET)
P.O. Box 4561
Oceanside, CA 92052-4561
Phone: (760) 806-3448
Fax: (760) 806-9449.
E-mail: resnet@earthlink.net
Web site: http://www.natresnet.org/

A national network of mortgage companies, real estate brokerages, builders, appraisers, utilities, and other energy and housing professionals dedicated to improving the energy efficiency of the nation's housing. Its provides state-by-state directories of conventional EEM lenders and energy raters.

U.S. Department of Veterans Affairs (VA)
Phone: 1-800-848-4904
VA Home Loan Guaranty Web site: http://www.homeloans.va.gov/

Web Sites

Consumer and Lender Resources for Energy Efficiency Financing and Home Energy Ratings
Alliance to Save Energy
Web site: http://www.ase.org/finance2.htm

Financing Solutions
U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
Web site: http://www.eren.doe.gov/financing/homeowners.html

Provides useful links to energy efficiency and renewable energy financing resources.

Reading List

The list is not exhaustive, nor does the mention of any publication constitute a recommendation or endorsement.

Borrower's Guide to Financing Solar Energy Systems: A Federal Overview, Second Edition, produced for the U.S. Department of Energy (DOE) by the National Renewable Energy Laboratory (NREL), 1999. Available in PDF on the DOE Million Solar Roofs Web site at http://www.eren.doe.gov/millionroofs/pdfs/26242.pdf or from NREL at (303) 275-4363.

Energy-Efficient Mortgage Homeowner Guide, Pacific Gas & Electric Company, 1996. Available on the Alliance to Save Energy Web site at http://www.ase.org/nrgymort.txt.

Financing Home Energy Efficiency: An EEM Handbook, R. Martin, Iowa Association of Municipal Utilities, 1997. Available on the Florida Solar Energy Center Web site at http://www.fsec.ucf.edu/ratings/LndrHndBk/.

A Shopper's Guide, Energy-Efficient Mortgages, More House for Less Money, DOE, 1999. Available from the DOE Office of Consumer Information through e-mail at consumer.information@hq.doe.gov or at 1000 Independence Ave., SW, 4A-227, MA-9, Washington, DC 20585.

Improving Air Distribution System (ADS) Performance in Manufactured Homes

Final Report to HUD for Cooperative Agreement Contract Number H-21353CA

Prepared in cooperation with:

U.S. Department of Housing and Urban Development
Affordable Housing Research and Technology Division
451 7th Street S.W.
Washington, DC 20410

Submitted by:

Manufactured Housing Research Alliance
2109 Broadway, Suite 203
New York, NY 10023
(212) 496-0900

January 2, 2003

Table of Contents

I. Executive Summary 1
II. Introduction 3
III. Identification of Manufactured Home Plants 4
IV. Testing and Evaluation Method and Materials 5
V. Manufactured Home Plant Diagnostics and Evaluation 8
VI. Production Staff Education and Training 12
VII. Dissemination 13

APPENDICES

Appendix A – Individual Plant Reports A-1
Appendix B – TECHNOLOGIES and *Modern Home* articles B-1

I. Executive Summary

Virtually all manufactured housing units in the nation use forced air systems for heating and cooling distribution. The typical manufactured home air distribution system (ADS) wastes a significant amount of energy through leakage of conditioned air to the exterior. Reductions in this leakage have the potential to reduce a home's annual energy bills by up to 10%; making improving ADS performance the single most important strategy for saving energy in manufactured housing.

Building scientists were sent to 16 manufactured home plants to develop and demonstrate techniques to build tighter duct systems and to train production personnel in these techniques. The three key steps in the ADS construction process that enabled individual plants to reach the target leakage levels were: cutting accurate holes for registers in floors and for duct connections by using templates, securely and mechanically fastening ADS components rather than using tape alone, and covering seams with proven durable sealants such as mastic or appropriate tapes. The scientists adapted standard duct leakage test protocols for use in the plant environment in order to quantify performance improvements. The training of plant staff and often the plant's Design Approval Primary Inspection Agency (DAPIA) was designed to enable the plant to maintain production of the improved ADS systems.

The lessons learned while working with the 16 plants was widely distributed to the industry through articles in ***TECHNOLOGIES*** and ***Modern Home,*** seminars and symposia at major industry trade events, and posting on the MHRA web site.

As a result of this effort, the efficiency of the air distribution systems (ADS) constructed at 16 manufactured home plants whose parent companies produce over 85,000 homes per year was dramatically improved. The average rate of duct leakage to the outside was reduced to 3.7% from 13.6% observed in earlier studies of homes produced at some of these plants.

II. Introduction

Virtually all manufactured housing units in the nation use forced air systems for heating and cooling distribution. A 1996 study suggests that the air distribution system (ADS) in these homes wastes significant amounts of energy[1]. This study revealed that average energy losses due to ADS system leakage, conduction, and infiltration account for 40% of total heating energy use and 15% of total cooling energy use. These are huge numbers, representing a large and readily available opportunity to improve the energy performance of manufactured homes by improving ADS performance. Prior efforts have demonstrated that ADS losses can be cut to the practical limit of 5% to 11%[2]. Applied to the average manufactured home, such reductions would reduce annual energy bills by approximately 20%. Without question, improving ADS performance is the single most important strategy for saving energy in manufactured housing. A large component (at least half) of this potential improvement can be realized by reducing ADS leakage.

Decisions made in the manufactured home plant (henceforth simply referred to as the plant) significantly impact the performance of duct systems. Manufactured homes leave the plant with over 95% of the construction work complete. The homes are then moved to the building site, installed on a support system, connected to utilities, and minor finish work is completed on the interior. While the duct system performance can be compromised by poor site installation, steps taken in the plant can minimize site-related installation errors. That is, a program to minimize ADS leakage by targeting duct design and installation at the plant level alone can be responsible for improving total home energy efficiency by 10%.

To achieve this goal, a building scientist conducted a flexible program at each plant that combined diagnostics and testing together with plant staff training and education. Diagnostics and testing established a metric for duct system leakage; arguably the most important element of ADS performance improvements. The building scientist recommended improvements to the home's design, component materials, installation and assembly methods. The building scientist and plant staff identified plant-specific strategies for achieving the target performance level via an iterative testing and redesign process.

Staff training and education was conducted hand-in-hand with the diagnostics efforts. These efforts were intended to help plant staff fully recognize the value of the improvements recommended by the building scientist, develop and demonstrate simple methods to accomplish improvements, equip the plant (or its contractors) with the tools needed to monitor air distribution system leakage, and develop improved methods for air delivery. The educational efforts were designed to sustain the advances engineered during the testing and redesign efforts.

The overall objectives of the project were to dramatically improve the performance of air distribution systems in homes built in manufacturing plants across the nation and encourage other plants to emulate the improvements. The major tasks were as follows:

1. Identify and select candidate plants
2. Develop testing and evaluation methods and materials
3. Conduct plant diagnostics and evaluation
4. Train production and engineering staff

---

[1] Alternative Energy Corporation, Air of Importance: A Study of Air Distribution Systems in Manufactured Homes, 1996

[2] Manufactured Homes: Heat Loss Assumptions and Calculations; Heat Loss Coefficient Tables; Prepared by Davis, Bob et. al. ECOTOPE, Seattle Washington, for the Bonneville Power Administration, Report No. DOE/BP-35738-3, March 1991

5. Document and disseminate results

III. Identification of Manufactured Home Plants

Of the 263 manufacturing facilities operating during the period this project was undertaken, a representative selection of 16 plants was selected for participation in this effort. Selection of plants was through a competitive process. Efforts were made to select a broad cross-section of companies, a mix of home types, and a geographic diversity of plant locations. Participating plants were required to make a financial contribution toward the project costs.

Table 1. Participating plants

Plant	City	State
Atlantic Homes	Henry, TN	TN
Castle Housing of Penn., Ltd.	Knox, PA	PA
Cavalier Homes, Inc.	Addison, AL	AL
Champion Home Builders	Lindsay, CA	CA
Champion Home Builders	Ridgeville, IN	IN
Chandeleur Homes, Inc	Boaz, AL	AL
Guerdon Enterprises, LLC	Boise, ID	ID
Homes of Legend, Inc.	Boaz, AL	AL
Horton Homes 1	Eatonton, GA	GA
Horton Homes 2	Eatonton, GA	GA
New Era Building Systems	Strattanville, PA	PA
Oakwood Homes	Etna Green, IN	IN
R-Anell Housing Group	Denver, NC	NC
Redman Homes	Sanford, NC	NC
Skyline Corp.	Goshen, IN	IN
Wick Building Systems, Inc.	Marshfield, WI	WI

Figure 1. Plant locations

The target audience

One of the distinguishing characteristics of the manufactured housing industry is that a few companies build a large share of the homes. The industry consists of 69 companies operating 263 plants and, in 2001, producing 193,229 homes, or approximately 735 homes per plant. However, this is only part of the story. The top ten manufactured housing producers sold nearly 155,000 homes in 2001, representing 80.1% of total industry shipments.[3]

Each manufacturer has a network of plants that are typically distributed across the major housing markets. Technologies that are successful in one plant are routinely transferred to sister plants operating under the same management. All of these companies have centralized engineering that act as a conduit for technology exchanges.

By involving many of the largest companies as well as several other smaller operations in this project, tens of thousands of homes per year are directly impacted by this effort. The plants selected were drawn from manufacturers representing approximately 45% of the total manufactured home shipments, or approximately 85,000 homes in 2001 as shown in Table 2.

An additional benefit of this project is that a number of the participating manufacturers build both HUD-code and modular homes within the same plant. Often times air distribution systems are included in the in-plant construction of the modular homes (in modular homes, ducts and heating equipment are not required to be completed in the plant as they are in HUD-code homes). In every observed case where modular homes included an in-plant duct system, improvements made to the HUD-code home air distribution systems were transferred to the modular homes as well.

Table 2. Production of participating manufacturers in 2001[4]

Manufacturer	HUD-code homes produced‡	Share of shipments
Champion Enterprises, Inc.	36,495	19.1%
Oakwood Homes Corporation	18,678	9.6%
Cavalier Homes, Inc.	12,669	6.6%
Skyline Corp.	10,148	5.3%
Horton Homes	5,288	2.7%
Wick Building Systems, Inc.	1,339	0.7%
New Era Building Systems / Castle Housing of Pennsylvania, Ltd.	910	0.5%
Guerdon Enterprises, LLC	*	*
R-Anell Housing Group	*	*
Total	**85,527**	**44.3%**

‡ Figures exclude modular production

* Independent companies producing less than 750 units (0.4% market share) in 2001

IV. Testing and Evaluation Method and Materials

The diagnostic, testing, and evaluation component of the project brought building scientists in direct contact with plant personnel. Together, they identified factors that impact air distribution system performance, such as duct layout, sealing methods, and assembly procedures and measured the duct leakage in typical home designs produced by each plant. Working cooperatively, the scientists and plant staff, together with product vendors, made a progressive series of changes in the air distribution

[3] Manufactured Home Merchandiser, June 2002

[4] Manufactured Home Merchandiser, June 2002

systems. The team periodically assessed performance improvement. The process continued until there was consensus that an optimal performance level had been achieved that could be sustained by plant staff alone without involvement of the building scientist.

A common index for duct leakage is cubic feet per minute of air leaking from a duct experiencing a 25 Pascal pressure, divided by the total interior floor area of the home, expressed as a percentage. (Indices using the air handler flow rate are not practical in a manufactured housing plant where the cooling plant and air handler flow rate is not known until site installation.) "Total" duct leakage is a straightforward measurement that includes air leaks to the outside and air leaks back into the conditioned space. However, it is only duct leakage to the outside that is of concern; as only the energy used to heat or cool this air is lost. Duct leakage to the outside can only be measured in a home that is sufficiently complete to contain pressure provided by a blower door apparatus; this can be a single section home, a home pulled together in a plant or retail center or a completely installed home. In the plant environment, only the total duct leakage can be measured; outdoor duct leakage can only be estimated. Field measurements of total and outside duct leakage can be used to establish a ratio of outside to total duct leakage that should be consistent for a plant, which is used to estimate leakage to the outside from measurements taken in the plant.

The equipment used for measuring duct leakage was from The Energy Conservatory, makers of the Minneapolis Duct Blaster and Blower Door. Testing was conducted in accordance with the testing equipment manufacturer's operation manual and test protocols[5]. This equipment and protocol permits quick and accurate measurements of total duct leakage in the plant environment.

Previous studies have measured ADS leakage to the outside from as low as 2% of floor area to as high as 50%, with averages ranging from 12% to 17%[6]. A target leakage rate of 5% was established based on the practical limit that a typical plant could achieve and maintain. A "stretch" goal of 3% was set if the 5% target was easily met. The use of these targets was supported by the success of the Pacific Northwest Manufactured Housing Acquisition Program and other incidental efforts to achieve these levels[7].

Several key practices were important to conducting fast, simple and accurate total duct leakage tests amidst active factory production:

- All equipment was contained and highly organized in a single rolling "luggage" bag. Contents included duct testing apparatus, hoses, tapes, extension cords, hand and power tools and educational props. Key items like multi-plugs prevented conflict with production staff over limited electrical outlets.
- Duct testing was conducted using the testing equipment manufacturer's protocol[8].
- Duct testing apparatus was left in a "plug-and-play" configuration; hoses and power cords remained connected while moving between different floors for testing.

---

[5] Minneapolis Blower Door Operational Manual for Model 3 and Model 4 Systems January 2001, and Minneapolis Duct Blaster Operation Manual March 1994, The Energy Conservatory 2801 21st Ave. S., Suite 160 Minneapolis, MN 55407, www.energyconservatory.com

[6] Alternative Energy Corporation, Air of Importance: A Study of Air Distribution Systems in Manufactured Homes, 1996; MHRA Moisture Study

[7] Field Measurements of the Heating Efficiency of Electric Forced-Air Furnaces in Six Manufactured Homes, Davis, B., and D. Baylon Prepared for the Bonneville Power Administration for the Manufactured Housing Acquisition Program, Contract No. DE-AM79-91BP13330, 1994

[8] Minneapolis Blower Door Operational Manual

- Floors with easy access to ducts were more often tested. Floors with air handlers were often tested because they were easily accessed; floors without air handlers were sometimes not tested unless the floors had the majority of the supply terminations. It was assumed that this gave conservative results as the air handler is typically a problem leakage site.
- In homes with low leakage rates, an in-line supply might be used as a location to connect the test fan to the duct on a home without an air handler. Connecting the test equipment to the crossover dropout collar was rarely done as it was the most time consuming and dangerous method for both equipment and testers.
- Whenever possible, the air handler blower was removed to provide a conveniently sized hole into the duct that accepted the duct testing fan and to eliminate errors from air handler cabinet leakage.
- Foam rubber plugs (sealed on two sides with mastic) were pre-made to fit common supply terminations and trunk dimensions in order to quickly seal these for duct leakage testing.
- Production activity rarely prevented testing from going forward. For example, if wallboard was stacked on one or more supplies such that they could not be sealed with tape, they were assumed to be sufficiently sealed and the test continued.
- A 50% minimum ratio of duct leakage to the outside to total duct leakage was assumed. If field data showed a higher ratio then that was used. If field data was inconsistent, than the highest ratio was used.

It was hypothesized that improvements to three key steps in the ADS construction process would allow individual plants to reach the target leakage levels. These were:

- *Cut accurate holes.* Use a template for cutting holes in floor sheathing and ducts rather than making freehand cuts. Even small cutting errors can create large leaks or lead to wasted time patching gaps. Making an accurate hole will reduce or eliminate the need for excessive sealing.
- *Fasten components mechanically.* Components should be rigidly connected; a common cause of complaints and high-energy bills is large leaks from failed or ineffective connections. For metal ducts, use durable fittings and sheet metal screws. For glass-fiberboard ducts, use folded tabs for fittings and connect trunk sections using suitable tape and staples; strap trunks securely to floor joists to prevent movement of trunk sections. Tape alone is not an adequate fastening system. Connect flexible ducts with suitable tape, straps, and for vertical crossover duct connections, screws as well.
- *Cover seams with proven durable sealants.* Mastics offer superior sealing performance over tapes - particularly on metal ducts – and have been shown to be durable and long lasting. Appropriate tapes are effective on fiberboard connections provided the components are rigidly fastened. Tapes must be used according to manufacturer's instructions, which may require the use of a solvent to remove oil from metal ducts prior to applying tape, and the use of a squeegee tool for applying tape to fiberboard ducts.

While all connections are important, researchers expected potential gains to be realized by correcting the following four problem areas:

- *Furnace plate.* Leaky connections at the furnace boot, where pressure differences are the highest, can exact the largest performance penalties.
- *Crossover duct collar.* The connection between the internal ducts and the crossover duct must be made with a durable mechanical connection. A less than secure and tight connection at a

location that is exposed to outside conditions is a recipe for disaster. Designing a nearly foolproof connection is critical as quality is difficult to monitor in the field.

- *In-line register risers.* By far the most common type of connection, in-line register connections are prone to poor installation practices such as freehand cutting of the trunk opening to receive the boot.
- *Inappropriate use of tape for sealing connections.* Not all tapes are up to the task of permanently sealing ducts, particularly metal ducts and inside of the duct. With some product types, significant leaks may develop after a few months as the tape exceeds its useful life. Tapes need to be applied according to manufacturer's instructions.

V. Manufactured Home Plant Diagnostics and Evaluation

At each of the 16 plants visited, a professional diagnostician and ADS expert made observations and conducted a series of tests and demonstrations to identify obvious flaws and gauge the performance of current ADS design and installation practices. The results of this preliminary analysis were shared with the plant management, design, quality control, production and purchasing teams along with Design Approval Primary Inspection Agency (DAPIA) and In-Plant Primary Inspection Agency (IPIA) representatives. A group redesign process was used to prioritize the deficiencies and to develop recommendations for their resolution.

Plant staff then implemented the recommendations, potentially combining alternative design strategies, changing plant construction techniques and/or specifying different materials. Changes included specifying different sized trunk ducts, different trunk connectors, different assembly procedures and alternative sealants. Incorporation of these changes often required obtaining approval from vendors, drafting and submitting to the DAPIA for approval, modifying construction drawings, exhausting old inventories and obtaining new materials. Thus the evaluation/redesign process was often drawn out before the target level of performance was reached. Changes were shared with all plant production staff through training.

The diagnostic and redesign process followed three steps for each plant:

1. In advance of the visit, the plant manager or designated plant contact received a copy of the MHRA publication ***Manufactured Housing Duct Systems: Guide to Best Practices***.
2. The plant representative and the building scientist reviewed logistics and the plant's current practices with respect to heating equipment and duct system specification.
3. Sample materials were shipped to the plant for use prior to, and during, the building scientist's visit. The materials included different types of duct sealant, sill plate gaskets, and plant-installed non-porous marriage line gaskets.

The building scientist conducted a three to four day visit to the plant, during which the following steps were followed:

1. **Plant staff briefing.** Inspected the plant and met with key plant staff (plant manager, quality control, production manager, engineering staff, and key station supervisors) to discuss the objectives and agenda for the visit and to answer questions.
2. **Initial testing.** Ducts were tested for air tightness using a calibrated duct leakage testing system to establish a baseline and, if possible, a demonstration was conducted to illustrate leakage sites by pressurizing an exposed duct system with smoke. Duct leakage tests were conducted on a set-up home to provide a method to estimate outside leakage from total leakage values measured in the plant. Often the plants had implemented ADS

improvement measures based on conversations with, and materials provided by, MHRA prior to the plant visit.

3. **Observe duct construction practices.** The building scientist observed all duct system strategies, materials, supplies, and tools and discussed alternatives with plant staff.
4. **Set targets.** All participants met to set performance targets and select improvement options.
5. **Begin new measures.** The building scientist trained station supervisors to implement new measures and evaluated the potential for different options.
6. **Testing.** The building scientist tested duct systems constructed using the improved methods and compared them to the initial tests to gauge improvement potential.
7. **Training.** The building scientist continued application of improvement strategies and conducted on-the-job training of plant personnel.
8. **Final testing.** The building scientist tested ADS leakage rates, with as many improvement measures implemented as possible.

Typical Problems

The majority of ADS leakage occurred in the following seven areas:

- *The section of duct directly beneath the air handler.* This site is where system pressures are greatest and the trunk is weakest. It often has a hole in the top of the trunk duct for the air handler and one in the bottom for the crossover. Personnel at several different work stations perform tasks at this site. Problems included: improper furnace plate depth, catastrophic failure of the trunk from stresses when the floor was flipped (poor mechanical connection), rapid failure of sealing tape (on metal), poorly made connections, misaligned trunks or sagging below the depth of the collar, crossover collar not secure and/or and not sealed.
- *Poorly sealed perpendicular trunk connections.* These connections are used to offset one or more supplies in an otherwise in-line supply design or to connect through-the-rim-joist crossovers. The trunks have a large hole where they are connected with an additional hole cut to provide access to the inside in an attempt to seal the connection, making this joint a relatively weak spot. Seals made solely with tape typically failed. The trunk may move during transportation or installation, breaking any potential seal if not securely (mechanically) attached to structural members. Some homes had as many as six of these types of connections.
- *Trunk connectors.* Although leakage from individual connections is relatively insignificant, the cumulative leakage from the many connectors in a single system is quite substantial. A perimeter system may have 15 supplies, each with three connections (trunk to metal collar, metal collar to flex duct, and flex duct to supply boot) for a total of 45 connections.
- *Vendor-supplied duct parts formed by bent and riveted metal.* These components often leaked significantly through their seams.
- *Inappropriate application of duct components.* For example, trunk connectors designed for flex duct were used on metal ducts resulting in a connection that was nearly impossible to seal.
- *Bottom board holes.* An intact bottom board redirects much of the air that leaks from the ducts back into the house. Leaky bottom boards allow this air to leak to the outside.

- *Through-the-rim-joist crossover connections*. Through-the-rim-joist crossover connections were sealed solely with fiberglass insulation. These connections required redesign with appropriate sealing to eliminate leaks.

Patching was rarely suggested as a primary improvement method. Only in the case where the trunk was not aligned with the furnace was a patching method offered as a leakage solution.

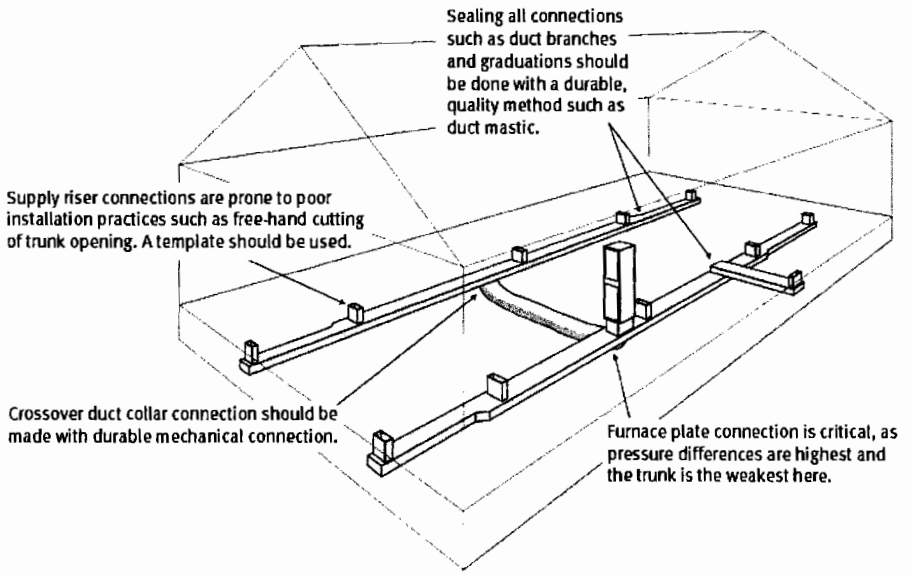


Figure 2. Typical ADS system recommendations

Evaluating the Data

This project was a diagnostic and educational effort aimed at improving air distribution efficiency and thereby reducing energy waste. It was not intended as a scientific comparison of existing ADS inefficiencies and their potential for improvement. The inefficiency of manufactured home air distribution systems has been well established and quantified in previous studies[9]. With this goal in mind, an emphasis was placed on improving ADS performance, rather than on measuring ADS efficiencies before and after implementation of remedial measures.

