BULKY DOCUMENTS

(Exceeds 100 pages)

Filed: 09-09-12

Title: Petition For Cancellation

Part 3 of 6 - Binder C

1811481

Binder C Contents

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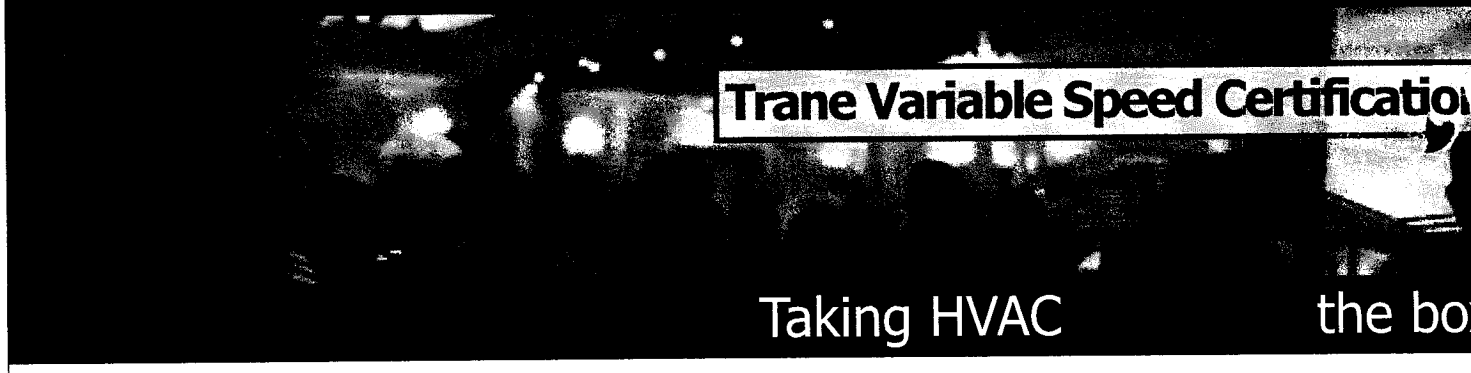
Air Purchases	Training 2011	(781) 273-2050						
Course	**Location**	**Date**	**Time**	**Day**	**Cost**			
VSPD ECM	Hyannis	3/10/2011	4PM-8PM	Thursday	$99.00			
VSPD ECM	Manchester	3/29/2011	4PM-8PM	Tuesday	$99.00			
VSPD ECM	Burlington	3/31/2011	4PM-8PM	Thursday	$99.00			
Comm Systems	Burlington	4/14/2011	4PM-8PM	Thursday	$75.00			
CommSystems	Hyannis	4/21/2011	4PM-8PM	Thursday	$75.00			
Comm Systems	Manchester	5/5/2011	4PM-8PM	Thursday	$75.00			
TTM/Hyp Rollout	Burlington	5/11/2011	4PM-8PM	Wednesday	No Cost			
Open NATE Exam	Burlington	5/12/2011	4PM-8PM	Thursday	$150 per test			
TTM/Hyp Rollout	Hyannis	5/18/2011	4PM-8PM	Wednesday	No Cost			
Open NATE Exam	Hyannis	5/19/2011	4PM-8PM	Thursday	$150 per test			
TTM/Hyp Rollout	Manchester	5/25/2011	4PM-8PM	Wednesday	No Cost			
Open NATE Exam	Manchester	5/26/2011	4PM-8PM	Thursday	$150 per test			
Gas Furnace	Burlington	9/15/2011	4PM-8PM	Thursday	$65.00			
Gas Furnace	Hyannis	9/29/2011	4PM-8PM	Thursday	$65.00			
Gas Furnace	Manchester	10/13/2011	4PM-8PM	Thursday	$65.00			
Heat Pump	Burlington	10/27/2011	4PM-8PM	Thursday	$65.00			
Heat Pump	Hyannis	11/10/2011	4PM-8PM	Thursday	$65.00			
Heat Pump	Manchester	12/1/2011	4PM-8PM	Thursday	$65.00			
Trane RTU	Burlington	12/15/2011	4PM-8PM	Thursday	$135.00			
Trane RTU	Hyannis	1/12/2012	4PM-8PM	Thursday	$135.00			
Trane RTU	Manchester	1/26/2012	4PM-8PM	Thursday	$135.00			
Cool Smart	**Alternate Tuesdays starting 3/1/11. See pdf for full information.**							
Classes offered:	**Duct Testing (DT) 101 (Alternate Tues starting 3/1/11) 8-11 a.m. Fee: $100** Open to all contractors**							
	QIV Refresher (Alternate Tues starting 3/8/11) 8-11 a.m. No cost. Must have valid 2010 Cool Smart Tech ID							
	Intro to Cool Smart (Tuesdays starting 3/01/11 11:30 - 1:00 p.m. No Cost. Open to all contractors.							
	All classes take place at Air Purchases in Burlington.							
	*** NO CLASSES ON 3/29/11**							
	**** $100 reimbursable fee (DT101) per tech when your company purchases duct blaster, tests a site, and**							
	submits Duct Sealing Reduction form in 2011. If multiple techs trained you must submit an equal number							
	of completed forms, and will be reimbursed $100 each, up to the total number of technicans trained.							

Air Purchases, Inc. 2011 Training Classe



Training Overview:

This course is designed for the dealer selling Trane ECM-based variable speed systems. We will cover the features and benefits of ECM systems as well as installation, set-up and servicing of ECM-based variable speed systems, including multi-stage 20 SEER split systems.

Outline:

- Consumer benefits of ECM technology
- Application and proper equipment selection for variable speed systems
- Installation, start-up and system charging
- Operation and service trouble shooting
- Wiring variations and effects on air flow

Course Materials Include:

- Trane ECM Service Manual
- Two-Step Scroll Systems Service Manual
- Regal Beloit ECM Manual
- Trane ECM Tester
- Trane ECM Go/No Go Tester

Attend at a location convenient to you (pizza included):

March 10	**March 29, 2011**	**March 31, 2011**
4-8 p.m.	4-8 p.m.	4-8 p.m.
Air Purchases	Engel HVAC	Air Purchases
Hyannis, MA	**Manchester, NH**	**Burlington, MA**

Registration: Mail or fax your completed form to Sharon Mangano, Air Purchases, 24 Blanchard Road, Burlington, MA 01803 Fax: (781) 229-0207. **Payment must be made in advance of class.** Check, VISA or MC only.

Name: _____

Company: _____

Address: _____

City _____ State: _____ Zip _____

Credit card# _____ Exp : _____ CCV: _____

Indicate location: [ ] Hyannis [ ] Manchester [ ] Burlington

Cost: $99.00

Qualifies for NATE CEUs

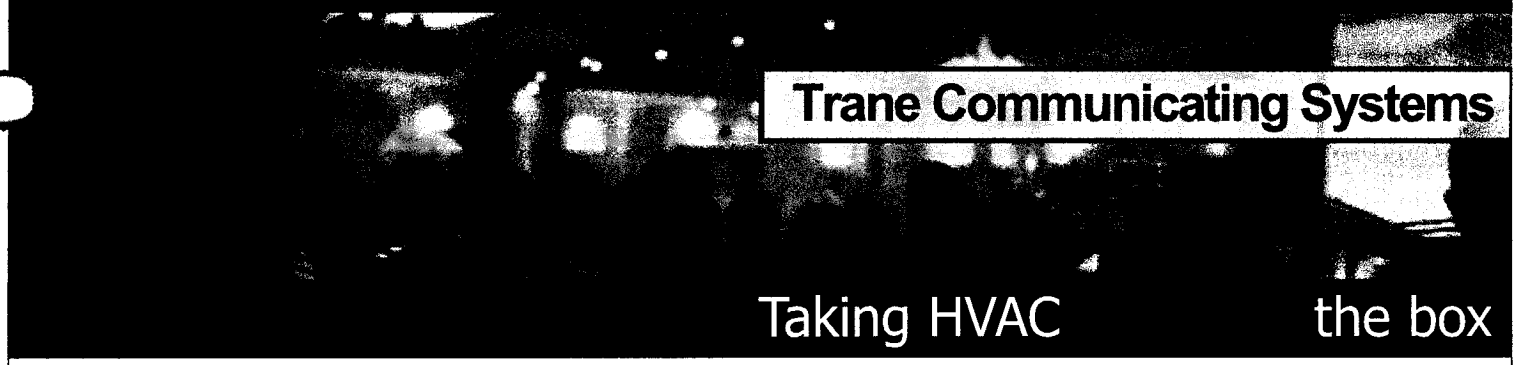
This course counts as 4 CEUs towards NATE recertification in the following specialties:

- AC Service
- AC Installation
- Gas Furnace Installation
- Gas Furnace Service
- Heat Pump Installation
- Heat Pump Service
- Air Distribution Installation
- Air Distribution Service
- Oil Furnace Installation
- Oil Furnace Service

NATE Course ID# 1813-0010
Air Purchases Ref# TRNVSPD0001

Air Purchases, Inc.
24 Blanchard Rd.
Burlington, MA 01803
(781) 273-2050
Fax: (781) 229-0207

Air Purchases, Inc. 2011 Training Classes



Training Overview:

Designed for installers and service technicians working with Trane communicating systems. Course covers features and benefits, installation application considerations, and trouble shooting.

Outline:

- **Applying Communicating Systems**
- **95% Efficiency 3-Stage Communicating Gas Furnace**
- **95% Efficiency Communicating/Modulating Gas Furnace**
- **80% Communicating Gas Furnace Models**
- **20 SEER XL20i Communicating Dual Compressor AC & Heat Pumps**

Course Materials Include:

- **Communicating Systems Service Manual**
- **Communicating 2 Compressor Service Manual**
- **Communicating Systems Troubleshooting Flow Chart Guide**
- **Alert Code Addendum**
- **Communicating Serial Motor Tester**

Attend at a location convenient to you (pizza included):

April 14, 2011	**April 21, 2011**	**May 5, 2011**
4-8 p.m.	4-8 p.m.	4-8 p.m.
Air Purchases	Air Purchases	Engel HVAC
Burlington, MA	**Hyannis, MA**	**Manchester, NH**

Registration: Mail or fax your completed form to Sharon Mangano, Air Purchases, 24 Blanchard Road, Burlington, MA 01803 Fax: (781) 229-0207. **Payment must be made in advance of class.** Check, VISA or MC only.

Name: _____

Company: _____

Address: _____

City _____ State: _____ Zip _____

Credit card# _____ Exp : _____ CCV: _____

Indicate location: [ ]Burlington [ ] Hyannis [ ] Manchester

Cost: $75.00

Qualifies for NATE CEUs

This course counts as 4 CEUs towards NATE recertification in the following specialties:

- **AC Service**
- **AC Installation**
- **Gas Furnace**
- **Gas Furnace Service**
- **Heat Pump Installation**
- **Heat Pump Service**

NATE Course ID# 1813-0018

Air Purchases, Inc.
24 Blanchard Rd.
Burlington, MA 01803
(781) 273-2050
Fax: (781) 229-0207

Air Purchases, Inc. 2011 Training Classes

Trane Hyperion™ Air Handler & XB30

Taking HVAC the box

Come and learn about these exciting new products from Trane!

▸ Trane Hyperion Air Handler

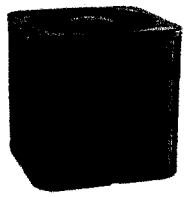
A highly advanced, industry-exclusive offering!

We will cover the selection, application, installation and set-up of the new Trane Hyperion TAM7 air handler with electronic TXV. The Hyperion will replace the current variable speed 4TEE air handlers.

- Air-Tite™ construction
- One-person install
- Side return
- Electronic TXV valve
- Multi-position

▸ Trane XB300 Family

We will also cover the special application requirements of Trane's XB300 family of condensing units with the new Climatuff coil with micro-channel.



- Trane's New 13 SEER competitive offering
- Smaller (all units 29" tall)
- Lighter 1 ½ ton is 177 lbs, 5 ton is only 194 lbs – fits easily in a van
- New micro channel coil
- Same durability and reliability you've come to expect from Trane

Attend at a location convenient to you (pizza included):

May 11, 2011	**May 18, 2011**	**May 25, 2011**
4-8 p.m.	4-8 p.m.	4-8 p.m.
Air Purchases	Air Purchases	Engel HVAC
Burlington, MA	**Hyannis, MA**	**Manchester, NH**

Registration: Mail or fax your completed form to Sharon Mangano, Air Purchases, 24 Blanchard Road, Burlington, MA 01803 Fax: (781) 229-0207. **There is no charge to attend this class.**

Name: _____

Company: _____

Address: _____

City _____ State: _____ Zip _____

Indicate location: [ ] Burlington [ ] Hyannis [ ] Manchester

Cost: No charge

Qualifies for NATE CEUs

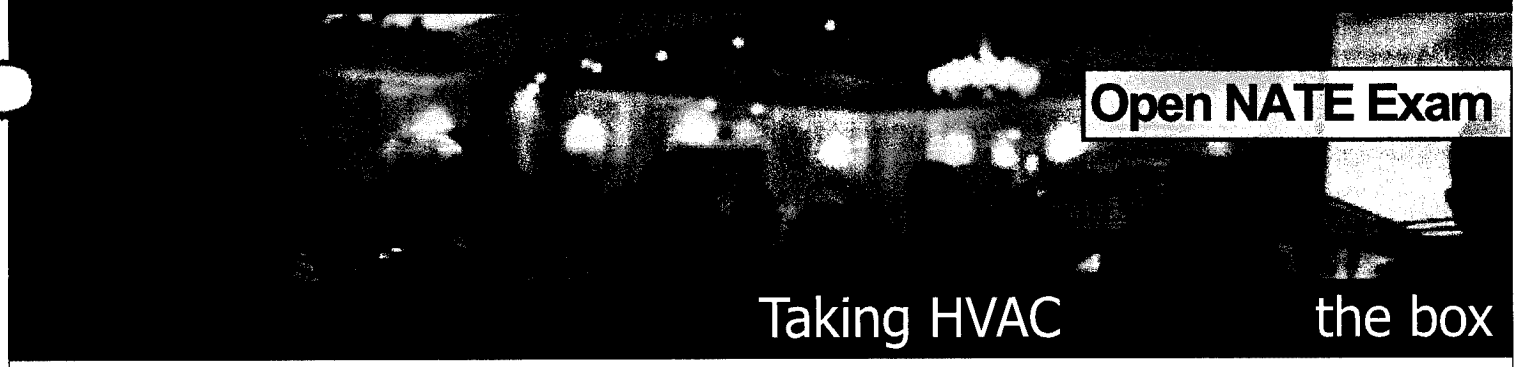
This course counts as 5 CEUs towards NATE recertification in the following specialties:

- **AC Service**
- **AC Installation**
- **Heat Pump Installation**
- **Heat Pump Service**
- **Air Distribution Install**
- **Air Distribution Service**
- **HVAC Efficiency: Senior**

Nate Course ID # 1813-0020

Air Purchases, Inc.
24 Blanchard Rd.
Burlington, MA 01803
(781) 273-2050
Fax: (781) 229-0207

Air Purchases, Inc. 2011 Training Classes



About You:

Last Name First Name MI

Daytime Phone# E-mail address

Mailing Address

City State Zipcode

About Your Employer:

Company Name

Daytime Phone# Fax

Mailing Address

City State Zipcode

Exam Info:

Please check off appropriate choices (either CORE plus one specialty, or TWO specialties). Cost is $150.00 per class.

[ ] CORE exam [ ] AC Speciality [ ] Air Distribution Specialty [ ] Gas Heating Speciality [ ] Heat Pump Speciality [ ] Oil Heating Specialty

Technician Info:

Please check ONE technician type. [ ] Installation [ ] Service

Attend at a location convenient to you (pizza included):

May 12, 2011	May 19, 2011	May 26, 2011
4-8 p.m.	4-8 p.m.	4-8 p.m.
Air Purchases	Air Purchases	Engel HVAC
Burlington, MA	**Hyannis, MA**	**Manchester, NH**

Please arrive 20 minutes prior to class time.

COST: $150.00 per class
Passing CORE and at least one speciality exam is required for certification. Exam lasts four hours, which is adequate time to take a CORE and ONE specialty exam.

Registration: Mail or fax your completed form to Sharon Mangano, Air Purchases, 24 Blanchard Road, Burlington, MA 01803 Fax: (781) 229-0207. **Payment must be made in advance of class.** Check, VISA or MC only.

Please complete:$150.00 x # classes _____ = $_____
Total Cost

Name on Credit Card (please print): _____

CC# _____ Exp : _____ CCV:_____

Billing address if different: _____

_____

Indicate location: [ ] Burlington [ ] Hyannis [ ] Manchester, NH

Air Purchases, Inc. 2011 Training Classes

Trane Furnace Installation & Service

Taking HVAC the box

Training Overview:

This course is for installation and service technicians looking for a greater understanding of Trane furnace installation, operation and troubleshooting techniques.

Outline:

- Furnace installation
- Confined space requirements
- Vent system applications
- Wiring
- Variable speed benefits
- Variable speed set up
- Enhanced mode operation
- Manufacture housing requirements
- Propane conversions
- Furnace service and trouble shooting techniques
- Ignition systems
- Variable speed inducers
- ECM blower trouble shooting

Course Materials Include:

- LitePort Troubleshooting Guide
- SINI Furnace Troubleshooting Guide

Attend at a location convenient to you (pizza included):

Sept 15, 2011	**Sept 29, 2011**	**Oct 13, 2011**
4-8 p.m.	4-8 p.m.	4-8 p.m.
Air Purchases	Air Purchases	Engel HVAC
Burlington, MA	**Hyannis, MA**	**Manchester, NH**

Registration: Mail or fax your completed form to Sharon Mangano, Air Purchases, 24 Blanchard Road, Burlington, MA 01803 Fax: (781) 229-0207. **Payment must be made in advance of class.** Check, VISA or MC only.

Name: _____

Company: _____

Address: _____

City _____ State: _____ Zip _____

Credit card# _____ Exp : _____ CCV: _____

Indicate location: [ ]Burlington [ ] Hyannis [ ] Manchester

Cost: $65.00

Qualifies for NATE CEUs

This course counts as 5 CEUs towards NATE recertification in the following specialties:

- Gas Furnace Installation
- Gas Furnace Service

NATE Course ID# 1813-0005
Air Purchases Ref# TRNFURN001

Air Purchases, Inc.
24 Blanchard Rd.
Burlington, MA 01803
(781) 273-2050
Fax: (781) 229-0207

Air Purchases, Inc. 2011 Training Classes

Training Overview:

This course is designed to provide attendees with a greater understanding of Trane heat pump operation, application, installation, and trouble shooting.

Outline:

- Equipment selection and the implications of unrated systems
- Line sizing
- Installation
- Electrical requirements and wiring
- Calculating system balance point
- Controls and operation
- Hybrids (dual-fuel systems)
- Variable speed set-up
- Measuring system airflow
- TXVs
- System charging
- Service troubleshooting

Course Materials Include:

HP Mini-Guide; HP Components Guide; HP Service Guide

Attend at a location convenient to you (pizza included):

Oct 27, 2011	**Nov 10, 2011**	**Dec 1, 2011**
4-8 p.m.	4-8 p.m.	4-8 p.m.
Air Purchases	Air Purchases	Engel HVAC
Burlington, MA	**Hyannis, MA**	**Manchester, NH**

Registration: Mail or fax your completed form to Sharon Mangano, Air Purchases, 24 Blanchard Road, Burlington, MA 01803 Fax: (781) 229-0207. **Payment must be made in advance of class.** Check, VISA or MC only.

Name: _____

Company: _____

Address: _____

City _____ State: _____ Zip _____

Credit card# _____ Exp : _____ CCV: _____

Indicate location: [ ]Burlington [ ] Hyannis [ ] Manchester

Cost: $65.00

Qualifies for NATE CEUs

This course counts as 5 CEUs towards NATE recertification in the following specialties:

- AC Installation
- AC Service
- Heat Pump Installation
- Heat Pump Service

NATE Course ID# 1813-0008
Air Purchases Ref# TRNHP0001

Air Purchases, Inc.
24 Blanchard Rd.
Burlington, MA 01803
(781) 273-2050
Fax: (781) 229-0207

Air Purchases, Inc. 2011 Training Classes

Trane Light Commercial Micro-Controls

Taking HVAC the box

Training Overview:

Course is designed for technicians servicing Trane Voyager and Precedent package units with micro-electronic controls.

Outline:

- Micro-electronic components and acronyms
- Micro-electronics operation
- Installation
- Micro-electronic troubleshooting procedures
- Voyager ignition and combustion

Course Materials Include:

- Voyager Ignition and Combustion Manual
- Voyager Micro-controls Manual
- Reliatel Microprocessor Controls Manual

Attend at a location convenient to you (pizza included):

Dec 15, 2011	**Jan 12, 2012**	**Jan 26, 2012**
4-8 p.m.	4-8 p.m.	4-8 p.m.
Air Purchases	Air Purchases	Engel HVAC
Burlington, MA	**Hyannis, MA**	**Manchester, NH**

Registration: Mail or fax your completed form to Sharon Mangano, Air Purchases, 24 Blanchard Road, Burlington, MA 01803 Fax: (781) 229-0207. **Payment must be made in advance of class.** Check, VISA or MC only.

Name: _____

Company: _____

Address: _____

City _____ State: _____ Zip _____

Credit card# _____ Exp : _____ CCV: _____

Indicate location: [ ] Burlington [ ] Hyannis [ ] Manchester

Cost: $135.00

Qualifies for NATE CEUs

This course counts as 5 CEUs towards NATE recertification in the following specialties:

- **AC Service**
- **AC Installation**
- **Gas Furnace Installation**
- **Gas Furnace Service**
- **Heat Pump Installation**
- **Heat Pump Service**

Nate Course ID # 1813-0011
Course # TRNMICROCONTROLS0001

Air Purchases, Inc.
24 Blanchard Rd.
Burlington, MA 01803
(781) 273-2050
Fax: (781) 229-0207

Air Purchases, Inc.

COOL SMART Contractor Training Opportunities

Air Purchases of Burlington MA

hosts trainings that are key to your success in earning top rewards as a Cool Smart contractor!

Class	Date	Time	Fee	Requirements
DUCT TESTING (DT) 101	Alternate Tuesdays, starting **3/01/11***	8:00am - 11:00am	$100**	Open to all contractors
QIV REFRESHER TRAINING	Alternate Tuesdays, starting **3/08/11**	8:00am - 11:00am	**No Cost**	**Must have valid 2010 Cool Smart tech ID**
INTRO TO COOL SMART	Tuesdays, starting **3/01/11**	11:30 -1:00pm	**No Cost**	Open to all contractors

Coffee and donuts will be served at the morning sessions

***There will be NO class on Tuesday, 3/29/11**. Sessions alternate or as demand for refreshers dictates.

** $100 *reimbursable fee* (for DT 101), per technician. Your Company will be reimbursed when you purchase a duct blaster, test a site, and submit a Duct Sealing Reduction form in 2011. If multiple technicians are trained, you must submit an equal number of completed forms in 2011, and will be reimbursed $100 each, up to the total number trained.

DUCT TESTING 101 (DT 101): HOW & WHY MEASURE AIRFLOW

- Learn and use the tools that measure system airflow and a Duct Blaster to measure system duct leakage
- See why proper airflow and sealed ducts mean that you can TRUST THE MANUAL J LOAD CALC
- Learn to beat your competition by selling high efficiency, right-sized systems
- You can earn a duct sealing reduction incentive of $2.00 per CFM reduction , up to $600 per house. Pre and Post Testing required

QIV REFRESHER TRAINING

Target Audience: Trained Technicians with valid ID numbers

- If you completed less than (5) QIVs in 2010 you must attend this class to remain active with Cool Smart QIV,
- Sharpen your knowledge of Superheat/Subcooling
- See how approved electronic tools improve accuracy and speed of measurements
- Q&A opportunity with our Technical Training Staff
- Calibrate your Cool Smart- approved QIV tools prior to attending or do it after class. ***MUST BRING TOOLS AND CHARTS TO CLASS!***

*This is a Refresher course for already trained technicians. For new technicians, attending the "Duct Testing 101" course is a prerequisite. *Do not attend this class if you do not have a valid Tech ID in 2010.* All techs with valid IDs from 2010 are welcome but limited to 20 techs per session.

INTRODUCTION TO COOL SMART

- 2011 Customer Rebates
- Duct Testing will add profit to every attic replacement
- Quality Installation Verification (QIV) incentives can be earned on Service and new installs
- Learn about Contractor Incentives that can total as much as $2,500 per job!

This class is recommended for Owner/Operators, Sales/Office Staff, Service and Installation Managers

We will get your staff into the correct courses to maximize your time and 2011 Contractor Incentives!

Don't delay, contact Sharon Carlino to register!

Phone: 508-365-3260 Email: sharon.c[illegible]o@csgrp.com

For more information on COOL SMART, vis[illegible]w.masssave.com

RST Thermal 2011 Training Schedule

372 University Avenue, Westwood, MA 02090
(781) 320-9910 Fax: (781) 320-9906

Contemporary Hydronics: A full-day class where you will learn about the heart of the RST Thermal Systems approach. Learn why, when and where to use condensing stainless steel boilers, smart pumps, residential and light commercial controls, and low water content, low temperature, low water radiators. This one-day class covers all aspects of hydronic system design and includes a discussion of the Twelve Commandments of Comfort.

April 13	9:00-4:00
May 11	9:00-4:00
June 22	9:00-4:00

Multi-Zoning Forced Hot Air: Covering the innovative solution to single-zoned forced hot-air heating systems, without opening up walls, ceilings and ductwork, and with new construction. A discussion about web-based home management systems that also monitor electrical and HVAC use in a simple platform.

Solar Thermal Technology: Covering the basics of thermal technology: applications, system sizing, collector types and controls. Featuring flat panel solar panels for residential and commercial hot water systems and evacuated tube solar systems with heat pipe principle.

Modern Pumping & Controls: Learn about pumps and controls, the last frontier for saving energy in a hydronic system. This seminar covers modern pumping using ECM technology, as well as controls for hydronic, geothermal, solar and snow melting systems. Learn when, where and why to use them, and how to get the most out of today's technology. Pipe it! Power it!

Session# 1 (7:30 a.m. – 9:30 a.m.)
April 20 – Solar Thermal Technology
April 27 – Multi-Zone Forced Hot Air
May 18 – Modern Pumping & Controls
June 1 Solar Thermal Technology

Session#2 10:00 a.m.- Noon
Modern Pumping & Controls

Training takes place at: 372 University Ave., Westwood, MA. Please give a 24-hour notice if you are unable to attend. Otherwise, you will be invoiced a no-show fee of $30.00.

[ ] Yes, please sign me up for:

Class title: _____ Date: _____

Your name: _____ Company: _____

Phone: _____ E-mail: _____

Fax registration to: 781-320-9906 or e-mail to: mehickey@rstreps.com

RST Thermal

RST Thermal 2011 Training Schedule

372 University Avenue, Westwood, MA 02090
(781) 320-9910 Fax: (781) 320-9906

Contemporary Hydronics: A full-day class where you will learn about the heart of the RST Thermal Systems approach. Learn why, when and where to use condensing stainless steel boilers, smart pumps, residential and light commercial controls, and low water content, low temperature, low water radiators. This one-day class covers all aspects of hydronic system design and includes a discussion of the Twelve Commandments of Comfort.

April 13	9:00-4:00
May 11	9:00-4:00
June 22	9:00-4:00

Multi-Zoning Forced Hot Air: Covering the innovative solution to single-zoned forced hot-air heating systems, without opening up walls, ceilings and ductwork, and with new construction. A discussion about web-based home management systems that also monitor electrical and HVAC use in a simple platform.

Solar Thermal Technology: Covering the basics of thermal technology: applications, system sizing, collector types and controls. Featuring flat panel solar panels for residential and commercial hot water systems and evacuated tube solar systems with heat pipe principle.

Modern Pumping & Controls: Learn about pumps and controls, the last frontier for saving energy in a hydronic system. This seminar covers modern pumping using ECM technology, as well as controls for hydronic, geothermal, solar and snow melting systems. Learn when, where and why to use them, and how to get the most out of today's technology. Pipe it! Power it!

Session# 1 (7:30 a.m. – 9:30 a.m.)
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Modern Pumping & Controls

Training takes place at: 372 University Ave., Westwood, MA. Please give a 24-hour notice if you are unable to attend. Otherwise, you will be invoiced a no-show fee of $30.00.

[ ] Yes, please sign me up for:

Class title: _____ Date: _____

Your name: _____ Company: _____

Phone: _____ E-mail: _____

Fax registration to: 781-320-9906 or e-mail to: mehickey@rstreps.com

Measuring Duct Leakage: It's Code

Did you know?

Effective 2010, the Massachusetts Energy Code Options became:

1: 780 CMR, Chapter 61 (Amended 7th edition) = 2009 IECC (International Energy Conservation Code)

OR

2. 780 CMR, Appendix 120 AA, also known as The Stretch Code - "a more energy efficient alternative to the base energy code" that municipalities may volunteer to adopt.

Testing the Duct System in NON-STRETCH CODE cities or towns (1 of the 4 Testing Options Required)

At rough-in, air handler not installed	Duct Blast Test - Duct Only	4
At rough-in, air handler installed	Duct Blast Test - Duct w/indoor unit	6
Post-construction, leakage to outdoors	Blower Door Test	8
Post-construction, total leakage	Duct, Registers, Indoor Unit	12

Important: Which test is required will be determined by the inspector. Be prepared! Call the City or Town Hall beforehand. "Ideally, at rough-in, air handler not installed" is more forgiving. **Stretch Code cities or towns require a Blower Door Test.**

Q: Why are there "Stretch Code" cities or towns? A: These towns get federal funding.

APPENDIX AA: STRETCH ENERGY CODE

The Stretch Energy Code is the ***International Energy Conservation Code*** (IECC) 2009 with Massachusetts Amendments (780 CMR 115.AA)

401.3 Prescriptive Option for Residential Additions: Additions to an existing building, building system, or portion thereof shall conform to IECC 2009 Chapter 4, and shall further demonstrate compliance with:

3. Ducts for new HVAC systems shall be sealed and tested post-construction to demonstrate leakage to outdoors of less than or equal to **4 cfm per 100 square feet of conditioned floor area,** except where the air handler and all ducts are located within ***conditioned space.***

Important: Blower Door Tests are required for Stretch Code cities or towns and are 50% more stringent (4 cfm vs 8 cfm) than non-Stretch Code areas.

Also see: Duct Leakage Q&As, and "Stretch Appendix to the Building Energy Code in Massachusetts, Q&A - October 2010.

Taking HVAC the box

Air Purchases, Inc., 24 Blanchard Road, Burlington, MA 01803 (781) 273-2050 www.airpurchases.com

Duct Testing Q&As

Q: How can I learn more about duct testing?

A: Reach out to Sharon Carlino at Conservation Services Group (CSG) 508-836-9500. Register for the Cool Smart "Duct Diagnostics 101 Course, which is held on a regular basis at Air Purchases in Burlington.

Q. Which cities and towns have adopted the "Stretch Energy Code?"
A: As of April 26, 2011, seventy-two municipalities have adopted the Stretch Code, but more are being added all the time. For a current list, Google "Stretch Codes Mass" or go to:
http://www.mass.gov/Eoeea/docs/doer/green_communities/grant_program/stretch_code_towns.pdf

Q: What if the duct already exists?
A: You do not have to test existing ductwork, however, if you add to the duct distribution system you will have to test the portion you have added.

Q: How much does a Duct Blaster test kit cost?
A: The price varies, but be prepared to invest approximately $1,800 for a TEC Duct Blaster or comparable system. **NOTE:** If you participate in the CoolSmart "CFM Leakage Reduction Program" you can earn $2.00 per cfm in leakage reduction, up to $600, plus you can get a significant savings on the cost of a Duct Blaster. Call Sharon Carlino at 508-836-9500 for more information.

Q: Can I do my own test?
A: You would need to confirm that with the municipality; some require third-party verification.

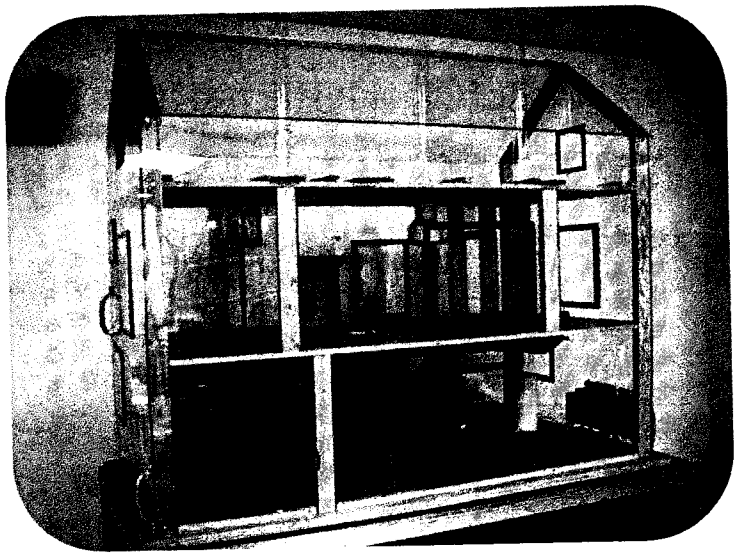
Q: How long does a Duct Blaster test take?
A: Approximately 45 minutes, once you have become comfortable with the process.

Important: Hidden or unexpected costs can eat significantly into your bottom line. Being prepared will allow you to cover these costs during the sales process. Know your marketing area and what is required there for Duct Leakage testing. Also be aware of what cities and towns are charging for Mechanical Permits. We have seen costs for such permits ranging from a flat fee to a percentage of the sold job of up to 10%.

Still have questions? Please feel free to contact Jim Travers, Air Purchases, 781-273-2050.

(Also see: "Stretch Appendix to the Building Energy Code in Massachusetts - Question & Answer, October 2010")

The House of Pressure



Anthony Cox, Technical Coordinator
New River Center for Energy Research and Training
550 Industrial Drive NE, Christiansburg, VA 24073
Phone: 540-260-9081 Fax: 540-260-9084
Email:acox990@aol.com

Description

- The House of Pressure is used to visually demonstrate Home Performance Testing using Pressure Diagnostics. The House is made of clear lexan *(High Strength Plastic Laminate)* so the inside of the House is visible from all 4 sides.

- The House has an operable Forced Air Duct System, a Dryer, Bathroom Fan, Fireplace, and Water Heater. There are smoke generators for the fireplace, water heater, and car exhaust.

Description (cont.)

- House of Pressure Bio
  - The House of Pressure has been in use for over 10 years. It has been used for presentations at DOE Regional and National Weatherization Conferences, Affordable Comfort Conferences, as well as numerous state weatherization conferences and trainings.
- Using House with Larger Groups
  - A camcorder and LCD projector can be used to display the House and testing procedures on the screen for larger audiences.

Testing

- Most tests performed on an actual home can be performed on The House of Pressure.

- The House can be used to demonstrate Blower Door testing using a Digital Manometer and a Minneapolis Duct Blaster. Zonal and Pressure Pan testing can also be demonstrated when performing Blower Door tests.

- The trainer can show duct leakage and how it can affect Health & Safety, Comfort, Durability, and Energy Efficiency by creating leaks in the supply ducts, return ducts or both.

Testing (cont.)

- It can be used to demonstrate the effect of thermal bypasses, show pressure and thermal boundaries and can simulate backdrafting conditions.

- There are operable doors from the bedroom and bathroom to the central living area that can be used to show the effects of door closure with a central return duct system. Pressure relief methods can be shown and discussed.

Testing (cont.)

- Combustion Appliance Zone testing can be shown by following a Worst Case test procedure while using a digital manometer.

- Our most requested handout is a laminated sheet that has color-coded hose hook ups for using the digital manometer.
  - One side of this sheet has setups for Blower Door, Zonal, and Pressure Pan testing.
  - The other side shows manometer setups for Combustion Appliance Zone, Dominant Duct Leakage, and Room Pressure Testing.

Automated Performance Testing (APT)

- We can also use The Energy Conservatory's APT system with the House of Pressure to, simultaneously show readings for different locations in the house.
- When you make changes to one part of the house you can see how it affects other areas with immediate feedback from the APT.
- Additional information can be provided regarding the purchase and/or use of an APT with the House

Costs

The cost to purchase a House of Pressure is $8000.00

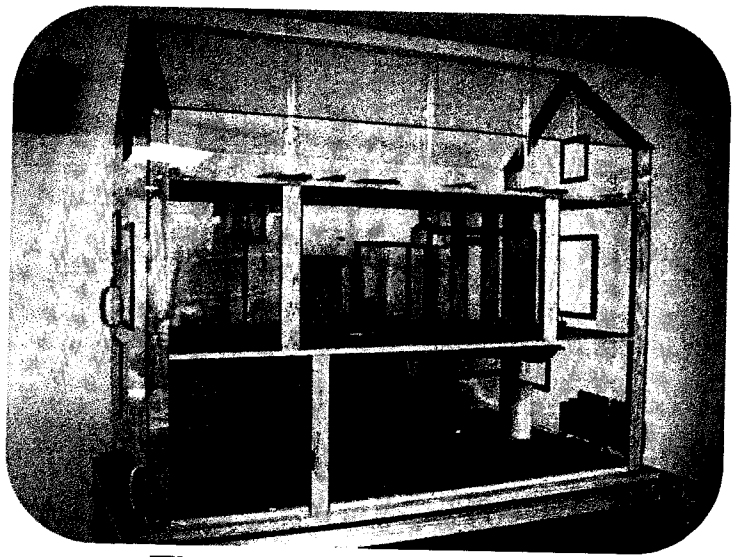
This includes…

- The House of Pressure
- Laminated Plywood Travel case with wheels
- Handouts that can be used with The House of Pressure
  - One electronic copy on a CD
- Copy of Power point presentation on CD that can be modified by you to fit your needs

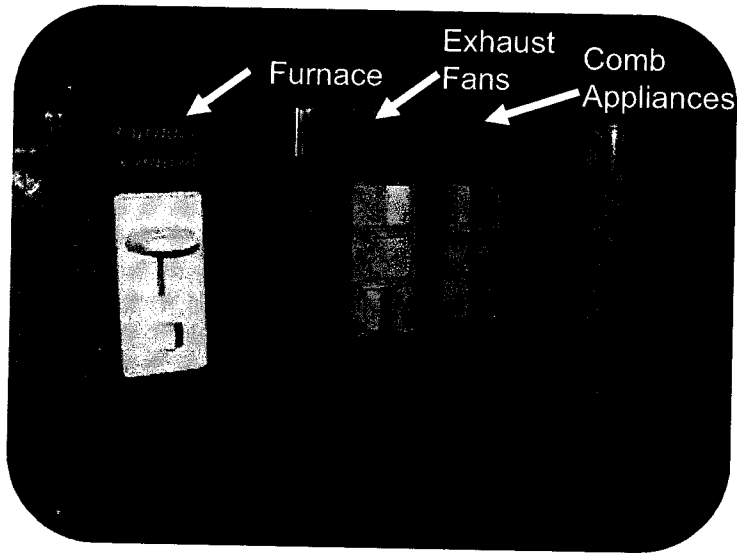
Costs (cont.)

This does not include

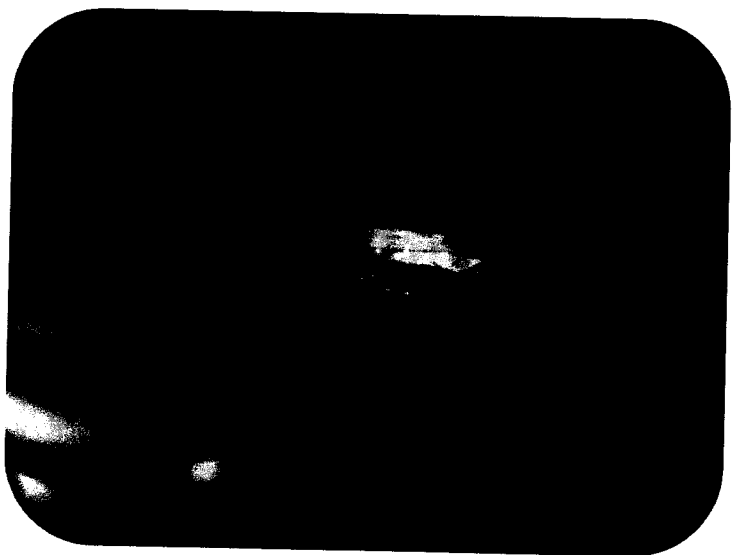
- Shipping
  - Estimated to be no more than $700 depending on location where the House is to be sent
- Minneapolis Duct Blaster, APT, or Digital Manometer
  - These can be purchased from The Energy Conservatory
  - We can also include this equipment in your quote, including setting it up for use with the House of Pressure.
- Train the Trainer training for using the House of Pressure is also available



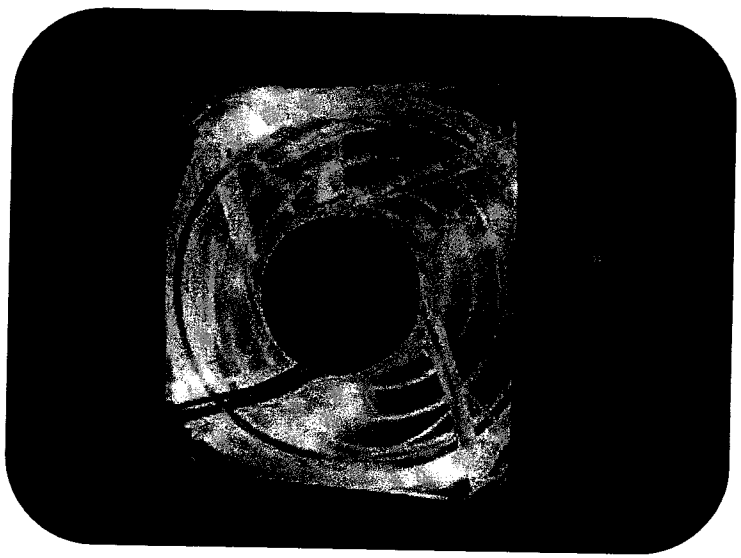
The House of Pressure



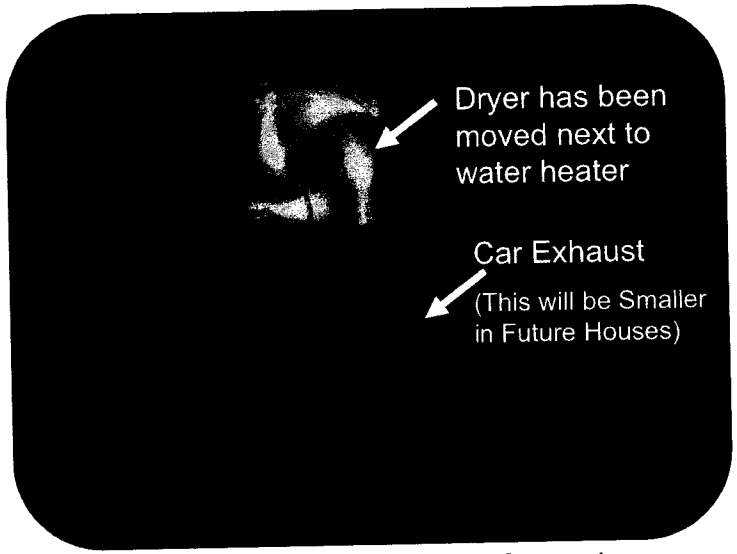
Control Panel



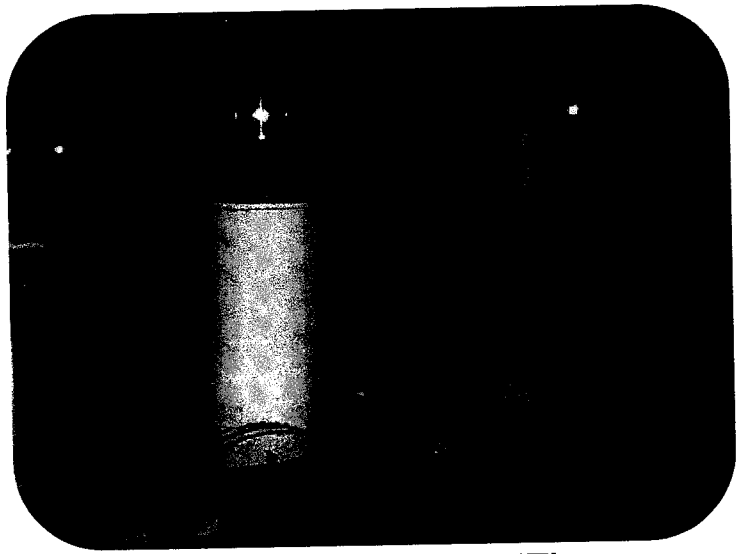
Kitchen with LED Lights when on



Bathroom Fan

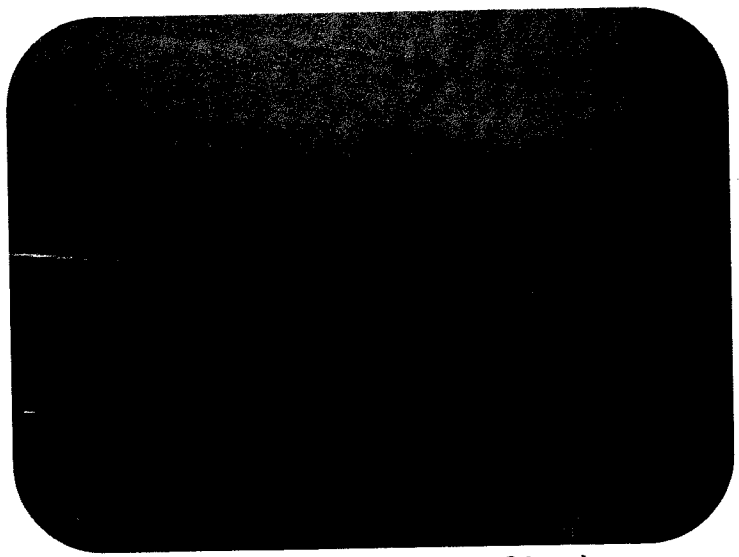


Dryer Fan & Car Exhaust

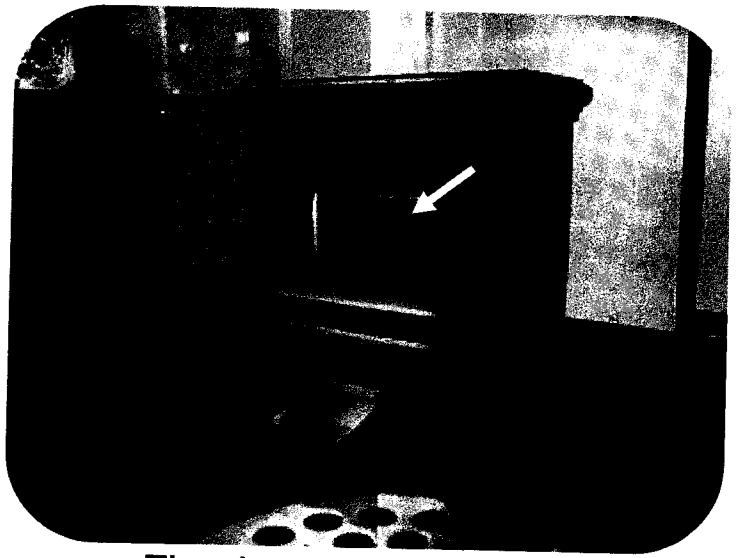


Water Heater (OFF)

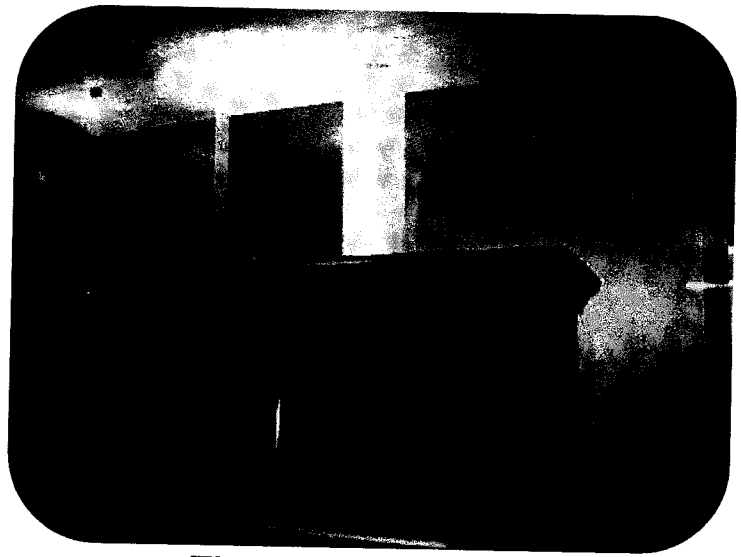
Water Heater (Backdrafting)



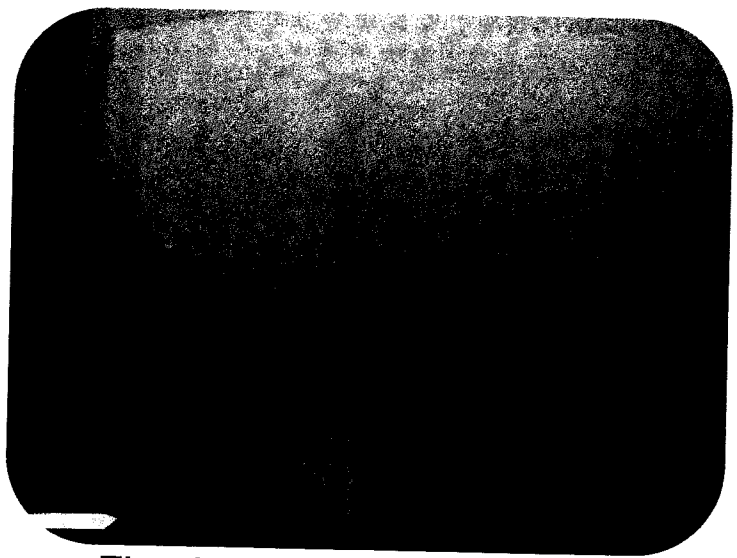
Water Heater (Drafting)



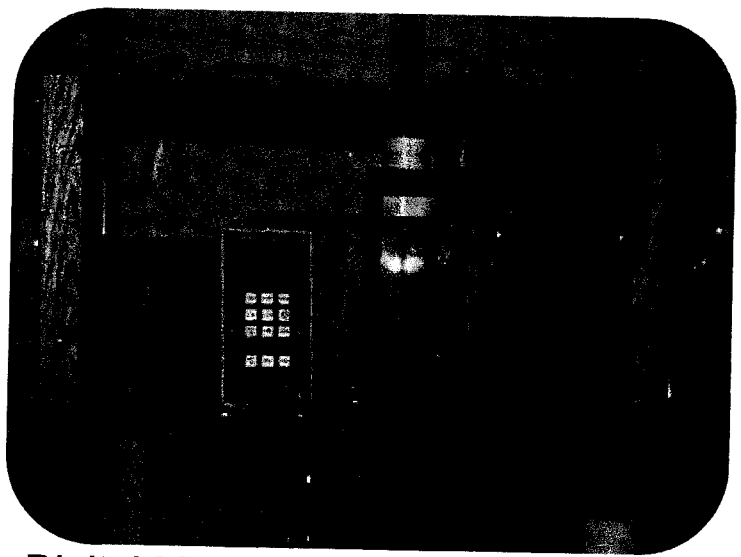
Fireplace (Backdrafting)



Fireplace (Drafting)

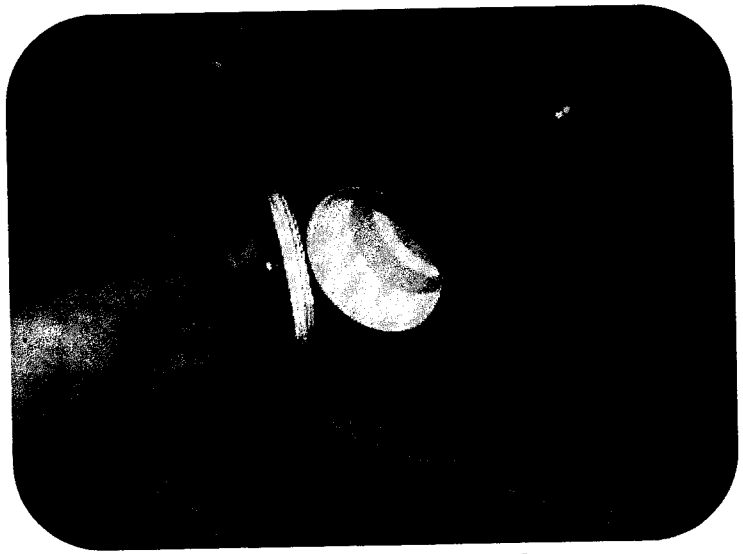


Fireplace Chimney (Drafting)



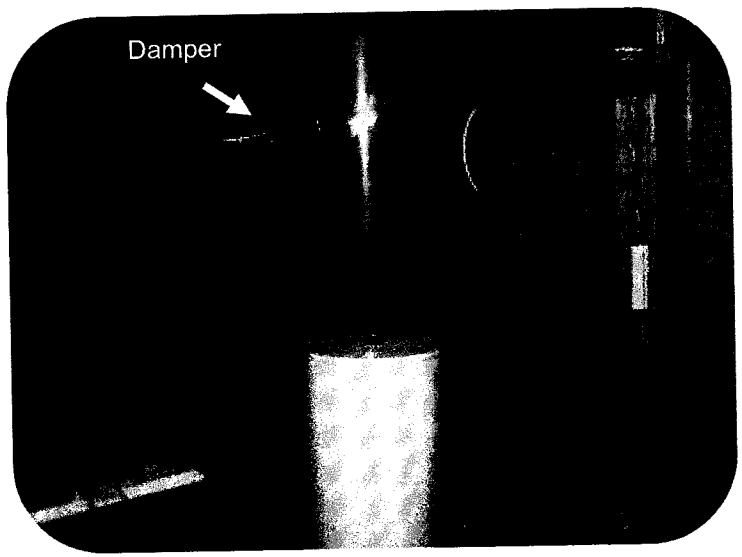
Digital Manometer Setup with House

Return Duct



Return Duct Leak

Supply Register (with streamers to show flow)

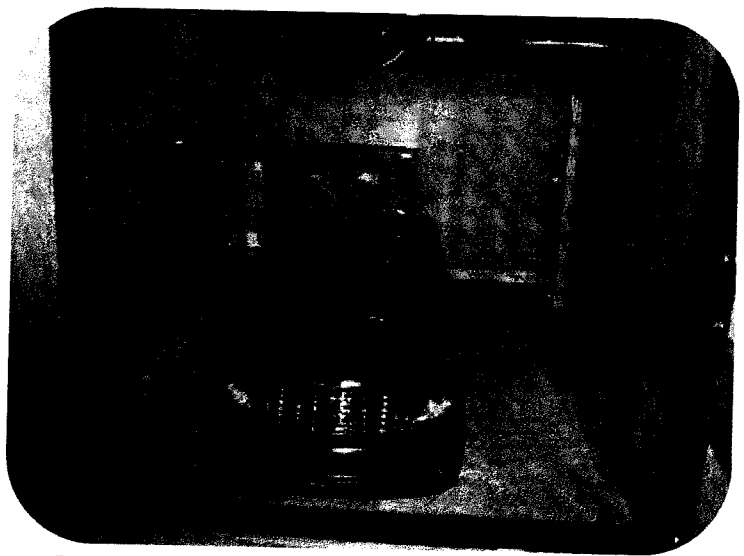


All Supply Ducts Have Dampers

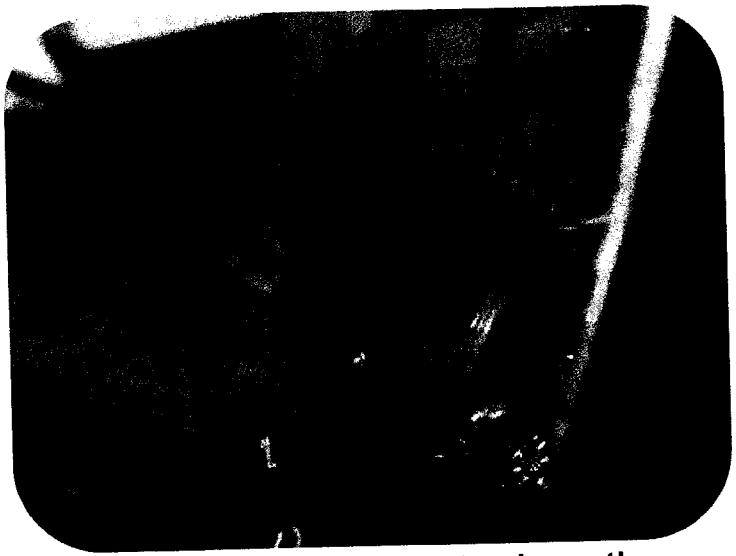
Supply Duct

Supply Duct Leak

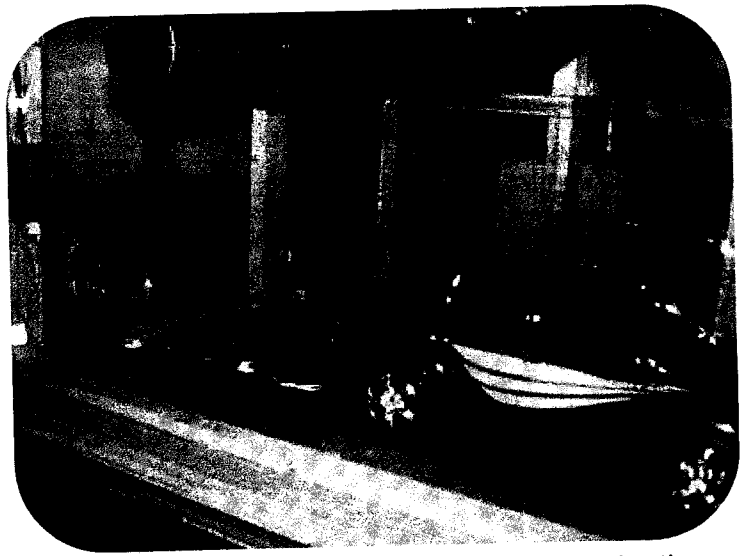
Car Exhaust (ON)



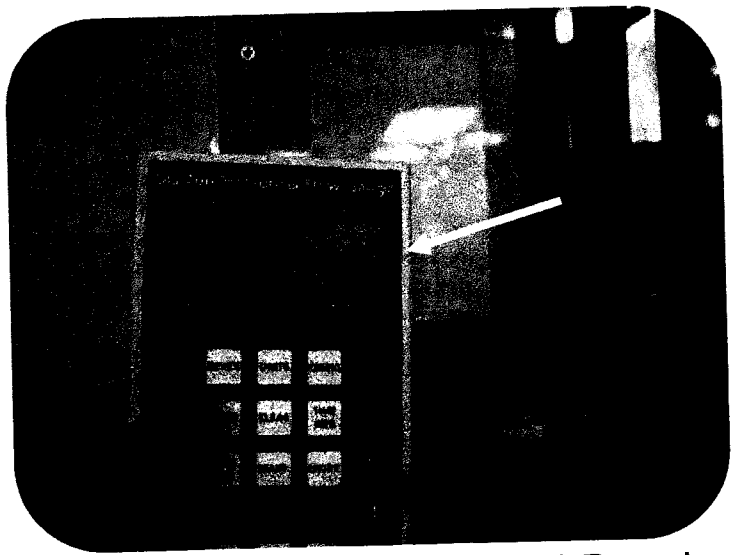
Car Exhaust Filling Tuck Under Garage



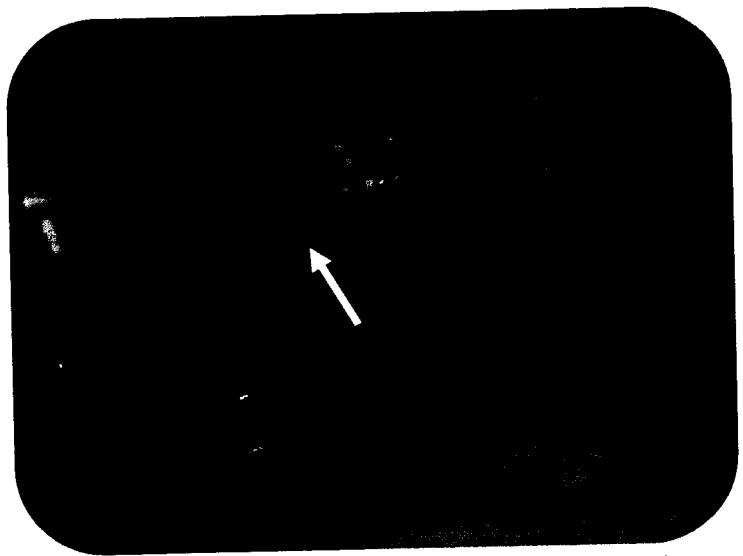
Car Exhaust Generator in action



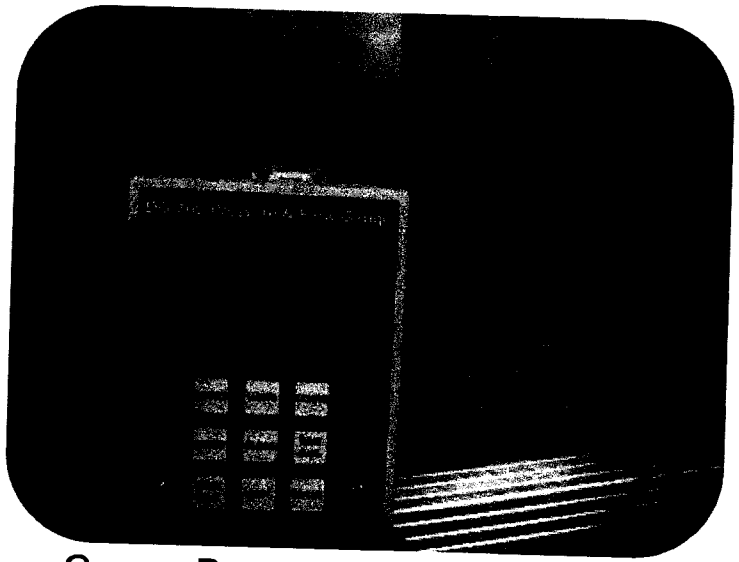
Exhaust Drawn into House by Depressurization