Measurements were taken on the first day of the building scientist's visit to the plant. At this point the plant staff had in many cases implemented a number of ADS improvements based on conversations with the building scientist and on the MHRA publication previously provided, **Manufactured Housing Duct Systems: *Guide to Best Practices***. As described earlier in this report, measurements were taken throughout the iterative redesign process. Even if all of the ADS improvements were implemented on the first day of the visit it would take several more days for the home construction to be completed, hence the building scientist was unable to test the completed home in the field on this visit. Improvements in the measured total leakage were noted and the final outside leakage was estimated. In some cases, a second visit to the plant afforded the opportunity to conduct leakage testing for set up homes with redesigned air distribution systems.

[9] Alternative Energy Corporation, Air of Importance: A Study of Air Distribution Systems in Manufactured Homes, 1996

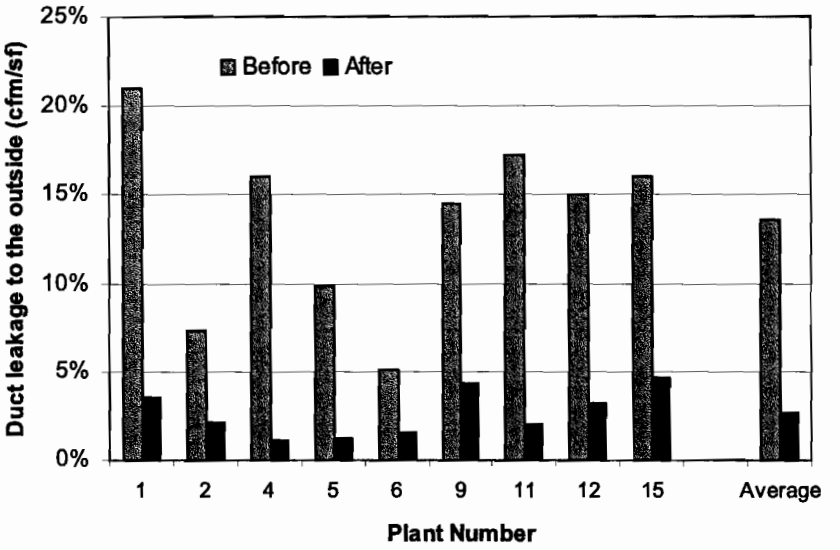
Table 3 shows average duct leakage levels achieved for a number of the plants. At least three systems were tested per plant before the building scientist judged that a consistent practice had been achieved. The average ADS leakage of all 59 homes tested for these plants upon completion of the redesign and testing process was 2.5%. This represents a more than fivefold improvement over previously cited ADS leakage rates.

Table 3. Leakage rates to the outside following implementation of ADS improvements

Plant number	No. homes tested	Leakage to the outside (cfm/sf floor area)		
		High	Low	Avg.
1	3	3.8%	3.3%	3.5%
2	3	2.3%	1.7%	2.1%
3	2	1.0%	1.0%	1.0%
4	4	1.5%	1.0%	1.1%
5	3	1.4%	1.1%	1.2%
6	4	2.6%	1.0%	1.6%
7	3	2.3%	2.1%	2.2%
8	6	5.2%	1.3%	2.1%
9	3	5.0%	3.3%	4.3%
10	5	3.0%	2.6%	2.8%
11	3	2.0%	2.0%	2.0%
12	6	5.0%	1.5%	3.2%
13	3	4.9%	0.6%	3.3%
14	2	4.5%	2.3%	3.4%
15	3	4.9%	4.5%	4.7%
16	6	5.7%	2.7%	3.7%

In nine plants, initial pre-improvement measurements were taken. Figure 3 compares the respective pre and post performance levels of eight plants in the study. The impressive improvements evidenced here demonstrate that the techniques brought to bear by the building scientist were capable of turning leaky duct systems into highly energy-efficient systems using the same production line and staff, merely by applying know-how and some inexpensive materials.

Figure 3. Pre-improvement and post-improvement leakage rates to the outside



VI. Production Staff Education and Training

In a parallel task to the testing and evaluation, key decision makers at each plant participated in a series of sessions intended to review good ADS practices and consider alternative designs to current methods that could increase overall operating efficiency. The MHRA publication, ***Manufactured Housing Duct Systems: Guide to Best Practices***, was the principal tool for the educational component of this project.

Participants in these workshops included designers, engineers, production supervisors, quality control personnel, and manufacturing crews. Product vendors, such as duct material suppliers, assisted in the educational component of the workshops. These sessions provided decision makers with crucial information needed to make design and manufacturing changes that improve energy performance; decisions whose impact they saw in the results of the performance assessment described in Section V.

The educational efforts included the following activities conducted with plant personnel:

- Identification of probable ADS problem sites through a visual assessment.
- Comparing plant's ADS design and construction to recommended practices described in ***Manufactured Housing Duct Systems: Guide to Best Practices.***
- Evaluating stresses to duct connections, such as flipping of floor system after ducts are installed.
- Smoke tests to demonstrate leakage sites.
- On-the-job training with production line workers, including training in the use of mastic, preferred hole cutting methods, and mechanical fastening of ducts.
- In-plant duct leakage tests of complete or partial ADS.

New ADS manufacturing and design procedures were incorporated into the plant's DAPIA-approved design manual. To facilitate retention of the new practices, examples of new procedures were left

with the plant and occasionally mounted on plant walls near the station where the relevant procedure was performed. Some manufacturers took photographs and video tapes of procedures for use in training. Others incorporated the new procedures into their training manuals. Return visits to plants have found good retention of ADS improvements.

Persistence of these duct sealing measures can be inferred from increased volumes of mastic and other indicator products purchased from vendors, as well as the number of duct blasters purchased by manufacturers and DAPIAs[10]. Continued use of a duct blaster by the manufacturer or DAPIA is important to ensure continuation of the improved ADS performance. A follow-up study consisting of return visits to the plants and/or installed homes would be useful in verifying consistency of improved ADS system design and installation practices.

VII. Dissemination

Among the merits of this project were the impressive improvements in energy efficiency of homes produced by individual plants and, more importantly, the likelihood of lower energy bills for owners of new manufactured homes.

As discussed in Section II, techniques to improve the manufactured housing product are easily transferred from plant-to-plant and from manufacturer-to-manufacturer. Consistency of manufacturing systems and methods is a powerful driver in rapidly pushing innovations through the industry.

Precise estimates of expected energy savings are difficult to develop because the data of energy use is several years old. One DOE EIA study[11] noted that the average annual consumption per manufactured home for space heating and cooling was 44.5 million Btus of electricity (electric heat is used in about 76 percent of all manufactured homes). As discussed above, savings associated with reducing ADS leakage are likely to be about 10% of total energy use per home. Current home models are more efficient; however they are also considerably larger than those produced five years ago. Assuming that total energy consumption per home is similar, the 10% reduction would yield an energy savings of nearly 4.5 million Btus per year for every new home. If the ADS improvement techniques described in this report reach 85,000 homes (total production of all plants in 2001 of the companies implementing ADS improvements as part of this project), total avoided energy use would be running at a rate of approximately 380 billion Btus per year.

The benefits are magnified by the fact that manufactured homes are the most affordable, unsubsidized housing available in the nation. It is estimated that a full 85% of all new homes costing less that $75,000 are manufactured homes. This population group is the most sensitive to energy costs and the one that will most appreciate the major gains in energy efficiency resulting from this effort.

[10] A Duct Blaster with accessory equipment costs $2,000 to $2,500.

[11] US Department of Energy, EIA, Household Consumption and Expenditures 1997: National Data

Poverty Conference 2006

Low-Income Weatherization

"Current Successes and Future Directions"

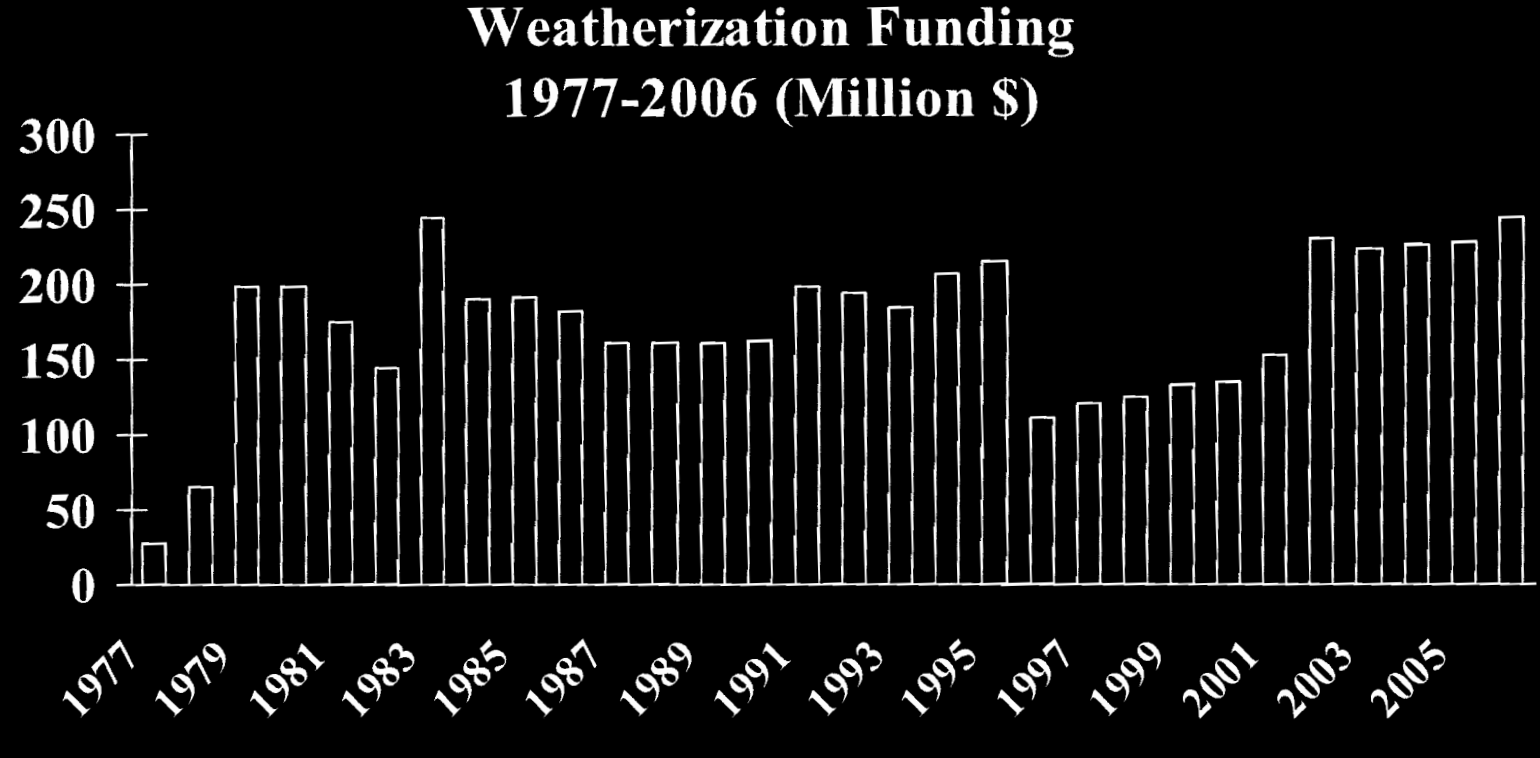
Dan Elliott
Oregon Low-Income Weatherization Coordinator

What is Weatherization? An Overview:

- The Weatherization Assistance Program reduces energy costs for low-income households by increasing the energy efficiency of their homes, while ensuring their health and safety.

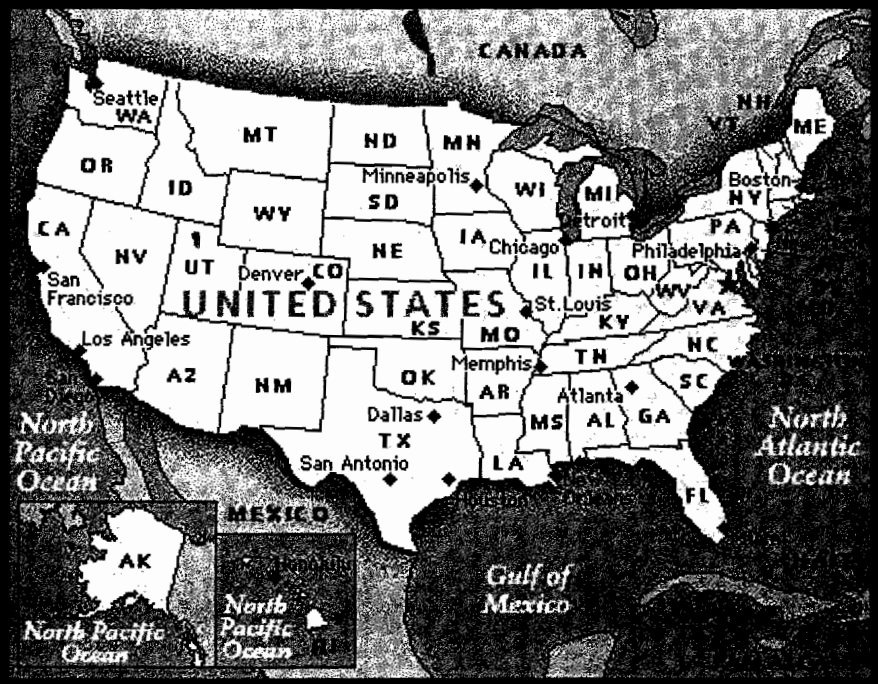
What is Weatherization?

- Nation's core program for delivering energy efficiency services to low-income homes



What is Weatherization?

- Operates in every state, District of Columbia, and among Native American tribes



What is Weatherization?

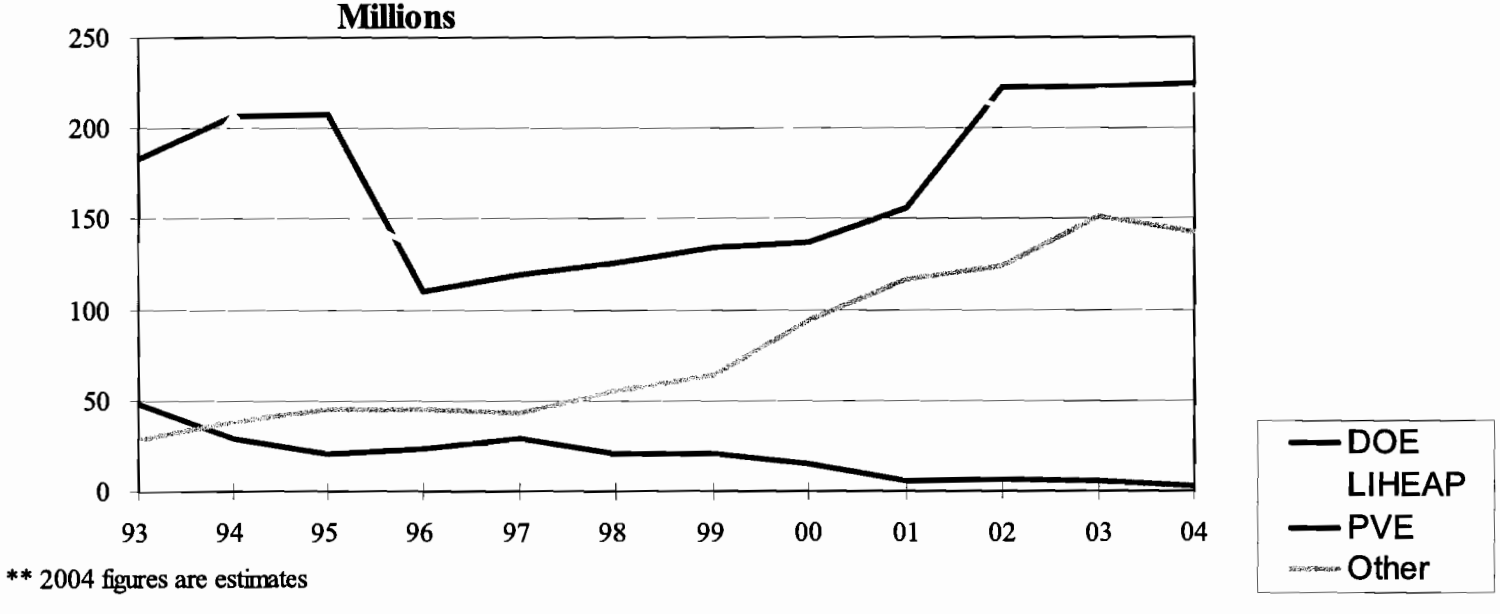
- Services delivered to single-family, multi-family, and mobile homes

Program Funding

- DOE provides core program funding
- States can use LIEAP funds from HHS, leverage funding from utilities and others

Program Funding

Weatherization Program Funding from Each Source, 1993-2004



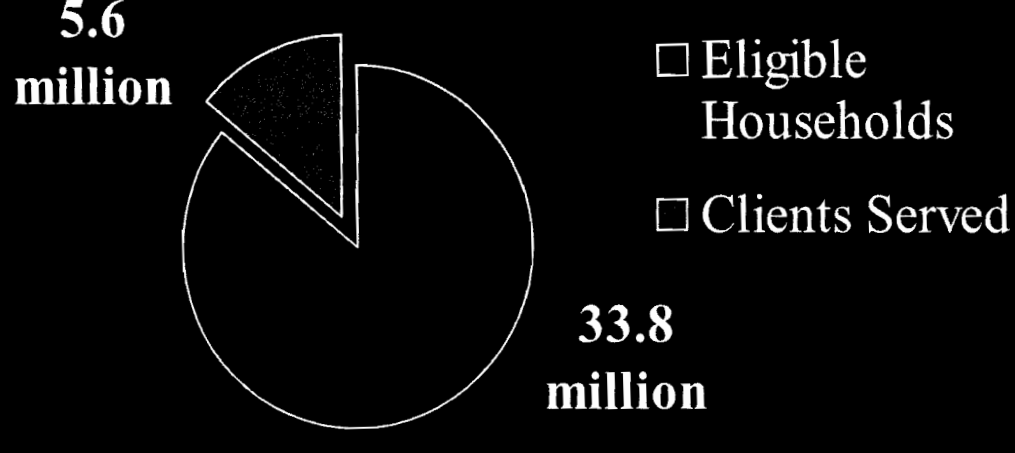
** 2004 figures are estimates

Why Weatherization?

- Heavy energy burden on low-income
  - Typically spend 16% of annual income on energy, compared with 5% for other households

Why Weatherization?

- Low-income families often choose between heat and other necessities
- 33.8 million households currently eligible for Weatherization services



Why Weatherization?

- Increases energy efficiency of the home
- Reduces energy costs year-round
- Provides long-term relief from expensive energy bills
  - Measures continue to save money every year
- Alleviates arrears, breaks destructive cycle of shut-offs and re-connections

What Results?

- Average annual energy savings = *$358 first-year savings per household
- Returns $1.53 in energy-related benefits for every $1 invested in the program
- Avoids 1 metric ton of carbon dioxide emissions for every gas heated home weatherized.
- Avoids 2 metric tons of carbon dioxide emissions every year for electric heated homes weatherized.
- Creates 52 direct jobs for every $1 million of funding nationally.
- Reduces national energy demand by 18 million barrels of oil per year.

**** Calculated January 2006 based on 20-year EIA annual price projections discounted to present value.***

Who Implements Weatherization?

- U.S. Department of Energy awards grants to states and tribal organizations
- States contract with local agencies to deliver services to low-income households
- Network of over 900 agencies reach every county in every state across the nation

How Does Weatherization Work?

- Client applies for services
- Energy audit conducted; technicians identify energy-related problems
- List of cost-effective measures developed
- Energy efficiency measures installed
- Client education
- Post-work inspection

Client Applies for Service

- Must meet income eligibility guidelines
- May receive priority
  - Elderly, disabled, family with children, household with high energy burden
- Renters eligible, must get approval from property owner
- When demand is high, client may be added to waiting list

Energy Audit

- Weatherization is a highly technical program
  - Energy professionals trained to conduct comprehensive energy analysis
- Diagnostic tools improve identification and remediation of energy problems
  - Also test for health and safety hazards (e.g., carbon monoxide)
- DOE-approved energy audit guides work

Energy Audit Conducted

- Auditor explains process to client
- Collects information on the home
  - Including results of diagnostic tests

Energy Audit Conducted

- Uses audit software or other method to estimate potential energy savings
- Develops list of cost-effective measures
- Identifies energy-related health and safety measures needed
- Oregon Weatherizatoin Assistance Program (WAP) uses REM/Rate but is currently in development of its own database and energy calculator

Diagnostic Tools: Blower Door

- Blower door test identifies air leakage
- Panel with fan is placed in a doorway to de-pressurize home
  - Exaggerates leakage so it can be measured

Diagnostic Tools: Blower Door

- Gauges indicate level of air leakage
- Used with other devices to locate leaks

Diagnostic Tools: Pressure Pan(then) and Manometer

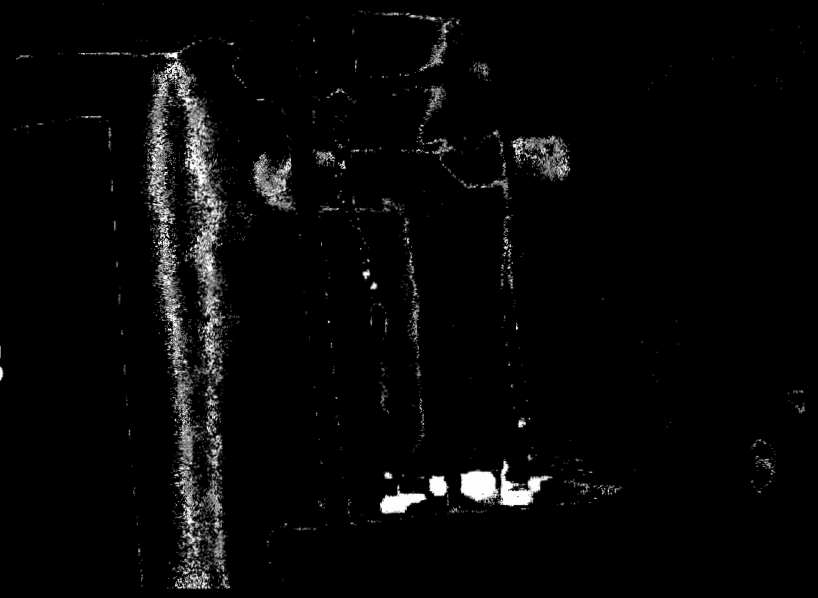
- Leaky ducts will increase heating and cooling costs by 10-30%
- While blower door runs, pressure pans were placed over air register (then)

Diagnostic Tools: Duct Blaster and Manometer

- Manometer measures pressure created by air leaking into ductwork
- Results help locate large leaks
  - Registers near leaks have higher readings
- Duct blower is used for more accurate readings and to balance systems

Diagnostic Tools: Infrared Camera

- Illustrates heat loss
- Guides air sealing and insulation
- Helps to educate clients
- Quality control for insulation and other measures



Diagnostic Tools: Combustion Analyzer

- Tests heating system for efficiency and safety
- Analyzes composition of flue gases
  - Indicates inefficient combustion, hazardous by-products (e.g., carbon monoxide)

Diagnostic Tools: Worst Case Draft Test

- "Backdrafting" can draw toxins into home
  - Negative pressure can pull carbon monoxide, radon, moisture, sewer gas, etc. into house
- To identify hazard, house is put in "worst case" condition by:
  - Turning on exhaust fans, dryer, furnace fan, etc.
  - Opening or closing basement door (depending on location of exhaust fans)
- Manometer measures pressure difference between furnace room and outside
  - Negative pressure difference means backdrafting is possible

Diagnostic Test: Gas Leak Detector

- Identifies natural gas leaks from stoves and furnaces
- Important health and safety test
- Effective tool for client education
  - Highlights dangers of gas leaks

Diagnostic Tools: Eyes, Ears, Intuition

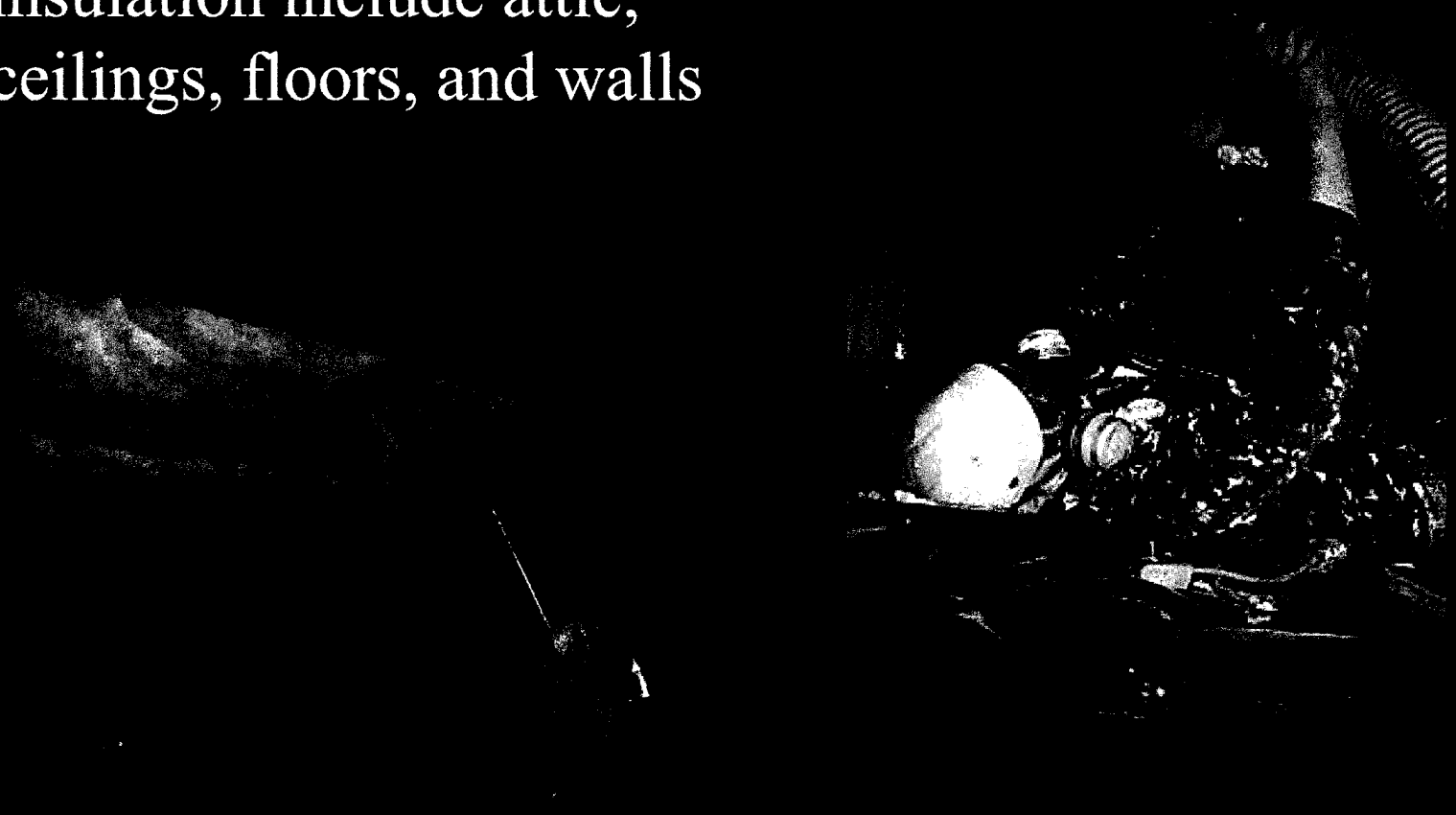
- Complex diagnostic instruments require knowledgeable, capable users
- No substitute for observant auditor
- Visual inspections key to identifying many problems
- Experienced technicians know to look for source of the problem, interaction issues

Energy Efficiency Measures: Air Sealing

- Blower-door guided air sealing locates leaks, indicates when "optimal" balance achieved
  - Visual inspections may miss "hidden" leaks, through floors, sealed fireplaces, cabinets
- Must know when to stop air sealing
  - Maintain minimum ventilation requirements
  - Ensure cost-effectiveness of measure

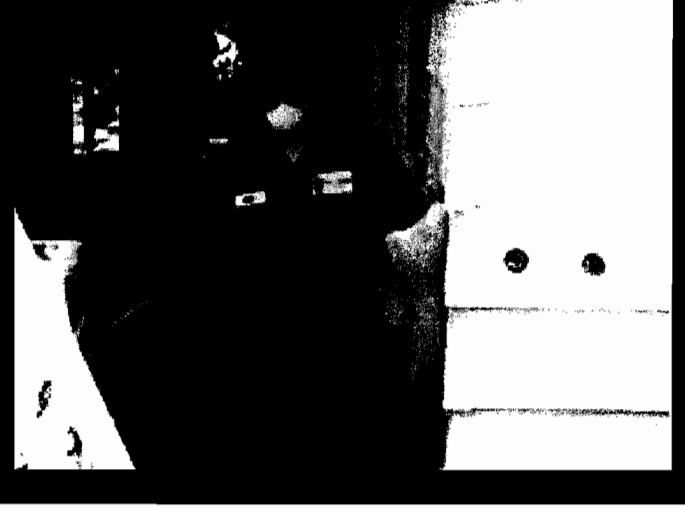
Energy Efficiency Measures: Insulation

- Potential areas for insulation include attic, ceilings, floors, and walls



Energy Efficiency Measures: Insulation

- Blown insulation most effective
  - Holes discreetly cut in walls or ceiling
  - Insulation is blown into space through a tube



Energy Efficiency Measures: Insulation

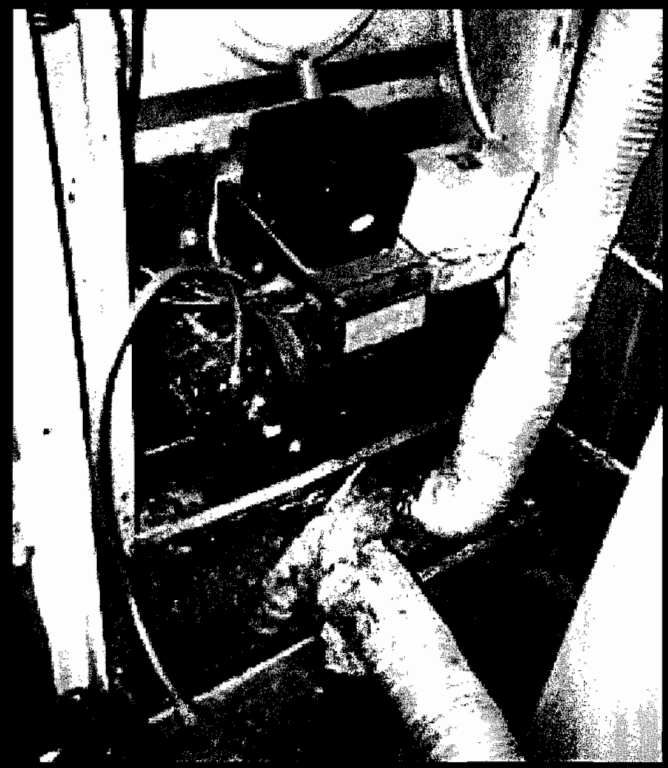
- Reduces air infiltration and heat loss
  - Dense-pack insulation often installed before air sealing, since it reduces leaks so effectively

Energy Efficiency Measure: Duct Sealing and Insulation

- Duct system may need sealing and/or balancing
- Duct tape is NOT be used
  - Apply mastic sealant
- Ducts in unconditioned spaces will be insulated

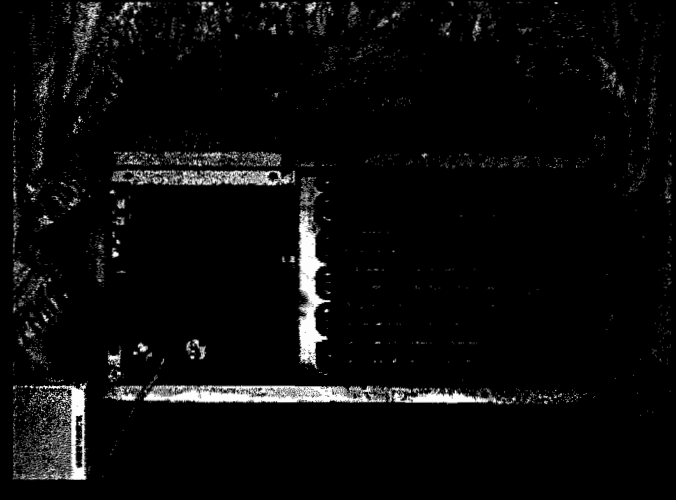
Energy Efficiency Measures: Heating System

- May need tune-up or basic repairs
- Can replace hazardous or inoperable furnaces
  - Due to funding limitations, leveraged resources often used to replace heating systems
  - Unvented space heaters pose large health and safety threat



Energy Efficiency Measures: Cooling System

- Technicians can tune-up or repair cooling systems
- Ducts may require sealing and/or balancing
- May add fans, ventilation for health and safety



Energy Efficiency Measures: Base Load Reduction

- Electricity consumption can be reduced through lighting, refrigerator, or water heater measures
- Equipment may need simple tuning
- Can replace to improve efficiency
- Base load reduction may help leverage utility resources

Energy Efficiency Measures: Other

- Wrap water heater tank and pipes
- Install set-back thermostat
- Repair/Replace broken and/or inefficient windows or exterior doors

Health and Safety

- Do no harm
- Conduct weatherization in a lead-safe manner
- May check for carbon monoxide, gas leaks, moisture/mold, electrical hazards
- Wear protective clothing, equipment
- Ensure safety of clients

Client Education

- Client education is a critical component
  - Ensure savings
  - Prevent health hazards
  - Prolong life of measures/equipment
- Conducted before and after measures are installed

Client Education

- Instructions on equipment operation and maintenance
- Tips on energy-saving actions
- Information on carbon monoxide and other hazards

Post-Work Inspection

- Blower door test ensures successful air sealing
  - Identifies any remaining air leaks
  - Indicates need for ventilation
- Insulation and other measures checked for quality and completion

Bridge Stories

- Before weatherization, Gracie A. lived in a house where temperatures barely rose above 40 degrees.
- A carbon monoxide test was done, and deadly levels of carbon monoxide were detected.
- A weatherization team installed a sealed, combustion heater as well as reinsulated her house.
- The assistance provided resulted in her health improving immediately.

Bridge Stories

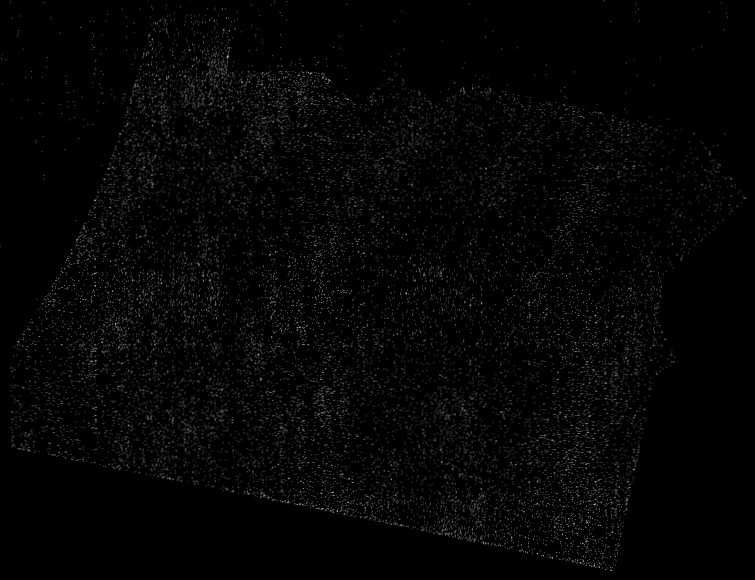
- Though Sarah C. rarely turned on the heat in her home, her utility bill ran nearly $250 each month.
- Weatherization discovered an electrical short that caused a constant flow of electricity.
- They fixed the problem, installed insulation in her floor and ceiling, and tuned the heating system.

Bridge Stories

- Before weatherization, Camille H. warmed her home with two space heaters and by boiling pots of water on a gas stove.
- Family members helped Camille purchase a new furnace.
- Weatherization technicians tested the system and installed energy efficiency measures throughout the house.

Improved Training Delivery

- In classroom and in field
  - Mobile home weatherization
  - Siding removal and sidewall insulation
  - Health and safety
  - Heating systems
  - Overview of new field standards
  - Diagnostics procedures
    - Blower door
    - Duct blaster
    - Worst-case draft testing
    - Etc...



OREGON

R.E.A.P. CERTIFICATION

Residential Energy Analyst Program

Oregon agencies increased output by <u>45%</u> in one year post inception of training programs.

ENERGY ANALYST CORE

BUILDING PERFORMANCE CORE

Analyst I
(3yr cert)

Diagnostic Tech I
(3yr cert)

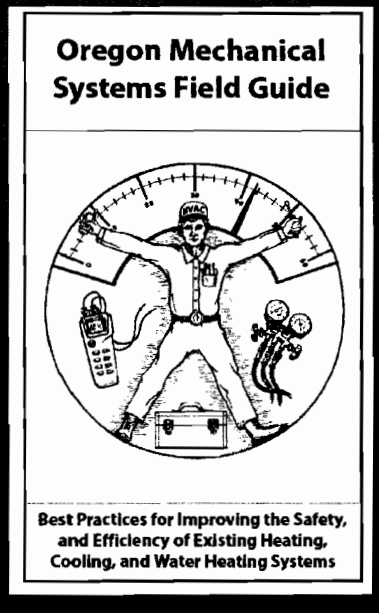
Shell Tech I
(3yr cert)

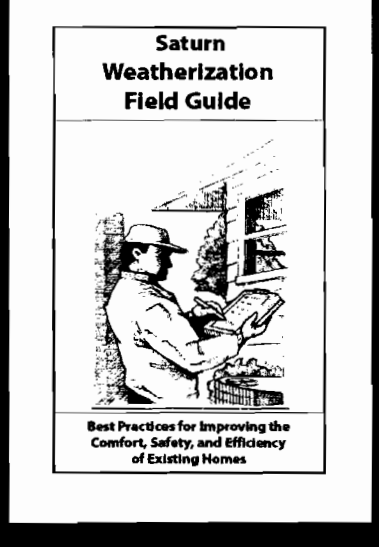
Analyst II
Requires Analyst I
Plus oneTech I cert

Building Performance Specialist I
Requires Diagnostic and Shell Tech 1 plus 1yr Field Experience with both certifications

Inspector
Requires Analyst I
Plus twoTech I cert

S.E.A.L.
Senior Energy Analyst Lead
(5yr certified at designation)
Inspector plus Building Performance Specialist satisfactory work and review as both
Re-certification is by T&TA council review for past work
**SEALs will be eligible for "Train the Trainer" classes





Update Field Standards

- Review of other state Wx field standards
- Based on review of best practices
- Flexible and adaptable document for future changes
- Review by Oregon Wx Technical Committee

Curriculum Development

Methods for Sustaining Program

- Comprehensive training program
- Regular technical committee meetings.
- Experimental/research philosophy in field
- Peer mentoring network
- Peer trainers
- Certification or merit-based rewards
- Proficiency testing

DOE Weatherization Plus-Next Generation

- Describes the whole-house approach to weatherization
- Incorporates advanced technologies
- Provides resources for community based efforts to: conserve energy, boost economic activity and improve the environment

Population Manufactured Dwellings

In 2005, 44% of all low-income homes weatherized in Oregon were manufactured homes

Population
Multi-Family Communities

In 2005, 22% of dwellings weatherized in Oregon were multi-family units.

Special Populations
Native Americans

- Native American total population in the state of Oregon represents 1.6%.(approx. 55,000 people)
- Approx 25,000 are part of the nine federally recognized tribes in Oregon
- 5,400 persons are low-income eligible in those tribes
- FACT: 24% of Native Americans in Oregon are low-income; higher than any ethnic population in the state

Special Populations
Native Americans

- Oregon has specific set-aside funds from DOE and BPA for this population (3%)
- In 2005, 4.6% of its total funding (all grant resources) were spent on this population
- Agencies leveraged $3.35 for every one dollar provided in federal set-aside
- Served a total of 236 men, women and children
- Tribes need more funding, training, and economic opportunity to increase self-sufficiency

Funding Resources

- DOE
- BPA
- LIEAP
- State Sponsored Programs
- Utility Programs
- Petroleum Violation Escrow
- Settlement Awards

Oregon WX Program Analysis

Multiple Benefits of Weatherization Programs

- Direct: Energy Conservation, Education
- Indirect: Housing, Environment and Homeland Security

This report specifically addresses Local and Statewide Economic Impacts associated with Oregon's Weatherization Program

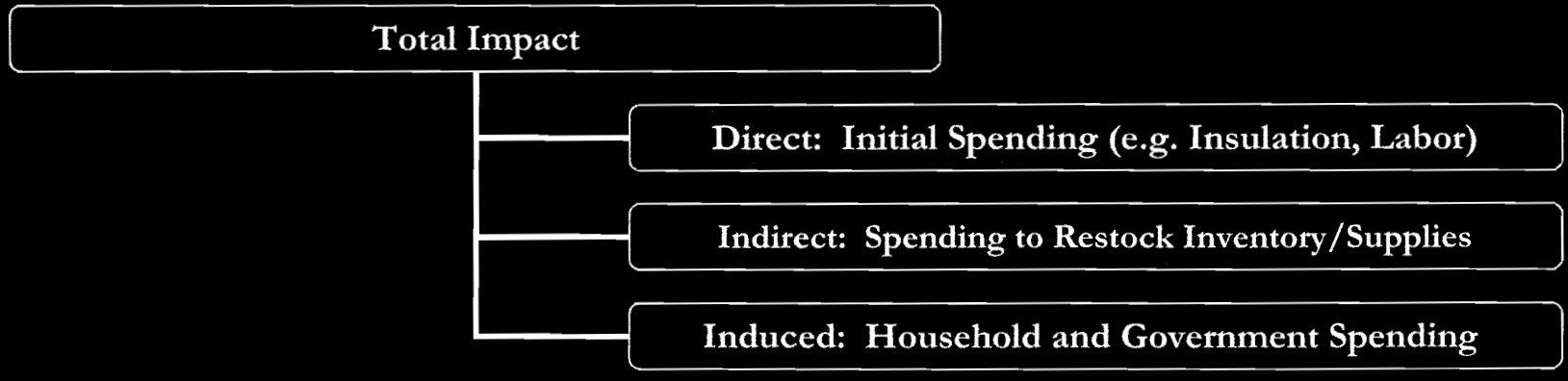
The Data

- Surveys: Agencies, OHCS
- Invoices: Sub-contractors, Agencies
- Interviews: Contractors, Agency Directors
- Program Spending (Labor and Materials)
- Administrative Expenditures and Energy Savings

Methods

Input Output Analysis

-How dollars move through the economy and "multiply"
-Aspects (Earnings, Employment, Output)
-Kinds of Spending (Direct, Indirect, Induced)



Rural and Urban Economies

Our Findings: Program Spending

- **Output -** For every weatherization program dollar spent in Oregon counties--up to another $.83 cents is generated locally and $1.11 statewide.
- **Earnings -** For each dollar spent on employee compensation through county weatherization programs, up to another $1.43 in labor income is produced within local communities.
- **Employment -** Each job associated with weatherization programs produce up to another 1.3 jobs locally, and 1.7 jobs statewide.

Our Findings: Energy Savings

- Dollars that would in most cases "leak" to out-of-town utility companies are instead spent in residents' own communities.
  - Every household dollar spent as a result of energy savings yields up to another $.63 within Oregon counties, and generates an additional $.85 statewide.

Our Findings: Administrative

- Administrative expenditures maintain the safety of program recipients and employees—as well as further the technology and efficiency of current weatherization program measures.

  - For every dollar spent on administrative costs, another .88 cents is generated statewide—and every administrative-related job yields another one and a quarter jobs across Oregon.

Conclusions

- According to our research, the economic effects of the Oregon Weatherization Program are significant--sometimes doubling the initial impacts made by program expenditures.
- Increased household spending as a result of energy savings also stimulates local economies--resulting in additional jobs, earnings and overall economic growth.
- These findings are valuable to both program managers and legislators at the state and federal levels. As agencies compete for limited funding, it is necessary to demonstrate that programs not only assist direct recipients, but entire communities across the state.

Suggestions for Further Research

- More research could be performed to examine:
  - Long Term Impacts
  - Affordable Housing
  - Health and Safety Benefits
  - Emotional Well-Being
  - Social Capital

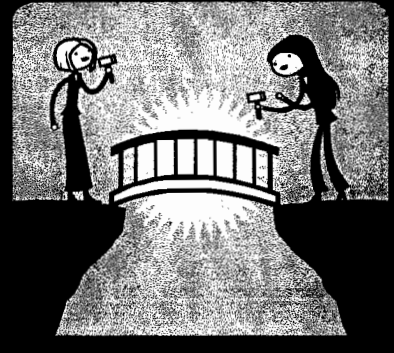
- Understanding weatherization outcomes and how they differ across communities will assist local program directors in developing realistic objectives for their programs, and will contribute to the formation of short and long-term weatherization goals for the State of Oregon.