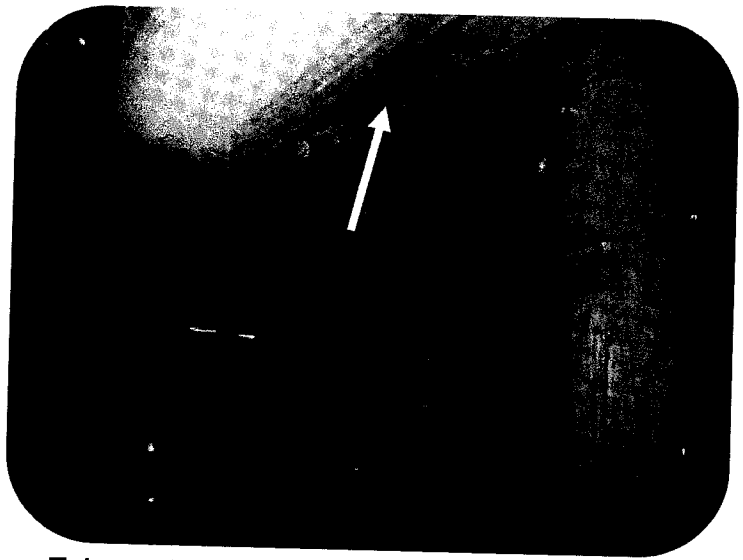
Bathroom Depressurized to -3.9 Pascal



Door from Garage to Basement

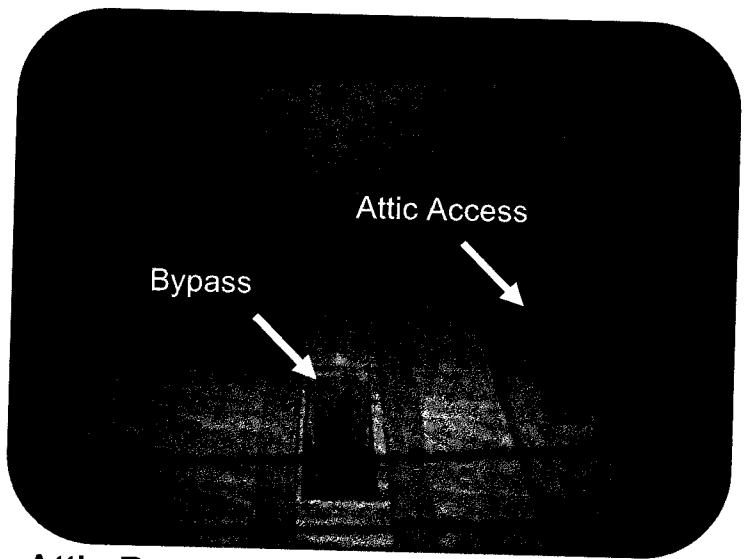


Garage Depressurized to -2.4 Pascal

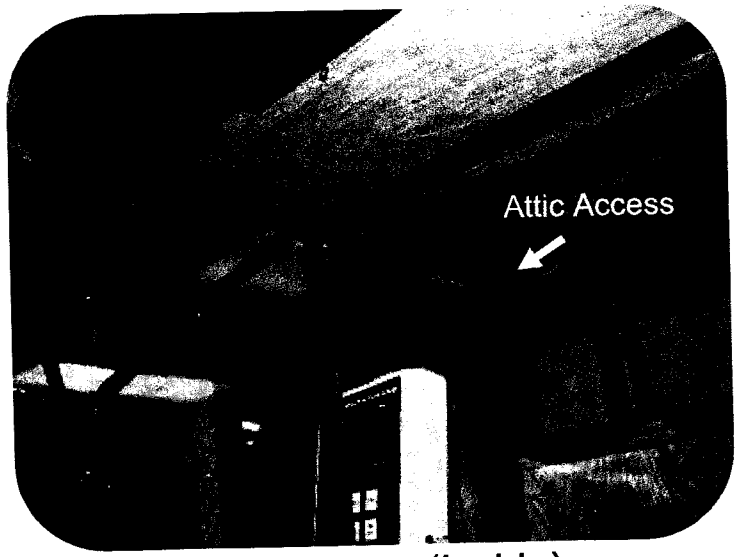


Exhaust Drawn into house thru Bypass in wall

Attic Bypass Opening



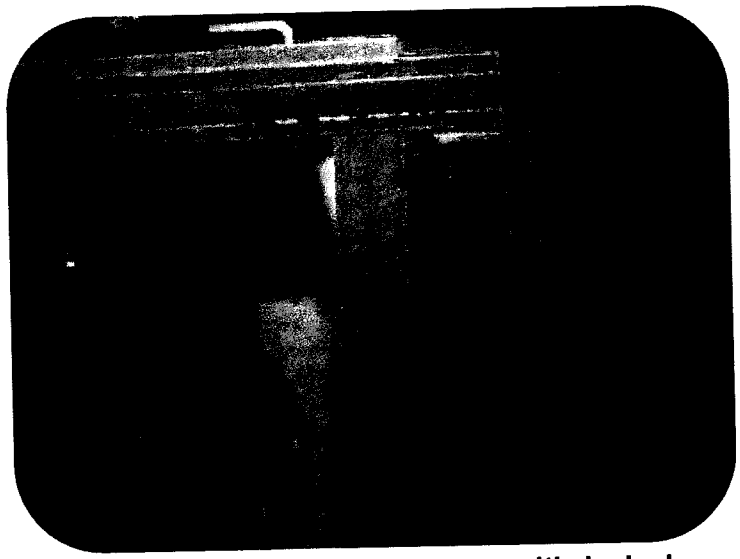
Attic Bypass Opening & Attic Access



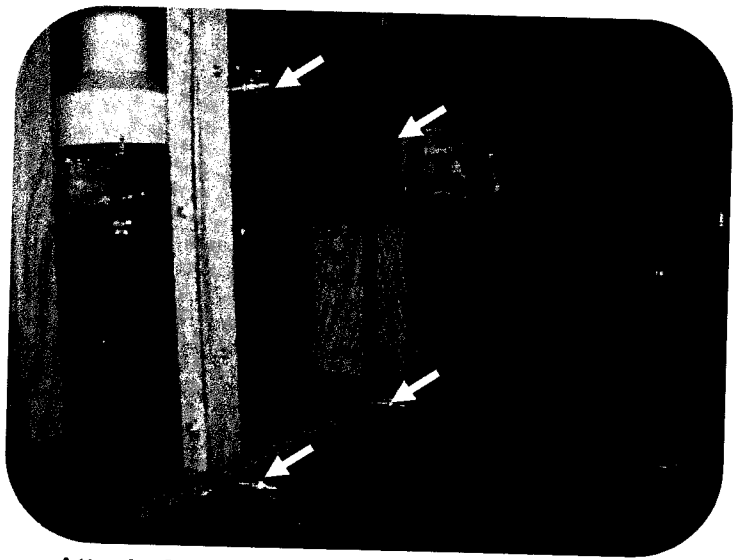
Attic Access (Inside)

Basement Access

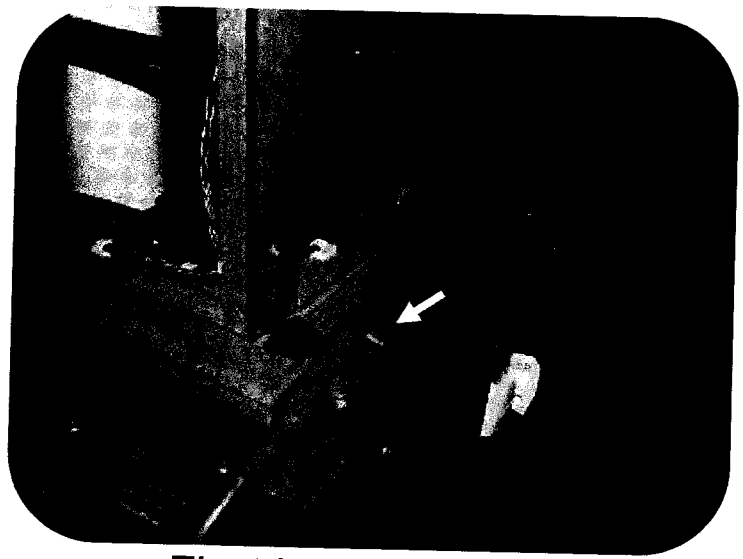
Operable Interior Doors



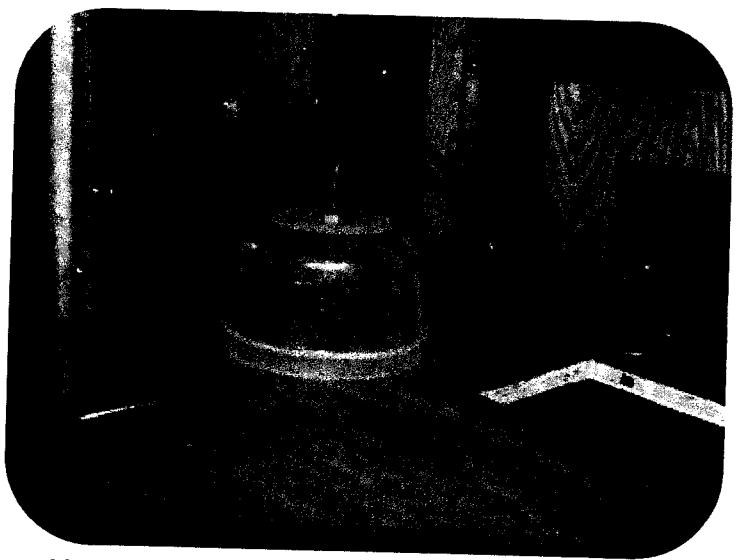
Magnetic Access Windows with Labels



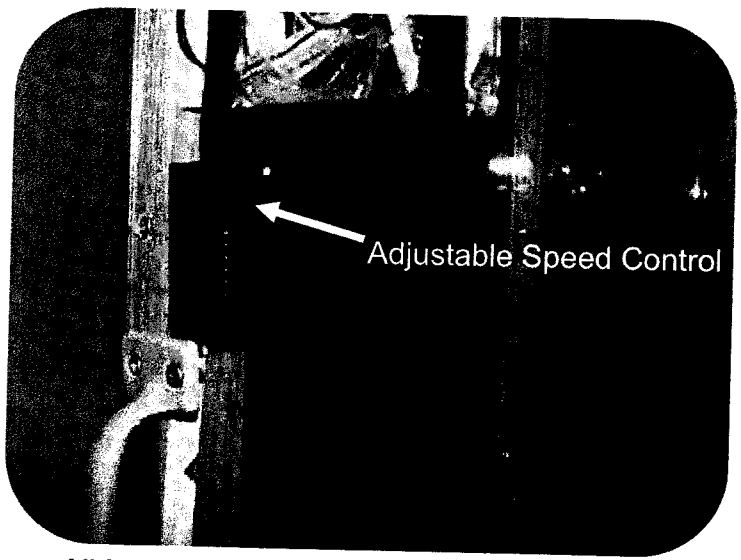
Attach Duct Blaster for Blower Door Testing



Electrical Connection

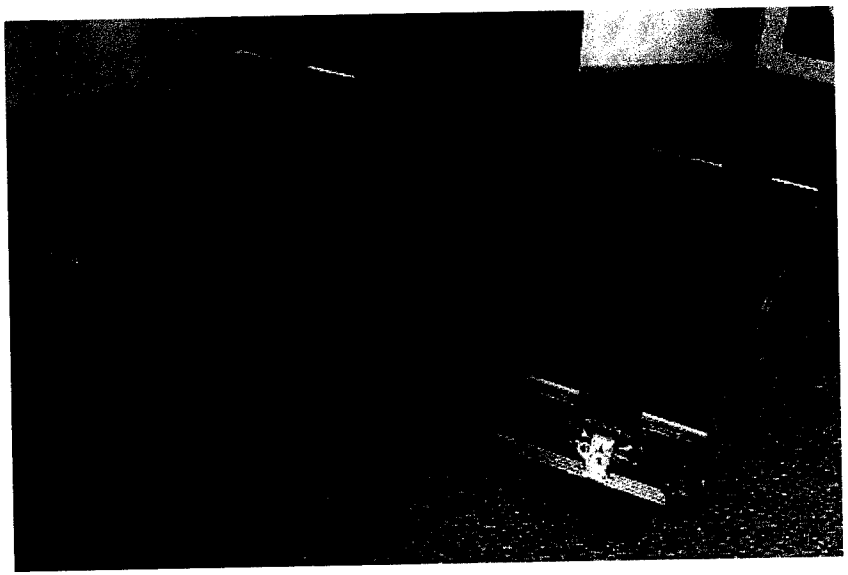


Using a Plastic Cup for Pressure Pan Testing



All Exhaust Fans Have Adj. Speed Controls

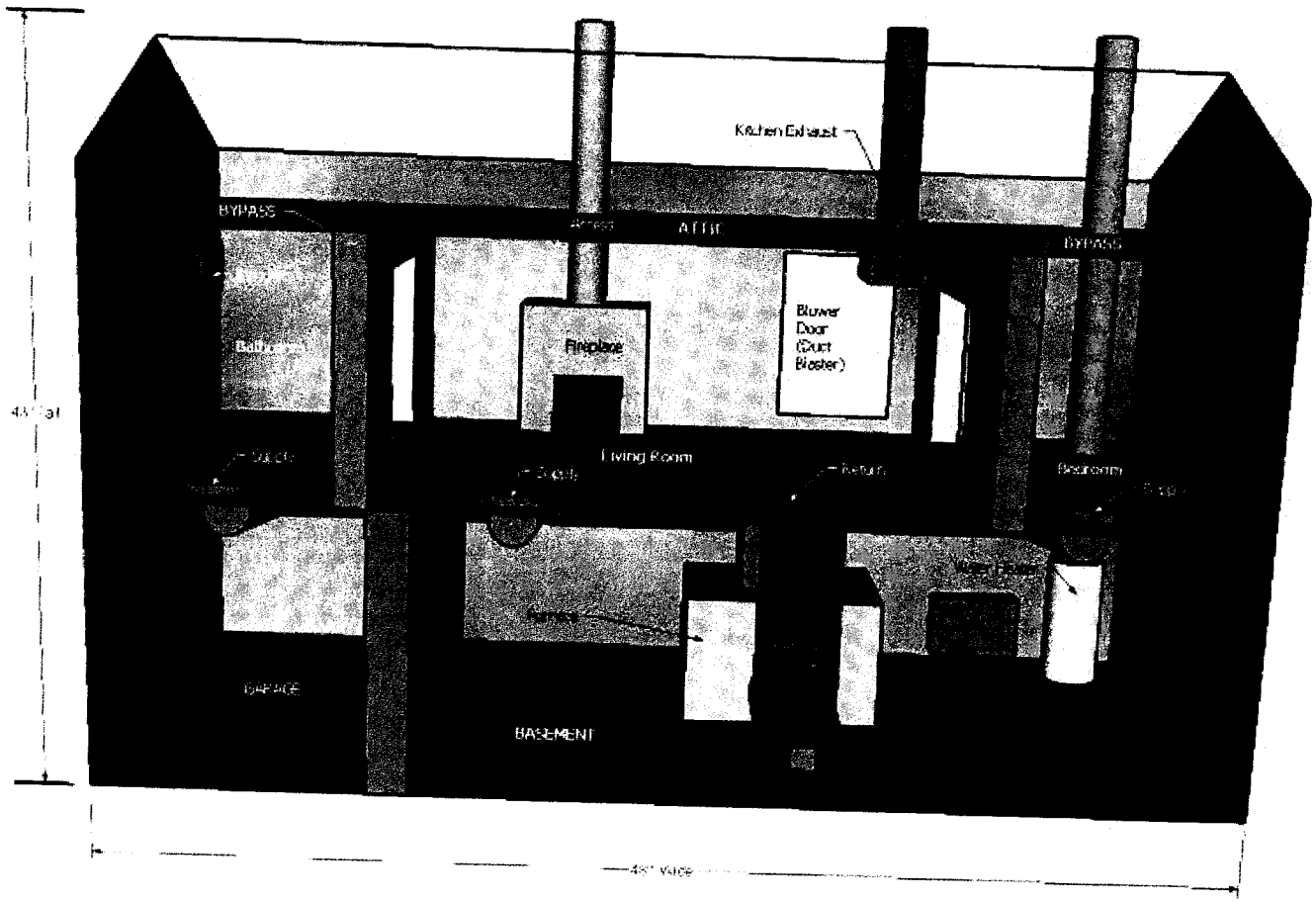
Travel Case / Stand

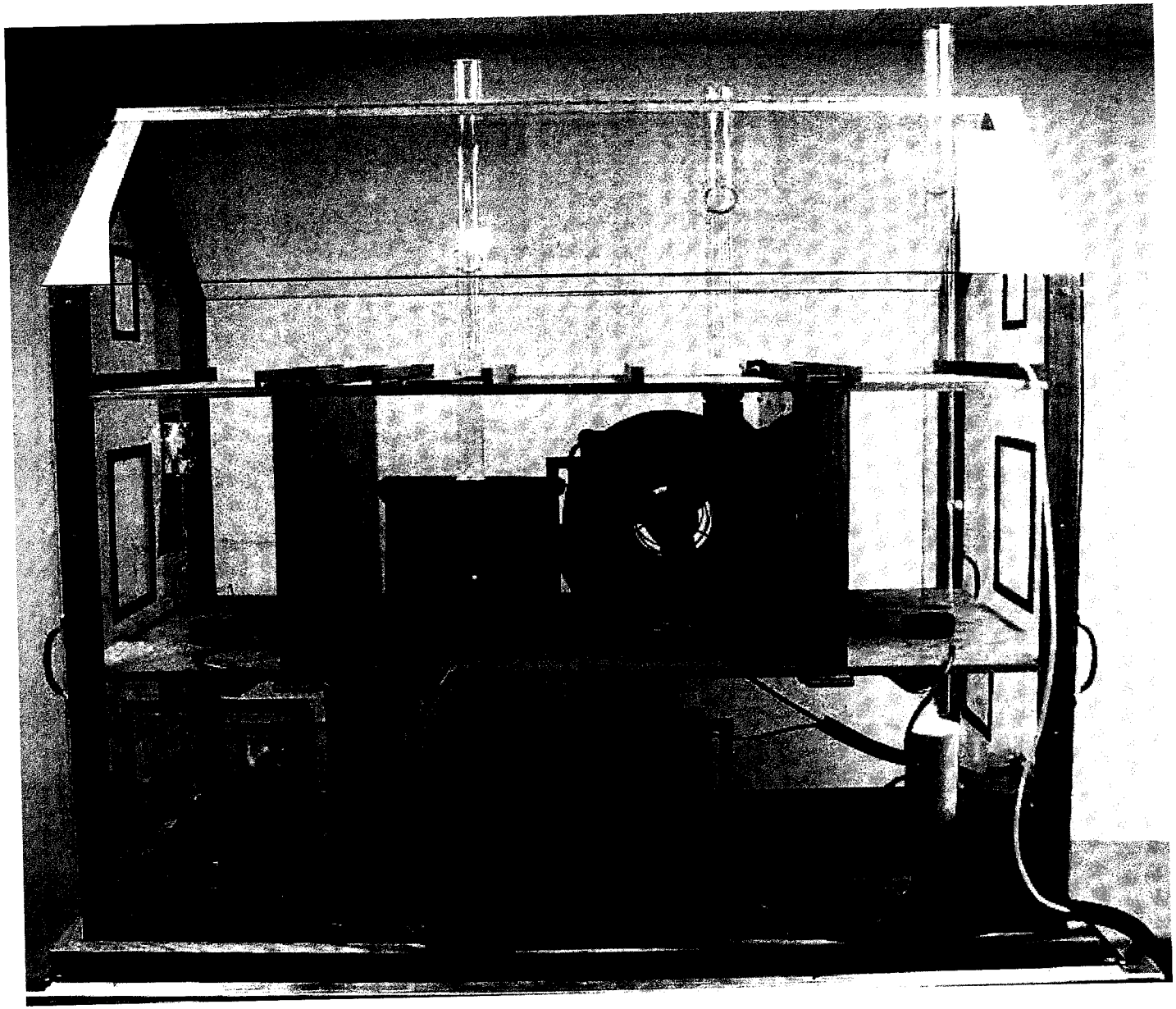


House Sits in Bottom of Case, top of Case is then placed over top of house and locked with latches

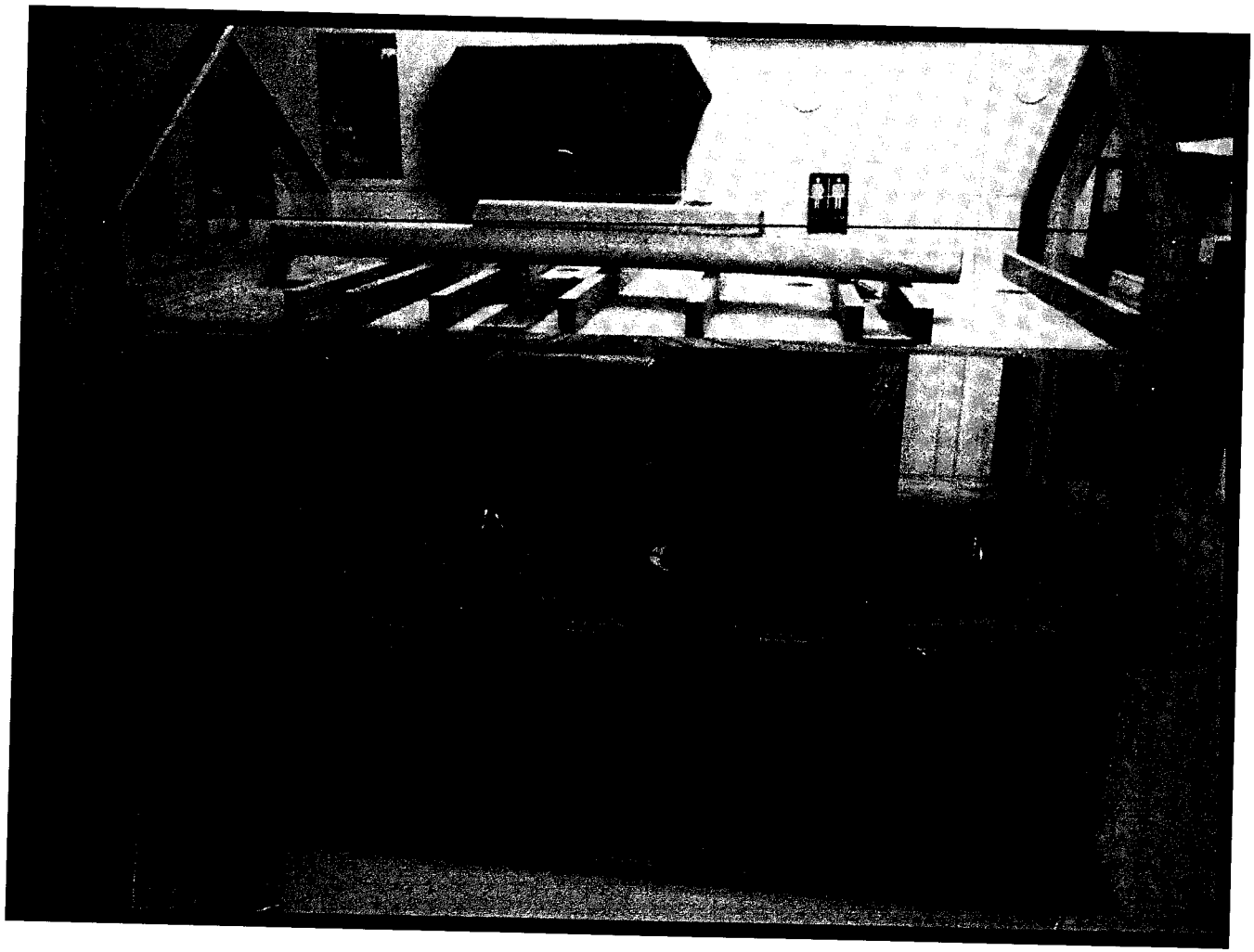
TOP OF TRAVEL CASE
(Also used for Display Table)

Sketch of the House of Pressure Model.

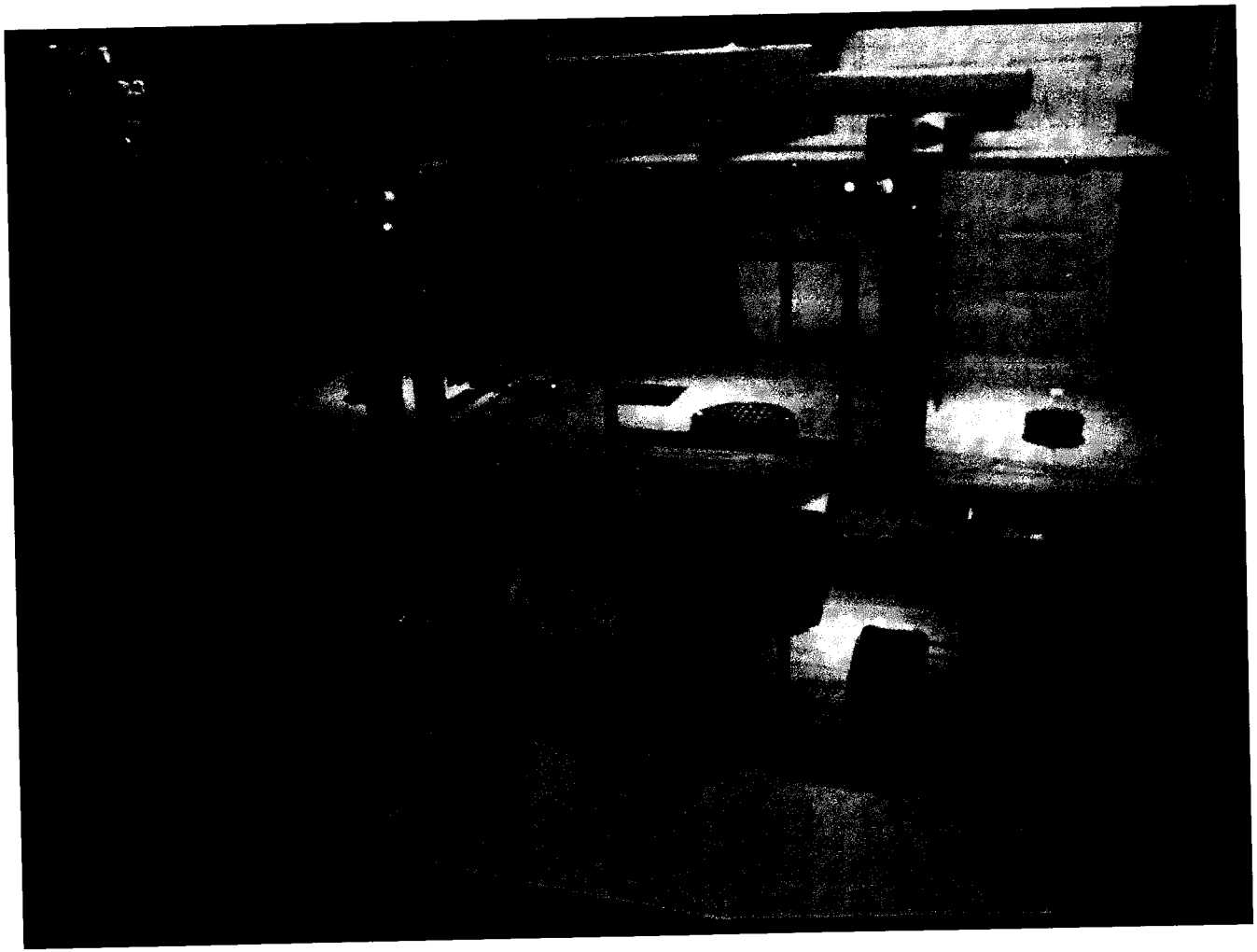




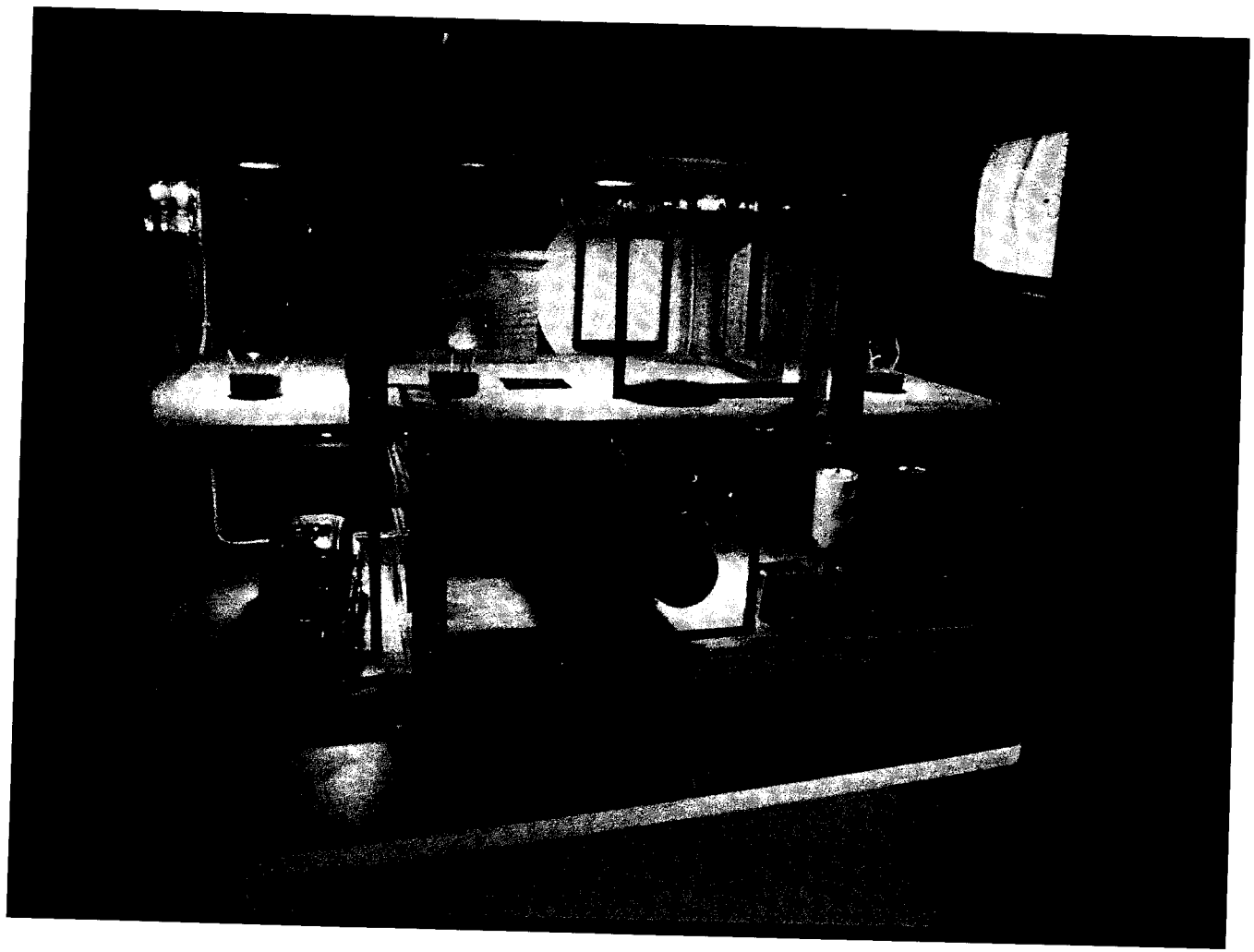
House of Pressure



Now has interior Lights



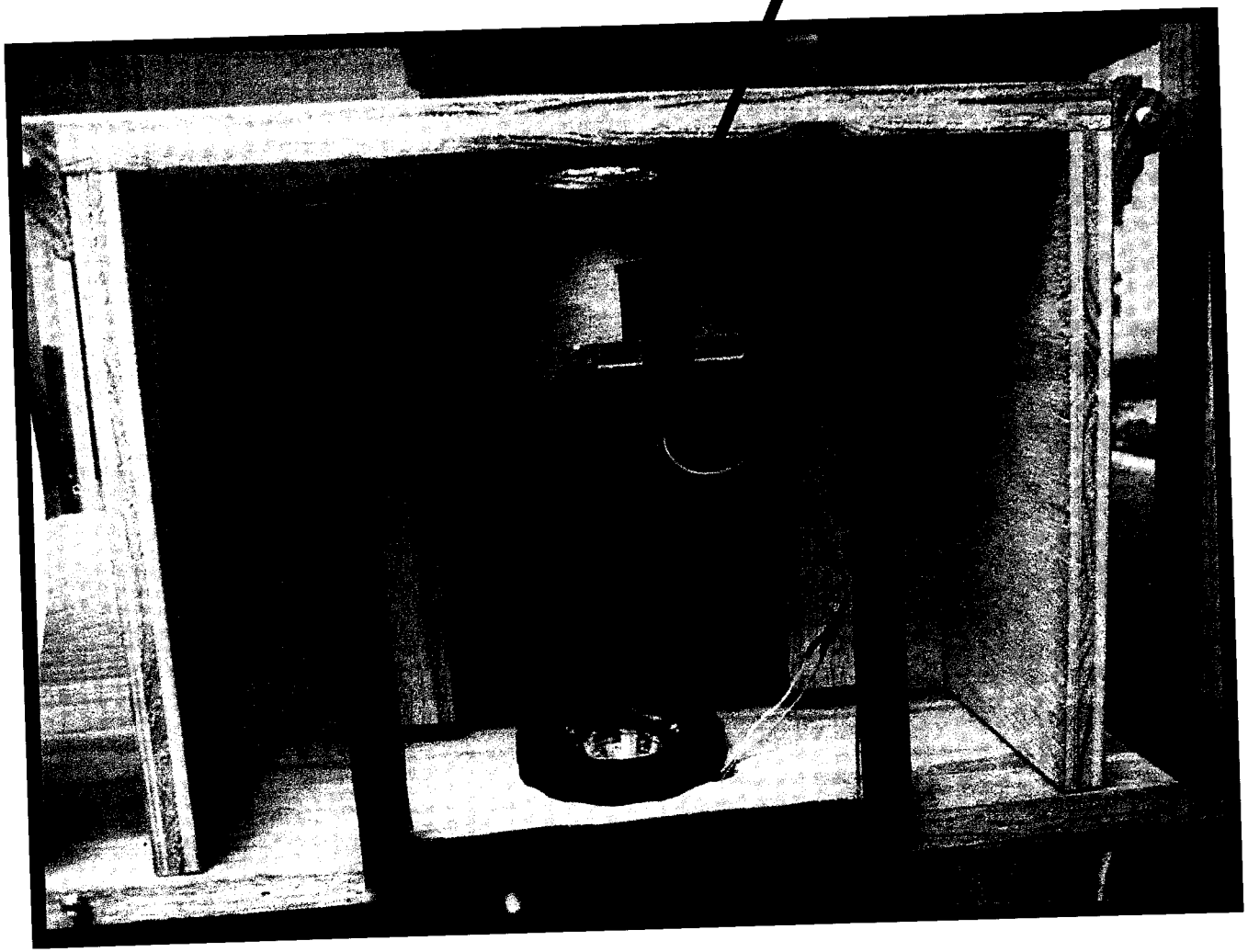
Lights & Appliances On



Speed Controls next to switches

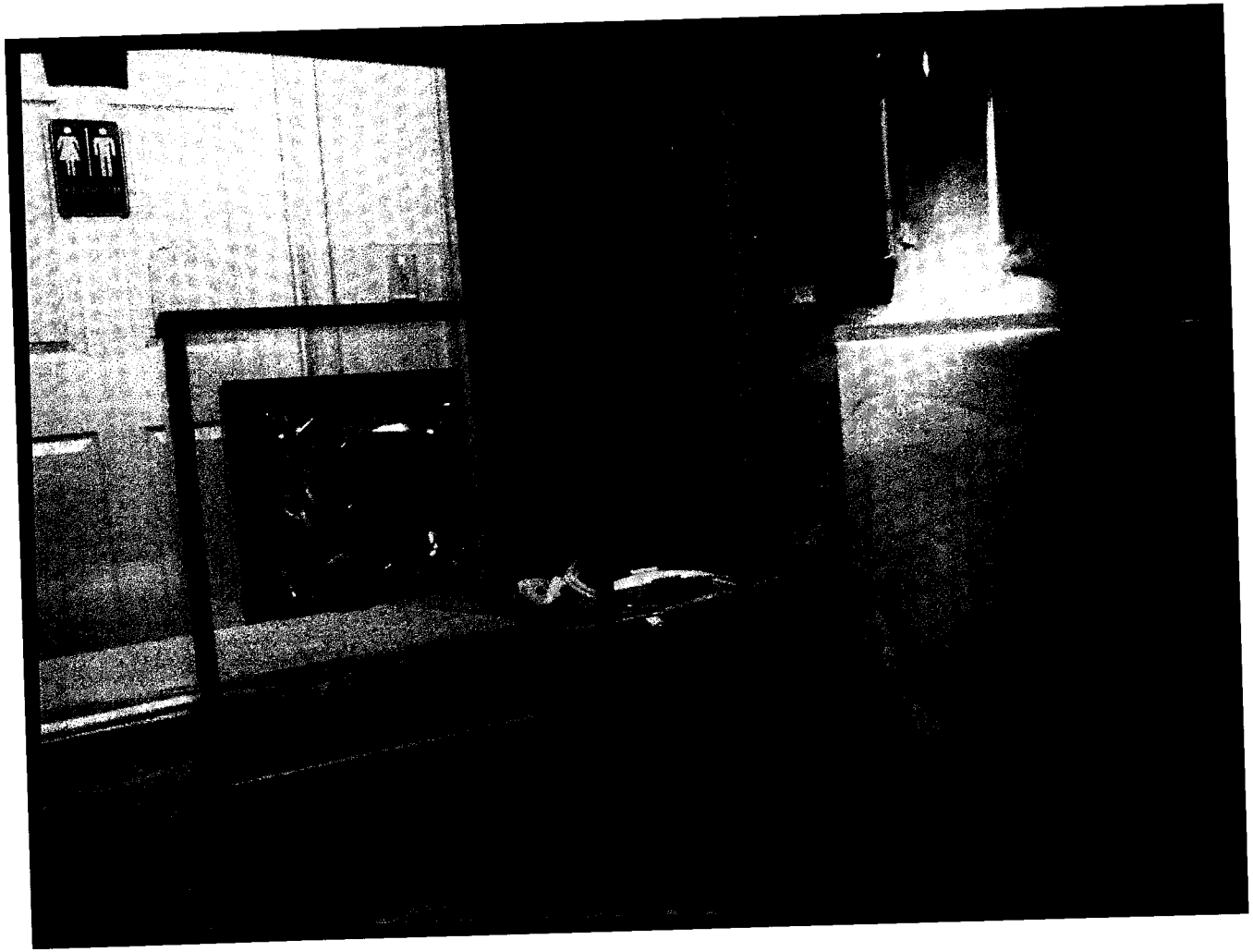
Fireplace

Back of Fireplace and Smoke Generator

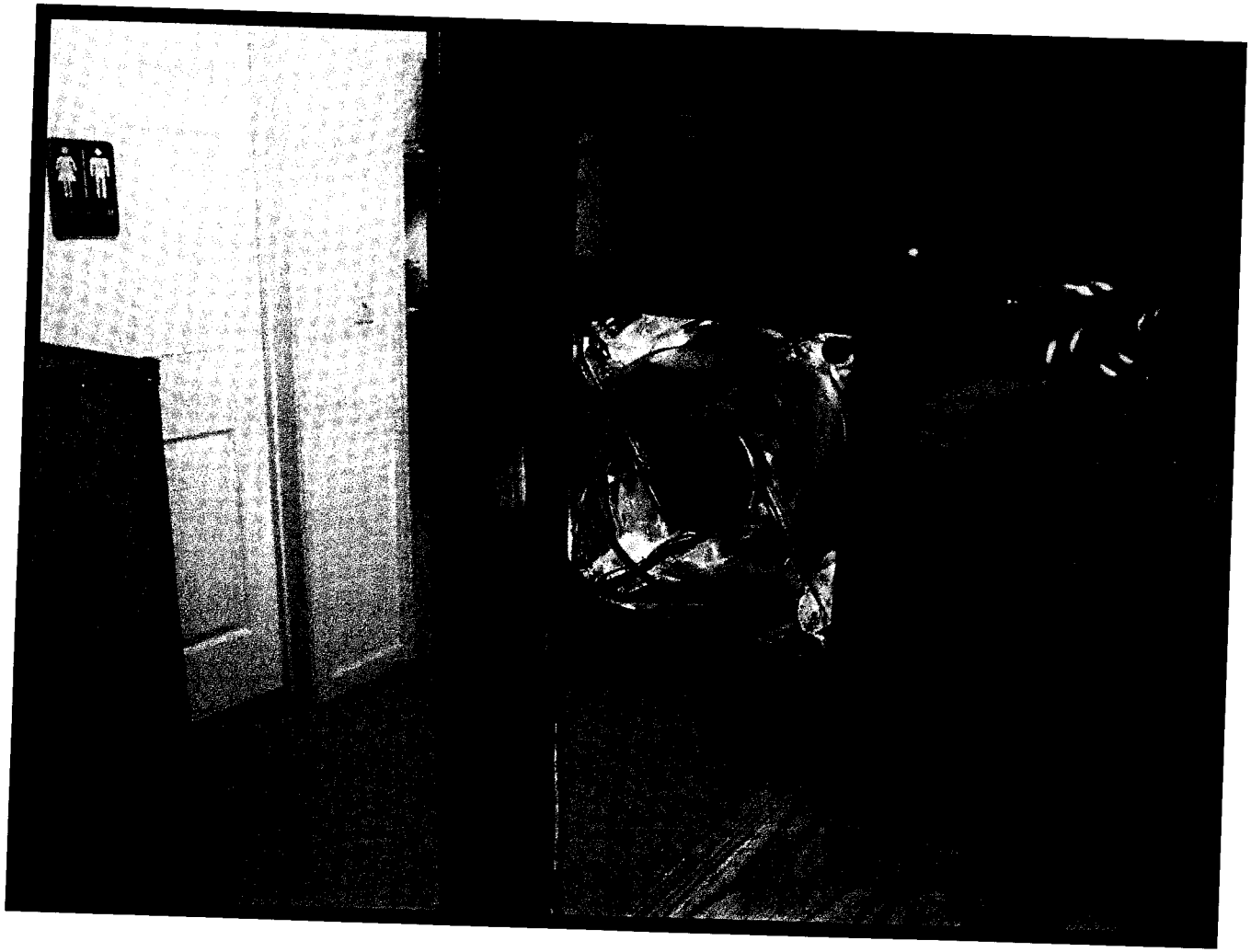


Garage

Dryer on,
Water Heater Backdrafting

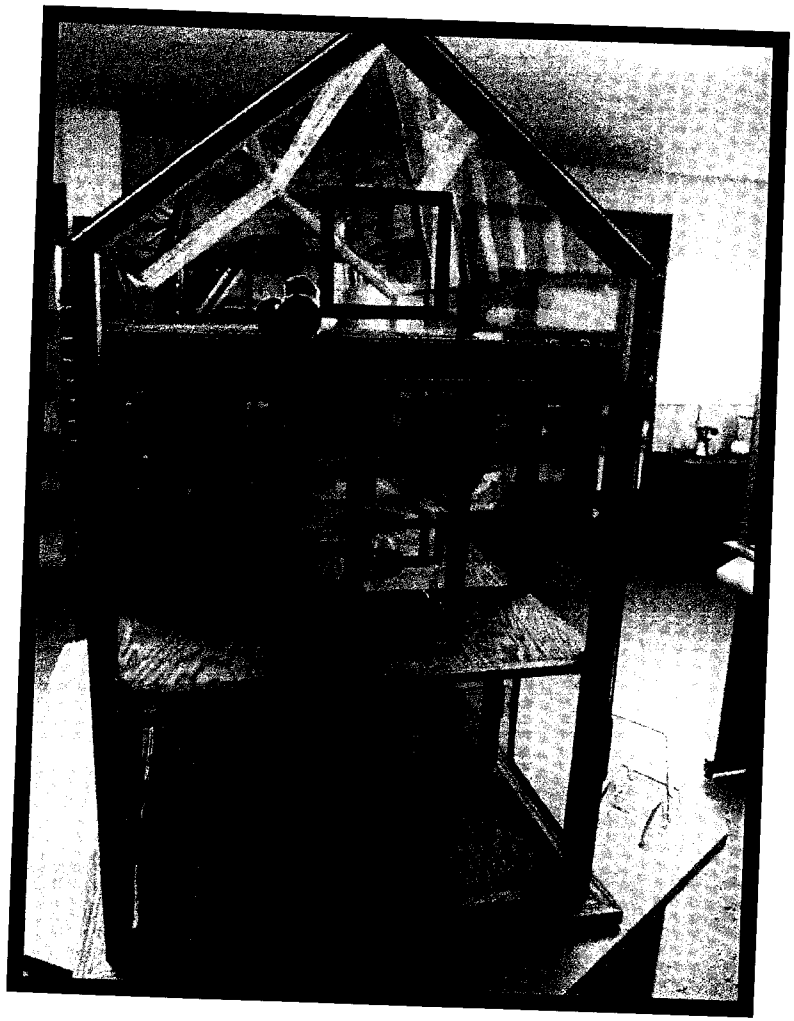


Bathroom Fan

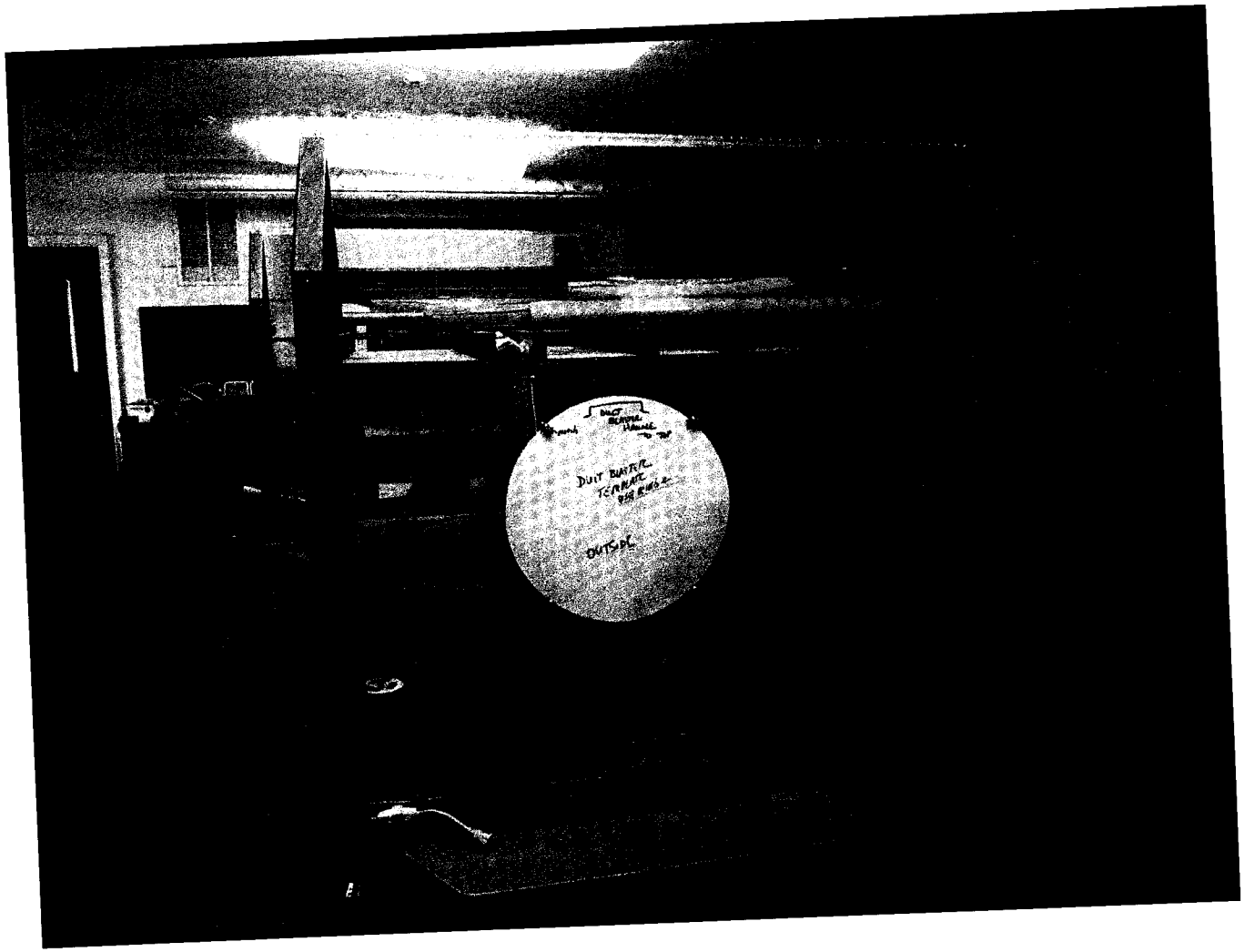


Kitchen Exhaust

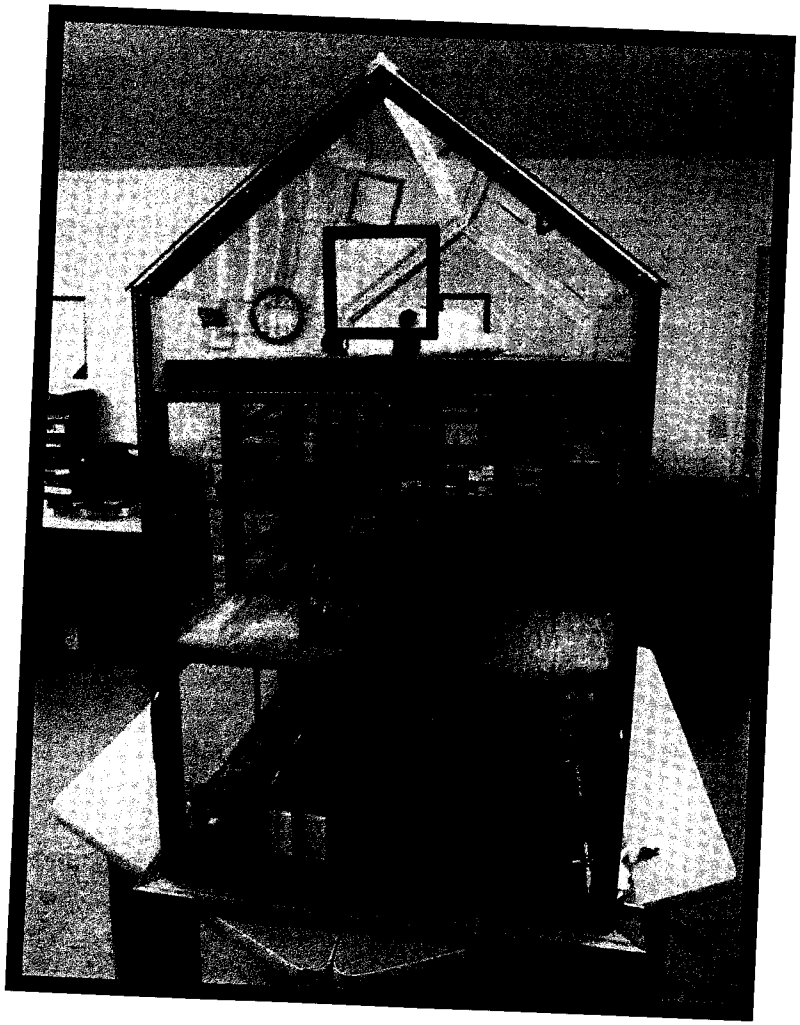
Left Side of House



Back of House

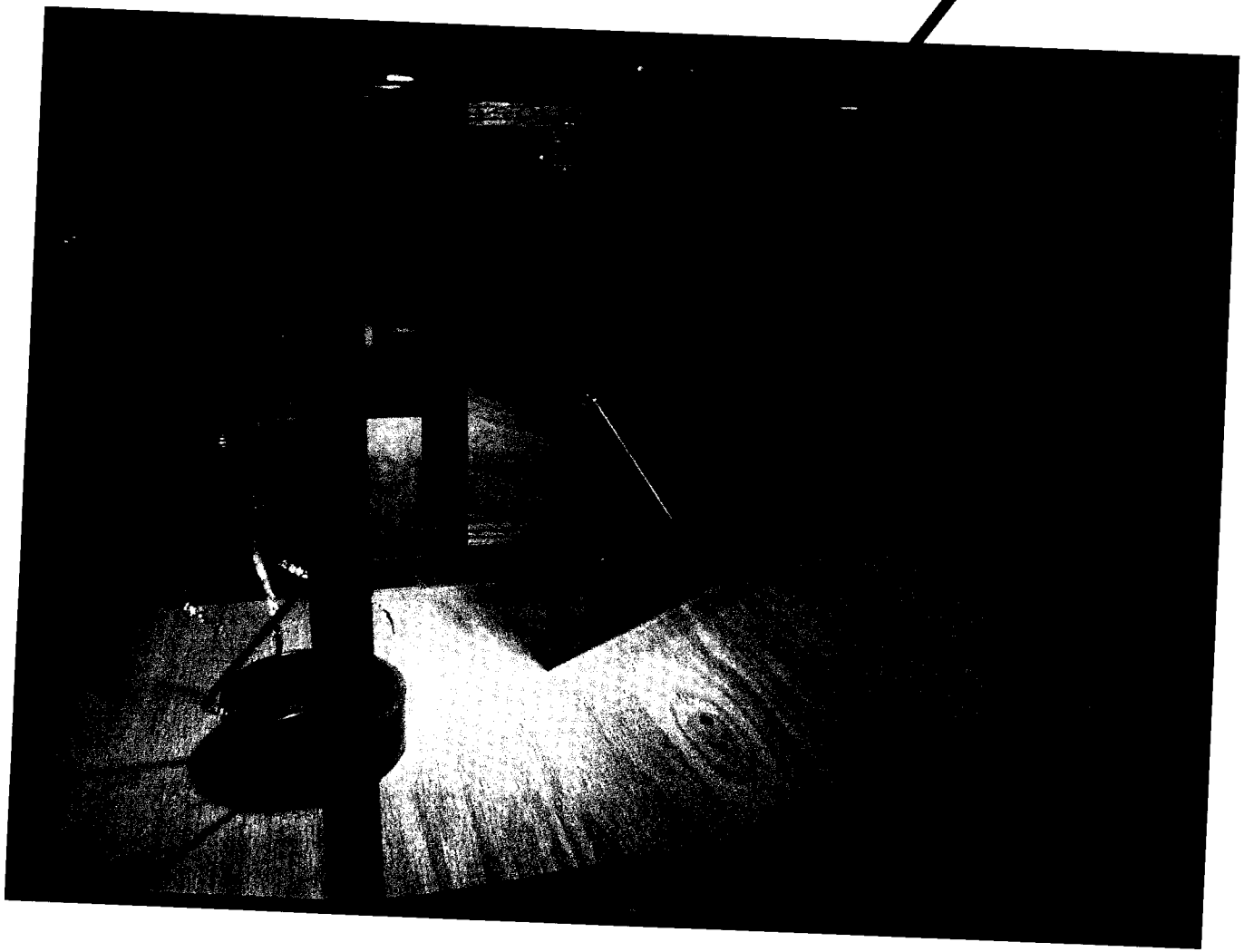


Right Side of House

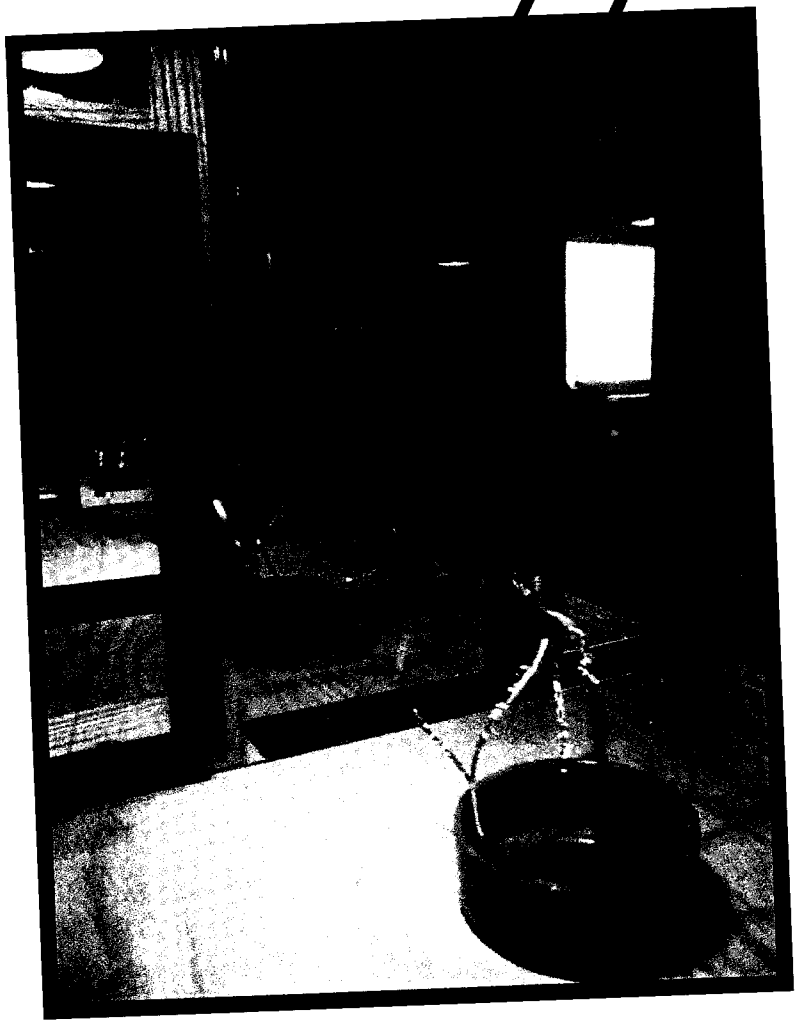


Interior Door Closed

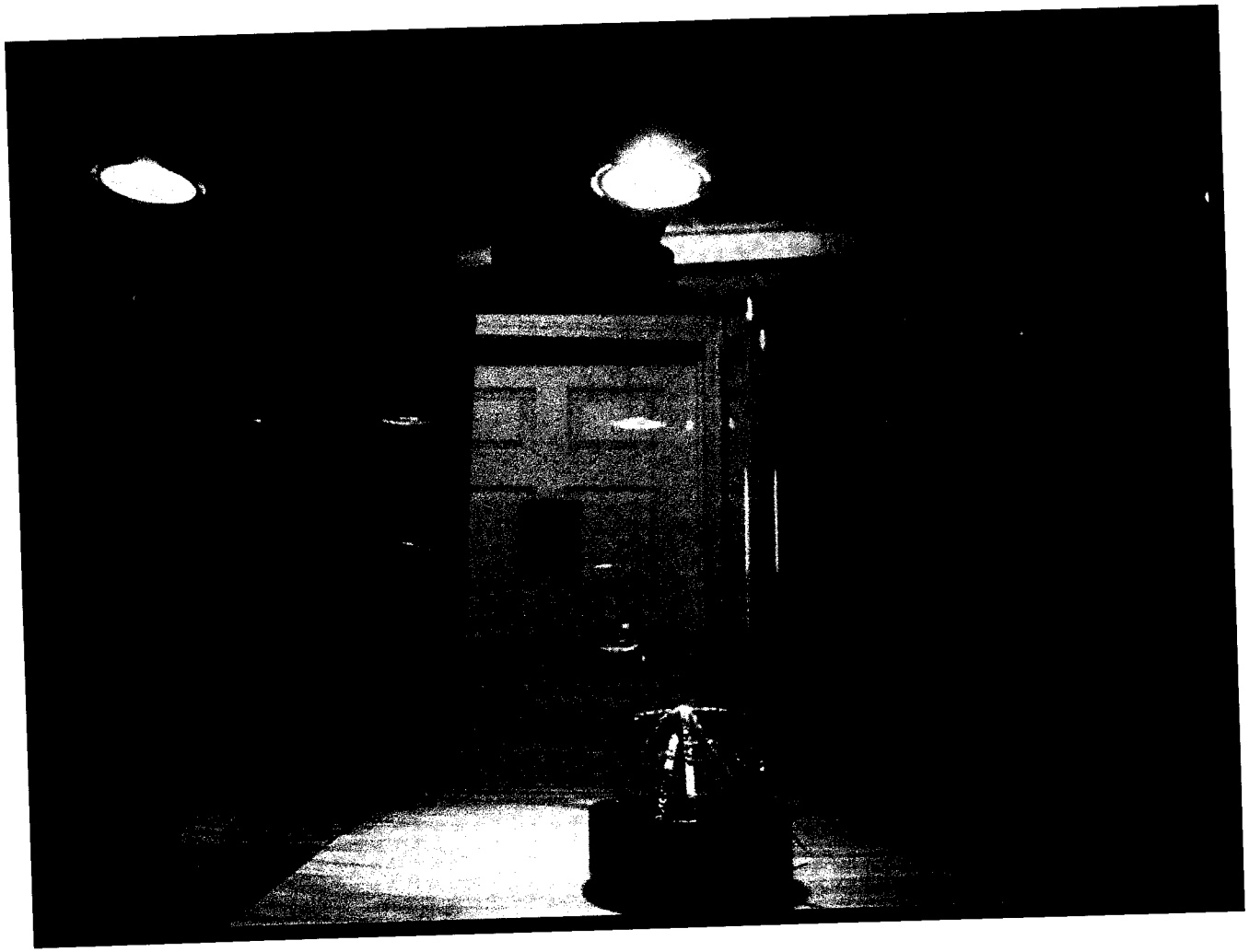
Interior Door Open

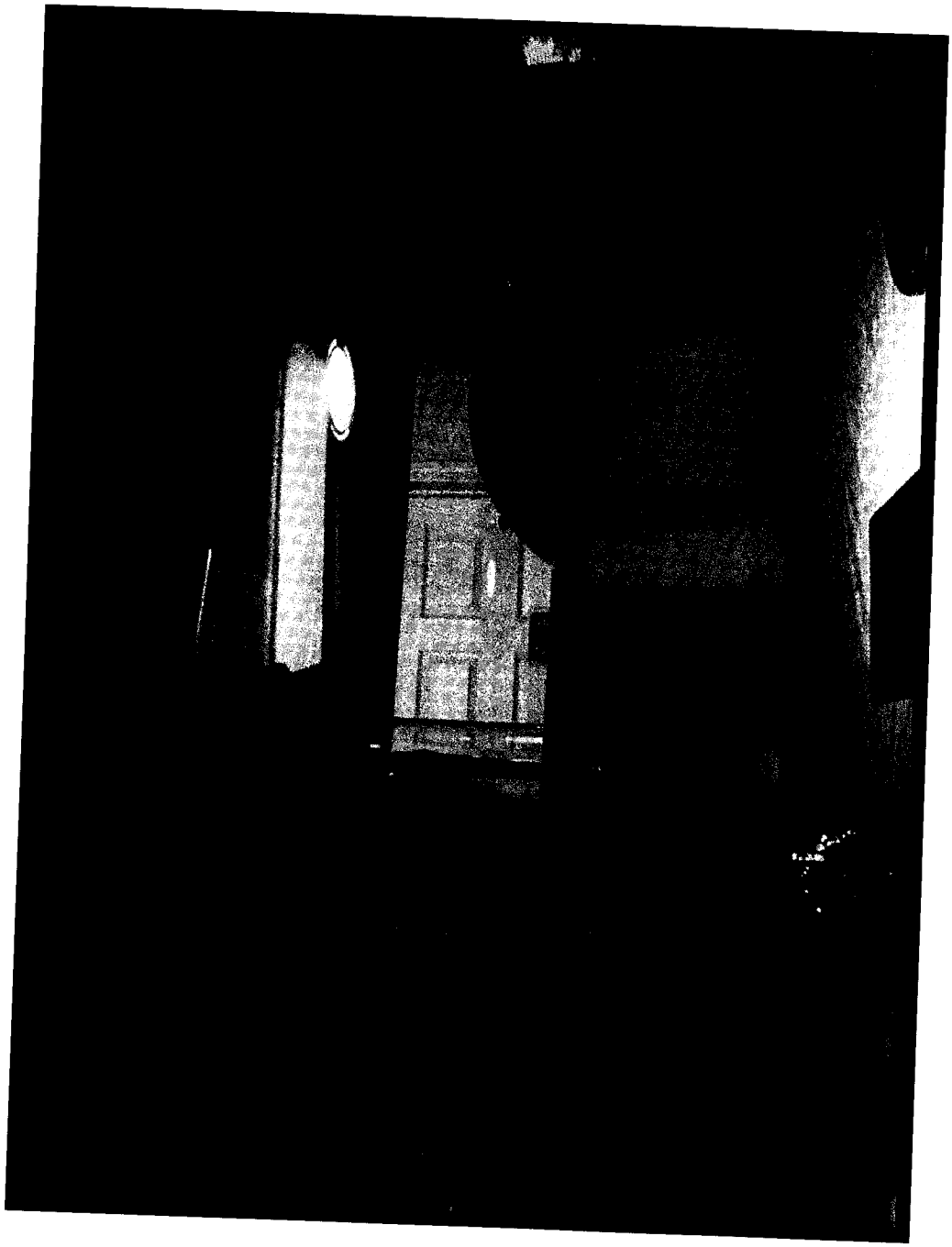


Passive Returns



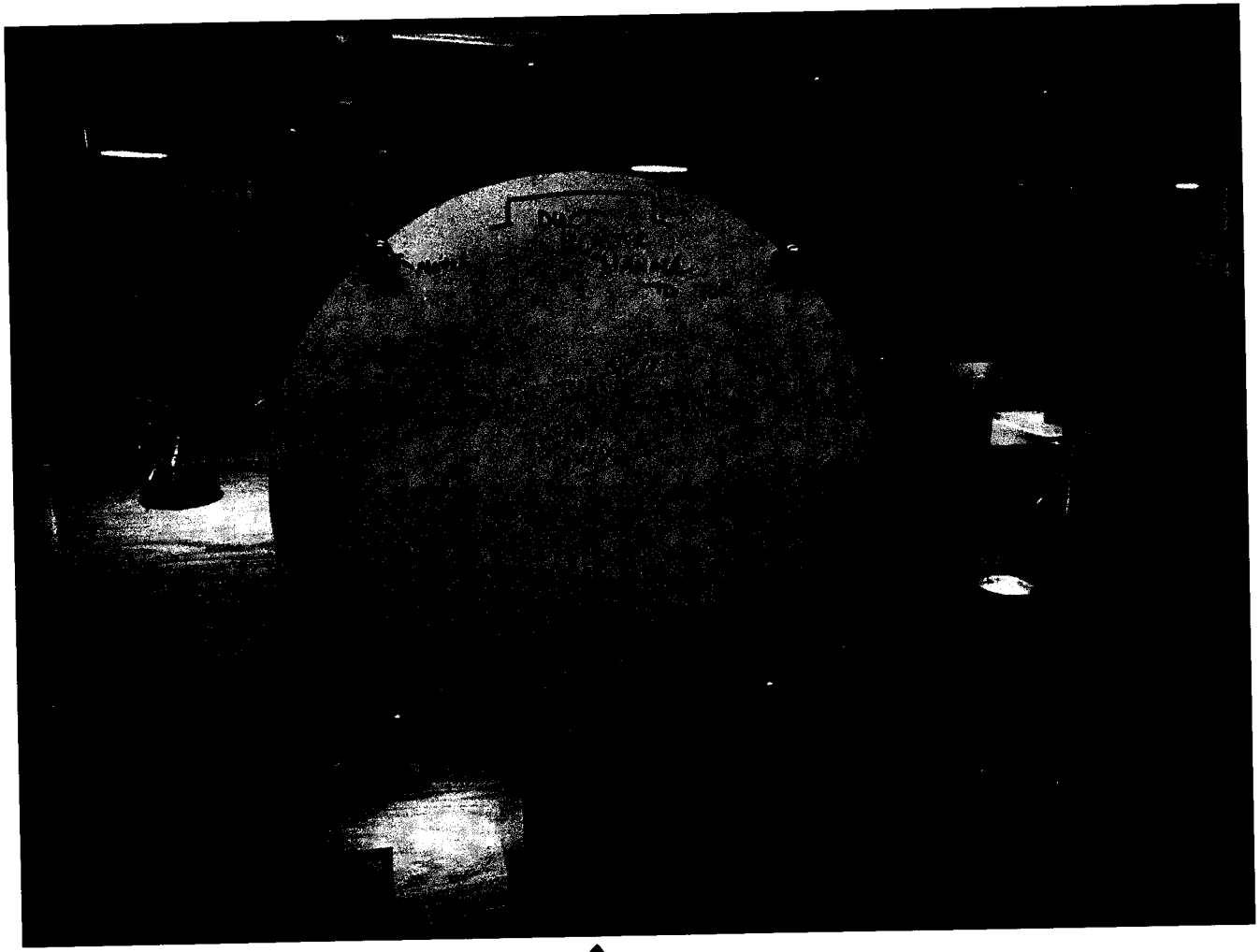
Interior Lights



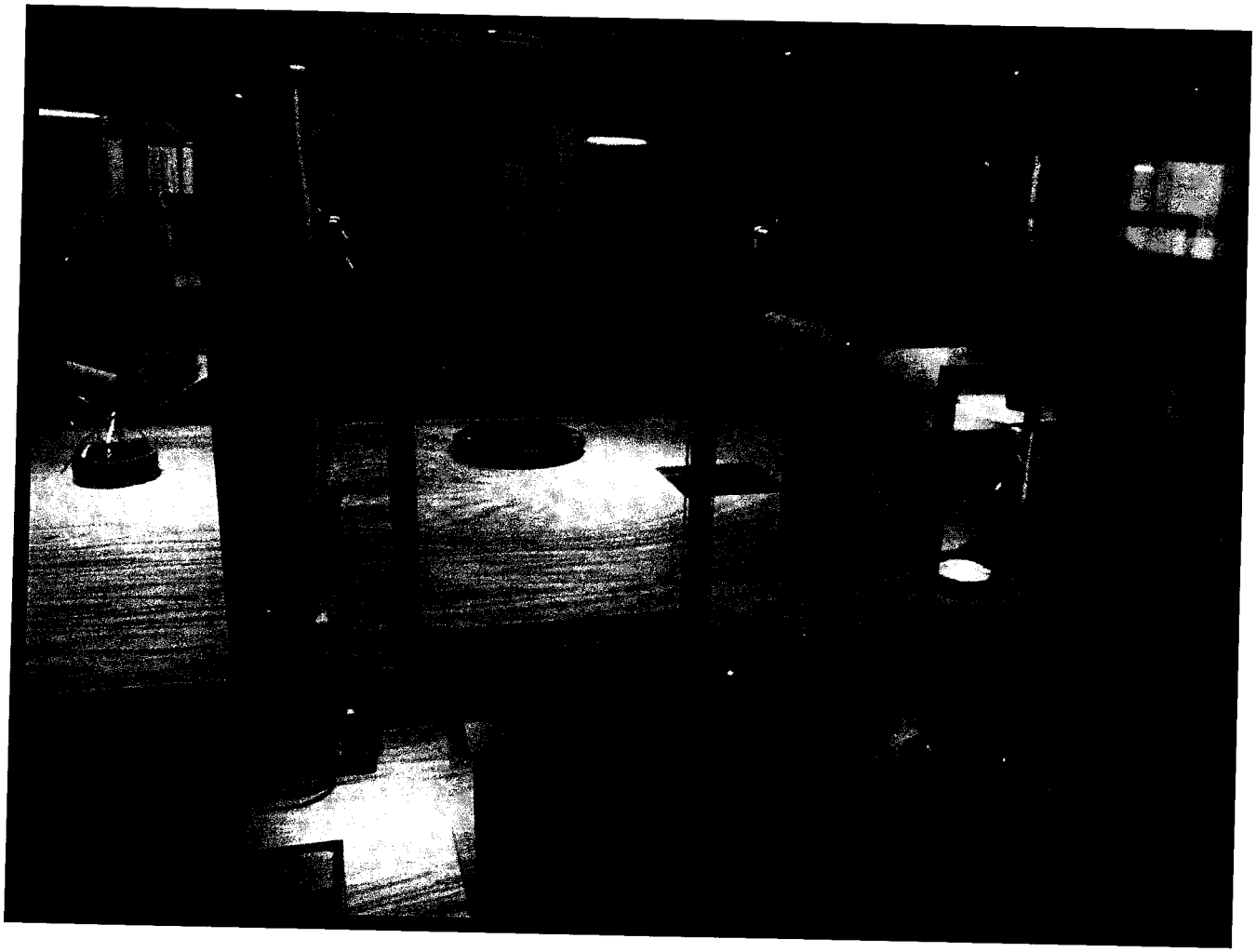


Duct Blaster Template

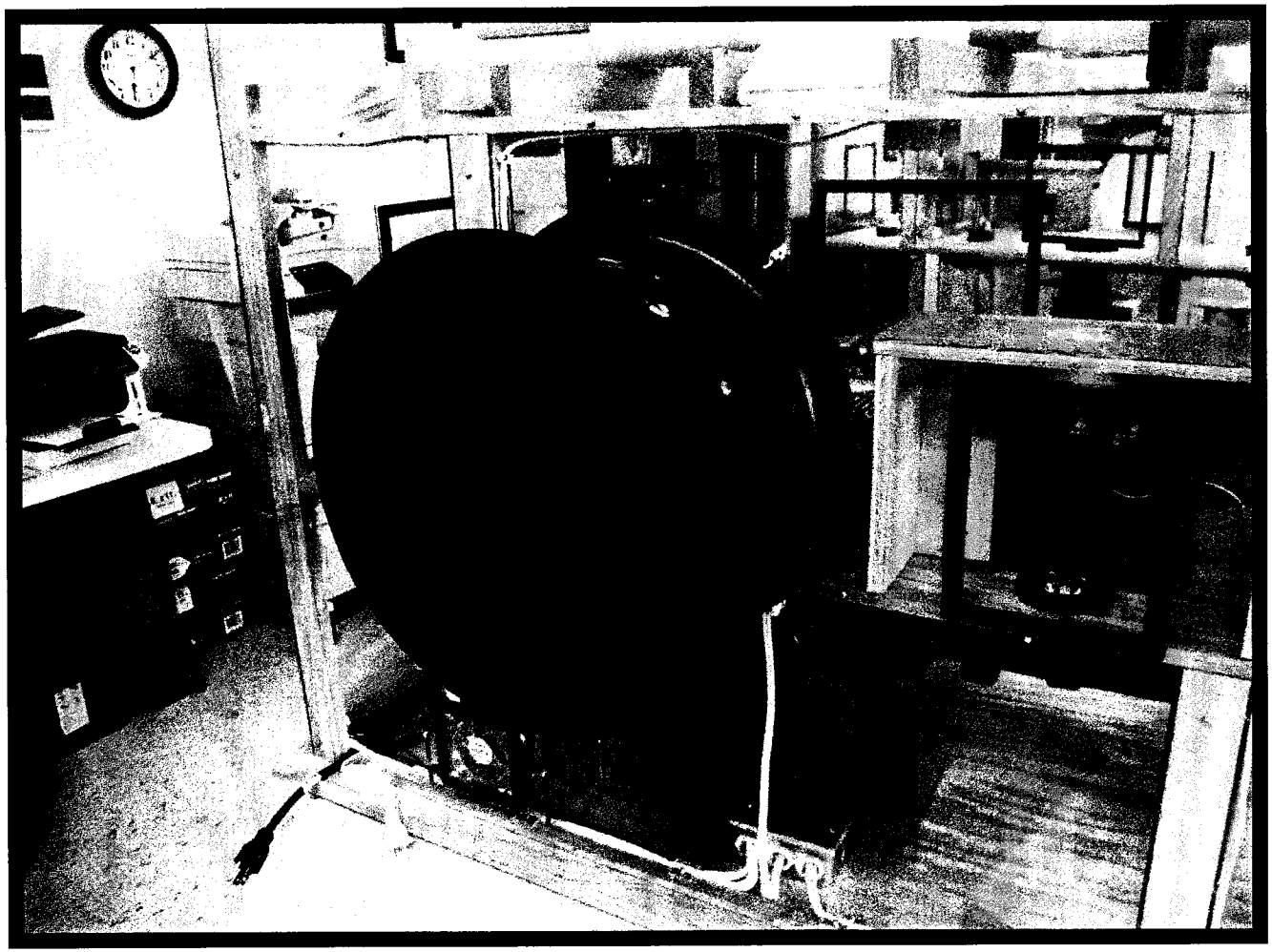
"Duct Blaster Not Included with House Cost"



Template Removed

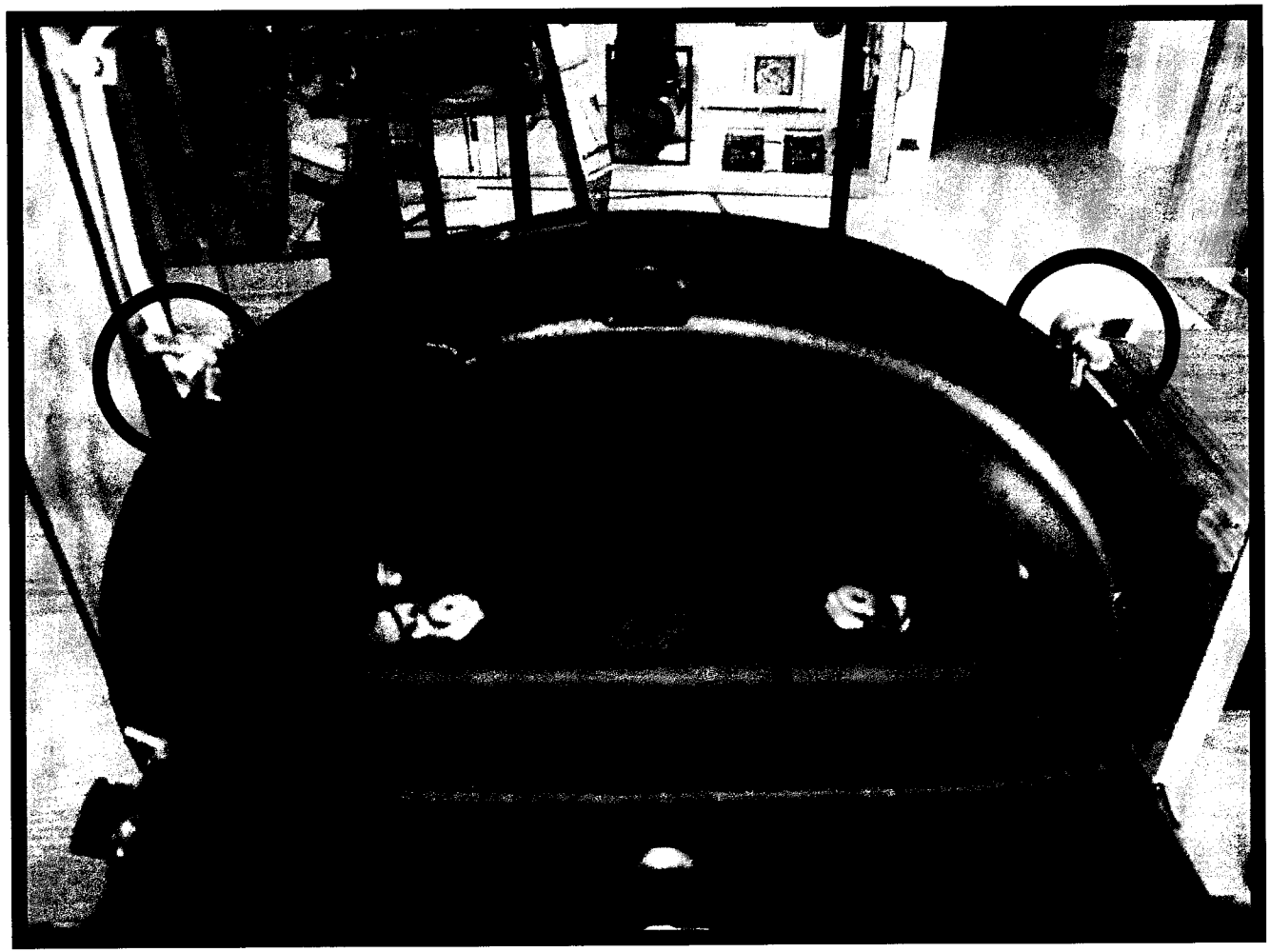


Duct Blaster Attached

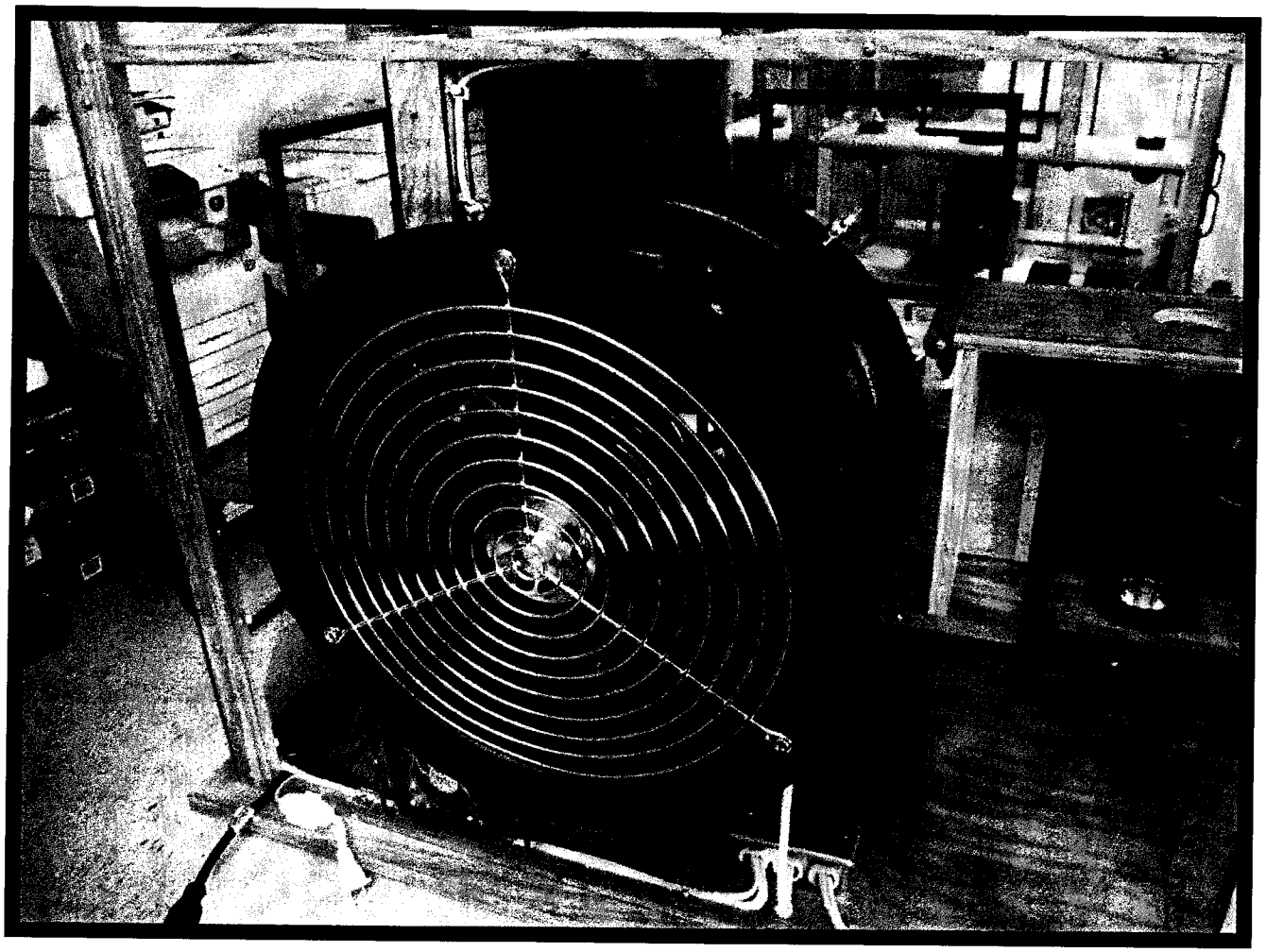


Fan Rests on 2 Screws at Bottom

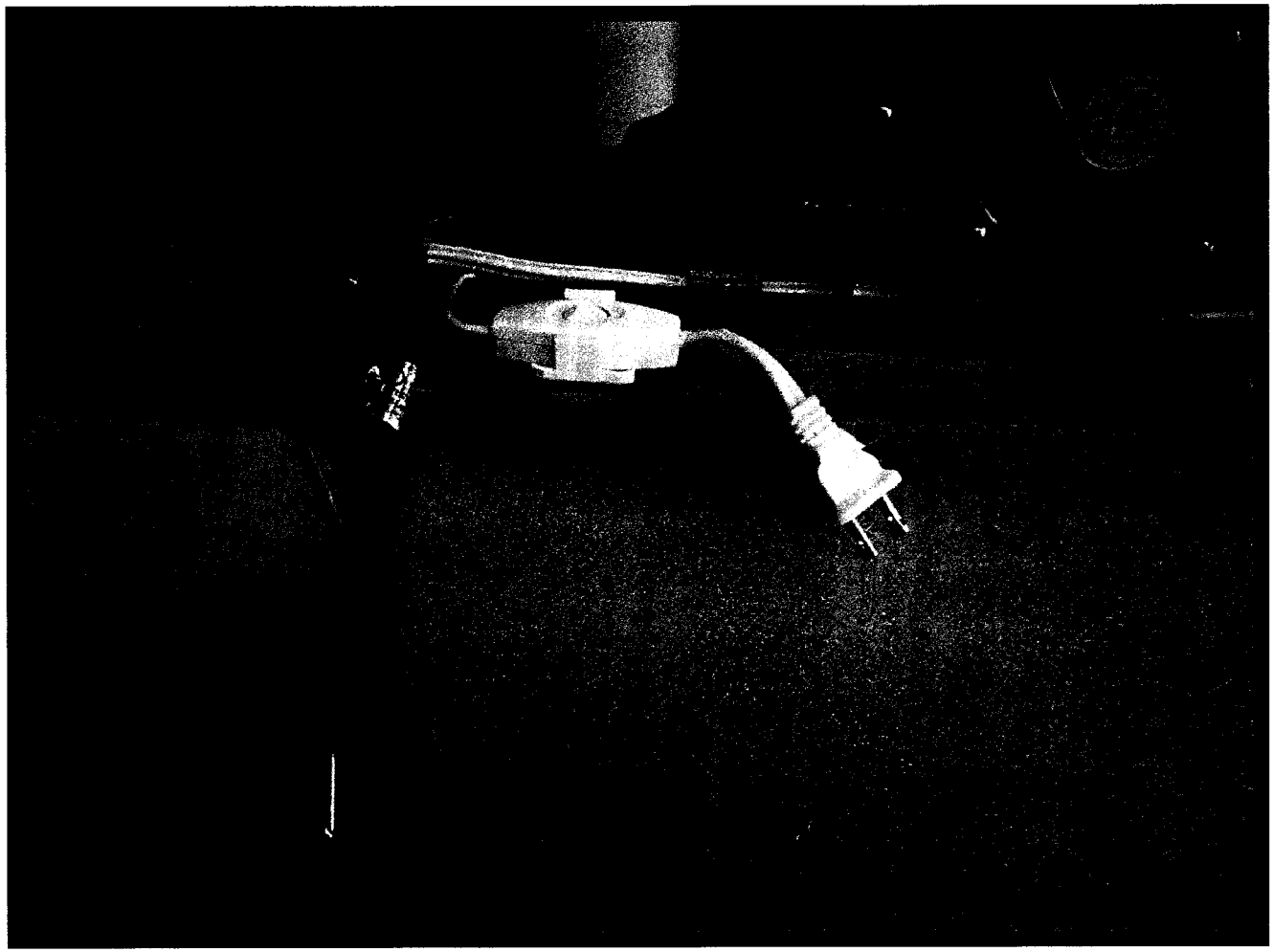
Fan Secured to House with Wing nuts at top.



Cover Removed



Power Cords



4

Energy Efficiency Improvements in New & Existing Homes

Matthew Phillips
Residential Energy Efficiency Program

matthew.phillips@austinenergy.com

Power Saver™ Program

Saving Energy Together

Residential Program

Austin Energy awarded:

ENERGY STAR AWARD 2006

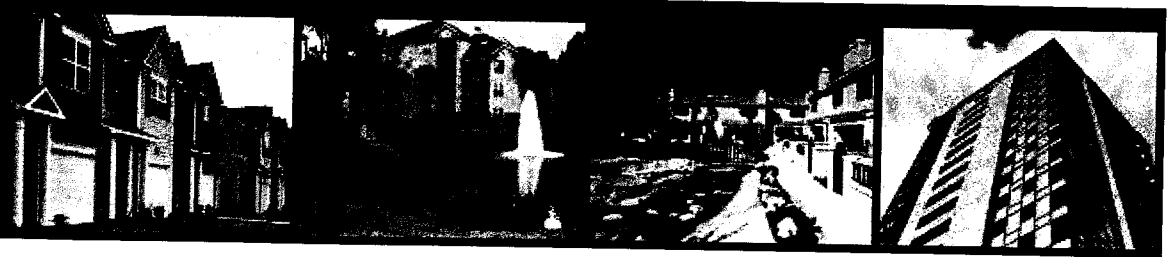
PARTNER OF THE YEAR

&

Sustained Excellence Award
2007-2009

Power Saver™ Program

Saving Energy Together



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 MW
  - *Coal 35%, Nuclear 28%, Gas 28%, Purchase Power 5%, Renewable 4%*

Power Saver™ Program

Saving Energy Together

Energy Efficiency

- **AE Energy Efficiency**
- Since 1982, conservation programs in Austin have reduced peak demand by 837 MW with more than 1 million Austinites and businesses participating.
- **Average annual results** over the past four years (2005-2008) :
  - 59 MW reduced peak demand
  - 103 million kWh saved
  - 45,700 customer participants
  - $9.8 million savings on electric bills

Power Saver™ Program

Saving Energy Together

City Council

- Resolution September 14, 1999
  "Cost-effective conservation programs shall be the first priority in meeting new load growth requirements of Austin Energy. "
- Clean Energy Resolution August 28, 2003

  ... Austin Energy Strategic Plan to ensure Austin remains a national and international leader in the development and use of clean energy

Promoting Energy Efficiency

1.) Aggressive incentives

2.) Cash rebates that pay 20-30% of cost

4.) Free Installations

- Direct installs
- Low-income weatherization
- Free home & business energy audits
- Partnership with local vendors, contractors
- Grass root outreach (newsletters, direct mail)
- Key account representatives

Power Saver™ Program

Saving Energy Together

Why Promote Energy Efficiency?

Power Plant – Fuel Type	Cost/kW
Natural Gas – Combined Cycle	$750
Pulverized Coal	$1,549
Nuclear	$2,800

Source – National Energy Technology Lab (NETL)

Energy Efficiency	$450
Austin Energy's Residential Program	
MW Saved 2007-2008	**9.27**

Power Saver™ Program

Saving Energy Together

Residential Program

Home Performance with ENERGY STAR®

October 2003:

Austin City Council approved the acceptance of the grant awarded from the U.S. Dept. of Energy

1st Quarter of 2004:

Austin Energy transitions the "Total Home Efficiency Program" to "Home Performance with Energy Star® Program"

27 Years Promoting Energy Efficiency!

Original Program Developed in 1982
- -Low Interest Loan Offered

Core Group of Contractors
- -4 to 5 Local Contractors

Home Improvement Offered
- -High Efficiency AC- 10.0 SEER
- -Home Sealing-Less than 0.7 ACH, Attic Insulation R-26

Energy Savings-Since Inception
- -Energy Savings
- -Demand Savings

Power Saver™ Program

Saving Energy Together

Today's Program

- **EPA Partnership in 2004**
- **2007-08 Results**
  - ***Current budget $1.65 Million***
  - ***Estimated 1,700 jobs***
  - **Average 2549 KWh per customer**

- **Recognition & Credibility**
  - ***Customers recognize ENERGY STAR***

- **Increased Contractor Participation**
  - ***Over 90 participating contractors***
  - ***AE Inspection group (6) conducts verifications and final inspections***

Residential Program

Program Offerings

- ***Home Performance with ENERGY STAR ®***
  - ***Rebates***
  - ***Loans***
- ***Appliance Efficiency Program***
- ***Solar Shading***
- ***Attic Insulation***
- ***Radiant Barrier***

Residential Program

Program Offerings (Continued)

- *Air Infiltration*
- *HVAC Replacement*
  - *Package Units*
  - *Central Split Systems*

Residential Program

Home Performance with ENERGY STAR®

System Replacement

- 14.0 SEER/11.5 EER or greater
- Air Conditioning/Heat Pumps

Attic Insulation

- R Value of 38

Solar Screens, Film, Low-E glass ($1.00 sq. ft.)

- South, East & West 1 Hour or more – 40% of Window

Residential Program

Home Performance with ENERGY STAR®

Duct Sealing & Replacement

- System integrity
- Proper air distribution
- Energy usage

Residential Program

Comprehensive

- Duct Replacement 50% or less of duct work
  - $1.75 per linear ft.
- Duct Insulation
  - $1.25 per linear ft.

Test out: Blower door, back draft and duct blaster is required

$0.12 per sq. ft.

Residential Program

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

Home Performance with ENERGY STAR®

Rebate Option

Weatherization Rebates

- Solar Shading
  - $ 1.00 Sq ft.
- Attic Insulation
  - Add R value x attic sq. ft x $ 0.0035 + $45 = Rebate
- Radiant Barrier
  - $0.10 per sq. ft.
- Duct Sealing
  - $ 0.12 per linear ft. condition space

Residential Program

Home Performance with ENERGY STAR®

Weatherization Bonus Rebate

All recommended measures must be completed and Air Conditioning System installed (size 600 sq.ft. per ton) 14.0 SEER/11.5 EER or greater.

Bonus Rebate is based on actual weatherization cost Bonus ranges from $200 to $650 may cover up to 20% of the Total Cost of the Job.

Power Saver™ Program

Saving Energy Together

Residential Program

Home Performance with ENERGY STAR®

Texas Gas Service Rebate

Rate Code: AUST I/S RES or SUNV I/S RES

Match Austin Energy's rebates on:
Attic Insulation ($0.0035 per sq. ft. per "R" + $45 Setup fee)

In addition to Austin Energy's rebates:
Duct Sealing = $.08 Linear ft. conditioned space
Furnace = $75.00
Duct Replacement = $1.75 Linear ft.

Residential Program

Home Performance with ENERGY STAR®

Loan Option

- *Velocity Credit Union*
- *0%-6.5% APR Unsecured Loans*
- *Single Family – Duplex Properties Eligible*

Residential Program

Home Performance with Energy Star® Loan

- **<u>Loan Option 1</u>:**
- **HOME PERFORMANCE WITH ENERGY STAR® Package**

- All Recommended Energy Improvements
- Duct System Performance Improvements
- Up to 2 HVAC System Replacement

Residential Program

Option 1 (Continued)

- 0% – 3.5% APR Home Improvement Loan
- 3 – 10 Year Term Options
- Up to $8,500 -Single Family; Up to $11,000 -2 HVAC System/Duplexes

Residential Program

Loan Option 2: RESIDENTIAL OPTIONAL MEASURES

- HVAC System Replacement and Duct System Performance Improvements
- - *Duct System Performance Testing Required*

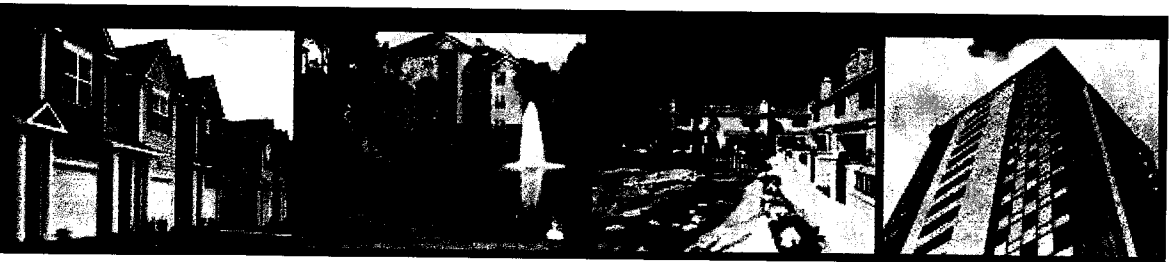
- Duct System Performance Improvements

- - *Duct System Performance Testing Required*
- Radiant Barrier - *Qualified products only*
- Attic Insulation - *Up to R-38*

Residential Program

Option 2- Residential Option Measures (Continued)

- Low-E Windows – *Energy Star® labeled with .40 Shading Coefficient or better*
- 1.9% – 5.0% APR Home Improvement Loan
- 3 – 10 Year Term Options
- Up to $11,000 – Single Family or Duplexes



Home Performance with Energy Star®
Contractor Equipment & Training Rebate

- Assist local Home Performance contractors with -
  - Specialized testing equipment;
  - Development of personnel for the home performance field
- Rebates are available for the purchased of specialized testing equipment
- Rebates are available for HVAC Industry and Home Performance Training Seminars
- Must be currently registered as a Home Performance with Energy Star® Participating Company with Austin Energy's Power Saver Program™.
- Must be currently registered as a vendor with the City of Austin's Purchasing Dept.
- Must have completed a minimum of (5) Home Performance with Energy Star® Program jobs in FY 2007-2008.

Residential Program

Appliance Efficiency Program

Existing Homes

- 14.0 SEER – 11.5 or greater
  - Air Conditioning/Heat Pumps
- ENERGY STAR - Room Air Conditioners (window units)
- Solar, Heat Recovery & Heat Pump Water Heaters

Residential Program

Free Weatherization Program

Eligible Improvements

- Attic Insulation
- Caulking and Weather-stripping
- Duct Sealing/Repair
- Solar Screens

Residential Program

Free Weatherization Program

Eligibility Requirements

Austin Energy Customer

- Value of the house cannot exceed $150,000
- Elderly (60 yrs +) & Disabled
  - 80% of medium income
- Regular weatherization
  - 50% of medium income
- 2007 HUD Income Guidelines

Residential Program

Free Weatherization Program

Window Unit Vouchers

- Must meet free weatherization income guidelines, participate in program.
- For customers with no A/C or old inefficient units-owners only.
- Provide $500 window unit voucher.
- Customers redeems voucher at participating retailer.

Residential Program

Refrigerator Recycling Program

Receive $50 when you recycle your old Refrigerator

- Turn Key Services Offered by Appliance Recycling Centers of America (ARCA)
  - Contact Customer Service
  - Pick Up/Recycle
  - Service of Single Family & Multi-Family Customers
- Must be in Working Condition

Residential Program

Refrigerator Recycling Program

Benefit to Austin Energy

Process/Recycling of:

Polyurethane Foam, Refrigerant,

Metals, Glass, Plastics, and Compressor Oil

Lighting Program

- **ENERGY STAR Lighting Coupon**
  - $2.00 & $4.00 off, Instant Coupon for Energy Star CFL's
  - $10.00 off, Instant Coupon for Energy Star Light Fixtures
  - Local Retailers Redeeming Coupons

Accomplishments

Past 27 Years!

- Demand Peak Savings 433 MW
- Energy Savings 414,000 MWH
- Number of Participants 555,000

Power Saver™ Program

Saving Energy Together

Strengths & Lessons Learned

Strengths:

- Marketing and educating to our customer base
- Remaining open to new energy efficient technologies
- One-on-one communication with contractors
- Solicitation of contractors' inputs on program
- HPwES Participating Contractor Web site- "free advertising"
- Program focused and contractor driven

Lessons Learned & Challenges:

- Contractors must be treated equally
- Miscommunication concerning technologies

Recommendations

Develop strategies to increase supply (contractors) and demand (consumer awareness) at the same time *(Olson)*

Ensure that good quality control checks are in place

Provide assistance to program sponsors

Questions?

Matthew Phillips

matthew.phillips@austinenergy.com

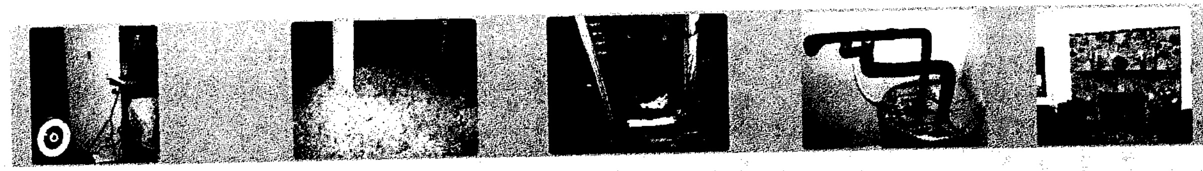
Phone # 512-482-5326

5

THE HEALTHY HIGH PERFORMANCE HOME

before renovation

RENOVATION



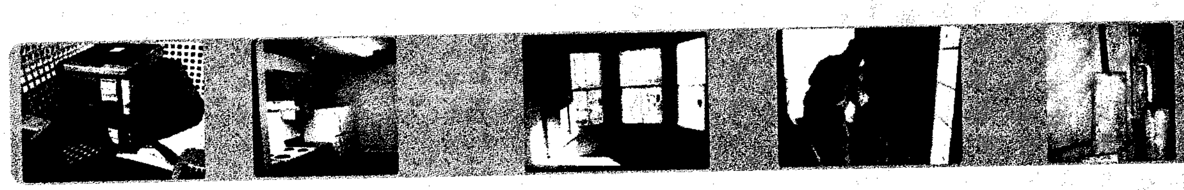
1 Perform blower door test to find leakage points. Increase comfort and decrease drafts by weatherstripping doors and windows, seal gaps at baseboards and mechanical chases into attics

2 R38 attic insulation provides comfort and energy savings for the resident. Blown cellulose insulation may be applied over existing insulation or directly on the attic floor

3 New duct systems should be installed within the building envelope, not in the attic or an unconditioned crawl space. Test duct systems for leakage with a duct blaster test.

4 electric 92% efficiency, gas 62% efficiency For efficiency, water heaters should be installed within conditioned space and wrapped in insulation. Gas appliances should be in air sealed closets and must be properly vented to the outdoors

5 For health and safety, sealed combustion units vent combustion gases to the outdoors



6 Use R410A coolant, 14 SEER or greater condensing unit. Air handlers operate more efficiently in conditioned space, gas units need to be vented directly to the outdoors

7 ... inefficient refrigerator, dishwasher, washing machine, bath fans and light fixtures with Energy Star appliances

8 Low-E windows reduce solar heat gain in summer and keep heat inside in the winter

9 Blown cellulose insulation provides thermal and sound insulation and reduces air infiltration. It should be installed in walls with sheathing and siding; insulation in walls with no sheathing will cause paint to crack and peel

10 ... recycle or refurbish old appliances and building materials

after renovation

A guide to renovation and new construction

Resources

EarthCraft Virginia
EarthCraft House
Implements EarthCraft single-family and multi-family programs for affordable housing and market rate projects for Virginia
(804) 225-9843 • www.earthcraftvirginia.org

ENERGY STAR® for Homes
U.S. Environmental Protection Agency
Energy efficiency certification for appliances and houses
(888)782-7937 (hotline)
www.energystar.gov

Southface Energy Institute
Sustainable land development and construction: Guidelines for the Southeast
Technical assistance for building science and environmental design, consumer education, free factsheets on green construction.
(404) 872-3549 • info@southface.org
www.southface.org

Virginia Sustainable Building Network
Promotes environmentally sound, green building practices for Virginia
(703) 486-2966 • www.vsbn.org

Home Builders Association of Virginia
Promotes the building industry by educating and interacting with government agencies
(804) 643-2797 • www.hbav.com

Low Impact Development Center
Information and resources on low impact development
(301) 982-5559
www.lowimpactdevelopment.org

Residential Energy Services Network
(RESNET) and Home Energy Raters (HERS)
RESNET is a national network of mortgage companies, real estate brokers, builders, appraisers, utilities, and energy professionals working towards improving the energy efficiency of the nation's housing stock. Search their Certified Rater Directory for a listing of certified home energy raters by state
(760) 806-3448
info@natresnet.org • www.natresnet.org

Home Performance Power
Fannie Mae's Guide to Buying and Maintaining a Green Home
Provider of Energy Efficient mortgages for new and renovated homes
(800) 732-6643

Frederick P. Rose Architectural Fellowship
Creates partnerships between emerging architects and community based organizations.
www.rosefellowship.org

Building Material Reuse Association
Facilitates building deconstruction and reuse/recycling of recovered building materials
(800) 990-2672 • www.ubma.org

Building Science Corporation
Builder's Guide to Mixed Climates
Building consultant firm provides energy analysis and design development
(508) 589-5100
info@buildingscience.com
www.buildingscience.com

Greenspec Directory
Information on 2000 screened building materials listed by CSI number within 250 categories
www.buildinggreen.com

Environmental Building News
Monthly green building journal
(802) 257-7300 • www.buildinggreen.com

Recycling resources in the state of Virginia

Virginia Department of Environmental Quality
Waste Management and Recycling Programs
Provides guidance on regulations and codes in the state as well as local and regional recycling program contacts
(804) 698-4000 • www.deq.state.va.us/waste/

Virginia Recycling Association
(888)867-1923 • www.vrarecycles.org

Virginia Tech – Cooperative Extension Service
www.ext.vt.edu
Xeriscape – Creating a Water-Wise Landscape
A guide to understanding and planning for a water efficient landscape

Habitat Re:Store
Re-sells donated construction material and will collect old appliances and excess building materials- affiliated with local Habitat for Humanity organizations in the USA
http://www.habitat.org/cd/env/restore.aspx

Charlottesville Community Design Center
Brings together citizens and design resources to create equitable, sustainable and beautiful communities
(434) 984-2232 • www.cvilledesign.org

Funding and Financing

The Home Depot Foundation
Affordable green building and tree planting
(866) 593-7019
www.homedepotfoundation.org

Green Communities Initiative
Enterprise Community Partners
Affordable green building grants and financing
(410) 715-7433
www.greencommunitiesonline.org

Local Initiative Support Corporation
Affordable green building grants and financing
(804) 644-0548 • www.virginialisc.org

U.S. Environmental Protection Agency
www.epa.gov/greenbuilding/tools/funding.htm

Sponsors:

Local Initiatives Support Corporation would like to thank the Home Depot Foundation, the Virginia Housing and Development Authority and DuPont for investing in the project and contributing to an important area of study that will encourage continued dialogue among many stakeholders.

For more information please contact
Joshua Galloway at
j.galloway@betterhousingcoalition.org

FOUNDATION DUPONT VHDA

Frederick P. Rose Architectural Fellowship

STUDIO

Better Housing Coalition LISC Virginia

How much more does it cost to build a healthy, high performance home?
It all depends on what you currently build. To upgrade from a basic, code-built home to a home like the one described here would cost three to five percent more. But once you factor in the decreased costs of ownership, it can be far less expensive. Utility costs are lower, and there are lower repair and replacement costs due to the durable methods and materials used in green building. But even beyond construction and maintenance costs, green homes make financial sense. They may be easier to sell and may fetch a higher price. An environmentally sensitive project can attract positive attention and help differentiate your homes from your competitors.

What are the best ways to save money with green building?
Work with experienced professionals from the beginning of the design process, they can help you avoid waste and make smart choices. Trying to retrofit existing plans can cost more and take longer. Some of the things experienced architects and builders can help with are material choices, advanced framing, efficient dimensions, and compliance with Energy Star specifications that can help the home qualify for an Energy Efficient Mortgage (EEM).

Is it worth just making a few small changes, or do you have to completely revamp a plan in order for a green building to work?
Yes, even a few small changes can improve the performance of a home. Many systems in a building affect each other in complex ways (for example, insulation and ventilation), and a professional who is familiar with healthy, high-performance building can help you figure out a way to proceed that makes sense for your specific project and budget.

What is advanced framing? Is it safe?
Advanced framing practices, which are allowed by the International Residential Code (IRC) 2003, are a safe and sustainable way to build. They save lumber and allow insulation to be installed at wall intersections that traditionally aren't insulated. Leaving these areas uninsulated can lead to moisture problems and mold growth, as well as heat loss.

Why is it important to air seal a house?
Air-sealing the inside of a house with a 50-year latex caulk pre[illegible]ts and keeps outside moisture from entering through the walls. Many insu[illegible]ctors offer a caulk and seal package prior to insulation.

Can the house be built too tight?
Not if the house is ventilated right. If spray foam insulation, Structural Insulated Panels (SIPS) or Insulated Concrete Forms (ICF) are used the home can be very airtight and require fresh-air ventilation. This may be done with an Energy Recovery Ventilator (ERV) or a dedicated duct that brings fresh outdoor air into the air handler where it is conditioned prior to distribution in the house.

Why is sealing ductwork important?
Leaky ductwork often accounts for 10-30 percent of total heating and cooling costs. While that cost is significant, protecting health and safety is the most important reason to seal ducts. Leaky ducts can draw air from crawl spaces into the home, and that air may be contaminated with dust, mold, and other potential toxins.

Don't crawl spaces need to be ventilated?
No. Sealed and conditioned crawl spaces act like mini-basements, which prevent moisture build-up, protect the floor framing, and help equipment and ductwork in the crawl space operate efficiently.

What is EarthCraft?
EarthCraft House is a green building program that serves as a blueprint for healthy, comfortable homes that reduce utility bills and protect the environment. EarthCraft House is a partnership between the Greater Atlanta Home Builders Association, Southface, and government and industry partners. EarthCraft Virginia is the local provider for the EarthCraft House multi-family and single-family programs. Staff will guide builders through the process of designing, building and testing EarthCraft certified homes.

Why is maintenance important?
A high performance home requires periodic maintenance to continue to be healthy and energy-efficient. Properly maintained heating and cooling equipment operates efficiently, providing a comfortable environment and lower operating costs. Keeping water away from the building with a good water management system makes the building last longer and helps maintain indoor air quality.

It's important to preserve the historic character of my area. Can new or renovated green homes fit into a historic neighborhood?
You can build sustainably in any architectural style, and new construction and renovation can both incorporate green technology. Whether you prefer cutting-edge contemporary or classic colonial, everyone appreciates increased natural light, good air quality, and lower maintenance and utility costs.

This poster was printed on DuPont's Tyvek® paper, a recyclable paper that is produced in Richmond, Virginia   Design by Anne James

THE HEALTHY HIGH PERFORMANCE HOME

What is v[redacted]low is it different than accessibility?

Visitability r[redacted]ble for people with impaired mobility to get in and out of a house and use the bathro[redacted]essentials for visiting a home. It also makes it easier for residents to stay in their homes if [redacted]y develop a temporary or permanent mobility impairment. Accessibility often refers to public buildings that require a 36" clear path throughout the building and a 5' diameter circle of clear floor space in the bathroom. To qualify as visitable, a home must have:

- One zero-step entrance
- All main floor interior doors with a 32" clear opening (at least a 34" door)
- A bath on the main floor with a 30"x48" clear space in front of the toilet and sink.
- A bedroom or convertible study on the main floor

Source: www.concretechange.org

Engineered wood
structural framing lumber made of ground wood and glue uses smaller trees and is stronger than dimensional lumber

Low/ no-VOC paint
interior paint with low levels of volatile organic compounds
www.epa.gov/iaq/voc.html

Energy Star light fixtures
light fixtures designed for optimum energy efficiency and compact fluorescent bulbs

Air sealing
seal all seams and joints between materials in exterior walls with water based caulk to prevent drafts and moisture leakage

Low-flow water fixtures
water fixtures designed for water conservation 2.0 gal/min faucets, 1.6 gallon toilets

Open web joists
resource efficient structural support that allows easy access for installation and of ductwork, wiring and plumbing

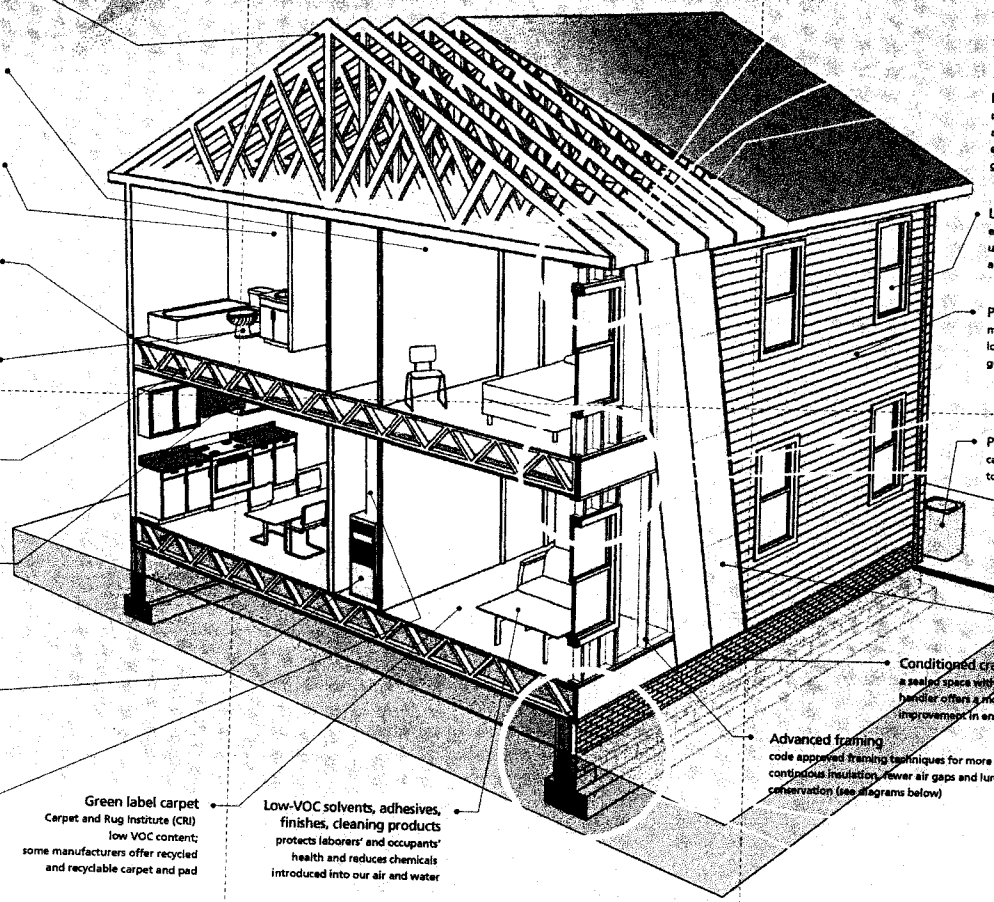
Energy Star rating
Environmental Protection Agency and Department of Energy program to label energy efficient appliances, products and homes, 5-star energy rating denotes an energy efficient home

Heating & cooling in conditioned space
heat pump and duct work within the building envelope improves efficiency, reduces potential for condensation and mold growth

Sealed duct system
tight ducts improve energy efficiency of the system and the comfort of the residents; mastic sealed ducts should have less than 5% leakage; duct blaster tests duct tightness

Green label carpet
Carpet and Rug Institute (CRI) low VOC content; some manufacturers offer recycled and recyclable carpet and pad

Low-VOC solvents, adhesives, finishes, cleaning products
protects laborers' and occupants' health and reduces chemicals introduced into our air and water



Blown cellulose insulation
recycled newspaper, treated for insect and fire resistance. Custom fit for every wall cavity, thermal mass and good sound attenuation

Low-E windows
energy efficient windows that block ultraviolet rays, summer heat gain and winter heat loss

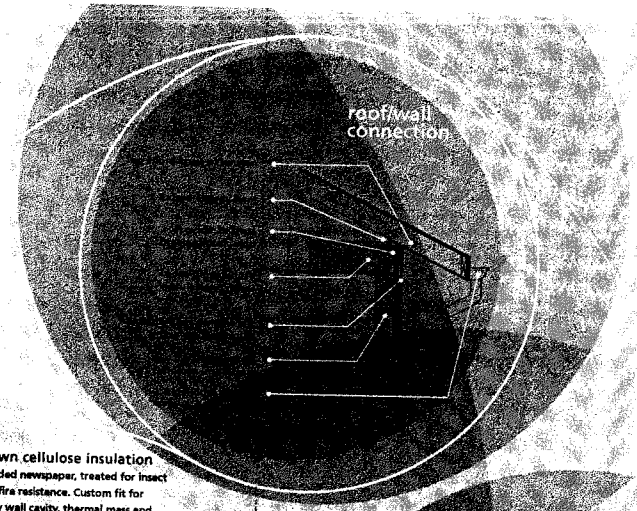
Pre-finished cement board siding
mix of cement and wood cellulose, durable, low-maintenance with a 15 year finish guarantee, 50 year product guarantee

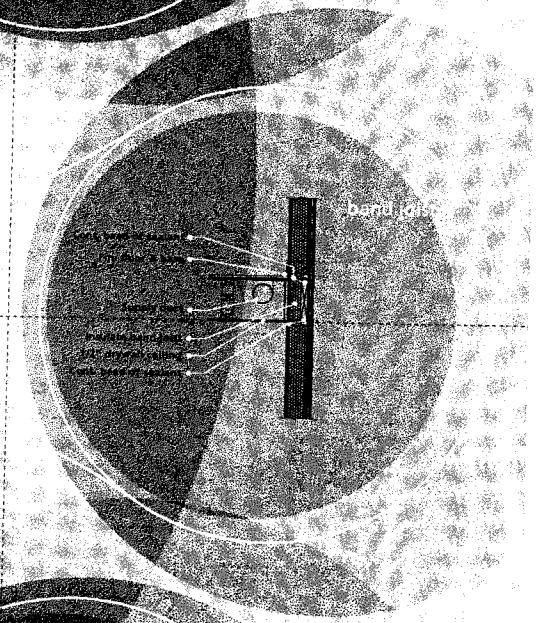
Proper Heating & Cooling Unit Size
calculate heat load/heat gain during design phase to ensure proper moisture control

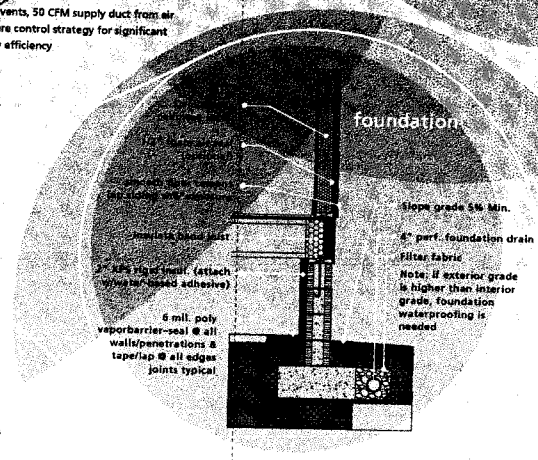
House wrap
a vapor permeable material used as a drainage plane to protect the structure of the home from water. All seams are taped to prevent leakage of water onto sheathing or framing

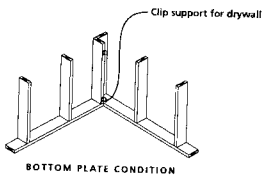
Conditioned crawl space
a sealed space with no vents, 50 CFM supply duct from air handler offers a moisture control strategy for significant improvement in energy efficiency

Advanced framing
code approved framing techniques for more continuous insulation, fewer air gaps and lumber conservation (see diagrams below)

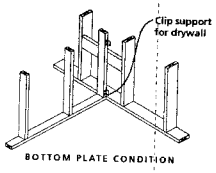




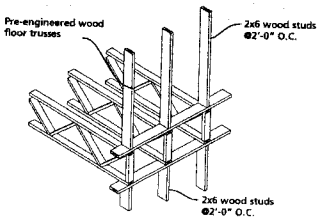


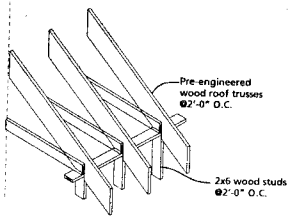


typical two stud cc



typical intersection at interior wall

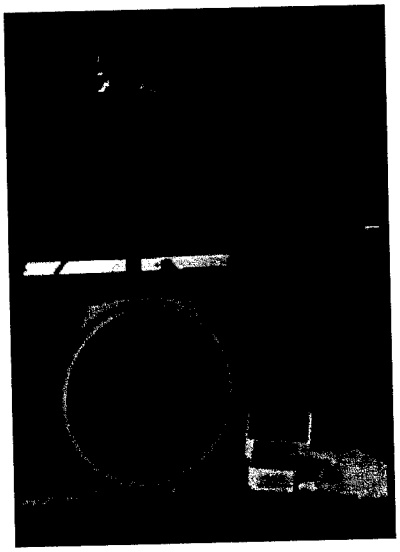




9

Retrotec Model Q46 Automated Blower Door

Quality and Accuracy with Automatic Pressure & Flow Control



Fan Flow (accuracy +/- 5%, +/- 3% with Auto-Correct in Retrotec software) Liters/s m3/h

	CFM	Liters/s	m³/h
Maximum Flow in Free Air	6,300	2,973	10,705
Maximum Flow at 50 Pascal test pressure	5,600	2,643	9,514
Minimum Flow on Range Configuration C1 at 10 Pa	38	18	65

Dimensions	inches	cm		inches	cm
Fan height	26	66	Fan Depth	9.5	24.1
Fan Inlet diameter	22	56	Panel height	76.5 to 87	194 to 221
Panel Case (included)	31 x 30 x 7	77 x 76 x 18	Panel width	28.5 to 41.5	72.4 to 105.4

Fan weight	34 lb.	15.4 kg.	Fan Motor	0.75 hp, 9.8 amps at 120 V 4.5 amps at 240 Volts
Panel weight	21.5 lb.	9.8 kg.		