The Low-Income Weatherization Builds Bridges!

✓For Families

✓For Communities

✓For the Nation



THANK YOU

FOR COMING

Presented by

Dan Elliott

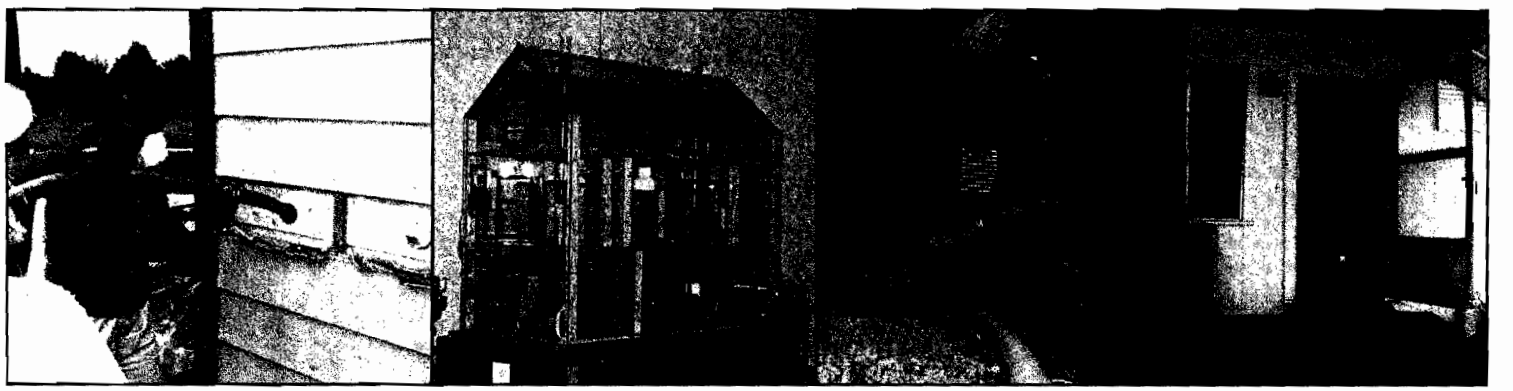
Oregon Housing and Community Services

Dan.elliott@hcs.state.or.us

503.986.2016

Weatherization Assistance Program

National Weatherization Training & Technical Assistance Plan



December 2009

Weatherization Works

Prepared by the U.S. Department of Energy, Office of Weatherization & Intergovernmental Program for the Weatherization Assistance Program

National Weatherization Training and Technical Assistance Plan
Weatherization Assistance Program

Concurrences:

Claire Johnson
Acting Program Manager, Weatherization & Intergovernmental Program

Kathleen Hogan
Deputy Assistant Secretary, Energy Efficiency

The U.S. Department of Energy
National Weatherization Training and Technical Assistance Plan

Table of Contents

I. WEATHERIZATION ASSISTANCE PROGRAM BACKGROUND 2

Weatherization Assistance Program Overview 2

Weatherization Workforce 3

Weatherization Training and Technical Assistance 3

II. VISION AND PURPOSE 6

The American Recovery and Reinvestment Act 6

Weatherization, the Changing Training Landscape, and Building a National Energy Efficiency Retrofit Market 6

III. DOE WEATHERIZATION PLAN 8

Goal 8

Task Overiew 8

Task Details 10

Task 1: Enhance communications, information exchange, and planning. 10
Task 2: Develop baseline technical training content and provide traditional training resources. 12
Task 3: Develop and deploy a national platform for weatherization training. 13
Task 4: Support the creation or expansion of comprehensive weatherization training centers and/or programs 15
Task 5: Support weatherization train-the-trainer, peer-mentoring, and peer-exchange activities. 16
Task 6: Develop national requirements for weatherization certification and accreditation standards. 17
Task 7: Provide expert services, technical assistance, and training to directly support the WAP network. 19
Task 8: Support WAP Grantee-directed pilots that advance state-of-the-art technologies and protocols 21
Task 9: Conduct comprehensive WAP impact and process evaluations. 22
Task 10: Develop and deploy an advanced online energy audit tool. 22
Task 11: Develop and implement a National Online Weatherization Information System. 23
Task 12: Provide for other services required during WAP Recovery Act implementation. 24

IV. APPENDICES

1) Comparison of Training Methodologies
2) Weatherization Core Competencies

I. WEATHERIZATION ASSISTANCE PROGRAM BACKGROUND

Weatherization Assistance Program Overview

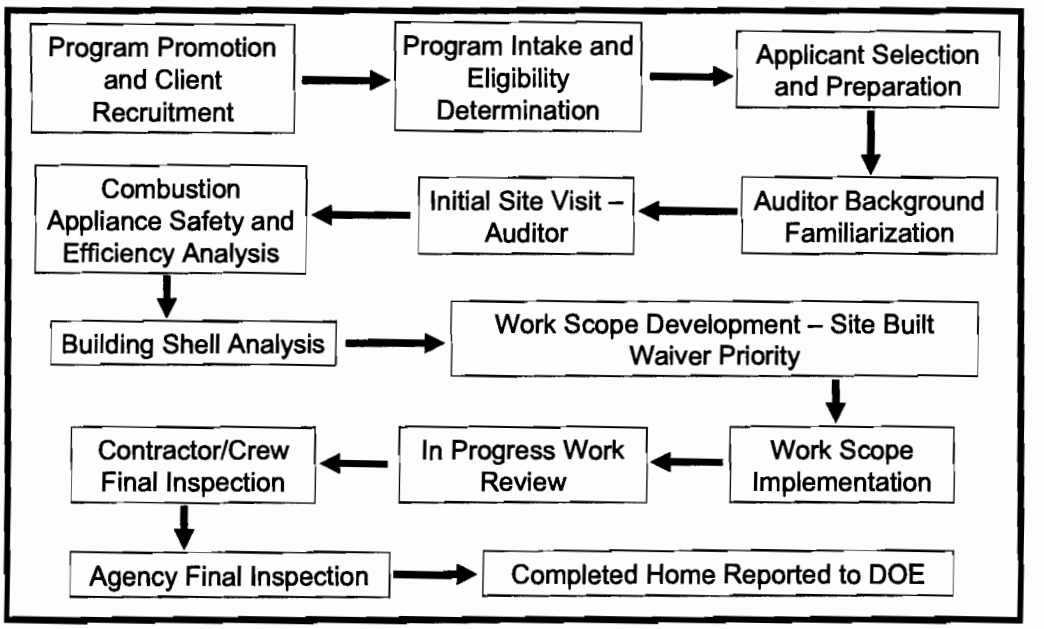
The U.S. Department of Energy's (DOE's) Weatherization Assistance Program (WAP) reduces energy costs for low-income families by increasing the energy efficiency of their homes, while ensuring their health and safety.

Weatherization works to:

- *Reduce energy costs and alleviate high energy burden for low-income families;*
- *Decrease the nation's energy consumption and avoid related emissions;*
- *Improve housing stock and neighborhood conditions;*
- *Provide an economic boost in low-income communities; and*
- *Educate consumers about energy efficiency practices.*

Weatherization service providers install energy efficiency measures in qualifying homes free of charge. In a comprehensive process that has developed over time, professionally-trained crews use computerized energy audits and advanced diagnostic equipment to determine the most cost-effective measures that are then installed, and work is inspected for quality and completeness (see Figure 1 below). Many of the building energy efficiency techniques considered standard procedure today were first developed and tested by the WAP. Typical measures can include installing insulation; sealing ducts; tuning, repairing, or replacing heating and cooling systems; mitigating air infiltration; and reducing electric base load consumption. These upgrades are cost-effective and inexpensive – historically, the average allowable expenditure limit has been $2,500[1] per home – and pay for themselves in a few years. DOE documents the savings and compares them to costs, allowing the Federal government to determine the efficacy of installed measures over time.

Figure 1: The Weatherization Assistance Program Process



[1] Many weatherization programs leverage additional funds through utility programs and other related Federal and state programs. By leveraging additional funds, weatherization programs can increase the average expenditure per home above the allowable DOE limit.

Weatherization programs operate in all 50 states and the District of Columbia, among Native American tribes, and in the U.S. territories. DOE provides funding and technical guidance to these "Grantees," which run their own programs and sub-contract to service providers – usually nonprofit agencies that serve families in their communities. Working together, this network delivers weatherization services to eligible residents in every county in the nation.

The WAP has served more than 6.3 million households since its inception more than 30 years ago. About 38 million households are currently eligible for weatherization services. The program prioritizes services to the elderly, people with disabilities, and families with children; high energy users or households with a high energy burden may also receive priority.

Weatherization Workforce

With a reputation for quality, the WAP has helped grow an energy efficiency industry for residential buildings. The industry employs thousands of people who work for low-income weatherization programs and companies that help homeowners increase their energy efficiency through low-cost measures.

A variety of people and skills are needed for weatherization programs to function effectively. In general, the weatherization workforce includes, but is not limited to, the following:

- **Auditors**, who assess eligible dwelling for potential weatherization services; visually inspect building shell and mechanical systems; conduct diagnostic, health, and safety tests; use computerized energy audit or priority list to select cost-effective measures; and prepare work orders to ensure the most appropriate measures are installed properly;
- **Installers,** who install weatherization measures (can be contractors or crew members);
- **Crew Chiefs,** who supervise crews of installers and direct their efforts;
- **Quality Control Inspectors,** who verify the proper selection, installation, and effectiveness of measures; review documentation; visually inspect; and perform diagnostic, health, and safety testing;
- **Trainers,** who provide training to weatherization staff;
- **Technical Monitors**, who monitor local agencies to ensure work quality, and often identify training needs and provide or recommend training;
- **Intake Eligibility Staff,** who determine the eligibility of prospective clients; and
- **State and Local Program Managers**, who manage day-to-day operations.

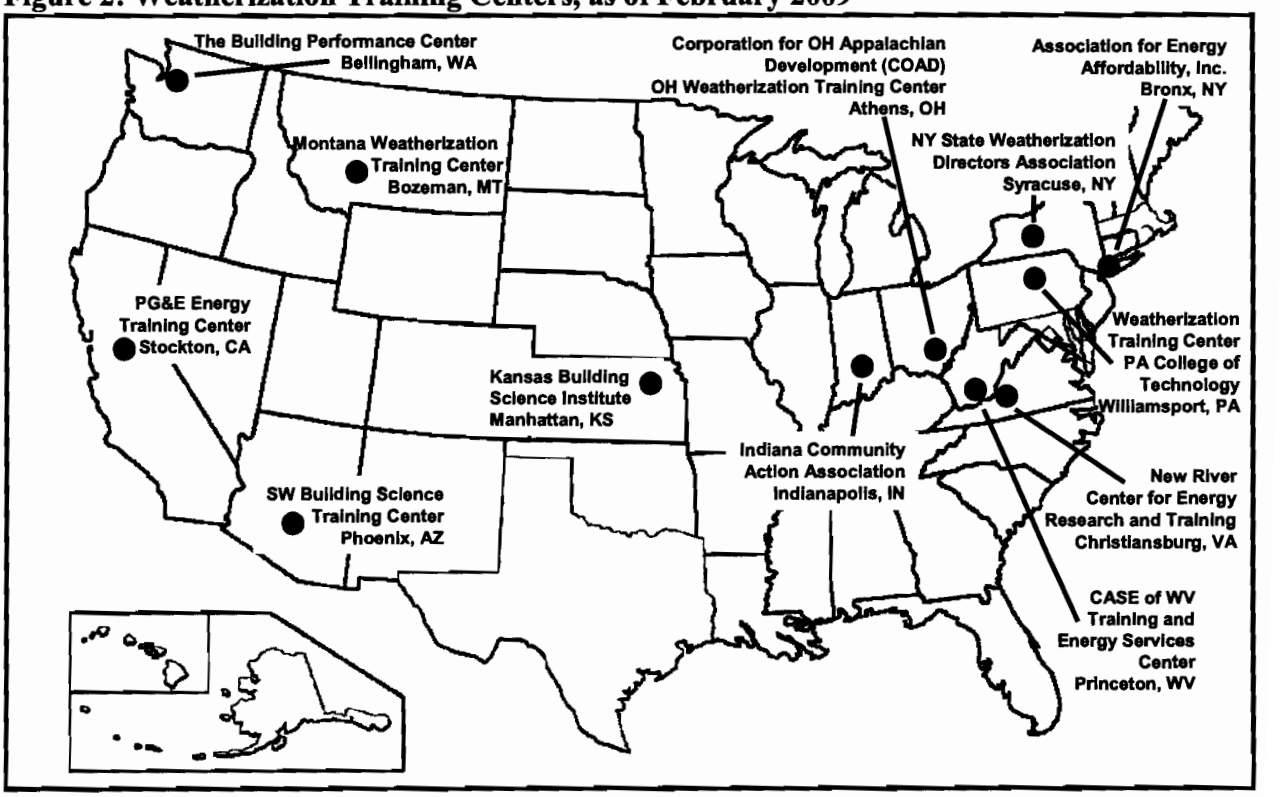
Weatherization Training and Technical Assistance

In addition to funds for weatherizing homes (also called "production"), the program statute has allowed up to 10% of the WAP annual appropriation to be used for training and technical assistance (T&TA) activities. Collectively, Grantees have received 8.5%; they decide how much to retain at the Grantee level and how much to provide to subgrantees. DOE has reserved 1.5% for national T&TA activities that benefit all Grantees.

WAP T&TA funds support a range of program operations activities including measuring and documenting performance, monitoring programs, promoting advanced techniques and collaborations to further improve program effectiveness, and training, including developing tools and information resources. Training can cover everything from program management to technical topics.

Historically, WAP Grantees and subgrantees have used T&TA funds to train individuals they have already hired, and they make their own decisions about how training is provided. While this creates variability across the country, it allows for tailored training programs that best suit individual needs. Some states benefit from a local weatherization training center, others may send workers to a weatherization training center in a neighboring state or a training facility that specializes in a particular training topic (e.g., heating, ventilating, and air conditioning), and still others may work with an expert training organization not housed in an actual center with ready access to weatherization training props and related equipment. Some states hire independent trainers with recognized weatherization expertise, and some use agency staff to provide training. Typically, Grantees choose to rely on a combination of training methodologies to meet their needs (see Appendix 1 for a comparison of methodologies). As of February 2009, prior to the passage of the Recovery Act, approximately 90% of states used state agency staff for training, approximately 75% used local agency peers for training, and approximately 70% of states used independent trainers. There were just twelve recognized weatherization training centers (see Figure 2).[2]

Figure 2: Weatherization Training Centers, as of February 2009[2]

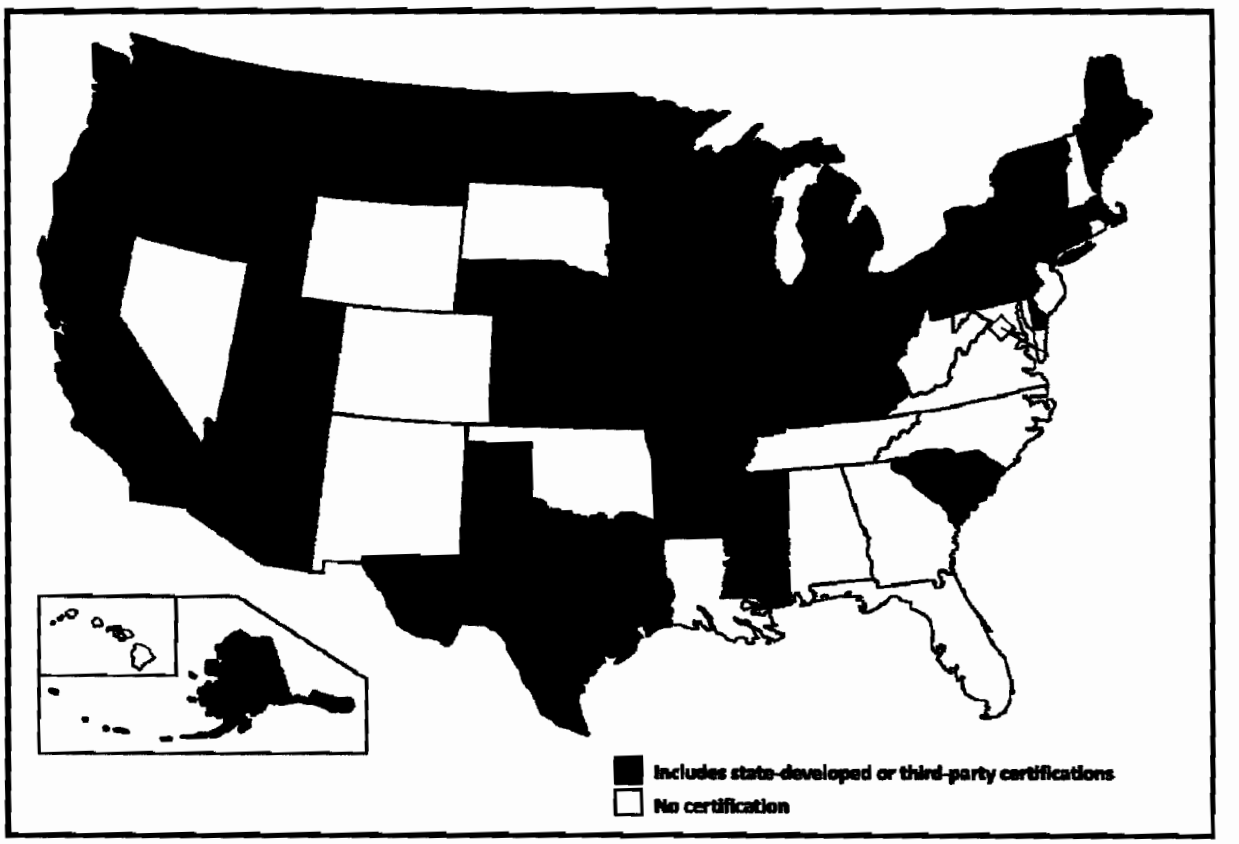


Grantees also make their own decisions regarding certification. Some require technical staff at local agencies to obtain certification from a national organization, while others have developed their own certification programs. Some Grantees have no formal certification requirements and

[2] Source: Weatherization Assistance Program Technical Assistance Center (WAPTAC), www.waptac.org, accessed July 2009

instead require local staff to attend standardized training courses. Some Grantees have no standardized certification or training requirements but offer training periodically, as needed. As of February 2009, prior to the passage of the Recovery Act, 31 Grantees required or offered certification for one or more job positions (see Figure 3).

Figure 3: States requiring or offering certification for one or more job positions, as of February 2009



DOE and the WAP network benefit from collective technical expertise of the Weatherization Trainers Consortium, a working group that includes a cross-section of weatherization training center staff, independent trainers, state and local agency staff, community and technical college instructors, and DOE managers. The consortium maintains up-to-date working knowledge of building science technologies, as well as building and safety codes and standards; facilitates the development of standardized minimum requirements to ensure quality results in areas including energy audits, work orders, curricula and training, and other subjects; and provides technical and programmatic support to DOE's national weatherization training efforts. It meets regularly to discuss critical issues and key topics that may require communication with the WAP network.

To help ensure consistent, high-quality training, the program drew upon the knowledge of the Weatherization Trainers Consortium to develop weatherization core competencies for each discipline, based on the skills needed for a given position (see Appendix 2). Many Grantees have developed their training programs around these core competencies. The increasing levels of competency provide a career or development path for agency and contractor personnel. For

example, the core competencies for an auditor build on those needed for a crew chief, which build on the skills needed for an installer.

II. VISION AND PURPOSE

The American Recovery and Reinvestment Act

Through the American Recovery and Reinvestment Act (Recovery Act), the Obama Administration made an unprecedented commitment to weatherizing and retrofitting our nation's residential building stock. In addition to investments in other Federal programs for residential energy efficiency and green workforce development, the Recovery Act provides the WAP $5 billion to significantly accelerate its efforts and expand the availability of weatherization services to low-income Americans. The White House Council on Environmental Quality coordinates related Federal efforts through a "Recovery through Retrofit" interagency taskforce, helping to ensure that these investments are the first step in creating a thriving market for home retrofits.[3]

The Recovery Act amended the WAP statute in several fundamental ways:

- *Increased income eligibility from 150% to 200% of poverty level;*
- *Changed the allowable costs from $2,500 to $6,500 per home;*
- *Increased the allowable T&TA funds from 10% to 20% of the total program allocation;*
- *Changed the date for assistance for previously weatherized units from September 30, 1993 to September 30, 1994; and*
- *Required compliance with the Davis-Bacon Act for use of prevailing wages.*

The Recovery Act changed the WAP in several ways (see box). Among them, it raised the allowable allocation for WAP T&TA activities from 10% to 20%, with 17% provided for Grantee-directed activities and 3% for DOE-directed, national activities. Therefore, of the $5 billion provided for WAP under the Recovery Act, Grantees may collectively use a total of $854 million for T&TA, and DOE is allocated $146 million.

Weatherization, the Changing Training Landscape, and Building a National Energy Efficiency Retrofit Market

The program's Recovery Act expansion requires a significant growth in training capacity beyond that of the current network. States and local agencies must very rapidly ramp up their production, which means they (or their contractors) must recruit, hire, and train workers to meet their needs quickly, while at the same time being careful to ensure the same level of quality service for which the WAP is well known.

The Recovery Act brings opportunities for innovative partnerships among network participants and between weatherization programs and external partners to leverage training resources and share best practices. Many states are developing or expanding training centers and conducting training boot camps to help ensure the availability of an adequate workforce. Grantees are also pursuing new ways to supplement their traditional training approaches, partnering with community college networks, state workforce investment boards, apprenticeship programs, and labor union programs. DOE seeks to facilitate and help replicate these kinds of partnerships to

[3] http://www.whitehouse.gov/the_press_office/Vice-President-Biden-Calls-for-Report-on-Green-Opportunities-for-the-Middle-Class/

not only leverage the nation's existing infrastructure and quickly build the training capacity needed for Recovery Act ramp up, but also better engage education and labor organizations capable of providing weatherization training to a larger audience over the long term.

DOE also seeks to ensure Recovery Act investments help build a better, stronger weatherization network that provides the foundation needed for a national energy efficiency retrofit market. Recovery Act funds allow the opportunity to develop and provide national baseline technical curricula anchored in sound building science and take advantage of technology to accelerate the pace of training and make it available to a much larger, national audience. Technology-enabled learning tools such as simulations and immersive environments can make learning more productive, compelling, personal, accessible, and adaptable to local needs. With stackable and transferable credentials, the new and growing green workforce can have the freedom of movement up a career ladder or mobility of a career lattice between the WAP and market-rate home energy retrofit or related renewable energy technology installation work. Training accreditation will help to ensure transparency of the training market and maintain quality assurance for workers seeking entry into the green, energy efficiency retrofit job market. New web-based tools will greatly increase the availability and accessibility of data and program results, allowing the WAP to communicate its progress quickly and easily – an advanced, online auditing tool will support a national database of retrofit measures with related costs and projected energy savings, and new national, web-based weatherization program management capability will increase the efficiency and ease of reporting across the network.