Calibration meets:	Canadian CGSB-149.1-2002 & SuperE, USA ASTM E 779 – 03, European EN 13829 & CEN, UK TM-23 Energy Standards, Rain Penetration Standards. NFPA 2001- 01, ISO 14520 and UBC-905 fire standards.

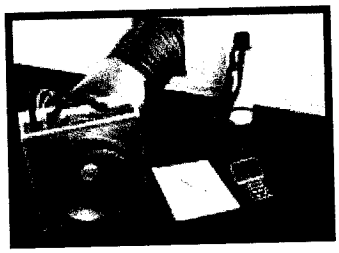
retrotec

0380450

Specifications are subject to change without notice.

Retrotec Q32 Duct Blaster Kit

Automated Duct Testing without a computer. Measure duct leakage in residential commercial buildings. Consists of Duc-Tester Module, DM-2A Digital gauge and 12 foot flex-duct with flanges for mounting on the return register. Click on the desired test pressure and walk away; the DM-2A will run the test for you. Case for DM-2A and grill mask dispenser not included.



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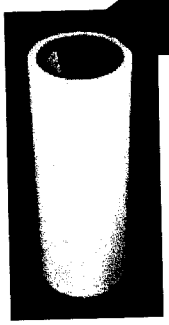
Grill Mask

Ideal for covering holes and duct registers, when testing enclosures, houses or duct work. Self adhesive, perforated rolls. 160 feet long and 12 inches wide.



retrotec

0380462

Pressure Pan

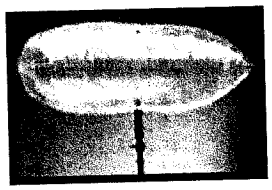
For duct diagnostics
Size: 12.5"x14.25"x4"

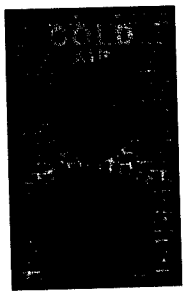
The pressure pan is a duct leakage diagnostic tool which is used along with the Blower Door and digital pressure gauge to identify exterior air leakage in duct systems. Includes 6' extension pole for high registers.

0380457

Chimney Balloon

Also known as a Chimney Pillow, is a reusable & durable device that has been saving home heat for more than 20 years. Used by chimney sweeps, energy auditors and fireplace owners to stop cold drafts, chimney odors, and bird and bug entry through the flue.





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English

0380452

Report BNL-71102-2003-IR

CHARACTERIZATION OF AIRFLOWS NEAR THE EXIT OF HVAC REGISTERS USING LASER DOPPLER VELOCIMETRY (LDV)

Narinder K. Tutu, C. R. Krishna, John W. Andrews, and Thomas A. Butcher

February 2003

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ABSTRACT

A facility to characterize the airflow at the exit of HVAC registers was designed and fabricated. The objective of this work is to obtain velocity and turbulence data at the exit of registers, which can then be used as an input boundary condition in a modern Computational Fluid Dynamics (CFD) code to predict the velocity and temperature distribution in an enclosure, and also the register performance parameters such as throw. During the course of this work, two commonly used registers were tested. Both registers were 8"x4" sidewall registers. Laser Doppler Velocimetry was used to measure the axial and vertical components of the velocity vector at various locations across the face of the registers. For the two cases of registers studied here, the results suggest that the velocity field at the very exit of each of these registers scales with the flow rate through the registers. This means that, in the mode of operation in which the supply fan (of an HVAC system) has a "High" and "Low" setting, similar velocity scaling would result for the type of registers tested here.

ACKNOWLEDGEMENT

The authors would like to thank Dave Elling for excellent cooperation and for efficient fabrication and assembly of the facility. The Office of Building Technologies in the Department of Energy is acknowledged for financial support of the work reported here.

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NOMENCLATURE

$< >$	Denotes averaging operator
U	Instantaneous velocity component in the axial (X) direction.
W	Instantaneous velocity component in the vertical (Z) direction.
$<U>$	Mean velocity component in the axial direction
$<W>$	Mean velocity component in the vertical direction
u'	root mean square (rms) fluctuation in the axial velocity component = $\sqrt{<(U-<U>)^2>}$
w'	rms fluctuation in the vertical velocity component
X	Axial distance from the register exit. (See Figure 1)
Y	Lateral distance from the center of the register. (See Figure 1)
Z	Vertical distance form the register center. (See Figure 5)
r	The radial distance from the physical centerline.

1. INTRODUCTION

Air distribution systems are used to supply conditioned air to a physical enclosure whose environment needs to be regulated within certain limits. The physical enclosure may be an office space, a room in a house, or an industrial space; and the limits may relate to air temperature, velocity, and turbulence level. Depending upon the season and application, the conditioned supply air may be warmer or cooler than the average temperature in the conditioned space. A key element of the air distribution system is the air supply outlet, which is called a *register*. Its design determines the manner in which the supply air is distributed within the enclosure (to be simply referred to as a room hereafter), and the resultant mixing of the ambient room air with the supply air. In order to determine the ability of a given register design to produce an acceptable performance, detailed velocity and temperature measurements downstream of the register exit in the entire room must be performed. However, such a task is time intensive and very costly. A more practical approach is to perform detailed velocity field measurements at the very exit of the register, and then use these measurements as the boundary condition for a modern Computational Fluid Dynamics (CFD) code to predict the velocity and temperature distribution within the room. The CFD predictions can then be used to determine the register performance parameters, for example, the "throw" as a function of flow rate. Some very limited velocity and temperature measurements at selected downstream locations in the room can be performed to test the validity of CFD predictions. Nevertheless, the detailed near-field velocity measurements at the very exit of the register are sufficient to characterize[1] the fluid dynamic performance of the register design.

During this investigation the near-field velocity measurements at the exit of two different commercially available registers were performed. One was a "Hart & Cooley" (Model A611MS) register and the other was a "Lima" (Series 10V) register. These registers were chosen in consultation with IBACOS, which is a member of DOE's Building America program.

A Laser Doppler Velocimeter (LDV) was used to measure two components of the velocity vector at the exit of the register at various locations across the face of the register. Details of the experimental facility and instrumentation are presented in the next section. The measurements for the Lima register are presented in Section 3 and the measurements for the Hart & Cooley register are discussed in Section 4. Finally, concluding remarks are presented in Section 5.

2. EXPERIMENTAL SET UP AND MEASUREMENT TECHNIQUE

2.1 Description

In order to ensure a well-characterized flow without any anomalies into the register, a flow conditioning system was designed and constructed. Although the duct systems used in most American homes and small businesses would not have standardized flow characteristics, it is nevertheless important to ensure that the airflow entering into the register-boot combination is relatively uniform and symmetric. Otherwise, any unanticipated or interesting observations will always be suspected as having been probably caused by the idiosyncrasies of the flow delivery system. Furthermore, this flow regime must be known (measured) prior to testing of the registers. A schematic of the flow conditioning system and the experimental apparatus is shown in Figure 1. Photographs of the test facility are shown in Figure 2. A variable speed 10-inch diameter duct blaster was used as a source for the air delivery. As shown in Figure 1, it delivers air to the flow conditioning system, which consists of a "diffuser" followed sequentially by a 4-feet long and 18-inch diameter settling chamber, a contraction, and a 5-feet long 7-inch diameter duct. The "settling chamber" has a six-inch deep "flow straightener" (denoted by EC in Figure 1), which consists of 6-inch deep and 1-inch square openings with a screen on either end. The

[1] As discussed later, the velocity field at the exit of the register is influenced by the design of the "boot" — the transition piece between the register and the supply duct. Thus, for practical applications the boot and the register should be considered as an integrated system.

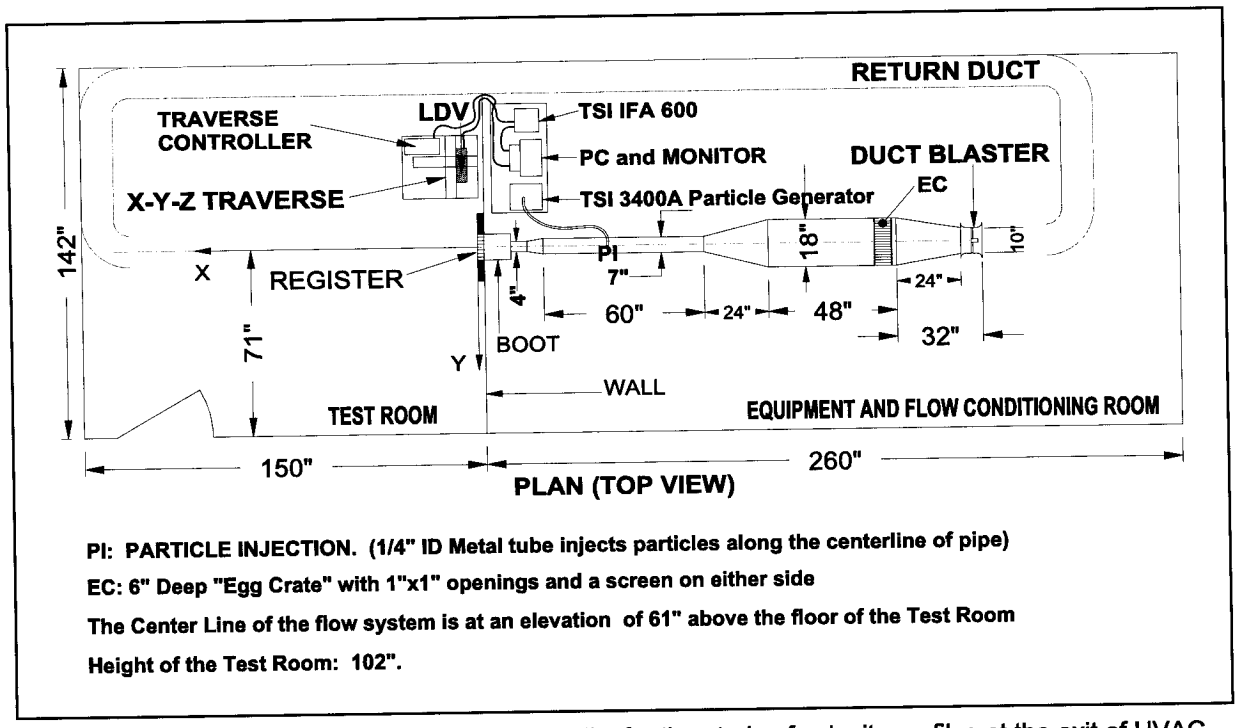

Figure 1. A schematic of the experimental facility for the study of velocity profiles at the exit of HVAC registers. X and Y are the axial and lateral coordinates respectively. Model number of the X-Y-Z traverse controller is: Velmex VP 9000 Motor Control Unit.

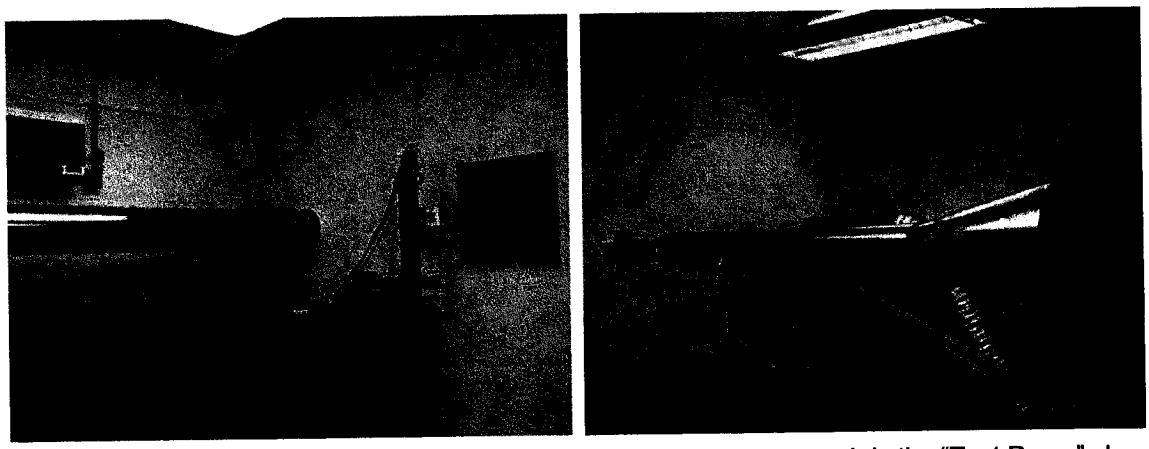

Figure 2. Photographs of the experimental facility. The left photograph is the "Test Room" showing the air outlet prior to installation of the boot and register, the LDV probe mounted on the X-Y-Z traverse, the traverse controller, and a part of the return air duct. The photograph on the right shows a partial view of the "Equipment and Flow Conditioning Room."

purpose of the flow straightener is to remove any swirling components of velocity from the airflow, and also to dampen any flow nonuniformities.

Since the laser Doppler technique uses the scattered light from particles in the flow to measure the flow velocities, particles need to be injected into the flow. A "TSI Model 3400A fluidized bed particle generator" was used for this purpose to inject titanium dioxide particles in the air stream. The particles were injected along the centerline of the 7-inch diameter duct via a ¼-inch internal diameter tube. The particle injection location is shown in Figures 1 and 2. The nominal mean diameter of these particles is 3 microns. The LDV system consists of the following components:

(a) TSI Laservec Model LDP 100, and
(b) TSI Model IFA 600 Digital Burst Processor.

The LDP 100 contains a single diode laser, optics (beam splitter, Bragg cell, lenses), and a detector. The laser has a wavelength of 685nm and a power of 50mW. The IFA 600 contains the electronics to process the signals from the LDP 100. It is controlled from a desktop personal computer (PC) via TSI supplied software, and the processed data is transferred to the PC. A 350-mm focal length lens is connected to the front end of the LDP 100. It outputs two laser beams that intersect at a distance of 350-mm. The beams are 50mm apart at the lens. To enable the measurement of the direction of the velocity component, the frequency of one of the beams is shifted by 40MHz by the Bragg cell in its path. The lens also serves the function of collecting the scattered radiation from the region of intersection, and focusing it on to a detector. The region of intersection of these two beams is therefore the measurement volume, i.e., the location at which the instantaneous velocity is measured. For the specific lens used here, this measurement volume is an elongated ellipsoid 3.8-mm in length with minor axes of 0.3 and 0.1 mm. For all the measurements performed here, the 3.8-mm long major axis was always aligned parallel to the lateral Y coordinate direction. Each time a particle crosses the measurement volume, the LDP 100 generates a signal and the IFA 600 processes the signal. If the signal satisfies certain requirements (for example, signal to noise ratio), the instantaneous velocity is transferred to the PC. As can be seen from the above description, the velocity data from a given location thus consists of a series of instantaneous values: $U_1, U_2, U_3 \ldots U_N$, which are recorded at discrete times $t_1, t_2, t_3 \ldots t_N$. These data can then be used to calculate such items as mean velocity and the root mean square velocity fluctuation.

The TSI LDP 100 probe was mounted on a motor-controlled 3-axis "BiSlide" traversing mechanism from Velmex Inc. The traverse has a total travel of 245-mm in each of the two horizontal directions, and a travel of 375-mm in the vertical direction. The position of the LDV probe is indicated on the front panel display of the Velmex VP 9000 controller with a resolution of 0.005-mm. This position is also transferred to the PC and recorded along with the velocity data. By installing a 90-degree bracket on the vertical traversing axis of the traversing mechanism, the LDP 100 can be rotated by 90 degrees, which effectively rotates the imaginary plane formed by the two laser beams leaving the LDP 100. Since the LDV measures the component of velocity along the plane of the laser beams and normal to a line that bisects the angle between the two beams, two orthogonal velocity components could be measured by rotating the LDP 100 by 90 degrees. During these experiments the axial (U) and the vertical (W) velocity components were measured. Although all the three velocity components are needed for the complete characterization of the velocity field, only two components of the velocity vector were measured. However, the chosen register designs were such that the velocity vectors at the exit of these registers have only two dominant velocity components. Excluding the outer edges of the flow, the mean value of the third velocity component (which was not measured) is expected to be very much smaller than the axial component. Therefore, and also because of time constraints, the third velocity component was not measured.

2.2 Velocity Profiles at the Exit of the Flow Conditioning System

The registers to be tested were 8"x4" in cross-section. These are typically screwed on to an 8"x4" boot. The boot, in turn, is connected to the air delivery system via a 4" diameter duct. As shown in Figure 1, a short length of 4" diameter sheet metal duct was connected to the end of the flow conditioning system. The flow conditioning system was then moved till the end of this duct was flush with the location where the register would be located during the tests. A photograph of this case is shown in Figure 3. The LDV instrumentation was then set up to measure velocity profiles at the exit of this duct.

Measurements of the axial velocity component along four different diameters, and at a distance of 20-mm from the duct exit, were performed. Both the mean and the turbulence level in the axial velocity were computed. These are plotted in Figure 4. As can be seen, the velocity profile is reasonably uniform and symmetric. Furthermore, the turbulence level is low. These measurements show no anomalies, and demonstrate that the flow conditioning system is working as designed. The nominal flow rate during these measurements was 82 cfm. This flow rate is in-between the two flow rate settings of 66 cfm and 126 cfm at which the measurements with the registers were made.

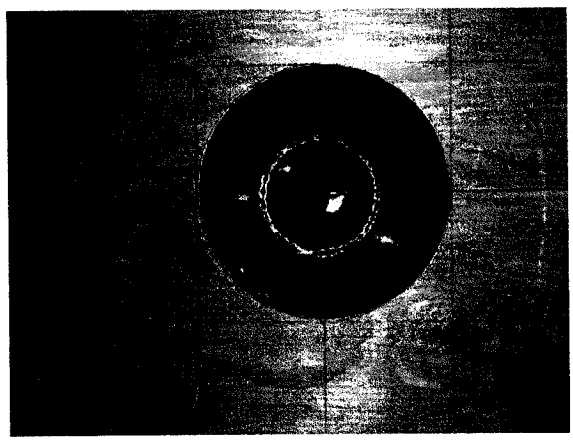

Figure 3. A photograph of the air outlet prior to installation of the boot and the register

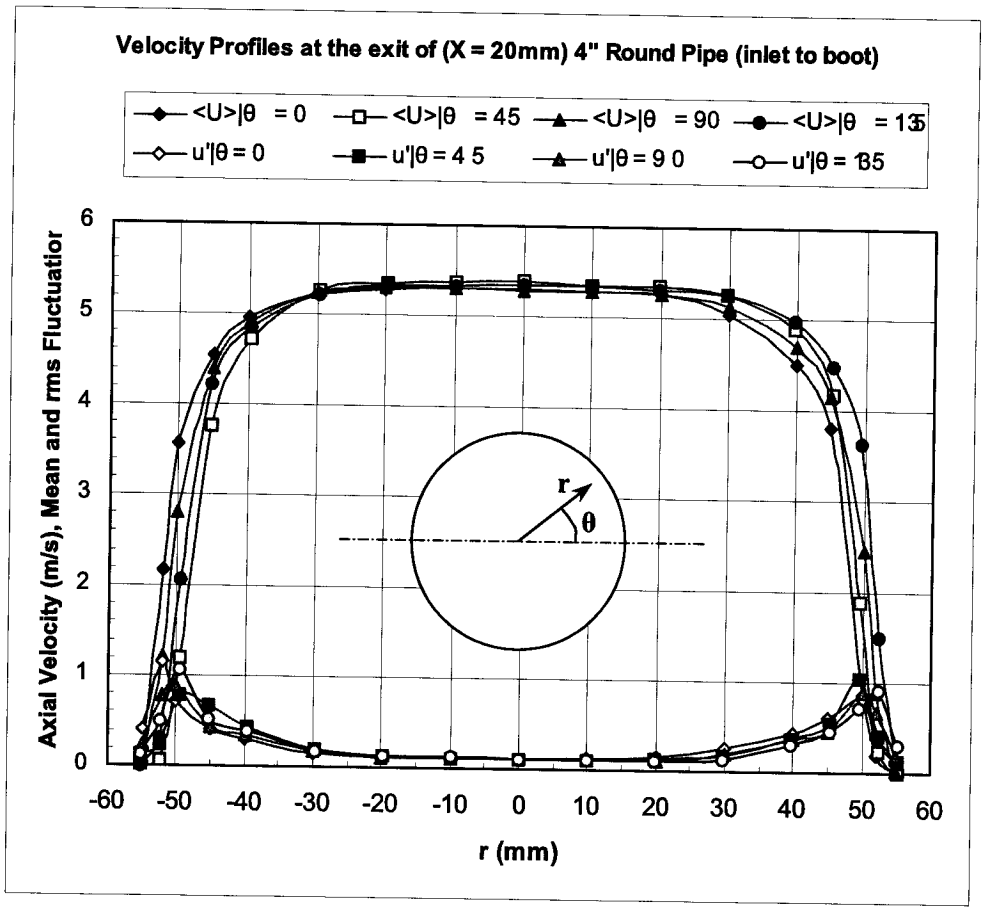

Figure 4. Mean axial velocity (<U>) and rms fluctuation in axial velocity (u') measurements 20-mm downstream of the 4" diameter duct.

3. VELOCITY MEASUREMENTS AT THE EXIT OF THE LIMA REGISTER

3.1 Introduction

Following the velocity measurements at the exit of the 4" diameter duct, an 8"x4" rectangular boot, shown in Figure 5, was installed at the end of this duct. The boot is 10 inches deep. As shown in Figure 5, the 8"x4" Lima register was then screwed on to the boot. This register is designed for flow rates from 65cfm to 125cfm. Therefore, velocity measurements were performed for two flow rates: (a) the "low flow" case, and (b) the "high flow" case. This was also true for the Hart & Cooley register, which is discussed in Section 4. For the "low flow" setting on the duct blaster speed control, the flow rate varied form 65cfm to 67.5cfm[2] during the experiments. The nominal value of the airflow rate at this setting was 66cfm. For the "high flow" case the flow rate varied from 124.8cfm to 126.5cfm. The nominal value of the airflow rate at this setting was 126cfm.

Velocity measurements were performed at three downstream locations (the X coordinate) for the Lima register: X = 5mm, X = 10mm, and X = 100mm. For each of these locations, measurements were

[2] The manufacturer provides an orifice-type of flow restricting ring that is installed at the inlet of the duct blaster for this purpose. The flow rate was measured by measuring the pressure difference across this flow-restricting ring. The calibration data provided by the duct blaster manufacturer was used for the flow rate measurement.

performed at various points across the face of the register. This register has two flow dampers (visible as two vertical lines behind the flow deflecting vanes in Figure 5) whose length is along the Z direction. For these experiments, the dampers were set in the fully open position.

3.2 Airflow Measurements for the Low Flow Case

3.2.1 The Axial Velocity Component

Axial velocity measurements at X = 5mm and Y = 0 as a function of the vertical coordinate Z are presented in Figure 6. The periodic variations in the mean velocity are clearly due to the deflecting vanes/blades of the register. These blades are fixed for the Lima register. The top set of blades point upwards and the bottom set of blades point downwards. We also note that the flow is reasonably symmetric about Z=0. Another point to note is that peak value of each cycle is not the same, but starts to drop off sharply after Z = ± 50mm even though more blades exist at either end. Thus the airflow drops off more rapidly with Z than would be expected from the register design itself. However, it is observed that this distance of 100mm (corresponding to Z = ± 50mm) is nearly the same as the diameter of the circular opening (101.6mm) at the inlet of the boot. Thus the sharp drop off in velocity beyond Z = ± 50mm is, as one might expect, related to the simple boot design that is a sudden expansion. A gentle (and longer) smooth expansion from the 4-inch diameter circular duct to the larger 8"x4"rectangular cross section should result in a more uniform flow. As one would expect from the central blade, which is normal to the axial flow direction, the mean axial velocity behind it near Z = 0 is very small and negative, indicating reverse flow. While the peak mean axial velocity is about 4m/s, the peak turbulent fluctuation (rms value) in the axial velocity is about 1m/s.

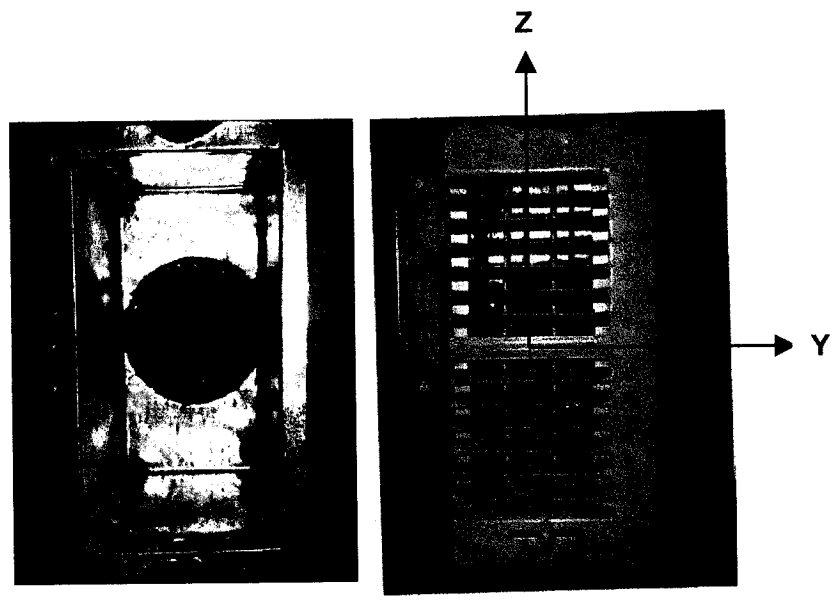

Figure 5. Photographs of the rectangular boot (left) and the installed Lima register (right). As indicated, the longer dimension of the boot is aligned with the vertical Z direction.

Axial mean velocity profiles from Y = -50mm to Y = 50mm are summarized in Figure 7 and 8. The velocity profiles are approximately symmetric about Z = 0 and Y = 0. The measured turbulent fluctuations in the axial velocity component are summarized in Figures 9 and 10.

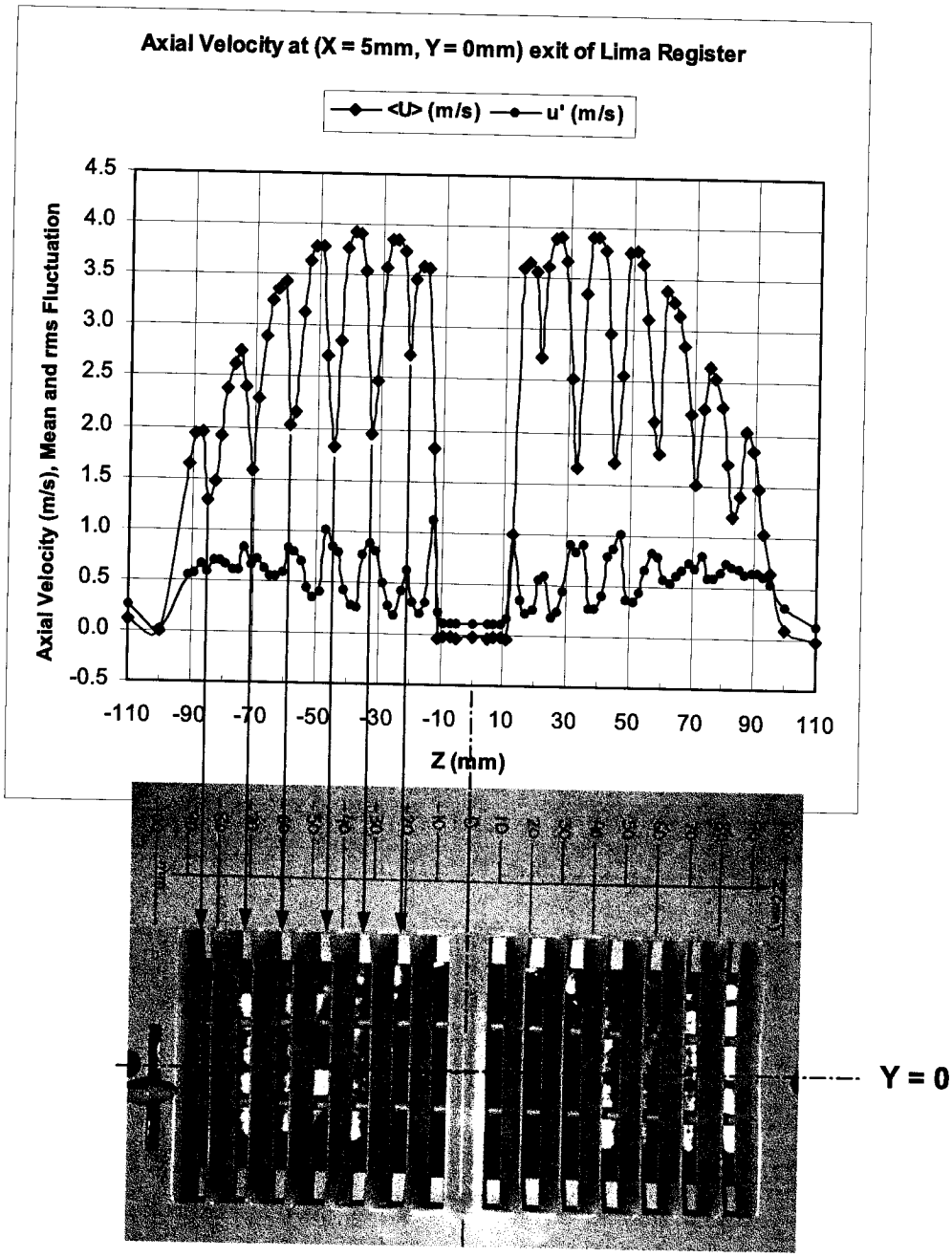

Figure 6. Measured mean and rms fluctuation of the axial velocity component at the exit of the Lima register. Nominal flow rate: 66cfm. A superimposed photograph of the register shows the correlation between the velocity variations and the deflecting vanes of the register. Measurements at 5mm downstream of the register exit and Y = 0mm. Note that Z is positive in the vertically upward direction

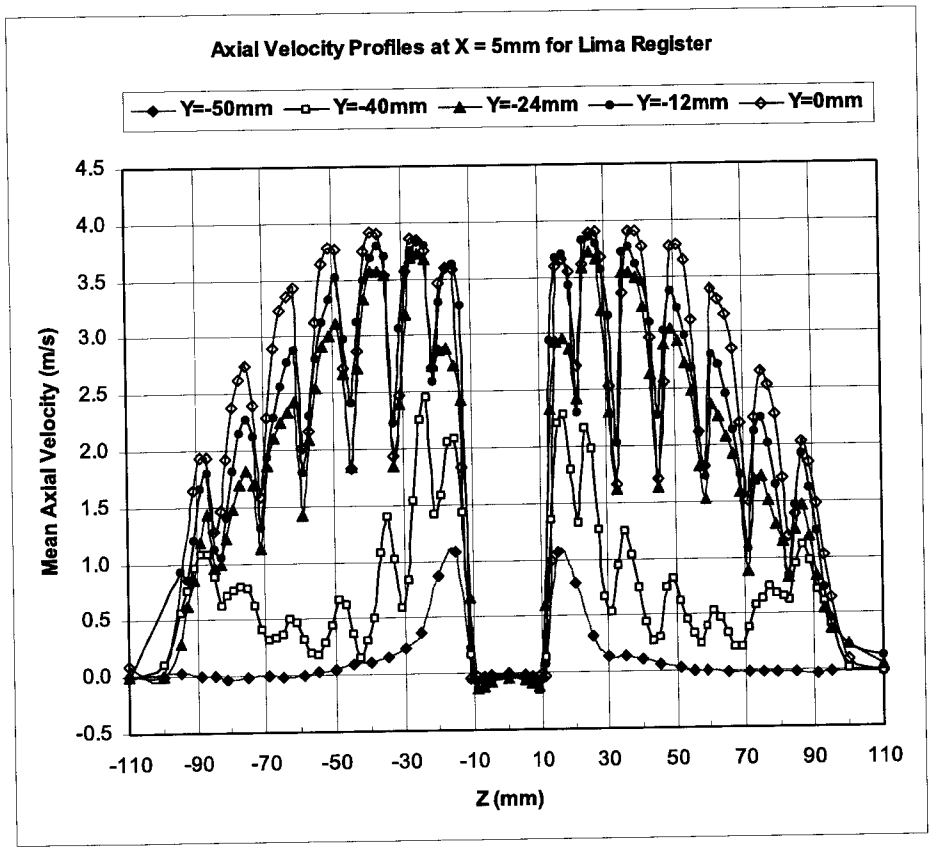

Figure 7. Measured mean axial velocity component (<U>) profiles at the exit of the Lima register. Measurements from Y = 0 to Y = -50mm at 5mm downstream of the register exit. Nominal flow rate: 66cfm.

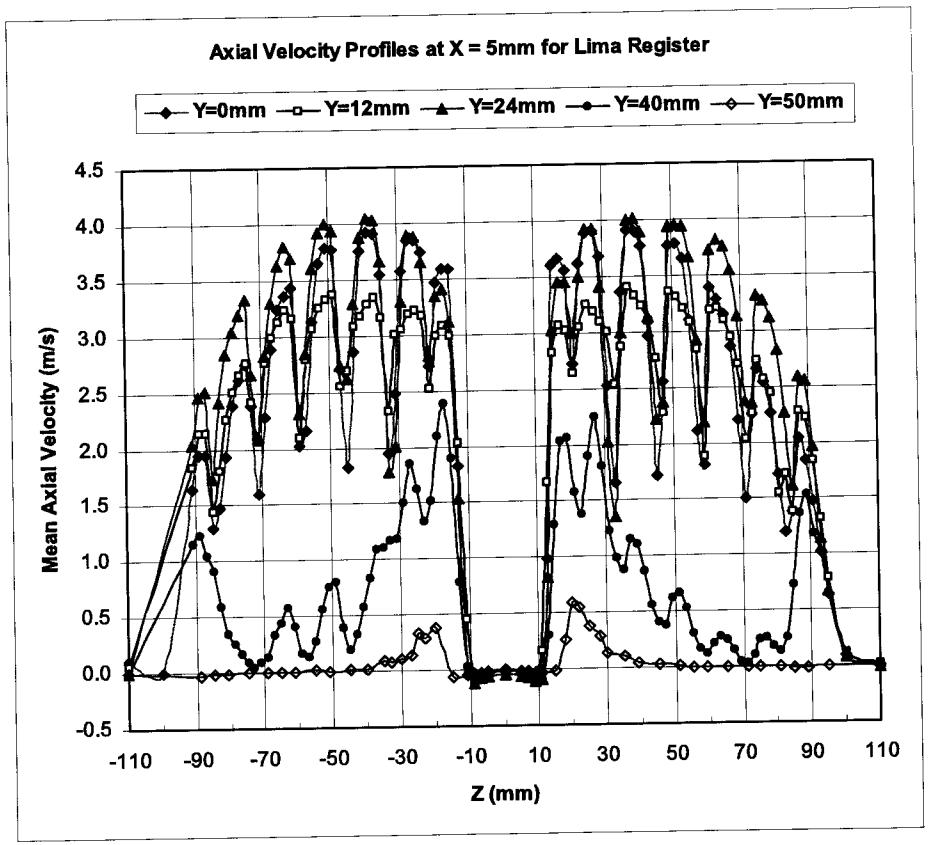

Figure 8. Measured mean axial velocity component (<U>) profiles at the exit of the Lima register. Measurements from Y = 0 to Y = 50mm at 5mm downstream of the register exit. Nominal flow rate: 66cfm.

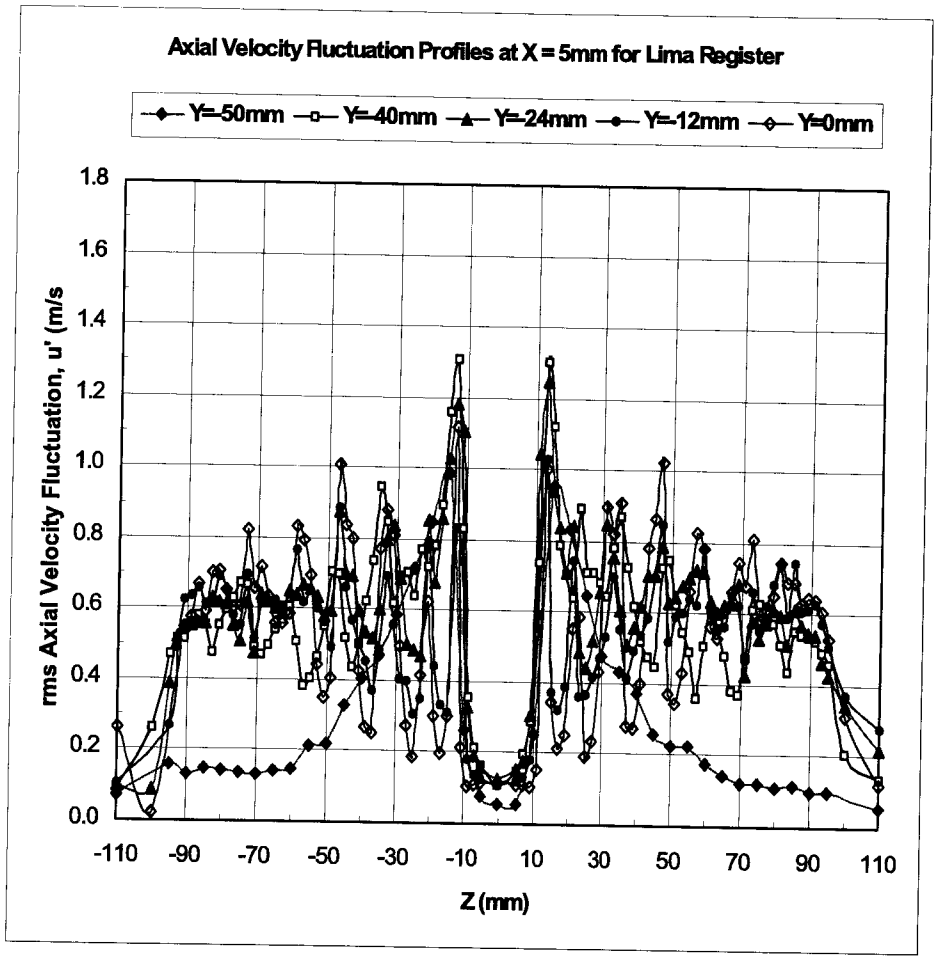

Figure 9. Measured turbulence level in the axial velocity component at the exit of the Lima register. Measurements from Y = 0 to Y = -50mm at 5mm downstream of the register exit. Nominal flow rate: 66cfm

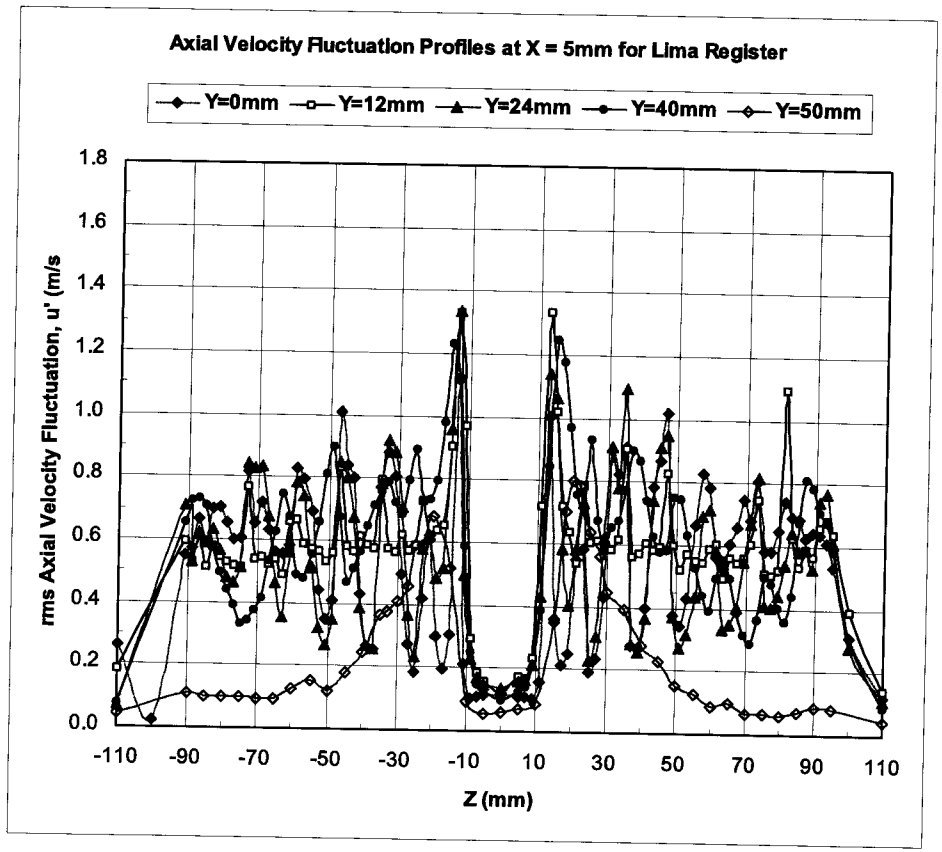

Figure 10. Measured turbulence level in the axial velocity component at the exit of the Lima register. Measurements from Y = 0 to Y = 50mm at 5mm downstream of the register exit. Nominal flow rate: 66cfm.

3.2.2 The Vertical Velocity component

After completing the axial velocity measurements, the LDV probe was rotated by 90 degrees and bolted on to the traversing mechanism via a right-angle bracket to allow the measurement of the vertical velocity component, W. During realignment of the laser beams it was found that the traversing mechanism could not be moved back to the axial position of X = 5mm at which the axial velocity component measurements were made. This was due to the fact that the LDV probe would physically hit the wall at approximately X = 8mm. Therefore, the *vertical velocity component* measurements were performed at X = 10mm. Time constraints did not allow another complete set of *axial* velocity measurements to be made at X = 10mm. However, one additional axial velocity profile measurement was made at X = 10mm and Y = 0mm.

The vertical velocity component measurements at Y = 0mm are shown in Figure 11. As can be seen from this figure, the flow is moving upwards (positive <W>) in the top region and downwards in the bottom region. This is, as one would expect from orientation of the blade angles in the register. Similar to the axial component, the vertical velocity component also exhibits periodic variations corresponding to the blades. This can be seen more clearly from Figure 12, which shows the measurements of the axial and vertical velocity components at the same location (X = 10mm, Y = 0mm). The correlation between the two components is strong. From these measurements the angle of the mean velocity vector in the Z-X plane to the X-axis was calculated. This angle, $\theta = \tan^{-1}(\langle W\rangle/\langle U\rangle)$, is plotted in Figure 13. As can be seen, the vector angle is fairly constant, about +37 degrees across the upper half of the register, and –36 degrees across the lower half of the register.

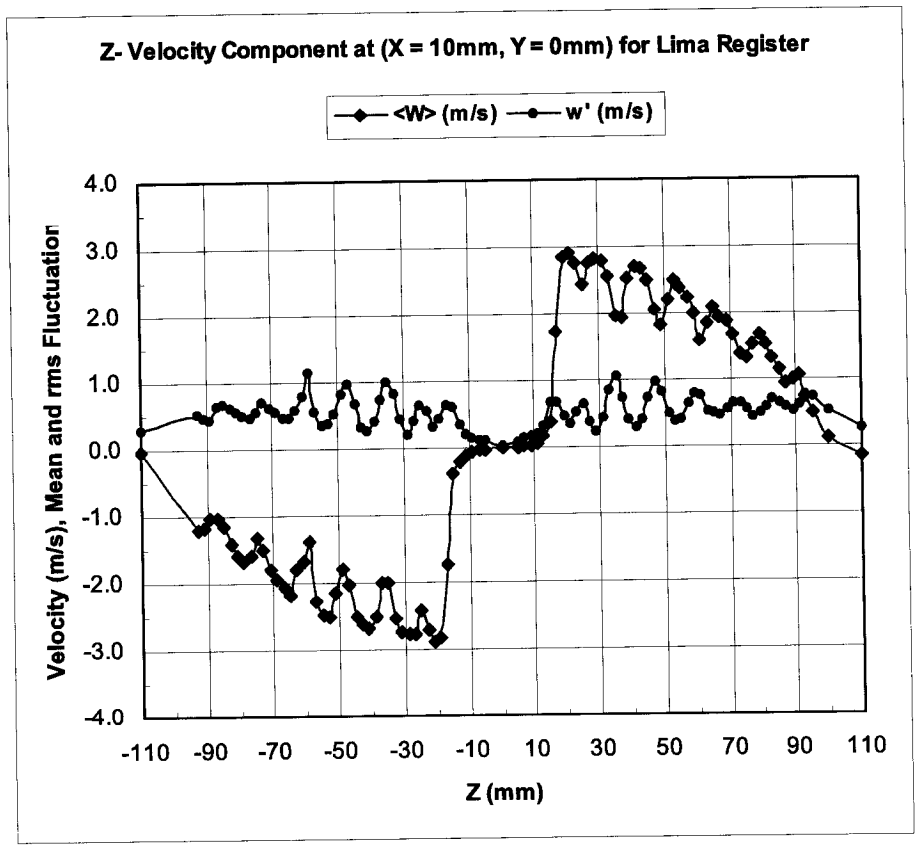

Figure 11. Measured mean and rms fluctuation of the vertical velocity component at the exit of the Lima register. Measurements at 10mm downstream of the register exit and Y = 0mm. Nominal flow rate: 66cfm

The mean vertical velocity component profiles from Y = -50mm to Y = 50mm are summarized in Figures 14 and 15. The profiles of the magnitude of the velocity component are approximately symmetric about Z = 0 and Y = 0. The measured turbulent fluctuations in the vertical velocity component are summarized in Figures 16 and 17.

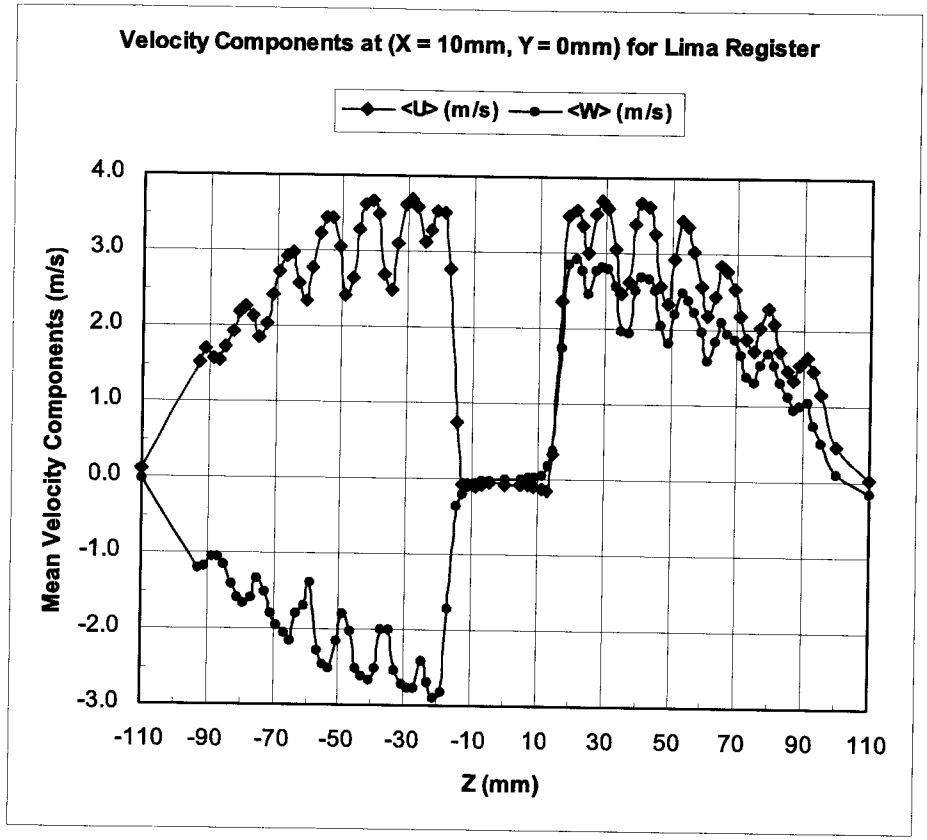

Figure 12. Measured mean axial and vertical velocity components at the exit of the Lima register. Measurements at 10mm downstream of the register exit and Y = 0mm. Nominal flow rate: 66cfm

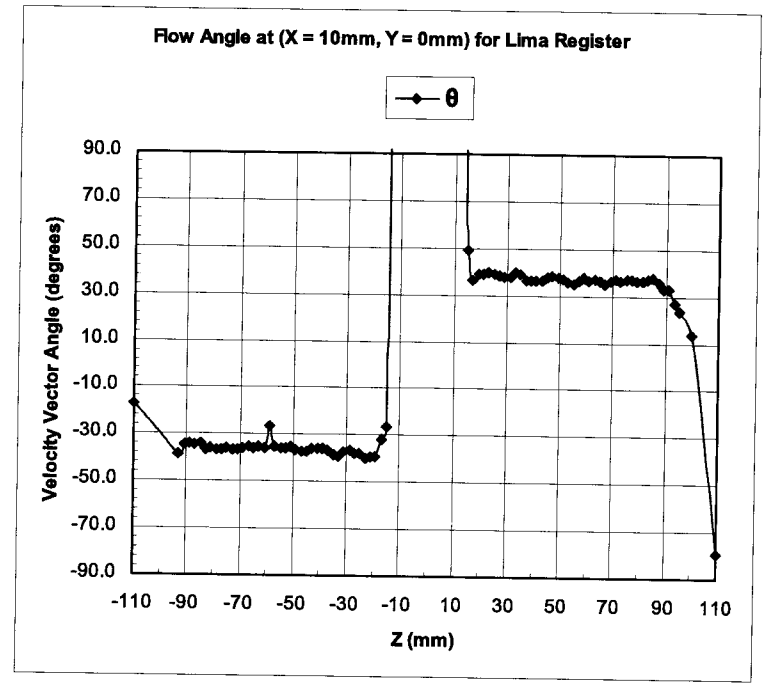

Figure 13. Velocity vector angle to the horizontal in the Z-X plane at 10mm downstream of the register exit and Y = 0mm. Nominal flow rate: 66cfm.
(Average angle: +37, -36 degrees)

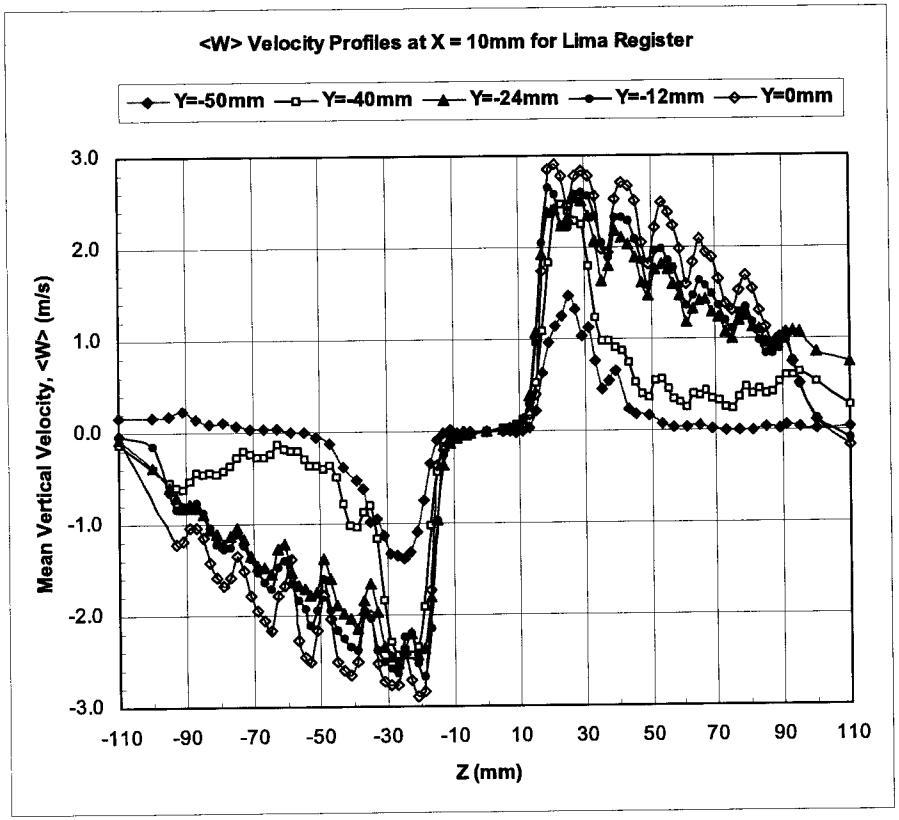

Figure 14. Measured mean vertical velocity component profiles at the exit of the Lima register. Measurements from Y = 0 to Y = -50mm at 10mm downstream of the register exit. Nominal flow rate: 66cfm

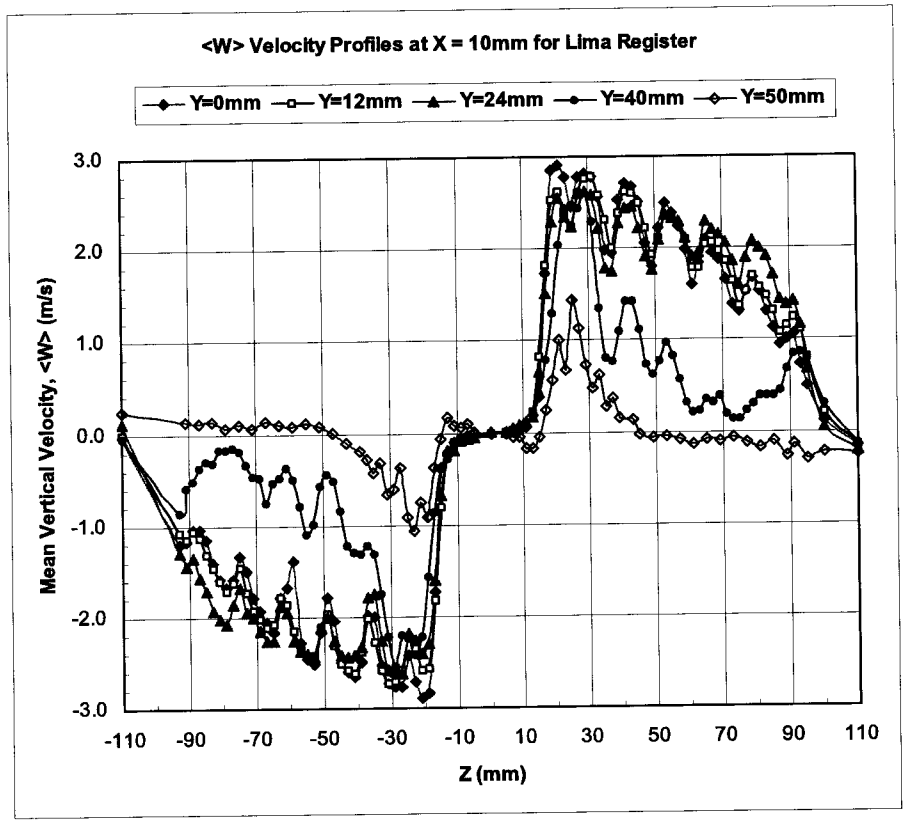

Figure 15. Measured mean vertical velocity component profiles at the exit of the Lima register. Measurements from Y = 0 to Y = 50mm at 10mm downstream of the register exit. Nominal flow rate: 66cfm

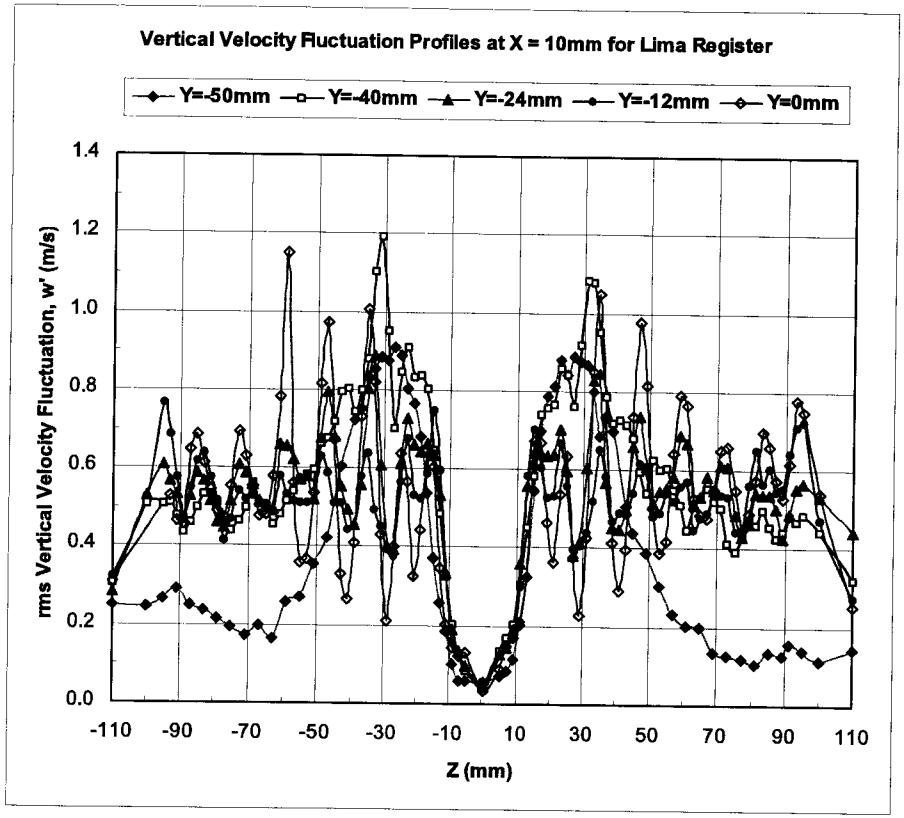

Figure 16. Measured turbulence level in the vertical velocity component at the exit of the Lima register. Measurements from Y = 0 to Y = -50mm at 10mm downstream of the register exit. Nominal flow rate: 66cfm

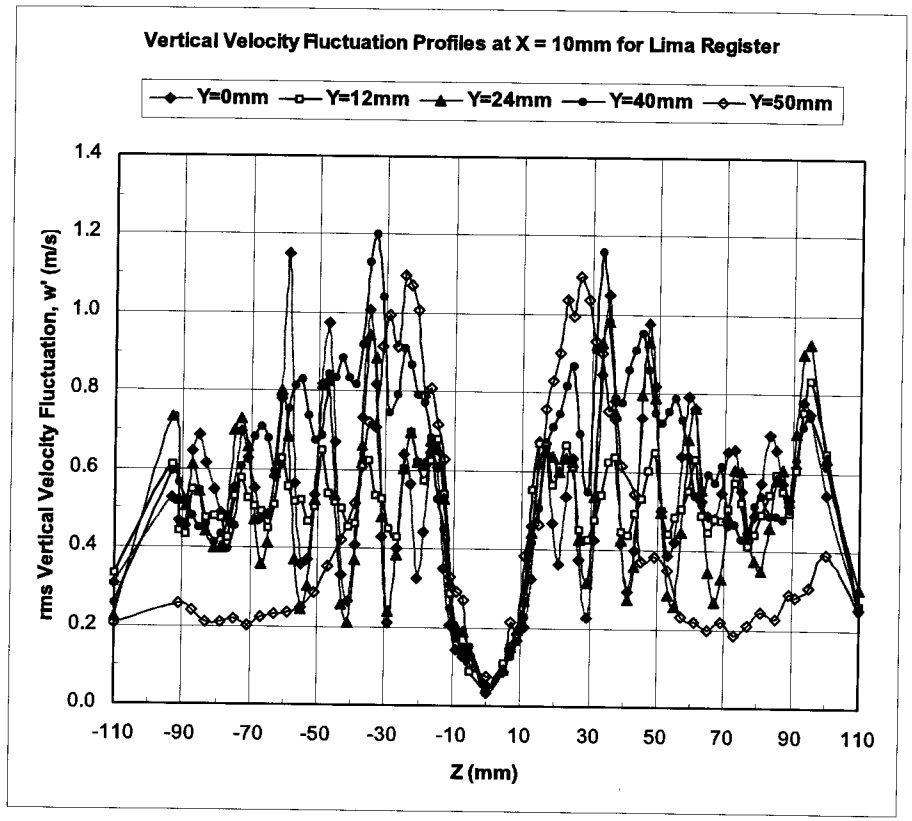

Figure 17. Measured turbulence level in the vertical velocity component at the exit of the Lima register. Measurements from Y = 0 to Y = 50mm at 10mm downstream of the register exit. Nominal flow rate: 66cfm

3.2.3 The Axial Evolution of the Velocity Components

The axial and vertical velocity components were also measured at a downstream distance of 100mm. The evolution of the axial velocity component with the downstream distance is shown in Figures 18 and 19.

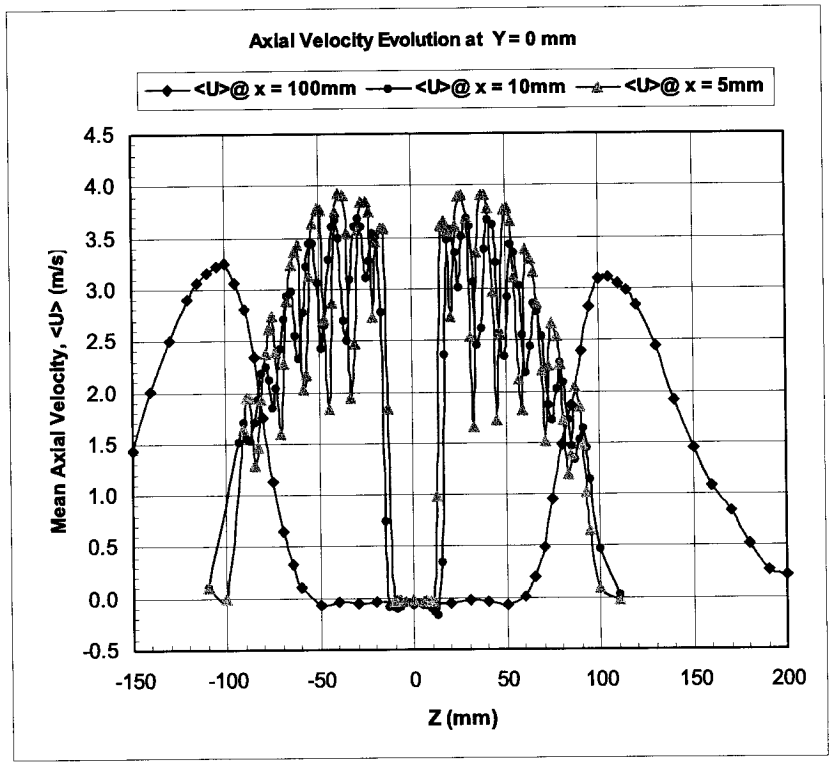

Figure 18. The evolution of the mean axial velocity component profiles with the downstream distance, X for the Lima register. Measurements at Y = 0. Nominal flow rate: 66cfm.

As can be see from these figures, the periodic variations in the magnitude of the velocity due the deflecting blades have completely vanished at X = 100mm. Furthermore, these plots suggest that this register is very effective in splitting the incoming airflow into two diverging jets — as the register designers presumably intended.

The measurements of the vertical velocity component at X = 100mm are presented in Figure 20. These measurements, together with the measurements of the axial velocity component, were used to generate a plot of airflow velocity vectors as projected on to the X-Z plane. The velocity vectors on the X-Z plane passing through Y = 0 are shown in Figure 21. The velocity vectors are to scale, and have been plotted for the two axial locations of X = 10mm and X = 100mm. As can be seen, in the neighborhood of Z = 0 there is a large region (of recirculating flow) with small velocities towards the register.

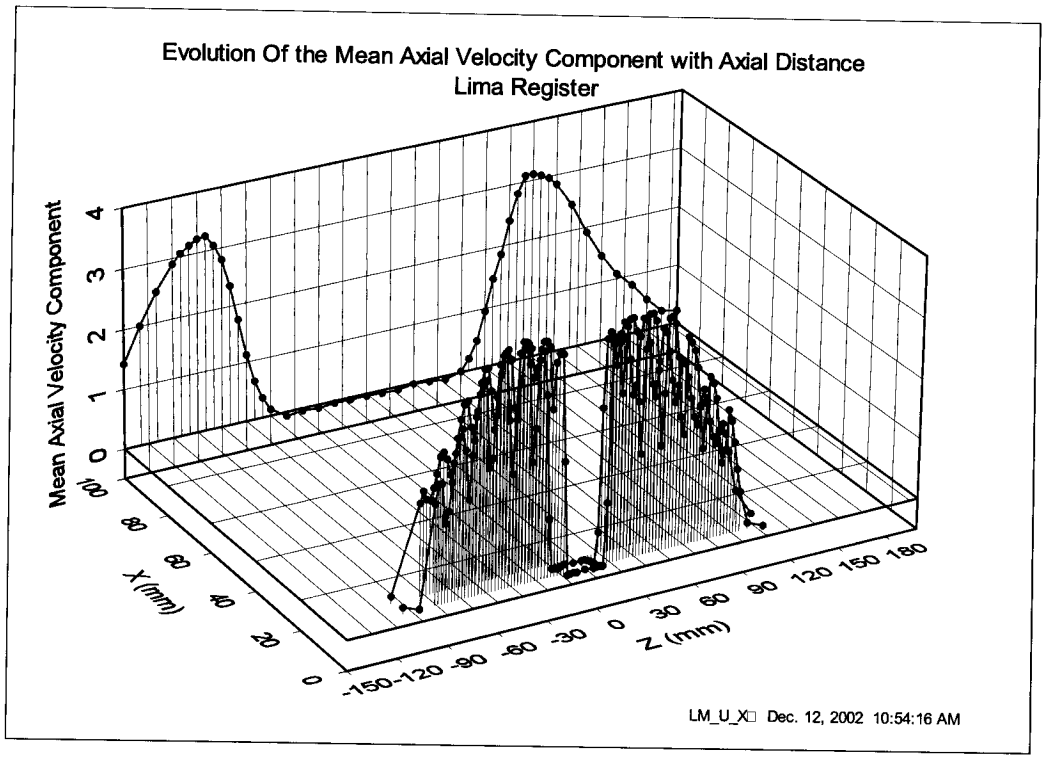

Figure 19. The evolution of the mean axial velocity component profiles with the downstream distance, X for the Lima register. Measurements at Y = 0. Nominal flow rate: 66cfm.

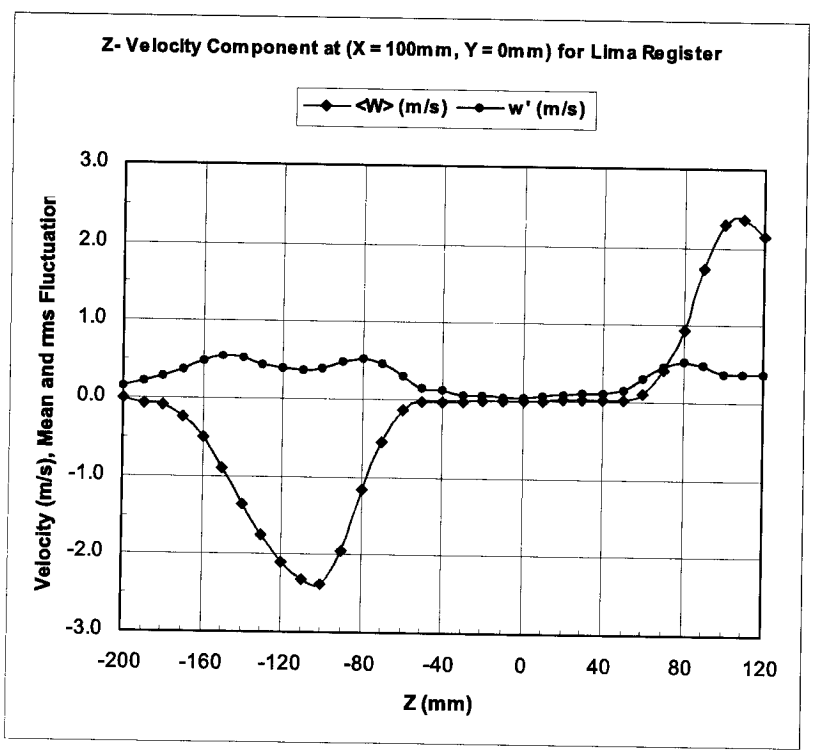

Figure 20. Measured mean and rms fluctuation of the vertical velocity component at the exit of the Lima register. Measurements at 100mm downstream of the register exit and Y = 0mm. Nominal flow rate: 66cfm

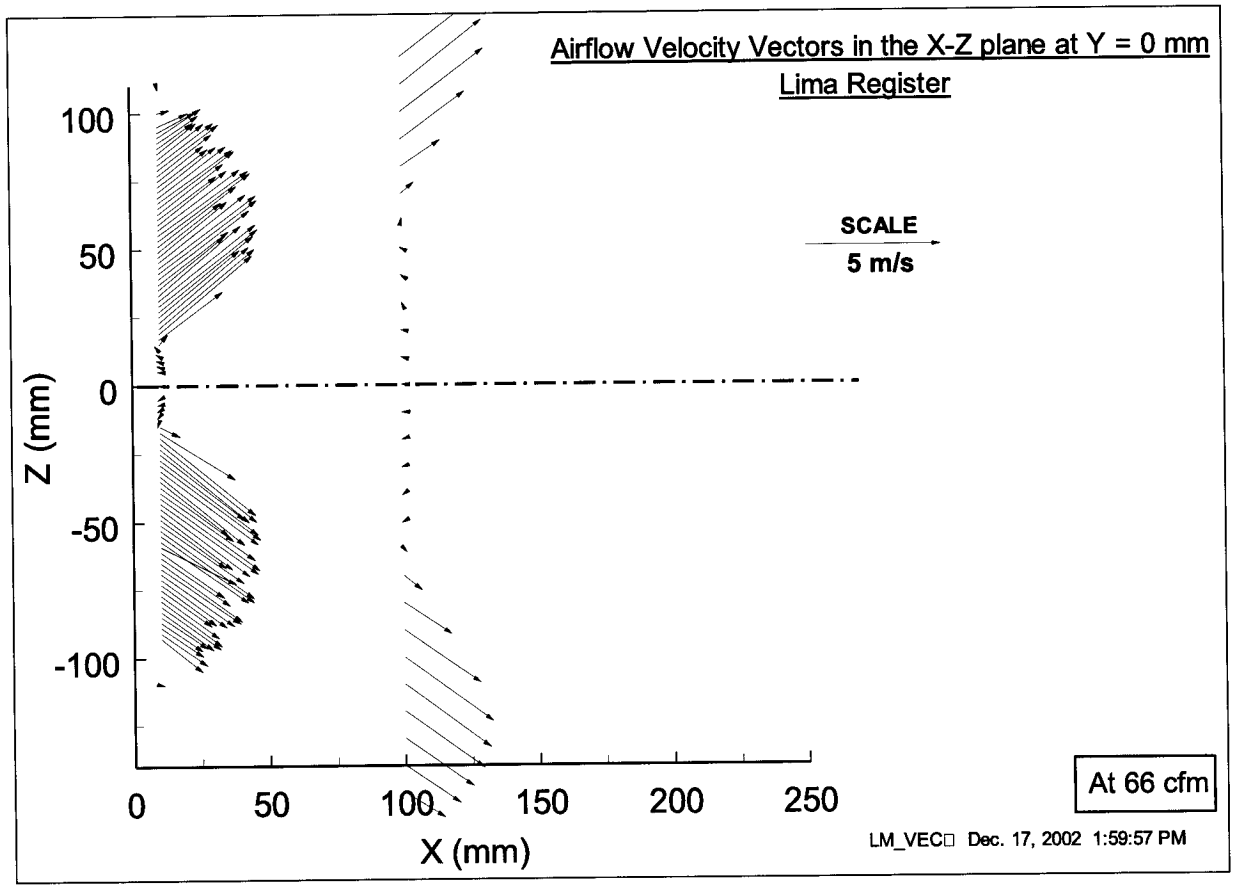

Figure 21. The measured mean velocity vectors in the X-Z plane at Y = 0 for two downstream locations (X = 10mm and X = 100mm) for the Lima Register exit.

3.3 Airflow Measurements for the High-Flow Case

3.3.1 The Axial and Vertical Velocity Components

Because of the observed symmetry of the velocity profiles (about Z = 0 and Y = 0) under low flow rate conditions, velocity profile measurements for the high-flow case were performed across only one quadrant of the Lima register outlet. A summary of the mean axial velocity component profiles and associated rms fluctuations in it at X = 5mm are presented in Figures 22 and 23. The measurements of the vertical velocity component are shown in Figures 24 and 25. The velocity profiles appear similar to the ones observed for the low-flow case. This is further discussed in the next section.

3.3.2 The Scaling of Velocity Components with Flow Rate for the Lima Register

The purpose of making velocity measurements for the high-flow case was to see if there was a significant change in the near-field velocity distribution at the exit of the register with the volumetric flow rate through the register. Normally, one would expect that if there is no flow regime change with the flow rate, the velocity profiles should scale with the flow rate. That is, if the velocity components are normalized with the flow rate, the scaled (or dimensionless) velocity profiles will be very nearly identical at different flow rates. (One such example of a flow regime change would be the onset of flow separation at a deflecting blade (straight or curved) at high flow rates and no separation at low flow rates.)

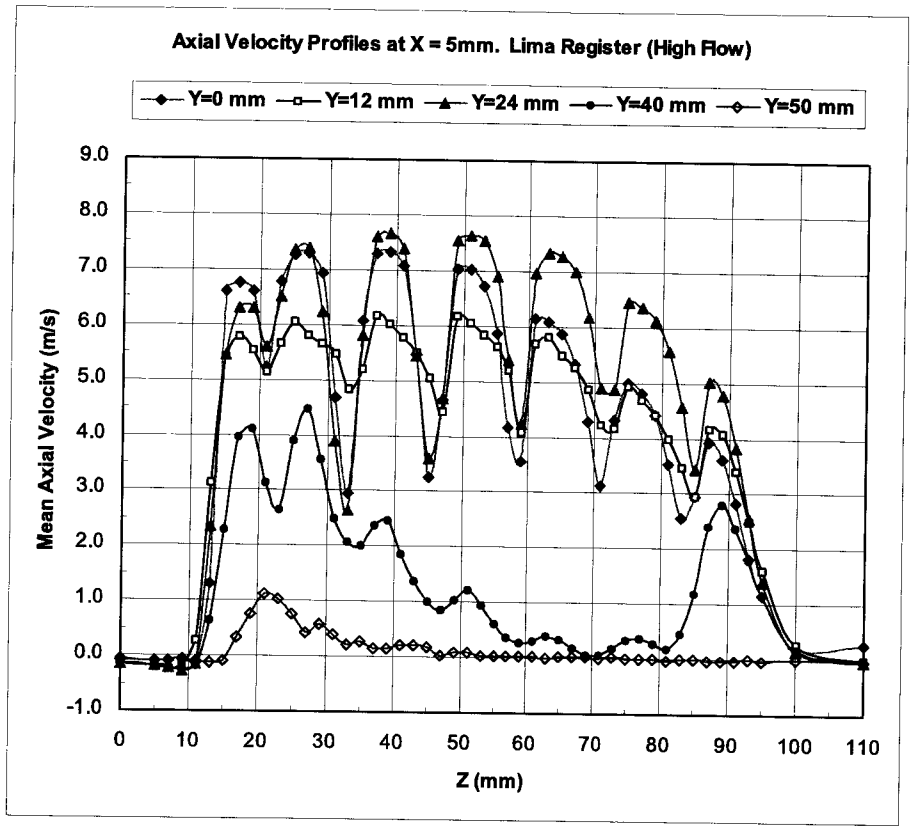

Figure 22. Measured mean axial velocity component (<U>) profiles at the exit of the Lima register. Measurements from Y = 0 to Y = 50mm at 5mm downstream of the register exit. Nominal flow rate: 126cfm

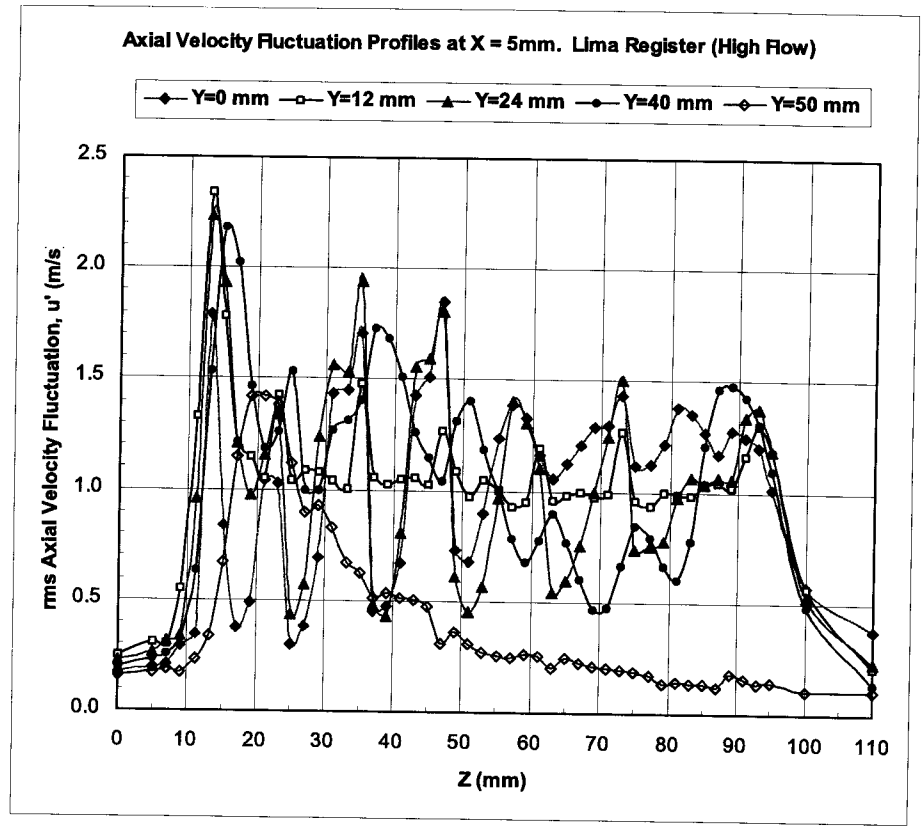

Figure 23. Measured turbulence level in the axial velocity component at the exit of the Lima register. Measurements from Y = 0 to Y = 50mm at 5mm downstream of the register exit. Nominal flow rate: 126cfm.

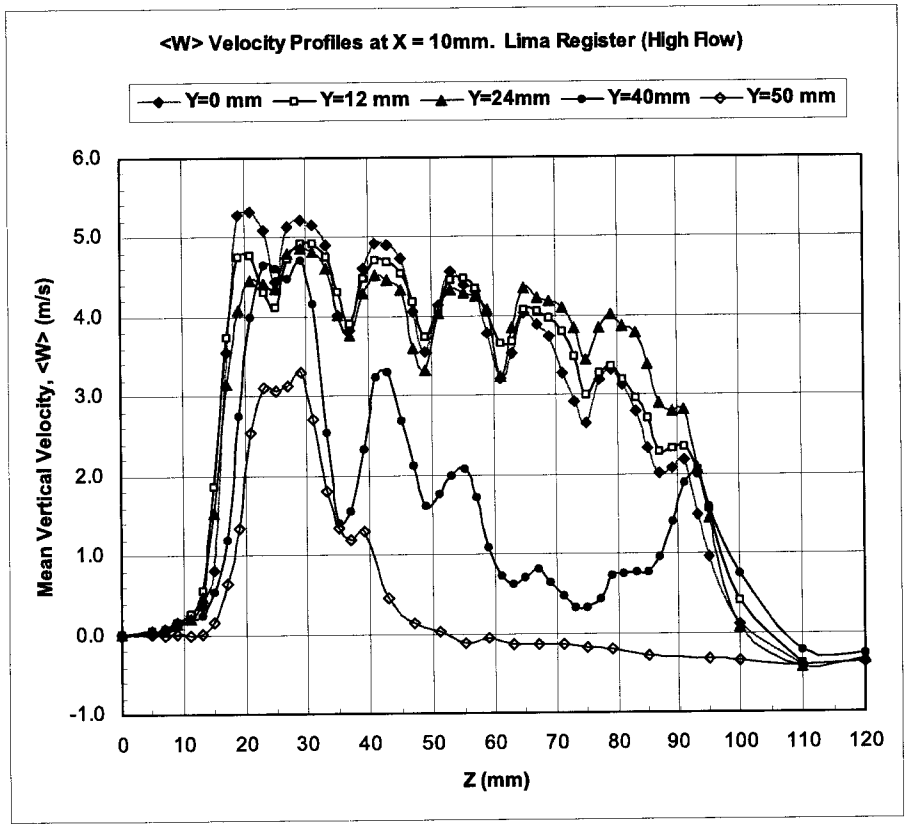

Figure 24. Measured mean vertical velocity component profiles at the exit of the Lima register. Measurements from Y = 0 to Y = 50mm at 10mm downstream of the register exit. Nominal flow rate: 126cfm.

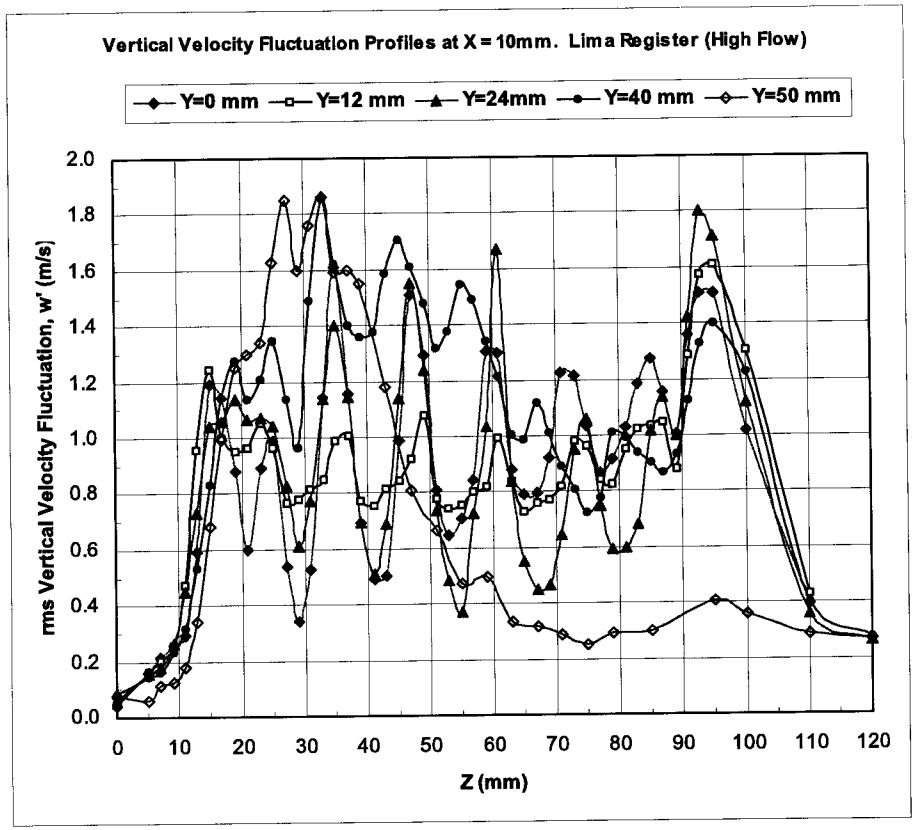

Figure 25. Measured turbulence level in the vertical velocity component at the exit of the Lima register. Measurements from Y = 0 to Y = 50mm at 10mm downstream of the register exit. Nominal flow rate: 126cfm.

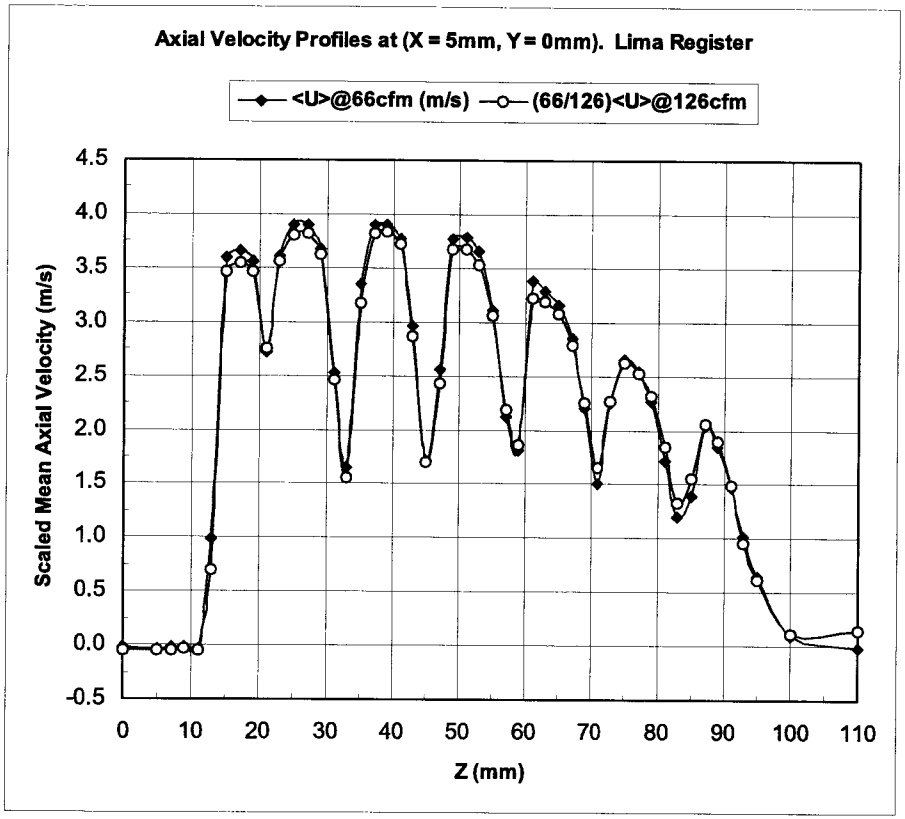

Figure 26. Comparison of mean axial velocity profiles at X = 5mm and Y = 0mm for the Lima Register at two flow rates. The measured mean velocity at 126cfm has been multiplied by the flow rate ratio of (66/126).

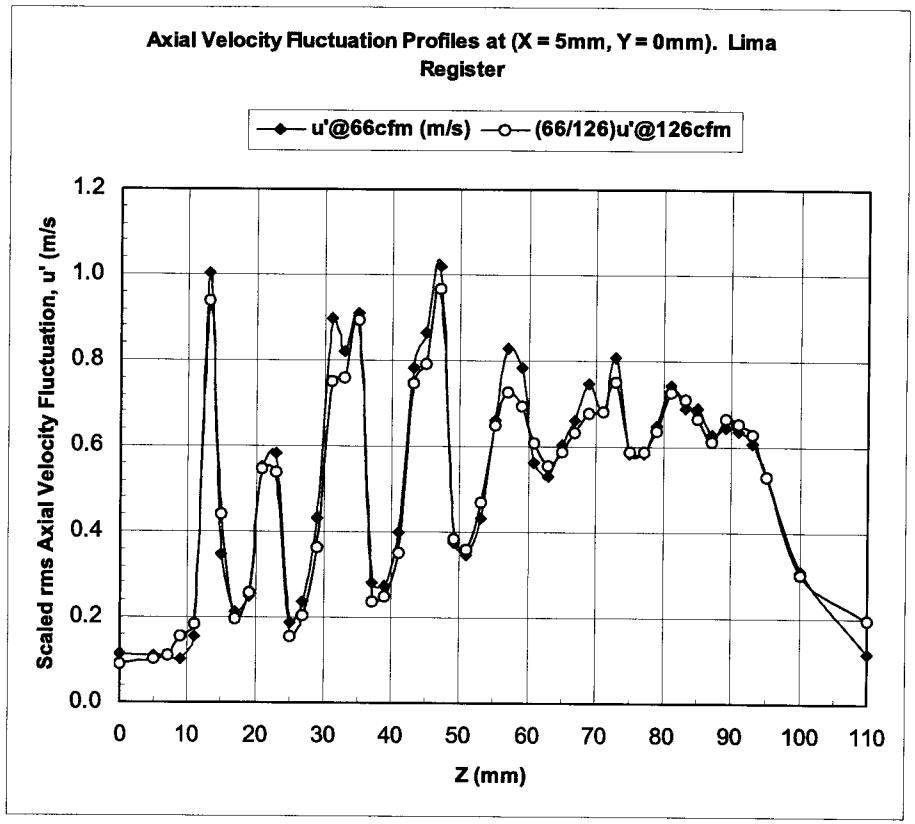

Figure 27. Comparison of turbulence level in the axial velocity component at X = 5mm and Y = 0mm for the Lima Register at two flow rates. The measured u' at 126cfm has been multiplied by the flow rate ratio of (66/126).

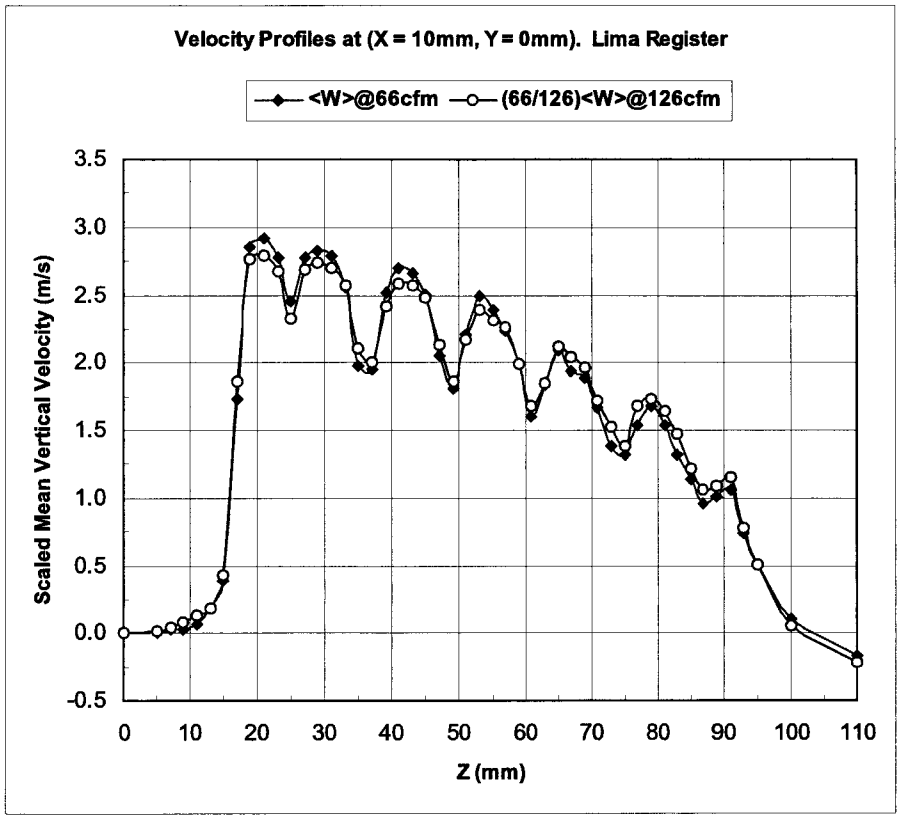

Figure 28. Comparison of mean vertical velocity profiles at X = 10mm and Y = 0mm for the Lima Register at two flow rates. The measured mean velocity at 126cfm has been multiplied by the flow rate ratio of (66/126).

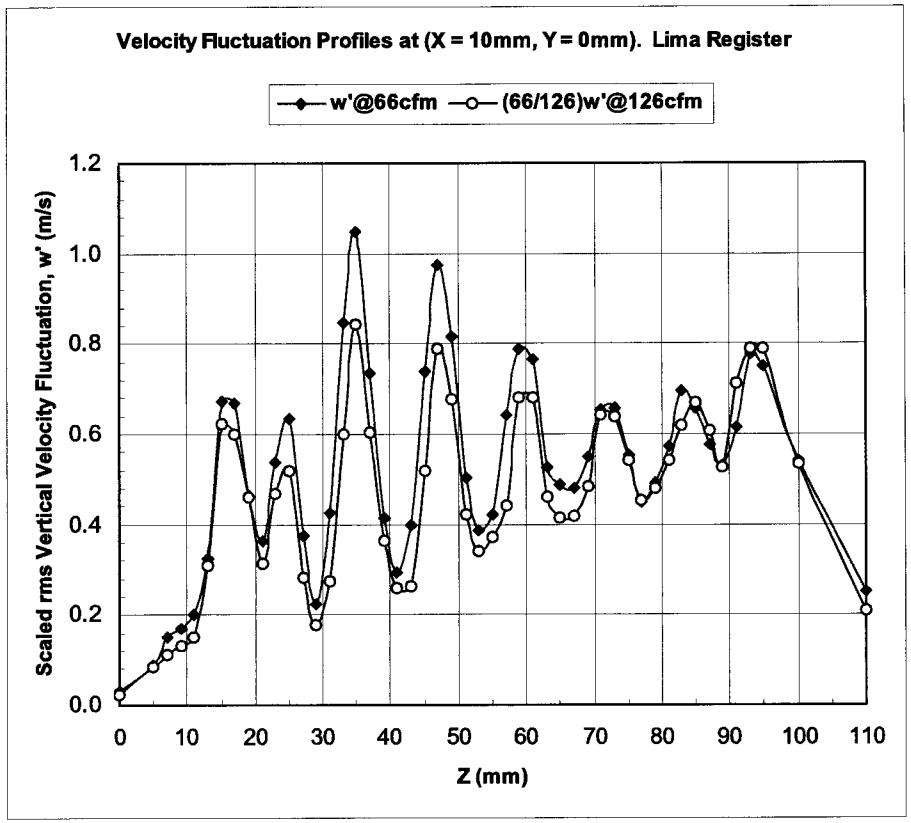

Figure 29. Comparison of turbulence level in the vertical velocity component at X = 10mm and Y = 0mm for the Lima Register at two flow rates. The measured w' at 126cfm has been multiplied by the flow rate ratio of (66/126).

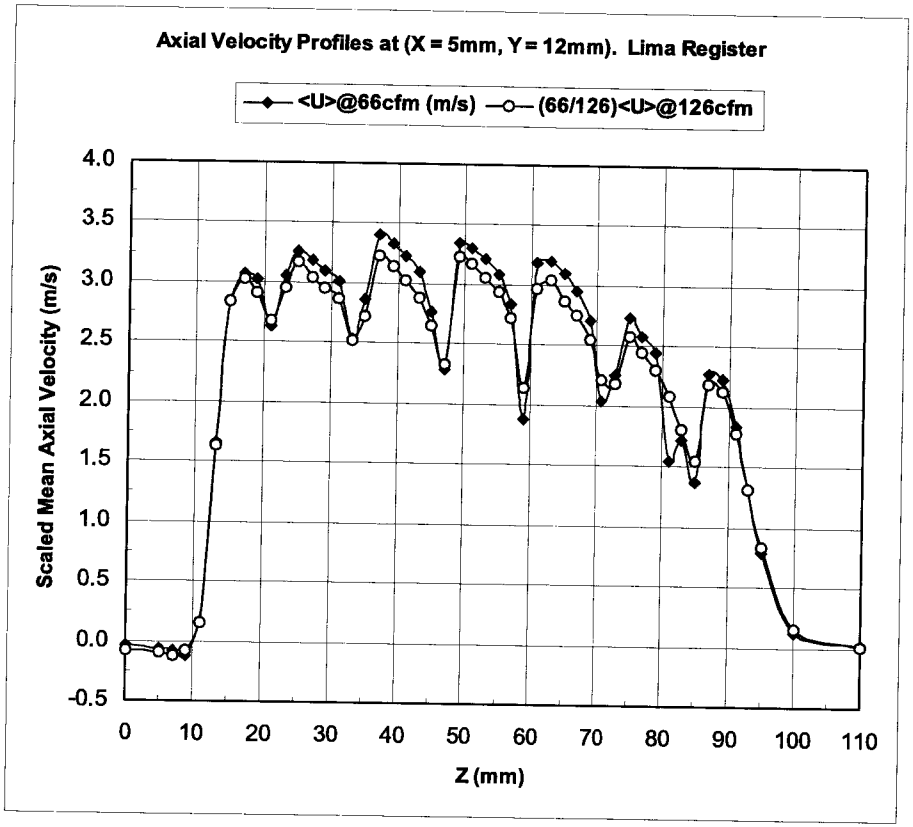

Figure 30. Comparison of mean axial velocity profiles at X = 5mm and Y = 12mm for the Lima Register at two flow rates. The measured mean velocity at 126cfm has been multiplied by the flow rate ratio of (66/126).

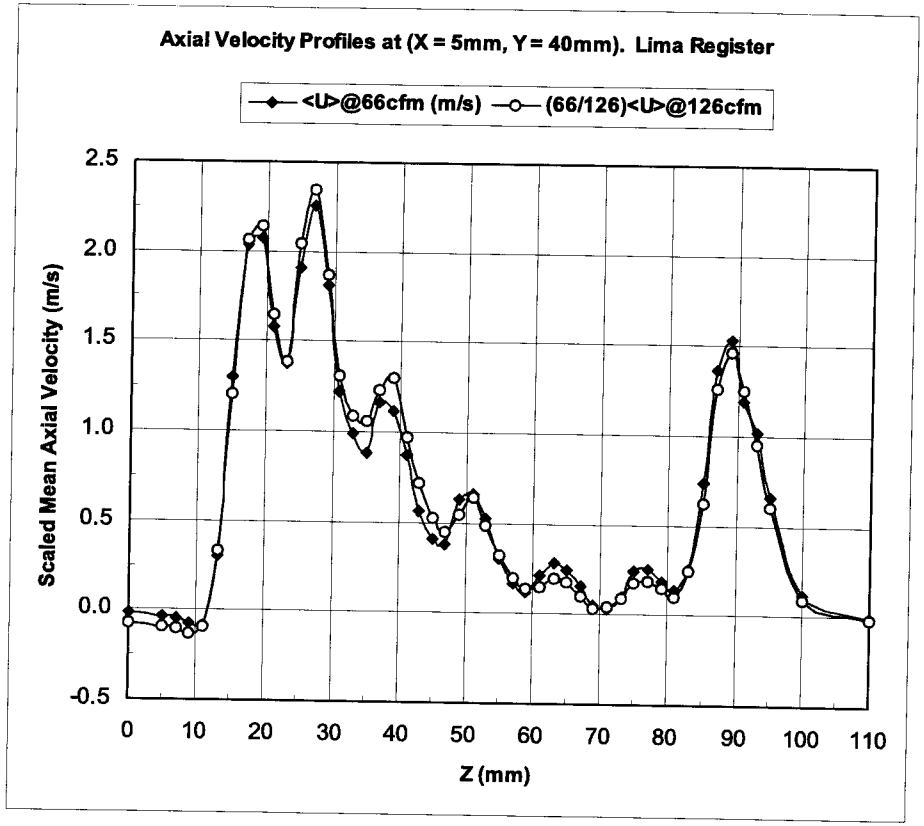

Figure 31. Comparison of mean axial velocity profiles at X = 5mm and Y = 40mm for the Lima Register at two flow rates. The measured mean velocity at 126cfm has been multiplied by the flow rate ratio of (66/126).

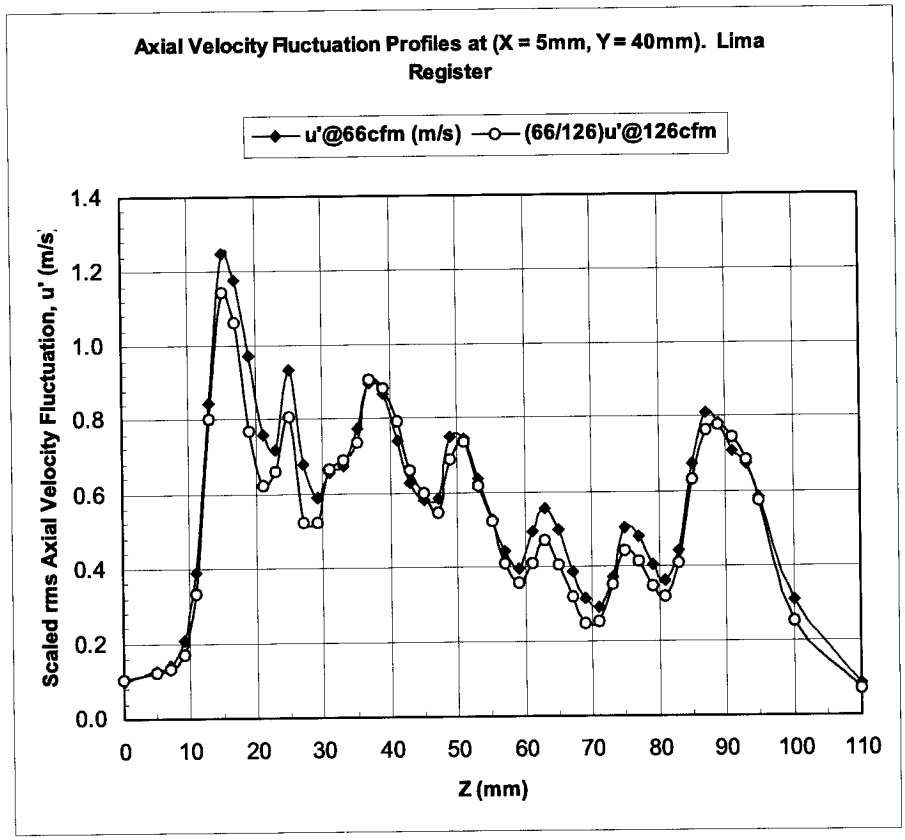

Figure 32. Comparison of turbulence level in the axial velocity component at X = 5mm and Y = 40mm for the Lima Register at two flow rates. The measured u' at 126cfm has been multiplied by the flow rate ratio of (66/126).

Figures 26 through 32 show a comparison of various velocity profiles at identical locations for the two flow rates of 66cfm and 126cfm. For comparison purposes the measured velocity at the higher flow rate has been normalized by the flow rate ratio of (66/126). These figures show that for this Lima register the near-field velocity profiles scale with the flow rate.

4. VELOCITY MEASUREMENTS AT THE EXIT OF THE HART & COOLEY REGISTER

4.1 Introduction

Following the velocity measurements discussed above, the Lima register was removed and the boot was rotated by 90 degrees. As shown in Figure 33, the Hart & Cooley register was then installed at the end of the boot. This register was installed with the longer cross-sectional dimension in the horizontal (Y) direction. As before, the velocity measurements were performed for the same two nominal volumetric flow rates of 66cfm and 126cfm. As shown in Figure 33, the axial coordinate X is measured from the flat face of the register and not from the trailing edge of the curved deflecting blades. Prior to installation of the Hart & Cooley register, the flow control dampers at the inlet of this register were removed. This was done in consultation with IBACOS since they had performed experiments with the same register without the dampers.

Velocity measurements were performed at two axial locations: X = 22mm and X = 120mm. The Z coordinate was traversed across the face of the register for many Y coordinate locations. Since the register has a natural symmetry about Y = 0, the measurements were not made across the entire right half of the register face. Instead, the Y coordinate was only varied in the range of -120mm to +30mm.

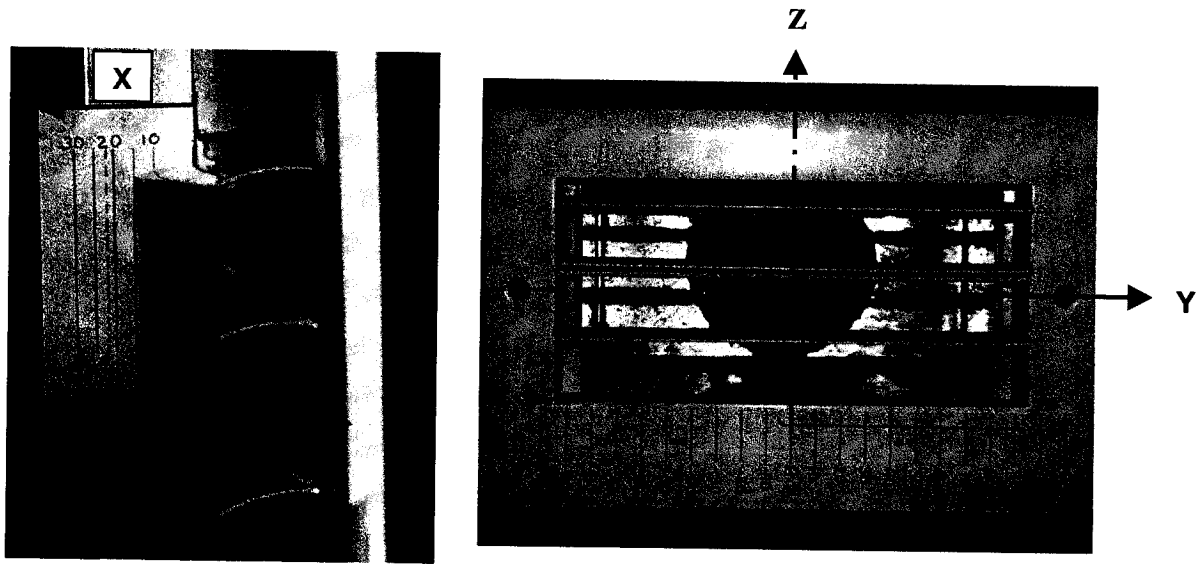

Figure 33. Photographs of the installed Hart & Cooley register together with the labeled coordinate axes. The flow control dampers have been removed from the register and all the three deflecting blades are in the horizontal position. The photograph on the left shows the zero of the X-axis and the measurement location of X = 22 mm (dotted line).

4.2 Airflow Measurements for the Low Flow Case

4.2.1 The Axial Velocity Component

The axial velocity measurements at X = 22mm and Y = 0 as a function of the Z coordinate are presented in Figure 34. This axial location is about 7mm downstream of the trailing edge of the blades. A photograph of a portion of the register is superimposed on these velocity measurements to show the correlation between the variations in the velocity profile and the location of the flow deflecting blades. While the maximum mean axial velocity component is about 4.5m/s, the maximum rms fluctuation in it is about 1.1m/s. As one would expect, the peaks in the rms fluctuation u' occur near the locations of maximum in the mean velocity gradient (region of maximum shear).

A summary of the mean axial velocity profiles (as a function of Z) for various Y locations at the downstream distance of X = 22mm is presented in Figures 35 and 36. The latter figure shows that the measurements at Y = 30mm are close to measurements at Y = -30mm, and the measurements at Y = 15mm are close to measurements at Y =-15mm, thus indicating reasonable symmetry of velocity profiles in the central region around Y = 0. These mean axial velocity profiles (for $Y \leq 0$) are further presented as a three-dimensional line plot in Figure 37. The observed sharp drop in the measured mean axial velocity component with the Y coordinate for $|Y| \geq 40$mm is seen more clearly in Figure 38. By observing the front face of the register in Figure 33 above, one would expect a fairly uniform velocity profile as a function of Y for at least $|Y| \leq 75$mm. This rather sharp variation of the velocity with the Y coordinate is clearly a result of the simple boot design, which is a sudden transition from a 4" diameter duct to a 4"x8" rectangular cross-section.

Measurements of the rms fluctuations in the axial velocity component, u', are summarized in Figure 39.

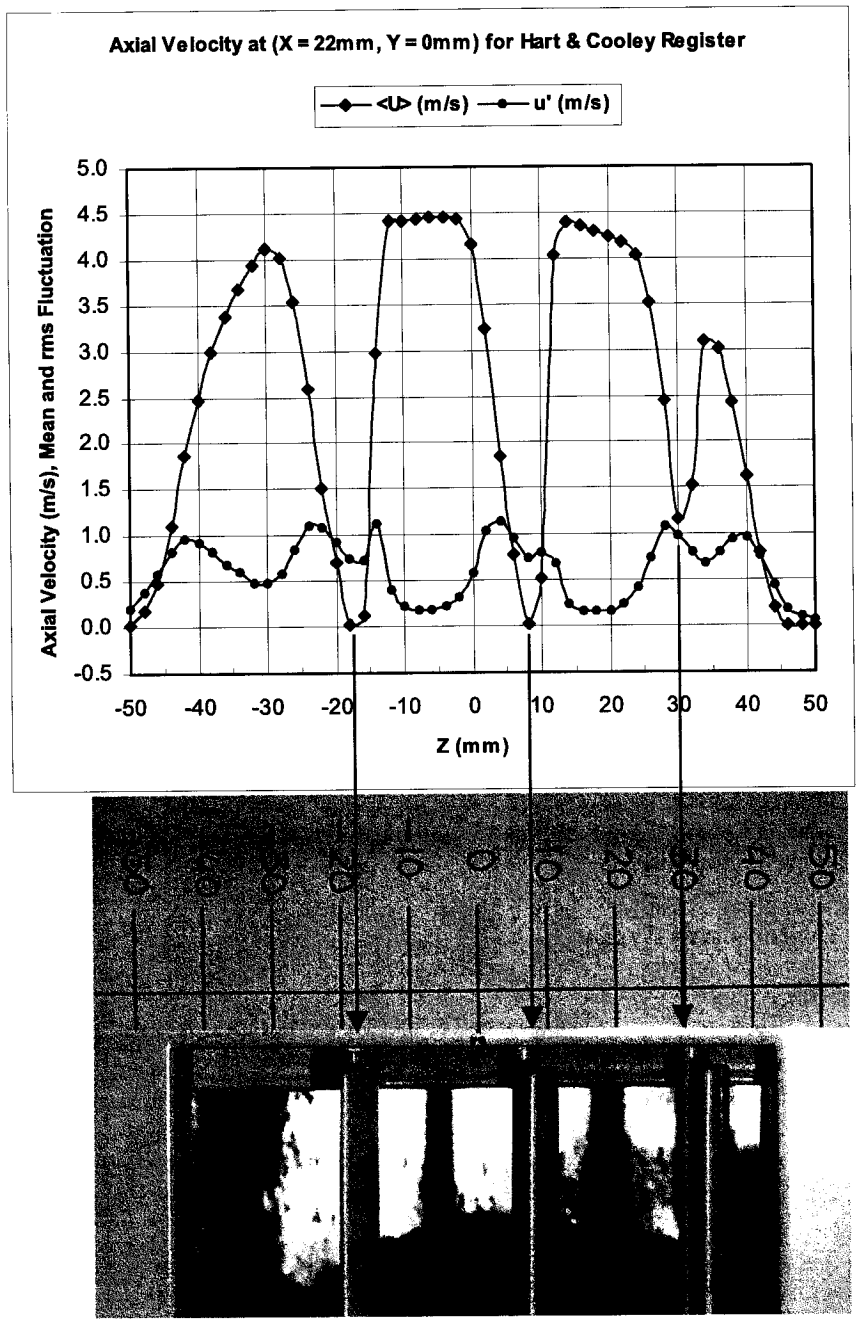

Figure 34. Measured mean and rms fluctuation of the axial velocity component at the exit of the Hart & Cooley register. Nominal flow rate: 66cfm. A superimposed photograph of the register shows the correlation between the velocity variations and the deflecting vanes of the register. Measurements at 22mm downstream of the register exit and Y = 0mm.

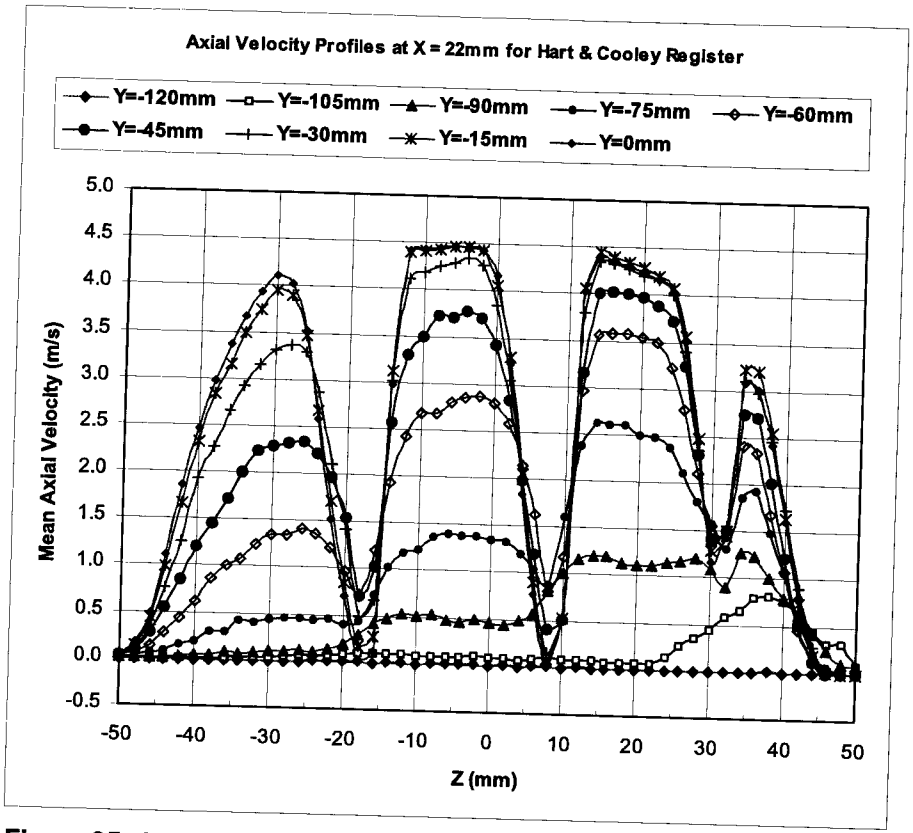

Figure 35. Measured mean axial velocity component (<U>) profiles at the exit of the Hart & Cooley register. Measurements from Y = 0 to Y = -120mm at 22mm downstream of the register exit. Nominal flow rate: 66cfm.

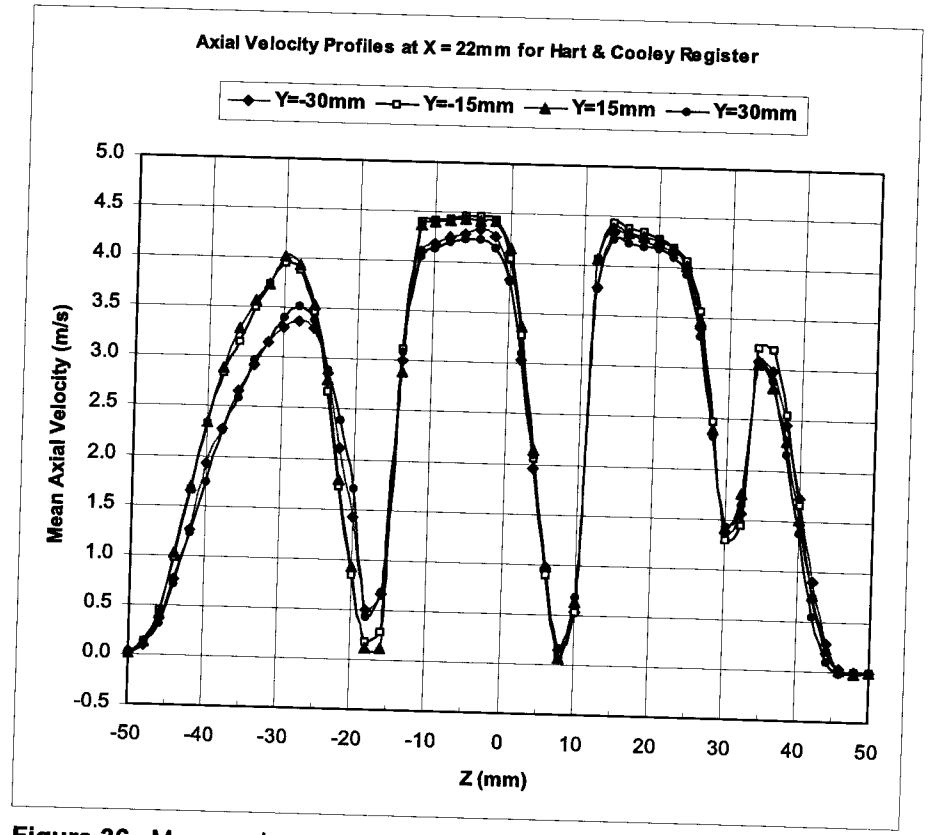

Figure 36. Measured mean axial velocity component (<U>) profiles at the exit of the Hart & Cooley register. Measurements from Y = -30mm to Y = 30mm at 22mm downstream of the register exit. Nominal flow rate: 66cfm.

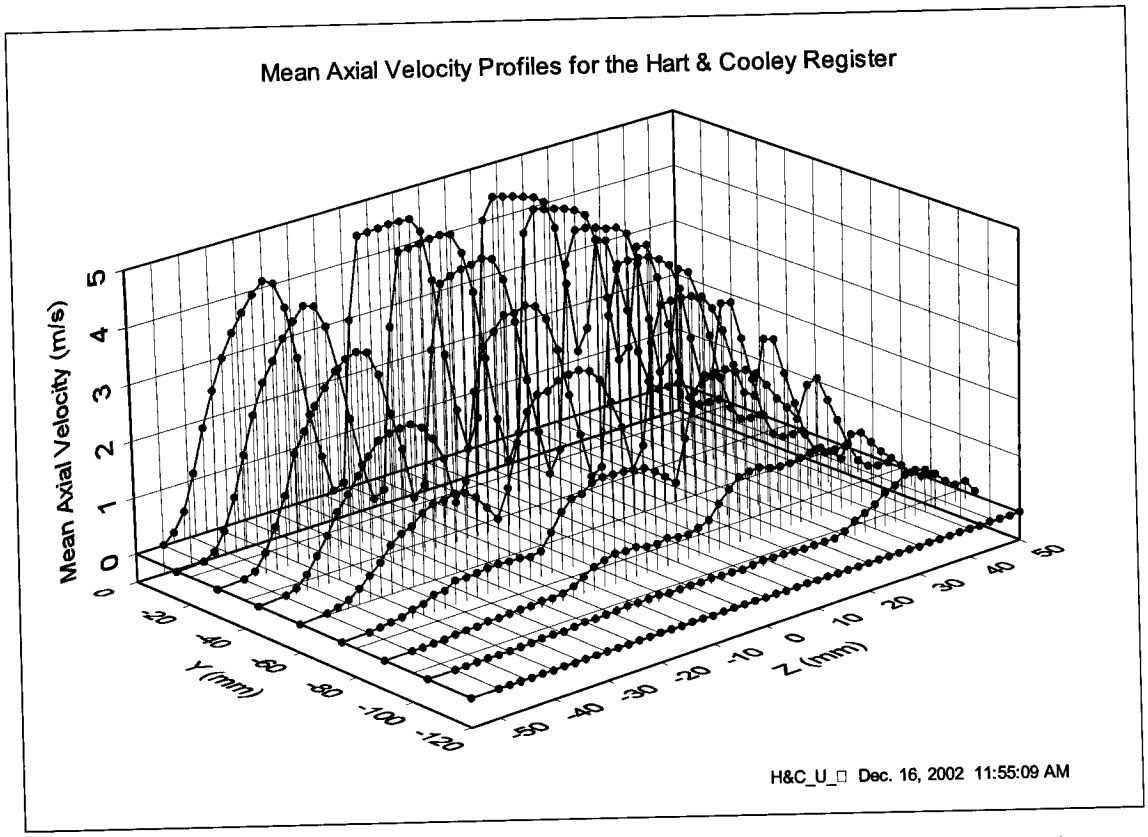

Figure 37. A three-dimensional line plot of the mean axial velocity component (<U>) at the exit of the Hart & Cooley register. Measurements at 22mm downstream of the register exit. Nominal flow rate: 66cfm. Note that Z is the vertical coordinate.

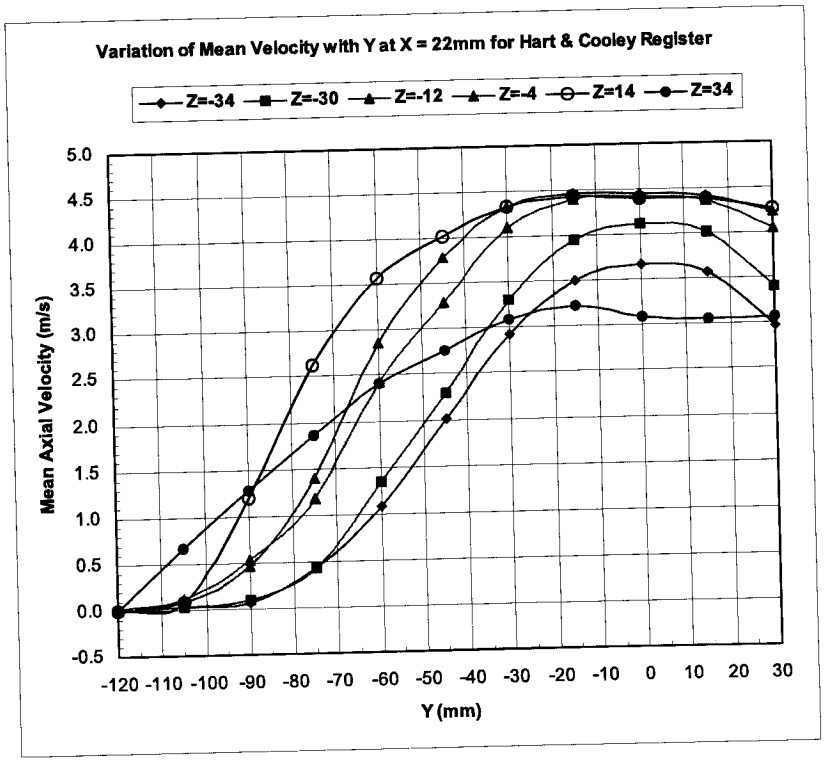

Figure 38. Variation of the mean axial velocity component (<U>) with the lateral coordinate Y showing the effect of the boot design on exit velocity profile. Nominal flow rate: 66cfm.