Inherent in this unprecedented opportunity afforded by Recovery Act funding is the responsibility to coordinate efforts with related programs and leverage both new and existing resources through partnerships that can extend Recovery Act investments well into the future. Within DOE's Office of Energy Efficiency and Renewable Energy, the Building Technologies Program (BTP) funds research and technology development to reduce residential building energy use. BTP's Building America Program provides best practices and case studies for major climate zones that can inform WAP technical training materials. The activities described in this plan will bring together weatherization and other technical experts to develop content delivered through a new national training platform that enhances traditional training methodologies. The activities in this plan are also intended to foster partnerships with related Federal residential retrofit programs and new efforts to building a green workforce through energy efficiency, as well as leverage labor union and technical college workforce training capabilities and infrastructure.

Over its more than 30 years of operation, the weatherization network has demonstrated its ability to improve the health, comfort, and safety of millions of low-income persons by increasing the energy efficiency of their homes. Recognizing the program's unique ability to quickly reduce energy use and carbon emissions, provide real dollar savings that can be reinvested in the economy, and stimulate growth of the green job market, the Recovery Act provided for a significant ramp up of WAP efforts. In response to this challenge and opportunity, the weatherization network is increasing its production while maintaining the quality workmanship for which it is known. Through the strategic use of Recovery Act investments outlined in this plan, DOE will build on Grantee and subgrantee activities to support weatherization and lay the

foundation for a national retrofit industry with ready access to a well-trained workforce and opportunities for worker mobility and career pathways.

III. DOE WEATHERIZATION PLAN

Goal

The overarching goal of DOE's training and technical assistance effort is the following: Build the training capacity to support the weatherization network Recovery Act ramp up and lay the foundation for a sustainable national retrofit industry with ready access to a well-trained workforce and opportunities for worker mobility and career pathways.

Tasks

The tasks, activities, and milestones described below are designed to support weatherization network ramp up and program implementation over the Recovery Act period, and also leverage WAP expertise to lay the foundation for a national energy efficiency retrofit market as described in Section II. As program implementation proceeds, new training needs may arise. *This plan is intended to be a living document with the flexibility to adjust tasks, activities, and milestones, as appropriate, to best serve the weatherization network, Recovery Act objectives, and national priorities for energy efficiency retrofit market development.*

Task Overview

Task 1: Enhance communications, information exchange, and planning.

- Project 1.1: STREAMLINE COMMUNICATIONS
- Project 1.2: FORM A DOE WORKING GROUP TO FACILITATE COORDINATION
- Project 1.3: CONDUCT WEATHERIZATION OUTREACH
- Project 1.4: FORM AND MANAGE NATIONAL ADVISORY COMMITTEE

Task 2: Develop baseline technical training content and provide traditional training resources.

- Project 2.1: MAKE AVAILABLE NATIONAL WAP BUILDING SCIENCE FUNDAMENTALS
- Project 2.2: DEVELOP STANDARDIZED TECHNICAL TRAINING MATERIAL CONTENT AND TRADITIONAL TECHNICAL TRAINING MATERIALS

Task 3: Develop and deploy a national platform for weatherization training.

- Project 3.1: DEVELOP AND DEPLOY A NATIONAL PLATFORM FOR WEATHERIZATION TRAINING (NPWT)
- Project 3.2: PROVIDE OUTREACH ON THE NPWT
- Project 3.3: PROVIDE TRAINING AND TECHNICAL ASSISTANCE TO SUPPORT THE DEPLOYMENT AND USE OF THE NPWT

Task 4: Support the creation or expansion of comprehensive weatherization training centers and/or programs

Task 5: Support weatherization train-the-trainer, peer-mentoring, and peer-exchange activities.

- Project 5.1: DEPLOY TRAIN-THE-TRAINER PROGRAMS
- Project 5.2: SUPPORT PEER-MENTORING AND PEER-EXCHANGE OPPORTUNITIES
- Project 5.3: ESTABLISH A COMMUNITY OF PRACTICE AMONG WEATHERIZATION TRAINING PROVIDERS

Task 6: Develop national requirements for weatherization certification and accreditation standards.

- Project 6.1: DEVELOP AND IMPLEMENT A NATIONAL WEATHERIZATION WORKER CERTIFICATION FRAMEWORK
- Project 6.2: DEVELOP A NATIONAL WEATHERIZATION TRAINING ACCREDITATION AND TRAINER CERTIFICATION PROGRAM

Task 7: Provide expert services, technical assistance, and training to directly support the WAP network.

- Project 7.1: DELIVER PROGRAM OPERATIONS TRAINING AND TECHNICAL ASSISTANCE
- Project 7.2: DELIVER FISCAL/PROCUREMENT TRAINING AND TECHNICAL ASSISTANCE
- Project 7.3: PROVIDE TARGETED TECHNICAL ASSISTANCE AND TRAINING
- Project 7.4: PROVIDE TARGETED LEVERAGING ASSISTANCE AND TRAINING

Task 8: Support WAP Grantee-directed pilots that advance the use of state-of-the-art technologies and protocols.

- Project 8.1: ISSUE OPEN CALL FOR PROJECTS
- Project 8.2: EVALUATE AND INCORPORATE PROJECT RESULTS INTO WAP TRAINING AND ACTIVITIES

Task 9: Conduct comprehensive WAP impact and process evaluations.

- Project 9.1: COMPLETE RETROSPECTIVE EVALUATION
- Project 9.2: COMPLETE RECOVERY ACT EVALUATION

Task 10: Develop and deploy an advanced online energy audit tool.

- Project 10.1: PROVIDE ONGOING GRANTEE SUPPORT OF AUDIT PROTOCOLS
- Project 10.2: MAINTAIN FIELD VERSIONS OF NEAT AND MHEA
- Project 10.3: DEVELOP A NEW, ONLINE AUDITING TOOL

Task 11: Develop and implement a National Online Weatherization Management Information System.

- Project 11.1: DEFINE SCOPE OF NATIONAL ONLINE WEATHERIZATION MANAGEMENT INFORMATION SYSTEM

- Project 11.2: DEVELOP NATIONAL ONLINE WEATHERIZATION MANAGEMENT INFORMATION SYSTEM
- Project 11.3: DEPLOY NATIONAL ONLINE WEATHERIZATION MANAGEMENT INFORMATION SYSTEM

Task 12: Provide for other services required during WAP Recovery Act implementation.
- Project 12.1: SUPPORT DATA ACCEPTANCE, ANALYSIS, AND RECONCILIATION
- Project 12.2: ENSURE QUICK RESPONSE RESEARCH/ANALYSIS ON "HOT TOPICS"
- Project 12.3: FACILITATE PROGRAM IMPLEMENTATION AND FUNCTION

Task Details

Task 1: Enhance communications, information exchange, and planning.

Project 1.1: STREAMLINE COMMUNICATIONS.
- **Project 1.1.1:** Maintain and update the Weatherization Assistance Program Technical Assistance Center (WAPTAC), www.waptac.org.
    - Upgrade the WAPTAC structure and platform to increase the site's usability and accessibility. Upgrades will clearly organize information, support online communities, and encourage connections to related programs and new content delivery mechanisms.
    - Provide maintenance and updating of current WAPTAC resources including program notices, public information materials, Grantee contact information, new information and training materials available to the network, health and safety protocols, tool-kits, presentation materials, training curricula, brochures, fact sheets, and other resources. WAPTAC will host all approved State Weatherization Plans (excluding detailed Grantee budgets and budget justifications).

  (Milestone: Launch new WAPTAC web site; Date: Q2 FY10)

- **Project 1.1.2:** Update DOE/EERE WAP website to highlight key communications from DOE to the WAP network; make use of links to align with and complement WAPTAC.

  (Milestone: Complete initial EERE/WAP web site update; Date: Q1 FY10)

- **Project 1.1.3:** Host a monthly webinar series (or similar technology-enabled vehicle) for WAP Grantees on "hot topics."

  (Milestone: Host first Hot Topics Webinar; Date: Q1 FY10)

- **Project 1.1.4:** Establish regular communication with other Federal agencies involved in workforce development for energy efficiency retrofits.

Project 1.2: FORM A DOE WORKING GROUP TO FACILITATE COORDINATION.
Establish regular working group meetings between the DOE WAP and the DOE Building

Technologies Program (BTP) to facilitate coordination of related training and technical assistance activities, as well as share research results and lessons learned from technology implementation. The working group will develop a comprehensive coordination plan and may have sub-groups that involve other stakeholders to focus on specific issues such as training material and certification.

(Milestone: Establish working group; Date: Q1 FY10)
(Milestone: Complete WAP-BTP coordination plan; Date: Q3 FY10)

Project 1.3: CONDUCT WEATHERIZATION OUTREACH.

- **Project 1.3.1:** Create communications materials for use by Grantees and DOE to articulate the goals and achievements of the program for both internal and external audiences; these materials will also include pieces that help the public understand "what weatherization is." Work with the BTP and other Federal agencies to share stories on energy efficiency upgrades.

  (Milestone: Create promotional video clips as well as clips that demonstration weatherization technologies and processes; Date: Q1 FY10)

- **Project 1.3.2:** Support Grantees that want to increase outreach about their programs but do not have adequate management staff available to ensure successful outreach events. Grantee outreach can inform the community about the availability of weatherization services.

  (Milestone: Support first Grantee public outreach event; Date: Q2 FY10)

Project 1.4: FORM AND MANAGE NATIONAL ADVISORY COMMITTEE. Form an advisory committee of private sector business leaders (e.g., home service professionals) that includes WAP, BTP, and other residential energy efficiency retrofit stakeholders, as well as Federal agencies representatives of the Recovery through Retrofit interagency task force. In compliance with Federal Advisory Committee Act guidelines, the committee will provide recommendations on issues related to weatherization and home energy retrofits.

(Milestone: Announce selection of advisory committee; Date: Q3 FY10)

Task 1 Expected Outcomes:

- Significantly upgraded technical web site
- Better coordination with EERE/BTP; coordination plan
- DOE webinar series for regular communication with WAP network
- Grantee public outreach events, communications resources/tools for DOE and Grantee use
- Federal advisory committee providing recommendations on key issues related to weatherization and coordination with the national retrofit community

Task 2: Develop baseline technical training content and provide traditional training resources.

Project 2.1: MAKE AVAILABLE NATIONAL WAP BUILDING SCIENCE FUNDAMENTALS. Provide technically-accurate resources based on sound building science, including peer-reviewed best practices, in a format that states can adapt to meet their needs.

- **Project 2.1.1:** Analyze the WAP and related residential retrofit programs to identify and understand the differences in program protocols, technology implementation, and training requirements.

  (Milestone: Complete analysis; Date: Q2 FY10)

- **Project 2.1.2:** Immediately inventory training materials, best practices, and other resources from national, state, and local weatherization and related retrofit and construction programs. Make materials available as appropriate. Efforts must be coordinated with other efforts to develop materials inventories as noted in this plan.

  (Milestone: Complete inventory; Date: Q2 FY10)

- **Project 2.1.3:** Using materials from the inventory (Project 2.1.2), develop and make available climate-specific, baseline best practice manuals for use among weatherization and home energy retrofit practitioners.

  (Milestone: Complete baseline best practice manuals; Date: Q3 FY10)

Project 2.2: DEVELOP STANDARDIZED TECHNICAL TRAINING MATERIAL CONTENT AND TRADITIONAL TECHNICAL TRAINING MATERIALS. Develop technical training content and traditional training materials based on sound building science and leveraging WAP, BTP, and other resources (e.g., EPA Lead-Safe Work Practices).

- **Project 2.2.1**: Develop baseline technical content for a comprehensive and scientifically-based national, standardized training curricula that covers the following:
  - Weatherization of –
    - Single-family homes
    - Mobile and manufactured homes
    - Multi-family residents
  - Train-the-Trainer

- **Project 2.2.2:** Provide the technical content drafts to the technical training sub-group formed under Project 2.1 for review, as appropriate.

- **Project 2.2.3:** Using the technical content, develop training curricula materials suitable for traditional, in-person content delivery. Work with the Weatherization Trainers Consortium to review materials and work with Grantees and others to pilot test it before official rollout.

Work with DOL and DOE to evaluate the effectiveness of the weatherization technical training materials in this project.

(Milestone: Release first three modules of single-family curricula: Installer Fundamentals; Installer Intermediate; and Energy Auditor; Date: Q1 FY10)
(Milestone: Release Mobile Home Installer's Module; Date: Q1 FY10)
(Milestone: Release second three modules of single-family curricula: Crew Chief Training, Train the Trainer, and Technical Monitor/Inspector; Date: Q2 FY10)
(Milestone: Release supplemental modules for multi-family curricula: Auditor; Heating Systems for Auditors and Inspectors; and Heating and Cooling Systems for HVAC Contractors; Date: Q3 FY10)
(Milestone: Release last two modules of single-family curricula: Heating System Training for Energy Auditors and Inspectors; and Heating and Cooling System Training for HVAC Contractors; Date: Q3 FY10)

- **Project 2.2.4:** Develop supplementary technical training tools, including but not limited to videos and simulations that can be used stand-alone, integrated into, or delivered through a technology platform.

  (Milestone: Upload first video segments to WAPTAC; Date: Q1 FY10)

Task 2 Expected Outcomes:
- Analysis of WAP and related programs' protocols and technologies
- Weatherization best practice manuals for multiple climates
- Comprehensive technical content and curricula (installer fundamentals and intermediate, mobile home installer, auditor, crew chief, train-the-trainer, technical monitor/inspector, supplemental modules for multi-family weatherization, heating and cooling systems, etc.)

Task 3: Develop and deploy a national platform for weatherization training.

The National Platform for Weatherization Training (NPWT) will take advantage of information technology (IT) tools for delivering training and providing performance-based testing that have been used successfully by the Department of Defense and innovative private sector companies. The NPWT will support interactive online instruction, computer simulations, and 3-D visualization tools that are appropriate for energy retrofitting work and will allow participants access to information and training on a wide variety of building types, HVAC systems, insulation materials, and other energy features without traveling to dozens of building locations. It will consist of two components:

1. An IT-enabled platform, which is a virtual analogy of a building with classrooms, services, and staff; and
2. IT-enabled modules, which are the software equivalent of training courses.

The NPWT is meant to enhance – not replace – traditional in-person, hands-on, and on-the-job training. It has been shown that IT-enabled training tools can reduce instruction time and improve student performance. While the NPWT will be open-source and available to everyone,

the training providers with which DOE partners (see below) will play a pivotal role in deploying these tools. DOE intends to introduce the NPWT in a phased approach.

Project 3.1: DEVELOP AND DEPLOY A NATIONAL PLATFORM FOR WEATHERIZATION TRAINING (NPWT). DOE will develop and deploy the NPWT in a phased approach as described below.

Phase 1 Development and Deployment

- **Project 3.1.1:** Develop a national platform that offers an enhanced web-based learning and content management system to manage training records and facilitate access to online courses for weatherization training.

  (Milestone: Complete the development of the phase 1 national platform; Date: Q2 FY10)

- **Project 3.1.2:** Using the standardized technical training content developed in task 2, develop interactive web-based training modules to be made available on the national platform. DOE will work with WAP Grantees and trainers to pilot test the modules as part of the development process.

  (Milestone: Complete the development of web-based training modules for installer fundamentals, installer intermediate, and energy auditor training and deploy on the phase 1 national platform; Date: Q2 FY10)

Phase 2 Development and Deployment

- **Project 3.1.3:** Increase the functionality of the phase 1 platform to accommodate immersive and experiential learning content. Development will include rapid prototyping, user testing and evaluation. Users will be able to access training that simulates the range of buildings, equipment, and other elements required to provide weatherization training. Tools will enable users to –
  - Collaboratively create, modify, and use digital materials;
  - Peer review;
  - Upload, access and store digital materials, behaviors and metadata;
  - Contact and manage development teams (link subject matter experts to experts in creating virtual objects);
  - Create and rate learning modules and assessments (e.g. a performance based challenge); and
  - Manage intellectual property and other rights.

  (Milestone: Begin iterative cycles of testing and evaluation of the phase 2 platform; Date: Q3 FY10)
  (Milestone: Complete development of the phase 2 IT-enabled platform; Date: Q2 FY11)

- **Project 3.1.4**: Develop a series of IT-enabled modules to be delivered via the phase 2 platform. Development of the modules will build on the web-based training developed in phase 1 and rely on the standardized technical training content developed in task 2. The modules will include computer simulations, 3-D visualization tools, and immersive

environments. DOE will work with WAP Grantees and trainers to pilot test phase 2 modules as part of the development process. Work will also be conducted in coordination with the Departments of Labor and Education to evaluate the effectiveness and increase the interoperability of the national training platform and curricula developed in this task to ensure it can become a national training system.

(Milestone: Begin iterative cycles of user testing of the phase 2 modules; Date: Q3 FY10)
(Milestone: Launch IT-enabled modules on the phase 2 platform; Date: Q2 FY11)

Project 3.2: PROVIDE OUTREACH ON THE NPWT. Outreach should promote the availability of the NPWT and its ability to increase the availability of training to a large audience and accelerate training in advance of hands-on and in-field training.

(Milestone: Complete development of NPWT outreach strategy; Date: Q2 FY10)

Project 3.3: PROVIDE TRAINING AND TECHNICAL ASSISTANCE TO SUPPORT THE DEPLOYMENT AND USE OF THE NPWT. Building on the outreach strategy developed under Project 3.3, DOE will establish a technical assistance team to support the launch, deployment, and use of technical training via the NPWT. The team will focus its initial efforts on weatherization training centers, both existing centers supporting the WAP and new centers or programs.

(Milestone: Establish NPWT training and technical assistance team; Date: Q2 FY10)

Task 3 Expected Outcomes:

- National, open-source, virtual learning system that rapidly accelerates the pace and expands the availability of weatherization training
- An easy-to-use set of tools and services that allows students and trainers to create, use, share, continuously-update, and collaboratively-improve training materials, as well as safely maintain student training records

Task 4: Support the creation or expansion of comprehensive weatherization training centers and/or programs.

DOE will form partnerships with training entities to expand existing or develop new weatherization training centers or programs that provide accelerated, holistic, standardized, and multi-tiered weatherization training. Through this effort, DOE will seek to support regions with the greatest need; develop training centers and/or programs that provide a combination of classroom, online, and hands-on learning; and to the greatest extent possible, facilitate partnerships with existing vocational training resources, including but not limited to DOL green workforce efforts, related retrofit training efforts, community or technical college programs, apprenticeship programs, and other union or organized labor programs. The training centers or programs developed under this effort will be encouraged to use the standardized technical training content developed under task 2 and integrate with the technology-enabled training system developed under task 3 to the greatest extent possible.

(Milestone: Announce new training center projects; Date: Q3 FY10)

Task 4 Expected Outcome: Expanded national network of comprehensive weatherization training centers/programs

Task 5: Support weatherization train-the-trainer, peer-mentoring, and peer-exchange activities.

Project 5.1: DEPLOY TRAIN-THE-TRAINER PROGRAMS. Focusing first on areas of greatest need, work with established training providers to offer train-the-trainer programs that include hands-on training, mentoring, and other professional development opportunities for instructors. To the greatest extent possible, this training will be designed to incorporate the standardized technical training content developed under task 2 and integrate with the technology-enabled training system developed under task 3.

(Milestone: Launch train-the-trainer programs in up to 6 different regions; Date: Q4 FY10)

Project 5.2: SUPPORT PEER-MENTORING AND PEER-EXCHANGE OPPORTUNITIES. Work with Grantees to expand the availability of on-the-job peer-training, peer-mentoring, and peer-exchange opportunities, with an emphasis on in-field and hands-on learning. These efforts could also include the use of technology enabled training systems and success stories from the deployment of technology-enabled programs.

(Milestone: Launch new peer-mentoring or peer-exchange activities in up to 6 different regions; Date: Q4 FY10)

Project 5.3: ESTABLISH A COMMUNITY OF PRACTICE AMONG WEATHERIZATION TRAINING PROVIDERS. Create a Community of Practice (CoP) that brings together weatherization trainers (representing training centers, training programs, and other relevant entities) to share what they know and learn from one another through online communities, focused conferences, and other means of networking and sharing information. The CoP will help to develop participants' weatherization training expertise and persist as long as there is an expressed interest in improving the practice.

(Milestone: Establish Weatherization Training Provider Community of Practice; Date: Q2 FY10)

Task 5 Expected Outcomes:

- Expanded network of expert trainers
- More "informal trainers" who teach through peer mentoring
- Better opportunities for trainers to learn from each other, share best practices and lessons learned

Task 6: Develop national requirements for weatherization certification and accreditation standards.

Project 6.1: DEVELOP AND IMPLEMENT A NATIONAL WEATHERIZATION WORKER CERTIFICATION FRAMEWORK.

- **Project 5.1.1:** Inventory and analyze all current weatherization-related worker certifications, including state-developed certifications, third-party certifications, and others. The analysis should identify any state-specific needs related to the implementation of worker certification programs and comparison of standards within each state.

  (Milestone: Publish a status document showing how each WAP Grantee addresses worker certification; based on analysis, the document will include recommendations for certification best practices; Date: Q2 FY10)

- **Project 6.1.2:** With WAP network representatives and participants from the DOE working group established in Project 1.2, bring together technology experts and stakeholders to form a certification sub-group to do the following:
  - Review top-of-class standards to identify standards that are consistent across the WAP and other related retrofit programs.
  - Develop a national weatherization worker certification framework that includes –
    - Types of weatherization worker certifications that should comprise a national certification framework, possibly focusing initially on auditors, inspectors, and crew chiefs; and
    - National performance-based minimum standards, to which Grantees will build their certifications. These standards will be tied to the national benchmark training materials developed in Task 2 of this plan. (Note: Grantees may choose to raise the standards beyond the minimum established by DOE.)
  - Determine the feasibility of a secured national database of certified workers.

  (Milestone: Distribute draft national certification framework for peer review; Date: Q4 FY10)

  - Recommend to DOE – (1) a process similar to the existing WAP audit approval process by which DOE determines whether existing certifications meet determined national baseline criteria, and (2) protocols for ongoing review of the certification process as well as procedures for certification approval renewal and audit and evaluation of the national certification framework.

  (Milestone: Issue working group report on national weatherization worker certification; Date: Q4 FY10)

- **Project 6.1.3:** Issue program notice announcing new national certification criteria and framework; the notice will:
  - Describe the vision and purpose;

- Require Grantees with existing certification programs to submit their certification protocols and applicable standards for DOE approval; approval package would also include the available training to achieve certification;
- Require Grantees that do not have existing certifications to develop a certification process based on the DOE baseline certification criteria, and submit for DOE approval a certification process document that describes the Grantee's new certification effort, including how it will manage and enforce the program;
- Describe plans for a phased approach for the implementation of the national certification framework.

(Milestone: Issue program notice on worker certification; Date: Q1 FY11)

- **Project 6.1.4**: Provide technical assistance to Grantees to support worker certification program development and implementation.

  (Milestone: Establish technical assistance team; Date: Q4 FY10)

- **Project 6.1.5:** Develop a matrix that describes the national certification baseline and state certifications (state-developed or third-party certification that a particular state uses); the matrix will provide the information needed for a national certification database that allows users to:
  - Compare state certifications to the national baseline;
  - Compare state certifications against each other; and
  - Identify any additional requirements for certification on a state-by-state basis (based on comparisons to the national baseline and comparisons between states), and link those requirements to specific training.