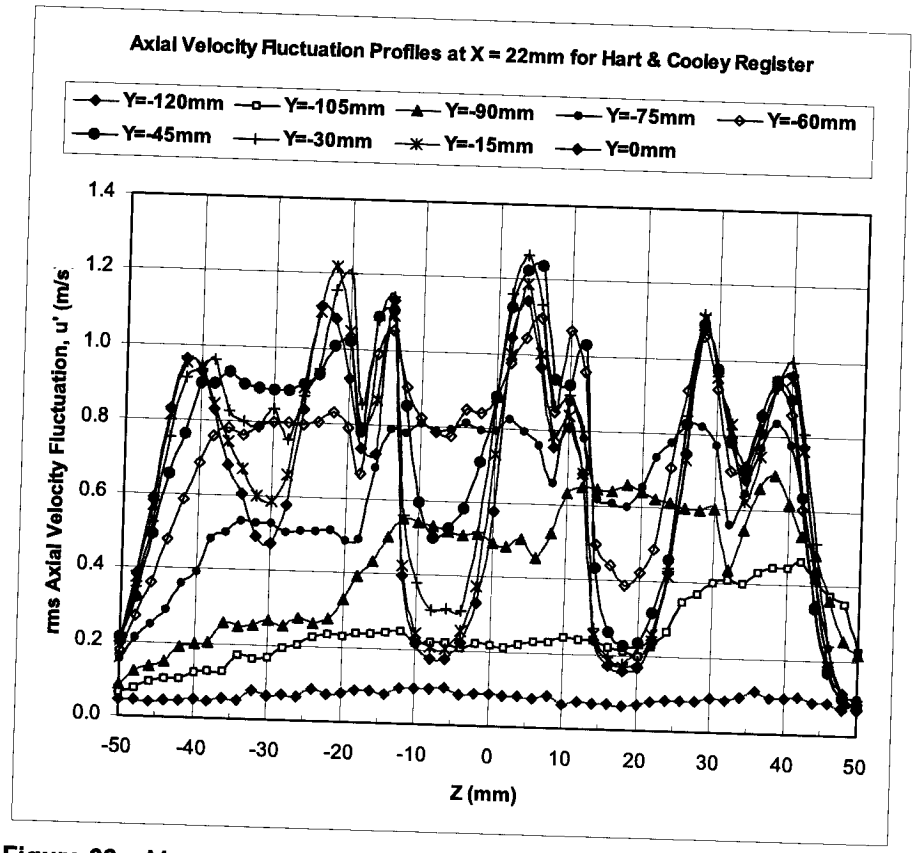

Figure 39. Measured turbulence level in the axial velocity component at the exit of the Hart & Cooley register. Measurements from Y = 0 to Y = -120mm at 22mm downstream of the register exit. Nominal flow rate: 66cfm.

4.2.2 The Vertical Velocity Component

The measurements of the mean vertical velocity component are summarized in Figures 40 and 41. The velocity profiles show periodic variations that are clearly a result of the deflecting blades. The magnitude of the vertical velocity component is much smaller than that of the axial velocity component. This is to be expected since the deflecting blades were set in the horizontal position. However, the direction of the velocity component shows a definite trend from top to bottom. Near the bottom, the flow is moving upwards, and near the top, the airflow is downwards. The measurements of the rms fluctuations in the vertical velocity component, w', are summarized in Figure 42. It is noted that the peak rms fluctuation in the vertical velocity component is larger than the peak value of the mean vertical velocity component. However, the peak values of u' and w' are of similar magnitudes.

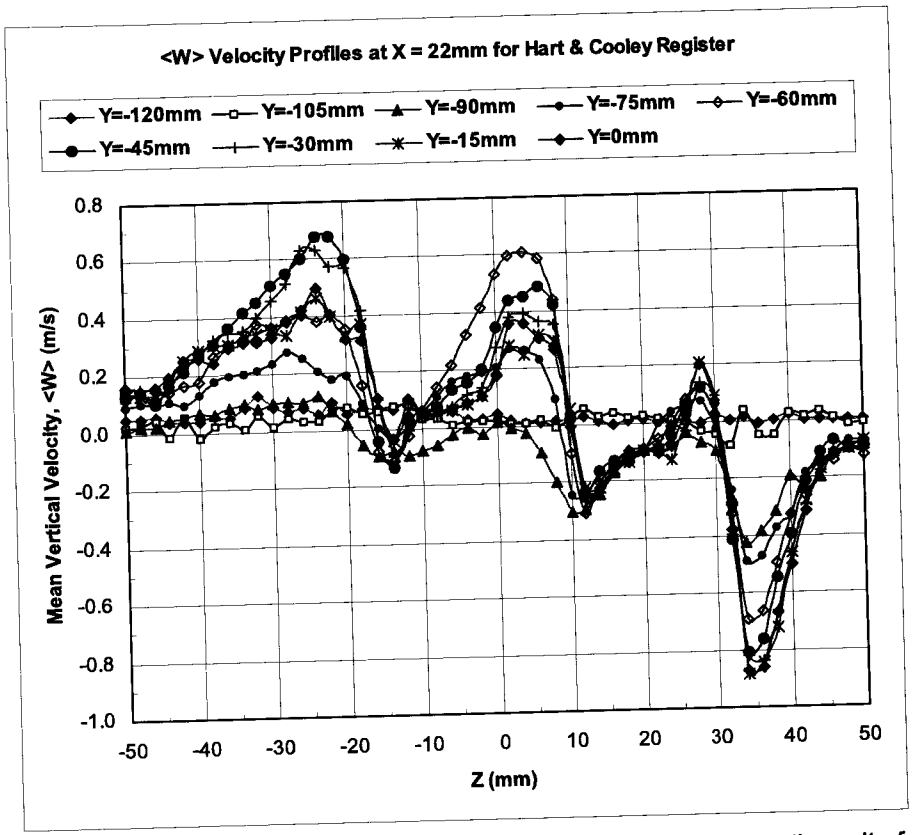

Figure 40. Measured mean vertical velocity component profiles at the exit of the Hart & Cooley register. Measurements from Y = 0 to Y = -120mm at 22mm downstream of the register exit. Nominal flow rate: 66cfm.

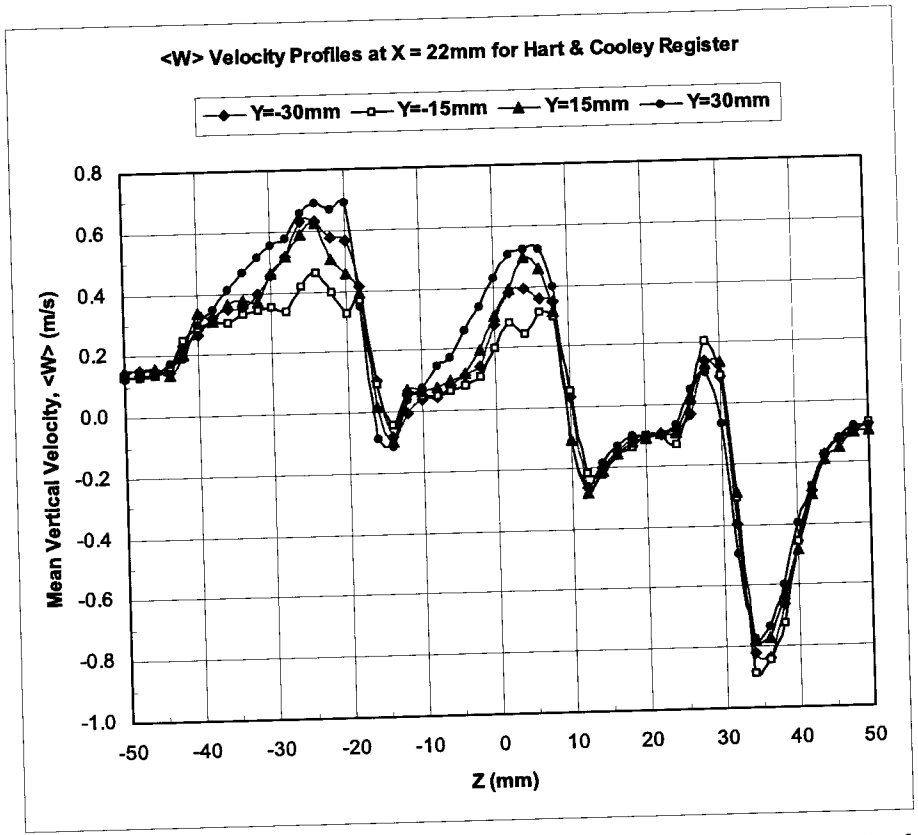

Figure 41. Measured mean vertical velocity component profiles at the exit of the Hart & Cooley register. Measurements from Y = -30mm to Y = 30mm at 22mm downstream of the register exit. Nominal flow rate: 66cfm.

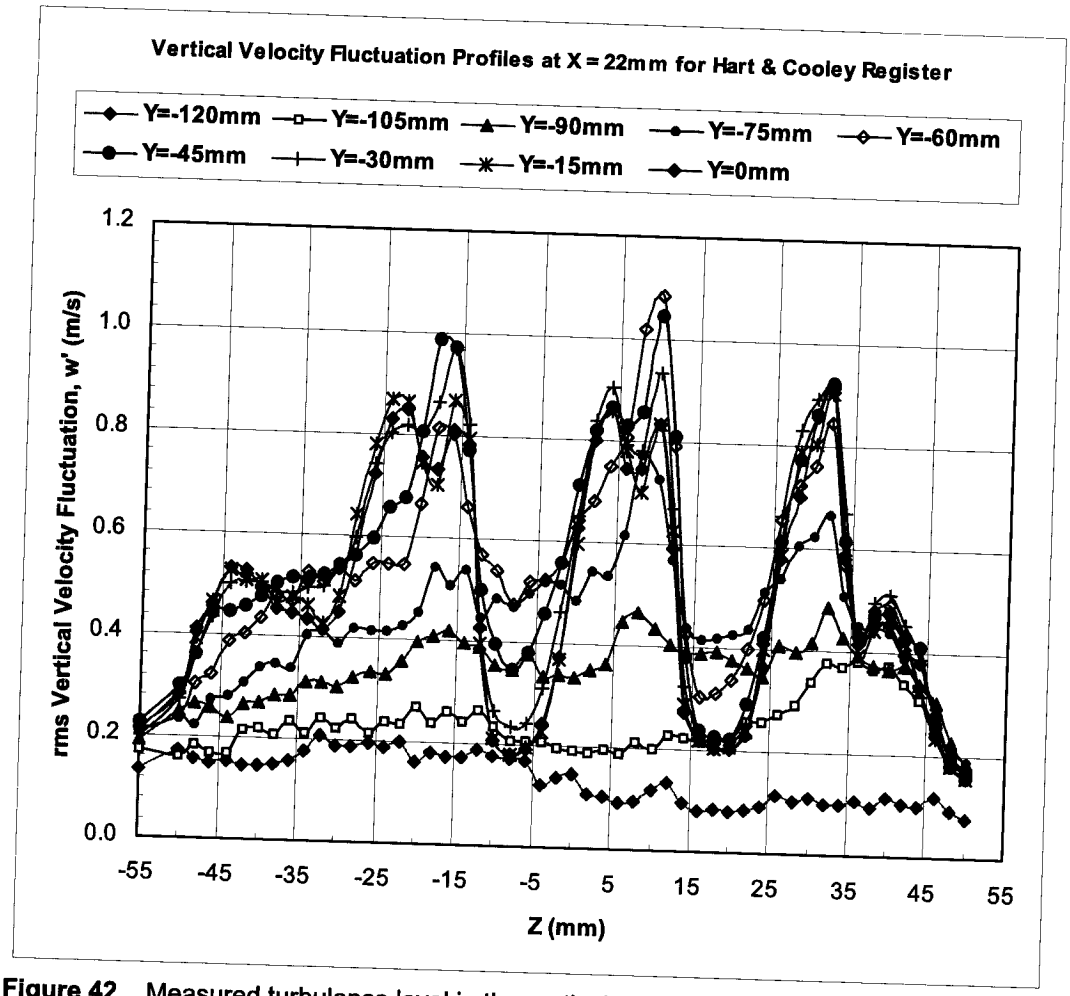

Figure 42. Measured turbulence level in the vertical velocity component at the exit of the Hart & Cooley register. Measurements from Y = 0 to Y = -120mm at 22mm downstream of the register exit. Nominal flow rate: 66cfm.

4.2.3 The Axial Evolution of the Velocity Components for the Hart & Cooley Register

The axial and vertical velocity components were also measured at the downstream location of X = 120mm. These measurements, together with the corresponding measurements at X = 22mm, are plotted in Figures 43 and 44. As can be seen from these figures, the turbulent mixing has completely diffused the periodic variations in the velocity components due to the deflecting blades in this short distance. We also note that that there is only minimal growth in the width of the airflow in the Z-direction while the flow moves from X = 22mm to X = 120mm. These measurements were used to generate a plot of airflow velocity vectors in the X-Z plane at Y = 0, and are shown in Figure 45. The influence of the three curved blades of the register on the velocity vectors near the exit (at X = 22mm) is clearly seen. In addition, the motion of entraining ambient air near the edges of the jet is also evident from this figure.

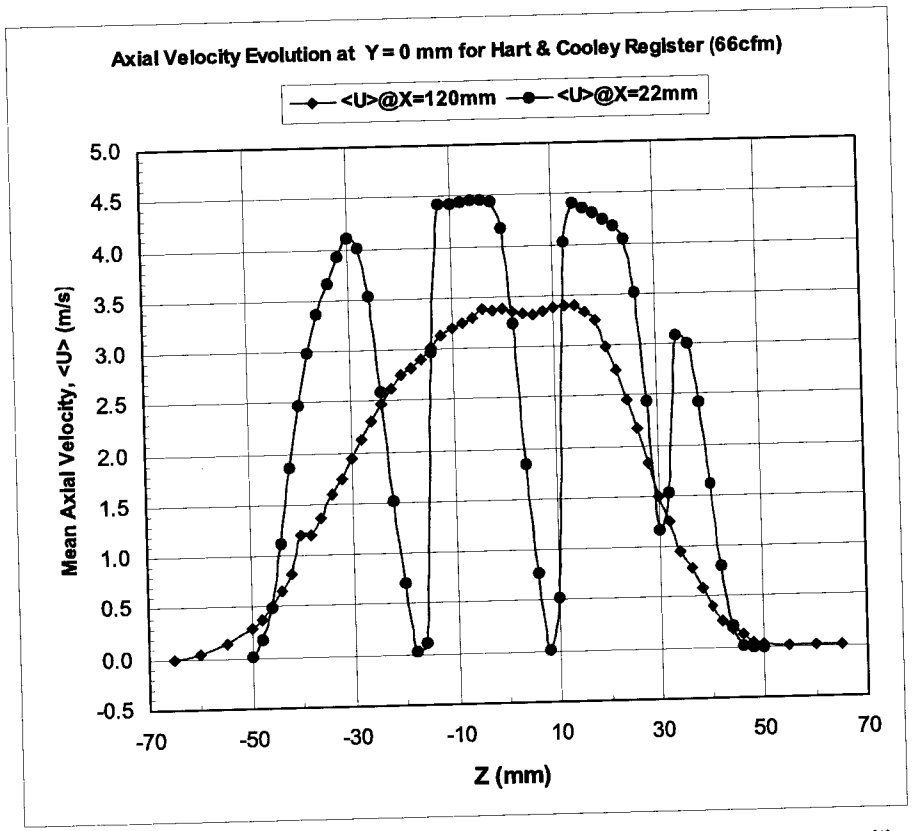

Figure 43. The evolution of the mean axial velocity component profiles with the downstream distance, X for the Hart & Cooley register. Measurements at Y = 0. Nominal flow rate: 66cfm.

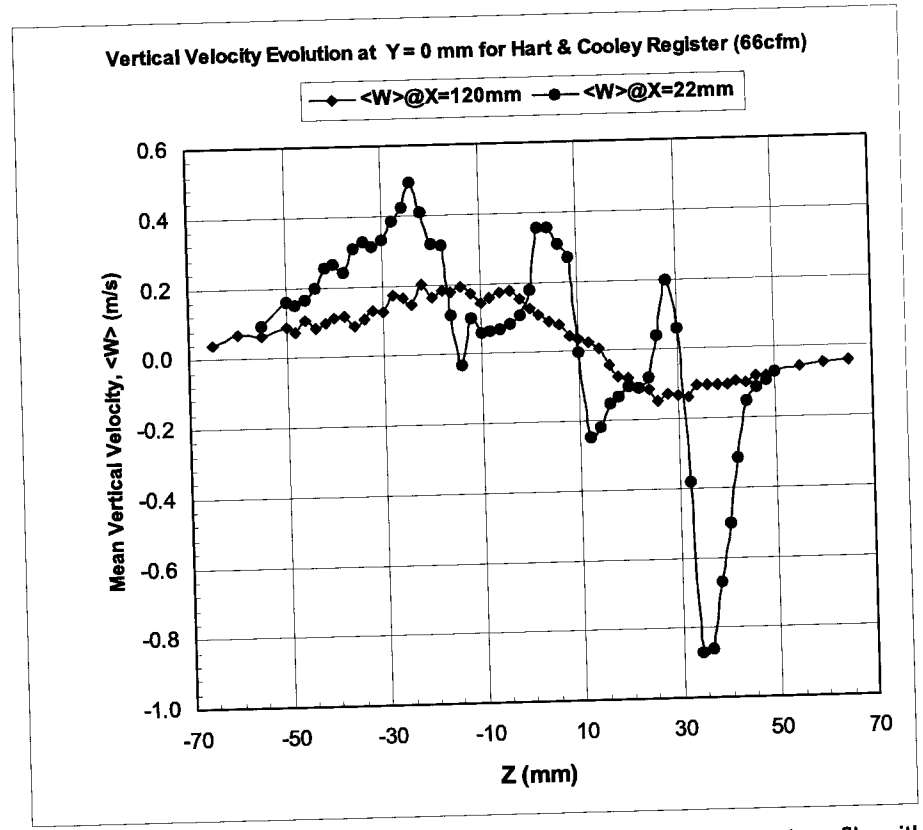

Figure 44. The evolution of the mean vertical velocity component profile with the downstream distance, X for the Hart & Cooley register. Measurements at Y = 0. Nominal flow rate: 66cfm.

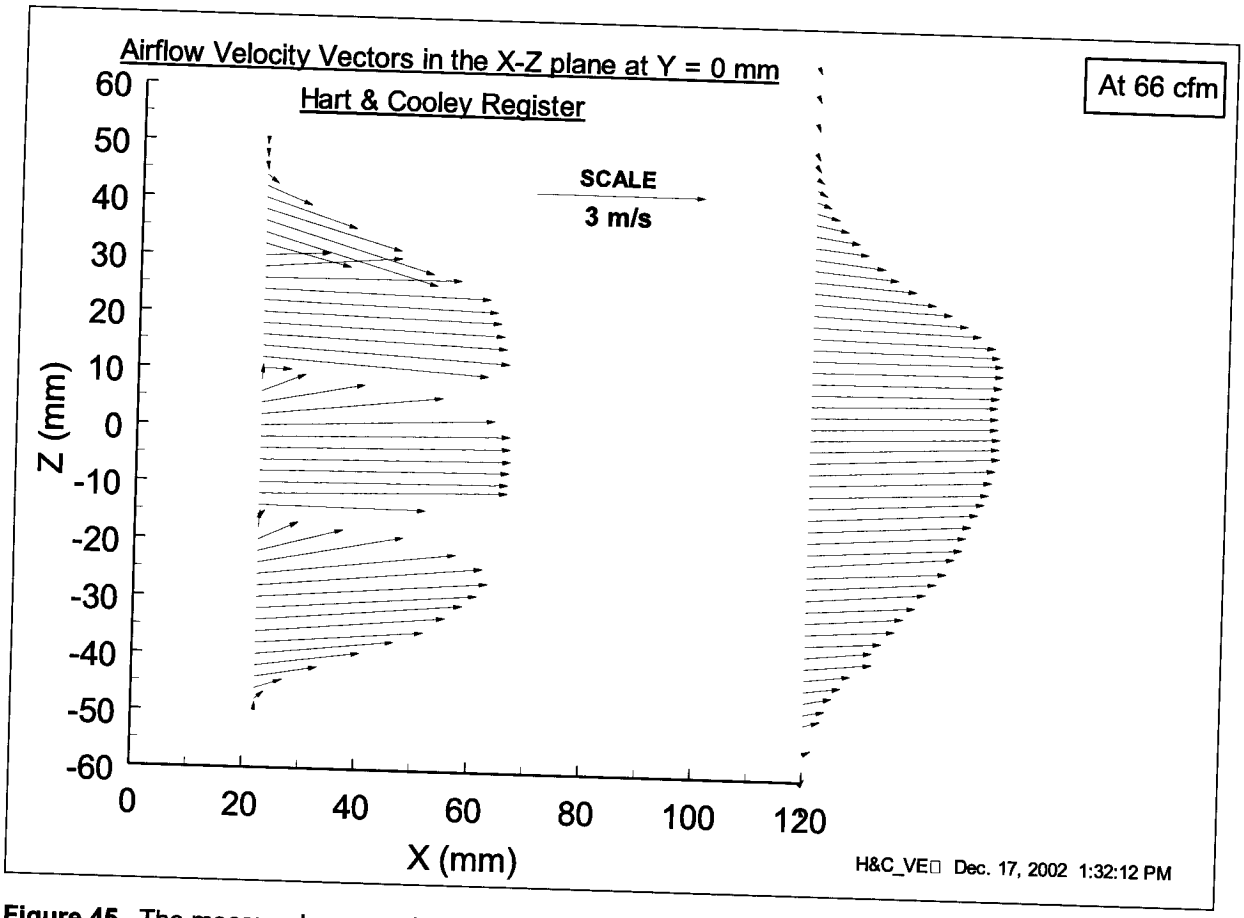

Figure 45. The measured mean velocity vectors in the X-Z plane at Y = 0 for two downstream locations (X = 22mm and X = 120mm) for the Hart & Cooley Register exit. Nominal flow rate: 66 cfm.

4.3 Airflow Measurements for the High-Flow Case

A limited number of velocity profiles measurements were also made at the high-flow rate setting of 126cfm for the Hart & Cooley register. Two profiles (as a function of the vertical coordinate, Z) along the central plane (Y = 0) at the two axial locations of 22mm and 120mm were measured for each of the axial and vertical velocity components. These measurements, together with the corresponding measurements at 66cfm, are presented in Figures 46 through 53. For comparison purposes, the measured velocities at 126cfm have been multiplied by the scaling factor of (66/126). These measurements show that if all the three blades of the register are set in the horizontal position, then, the velocity field near the exit of the register may be expected to roughly scale with the total airflow rate through the register (in the range of 65 cfm to 126cfm). However, the vertical velocity component shows some minor departures from similarity at X =22mm (see Figure 48). A plot of the airflow vectors for the high-flow case is shown in Figure 54. When compared to the corresponding plot for the low flow case in Figure 45, only minor deviations at X = 22mm are noticed.

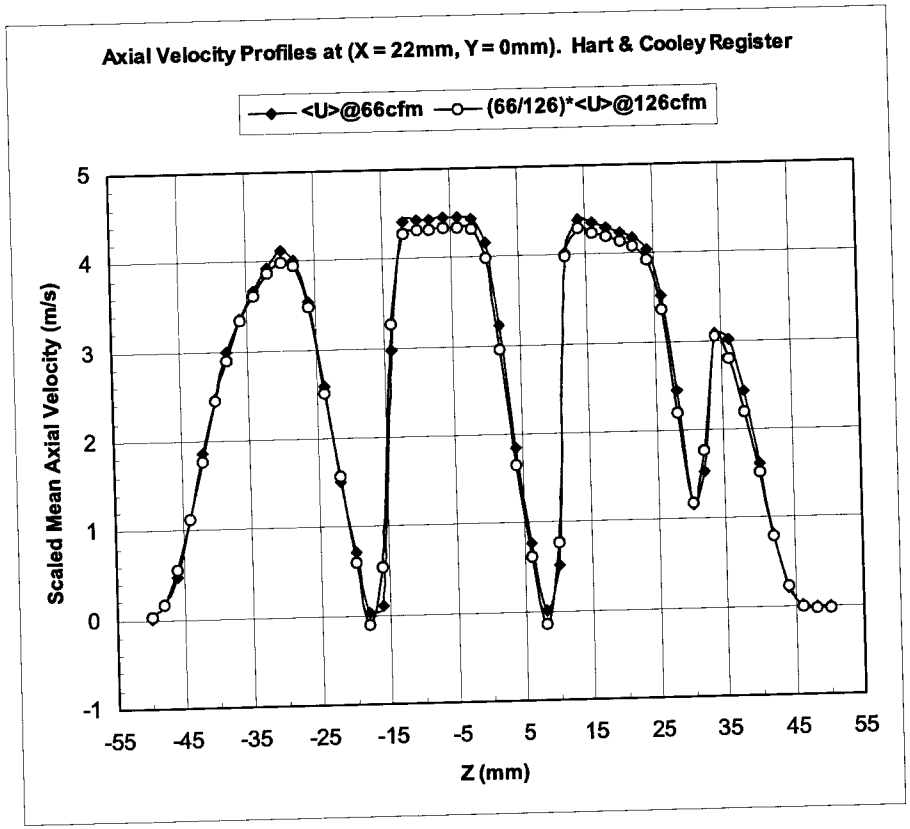

Figure 46. Comparison of mean axial velocity profiles at X = 22mm and Y = 0mm for the Hart & Cooley register at two flow rates. The measured mean velocity at 126cfm has been multiplied by the flow rate ratio of (66/126).

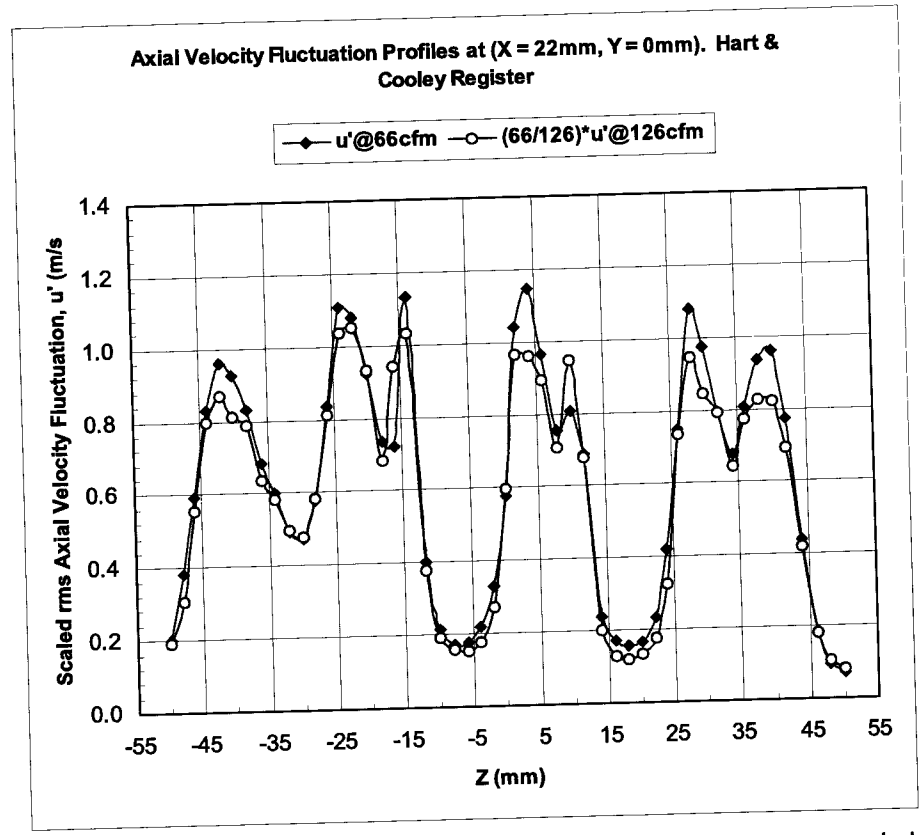

Figure 47. Comparison of turbulence level in the axial velocity component at X = 22mm and Y = 0mm for the Hart & Cooley register at two flow rates. The measured u' at 126cfm has been multiplied by the flow rate ratio of (66/126).

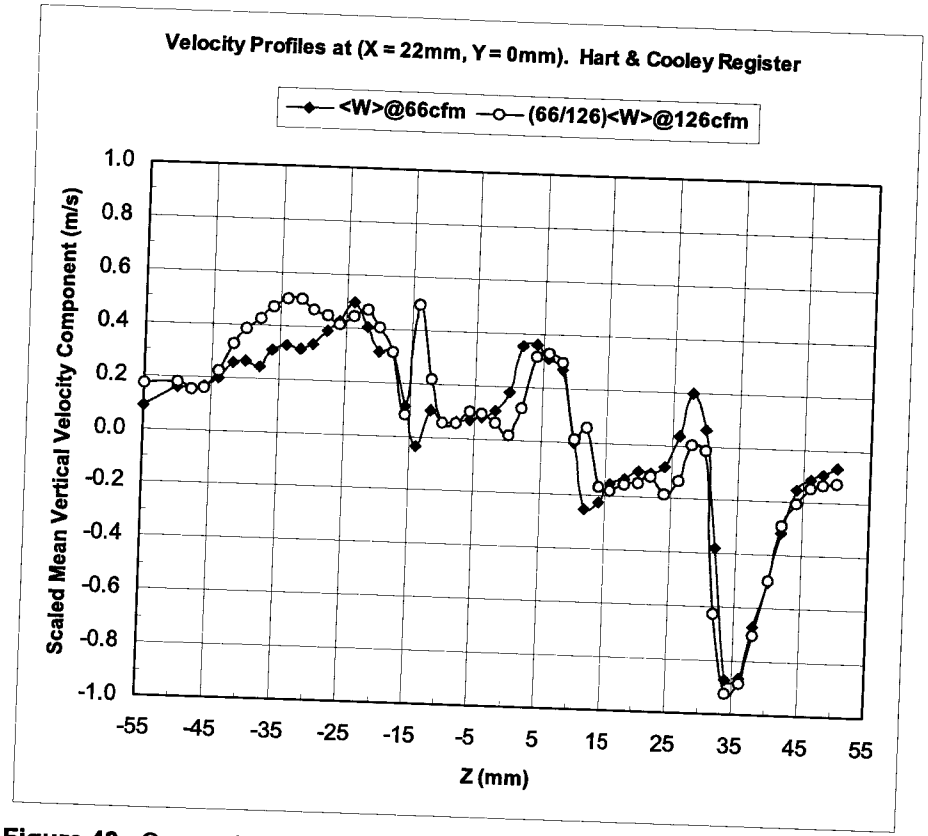

Figure 48. Comparison of mean vertical velocity profiles at X = 22mm and Y = 0mm for the Hart & Cooley register at two flow rates. The measured mean velocity at 126cfm has been multiplied by the flow rate ratio of (66/126).

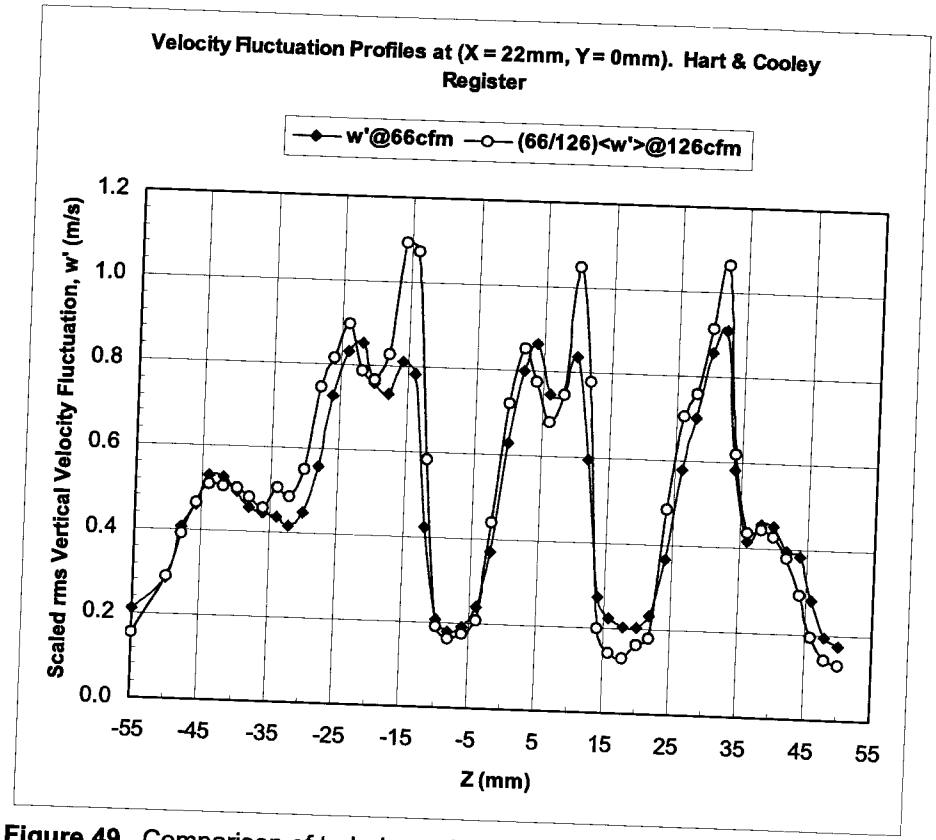

Figure 49. Comparison of turbulence level in the vertical velocity component at X = 22mm and Y = 0mm for the Hart & Cooley register at two flow rates. The measured w' at 126cfm has been multiplied by the flow rate ratio of (66/126).

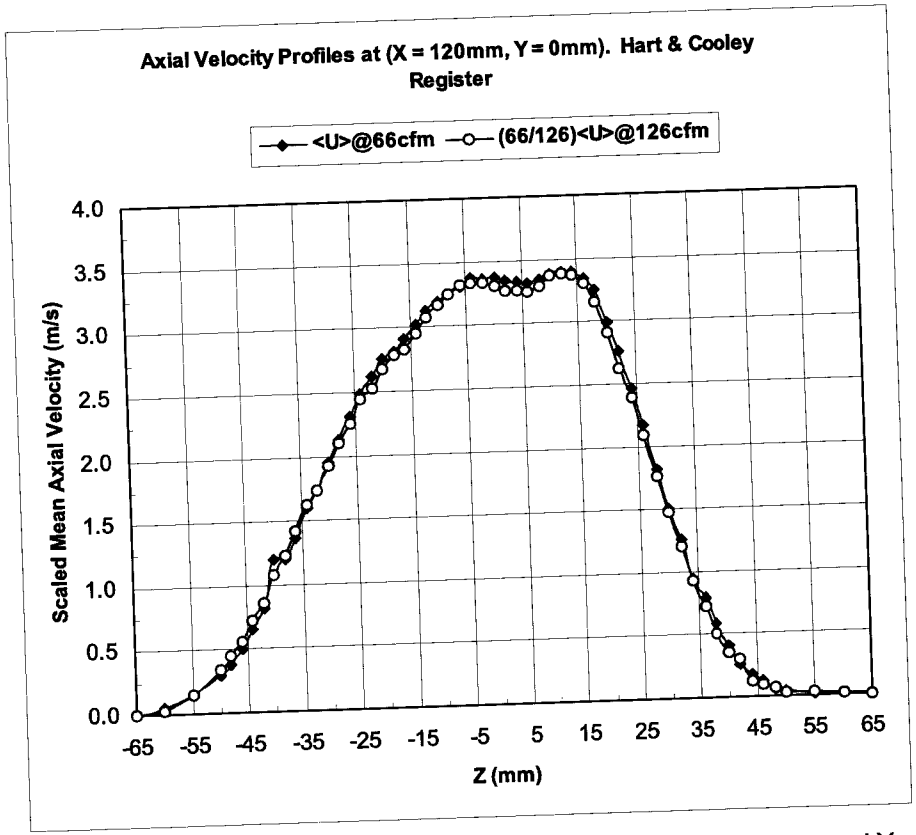

Figure 50. Comparison of mean axial velocity profiles at X = 120mm and Y = 0mm for the Hart & Cooley register at two flow rates. The measured mean velocity at 126cfm has been multiplied by the flow rate ratio of (66/126).

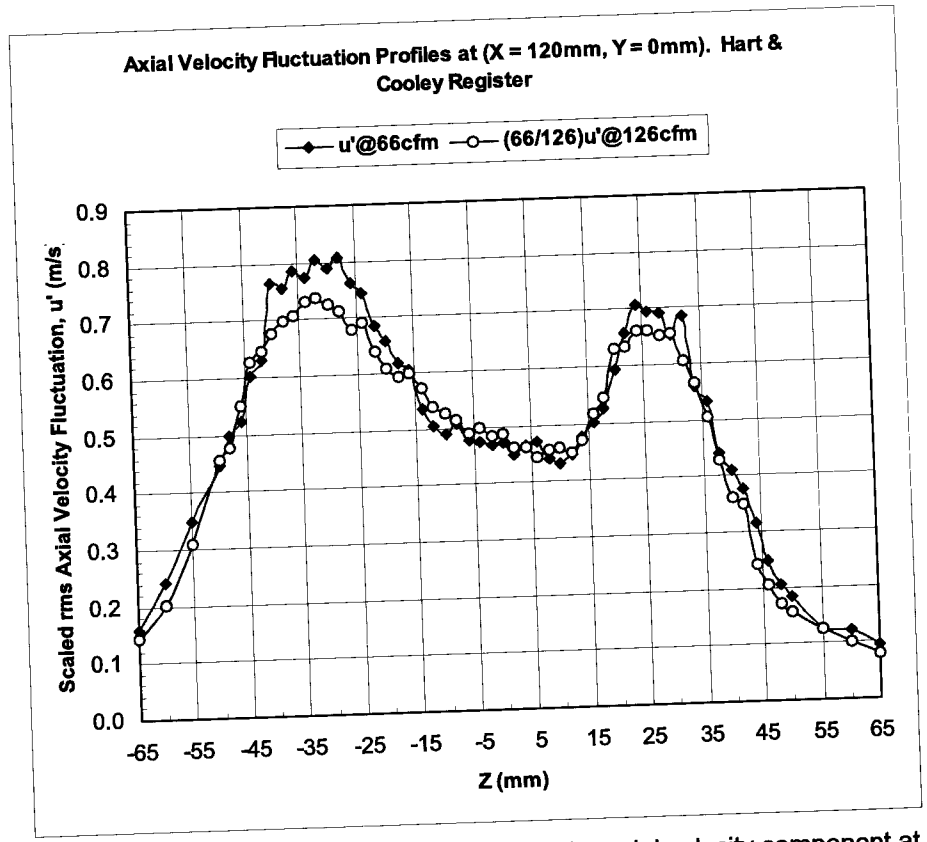

Figure 51. Comparison of turbulence level in the axial velocity component at X = 120mm and Y = 0mm for the Hart & Cooley register at two flow rates. The measured u' at 126cfm has been multiplied by the flow rate ratio of (66/126).

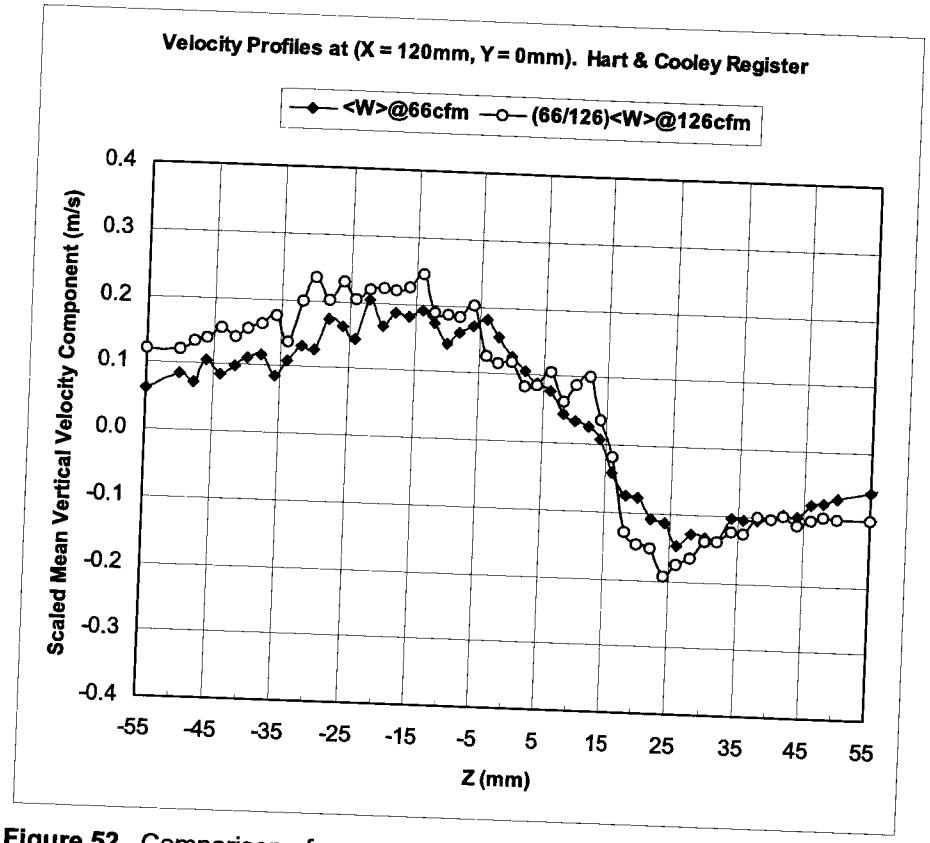

Figure 52. Comparison of mean vertical velocity profiles at X = 120mm and Y = 0mm for the Hart & Cooley register at two flow rates. The measured mean velocity at 126cfm has been multiplied by the flow rate ratio of (66/126).

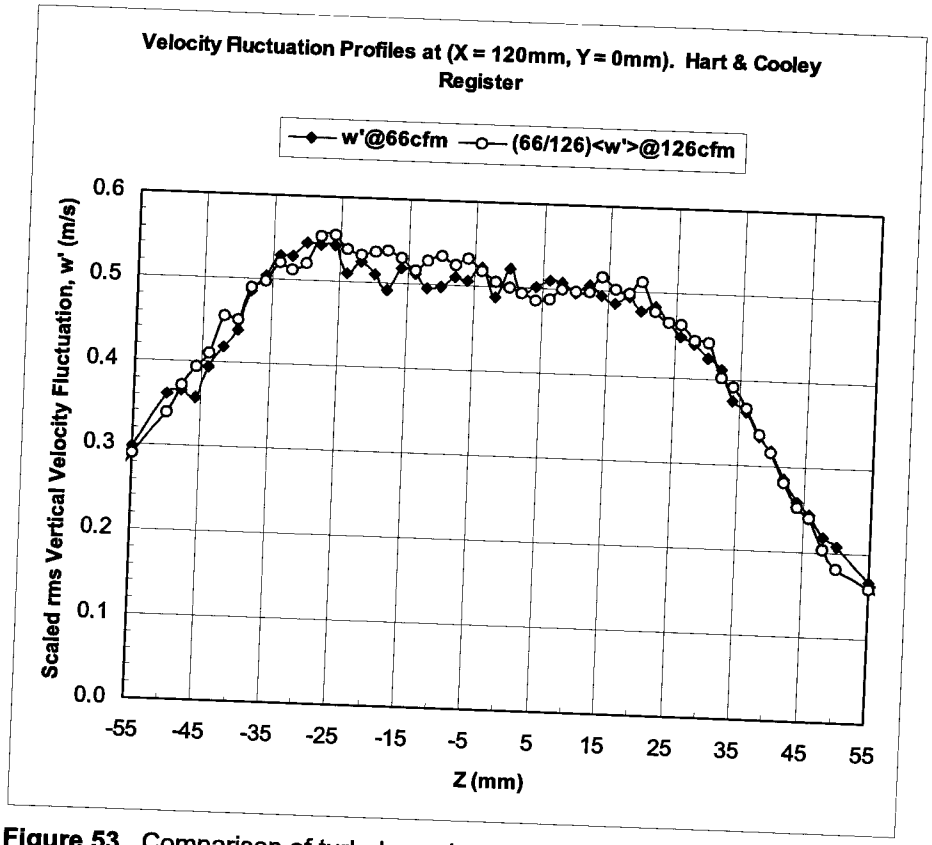

Figure 53. Comparison of turbulence level in the vertical velocity component at X = 120mm and Y = 0mm for the Hart & Cooley register at two flow rates. The measured w' at 126cfm has been multiplied by the flow rate ratio of (66/126).

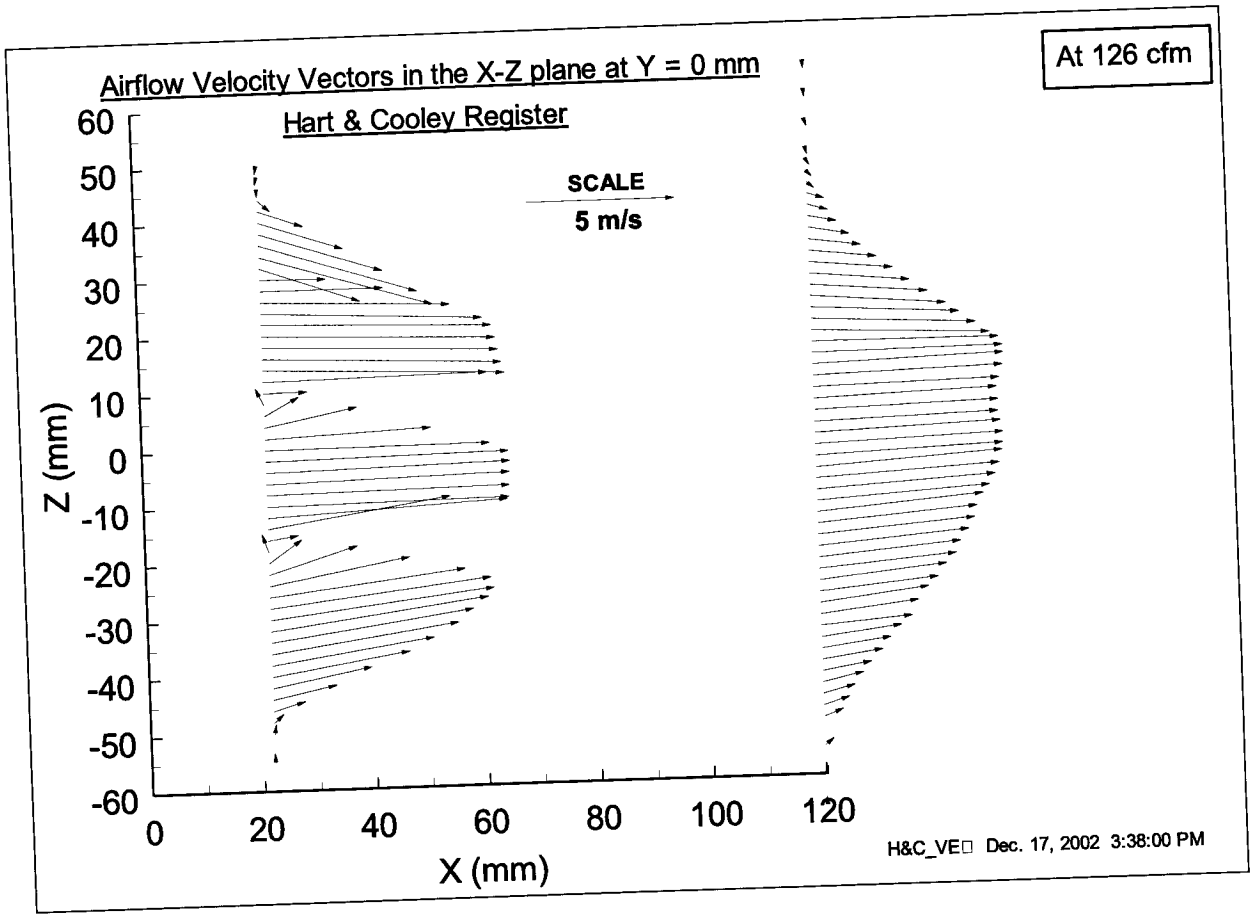

Figure 54. The measured mean velocity vectors in the X-Z plane at Y = 0 for two downstream locations (X = 22mm and X = 120mm) for the Hart & Cooley Register exit. Nominal flow rate: 126 cfm.

5. CONCLUDING REMARKS

A facility to test and measure the airflow distribution at the exit of HVAC registers was designed and fabricated. The objective of this facility is to provide velocity data at the exit of registers that can then be used as an input boundary condition in a modern Computational Fluid Dynamics (CFD) code to predict the velocity and temperature distribution in an enclosure (whose atmosphere is to be conditioned by the airflow from the register). Thus register performance parameters (for example, "throw") can be predicted as a function of variables like the flow rate from the register. Towards this end, during the course of this work, two commonly used registers were tested. Both registers were 8"x4" sidewall registers. Laser Doppler Velocimetry was used to measure the axial and vertical components of the velocity vector at various locations across the face of the registers. The measurements are presented in this report. For the two cases (Lima register and the Hart & Cooley register with blades in the horizontal position) studied here, the results suggest that the velocity field at the very exit of each of these registers scales with the flow rate through the registers. However, this was observed only for the case when *the duct blaster* varies the flow rate through the register directly. This would correspond to the mode of operation in which the supply fan (of an HVAC system) has a "High" and "Low" setting. This conclusion may not be true when the *built-in* register dampers are used to adjust the flow rate. During the second phase of this work, these results will be used to make CFD predictions of the register performance in an enclosure.

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Tankless and Solar Hot Water Heating Integration Research

Research Report - 0806
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Armin Rudd

Abstract:

The combination of tankless hot water heating and solar hot water heating creates some challenges that we have been researching with our builder partner, Coastal Habitats/Coastal Green Building Solutions, Hilton Head Island, SC. Sending solar preheated water into a tankless water heater can cause wide temperature fluctuations at the domestic taps. The purpose of this research project is to design and install a solar hot water system that features a tankless water heater integrated with a solar hot water panel such that consistent temperature control can be achieved at the domestic taps.

5. TANKLESS AND SOLAR HOT WATER HEATING INTEGRATION RESEARCH

5.1 Executive Summary

5.1.1. Solar Hot Water Research Overview

The combination of tankless hot water heating and solar hot water heating creates some challenges that we have been researching with our builder partner, Coastal Habitats/Coastal Green Building Solutions, Hilton Head Island, SC. Sending solar pre-heated water into a tankless water heater can cause wide temperature fluctuations at the domestic taps. The purpose of this research project is to design and install a solar hot water system that features a tankless water heater integrated with a solar hot water panel such that consistent temperature control can be achieved at the domestic taps.

5.1.2. Key Results

BSC worked directly with the builder and plumbing contractor at the Building America Prototype house (Bryant Park Cottages, Molly, Lot #8) to install a prototype system which integrated a solar hot water heater with a tankless water heater plus small storage tank and circulator. Temperature sensors, flow meters, valves, and bypasses were also installed accommodate monitoring of the system performance during short-term tests and long-term monitoring.

Short-term testing confirmed that the solar/tankless hot water heating system, without the small storage tank and circulator modifications suggested by BSC, would not reliably provide the expected hot water temperature to the domestic taps at low flow rates. Addition of the small storage tank successfully resulted in hot water reaching the taps at very low flow rates, and when the water temperature supplied to the tankless heater from the solar collector was elevated but still less than 130°F. However, other unexpected temperature instability issues with the prototype design were observed and we are continuing to work toward the best resolution.

At a different test house, water quality issues, causing too frequent clogging of the tankless hot water heater inlet filter and mineral scaling of pipe fittings, were found to be the only problems in a prototype tankless/combination space and domestic hot water heating system. Electronic water conditioning and pre-filtering are solutions that were investigated and seem to be working well.

5.1.3. Gate Status

5.1.3.1. Source Energy Savings and Whole Building Benefits ("must meet")

This project meets the Gate 1B "must meet" requirement for source energy savings. The prototype system which couples a solar hot water heater with a tankless water heater plus small storage tank and circulator, is expected to save energy relative to the same solar hot water heater coupled with a standard storage type water heater. The prototype system is also expected to reduce inefficient tankless hot water heater cycling and reduce hot water use while improving temperature control at the domestic taps.

5.1.3.2. Performance-Based Code Approval ("must meet")

This project meets the Gate 1B "must meet" requirement for performance-based and safety, health and building code requirements for new homes. The solar hot

water/tankless water heater integrated installation will be fully compliant with all relevant performance-based codes.

5.1.3.3. Prescriptive-Based Code Approval ("should meet")

This project meets the Gate 1B "should meet" requirement for prescriptive-based safety, health and building code requirements for new homes. The solar hot water/tankless water heater integrated installation will be fully compliant with all relevant prescriptive-based codes.

5.1.3.4. Cost Advantage ("should meet")

This project is expected to meet the Gate 1B "should meet" requirement for strong potential to provide cost benefits relative to current systems. The prototype system which couples a solar hot water heater with a tankless water heater plus small storage tank and circulator, is expected to provide energy savings, water savings, and increased temperature control at the domestic taps at a small incremental cost relative to the same solar hot water heater coupled with only a tankless water heater.

5.1.3.5. Reliability Advantage ("should meet")

This integrated product should meet the Gate 1B "should meet" requirement to meet reliability, durability, ease of operation and net added value requirements for use in new homes. Sensitivity to water quality resulting in too frequent clogging of the tankless heater inlet filter, and scaling inside pipe fittings, presents some reliability concerns that would be common to similar systems with or without the prototype modifications of a small storage tank and circulator.

5.1.3.6. Manufacturer/Supplier/Builder Commitment ("should meet")

BSC has discussed these system issues with technical staff at a major tankless water heater manufacturer (Rinnai America Corp.). They were more willing to discuss the water quality issues than the solar integration or the combination space and domestic hot water system integration (they said we were on our own with those systems). BSC will continue to conduct more research on this advanced subsystem in partnership with our builder partner and NREL before approaching a manufacturer about collaboration toward wider market solutions.

5.1.3.7. Gaps Analysis ("should meet")

Outstanding issues that our research aims to more fully determine include: 1) prototype system performance and occupant acceptance regarding temperature stability at the domestic water taps over a year of occupied monitoring; 2) the frequency of temperature instability at the taps if the small storage tank and circulator modifications were not used; and 3) annual energy, water, and cost savings.

5.1.4. Conclusions

BSC was successful in creating a prototype water heating system that merged an Integral Collector Storage (ICS) solar hot water heater with a tankless water heater plus small storage tank and circulator. The system achieved the goal of providing temperature control at the domestic taps regardless of very low flow, frequent on/off flow, or solar pre-heated water supply. The system is expected to provide energy savings, water savings, and increased temperature control at the domestic taps. An important but easy to implement improvement was already made. Another proposed improvement is

scheduled to be implemented and retested. Long-term monitoring under normal operating conditions will begin once the house is sold and occupied.

5.2 Introduction

Tankless domestic hot water heaters are becoming standard practice for many high-performance homes. Domestic hot water heating amounts to 10 to 15 percent of total energy use in these homes. Upgrading from a standard tank/storage type gas water heater with an Energy Factor (EF) of 0.56 to a tankless hot water heater with EF between 0.82 (natural gas) and 0.85 (propane) can save 40 to 50 percent on hot water heating energy use, for a total energy use savings of around 5 percent.

The combination of tankless hot water heating and solar hot water heating creates some challenges that we have been researching with our builder partner, Coastal Habitats/Coastal Green Building Solutions, Hilton Head Island, SC. Sending solar pre-heated water into a tankless water heater can cause wide temperature fluctuations at the domestic taps. All gas-fired tankless hot water heaters have a minimum firing rate_usually not less than 15 kBtu/h. If the entering water temperature is too close to the outlet temperature setpoint, then the unit may not fire, causing wide temperature fluctuations at the domestic taps. One major manufacturer recommends that the water going into the unit be no warmer than 75°F because 15 kBtu/h will give a 50°F temperature rise at 0.5 gpm (the lowest flow rate to activate the heater) and 75+50=125, which is the highest recommended domestic hot water temperature.

Referring to Figure 5.1, at the minimum hot water draw rate of 0.5 gpm, the minimum firing rate will produce a 50°F temperature rise. That means that if the water heater outlet set-point is 125°F, and the inlet water temperature is greater than 75°F, then the water heater will shut off, delivering water to the tap as low as 75°F. If the flow rate increases, or if the inlet water temperature falls, then the heater will fire again and start delivering 125°F water to the tap. Referring again to Figure 5.1, depending on the water flow rate (between the minimum and maximum allowed by the unit) this type of temperature fluctuation can occur with solar preheated water anywhere between 75°F (at 0.5 gpm) and 121°F (at 8.5 gpm). It is very likely that the solar preheated water will quite often fall within that range.

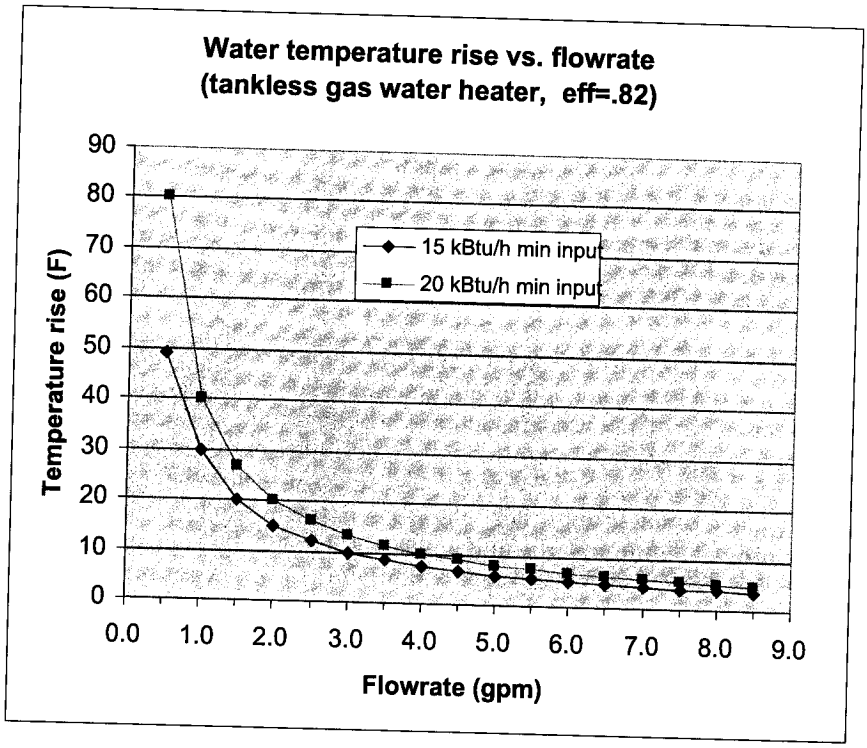


Figure 5.1: Water temperature rise versus flow rate for a typical gas tankless hot water heater

Tankless water heaters can cause annoying temperature fluctuations at the taps for other reasons as well:

1. Tankless hot water heaters are activated when water is drawn through the unit. If the water flow rate is below the typical 0.5 to 0.9 gpm minimum to activate the unit, the unit will not fire, delivering water to the taps at the water main temperature. That can cause occupants to increase the flow rate beyond what was needed in order to get hot water. Energy and water savings could be realized if that limitation was eliminated.

2. With frequent on/off type water use, hot and cold water will be intermittently delivered to the tap due to water heating delay times as the burner cycles on and off. It can take 10 seconds after the beginning of a hot water draw for a tankless heater to prove proper draft and fire the gas burner. Rinnai now keeps the vent blower running for about one minute after the end of each hot water draw in order to reduce the re-firing time to a few seconds. So, delivery of cold water between on/off hot water demand can typically last from a few seconds to 10 seconds. Not only is frequent equipment cycling inefficient, but hot water waste could be significant as occupants leave the water on when it is not needed in order to avoid the temperature fluctuations.

Field research is being conducted to evaluate whether these situations are actuality a significant threat to the success of tankless hot water heating systems in high-performance homes, and whether or not there are cost effective solutions. In 2007, the systems shown in **Figure 5.8** and Figure 5.9 were proposed by BSC as solutions, with an initial focus on the integration of solar hot water heating with tankless hot water heaters.

The system of **Figure 5.8** adds a small, well-insulated storage tank that is backed up with electric heat to a setpoint approximately 10°F below the tankless hot water heater outlet setpoint. In that way, the temperature fluctuation delivery problem should be resolved for conditions when:

1. The hot water demand is below the minimum flow rate to fire the gas heater: and
2. The inlet water is warm enough that the water heating capacity needed is below the minimum firing capacity of the gas heater. The frequency and duration of this condition, and the heat loss from the tank will impact how often the electric heating element will need to come on.

The mixing valve shown in **Figure 5.8** and Figure 5.9 is required for when the solar pre-heated water is too hot for delivery to the domestic taps, and when the storage tank temperature needs to be high for space heating applications.

The system of Figure 5.9 goes further than the system of **Figure 5.8** by eliminating the short-cycling inefficiency of the gas heater and by eliminating the need for any electric heating. The system adds a pumped circulation loop from the side of the small, well-insulated storage tank to the tankless water heater, much like a typical boiler plus indirect water heater system. Whenever the thermostat switch on the storage tank closes, the circulator will be energized, moving water through the gas heater. Tankless hot water heaters have a relatively high flow resistance; the pump needed to force water through the unit will draw about 90 W—not an insignificant amount of pump energy. Therefore, while this system will provide the best operation in terms of supplying regulated temperature water to the taps, and it does not require an electric heating element, there will be circulator energy and storage tank losses that need to be better understood.

The system of Figure 5.9 also has the advantage of being easily adapted to combination space and domestic hot water heating applications as shown in Figure 5.2 In that configuration, the storage tank needs to have 2 additional side ports available for the pumped loop to the hot water coil in the space heating process air stream. Small, 12 gallon tanks of with 4 side ports and 2 top ports are readily available (such as Whirlpool md# E1F12US015V made by US Craftmaster, sold at Lowe's for about $210).

5.3 Prototype Testing Results for Integration Of Tankless Hot Water Heating With Solar Hot Water Heating

BSC worked directly with the builder and plumber at the Building America Prototype house (Bryant Park Cottages, Molly, Lot #8) to install the tankless domestic hot water heating integrated with solar hot water heating system shown in Figure 5.9. Temperature sensors, flow meters, valves, and bypasses were also installed according to Figure 5.2 to accommodate monitoring of the system performance during short-term tests and long-term monitoring.

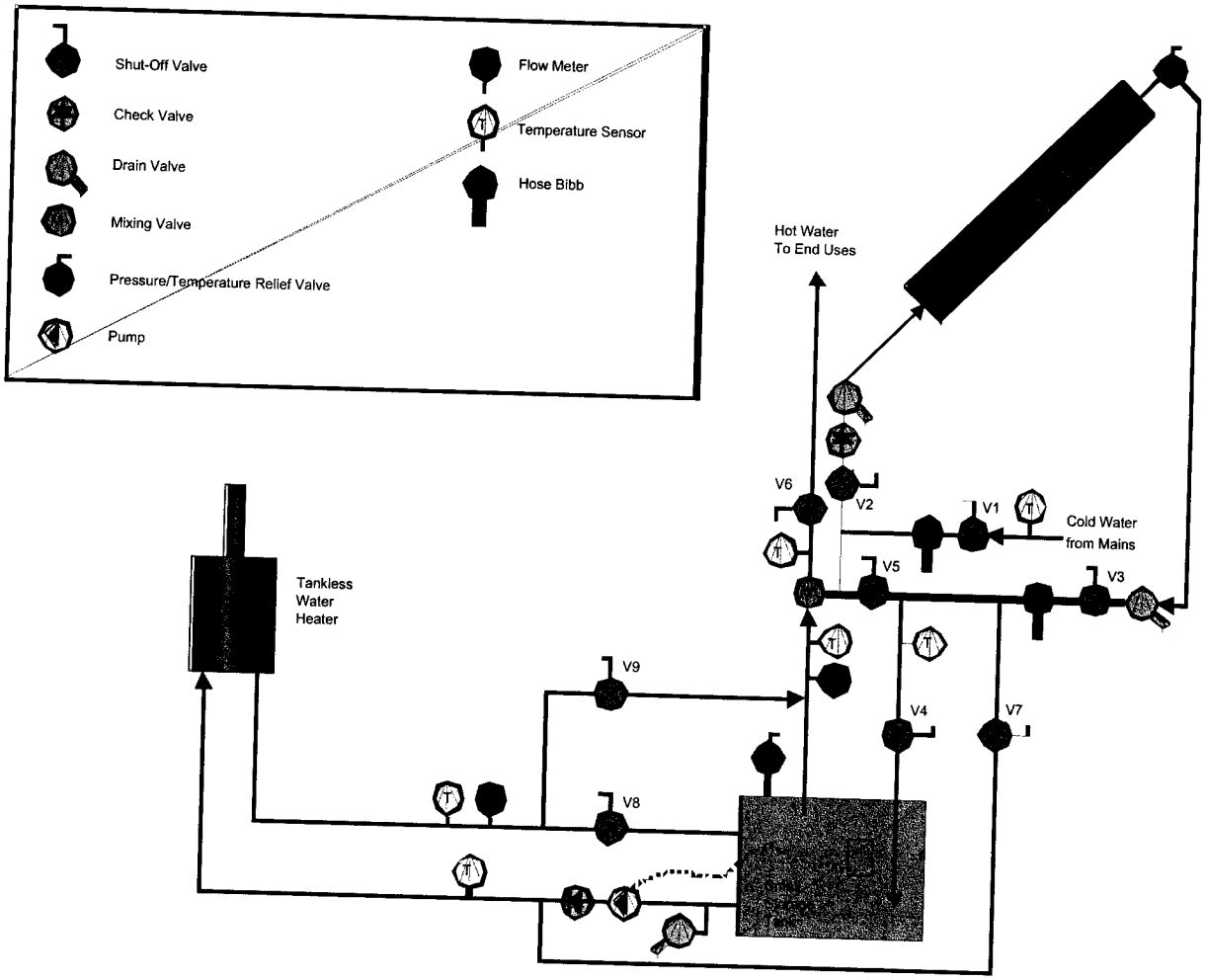


Figure 5.2: Locations of flow meters, temperature sensors, bypass loops, and hose bib connections for short-term testing

NREL researchers later installed the data monitoring system and conducted short-term tests, according to the test plan as described in Appendix A. Observations from the short-term testing were as follows:

1. The solar collector appears to be working well based on preliminary testing. The collector efficiency was 42% based on a test where the collector was drained at the beginning and end of the day, which is very consistent with our expectations given the system design and the weather conditions during the test. There is a section of PEX piping near the outlet of the solar hot water system inside the house that could see temperatures in excess of the PEX rating (peak temperature measured right after long-term stagnation of collector was 176°F). PEX is rated to 180°F, so that section of pipe should be replaced with copper to be sure that there will be no pipe failure if the collector should exceed 180°F due to no domestic hot water use for long periods of sunshine.

2. The following issues were confirmed during short-term tests where the small storage tank was bypassed:

   - The tankless heater doesn't fire at low flow rates (<0.5 gpm). The Rinnai tankless water heater does not turn on when its internal logic determines that the combination of flow rate and inlet temperature would result in the outlet temperature exceeding the set-point even at the lowest burner setting.

   - The tankless water heater doesn't fire when there is an elevated supply temperature from the solar collector combined with slightly higher flow rates (0.5-0.8 gpm).

   - With solar pre-heated water, the tankless heater sometimes shuts off after turning on for a few minutes, probably caused by the tempering valve gradually decreasing the hot water flow rate, causing the maximum outlet temperature of the tankless heater to be exceeded.

3. Addition of the small storage tank successfully results in hot water reaching the taps at very low flow rates, and when the water temperature supplied to the tankless heater is too high.

4. The tempering/mixing valve seems to have a minimum cold water flow. It cannot maintain set point at 120°F when water entering the valve is below about 130°F . A different tempering valve without a minimum cold water flow or raising the storage tank thermostat setpoint should resolve that issue.

5. The hot water system exhibited some temperature stability issues when using the small buffer tank at higher hot water flow rates. With the storage tank thermostat set at 125°F and the tankless heater outlet temperature set at the maximum of 140°F for the residential heater, a temperature droop was observed at the domestic taps a minute or two after the water draw began. After the circulator started moving water through the tankless heater, the water temperature delivered to the taps increased more slowly than expected. Moving the storage tank thermostat set-point closer to the heater output set-point helped but not enough to resolve the problem. Unless the lower limit of the temperature droop response is above at least 105°F, this would likely result in comfort problems when the occupants take showers at high total hot water flow rates.

To resolve these temperature instability issues, BSC is working with the builder to replace the residential unit with the same size commercial unit which can be set for a higher outlet

temperature (up to 180°F). That will allow the storage tank temperature to be increased such that the lower limit of the temperature droop will stay above a comfortable shower temperature. After that system change, some short-term tests will be repeated in cooperation with NREL.

Photographs of the installed system, showing the extensive extra piping, valves, and sensors required to conduct system testing in a number of operational modes, are shown in Figure 5.3.

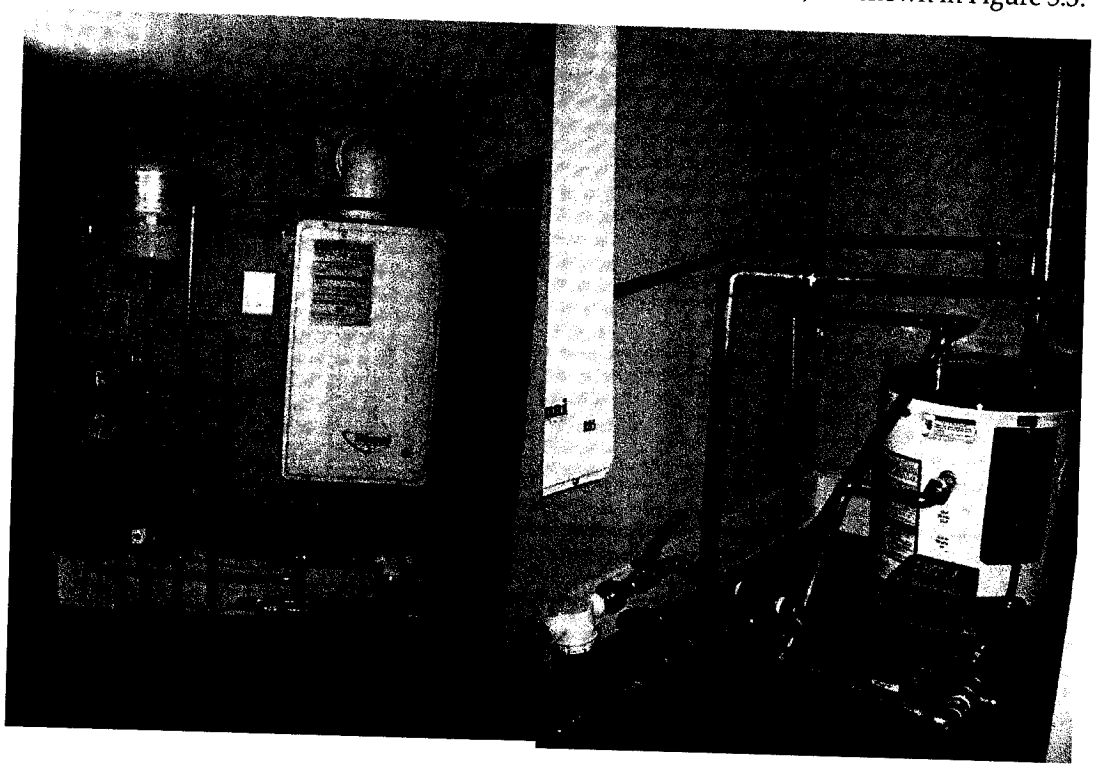


Figure 5.3: Photos of installed hot water heating system at Bryant Park Cottages, Molly plan, Lot #8

Figure 5.4 through 5.9 show details of the system testing that exposed the temperature droop issue and identified an important but easy system improvement.

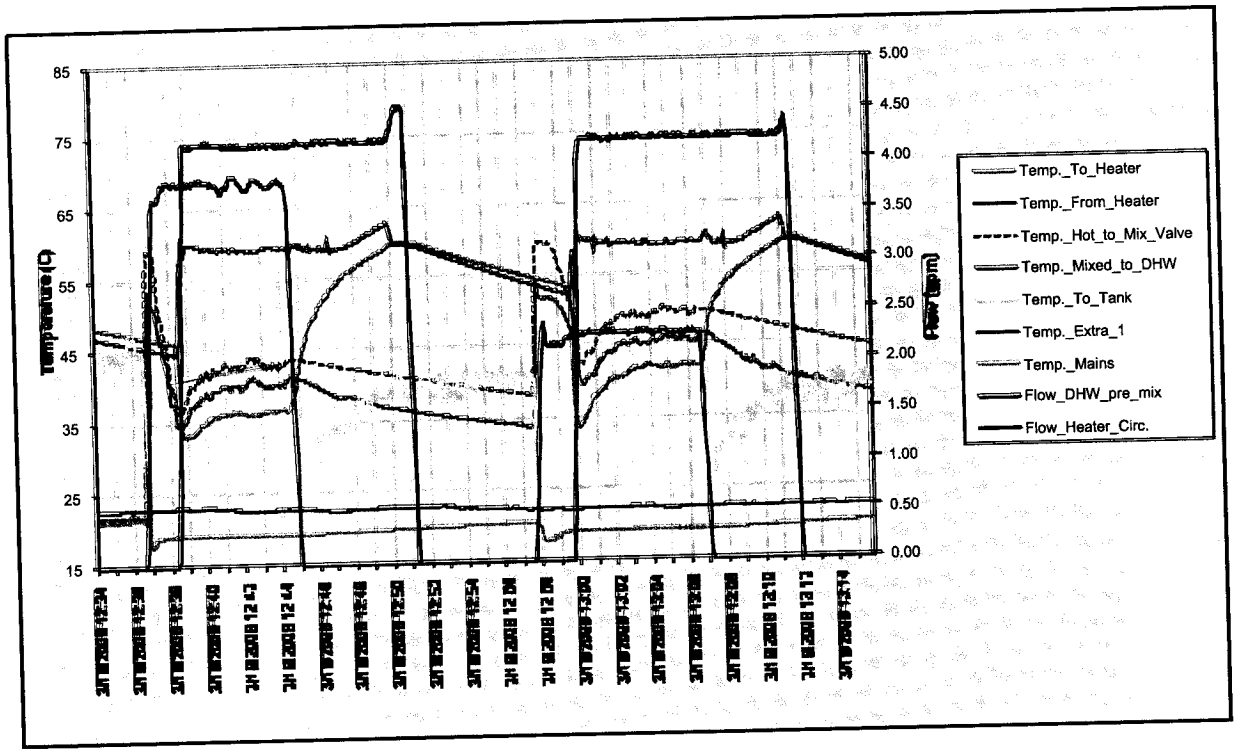


Figure 5.4; Temperature droop response at 4 and 2 gpm hot water flow rate

Two cycles of hot water draw, the first at 4 gpm and the second at 2.25 gpm, were made with the tankless hot water heater outlet set-point at 140°F and the 6 gallon storage tank circulator set-point at 130°F. This is shown in Figure 5.4. The data show a droop in water temperature delivered to the domestic taps (purple plot line) after the draw starts and slower than expected recovery after the pump starts circulating water between the small storage tank and the water heater. The droop occurs more quickly and more deeply at the higher flow rate than at the lower flow rate. The lower limit of the droop was 35 C (95°F) at 4 gpm and occurred over the course of 1 minute. The lower limit was 40 C (104°F) at 2.25 gpm and occurred over the course of 2 minutes. A person taking a shower using 2.25 gpm of hot water would have to adjust the shower valve to 100% hot sometime during the second minute to accommodate for the temperature droop. From the data, it appears that the thermostat activation point changes depending on the draw flow rate. It could be that mains water entering the tank is partially bypassing the thermostat, or that the thermostat response is slow enough that the water in the tank cools down too much before the thermostat activates the circulator.

Two solutions were postulated, one was to install a faster responding temperature sensor to control circulator activation, and the other was to change the circulator control method from temperature activation only to temperature and draw activation via an inline flow switch. The later meant that the circulator would be activated by either a drop in tank temperature or by a hot water draw event. Activating the circulator upon a draw event will push the room-temperature water in the pipes into the tank at the beginning of the draw eliminating the temperature dip that occurs later in the draw. Both solutions would require additional cost and neither solution was feasible to implement during the limited time scheduled for the short-term testing.

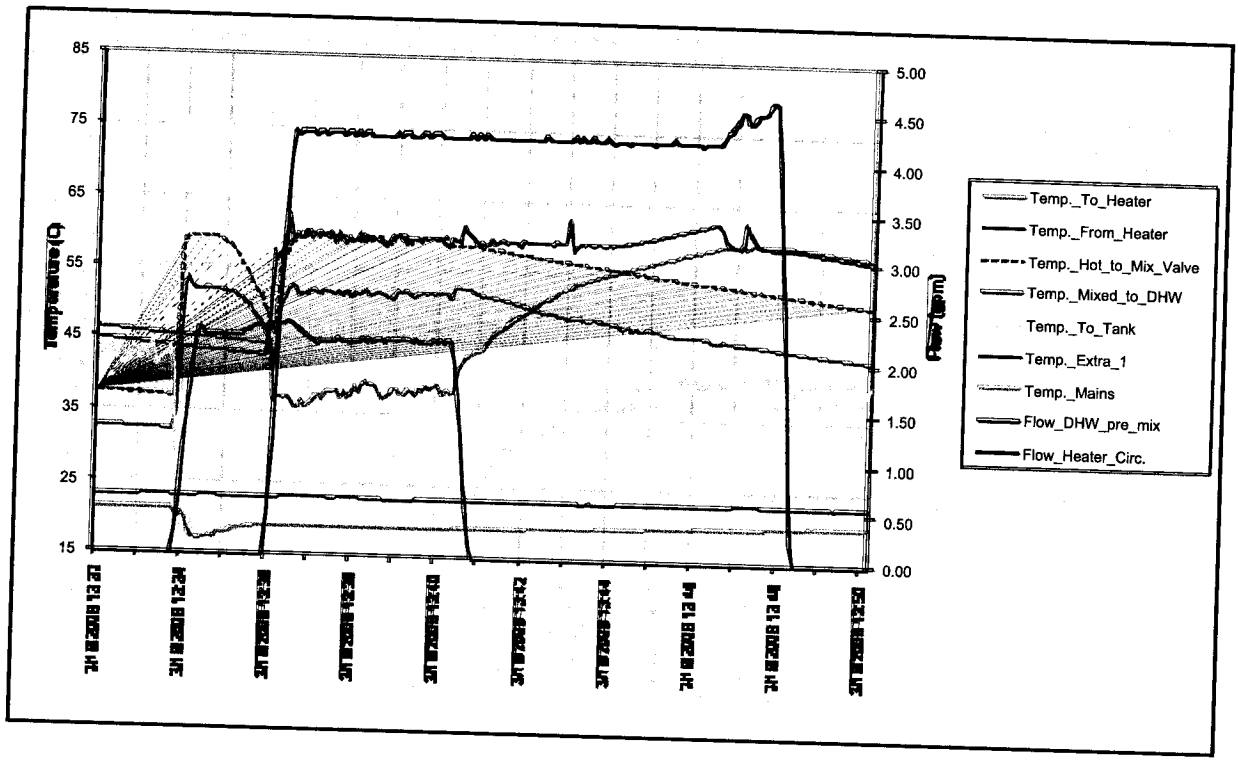


Figure 5.5: System response improvement by changing valve 8 and 9 positions

Further testing revealed an important but easy change to improve the system. Closing valve 8, shown Figure 5.2, and opening valve 9 worked much better than the original configuration of valve 8 open and valve 9 closed. Initially, valves 8 and 9 were installed in the system for testing purposes only-- to allow bypassing the small storage tank entirely. As it turned out, even when using the tank, piping hot water from the heater back to the tank hot water outlet pipe, instead of directly to the tank, sent hot water immediately to the taps after the circulator was activated. That is shown by the purple plot line in Figure 5.5.

For combination space and domestic hot water heating systems (discussed below), the valve change would also provide a built-in domestic hot water priority function. When domestic hot water is drawn, the hottest available water will go to the taps first before mixing in the tank. If no domestic hot water is drawn, hot water from the heater will flow back into the tank through the top port, instead of the side port, keeping the tank hot for space heating operation.

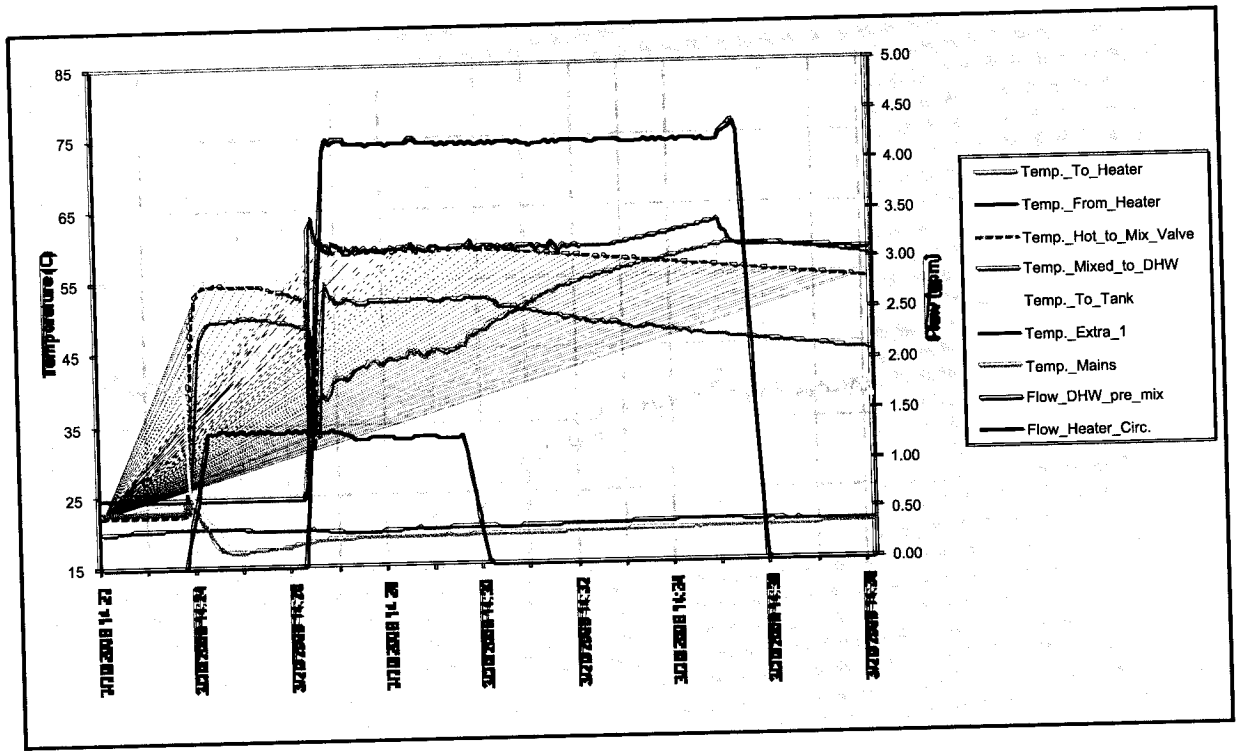


Figure 5.6: Temperature droop response at 1.5 gpm hot water flow rate

The test shown in Figure 5.6 was also run with valve 8 was closed and valve 9 open, but the draw rate was reduced to 1.5 gpm. At that lower draw rate, the temperature droop seen before after the draw started was nearly non-existent. When the circulator started, a sharp decrease in hot water temperature to the taps occurred for 10 seconds. The lower limit of that droop was 35 C (95°F).

The tankless hot water heater that was already installed at this project was the Rinnai R85i (residential, 8.5 gpm max flow, internal mounting). It works the same as the commercial C85i except the C85i output temperature can be set as high as 185°F instead of 140°F max for the residential unit. The commercial versions apparently have a coating inside the heat exchanger to make them more durable. For that reason, Rinnai recommends using the commercial version whenever pumping water through the heater. Since the installed system (Figure 5.9) involves pumping through the unit, the R85i will be replaced with the C85i. That will also allow us to increase the water heater and storage tank set-points 10°F, which will make sure that the temperature droop observed is always above a comfortable shower temperature.

The house is not sold or occupied yet, but once that happens, we will begin to get measured performance data based on actual system use. That data will provide valuable information on how the system responds and performs with naturally varied hot water draw rates and durations over the course of a year.

5.4 Prototype Testing Results for Integration Of Tankless Hot Water Heating With Space Heating

The system of Figure 5.2 was evaluated at an existing home having a tankless domestic hot water heater integrated with space heating (combination space and domestic hot water heating system). Figure 5.7 is a photo of the hot water heating side of the system.

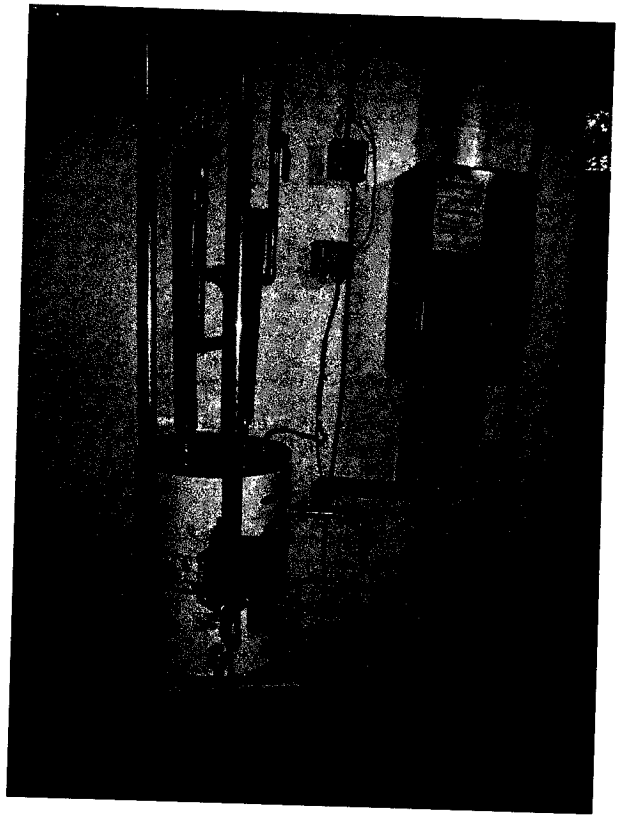


Figure 5.7: Hot water heating side of combination space and domestic hot water heating system utilizing a sealed-combustion tankless water heater

This tankless heater for this system was the Rinnai commercial C53i (5.3 gpm max). Testing of this system also showed a similar temperature droop to that observed in the solar integrated system of Figure 5.9, but, in this case, the lower limit of the droop was always above the required domestic hot water delivery temperature because the water heater output setpoint was 160°F and the tank setpoint was 145°F. Therefore, we believe that the same settings will be the best solution for the system at the Hilton Head project.

Same as for the solar integrated system, the circulator that moves water from the tank through the tankless water heater is activated by the thermostat that comes with the electric water heater tank. However, in the combination space and domestic hot water heating system, another smaller circulator moves water from the tank through a hot water coil in the process air stream of the central heating system. Evaluation through the 2007-2008 heating season has shown the system to work well.

However, a problematic issue arose related to water quality. Mineral scaling in the piping system, especially in galvanized nipples and dielectric union fittings (Figure 5.12), and frequent clogging of the inlet filter to the tankless heater by crystallized mineral deposits was observed (Figure 5.10 and Figure 5.11).

The water heater manufacturer (Rinnai) states that the product warranty does not apply if the water supply exceeds chemistry or impurity limits as shown in the list below:

pH 6.5 to 8.5

TDS (Total Dissolved Solids) up to 500 mg/L

Total Hardness up to 11.7 grains/gallon

Aluminum up to 0.2 mg/L

Chlorides up to 250 mg/L

Copper up to 1.0 mg/L

Iron up to 0.3 mg/L

Manganese up to 0.05 mg/L

Zinc up to 5 mg/L

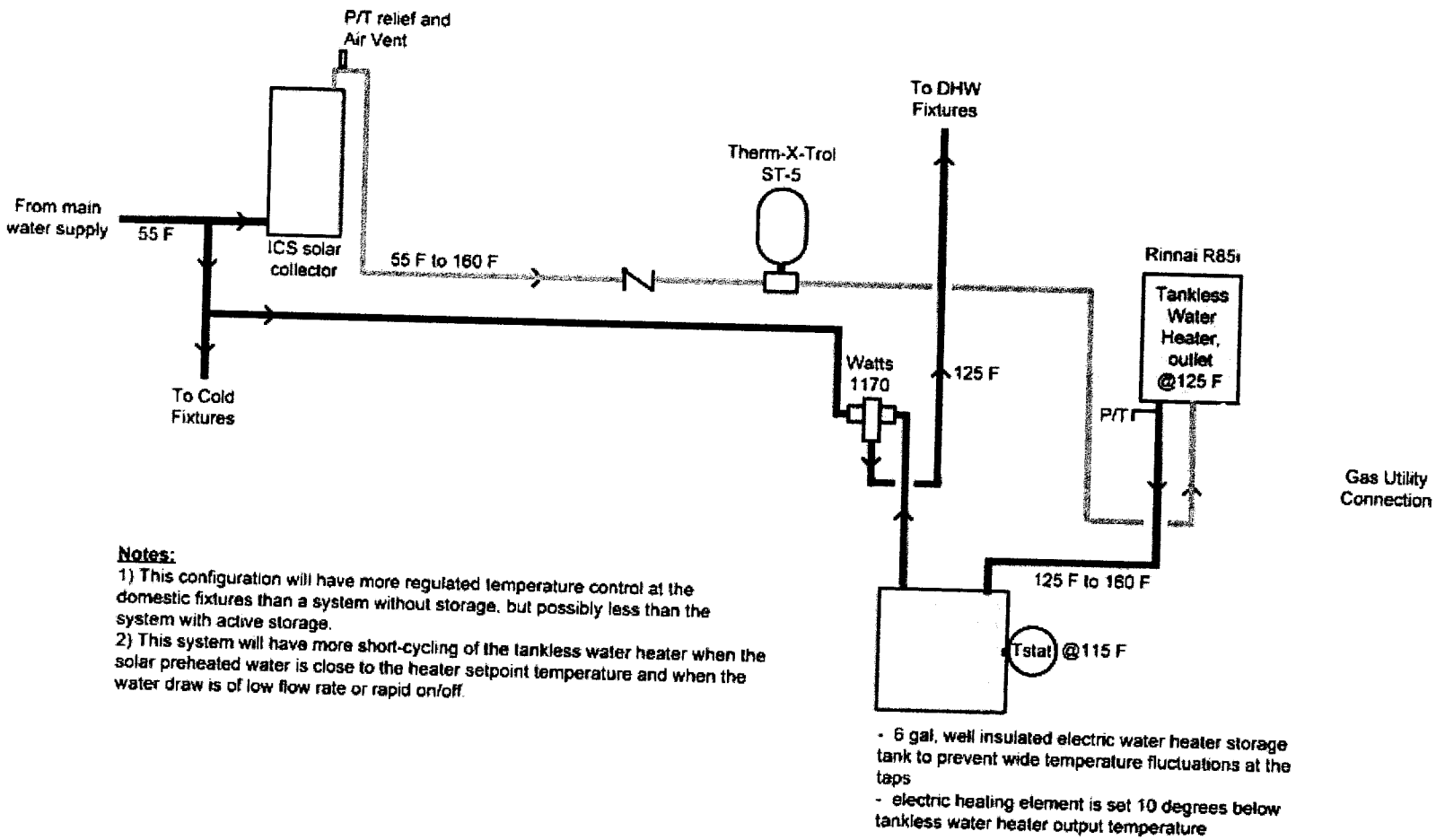
Water tested from the house taps showed that the water supply chemistry and impurity levels were within the required specifications. It is well known that mineral scaling and deposition is accelerated by the relatively high temperatures required for space heating. Based on recent discussions with our builder partner in Albuquerque, NM (Artistic Homes) who has thousands of combination space and domestic hot water heating systems installed, scale and mineral buildup in piping and hot water coils can be with a problem with these systems. The solution that seems to be working at this test site has been:

1) Installation of a large 80 mesh (175 micron) pre-filter before the small 60 mesh (238 micron) filter in the inlet of the tankless water heater (shown in Figure 5.14); and

2) Installation of an electronic water conditioner that keeps minerals such as calcium and manganese from collecting and sticking to surfaces (shown in Figure 5.15).

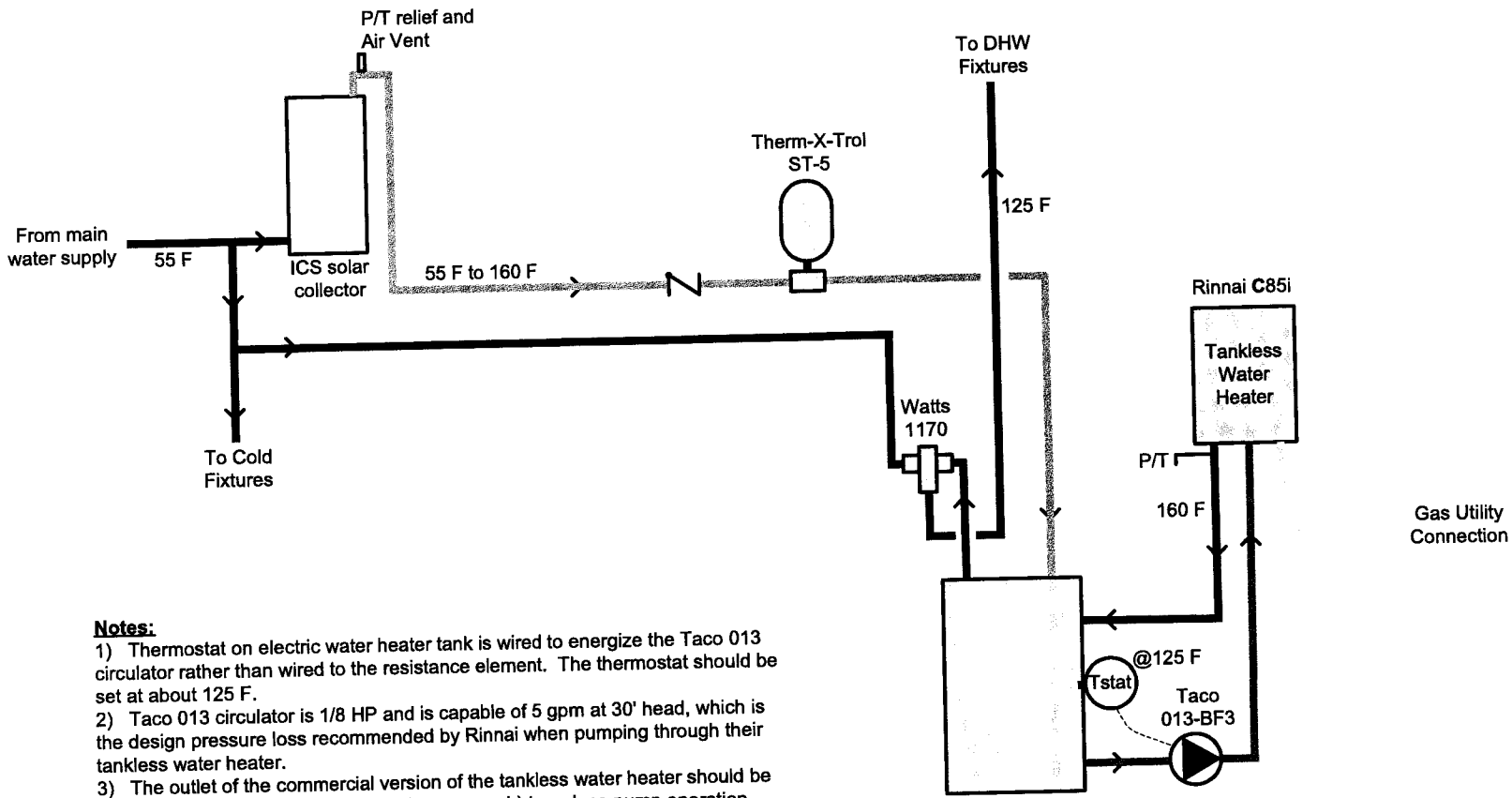
The larger surface area of the pre-filter has reduced the maintenance requirement from weeks to many months. As advertised, the electronic water conditioner seems to be clearing the system of mineral scale that had collected over time (Figure 5.13).

Understanding how and when to best apply these systems and solutions will increase the reliability and long-term successful performance of high-performance homes in the Building America program.



Notes:
1) This configuration will have more regulated temperature control at the domestic fixtures than a system without storage, but possibly less than the system with active storage.
2) This system will have more short-cycling of the tankless water heater when the solar preheated water is close to the heater setpoint temperature and when the water draw is of low flow rate or rapid on/off.

Figure 5.8: Tankless domestic hot water heater application with solar preheat and passive storage tank



Notes:

1) Thermostat on electric water heater tank is wired to energize the Taco 013 circulator rather than wired to the resistance element. The thermostat should be set at about 125 F.

2) Taco 013 circulator is 1/8 HP and is capable of 5 gpm at 30' head, which is the design pressure loss recommended by Rinnai when pumping through their tankless water heater.

3) The outlet of the commercial version of the tankless water heater should be set at 160 F in order to: a) have quick recovery, b) to reduce pump operation time, and c) to allow at least a 30 F temperature rise through the heater which occurs at the minimum firing rate at 1 gpm.

4) Electric water heater storage tank is available from Whirlpool at Lowe's, with all the ports neccessary.

5) This configuration will have the most regulated temperature control at the domestic fixtures. This system will also have the least short-cycling of the tankless water heater.

- 6 gal well insulated electric water heater storage tank to prevent wide temperature fluctuations at the taps and short-cycling of tankless heater;
- thermostat on storage tank controlled to 125 F minimum, but the water can get hotter depending on the solar input

Figure 5.9: Tankless domestic hot water heater application with solar preheat and active storage

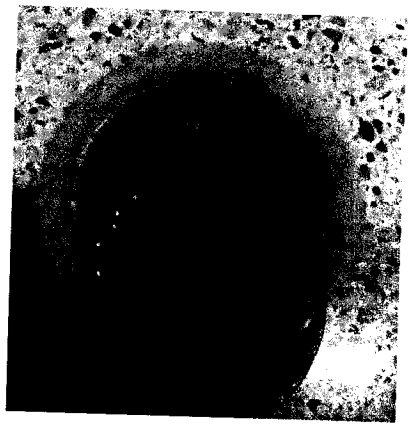


Figure 5.10: Mineral deposition clogging the small tankless water heater inlet filter

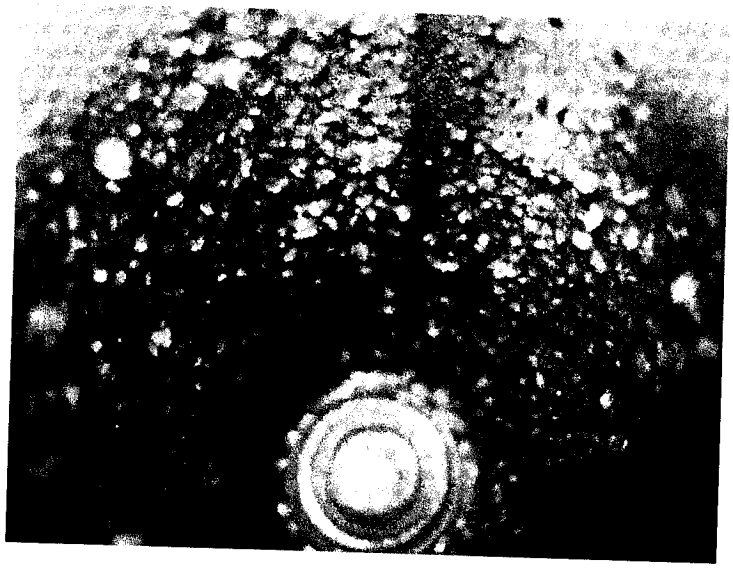


Figure 5.11: Mineral deposition eventually clogging the large pre-filter installed before the water heater inlet

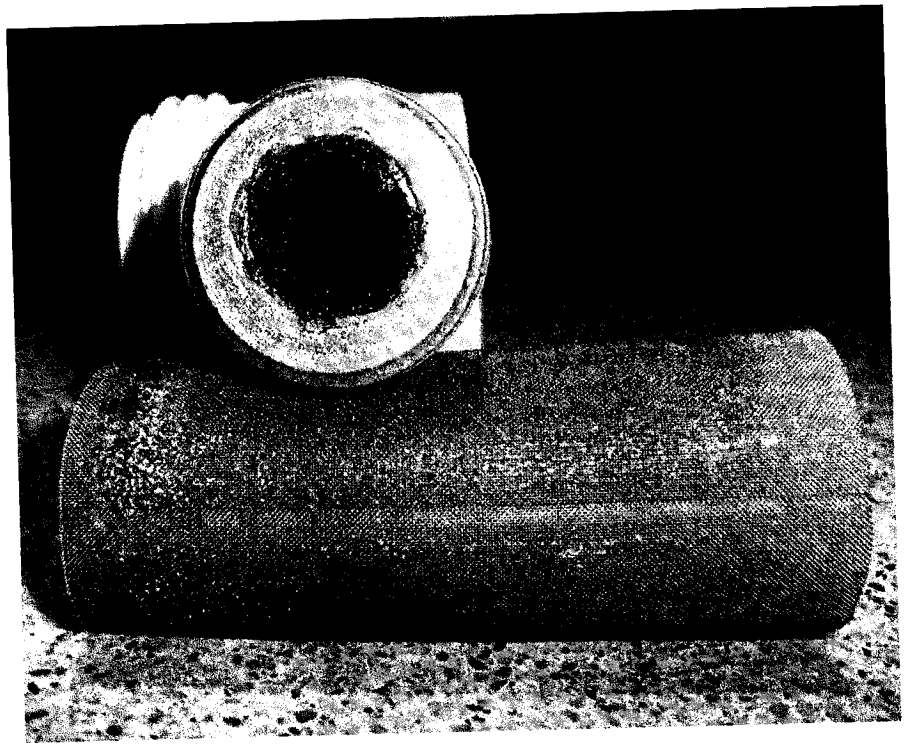


Figure 5.12: Scale buildup in galvanized steel dielectric union fitting and mineral deposition on large pre-filter

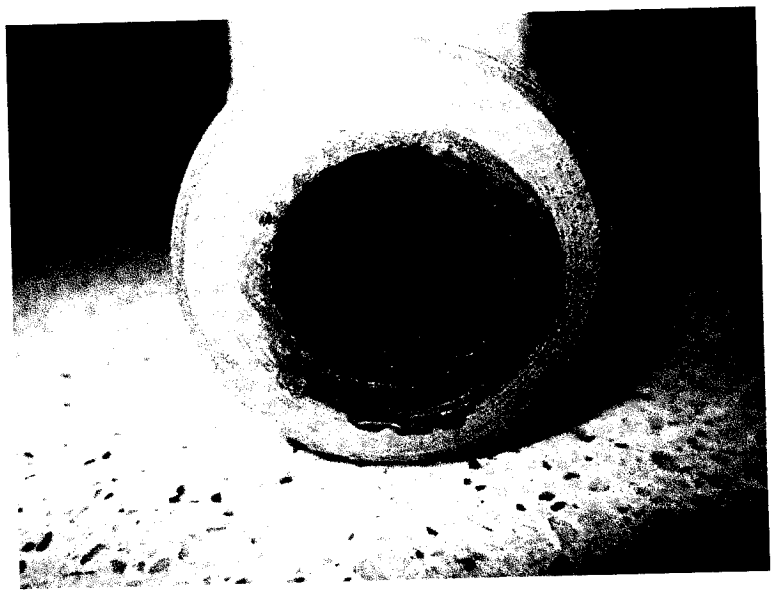


Figure 5.13: Scale being cleaned from a galvanized steel dielectric union fitting by the electronic water conditioner

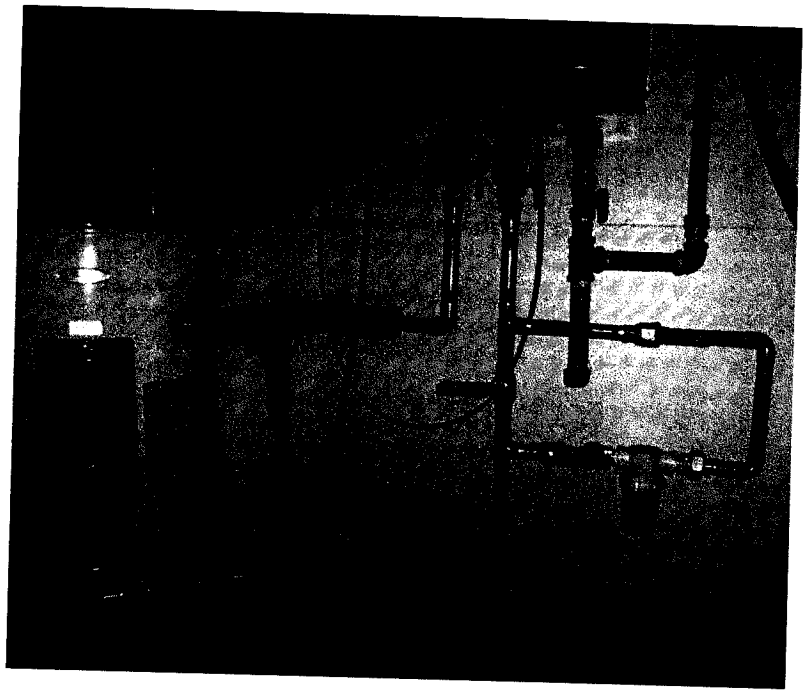


Figure 5.14: Pre-filter installed in bypass loop before the inlet to the tankless water heater

Figure 5.15: Clearwave electronic water conditioner

5.5 Project Evaluation

5.5.1. Source Energy Savings and Whole Building Benefits

This project meets the Gate 1B "must meet" requirement for source energy savings. The prototype system which couples a solar hot water heater with a tankless water heater plus small storage tank and circulator, is expected to save energy relative to the same solar hot water heater coupled with a standard storage type water heater. The prototype system is also expected to reduce inefficient tankless hot water heater cycling and reduce hot water use while improving temperature control at the domestic taps.

5.5.2. Performance-based Code Approval

This project meets the Gate1B "must meet" requirement for performance-based and safety, health and building code requirements for new homes. The solar hot water/tankless water heater integrated installation will be fully compliant with all relevant performance-based codes.

5.5.3. Prescriptive-based Code Approval

This project meets the Gate1B "should meet" requirement for prescriptive-based safety, health and building code requirements for new homes. The solar hot water/tankless water heater integrated installation will be fully compliant with all relevant prescriptive-based codes.

5.5.4. Cost Advantage

This project is expected to meet the Gate 1B "should meet" requirement for strong potential to provide cost benefits relative to current systems. The prototype system which couples a solar hot water heater with a tankless water heater plus small storage tank and circulator, is expected to provide energy savings, water savings, and increased temperature control at the domestic taps at a small incremental cost relative to the same solar hot water heater coupled with only a tankless water heater.

5.5.5. Reliability Advantage

This integrated product should meet the Gate 1B "should meet" requirement to meet reliability, durability, ease of operation and net added value requirements for use in new homes. Sensitivity to water quality resulting in too frequent clogging of the tankless heater inlet filter, and scaling inside pipe fittings, presents some reliability concerns that would be common to similar systems with or without the prototype modifications of a small storage tank and circulator.

5.5.6. Manufacturer/Supplier/Builder Commitment

BSC has discussed these system issues with technical staff at a major tankless water heater manufacturer (Rinnai America Corp.). They were more willing to discuss the water quality issues than the solar integration or the combination space and domestic hot water system integration (they said we were on our own with those systems). BSC will continue to conduct more research on this advanced subsystem in partnership with our builder partner and NREL before approaching a manufacturer about collaboration toward wider market solutions.

5.5.7. Gaps Analysis

Outstanding issues that our research aims to more fully determine include: 1) prototype system performance and occupant acceptance regarding temperature stability at the domestic water taps over a year of occupied monitoring; 2) the frequency of temperature instability at the taps if the small storage tank and circulator modifications were not used; and 3) annual energy, water, and cost savings.

5.6 Conclusions/Remarks

BSC worked directly with the builder and plumbing contractor at the Building America Prototype house (Bryant Park Cottages, Molly, Lot #8) to install a prototype system which integrated a solar hot water heater with a tankless water heater plus small storage tank and circulator. Temperature sensors, flow meters, valves, and bypasses were also installed accommodate monitoring of the system performance during short-term tests and long-term monitoring.

Short-term testing confirmed that the solar/tankless hot water heating system, without the small storage tank and circulator modifications suggested by BSC, would not reliably provide the expected hot water temperature to the domestic taps at low flow rates. Addition of the small storage tank successfully resulted in hot water reaching the taps at very low flow rates, and when the water temperature supplied to the tankless heater from the solar collector was elevated but still less than 130°F. However, other unexpected temperature instability issues with the prototype design were observed and we are continuing to work toward the best resolution.

At a different test house, water quality issues, causing too frequent clogging of the tankless hot water heater inlet filter and mineral scaling of pipe fittings, were found to be the only problems in a prototype tankless/combination space and domestic hot water heating system. Electronic water conditioning and pre-filtering are solutions that were investigated and seem to be working well.

BUILDING AMERICA FIELD TEST PLAN
MARCH 10, 2008

NREL / Building Science Consortium
Coastal Habitats
Hilton Head, South Carolina
Hot Humid Climate Region, 40% Energy Savings Level
Gate 2: Prototype House Evaluation
Expected Test Dates: March 13-23, 2008

Description: Coastal Habitats is constructing a series of Building America homes at the Bryant Park community in Hilton Head, SC. Based on analysis by Building Science Corporation (BSC), the homes will reach 30%+ source energy savings compared to the Building America (BA) Benchmark through the use of air-tight spray foam insulation, low-e windows, and high efficiency mechanical systems. The ventilation system features an innovative combination of central-fan-integrated supply (CFIS) and single-point exhaust methods. The Molly plan proposed here for detailed testing will also have solar domestic hot water (SDHW), resulting in projected source energy savings of 46% over the BA Benchmark. An additional Molly plan without solar hot water will be used for ventilation system testing. The test houses will be at Lot 8 and Lot 9. An elevation drawing of the Molly is shown in Figure 1, the community layout is shown in Figure 2, a schematic of the SDHW system is shown in Figure 3, and the first and second floor plans are shown in Figures 4 and 5. The key specifications are listed in Table 1. The preliminary BSC analysis results are summarized in Tables 2 and 3.

Figure 1: Molly test house front elevation.

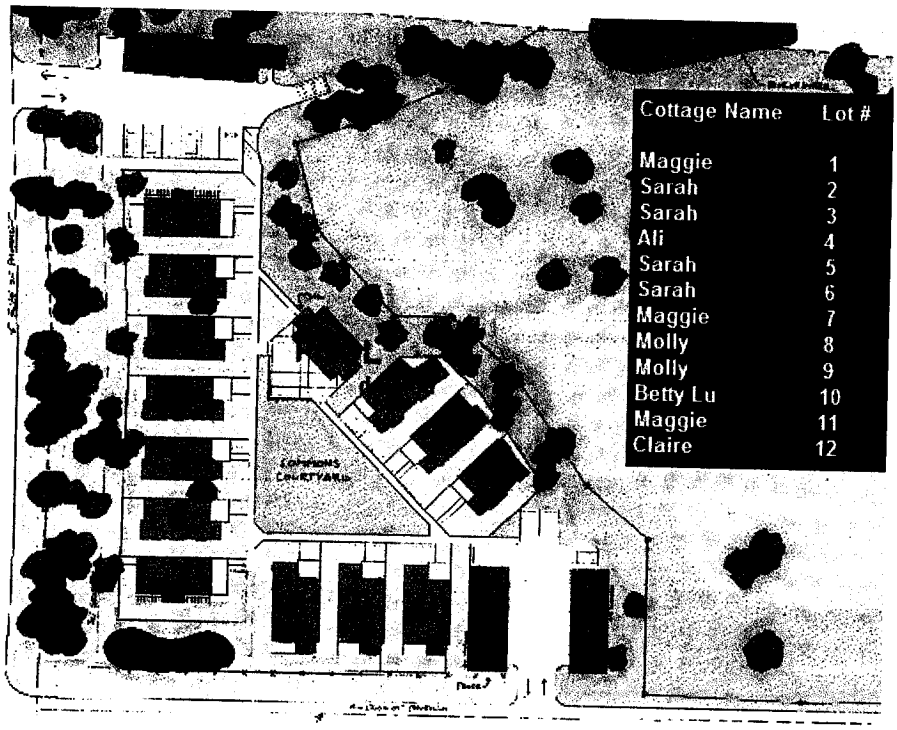


Figure 2: Bryant Park Cottages Site Plan

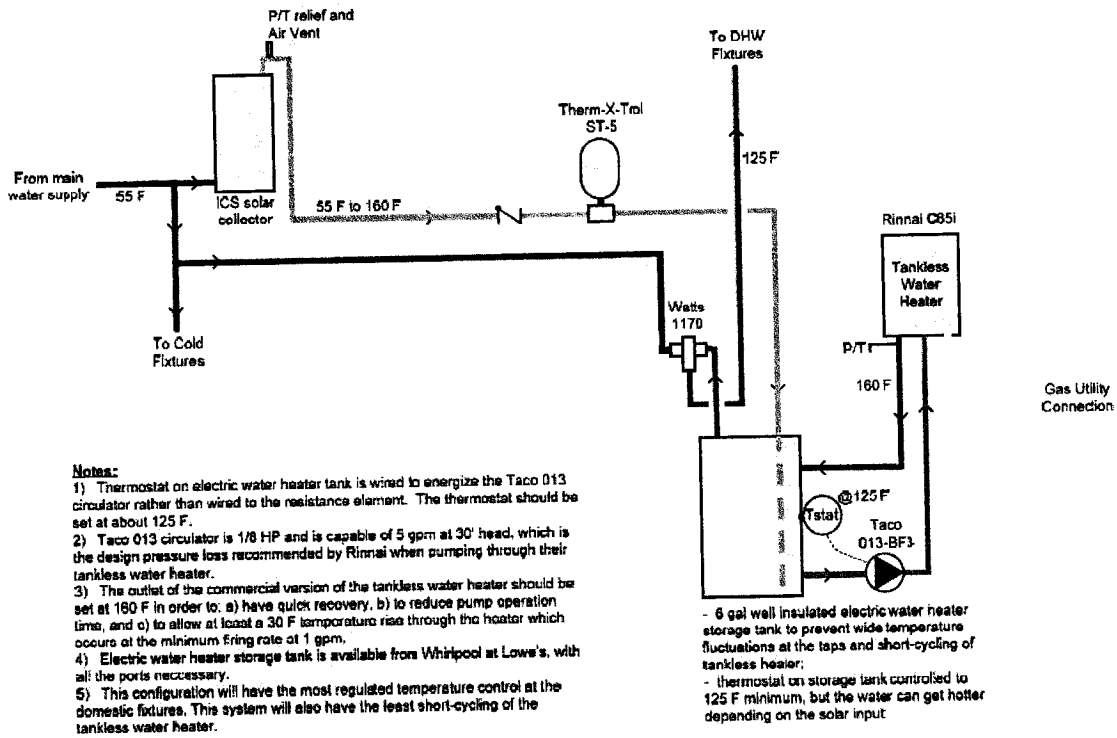


Figure 3. Schematic of the water heating system, in a hybrid configuration designed to avoid shortcomings of integrating a tankless hot water heater with solar pre-heat.

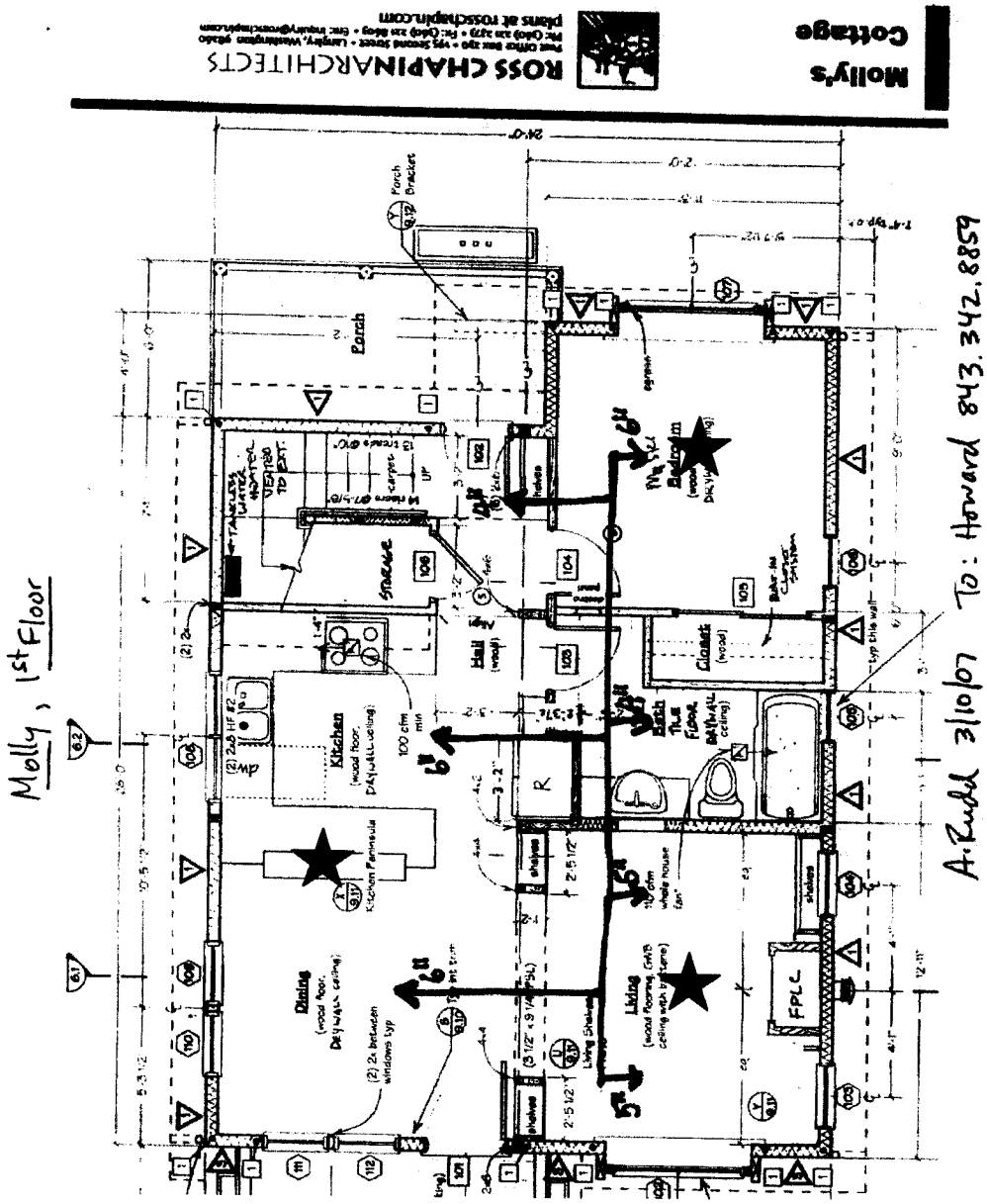


Figure 4. Molly 1st floor plan, with tracer gas measurement points indicated by stars.

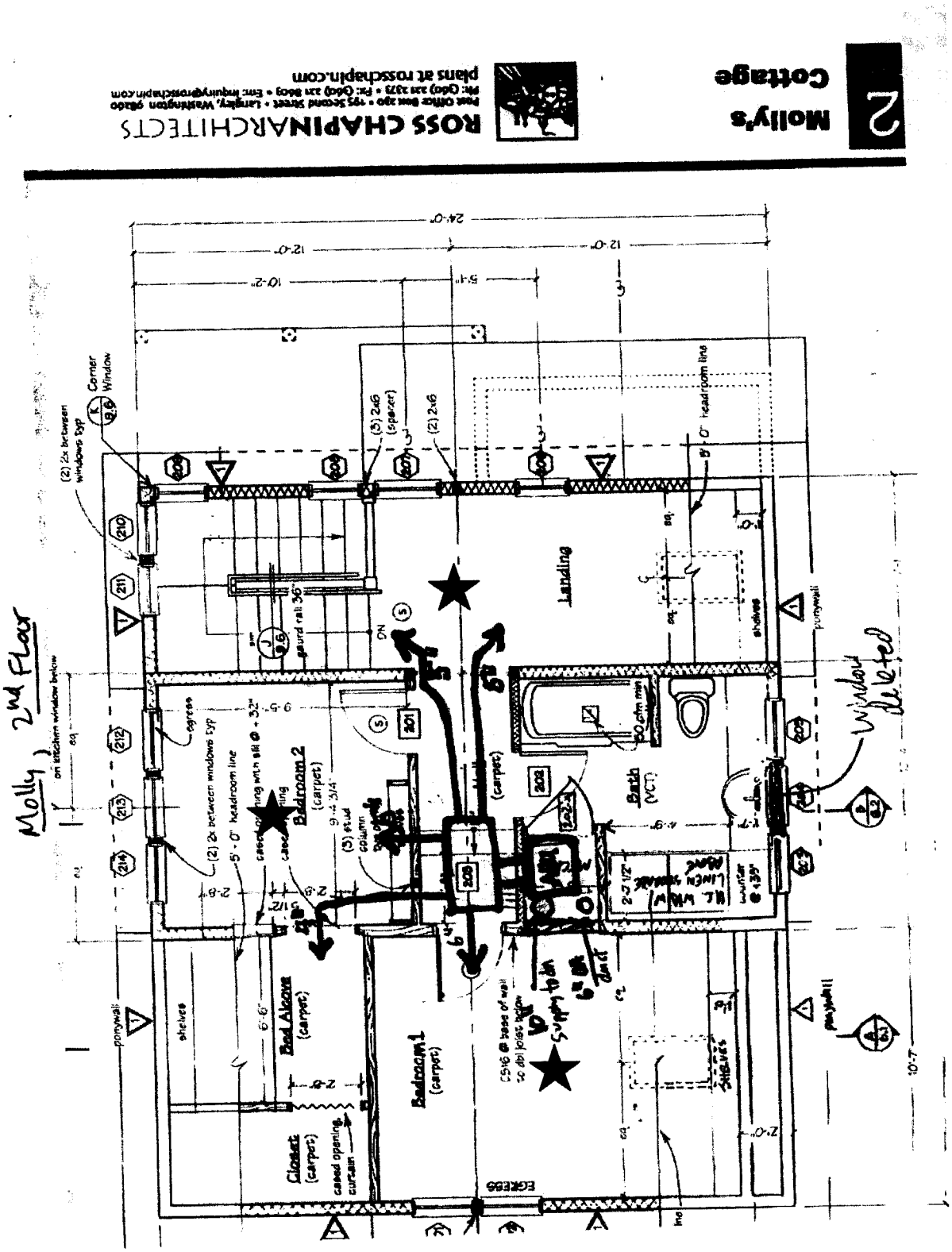


Figure 5. Molly 2nd floor plan, with tracer gas measurement points indicated by stars.