  (Milestone: Publish national certification program database on (or linked to) WAPTAC; Date: Q2 FY11)

Project 6.2: DEVELOP A NATIONAL WEATHERIZATION TRAINING ACCREDITATION AND TRAINER CERTIFICATION PROGRAM.

- **Project 6.2.1:** Identify models and best practices for training program accreditation and trainer certification. Analyze pros and cons of different accreditation and certification processes. Identify potential industry and/or association partners as appropriate.

  (Milestone: Complete training program accreditation and trainer certification analysis and best practices document; Date: Q2 FY10)

- **Project 6.2.2:** Through a collaborative process involving DOE WAP experts and others, as appropriate, develop criteria for (1) training program accreditation (that includes audits to assure quality) and (2) trainer certification and distribute for peer review by related Federal agencies (including the Recovery through Retrofit task force), industry professionals, and state programs.

  (Milestone: Distribute criteria for peer review; Date: Q4 FY10)

- **Project 6.2.3:** Using the analysis completed in Project 5.2.1, establish a process by which weatherization training programs are accredited (and subject to quality control/assurance audits) and weatherization trainers are certified.

  (Milestone: Announce new process; Date: Q1 FY11)

Task 6 Expected Outcomes:

- National weatherization worker certification framework and program in which WAP Grantees must meet DOE-developed criteria
- National database that connects specific state certification requirements to training, allowing for worker mobility via career ladders and lattices
- National weatherization training accreditation and trainer certification programs that increase transparency of the training market and provide quality assurance to workers

Task 7: Provide expert services, technical assistance, and training to directly support the WAP network.

Project 7.1: DELIVER PROGRAM OPERATIONS TRAINING AND TECHNICAL ASSISTANCE. Provide training and technical assistance to Grantee program staff to ensure consistent understanding and implementation of program requirements including performance monitoring, reporting and recordkeeping, contract compliance, health and safety, inspection requirements, policies and procedures, installation standards, and resource documents.

- **Project 7.1.1:** Identify the programmatic and regulatory competencies and skills required to implement weatherization assistance programs.

  (Milestone: Publish competencies document; Date: Q2 FY10)

- **Project 7.1.2:** Inventory programmatic training materials and other resources and make available, as appropriate; example topics include program management and operations, recruiting and managing contractors, monitoring, reporting, regulations, and client education. Efforts must be coordinated with other efforts to develop materials inventories as noted in this plan.

  (Milestone: Publish initial training materials inventory on WAPTAC site; Date: Q2 FY10)

- **Project 7.1.3:** Develop comprehensive manual and best practices guide for training employees in the primary tasks required for managing weatherization programs.

  (Milestone: Publish manual/best practices guide; Date: Q4 FY10)

- **Project 7.1.4:** Provide technical assistance and support to the weatherization network at multiple levels with the integration of Recovery Act requirements including Davis-Bacon provisions, national historic building provisions, monitoring/oversight requirements, etc.

Project 7.2: DELIVER FISCAL/PROCUREMENT TRAINING AND TECHNICAL ASSISTANCE. Provide the information necessary to help WAP Grantees implement their Recovery Act programs using appropriate and/or required financial management and procurement practices

- **Project 7.2.1:** Identify and make available current procurement best practices via DOE, WAPTAC and other relevant websites. Efforts must be coordinated with other efforts to develop materials inventories as noted in this plan.

  (Milestone: Publish initial training materials inventory on WAPTAC site; Date: Q2 FY10)

- **Project 7.2.2:** Create a procurement tool kit to clearly explain Federal procurement requirements and provide best practices for selecting procurement methods, developing solicitations, and managing activities to meet program purchasing needs while complying with Federal regulations.

  (Milestone: Announce availability of procurement toolkit; Date: Q3 FY09)

Project 7.3: PROVIDE TARGETED TECHNICAL ASSISTANCE AND TRAINING. Support the weatherization network by providing targeted technical assistance as needed and through recurring training opportunities at various forums to ensure accurate dissemination of technical information and continual skill development.

- **Project 7.3.1**: Provide and/or support training on a host of topics, including but not limited to health and safety, technical topics, technical training for non-technical staff, monitoring practices for field workers, and integration of baseload measures, at various recurring forums, as appropriate.

- **Project 7.3.2:** Create a T&TA team to assess needs. Provide specialized training and technical assistance targeted to specific regions/states/locales to ensure integration of best practices and support of hiring and training needs. The T&TA team will prioritize target areas and work with Grantees to develop comprehensive T&TA plans that meet their needs. Can include technical assistance related to training center development and operation. Efforts will require strong coordination between the T&TA team, DOE staff, Grantees, and entities involved in Task 3.

  (Milestone: Complete initial outreach and work with new Grantees (e.g., territories) to establish weatherization programs; Date: Q4 FY09)
  (Milestone: Establish technical assistance team; Date: Q2 FY10)
  (Milestone: Complete T&TA needs assessment that includes prioritized target areas; Date: Q2 FY10)

Project 7.4: PROVIDE TARGETED LEVERAGING ASSISTANCE AND TRAINING. Support the weatherization network by providing targeted technical assistance to the Grantee and subgrantee network through developing fee-for-service mechanisms and other leveraging-focused assistance for the purpose of maintaining current funding/production levels for Weatherization Programs.

- **Project 7.4.1**: Provide and/or support training and expert technical assistance to assist agencies in developing the framework necessary to continue providing services. This may include, but is not limited to instruction for developing "fee for service" mechanisms in non-profit agencies, assisting in leveraging activities to secure future investments by non-federal sources, researching synergies between the Weatherization Program and other investment mechanisms, or any other leveraging activity that can sustain the ARRA investment in workers and help sustain the current ARRA level of production.

Task 7 Expected Outcomes:
- WAP programmatic and fiscal/procurement training materials inventory and best practices documents
- Procurement tool kit that clearly explains requirements and best practices
- Expert technical assistance team to assess needs and provide specialized training that can prevent problems before they occur
- Develop mechanisms and leverage resources that will allow the agencies to sustain current funding levels in post-ARRA environment

Task 8: Support WAP Grantee-directed pilots that advance the use of state-of-the-art technologies and protocols.

Project 8.1: ISSUE OPEN CALL FOR PROJECTS. Support pilots that evaluate new technologies and protocols with the potential to be highly cost-effective.

(Milestone: Announce new projects; Date: Q4 FY10)

Project 8.2: EVALUATE AND INCORPORATE PROJECT RESULTS INTO WAP TRAINING AND ACTIVITIES. Manage the WAP System for Reviewing Techniques and Technologies (SIRTT, www.wapsirtt.org) to evaluate project results (achieved through 7.1). Promote results to ensure information is broadly available to the weatherization community and incorporated in curricula, best practices, and other resources, including technology-enabled content delivery tools.

(Milestone: Integrate SIRTT with WAPTAC for broad reach to WAP network; Date: Q2 FY10)

Task 8 Expected Outcomes:
- Evaluation and confirmation of cost-effective weatherization technologies and protocols
- Web site that documents and broadly shares cost-effective technologies and protocols
- Mechanism for helping to ensure WAP procedures remain based on sound and state-of-the-art building science

Task 9: Conduct comprehensive WAP impact and process evaluations.

Conduct national, statistically-valid impact evaluations to assess the energy savings of weatherized households of different types in different regions and the relationship between program procedures, structure, and effectiveness.

Project 9.1: COMPLETE RETROSPECTIVE EVALUATION. Complete study by analyzing utility billing data and program information from 2006-2008.

(Milestone: Publish initial WAP 2006-2008 evaluation report; Date: Q3 FY10, with additional reports periodically through 2012)

Project 9.2: COMPLETE RECOVERY ACT EVALUATION. Design and implement an impact and process evaluation of the WAP for the Recovery Act period including randomized assignment design; include studies of alternative delivery mechanisms, alternative delivery networks, and alternative training systems.

(Milestone: Publish WAP Recovery Act evaluation report; Date: Q3 FY11, with additional reports through 2013)

Task 9 Expected Outcome: National, statistically-valid impact evaluations – (1) for 2006-2008, and (2) for the Recovery Act period – that describe the energy savings of weatherized households of different types in different regions as well as the relationship between program procedures, structure, and effectiveness

Task 10: Develop and deploy an advanced online energy audit tool.

A new online advanced energy audit tool, currently under development at Lawrence Berkeley National Laboratory using non-WAP funds, will be supported by a national database of retrofit measures with their related costs and projected energy savings, and updates to the audit tool will be universal. The new online audit tool will be highly user-friendly and will facilitate rapid reporting of energy audit results.

Project 10.1: PROVIDE ONGOING GRANTEE SUPPORT OF AUDIT PROTOCOLS. Support Grantees in establishing, reviewing, and renewing energy audit protocols to ensure the most cost-effective measures are installed and the procedures in place concur with the state-established standards for installation.

Project 10.2: MAINTAIN FIELD VERSIONS OF NEAT AND MHEA. Continue to support the energy auditing tools currently made available to all Grantees (National Energy Audit Tool and Manufactured Home Energy Audit tool).

Project 10.3: DEVELOP A NEW, ONLINE AUDITING TOOL.

- **Project 10.3.1:** Develop a plan to assist users with the transition to the new online audit tool. Establish a "WAP users group" to ensure WAP network needs are met with the integration to an online tool.

(Milestone: Complete assistance plan; Date: Q1 FY10)

- **Project 10.3.2:** Conduct multiple pilot testing phases with WAP auditors and use their feedback to improve the audit tool usability and functionality. (Note: Using non-WAP funds, DOE will also improve the audit tool based on pilot testing with home inspectors.)

  (Milestone: Conduct standard audit review outlined in Weatherization Program Notice 01-4 to ensure new tool meets current WAP requirements; Date: Q1 FY10)
  (Milestone: Initiate first phase of pilot testing with a small pool of users; Date: Q1 FY10)
  (Milestone: Initiate second phase of pilot testing with a larger pool of users; Date: Q1 FY10)

- **Project 10.3.3:** Incorporate health and safety inputs (such as fire detectors and CO detectors) into the online audit tool.

  (Milestone: Incorporate health and safety inputs into online audit tool; Date: Q1 FY10)

- **Project 10.3.4**: Announce launch of new, online auditing tool and provide technical assistance to WAP network to support its use.

  (Milestone: Host initial webinar series on new, online audit tool use; Date: Q2 FY10)

- **Project 10.3.5:** Expand the functionality of the online audit tool to perform audits for small multifamily units and large multifamily units.

  (Milestone: Complete development of small multifamily and large multifamily audit functionality; Date: Q4 FY10)

Task 10 Expected Outcomes:
- An advanced, user-friendly, online auditing tool that supports a national database of retrofit measures with related costs and projected energy savings
- Increased availability and accessibility of WAP data and energy audit results

Task 11: Develop and implement a National Online Weatherization Management Information System.

The National Online Weatherization Management Information System will be a web-based program management system built using the existing PAGE system as a core component, to capture information from all WAP Grantees to increase the efficiency and ease of reporting from local agencies to Grantees and to DOE. The system will cover most WAP work areas, from Grantee and financial auditors to program and inventory managers, and from technical inspectors to field staff.

Project 11.1: DEFINE SCOPE OF NATIONAL ONLINE WEATHERIZATION MANAGEMENT INFORMATION SYSTEM. Draft a scoping document to address the system architecture, design, and policies, as well as integration into DOE, Grantee, and

subgrantee operations. The document, to be developed with significant input from WAP Grantees, will address integration of existing DOE and Grantee tools and resources. It will also define user groups, user tasks, user policies, messaging standards, reporting standards, and other relevant standards, specifications, and policies.

(Milestone: Complete scoping document that also defines user groups, tasks, and standards; Date: Q2 FY10)

Project 11.2: DEVELOP NATIONAL ONLINE WEATHERIZATION MANAGEMENT INFORMATION SYSTEM. Build the components needed to address the requirements for the National Online Weatherization Information System users and tasks, as defined in Project 10.1. For example, this may include building support tools and functionality to allow for the integration of third-party tools, plug-ins, and modifications. And, based on the outcomes of Project 10.1, this may include creation of a component to support information management between Grantees and sub-grantees. Perform quality assurance and stress testing, and work with Grantees, and potentially, subgrantees to pilot the system.

(Milestone: Complete first version of project management and user management system; Date: Q3 FY10)

Project 11.3: DEPLOY NATIONAL ONLINE WEATHERIZATION MANAGEMENT INFORMATION SYSTEM. In stages, roll out the portal to all Grantees. Provide training and technical assistance to Grantees for the adoption and use of the management portal.

(Milestone: Establish training and technical assistance mechanism; Date: Q3 FY10)
(Milestone: Issue program notice with new guidance on the system and reporting requirements, and begin system roll out to Grantees; Date: Q3 FY10)

Task 11 Expected Outcomes:

- A web-based program management system that covers most WAP work areas, from Grantee and financial auditors to program and inventory managers, and from technical inspectors to field staff
- Increased efficiency and ease of reporting across the WAP network

Task 12: Provide for other services required during WAP Recovery Act implementation.

Project 12.1: SUPPORT DATA ACCEPTANCE, ANALYSIS, AND RECONCILIATION. Verify, update, and reconcile the data received from field to ensure the data integrity.

Project 12.2: ENSURE QUICK RESPONSE RESEARCH/ANALYSIS ON "HOT TOPICS." Provide immediate response to questions that may include development of white papers and convening working groups, as needed, to discuss topics and provide DOE critical information.

Project 12.3: FACILITATE PROGRAM IMPLEMENTATION AND FUNCTION. Plan and facilitate conference calls, small working groups, and committees, specifically supporting ad hoc and staffing special quick response projects that include collaboration among DOE headquarters and field personnel, outside agencies, state/local stakeholders, associations, etc.

Task 12 Expected Outcomes:

- Well-coordinated, seamless program operation
- Rapid response capability

Appendix 1: Training Methodologies (in alphabetical order)

Types	Advantages	Disadvantages	Student-Teacher Ratio
Conferences: Typically held in large meeting spaces. Primary training delivered lecture-style but can include some demonstration and/or hands-on training, as well as "crew competitions."[1, 2]	• Classrooms can accommodate large numbers of trainees; • Cost per trainee can be low; • Opportunity for trainees to meet with experts and exchange with peers; • Can offer many different training topics simultaneously; • Participants are exposed to new ideas; and • Controlled environment minimizes disruptions and distractions.	• A less effective way to teach mechanical and hands-on skills; • Challenge to engage all participants, particularly those used to field work; • Time constraints limit depth and detail of training; and • May only serve to expose trainees to a topic rather than provide competency levels or test-out opportunities.	Class size should be kept below **20 trainees per trainer**.
Field Training: Typically conducted on an eligible home to demonstrate skills or follow protocols in a real world environment. Trainers must choose a house that represents the typical housing stock on which trainees will work. Homes that provide good training opportunities have a gas or propane furnace to allow for combustion appliance safety testing; homes with forced-air heating systems allow training on duct leakage testing and duct sealing.[3]	• Training takes place on WAP-eligible home, using actual equipment and techniques; • Some production is accomplished as a result of training; • Trainees usually travel short distances from surrounding communities; • Hands-on experience is most effective for learning and retaining skills; • Trainees can practice client education with real clients; and • Can be combined with local or regional classroom training.	• If local agency equipment is used, training may be compromised by inadequate or poorly-maintained equipment; • Significant planning is required to select and prepare a good training house; • May try to demonstrate too much; • Trainers may become crew members to complete work in time; • Class size is very limited; and • Unforeseen problems (e.g., structural, human, weather) may disrupt training.	• Activities outside the home: **8 to 1** • Activities inside the home: **5 to 1,** depending on activity and house layout

[1] In crew competitions, participants demonstrate their competency in a specific skill. Standardized tests include props. Judges score participants on predetermined assessments of important skills or knowledge.

[2] Typical training topics include introduction to energy conservation principles; fundamentals of air exchange, air barriers, air sealing, and ventilation; basic auditor training and/or audit protocol introduction; overviews of energy-saving measures for building components or service delivery; health and safety overview including carbon monoxide and lead based paint policies; client education methods and examples; and administrative topics for overall program management.

[3] Topics well-suited to field training include sidewall insulation; air sealing; attic insulation; blower door and pressure diagnostics; duct testing, repair, and sealing; mobile home weatherization techniques; carbon monoxide testing; combustion appliance safety testing; and mechanical ventilation.

Types	Advantages	Disadvantages	Student-Teacher Ratio
Hiring Outside Trainers: States without full-time training staff may hire outside trainers to provide skills enhancement. Considerations include – • Trainers must possess adequate skills (e.g., Can they conduct a training needs analysis? Can they effectively present and relate to adult learners?); • Trainers must be familiar with state policies to ensure consistency of message; and • Hiring agency and trainer must agree to the agenda, course outline, facility expectations, access to materials after the training (including for new employees), and trainee follow up.	• Curricula are already developed; • Outside trainers can bring new ideas, concepts, and techniques that can benefit the program; and • Can enhance local staff acceptance of new procedures.	• Can be costly; • Can be a one-time effort with no follow-up or support; and • Consultants can create confusion by conducting training that conflicts with current standards or approaches.	• Classroom: **20 to 1** • Hands-on training (props): **6 to 1** • Activities outside the home: **8 to 1** • Activities inside the home: **5 to 1** depending on activity and house layout
Mobile Training Unit: Trainers use props, equipment, tools, and materials. Can be combined with field training at a home being weatherized. Like field training, a mobile training unit can support classroom training if adequate meeting space is available nearby.	• Trainers arrive with adequately-sized, properly-maintained equipment; • Trainers can have new or unusual materials in stock; • Training can take place on actual WAP-eligible homes, using actual equipment and techniques; • Some production can be accomplished as a result of training; • Trainees usually travel short distances; • Hands-on experience is effective for learning and retaining skills; • Trainees can practice client education with real clients; and • Can be combined with local or regional classroom training.	• Constant travel can lead to trainer burnout; • Requires planning to select and prepare a training house; • Class size very limited; • Cost of vehicles and equipment can be significant; • Temptation to completely weatherize house during training; • Trainers may supplant crew members to finish work on time; • Mobile training unit must be cleaned, reorganized, and restocked after every training; • May still require a home and a meeting room; and • Unforeseen problems (e.g., structural, human, weather) may disrupt training.	• Activities outside the home: **8 to 1** • Activities inside the home: **5 to 1** depending on activity and house layout • Classroom: **20 to 1**

Types	Advantages	Disadvantages	Student-Teacher Ratio
Mobile Training Unit (Single Purpose): A self-sufficient unit that concentrates on a single topic or skill.	• Trainers arrive with properly-maintained equipment; • Trainer is familiar with equipment so there are fewer surprises and disruptions; • Trainees usually travel shorter distances since training comes to them; • Offers hands-on learning opportunities without an actual house; and • Can be combined with local or regional classroom training.	• Constant travel can lead to trainer burnout; • Cost of vehicle and equipment can be significant; • Does not require the identification and preparation of a training house; • Variety of training opportunities is limited; and • May still require a meeting room.	• Heating labs: **6 to 1** • Classroom: **20 to 1**
Online Training and Distance Learning: Similar to lecture-style classroom training but available via the web or at video conferencing facilities. Distance learning classes can be hour-long overviews of a single topic or months-long to cover topics in depth.	• Aside from bandwidth, there is no limitation on class size; • No travel required; most communities have access to a video conferencing facility; • Content and instruction can be consistent across country; • Trainees may be able to repeat content until mastered; and • Can be used as an introduction to allow hands-on training to start at a higher level.	• No hands-on component; and • Online training often requires a broadband connection.	Classroom size limited only by bandwidth.
Peer Training: Expert staff from within the agency or from another local agency typically provide peer training. Field training is the typical delivery mechanism. In some cases, the peer trainer comes to the local agency to work on its housing stock; in others, the local agency crew will travel to the peer trainer's location to see how an experienced crew implements a particular measure or technique.[4]	• Trainees may be more comfortable with their peers and accept training more readily; • Training takes place on actual WAP-eligible homes, using actual equipment and techniques; • Some production is accomplished as a result of training; • Usually does not require trainees to travel; and • Hands-on experience is most effective for learning and retaining skills.	• Frequent travel by trainers can lead to burnout; • If local agency equipment is used, training can be compromised by inadequate or poorly maintained equipment; • Class size very limited; and • Unforeseen problems (e.g., structural, human, weather) may disrupt training.	• Activities outside the home: **8 to 1** • Activities inside the home: **5 to 1** depending on activity and house layout

Types	Advantages	Disadvantages	Student-Teacher Ratio
Technical Fairs: Focus on hands-on activities rather than classroom, lecture-style sessions. Trainees learn specific skills using materials, tools, and equipment common in field applications. Some rely solely on demonstrations; others feature "crew competitions" as an added component.[1]	• Great opportunity for peer exchange; • Hands-on activities reinforce classroom learning; • Competition creates interest in improving techniques and skills; and • Feedback between judges and competitors is high-value training.	• Logistics of building large numbers of props can be a challenge; • Cost of building props can be significant; • Judging each event requires knowledgeable staff, clear criteria, and time; and • Inconsistent acceptance of results can be a disincentive for some crewmembers.	Ideally set at **10 – 15 to 1**
Training Centers: Typically have classroom/laboratory space that allows for the long-term set-up of training aids and props. Also can include labs for shell and mechanical retrofits, computer application, and health and safety protocols, which allow for a mix of lecture-style workshops and hands-on training in a controlled environment.[4]	• Allows for standardized learning environment; • Standardization makes a certification program easier to implement; • Hands-on training is more effective for retaining skills; • Can increase trainee-to-trainer ratio over field training; • Can be cost-effective when a large number of participants need on-going training; and • Required attendance is easier to enforce.	• Cost to establish and maintain can be significant; and • Single location may not be convenient for all trainees and may require travel within the state or region.	• Heating labs: **6 to 1** • Computer labs: **15 to 1** • Classroom: **20 to 1** • Hands-on training (props): **6 to 1**

[4] Training topics well-suited to training center curricula include installation skills training in insulation techniques, air sealing, and duct sealing and insulation; heating system inspection, installation, and repair; combustion appliance safety testing; computerized energy audit; blower door set-up and use; pressure pan, manometer, infrared camera, and other diagnostic equipment; base-load metering; lead-safe weatherization work practices; electrical safety; and equipment maintenance and safety.

Weatherization Works

CORE COMPETENCIES FOR THE WEATHERIZATION ASSISTANCE PROGRAM

DEVELOPED BY:

THE WEATHERIZATION TRAINERS CONSORTIUM

FOR:

U.S. DEPARTMENT OF ENERGY
WEATHERIZATION ASSISTANCE PROGRAM

CREATED: MARCH 26, 2007
UPDATED: DECEMBER 2, 2009

OVERVIEW

The Weatherization Trainers Consortium developed this document for the U.S. Department of Energy's (DOE's) Weatherization Assistance Program for Low-Income Persons. The Weatherization Trainers Consortium represents weatherization training centers, independent trainers, state program managers, and state monitors from across the country.

The Weatherization *Plus* Committee is a group the weatherization stakeholders charged with helping DOE to strategically plan the evolution of the Weatherization Assistance Program. A Weatherization Plus subcommittee organized a conference call among a group of weatherization trainers to obtain their input on a Weatherization *Plus* initiative to ensure the consistent delivery of high-quality weatherization services nationwide. The trainers saw the benefit of regular communication to network and share training resources. An initial face-to-face meeting of weatherization trainers was organized at the 2005 National Weatherization Technical Training Conference in Atlanta, Georgia, and monthly conference calls have been conducted ever since.

From these conversations, the Weatherization Trainers Consortium was formalized and the need identified for a set of core competencies for the various staff positions that implement the Weatherization Program. The Consortium believes this working document can:

- Increase awareness of the specialized skills and knowledge that are required to run an effective weatherization program;
- Help state and local weatherization agencies hire staff with a strong potential to perform well and prosper in the program;
- Serve as a foundation in establishing standardized curricula to ensure the consistent delivery of high-quality weatherization services nationwide; and
- Put upward pressure on salaries to reduce staff turnover.

As a working document, suggestions for improvement are continually sought. Please forward suggestions to:

Kelly Cutchin
SMS
1 Research Court
Rockville, MD 20850
(301) 299-2977
kcutchin@sms-results.com

CORE COMPETENCIES FOR THE WEATHERIZATION ASSISTANCE PROGRAM

INTRODUCTION

Specialized knowledge and skills are required at the local, state, and federal level to run an effective Weatherization Program. While there is a general understanding of the competencies required, these have not been articulated on a national scale.

As part of the Weatherization *Plus* effort to plan the continued evolution of the Weatherization Program, a subcommittee was formed to increase the consistency of quality weatherization services delivered to low-income homes across the country. The goal is that every house that is weatherized receives all appropriate, cost-effective measures installed properly to provide long-term savings.

As a first step, this means recognizing the varying approaches states use to train staff.

- Some states require technical staff at local agencies to obtain certification from an organization such as the Building Performance Institute, while other states have developed their own certification criteria.
- Many states do not have formal certification requirements, but instead require local weatherization staff to attend standardized training courses offered on a regular basis.
- Others have no standardized certification or training requirements, but offer training periodically as the need is perceived and funds allow.

Technical weatherization training for auditors, technicians, and monitors is available from many training centers and independent trainers across the country. Only a few states have developed administrative training for weatherization program managers at the local level. In-depth administrative training for state weatherization staff is even harder to find outside National Association for State Community Services Programs (NASCSP) conference "newcomer" sessions.

The Weatherization *Plus* subcommittee and the Weatherization Trainers Consortium believe that publishing a set of core competencies will increase awareness and raise expectations. Not all the competencies will be appropriate for every state. Workers repairing or replacing heating and cooling systems often require certification or licensing from the state. Therefore, this work may be subcontracted to licensed contractors outside the Weatherization Program. However, just because a heating, ventilation, and air conditioning (HVAC) contractor is licensed by the state does not mean they possess the HVAC competencies required by the Weatherization Program. Someone at the local agency must be competent to specify what work the contractor is to do and to verify that the completed work complies with state and local codes as well as the technical standards of the Weatherization Program.

The competencies that a weatherization worker should possess depend on their position. For example, an auditor needs to conduct diagnostic testing that may not be required of an installer. The point of entry also dictates which core competencies are required. An

entry-level installer requires a minimum set of competencies. This installer must acquire additional skills to become a crew chief, and still more to become an auditor. A new auditor hired off the street must already possess auditor-level competencies as a condition of hire. These increasing levels of competency also provide a career or development path for agency and contractor personnel.

The following core competencies were compiled from course offerings of several weatherization training centers and from the technical program standards of a handful of states. Core competencies for the following topical areas are listed:

- Basic competencies,
- Safe work practices,
- Building evaluation,
- Measure installation,
- Final inspection,
- Consumer education,
- Monitoring,
- Program management, and
- Training.

Definitions

- ***Competency*** means the possession of a minimum level of knowledge and proficiency required to collect appropriate information, make informed decisions, and physically take the needed actions to deliver the high-quality weatherization service in question.
- ***Possess a working knowledge of*** means to:
  - Know how a particular topic impacts the weatherization process;
  - Have the relevant information committed to memory or be able to locate it in readily available sources; and
  - Use the knowledge to make informed decisions and guide weatherization work.
- ***Demonstrate the ability to*** means to:
  - Physically conduct a test, procedure, or technique on an actual house, a prop, or in a training lab in the presence of someone qualified to assess the particular competency.

BASIC COMPETENCIES

All weatherization workers must possess the following Basic Competencies:

- Ability to read and write legibly;
- Basic verbal and written communication skills;
- Basic construction knowledge;
- Basic math skills (see appendix for a test to verify basic math skills); and
- Basic computer skills (see appendix for a test to verify basic computer skills).

Depending on the position of the weatherization worker, the following Core Competencies help ensure the delivery of effective weatherization services.

SAFE WORK PRACTICES

All field workers must exhibit safe work practices by possess the following competencies.

- Possess a working knowledge of:
  - U.S. Department of Energy (DOE) program regulations/policy and Environmental Protection Agency (EPA) guidelines for asbestos, lead, mold, and other health hazards;
  - Material Safety Data Sheets; and
  - Occupational Safety and Health Act (OSHA) standards:
    - Ladder safety;
    - Fall protection;
    - Personal protective equipment;
    - Respiratory protection;
    - Motor vehicles;
    - Power-operated hand tools;
    - Fire prevention;
    - Permit-required confined spaces;
    - Other worker-related OSHA standards.
- Demonstrate the ability to:
  - Select, fit, and use the appropriate Personal Protection Equipment for a particular task;
  - Safely use basic hand and power tools;
  - Use a basic first aid kit to treat common job-site injuries;
  - Work lead safe;
  - Identify serious mold conditions; and
  - Assess work area safety hazards.

INSTALLER

The following competencies are required by workers that install weatherization measures.

- ***Prerequisites***
  - Possess *Safe Work Practices* competencies
- ***Air Sealing***
  - Possess a working knowledge of:
    - Proper materials selection based on location of leakage areas
    - Minimum ventilation rates.
  - Demonstrate the ability to:
    - Use the blower door to locate leakage sites within the building
    - Seal attic and floor bypasses at penetrations for plumbing, electrical wiring, flue vents, ducts; dropped soffits, and balloon-framed walls;
    - Seal typical bypasses in kneewalls and finished attic spaces;
    - Seal basement band joists;
    - Properly apply caulk and spray foam insulation;

- Identify, select, and install weatherstripping on doors, windows, and attic hatches;
- Cut glass, replace broken window panes, and apply glazing compound;
- Repair plaster and sheetrock (drywall); and
- Modify or install mechanical ventilation to ensure acceptable indoor air quality for post-air-sealing conditions.

- ***Duct Sealing***
  - Demonstrate the ability to:
    - Properly seal duct connections with mastic and fiberglass mesh tape or other approved material; and
    - Repair or modify duct systems as specified in a work order.
- ***Insulation***
  - Possess a working knowledge of:
    - Properties and appropriate application of different insulation materials; and
    - Potential hazards of insulating around knob-and-tube wiring.
  - Demonstrate the ability to:
    - Install blown and batt attic insulation;
    - Access closed wall cavities and properly install dense-packed wall insulation including removing and replacing siding;
    - Install blown insulation and batt insulation in a floor;
    - Install water heater insulation blankets;
    - Install insulation on ducts, hydronic distribution pipes, and domestic hot water pipes; and
    - Safely operate and properly maintain insulation blowing machines and generators.
- ***Base-Load Measures***
  - Demonstrate the ability to:
    - Replace incandescent light bulbs with compact fluorescent lamps while maintaining or improving lighting levels; and
    - Install low-flow showerheads and faucet aerators;
      - Assess the existing condition of plumbing pipes and faucets that may prohibit these measures.

CREW CHIEF

Personnel that supervise field workers such as *Installers* must possess the following competencies.

- ***Prerequisites***
  - Possess *Safe Work Practices* and *Installer* competencies.
  - Possess a working knowledge of building science principles.
- ***Project Management***
  - Demonstrate the ability to:
    - Manage a crew of *Installers* so weatherization work is conducted safely, effectively, and efficiently;
    - Ensure that the job site and *Installers* comply with the *Safe Work Practices* described previously;

- Maintain quality control of weatherization work and ensure it meets program standards;
- Understand a work order;
- Order and obtain materials, supplies, and equipment in time to avoid delays and wasted time on the job site; and
- Warehouse materials as necessary to avoid delays in completing weatherization work.

- ***Inspection and Measurement***
  - Possess a working knowledge of:
    - Air and heat flow in buildings;
    - Factors that affect building heat loss;
    - Construction features and critical junction points of common housing types;
    - Insulation R-values;
    - Different insulation materials and installation techniques;
    - Various air-sealing techniques and appropriate materials;
    - Causes of and remedies for existing and potential moisture problems;
    - Causes of and remedies for other existing and potential indoor air quality problems;
    - Residential mechanical ventilation systems;
    - Minimum ventilation rates/building tightness limits based on the appropriate ASHRAE 62 standard; and
    - Electric base-load usage.
  - Demonstrate the ability to:
    - Measure the dimensions of floors, walls, ceilings, windows, and doors, and compute surface areas;
    - Compute the volume of conditioned space of a building;
    - Define the thermal envelope of a building; and
    - Assess the effectiveness of existing insulation and the effective R-values.
- ***Diagnostic Testing***
  - Blower door
    - Possess a working knowledge of:
      - Principles of air movement and how they relate to building heat loss;
      - Typical air leakage problems in common housing types; and
      - Minimum ventilation rates.
    - Demonstrate the ability to:
      - Set up a blower door;
      - Prepare a building for a blower door test; and
      - Take blower door reading and interpret results.
  - Zone pressure diagnostics
    - Possess a working knowledge of:
      - The air barrier of a building and the importance of aligning it with the thermal barrier; and
      - Primary and intermediate zones of a house.
    - Demonstrate the ability to:
      - Conduct zone pressure diagnostics and interpret results; and
      - Determine the location and effectiveness of the air barrier of a house.

- Duct testing
  - Possess a working knowledge of:
    - Problems associated with different types of duct leakage.
  - Demonstrate the ability to:
    - Determine dominant duct leakage;
    - Determine the amount of duct leakage or at least the existence of significant duct leakage by conducting pressure pan, duct blaster, or delta Q tests.
    - Measure room pressure imbalances in houses with forced-air systems.
    - Resolve room pressure imbalances.

- ***Combustion Appliance Safety***
  - Possess a working knowledge of:
    - CO action levels;
    - Common code requirements related to:
      - Vent system sizing, materials, clearances, and installation;
      - Safety shut-off devices;
      - Gas line sizing; and
      - Combustion air;
    - Causes of and remedies to common vent system problems.
  - Demonstrate the ability to:
    - Measure the CO level in ambient air;
    - Measure the CO level of vented and unvented combustion appliances;
    - Measure the CO levels of gas- or propane-fired cook stoves (oven and burners) and remedy high CO levels through basic cleaning and adjustments;
    - Understand the difference between as-measured and air-free CO readings;
    - Detect gas, propane, and fuel oil leaks; and
    - Conduct a worst-case draft test of a combustion appliance zone; and
    - Measure the steady-state efficiency of a vented combustion appliance.

- ***Insulation***
  - In addition to the insulation-related *Installer* competencies, possess a working knowledge of:
    - Local codes relating to attic ventilation.

- ***Training***
  - Possess a working knowledge of:
    - Adult learning concepts; and
    - Benefits of cross training on-site personnel.
  - Demonstrate the ability to:
    - Provide on-site training to *Installers* in a positive environment to strengthen competency in existing skills and increase the number of skill areas.

AUDITOR

- ***Prerequisites***
  - Possess *Safe Work Practices, Installer,* and *Crew Chief* competencies.
  - Possess a working knowledge of building science principles.
- ***Inspection and Measurement***
  - Possess a working knowledge of:
    - Air and heat flow in buildings;
    - Factors that affect building heat loss;
    - Construction features and critical junction points of common housing types;
    - Insulation R-values;
    - Different insulation materials and installation techniques;
    - Various air-sealing techniques and appropriate materials;
    - Causes of and remedies for existing and potential moisture problems;
    - Causes of and remedies for other existing and potential indoor air quality problems;
    - Residential mechanical ventilation systems;
    - Minimum ventilation rates/building tightness limits based on the appropriate ASHRAE 62 standard; and
    - Electric base-load usage.
  - Demonstrate the ability to:
    - Measure the dimensions of floors, walls, ceilings, windows, and doors, and compute surface areas;
    - Compute the volume of conditioned space of a building;
    - Define the thermal envelope of a building;
    - Assess the effectiveness of existing insulation and the effective R-values; and
    - Analyze utility bills including breaking out base-load usage from heating and cooling usage.
- ***Diagnostic Testing***
  - Blower door
    - Possess a working knowledge of:
      - Principles of air movement and how they relate to building heat loss;
      - Typical air leakage problems in common housing types; and
      - Minimum ventilation rates.
    - Demonstrate the ability to:
      - Set up a blower door;
      - Prepare a building for a blower door test; and
      - Take blower door reading and interpret results.
  - Zone pressure diagnostics
    - Possess a working knowledge of:
      - The air barrier of a building and the importance of aligning it with the thermal barrier; and
      - Primary and intermediate zones of a house.
    - Demonstrate the ability to:
      - Conduct zone pressure diagnostics and interpret results;
      - Determine the location and effectiveness of the air barrier of a house; and
  - Duct testing

- Possess a working knowledge of:
  - Problems associated with different types of duct leakage.
- Demonstrate the ability to:
  - Determine dominant duct leakage; and
  - Conduct pressure tests. Potential tests include:
    - Pressure pan
    - Duct Blaster
    - Delta-Q
  - Seal duct leaks with appropriate materials and good workmanship.
  - Measure room pressure imbalances in houses with forced-air systems.

- Steam and hot water distribution system testing
  - Possess a working knowledge of:
    - The components of typical steam and hot water distribution systems and the characteristics of their proper operation.
  - Demonstrate the ability to:
    - Test air vents, steam traps, thermostatic radiator valves, and hot water zone valves; and
    - Estimate the energy impacts of existing overheating problems.
- Base-load systems
  - Demonstrate the ability to:
    - Meter electrical devices to determine their annual energy consumption.

- ***Combustion Appliance Safety***
  - Possess a working knowledge of:
    - CO action levels;
    - Common code requirements related to:
      - Vent system sizing, materials, clearances, and installation;
      - Safety shut-off devices;
      - Gas line sizing; and
      - Combustion air;
    - Causes of and remedies to common vent system problems.
  - Demonstrate the ability to:
    - Measure the CO level in ambient air;
    - Measure the CO level of vented and unvented combustion appliances;
    - Measure the CO levels of gas- or propane-fired cook stoves (oven and burners);
    - Understand the difference between as-measured and air-free CO readings;
    - Detect and natural gas, propane, and fuel oil leaks;
    - Conduct a worst-case draft test of a combustion appliance zone;
    - Measure the CAZ to assure sufficient volume for combustion air;
    - Clock a gas meter to determine the actual input of a gas-fired combustion appliance;
    - Conduct basic temperature-rise and static-pressure-drop tests on forced-air furnaces;
    - Measure the steady-state efficiency of a vented combustion appliance; and
    - Assess the potential inadequacy of supply and return plenum and duct sizes for forced-air systems.

- ***Measure Selection***
  - Possess a working knowledge of:
    - What materials are allowed to be installed based on 10 CFR 440 Appendix A;
    - The regulatory and policy requirements for selecting weatherization measures using DOE-approved energy audit software or priority lists; and
    - The interaction between typical weatherization measures (e.g., the impact of air-sealing and insulation measures on the potential savings of heating efficiency improvements).
  - Demonstrate the ability to:
    - Use a DOE-approved energy audit to input accurate building data and recommend appropriate, cost-effective weatherization measures;
    - If required, use a DOE-approved priority list to select appropriate, cost-effective weatherization measures;
    - Prioritize air-sealing efforts;
    - Estimate the heating and/or cooling load of a dwelling to ensure proper equipment sizing if the heating or cooling system is to be replaced;
    - Select the proper CFL to replace an incandescent lamp while maintaining or improving lighting levels; and
    - Meter an existing refrigerator or locate its DOE tested usage in a database to estimate annual energy consumption.
- ***Work Scope Development***
  - Demonstrate the ability to:
    - Accurately estimate the type and quantity of materials required to cost-effectively weatherize an eligible dwelling unit; and
    - Prepare clearly written work orders for work crews or contractors.

CONTRACTOR

Contractors hired by local weatherization agencies to perform weatherization work must possess the following competencies. See *HVAC Installer/Contractor* for the competencies required of these specialty contractors.

- ***Prerequisites***
  - Possess *Safe Work Practices, Installer, and Crew Chief* competencies.
  - Possess a working knowledge of building science principles.
- ***Business Management***
  - Demonstrate the ability to:
    - Maintain the licenses required by the state and local jurisdiction for the type of work the *Contractor* is hired to perform;
    - Possess adequate insurance;
    - Employ U.S. citizens or properly documented aliens; and
    - Bid, negotiate, and sign contracts, as necessary.

- ***Project Management***
  - Demonstrate the ability to:
    - Manage a crew of *Contractor*-employed *Installers* so weatherization work is conducted safely, effectively, and efficiently;
    - Ensure that the job site and *Contractor*-employed *Installers* comply with the *Safe Work Practices* described previously;
    - Understand a work order;
    - Maintain quality control of weatherization work and ensure it meets program standards;
    - Order and obtain materials, supplies, and equipment in time to avoid delays and wasted time on the job site; and
    - Warehouse materials as necessary to avoid delays in completing weatherization work.

Depending on the type of work the *Contractor* is hired to perform, the following inspection, diagnostic testing, combustion appliance safety, and/or insulation competencies may be required.

- ***Inspection and Measurement***
  - Possess a working knowledge of:
    - Air and heat flow in buildings;
    - Factors that affect building heat loss;
    - Construction features and critical junction points of common housing types;
    - Insulation R-values;
    - Different insulation materials and installation techniques;
    - Various air-sealing techniques and appropriate materials;
    - Causes of and remedies for existing and potential moisture problems;
    - Causes of and remedies for other existing and potential indoor air quality problems;
    - Residential mechanical ventilation systems;
    - Minimum ventilation rates/building tightness limits based on the appropriate ASHRAE 62 standard; and
    - Electric base-load usage.
  - Demonstrate the ability to:
    - Measure the dimensions of floors, walls, ceilings, windows, and doors, and compute surface areas;
    - Compute the volume of conditioned space of a building;
    - Define the thermal envelope of a building; and
    - Assess the effectiveness of existing insulation and the effective R-values.
- ***Diagnostic Testing***
  - Blower door
    - Possess a working knowledge of:
      - Principles of air movement and how they relate to building heat loss;
      - Typical air leakage problems in common housing types; and
      - Minimum ventilation rates.
    - Demonstrate the ability to:
      - Set up a blower door;
      - Prepare a building for a blower door test; and

        - Take blower door reading and interpret results.
    - Zone pressure diagnostics
        - Possess a working knowledge of:
            - The air barrier of a building and the importance of aligning it with the thermal barrier; and
            - Primary and intermediate zones of a house.
        - Demonstrate the ability to:
            - Conduct zone pressure diagnostics and interpret results; and
            - Determine the location and effectiveness of the air barrier of a house.
    - Duct testing
        - Possess a working knowledge of:
            - Problems associated with different types of duct leakage.
        - Demonstrate the ability to:
            - Determine dominant duct leakage;
            - Determine the amount of duct leakage or least the existence of significant duct leakage by conducting pressure pan, duct blaster, or delta Q tests;
            - Measure room pressure imbalances in houses with forced-air systems; and
            - Resolve room pressure imbalances.
- ***Combustion Appliance Safety***
    - Possess a working knowledge of:
        - CO action levels;
        - Common code requirements related to:
            - Vent system sizing, materials, clearances, and installation;
            - Safety shut-off devices;
            - Gas line sizing; and
            - Combustion air;
        - Causes of and remedies to common vent system problems.
    - Demonstrate the ability to:
        - Measure the CO level in ambient air;
        - Measure the CO level of vented and unvented combustion appliances;
        - Measure the CO levels of gas- or propane-fired cook stoves (oven and burners) and remedy high CO levels through basic cleaning and adjustments;
        - Understand the difference between as-measured and air-free CO readings;
        - Detect gas, propane, and fuel oil leaks; and
        - Conduct a worst-case draft test of a combustion appliance zone; and
        - Measure the steady-state efficiency of a vented combustion appliance.
- ***Insulation***
    - In addition to the insulation-related *Installer* competencies, possess a working knowledge of:
        - Local codes relating to attic ventilation.

HEATING, VENTILATION, AND AIR CONDITIONING (HVAC) INSTALLER/CONTRACTOR

- ***Heating and Cooling Equipment***
  - Prerequisites:
    - Possess *Auditor/Combustion Appliance Safety* and *Safe Work Practices* competencies; and
    - Possess the HVAC certifications and licenses required by the state and local jurisdiction.
  - Possess a working knowledge of:
    - The components of typical steam and hot water distribution systems and the characteristics of their proper operation.
  - Demonstrate the ability to:
    - Maintain quality control of weatherization work and ensure it meets program standards;
    - Repair or replace heating and cooling equipment in a code-compliant manner;
    - Estimate the heating and/or cooling load of a dwelling per Manual J to ensure proper sizing of replacement heating or cooling systems;
    - Repair or replace vent systems of combustion appliances in a code-compliant manner;
    - Repair or replace a water heater in a code-compliant manner (some states may require a licensed plumber to replace a water heater);
    - Ensure proper sizing of gas lines;
    - Assess the adequacy of supply and return plenum and duct sizes for forced-air systems;
    - Add return and supply plenums and ducts as required;
    - Determine dominate duct leakage;
    - Conduct duct pressure tests, which could include:
      - Pressure pan;
      - Duct Blaster; and
      - Delta-Q;
    - Measure and solve room pressure imbalances is houses with forced-air systems;
    - Test air vents, steam traps, thermostatic radiator valves, and hot water zone valves;
    - Bleed unwanted air from a hot water distribution system;
    - Estimate the energy impacts of existing overheating problems in steam and hot water heating systems;
    - Warehouse materials as necessary to avoid delays in completing weatherization work; and
    - Test out to assure system is operating properly and safely.

INSPECTOR

- Prerequisites:
  - Inspectors should possess *Safe Work Practices, Installer*, and *Auditor* competencies.
- Possess a working knowledge of:
  - Relevant DOE Weatherization Program regulations and policy;
  - Building science principles; and
  - Relevant local codes.
- Demonstrate the ability to:
  - Verify that the weatherized house is safe by conducting all appropriate combustion appliance safety tests;
  - Evaluate the allowability and appropriateness of the installed weatherization measures taking into consideration program regulations, policy, energy audit results, and/or priority lists;
  - Assess whether the measures were installed with good workmanship, proper materials, and in such a manner to comply with local code and ensure long-term energy savings over the life of the measures;
  - Ensure that all measures charged to the job were actually installed; and
  - Verify the effectiveness of air-sealing efforts by conducting a blower door test and zone pressure diagnostics.

CONSUMER EDUCATION

- Competency
  - Principles of adult education
- Possess a working knowledge of:
  - What actions can be taken to reduce energy use in the home;
  - The basic steps in the Weatherization process from auditing, testing, installation, inspection, and monitoring;
  - The purpose of the basic equipment involved in weatherizing a house, including a blower door, pressure pan, combustion analyzer, gas leak detector, insulation blowing machine, and generator; and
  - What actions need to be taken to maintain a healthful indoor environment.
- Demonstrate the ability to:
  - Estimate the economic impacts of suggested actions to bolster customer commitment to change.

MONITOR (TECHNICAL)

- Prerequisites:
  - Monitors should possess all *Safe Work Practices*, *Auditor*, and *Inspector* competencies.
  - Monitors should be knowledgeable of *Installer* competencies.
- Possess a working knowledge of:
  - Principles of building science; and
  - Principles of adult education.
- Demonstrate the ability to:
  - Produce written reports that clearly identify weaknesses and provide sound solutions;
  - Provide on-site training and technical assistance; and
  - Solve complex technical problems.

MONITOR (ADMINISTRATIVE)

- Possess a working knowledge of:
  - Principles of adult education;
  - Enabling legislation governing the U.S. Department of Energy's (DOE's) Weatherization Assistance Program;
  - DOE program regulations 10 C.F.R. 440;
  - DOE program guidance and policy issued via Weatherization Program Notice or memoranda;
  - Federal, state, and local budget processes;
  - Federal financial assistance regulations 10 C.F.R. 600 and relevant OMB circulars;
  - Applicable state procurement regulations; and
  - State and local approaches to monitoring, training, and technical assistance.
- Demonstrate the ability to:
  - Produce written reports that can clearly identify weaknesses and provide sound solutions; and
  - Provide on-site training and technical assistance;

PROGRAM MANAGER

- Possess a working knowledge of:
  - Enabling legislation governing the U.S. Department of Energy's (DOE's) Weatherization Assistance Program;
  - DOE program regulations 10 C.F.R. 440;
  - DOE program guidance and policy issued via Weatherization Program Notice or memoranda;
  - Federal, state, and local budget process;
  - Federal financial assistance regulations 10 C.F.R. 600 and relevant OMB circulars;
  - Applicable state procurement regulations;
  - State and local approaches to monitoring, training, and technical assistance;

- Applicable computer databases and tracking systems and the importance that they remain up-to-date, are secured and backed-up, and are used effectively to manage the program; and
- Building science principles.

- For state staff:
  - Demonstrate the ability to:
    - Prepare an annual state plan;
    - Prepare an annual weatherization grant application;
    - Submit accurate financial and production reports in a timely manner;
    - Develop, maintain, and enforce state technical program standards;
    - Provide adequate technical and administrative training for coordinators, auditors, technicians, and inspectors directly employed by local agencies, and ensure that subcontractors receive appropriate technical training;
    - Develop and manage an effective monitoring program;
    - Coordinate resources;
    - Develop and implement innovative leveraging strategies; and
    - Process reimbursement requests in a timely manner.
- For local agency weatherization coordinators:
  - Demonstrate the ability to:
    - Effectively communicate and manage weatherization staff and subcontractors;
    - Prepare and track a budget for implementing a local weatherization program;
    - Maintain a purchase order system to track contracted services and materials and tool requisitions;
    - Maintain a coding system to assure expenditures are charged to the correct budget category;
    - Maintain inventory tracking system for materials, tools, and equipment;
    - Submit accurate financial and production reports in a timely manner;
    - Comply with federal limits on administrative expenses;
    - Manage a small construction/production-focused operation;
    - Ensure rigorous, unbiased, and accurate final inspection of all completed units;
    - Provide adequate technical training for auditors, technicians, and inspectors directly employed by the local agency, and ensure that subcontractors receive appropriate technical training;
    - Ensure that weatherization work complies with state technical program standards;
    - Coordinate resources; and
    - Develop and implement innovative leveraging strategies.

TRAINER

- Prerequisites:
  - Trainers should possess *Safe Work Practices*, *Auditor*, and *Inspector* competencies;
  - Trainers should be knowledgeable of *Installer* competencies;
  - Completion of adult education training program; and
  - Certification in subject areas of presented training.
- Possess a working knowledge of:
  - Principles of building science;
  - Principles of adult education;
  - Benefits of cross-training;
  - Building codes, especially energy and health/safety-related codes;
  - Allowable activities at the location of training (e.g., knob-and-tube wiring requirements); and
  - Available resources to aid students in future understanding and application.
- Demonstrate the ability to:
  - Develop curriculum based on student needs;
  - Tailor each class to the experience and needs of the students;
  - Motivate students through inspirational presentations;
  - Provide hands-on training;
  - Use technology to enhance the learning experience, especially as related to adult education principles; and
  - Direct students to other resources to get answers beyond the capacity of the trainer to provide.

Appendix A: Math Pre-Test

You may use a calculator to solve the following questions. Answers may be expressed in decimal or fraction form. (15-minute time limit)

You must score 73% or higher, (answer at least eleven (11) out of fifteen (15) correct). Failure to do so will require additional basic math skills before attending the Initial Inspection course at the OWTC.

1. 8 1/2"
17 3/4"
+ 23 3/8"

2. 23 1/4"
- 7 1/8"

3. 23.25
x 12.75

4. 350/40 = _____

5. 3/8 x 120 = _____

6. How many inches are in 5 feet? _____

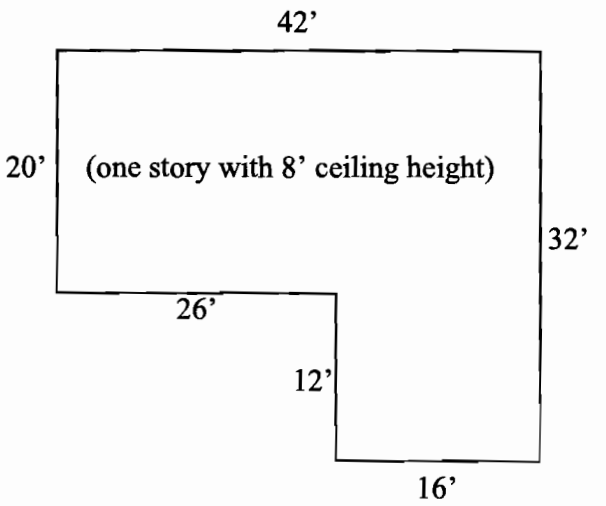
7. One square foot equals how many square inches? _____

8. What is the perimeter of the house diagramed below? _____feet.

9. What is the area of the house diagramed below? _____square feet.

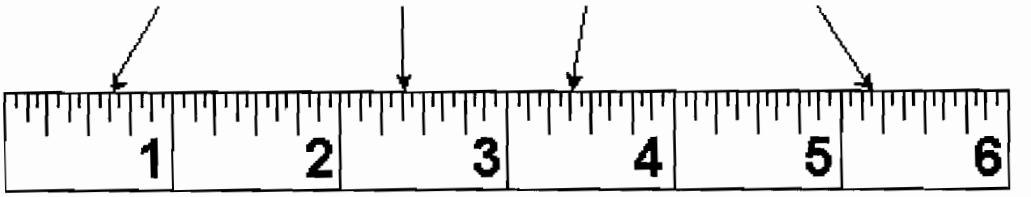
10. What is the volume of the house diagramed below? _____cubic feet.

11. What is 75% of 2400? _____.



12-15. Write in the measurement indicated by the arrow pointing at the tape measure.

12._____ 13._____ 14._____ 15._____



Appendix B: Computer Skills Pre-Test

Basic Computer Skills Survey

1. Have you used a computer before? ____Yes ____No

2. Do you own a computer? ____Yes ____No

3. How well can you type? ____Good ____OK ____Not Good

4. What software programs have you used?

   a. Microsoft Word or other word processor? ____Yes ____No
   b. Excel or other spreadsheet program? ____Yes ____No
   c. Outlook or other email program? ____Yes ____No
   d. Internet Explorer or other Internet browser? ____Yes ____No
   e. NEAT, MHEA, or other energy audit software? ____Yes ____No

Windows Basics Test
Perform the following tasks on the computer.

1. Open three different software programs, resize and position the windows so you can see all three applications on the screen at once.

2. Minimize all three programs and create a new folder on the desktop.

3. Create a word-processing file and save it on the desktop

4. Move this new file into the new folder using drag and drop.

5. Open the folder and confirm you successfully moved the file.

6. Using the Windows Help menus locate instructions for cut and paste and drag and drop. Point to what tutorials come with windows for learning file management. (copy, delete, move, rename, view properties)

File Management Basics Test
Nearly everything you'll do with computers revolves around creating content in the form of different types of files using different software programs. You'll need to be comfortable with creating, saving, opening, and editing files. Then you'll need to understand storing, organizing, renaming, moving, copying, deleting and backing up your important files. Plan on learning by doing. Mistakes are considered positive learning experiences and are an essential part of using and learning computers. Trouble-shooting gets easier with practice.

Begin by drafting a personal list of the computer skills you have and the skills you want to learn. Then complete the following tests.

1. Create a new folder on the desktop named "Test Folder #1" and save a simple word processing document to this folder.

2. Create a folder named "Test Folder #2" within "Test Folder #1" and move the word processing file into this new folder.

3. Put a copy of this file into the first folder you created.

4. Rename this file.

5. Create another new folder on the desktop named "Test Folder #3" and move Test Folder #2 into this folder.

6. Delete all these folders and files.

Copy and Paste Basics Test
Perform the following tasks on the computer.

1. Highlight a section of text in a document and copy it to another location.

2. Highlight a section of text in a document and move it to a new location.

3. Highlight an image in a document and copy it to another location. Then, move the image to new location.

Spreadsheet Basics Test
Circle the letter of the best answer.

1. Spreadsheets:
   a. Are large amounts of information
   b. Organize text and numbers into columns and rows
   c. Are usually graphics

2. Columns are:
   a. Labeled with numbers
   b. Not labeled
   c. Labeled with letters

3. Rows are:
   a. Labeled with numbers
   b. Not labeled
   c. Labeled with letters

4. What are the intersection of a column and a row?
   a. Formulas
   b. Entries
   c. Cells

5. The column and row label combined at the point of intersection is known as the:
   a. Active cell
   b. Cell name
   c. Formula

6. What are the sets of instructions that produce a value for a cell?
   a. Addresses
   b. Spreadsheets
   c. Formulas

7. What character should start any formula?
   a. Plus sign (+)
   b. Any operator (+,-,*,/)
   c. Equals sign (=)

8. Which formula will produce the total cost of all weatherization measures?

	A	B	C	D	E	F
1	**Measure**	**Hours**	**Rate**	**Labor**	**Materials**	**Total**
2	Air sealing	4	$30	$120	$200	$320
3	Attic insulation	3	$30	$90	$324	$414
4	Sidewall insulation	8	$30	$240	$312	$552
5	Water heater wrap	0.5	$30	$15	$14	$29

   a. =SUM(F2:F5)
   b. =F2+F3+F4+F5
   c. =SUM(B5:F5)
   d. Both a and b

Appendix C: Glossary

Air Barrier – The air barrier of a dwelling, also known as the pressure boundary, is the building shell surface that limits airflow between inside and outside. For maximum energy efficiency and comfort, the air barrier and thermal barrier should be continuous and in contact with each other.

ASHRAE – American Society of Heating, Refrigeration, and Air Conditioning Engineers

ASHRAE 62 – ASHRAE 62 is a group of ASHRAE standards for minimum building ventilation requirements. ASHRAE 62.1-2004, entitled Ventilation for Acceptable Indoor Air Quality, cover general topics and requirements for commercial and high-rise residential buildings. ASHRAE 62.2-2004, Ventilation for Acceptable Indoor Air Quality in Low-Rise Residential Buildings, has a self-explanatory title.

Attic Ventilation – Building codes require attic openings to outside to induce airflow that cools the attic in summer and exhausts moisture. There is a growing consensus that unvented attics have energy benefits and that in hot, humid climates attic ventilation brings in more moisture from outside than it purges.

Auditor – An auditor is a weatherization worker that assesses an eligible dwelling for potential weatherization services. Auditors visually inspect the building shell and mechanical systems; conduct diagnostic, health, and safety tests; record the location, condition, and dimensions of walls, ceilings, floors, windows, doors, and mechanical systems; enter data into computerized energy audit or use a priority list to select cost-effective measures; and prepare clear and accurate work orders to ensure the most appropriate measures are installed properly.

Balloon-Framed Walls – Balloon-framed walls are built without top or bottom plates. This type of framing often provides an air channel from the basement or crawlspace to the attic that allows outside air to flow through the walls resulting in excessive heat loss/gain.

Band Joist – Band joists are the floor joists that run around the perimeter of the house. There are two types of band joists - header joists that run perpendicular to the floor joists and rim joists that run parallel. A typical weatherization measure involves insulating the header joist spaces between floor joists and along the rim joists.

Base Load – Base loads are energy loads from appliances that are on most of the time and do not vary with changing climate. Base loads include refrigerators, water heaters, and lights. Base loads are often thought to be primarily electric loads, but can be fueled by other energy sources.

Batt Insulation – Batts are insulation manufactured in rolls precut to standard widths to fit snugly between framing (joists, rafters, or studs) on 16-inch or 24-inch centers in ceilings, floor, and walls. While often made with a "Kraft" paper facing designed to

retard vapor transmission, batt insulation is also available without the paper facing (unfaced batts).

Blower Door – A blower door is a device for testing the airtightness of a building. A blower door consists of a calibrated fan for measuring an air flow rate and a pressure sensing device to measure the pressure created by the fan flow. The combination of pressure and flow can be used to estimate the airtightness.

Building Performance Institute (BPI) – BPI is an organization that supports the development of a professional building performance industry through individual and organizational credentialing and a quality assurance program. BPI offers certification of individuals in evaluation, mechanical, envelope, mobile home, and multi-family designations, as well as accreditation of organizations committed to using a quality management system.

Building Science – Building science is the collection of scientific knowledge that focuses on the analysis and control of the physical phenomena affecting buildings. This includes the detailed analysis of building materials and building envelope systems.

Building Tightness Limit – Also known as the minimum ventilation rate, the building tightness limit is the least amount of fresh air that must be drawn through a house (by either natural or mechanical means) to ensure acceptable indoor air quality.

Bypass – A bypass is a hole between conditioned and unconditioned space that allows air leakage through the pressure boundary, or air barrier, of a dwelling.

CAZ – A combustion appliance zone, or CAZ, is any zone containing a combustion appliance.

CO – Carbon monoxide

Combustion Air – Complete combustion of fossil fuels such as natural gas, propane, and fuel oil requires an adequate supply of air. Inadequate combustion air causes incomplete combustion, which generates carbon monoxide.

Combustion Appliance – A combustion appliance is a furnace, boiler, space heater, wood stove, water heater, cook stove, or other device that burns wood or fossil fuel such as natural gas, propane, or fuel oil.

Compact Fluorescent Lamp – A compact fluorescent lamp (CFL) is a type of fluorescent lamp that screws into a regular light bulb socket or plugs into a small lighting fixture. In comparison to incandescent light bulbs, CFLs have a longer rated life and use less electricity.

Competency – Competency means the possession of a minimum level of knowledge and proficiency required to collect appropriate information, make informed decisions, and

physically takes the needed actions to deliver the high-quality weatherization service in question.

Consumer/Client Education – Consumer or client education includes discussion, instruction, brochures, and pamphlets that explain the weatherization process, the measures installed in the client's house, how to use certain measures (such as programmable thermostats), and low-cost/no-cost ways to save energy and reduce energy costs.

Crew Chief – A crew chief is a weatherization worker that supervises a crew of installers and directs their efforts to weatherize eligible dwellings.

Critical Junction Point – Critical junction points are areas in building construction that typically exhibit air leaks or are inadequately insulated. Critical junction points include the intersection of ceilings and walls, cantilevers, and finished-attic kneewalls.

Cross Training – Training every member of a crew to be able to do every job is known as cross training. While certain crew members may specialize in specific tasks, a cross-trained crew understands how their specialty impacts all others and can adjust to staff turnover.

Delta Q – Delta Q is a testing protocol to measure duct leaks to the outside under actual operating conditions.

Demonstrated Ability – A demonstrated ability is the physical performance of a test, procedure, or technique on an actual house, a prop, or in a training lab in the presence of someone qualified to assess the particular competency.

Dense-Packed Insulation – Loose-fill insulation (cellulose or fiberglass) is blown into closed building cavities (usually walls, but also floor and roof/ceiling cavities) to a density of 3½ or 2 ½ pounds per cubic foot[1], respectively, to air seal as well as insulate.

DOE – U.S. Department of Energy

Dropped Soffit – A dropped soffit (or simply drop soffit) is built from framing and drywall over kitchen cabinets to give a more finished appearance than just hanging wall cabinets with a foot or so gap between the top of the cabinet and the ceiling. From the attic, a dropped soffit looks like a big hole in the floor and often causes breaks in the attic thermal and air barriers.

Duct Blaster – A Duct Blaster is a calibrated airflow measurement system designed to test and document the air tightness of forced-air duct systems. Duct Blaster is the trade name of the device manufactured by the Energy Conservatory of Minneapolis,

[1] Guidelines are based on infiltration reduction lab and field results and subject to change as more data becomes available.

Minnesota. Other competing companies such as Infiltec and Retrotec manufacture similar systems.

EPA – U.S. Environmental Protection Agency

HVAC – Heating, ventilation, and air conditioning

HVAC Installer/Contractor – A HVAC installer/contractor is a crew member or contractor trained and licensed to repair and replace furnaces, boilers, air conditioners, and related equipment.

Hydronic Distribution Pipes – Hydronic distribution pipes deliver hot water or steam from a water heater or boiler to baseboard convectors or radiators located throughout a house.

Inspector – An inspector verifies the proper selection, installation, and effectiveness of weatherization measures installed in eligible dwellings through review of documentation, visual inspection, and performance of diagnostic, health, and safety testing.

Installer – An installer is a crew member or contractor that installs weatherization measures in eligible dwellings.

Knob-and-Tube Wiring – Older homes may have "knob-and-tube" electrical wiring, where two separate wires run through ceramic posts (knobs) attached to the top of ceiling joists or through ceramic tubes inserted into holes drilled in the wall or roof framing. Since this type of wiring was designed to dissipate heat to the attic air, insulating over knob-and-tube wiring can cause dangerous overheating.

Lead-Safe Work Practices – Lead-safe work practices are the use of specific precautions in the conduct of weatherization activities designed to avoid contaminating homes with lead-based paint dust and debris, and to avoid exposing the clients, weatherization workers, and their families to this hazard.

Mastic – Mastic is a material used to seal duct leaks. It is the consistency of drywall joint compound when applied, but dries to a hard, durable finish. To seal duct leaks larger than ¼ inch, mastic is applied over a specially made fiberglass mesh tape.

Material Safety Data Sheet (MSDS) – A material safety data sheet or MSDS describes the properties of a particular substance (e.g., caulk, mastic, sealant). An important component of workplace safety, it is intended to provide workers and emergency personnel with procedures for handling or working with that substance in a safe manner.

Mechanical Ventilation – Mechanical ventilation is the controlled exhaust of indoor air, intake of fresh outdoor air, or a combination of both through the use of fans, controls, passive air intakes, and sometimes ducts, registers, and air-to-air heat exchangers.

Minimum Ventilation Rate – Also known as the building tightness limit, the minimum ventilation rate is the least amount of fresh air that must be drawn through a house (by either natural or mechanical means) to ensure acceptable indoor air quality.

Monitor (Administrative) – An administrative monitor is someone employed or contracted by a state to review the administrative and programmatic activities of local weatherization agencies (subgrantees) to ensure compliance with applicable laws and programmatic and financial regulations.

Monitor (Technical) – A technical monitor is someone employed or contracted by a state to review the technical and field activities of local weatherization agencies (subgrantees) to ensure compliance with the enacting federal legislation, federal program regulations, and state technical program standards.

NASCSP – National Association for State Community Services Programs is a national association charged with advocating and enhancing the leadership role of states in preventing and reducing poverty. NASCSP's members are state administrators of the U.S. Department of Health and Human Services' Community Services Block Grant (CSBG) and the U.S. Department of Energy's Weatherization Assistance Program. NASCSP keeps its members, the federal government, and other interested parties informed about issues related to CSBG and the Weatherization Program through its publications and training.

OSHA – The Occupational Safety and Health Administration's mission is to assure the safety and health of America's workers by setting and enforcing standards; providing training, outreach, and education; establishing partnerships; and encouraging continual improvement in workplace safety and health.

Personal Protective Equipment – Equipment such as respirators, safety goggles, disposable coveralls, and hard hats worn by weatherization workers to protect them from jobsite hazards.

Plenum – A plenum is the initial duct on the supply and return side of an air handler.

Pressure Pan – A pressure pan resembles a cake pan and is used to locate duct leakage with a digital manometer while a blower door is running.

Priority List – A priority list is a list of weatherization measures appropriate for typical housing stock ordered by descending cost effectiveness. DOE-approved energy audit software is used to verify the cost effectiveness of the measures and account for the interaction between measures.

R-Value – R-value is a measure of resistance to heat flow. Insulation with an R-value of R-38 resists heat loss better than R-19 insulation.

Room Pressure Imbalances – Pressure imbalances happen when the conditioned air supplied to a room does not equal the airflow returned to the furnace or air conditioner. In dwellings with forced-air distribution and a central return system, closing bedroom doors can cause the bedrooms to experience a positive pressure and rooms that are open to the return grille see a negative pressure. Atmospherically vented combustion appliances can backdraft if they are located in a zone with negative pressure.

Steam Trap – Steam traps are automatic valves used in steam heating systems to remove condensed steam (hot water) from the steam pipes and return it to the boiler.

Temperature-Rise Test – A temperature-rise test is conducted on a furnace by measuring the temperature of air entering the furnace and of the air exiting the furnace. The difference between these two temperatures is known as the temperature rise and is compared to the normal range indicated on the nameplate to verify proper operation of the furnace.

Thermal Barrier – The thermal barrier of a dwelling is the building shell surface that limits heat flow. For maximum energy efficiency and comfort, the air barrier and thermal barrier should be continuous and in contact with each other.

Unvented Combustion Appliance – An unvented combustion appliance vents combustion gases to the living space instead of outside as does a vented appliance.

Weatherization *Plus* – The U.S. Department of Energy's effort to plan the continued evolution of the Weatherization Program for the next five years through activities designed to expand resources (leveraging and partnerships), share relevant information with the weatherization network, and increase the consistent delivery of high-quality weatherization services nationwide.

Work Order – A work order describes what weatherization measures are to be installed in an eligible dwelling and includes a list of the type and quantity of materials that are required to complete the job.

Working Knowledge – Working knowledge of means to:

- Knowing how a particular topic impacts the weatherization process;
- Having the relevant information committed to memory or being able to locate it in readily available sources; and
- Using the knowledge to make informed decisions and guide weatherization work.

Worst-Case Draft Test – A worst-case draft test is procedure used to verify the ability of a combustion appliance to safely exhaust combustion gases outside even when exhaust fans, pressure imbalances, and the stack effect are fighting its ability to properly draft.

Zone Pressure Diagnostics – Test procedures used with the blower door to locate air leakage are known as zone pressure diagnostics.