One focus of the field test will be the 50 gallon 32 ft^2 integrated collector-storage (ICS) solar hot water system, which will be coupled with a tankless water heater. A potential problem when using solar preheat with a tankless gas water heater is that the preheated water can be in a temperature range too low for use as hot water, but too high to be heated by the tankless water heater to a suitable temperature at its minimum firing rate. This issue is addressed in the design developed by BSC and illustrated in Figure 2. Mains water will first flow through the TCT ProgressiveTube® collector then into a small storage tank where the hot water will be topped off as needed by a pumped loop to the tankless water heater. Hot water is not provided directly by the tankless water heater. A larger than normal pump (5 gpm) is used to ensure that the water provided by the tankless heater is maintained near the 120°F setpoint. A mixing valve will be installed on the outlet of the domestic water heater to prevent overheated water from going to fixtures when the solar collector heats the storage tank about 120°F. This design should also avoid the possibility of hot water draws that are not met because the flow rate is too low for the tankless water heater.

We will also evaluate the performance of a next generation ventilation controller being developed by BSC and Lipidex Corporation. This controller will combine the operation of a separate exhaust ventilation fan with Central Fan Integrated Supply (CFIS) ventilation. The purpose of this coupling is to lower the ventilation costs and meet the recommendations of ASHRAE 62.2 by operating the exhaust ventilation fan when air handler operation is not called for.

Table 1: Molly test house characteristics. (Lot 8)

	Building America Version
Building envelope	
Ceiling	R-34 cathedralized attic
Walls	R-20 Icynene + 1" R-1.25 XPS
Foundation	Slab on grade exposed
Windows	Spectrally Selective LoE2 U=~0.32, SHGC=~0.33
Skylights	Spectrally Selective LoE2 U=~0.48, SHGC=~0.33
Infiltration	2.5 sq in leakage area per 100 sf envelope
Mechanical systems	
Heat	8.5 HSPF air source heat pump with AHU in conditioned space
Cooling	16 SEER air source heat pump with AHU in conditioned space
DHW	0.82 EF propane instantaneous water heater with solar preheat; 50 gallon 32 ft^2 integrated collector-storage (ICS) solar system; TCT ProgressiveTube® collector
Ducts	R-4.2 flex runouts in dropped ceiling or in floor joists
Leakage	none to outside (5% or less)
Ventilation	CFIS coupled with exhaust ventilation fan - Next generation controller, AirCycler at 33% duty cycle, ~50 cfm flow for both systems

Dehumidification	Aprilaire 1700 coupled with HVAC supply plenum
Return Pathways	jump ducts at bedrooms

Table 2: Annual site energy comparison predicted by BSC

	Annual Site Energy			
	BA Benchmark		BA Prototype	
End-Use	kWh	therms	kWh	therms
Space Heating	3666	0	1253	0
Space Cooling	6315	0	1810	0
DHW	0	164	212	38
Lighting	1830		608	
Appliances + Plug	7285	0	6981	0
OA Ventilation	35		17	
Total Usage	*19131*	*164*	*10881*	*38*
Site Generation	*0*	*0*	*0*	*0*
Net Energy Use	*19131*	*164*	*10881*	*38*

Table 3: Annual source energy comparison predicted by BSC

	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	40	14	66%	12%
Space Cooling	68	20	71%	22%
DHW	17	6	63%	5%
Lighting	20	7	67%	6%
Appliances + Plug	79	75	4%	1%
OA Ventilation	0	0	51%	0%
Total Usage	*223*	*121*	*46%*	*46%*
Site Generation	*0*	*0*		*0%*
Net Energy Use	*223*	*121*	*46%*	*46%*

Research Questions:

1. What are the basic air leakage and flow characteristics of both test houses measured using a blower door, duct blaster, and flow hood? (Short term testing)
2. What is the hourly air infiltration rate of Lot 9 during typical spring weather conditions, with and without the air handlers operating? With the outside air duct sealed and unsealed? (Short term testing)
3. Is the maximum room-to-room pressure differential below the design goal of 3 Pa? (Short term testing)

4. What is the projected fraction of total hot water load met by the solar hot water system? (Short-term testing and simulation) What is the actual fraction? (Long-term monitoring) What is the economic value of the solar hot water system in terms of annual energy cost savings? (Simulation)
5. What is the difference in annual energy use for the installed hot water system compared to a stand-alone tankless propane water heater using Benchmark operating conditions and TMY2 weather conditions for Savannah, GA? Compared to a condensing propane storage tank water heater? With and without the solar preheat system? Using a 1-gallon storage tank? Using a 2 gpm pump instead of 5 gpm for the tankless? (Short term testing and simulation)
6. Is there potential for unstable, fluctuating hot water supply temperatures when the hot water tank, the 5 gpm pump, and the mixing valve are removed from the system or de-activated? If so, across what combinations of flow rates, fixtures, and solar water heater delivery temperature does the problem occur (see test matrix in Table 4)? (Short-term testing) How large are the temperature fluctuations, and over what time period to they occur? How much damping of these fluctuations occurs at different distances from the water heater? (Short-term testing) How frequently are these conditions expected to occur assuming 2008 Benchmark event schedules and the expected solar hot water outlet temperature using TMY2 weather data? (Simulation) Does the addition of the tank and pump avoid or mitigate the problem? (Short-term testing) What alternative solutions are available (see Figure 9 of BSC Deliverable 15.C.3.c), and how does the annual energy use for those approaches compare to the tested system design? (Simulation)
7. At what flow rate are hot water draws unmet by the tankless system when the solar system, the hot water tank, the 6 gpm pump, and the mixing valve are removed from the system or de-activated? (Short-term testing) How frequently are such low flow rates expected to occur assuming 2008 Benchmark event schedules, and what would be the expected reduction in annual hot water volume? (Simulation) If it assumed that occupants will increase the flow rate as necessary to ensure hot water delivery, what is the increase in annual hot water volume and energy use caused by this effect? (Simulation) Does the addition of the tank and pump avoid or mitigate the problem? (Short-term testing)
8. What is the difference in air exchange and energy consumption with the Enhanced System Ventilation Controller in various settings (balanced vs. unbalanced and intermittent vs. continuous)? (Short-term testing and simulation) What is the predicted difference in annual energy use for the enhanced ventilation controller operating according to BSC recommendations compared to a continuous exhaust fan with the same nominal flow rate per ASHRAE Standard 62.2? Compared to a central-fan integrated supply ventilation system with the same average flow rate? (Simulation)
9. What are the air distribution characteristics of the CFIS, the stand-alone exhaust ventilation fan and the two combined using the intended control strategy during actual weather conditions and with bedroom doors closed? Are the decay curves sufficiently stable to accurately calculate reciprocal age-of-air? (Short-term testing)
10. How sensitive are the reciprocal age-of-air measurements to significantly different weather conditions at night and during the day? (Short-term testing)
11. What are the pros and cons of using the room mixing fans in the outside-air distribution test protocol? (a) How much does the age-of-air vary within a room during the decay test, when there is no mixing, with doors open and with doors closed? (b) How much do the room mixing fans change the amount of room-to-room variation in age-of-air? Does the shape of the decay curve vary within a room when there is no mixing? (Short-term testing)
12. What is the moisture removal rate of the dehumidifier compared to the heat pump over the course of a year? (Long term monitoring) What is the relative humidity in the house under various weather conditions? (Long-term monitoring)
13. What is the projected annual energy savings of the test house compared to the Benchmark, Regional Standard Practice, and Builder Standard Practice? (Simulation)

14. What is the energy use of the test house under occupied conditions? (Long term monitoring) How does the actual energy use compare to the simulations when actual weather and operating conditions are used? (Simulation)

Optional Questions if Time and Resources Permit:

15. How different are the reciprocal age-of-air measurements for nominally identical Molly floor plans on Lot 8 compared to Lot 9 under similar weather conditions?
16. What is relationship between outdoor weather conditions (temperature, wind speed, wind direction) and interzonal airflows for the test house? How large are the errors introduced into the reciprocal age-of-air calculations by the actual weather conditions during each test? (Short-term testing and simulation)
17. What is the predicted annual energy use of the dehumidifier? (Simulation) How frequently would the indoor relative humidity exceed 60% for more than 4 hours without the dehumidifier? (Simulation)

Table 4. Matrix for tankless hot water instability testing.

Test #	DHW Configuration	Fixture	Flow Rate	Temperature Entering Tankless
1	No solar, no tank	Kitchen Sink	~0.7 gpm	70°F
2	No solar, no tank	Kitchen Sink	~0.7 gpm	80°F
3	No solar, no tank	Kitchen Sink	~0.7 gpm	90°F
4	No solar, no tank	Kitchen Sink	~0.7 gpm	100°F
5	No solar, no tank	Kitchen Sink	~0.7 gpm	110°F
6	No solar, no tank	Kitchen Sink	~0.7 gpm	120°F
7	No solar, no tank	Bath 2 Shower	~0.7 gpm	70°F
8	No solar, no tank	Bath 2 Shower	~0.7 gpm	80°F
9	No solar, no tank	Bath 2 Shower	~0.7 gpm	90°F
10	No solar, no tank	Bath 2 Shower	~0.7 gpm	100°F
11	No solar, no tank	Bath 2 Shower	~0.7 gpm	110°F
12	No solar, no tank	Bath 2 Shower	~0.7 gpm	120°F
13	No solar, no tank	Bath 2 Shower	~2.5 gpm	70°F
14	No solar, no tank	Bath 2 Shower	~2.5 gpm	80°F
15	No solar, no tank	Bath 2 Shower	~2.5 gpm	90°F
16	No solar, no tank	Bath 2 Shower	~2.5 gpm	100°F
17	No solar, no tank	Bath 2 Shower	~2.5 gpm	110°F
18	No solar, no tank	Bath 2 Shower	~2.5 gpm	120°F
19	No solar, with tank	Kitchen Sink	~0.7 gpm	70°F
20	No solar, with tank	Kitchen Sink	~0.7 gpm	80°F
21	No solar, with tank	Kitchen Sink	~0.7 gpm	90°F
22	No solar, with tank	Kitchen Sink	~0.7 gpm	100°F
23	No solar, with tank	Kitchen Sink	~0.7 gpm	110°F
24	No solar, with tank	Kitchen Sink	~0.7 gpm	120°F

Table 5. Matrix for single and multi-zone tracer gas testing in Lot 9.

1. Single Mixed Zone Tracer Gas Ventilation Bump Testing (2 days) a. Deploy destratification and mixing fans with the aim to create a single well-mixed zone in the whole house. Position sampling points on each floor of the home as shown in Figures 4 and 5. Perform standard tracer gas tests with ventilation off, with exhaust ventilation on, and with the air handler operating (supply ventilation on). Check the data to see if a single mixed zone was achieved. If a single mixed zone is achievable, proceed with tracer gas decay testing. b. Evaluate whether a single mixed zone is achievable and the home is sufficiently tight to proceed with the age-of-air testing outlined below.
2. Air-of-air Tracer Gas Testing – all six sample points in one zone (2 days) a. Master bedroom zone – exhaust ventilation - bedroom doors open - mixing fan off b. Master bedroom zone – exhaust ventilation - bedroom doors open - mixing fan on c. Master bedroom zone – exhaust ventilation - bedroom doors closed - mixing fan off d. Master bedroom zone – exhaust ventilation - bedroom doors closed - mixing fan on (if necessary based on results of (b))* e. Repeat (a) with outside air damper open*
3. Air-of-air Tracer Gas Testing – Multi-zone (4 days) a. Exhaust ventilation - bedroom doors closed - mixing fans on (overnight) b. Repeat (a) during the day in different weather c. Exhaust ventilation - bedroom doors open - mixing fans on d. Exhaust ventilation - bedroom doors open - mixing fans off e. Exhaust ventilation - bedroom doors closed - mixing fans off (if necessary based results of (2a-d))* f. Supply ventilation @ 33% duty cycle - bedroom doors closed - mixing fans on (overnight)* g. Ventilation controls operating as recommended by BSC - bedroom doors closed - mixing fans on h. Repeat (a) in Lot 8 overnight in similar weather*

* Lower priority tests if time runs out

Preliminary Time Frame: The test house should be available for testing on March 13, 2008.

Day #1 (March 13)	Arrive at site and meet with Coastal Habitats representative for keys to house. Transport equipment from NREL to test house.
Days #1-10	Hot water system testing at Lot 8. Multi-zone tracer gas testing of Lot 9. Long-term monitoring installation at Lot 8.
Day #10 (March 22)	End test and transport equipment back to NREL.

Requested Action Items for Team and Builder:

1. Let NREL know with as much advance notice as possible when this house will be available for testing.
2. Have the house fully finished prior to testing if possible.
3. Install instrumentation and additional piping to DHW system in accordance with Figure 6.
4. Have any building commissioning activities deemed necessary by the team performed prior to testing (i.e., balance air distribution system).

5. Conduct full battery of performance testing including. This includes blower door, duct blaster, HVAC static pressures, register flows, and ventilation measurements.
6. Inform NREL test engineer if builder or sales personnel require access to the house while testing is underway.

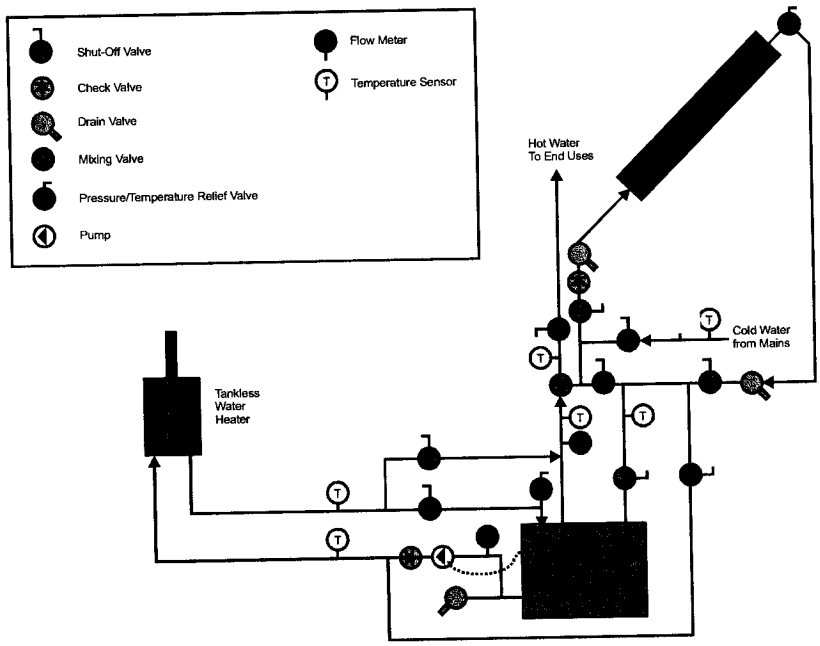


Figure 6. Locations of flow meters, temperature sensors, and bypass loops.

Directions

Jobsite: 625 Spanish Wells Road, Hilton Head, SC 29926. (See Figure 7)

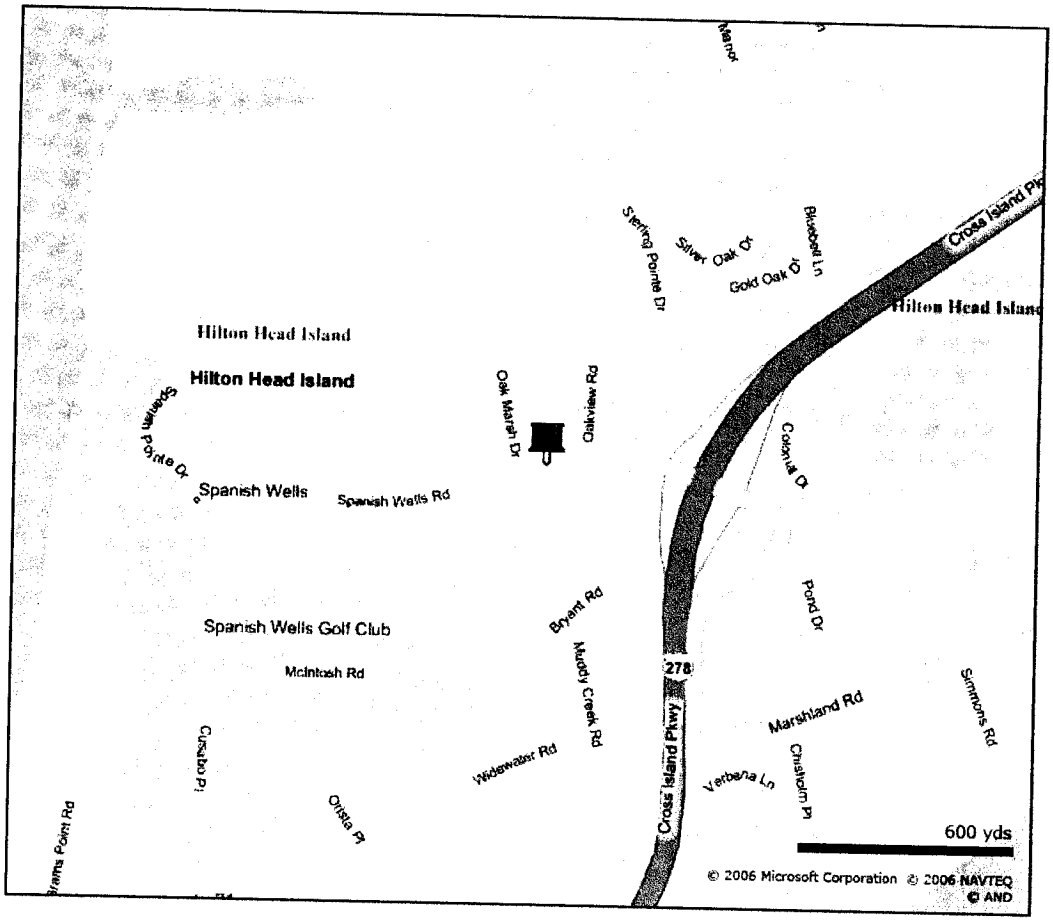


Figure 7: Bryant Park Cottages Site Location

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DEVELOPMENT WEB SITE HTTP://WWW.BRYANTPARKCOTTAGES.COM/

BUILDER WEB SITE HTTP://WWW.COASTALHABITATS.NET/

About this Report

This report was prepared with the cooperation of the U.S. Department of Energy's, Building America Program.

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THE EFFECTS OF ENERGY EFFICIENCY TREATMENTS ON HISTORIC WINDOWS

January 24, 2011

CENTER FOR ReSource CONSERVATION

Project Title:

THE EFFECTS OF ENERGY EFFICIENCY TREATMENTS
ON HISTORIC WINDOWS

Project # 2008-M1-024
Grant Recipient: The Center for ReSource Conservation

Deliverables:
07. Testing Results – Field
08. Testing Results – Lab
11. Final Report Findings

This project was partially funded by a State Historical Fund grant award from History Colorado, the Colorado Historical Society, as well as the City of Boulder, Local Environmental Action Division (Formerly the Office if Environmental Affairs) and with materials provided by Alpen Energy Group.

By

Larry Kinney and Amy Ellsworth

Comments on the form and content of this report are welcome. Please direct feedback to:

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Appendix B. Window Test Facility Construction

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Appendix D. Alternative Approach to Air Sealing and Insulating Counterweight Pockets in Historic Double Hung Windows

Appendix E. Key Members of the Project Team

Acknowledgements

This study of the effects of energy efficient treatments on historic windows was developed with extensive help and support from many collaborators who contributed materials or worked tirelessly for little or no compensation to achieve research results. Our thanks go to Doug Ward our volunteer craftsman and Gary Cler, part of the project's technical team who helped construct the project's testing laboratory and spent many hours testing windows; Wyncia Clute, of Synertech Systems Corporation, who worked in the field, at the chamber, and on her computer in support of all aspects of the project; Brad Begin of Alpen Energy Group, who supplied abundant practical wisdom and other support throughout the project including space to house the laboratory; Lynn Bingham and the team of craftsmen, including Glenn Bingham and Jeff Griffin of Phoenix Window Restoration; Gary Nelson, President, and his colleagues of the Energy Conservatory who custom-calibrated the duct blaster and two digital pressure gauges *gratis* for this project; Leonard May of the City of Boulder's Historic Preservation Society and Landmarks Board; ReSource building material salvage yard, for supplying several free historic windows for testing in the lab; and the Colorado Historical Society. Finally, we wish to thank Gretchen Lang and Michael Wilkins, who opened their lovely historic home to the technical team and equipment used in this study. It is our fervent hope that their home is more comfortable, attractive and energy efficient as a result.

Dedication

Dedications are not routinely a part of technical reports, but the present case is exceptional. Our dear friend and colleague Gerald Lee Cler died an untimely death on October 8, 2010. Gary put in many long hours on the present project and contributed to it in a myriad of useful ways. It is singularly appropriate that this report is dedicated to his memory.

Unlike most mechanical engineers in modern times, Gary gained a world of practical wisdom even before completing his formal education. After graduating from high school in Illinois, he worked in his uncle's machine shop for seven years, where he became an excellent machinist. This experience provided clarity about what he wanted to study in college. Gary did undergraduate work in mechanical engineering at the University of Illinois and then earned an MS at Colorado State University. By the time I met him early in 2000, he had made numerous contributions to the advancement of energy efficiency and renewable energy.

We were colleagues at E-Source in Boulder and immediately formed a strong friendship. We shared the view that many broadly held opinions about energy efficiency merit careful re-examination, and that many potentially useful inventions were waiting for someone to bring them to life. So we set about inventing tools for saving energy, mostly in the areas of natural daylighting and fenestration.

Gary rarely designed things he couldn't fabricate himself (usually in his brother Larry's machine shop.) Further, he always made things as simple as they could practically be—but no simpler. We frequently found ourselves sharing ideas and building on one another's thoughts with drawings that filled the backs of bar napkins. Some of these sketches (slightly modified, to be sure) are now part of the patent literature.

Most important, as our friendship grew during the last decade, my wife Wyncia and I found ourselves in the presence of not only an excellent, creative engineer, but also a large, ancient soul. Gary was a deeply moral man who both loved life and befriended a host of people whose lives he enhanced in many ways.

It was an honor and a privilege to have known him. Gary is sorely missed.

Larry Kinney
November 2010

EXECUTIVE SUMMARY

This study focused on empirical testing of the energy efficiency and economy of a range of options for upgrading the energy performance of historic windows. The study involved retrofitting windows in a test home in a historic district in Boulder, Colorado. It included testing in a window laboratory facility developed for the study.

The 108 year old 2700 square foot brick test home includes numerous original double-hung, wood-framed, single-glazed windows. The study focused on three on the south façade and three on the north. Each was equipped with aluminum storm windows and associated screens that were added several decades ago.

During the study, five of the six windows were carefully rebuilt in ways that retained their historical character. The sixth, a small window in poor condition in a bathroom, was replaced by a custom-built wood frame window that matched the aesthetics of the original but was carefully air sealed and designed to provide ventilation through a screen when desired. Blower door testing revealed that counter weight pockets in the other five windows were leaky – these had weights removed, then were insulated and air sealed. Windows were then equipped with spring systems, which provide the functionality of the counter weight approach but cannot be seen[1]. Other improvements included filling holes, removing old paint and glazing compound, restoring the functionality of the original sliding mechanisms, installing weather stripping, sealing wood surfaces, installing new glazing compound, and adjusting (or replacing if appropriate) lock mechanisms. Post-retrofit blower door testing at the home revealed an average of about 6 therms of natural gas savings per window per heating season from diminished convective losses alone.

The work of carefully rebuilding old windows is practiced primarily by professional craftsmen who work with specialized tools and equipment. Some, like Phoenix Windows, employ a portable shop which they bring on site to enable rebuilding multiple windows in several days time. This process can breathe new life into old windows and dramatically improve comfort and energy efficiency. However, because the work is painstakingly conducted by a skilled craftsman, the cost is very different from window systems manufactured off site and left to a homeowner or local technician to install.

In addition to the above-mentioned retrofits, insulated glass units were installed in a 16 square foot window on the south facade (one whose original lites had been replaced years ago). Finally, at the request of the homeowners, three wooden storm windows designed to cohere with the character of the home were built for the project. One storm window incorporated single glazing and the other two were equipped with insulating glass units. One of these latter storm windows had fixed insulation integrated into the interior of the frame.

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[1] Replacement of counterweight systems with spring systems should not be undertaken in properties listed in the National Register of Historic Places as this technique does not comply with the Secretary of the Interior's Standards for the Treatment of Historic Properties. An alternative approach to sealing and insulating counterweight pockets, which does comply with the Standard, is provided in Appendix D of this report.

Energy losses or gains through windows vary directly with their size, the temperature difference between inside and out, and the heat transfer coefficient (U-factor), a parameter reflective of the combined thermal characteristics of both frame and glazing. (U-factors are the inverse of R-values, where R is the resistance to heat flow.) In practice, it is exceedingly difficult to measure U-factors in the field, so members of the project team built and instrumented a testing facility to measure U-factors and study air leakage. The testing facility features a super-insulated 390 cubic foot inner chamber designed to measure fenestration samples of up to 20 cubic feet. It is surrounded by another well-insulated chamber. The inner chamber is heated by electric resistance radiant panels and the outer is cooled by chilled air. The result is a difference in temperature that averages 70 degrees F. Heating energy required to maintain this temperature difference is measured precisely, as is temperature from a number of probes inside the hot chamber and between the hot and cold chambers. Data loggers record energy use and temperatures each minute for subsequent analysis.

In addition, a calibrated variable speed fan and associated two-channel digital manometer is used with the inner chamber to determine that samples are tightly mounted in the test facility and to quantify the extent of air leakage associated with cracks between fixed and moveable portions of frames.

The solar heat gain coefficient (SHGC) is the fraction of solar radiation admitted through a window that is directly transmitted and absorbed, and subsequently released inward. In this project, the team used a factory-calibrated pyranometer to take readings in both the test home and the laboratory.

Table ES-1 shows key results of laboratory testing on ten combinations of fenestration systems.

Table ES-1. Measurements of U-factors and R-values

Description	*Number of test runs*	*Total test hours counted in calcs*	*Standard Deviation of hourly U-value*	*Weighted Average (U)*	*Weighted Average (R-value)*	*Wind adjusted R*	*Wind adjusted U*
Old double hung from window 5	4	102	0.000872	0.78	1.29	0.79	1.27
Single glazed original alum storm	2	39	0.000872	0.97	1.03	0.53	1.88
New Storm w/o insulated frame	2	32	0.00132	0.27	3.65	3.15	0.32
New Storm w insulated frame	1	16	0.00077	0.24	4.11	3.61	0.28
New Storm single glazed	2	40	0.001045	0.76	1.31	0.81	1.23
Old DH from 5 + new storm w/o Ins	2	39	0.000908	0.21	4.87	4.37	0.23
Old DH from 5 + new Storm w/ Ins	1	42	0.001054	0.19	5.18	4.68	0.21
Retrofitted double hung from wind 5	1	24	0.000862	0.48	2.07	1.57	0.64
Ret DH from 5 + new storm w/o ins	2	39	0.000958	0.19	5.32	4.82	0.21
Ret DH from 5 + new storm w/ ins	3	91	0.000958	0.17	5.83	5.33	0.19
Ret DH from 5 + sg wood storm w/o ins	3	116	0.000926	0.33	3.00	2.50	0.40
New Vinyl Window	3	110	0.000926	0.36	2.75	2.25	0.45

The low standard deviations indicate consistency in measuring techniques and lend credence to the relative results of U-value testing. The wind-adjusted U-factors and R-values reflect canonical parameters of the difference in the insulating value of a still air film and an air film associated with a 15 mph wind on the exterior of a structure.

Each of the storm windows was tested on its own and with several combinations of storm windows with existing and retrofitted double hung windows. Note that the single-glazed storm outperformed the existing aluminum storm by a factor of 1.5; the new storm without insulation in the frame outperformed the aluminum storm by a factor of 5.9, and the storm with insulated frame outperformed the aluminum storm by 6.8 fold. Retrofitting the old double hung improved performance by a factor of two over the existing old double hung, whereas replacing it with a new vinyl window yielded an improvement of 2.9 fold. The overall best performance was achieved by retrofitting the old double hung then installing a new storm window whose frame was partially insulated. This yielded a 6.8 fold improvement in energy performance over the old double hung in its original condition.

Knowledge of fenestration areas, solar heat gain coefficients, and U-values can be combined with typical meteorological year (TMY) solar radiation and temperature data to calculate hourly energy gains and losses for virtually any fenestration system for which TMY data are available.

RESFEN software developed by Lawrence Berkeley National Laboratory was used to estimate the summer and winter energy performance of each of the fenestration systems shown in Table ES-1 in seven American cities: Anchorage, Atlanta, Boston, Denver, Minneapolis, Phoenix, and Sacramento. A set of tables in Section 4 of this report, and in the table below, show energy and economic performance figures based on 100 square feet of the fenestration systems installed on each of four facades. The calculations assume a retrofit cost for low-U storm window of $25per square foot, a rough average of the cost of this type of retrofit as practiced in this project and other areas of the country.[2] The data also reflects local costs of gas and electricity, which can differ substantially. For example, residential consumers in Anchorage pay $0.441 per therm for natural gas while those in Phoenix pay $1.43, three and a quarter times as much. Homeowners in Boston pay $0.17 per kWh for electricity while those in Atlanta pay $0.071, a factor of 2.4 difference.

Table ES-2 examines the old double hung window compared to the same window with a new Low U-value storm window in each of the seven cities. Absolute savings are expressed in millions of British thermal units (MBtu) where ten therms of gas = 1 MBtu and 293 kilowatt hours of electricity = 1MBtu. A million Btu is roughly the energy equivalent of a person year of labor.

Table ES-2. Savings from retrofitting double-hung window with a Low U-value storm

City	*Old DH (MBtu/yr)*	*Old DH + New Lo U Storm (MBtu/yr)*	*Absolute Savings (MBtu/yr)*	*Relative Savings (%)*	*Savings ($/yr)*	*Retrofit window cost ($)**	*Simple payback (years)*
Anchorage	95.2	17.9	77.3	81.2%	$342	$9,600	28.0
Atlanta	26.4	1.2	25.2	95.4%	$297	$9,600	32.3
Boston	56.1	5.7	50.3	89.8%	$806	$9,600	11.9
Denver	44.5	5.2	39.3	88.3%	$424	$9,600	22.6
Minneapolis	76.7	11.3	65.4	85.3%	$686	$9,600	14.0
Phoenix	33.1	4.5	28.6	86.4%	$491	$9,600	19.5

[2] Typical "thorough" jobs are described and illustrated in Section 3.1 of the report.

Sacramento	25.1	0.6	24.5	97.7%	$311	$9,600	30.9
Averages	51.0	6.6	44.4	87.0%	$480	$9,600	20.0

* Retrofit cost is based on $25 per square foot for 100 square feet of window area on each of four facades for a total of 400 square feet (400 x $24 = $9600).

In this case, savings average 44.2 MBtu and 87%. Dollar savings are over $800 per year in Boston and average $480 overall. The savings in Anchorage are the energy equivalent of 77 person years of labor, yet paybacks are 28 years.

Assumptions and caveats associated with the above analyses are:

- The assumed cost of a highly-energy-efficient storm window reflects no economies of scale and assumes a wood frame, which is labor intensive to manufacture and has an R-value that is three times less than that of fiberglass or vinyl.
- No local, state, federal, or utility incentives are taken into account.
- The analysis does not account for such benefits as increased comfort, yet many consumers count this as a primary consideration in their decisions about windows.
- The analysis does not account for the likely increase in the lifetime of the primary window resulting from either retrofit or adding an energy-efficient exterior storm window.
- There are many circumstances in the real world in which useful lifetimes of various window treatments may be less than payback periods. These factors are notoriously difficult to quantify and therefore have not been considered in payback calculations.
- Cost-benefit calculations assume the rate of inflation in energy costs is identical to the overall rate of inflation. Accordingly, the analysis is likely to be conservative.

Before drawing inferences from the above findings, it is useful to take note of the key role played by frames in determining window energy performance. Historic window frames are typically made of wood; glazing is routinely single. An inch of dry white pine has an R-value of one (1/Btu/ft2/F). Single glazing also has an R-value of approximately one. Accordingly, **when both the frame and glazing have roughly the same R-value** (as in the case of older single-glazed windows with wood frames), **conductive losses do not change much with the ratio of the cross sectional area of glazing to frame**. However, when glazing is more efficient—modern large insulating glass units (IGUs) have R-values that approach ten—frame R-values significantly alter the overall efficiency of the window.

Frames made of either vinyl or fiberglass have R-values in the area of 3 per inch, more if insulation such as urethane is used on their interiors.

Accordingly:

- Improving the R-value of frames is highly important. (In particular, improving the R-value of a substantial portion of the fixed part of the frame of an older double hung window--like the counter weight box--can be very effective in lowering energy waste.)
- Raising the glazing-to-frame ratio of any window system whose frames have an R-value of one or less makes good sense.

- Investing in high R-value IGUs is increasingly cost effective when frame portions of the window become smaller and frame R-values higher.
- Retrofit storm windows with high R-value glazing are increasingly cost effective when frames are relatively small and have good R-values.

Modeling the case of an efficient IGU with fiberglass frames used with the existing double hung windows showed improvements in energy performance over the double-hung alone of 96%.

Final conclusions

Adding an efficient IGU to windows, in combination with air sealing and insulating the existing window and its weight pockets yields good energy savings. However, if a wooden frame dominates a window, the only practical option to achieve excellent savings while retaining the historic window is to install an energy-efficient storm window.

Adding storm windows has aesthetic advantages as well as significant thermal ones. Even with a wooden frame (whose proportions were modest while being consistent with traditional historic aesthetics), performance was well more than four times that of the original window. Switching to an energy-efficient fiberglass frame would improve the performance a great deal, probably raising the overall efficiency of the window system by a factor of six or more over a single-glazed wooden window. It is possible to fabricate fiberglass frames that appear to be virtually identical to wooden frames. Such a storm window could be manufactured at a lower cost than a wooden storm window. It would also achieve better comfort, longer life, and greater energy savings.

As far as we know, this type of frame for storm windows is not currently commercially available; however, a mass-produced, semi-custom fiberglass frame solution may find strong commercial demand among both historic homeowners and others. Analysis suggests that ten square feet or larger storm windows with fiberglass frames could be sold in bulk quantities (20 or more) for a price ranging from $14 to $18 per square foot. In the seven cities analyzed, such a system would have about the same payback period as installing a lower-end vinyl replacement window.

In general, improvements in U-factors result in lower SHGCs. Sometimes this is desirable, particularly in cooling-dominated climates and on west and east elevations. When designing appropriate storm windows for historic buildings, matching U-values and SHGC to facades is quite important. In Boulder and other climates with good sunlight for much of the year but also substantial heating loads, ensuring high SHGCs for south-facing window systems that are not substantially shaded by trees or neighbors is much more important to a home's overall wintertime energy performance than is achieving the lowest possible U-factors.

The most important conclusion flowing from this research is that it is possible to improve the overall energy performance of existing window systems by well over four fold through repairs and sealing plus the installation of an excellent storm window without altering their historic character. This strategy also protects the original window and gives it new life and functionality. In many cases, old windows can be saved while raising the overall efficiency of a home, improving its comfort, and retaining its aesthetic charm.

When combined with appropriate insulation and high-quality air sealing (of envelopes as well as duct systems), using window systems such as these would open the way to improvements of 60% to 80% over historic buildings that are leaky, have little insulation, and are equipped with wood-framed, single-glazed windows.

1. INTRODUCTION

This report summarizes the results of a research project aimed at gaining a better understanding of the efficiency implications associated with the application of practical techniques for improving the energy performance of window systems commonly found in historic homes in Colorado and in other states. The study evaluated the energy-related effects of various efficiency treatments including reparation, replacement, and supplement (such as storm windows). The work was funded by the Colorado State Historical Fund (SHF), Alpen Energy Group, Phoenix Window Restoration, and the City of Boulder's Community Planning and Sustainability Office. The research was accomplished by an interdisciplinary team representing the Center for ReSource Conservation, the Synertech Systems Corporation, and Phoenix Window Systems. All members of the team contributed substantial labor as well as tools and materials in support of the aims of the project.

Historic windows are widely viewed as key features of historic structures that are essential in retaining a building's historic integrity. Accordingly, restoration versus replacement of historic windows has become a prominent issue in the Rocky Mountain West and throughout the US. Windows can be the source of considerable energy waste and associated discomfort, particularly in older homes which have not benefited from recent advancements in window technology. While replacing inefficient, single-glazed windows can save considerable energy, the benefit of replacing historic windows must be weighed in the light of energy and resource costs and environmental impacts associated with materials use as well as the societal value of historic structures.

Owners of historic homes, local regulatory bodies, and the preservation and conservation communities need unbiased information based on empirical data to help guide historic preservation policy development and energy saving decisions. The driving hypothesis of the team's work is that better decision-making in the historic window area is likely to flow from accurate data representing a range of practical options.

In preparation for the study, the team reviewed existing studies of historic window efficiency treatments conducted over the past 25 years and found only limited evidence of measured data (see Annotated Bibliography, Appendix A). Those that have attempted to measure window performance in existing structures have been unable to overcome the common barrier that makes such a study immensely difficult -- that is measuring heat transfer and air leakage through a window system while accurately accounting for on-site conditions that can skew study results. It is difficult to assign cause and effect associated with a given window (or even a set of them) since many variables unrelated to windows can overwhelm moderate changes in window leakiness, insulating properties, and heat gain or loss. Accordingly, the study team set out to overcome these limitations by using a test chamber to assess window systems in a controlled environment.

The efficiency of a window is the product of multiple factors. The amount of radiation transmitted through a window's glazing, expressed as solar heat gain coefficient; heat transfer, measured n terms of U-factor; and leakiness, or the amount of air passing through the window system all effect the window's energy performance. The visual light that flows through a window, known as visual transmittance, also affects daylighting, which may impact the home's energy use as a whole. Developing practical schemes for measuring these factors in both the field and the laboratory to the degree possible in each was a central aim of this work.

The Study Team theorized that certain retrofit options would enable achieving energy efficiency gains that would nearly match the gains available by replacing window systems with good-quality, commercially-available windows. To test this theory, the study team conducted empirical testing on a range of alternative window efficiency treatments utilizing three distinct testing approaches and calibrating the results to arrive at a reasonable quantitative metric by which efficiency alternatives may be measured against each other and with respect to the option of replacement. Each of these methodologies plays a valuable role in understanding how historic windows perform in a variety of conditions. The methodologies included:

1) Field testing within an historic home. This process began with a thorough energy audit to assess baseline conditions. The study team then applied of a series of efficiency treatments to windows on the north and south side of the home and measured the effects of each on the window's solar heat gain and visual transmittance.

2) Testing within a special chamber designed, fabricated, instrumented, and calibrated specifically for the project. More than 200 tests for heat transfer (U-value) were run in the test chamber with an average length of 26 hours. Scores of tests for air leakage were conducted as well. In addition, a number of infrared scans were conducted to identify areas of conductive and convective losses. Tests for solar heat gain and visual transmittance were also conducted at the window testing facility.

3) Computer modeling. The study team used RESFEN, widely considered to be the best software currently available to analyze residential fenestration systems, to evaluate window performance. RESFEN was developed by Lawrence Berkeley National Laboratory (LBNL) and other national labs; it incorporates weather data from the National Oceanic and Atmospheric Administration (NOAA) to estimate window performance in different climate zones and for hundreds of cities all over the U.S. The use of RESFEN combined with data gathered in the laboratory and field allowed the team to extrapolate energy and economic performance to any location where historic weather data and utility cost information are available.

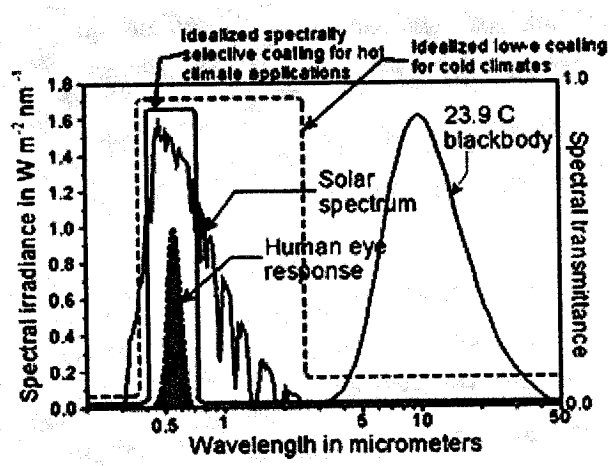
The sections of this report that follow provide details on these methodologies, results of the testing, and analyses undertaken as part of this effort. The study team is hopeful that the results will provide useful data to owners of historic dwellings, preservationists, environmentalists, and local regulators to inform decision-making on energy matters in a variety of historic structures.

2. METHODOLOGY

2.1 Window Energy Performance

Windows transfer energy by radiation, conduction, and convection. Under many conditions, radiation predominates. Our eyes see only a narrow range of wavelengths, slightly less than half of the solar spectrum. Figure 2-1 depicts the irradiance from the sun as a function of wavelength after it has been filtered by passing through the atmosphere. Note that the peak of our eye's sensitivity curve (a wavelength of around 0.6 micrometers which we call yellow) corresponds closely with the peak of the sun's output.

Figure 2-1. Irradiance of the Sun Versus Wavelength



Source: Ross McCluney, Florida Solar Energy Center

2.1.1 Thin Films

Over the last several decades, manufacturers have developed the means to produce windows that selectively filter and reflect different portions of the spectrum. The technique involves depositing very thin layers of metal on a surface of glass or plastic substrate. First generation systems resulted in "low-E" coatings or films that let through most of the sun's shorter wavelength radiation, but reflect longer-wavelength radiation away from room temperature sources (75°F is represented in the figure, with dashed lines illustrating the filtering action of low-E coatings). The result is good window performance in the wintertime since it transmits most of the spectrum of solar radiation yet reflects longer wavelength radiation from objects at room temperature. Newer, second generation window technology can be much more carefully tuned to filter just the wavelengths desired. For example, it is possible to filter only the infrared and ultraviolet portions of the spectrum while allowing most of the visible portions to be transmitted. This "spectrally selective" property is illustrated by the solid line in Figure 2-1. The resulting window performance is much better adapted to warmer climates where cooling concerns are primary. This style of window keeps out a large portion of the radiation that would heat up a room and increase air conditioner use, while allowing unobstructed viewing and substantial daylight to pass through the window.

Under most circumstances, radiation plays a much larger role in window energy transfer than leakage. The effects of radiant heat transfer properties of a window system are expressed as solar heat gain coefficient and visual transmittance.

Solar heat gain coefficient (SHGC) is the fraction of solar heat transmitted through a window system (plus absorbed energy that ends up supplying heat inside) compared to the amount of solar heat that would flow through an unimpeded opening of the same size. SHGC is a dimensionless number that can range between 0 and 1. SHGC's of clear single and double-glazed window systems run from 0.7 to 0.9, whereas windows with spectrally-selective glazing typically run from 0.2 to 0.5.

Visual transmittance (Vt) is the fraction of visible light transmitted through a window system with respect to the amount of visible light that would flow through an unimpeded opening of the same size. It is also a dimensionless number that can range between 0 and 1. The Vt of clear single and double-glazed glass runs from 0.8 to 0.9, whereas heavily-tinted glass can have a Vt of 0.1 or even lower. Double-glazed spectrally-selective glazing typically runs from 0.4 to 0.7 Vt

2.1.2 Conduction and Convection

Windows also lose energy by conduction and convection. Insulation performance in walls and ceilings, for example, is usually given as an R-value, which is a measure of the resistance to heat flow that occurs because of the temperature difference across a wall or window and the thermal characteristics of the material in between them. During cold weather, windows with high insulation values are significantly warmer on the inside surface than are windows with low insulation values. This provides several benefits: moisture from condensation is reduced or eliminated, occupant comfort is increased, thermostat set-points can be lowered, the home's heating system may be downsized, and costs for space conditioning are reduced. During the summer, well-insulated windows (particularly those that also have low SHGCs) are more comfortable when outside air temperatures exceed indoor air temperatures thereby allowing for higher thermostat set points and downsizing of the cooling system.

The conductivity of a window system is measured in terms of its **U-factor**. Under most circumstances, a lower U-factor equates to higher efficiency. The U-factor is the reciprocal of R-value and is the rate of heat loss through a window *system* (which includes its frame) measured in Btu per hour per square foot, per degree Fahrenheit (Btu/h-ft^2-°F). **U-value** is measured in the same units, but refers to the conductivity through the center of glass only. Unlike the ratings for insulation products and other building sections, window U-factors and U-values include the insulating effects of indoor and outdoor films.

Glass itself is a fairly good conductor (a bad insulator), so its U-factor is quite high and R-value is low. The R-value of a single-glazed window system is a product of the still air layer immediately next to the pane on the inside and the not-so-still air on the outside. (R-values of 0.68 for inside surfaces and 0.15 for outside surfaces are frequently attributed to air films.)

Adding more layers of glazing (or suspended film) adds more still air spaces. Substituting an inert gas for air lowers the U-factor of the space even more. In general, tactics that lower U-values in insulating glass units lower SHGC as well. This tends to be good news during summer months on all facades of a building, but not-so-good-news during winter months, particularly for south-facing facades, because passive solar gain is attenuated.

2.1.3 IGUs

Insulated glass units (IGUs) have multiple glazings (lites) and sometimes films, either suspended between other elements or adhered to them. They frequently include an inert gas that enhances R-value. Of important energy consequence, they use spacers around their edges to hold the IGU together and to ensure that the spacing between elements is maintained evenly. Generally, spacer material is made of thin, roll-formed metal that is strong enough to ensure good mechanical properties yet small enough to keep edge-of-glass conductive losses relatively low. However, as IGU techniques in achieving high center-of-glass R-values improve (R-values of over 10 are now achievable), edge-of-glass losses represent an increasing portion of overall losses through IGUs. Since spacers tend to be the same size for IGUs of all sizes, **edge losses are substantially more pronounced for smaller IGUs than for larger ones**. Not surprisingly, the industry is working to develop edge materials that have lower conductive losses with excellent strength. The problem is complicated by the fact that coefficients of linear expansion with temperature of glass tend to be much lower than expansion coefficients of plastics and other materials of low conductivity, thereby increasing the risk of IGU leakage under conditions of large temperature swings.

Historic windows usually include three properties that contribute to inefficiency: counter weights, wood frames, and single glazing.

2.1.4 Counter Weights

Unlike newer windows, older double-hung window systems routinely use counter weights to aid opening and closing the window. Counter weights are heavy solid iron castings attached to ropes that run through pulleys then attach to the edges of window frames. These weights slide up and down in uninsulated vertical boxes on each side of the window. The result is counter-balancing forces that aid in opening the windows and holding them open to the degree desired. The counter-weight boxes constitute a large portion of the fixed part of the window frames. A combination of visual inspection, blower door testing, and infrared scans reveal that these boxes are frequently the source of substantial convective and conductive energy losses in both summer and (especially) winter.

Figure 2-2. Counterweights common to many historic window systems

2.1.5 Wood Frames and Single-glazing

Frames are typically made of wood; glazing is typically single. An inch of dry white pine has an R-value of one (1/Btu/ft2/F). The R-value of single glazing is approximately the same due primarily to a dead air space close to the surface on the inside whose R-value is 0.68 and an air space on the outside that varies with wind speed. Accordingly, **when both the frame and glazing have roughly the same R-value** (in the case of older single-glazed windows with wood frames), **conductive losses do not change much with the ratio of the cross sectional area of glazing to frame**.

Older double hung windows with counter-weight boxes can have fixed plus moveable frames with about the same cross section area as the glazing. In such a case, if the single glazing is replaced by, for example, a double glazed IGU with low-E hard coat with a U-value of 0.36 (R =

2.8), the overall window system is improved from R-1 to only 1.46. Indeed, if an R-10 IGU is combined with an R1 frame whose area is half of the window system, improvement to the system is from R-1 to only R-1.8. In such cases, frames constitute thermal short circuits – a potent cause of inefficiency in windows.

2.2 Data Gathering

To assess and quantify energy and heat loss through window systems, the study team determined five testing parameters:

Window size, framing and glazing individually and their sum. This measurement was accomplished in both the field and the lab using a tape measure.

Visual transmittance (Vt). This measurement was accomplished in both the field and the lab using a digital light meter. Visual transmittance is not used in calculations of thermal energy performance but is important for daylighting and related considerations.

Solar Heat Gain Coefficient (SHGC). This measurement was accomplished in both field and the lab using a pyranometer with modeled corrections to account for gains associated with net heat transfer through frames. Local shading factors were also estimated in the case of field measurements.

Heat transfer coefficient of the window system, including frame (U-factor). This measurement was accomplished in the lab only.

Leakiness or air flow in cubic feet per minute. This was measured (a) in the field using a blower door to test individual rooms containing single sample windows and (b) in the lab using a factory-calibrated duct blaster.

2.2.1 Treatments Tested

Using these measured parameters as inputs into RESFEN software, the team estimated the seasonal energy performance of common and innovative options to restore or increase the efficiency of historic wood windows, including:

1. Adding removable films to windows such as those commonly found at home improvement stores and can be applied easily by a homeowner using scissors and a squeegee.

2. Installing aluminum-framed exterior storm windows. Such storm windows have been in widespread use for many decades. While the design and manufacture of these types of storm windows have evolved and improved over time, the study team evaluated an older type of triple-track storm window that had been in use at the field study home.

3. Repairing and air sealing historic wood-framed windows using state-of-the art historic window restoration techniques. This work was performed by the team of Phoenix Window Restoration on the six historic windows selected for the study. The Phoenix team's work included silicone compression bulb weather-stripping on the horizontal rails, felt pile weather-stripping on the vertical parting bead and both interior and exterior sash stops, and sealing and insulating open window frame pockets using a methodology that involves replacing the rope and pulley systems with a hidden spring and stuffing the box with fiberglass insulation. Replacement of counterweight systems with spring systems should not be undertaken in properties listed in the National Register of Historic Places

as this technique does not comply with the Secretary of the Interior's Standards for the Treatment of Historic Properties. An alternative approach to sealing and insulating counterweight pockets, which does comply with the Standard, was also performed in the home (described below and with greater detail in Appendix D of this report).

4. Replacing single glazing with an insulating glass unit containing a low emissivity surface and krypton gas in an existing historic wooden sash. All original glass, wood sash and wood frames were maintained in the test home, with the exception of one window on the south elevation.[3] This window received the same weatherization treatment as described above; however, the single pane glass was replaced with an insulated Low E IGU.

5. Sealing and insulating open window frame pockets using a methodology that retains the use of original weight and pulley systems. As mentioned, counterweights in open pockets can be a potent source of air leakage and conductive losses. The study team used a novel technique to insulate and air seal counterweight pockets while retaining their original functionality and the appearance of the window. The technique involves taking out the sashes and opening the pocket, then enclosing the counter weights in thin wall PVC pipe, whose inside diameter is slightly greater than the outside diameter of the counter weights. Next, after blocking off the top and bottom of each PVC pipe, urethane insulation/sealant is applied to the back of the pocket, the PVC tube is nested in the freshly applied urethane, and more urethane is sprayed on top and secured in the pocket. This technique is described more fully in Appendix D.

6. Installing custom-made, wood-framed, historically-appropriate exterior storm windows. It was reasoned that well-designed storm windows could extend the lifetime of the original windows by protecting them from weather while upgrading the efficiency and comfort of the resulting fenestration system. These exterior energy-efficient storm windows were custom designed and built specifically for the study. They may be used in conjunction with original windows, whether repaired or not. A key consideration was the importance of largely emulating the appearance of the less-efficient storm windows of yesteryear while nonetheless achieving good energy performance and long life.

7. Installing new windows. Fiberglass and vinyl frames are both becoming more widespread than wood or aluminum in new windows. Of the two, fiberglass is much longer lasting and has a lower coefficient of linear expansion than does vinyl. However it is somewhat more expensive. The manufacture of vinyl also entails additional adverse environmental consequences. Both have R-values of around 3. When laced with urethanes or other high-quality insulators, frame R-values can be improved somewhat from R-3, though how much was not explored under this project. The study team removed two historic windows from the study home temporarily and replaced one with a typical double-paned, low-E window of the same size and design.[4]

   This allowed the team to 1) test the efficiency of the new window in the field using the same field testing techniques used for other applications and 2) test the efficiency of the

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[3] This glazing of this window was not original to the home and therefore was selected for field testing the application of new glass in the existing frame.

[4] Jeld Wen window. National Fenestration Rating Council certified: U-factor .34; SHGC 0.36 and a visual transmittance 0.60

removed historic windows in the test chamber. Following these tests, the original historic window was replaced in the home.

The team tested each of the energy efficiency treatments to the extent practical in a test home and in the laboratory chamber. Then, using RESFEN Software, the team was able to predict each treatment's energy performance at any orientation (north, east, south and west) at any location for which historic weather data is available. Results of this analysis for Atlanta, Anchorage, Denver, Boston, Minneapolis, Sacramento, and Phoenix are included in Section 4.

Testing techniques are described in more detail below.

2.2.2 Field Testing Procedures

The team examined several historic homes and interviewed homeowners in Boulder, Colorado before identifying an appropriate home for the study. It is a charming 2700 square foot brick home built in 1902. The home has many original single-glazed windows, most covered by triple-track aluminum storm windows. It is heated by a wood stove in a chimney plus a natural gas-fired boiler that provides hot water to conventional radiators. Since heating energy from the boiler is circulated through pipes, the only duct work of consequence provides supply air from a roof-mounted evaporative cooler that pushes cooled air through the home towards partially-open windows.

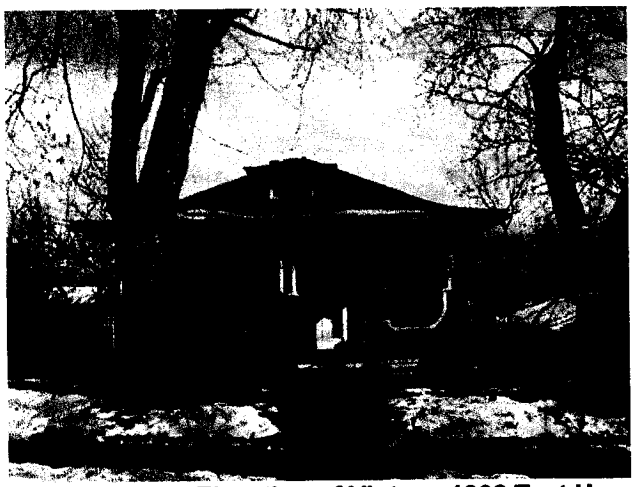

Figure 2-3. West Elevation of Vintage 1902 Test Home

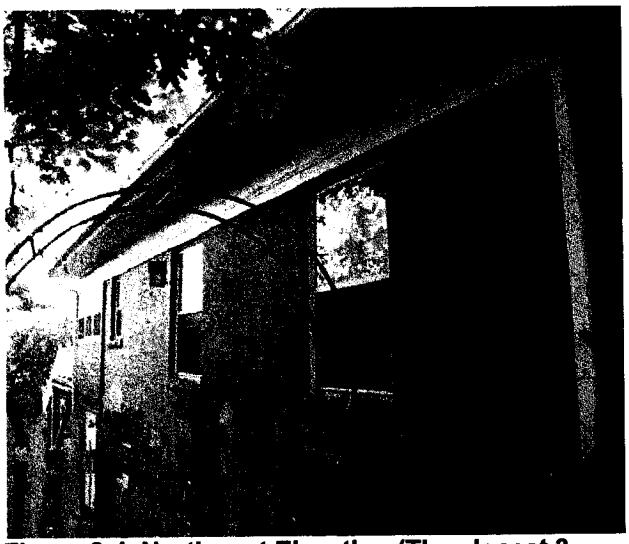

Figure 2-4. Northwest Elevation (The closest 3 windows were chosen for retrofit)

Figure 2-5. Sample window on south elevation

The study team identified three window systems on the north and three on the south of the home to be studied (see Figures 2-4 and 2-5). The three windows of interest on the south side of the home are each associated with single rooms. The team was able to largely isolate two of these from the rest of the dwelling for testing (the third cannot be fully isolated from a foyer in the front of the home).

The windows on the north are part of large open areas that cannot be isolated from the rest of the dwelling; however, with the blower door depressurizing the home in the post-retrofit period, no leakage whatever was felt from these windows. Since these are in all practical aspects identical to the windows that were tested in the lab—same construction, materials, size, etc—and were treated to the same comprehensive retrofit procedures, it's likely that their energy-related parameters are within several percent of those of the windows that were tested.

An energy audit of the home was conducted to gather and document baseline conditions and to explore any variables that would likely impact the study (see Appendix C). Overall convective losses were quantified using a blower door and the windows were evaluated to assess their circumstances and identify repairs needed.

After taking measurements for both SHGC and Vt to assess the performance of the windows systems, a blower door was set up in the doorways associated with each of the three windows on the south side and the main doorways of the home were opened. The study team used a Model 3 Minneapolis Blower Door produced by the Energy Conservatory. This is the most widely-used instrument in the industry; tens of thousands are in use to assess the leakiness of buildings and measure the degree of success achieved in air sealing. In this project, the team took measurements of the whole house and in the three rooms housing the test windows before and after window retrofits were installed.

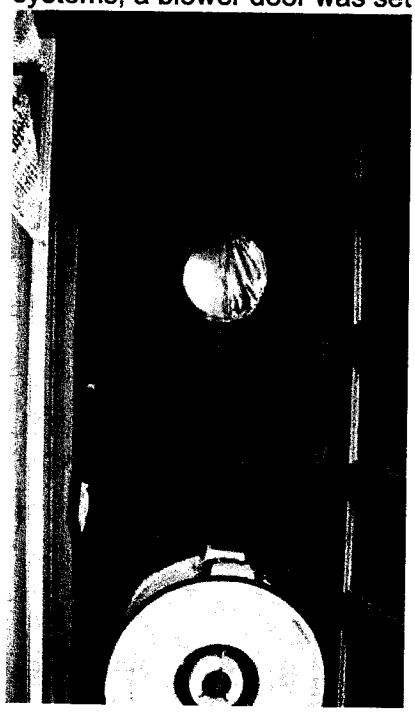

Figure 2-6. Blower Door Installed in Bathroom Doorway

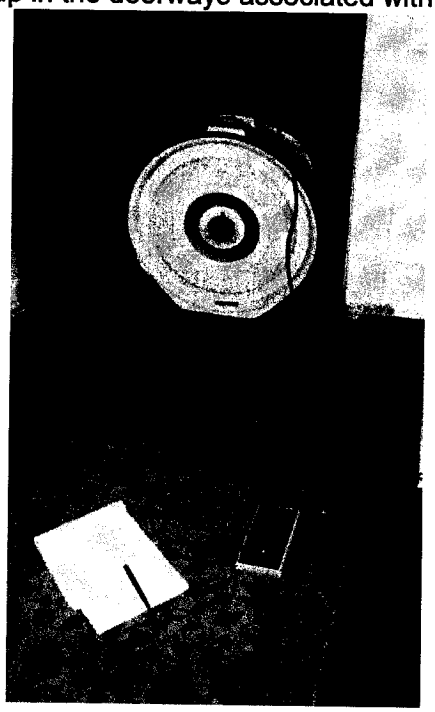

Figure 2-7. Blower Door Installed in Bedroom
(Speed control on floor on right; digital manometer in center)

A blower door consists of a calibrated, variable-speed fan mounted in a shroud that is tightly fitted into a doorway. Running the fan depressurizes the home, allowing a technician to readily find leakage areas with the back of a hand or by observing the movement of artificial smoke. Those skilled in the craft of weatherization use blower doors not only to find leakage areas, but also to estimate the degree to which subsequent air sealing work has been effective. Photos of the blower door installed in interior doorways are shown in Figures 2-6 and 2-7.

Since the areas associated with the study windows were small, a low-flow plate was employed on the blower door to maximize its sensitivity to small flow rates. The result was a measure of all leakage areas in the depressurized room, those associated with the window, plus all others. A second test taken after installing air sealing measures on the window should in principle, reveal changes due only to air sealing the window. Thus, although it is not possible to ascertain ***absolute*** leakage associated with the window work by this field method, the study team was able to measure the value of the ***change*** in air leakage due to retrofit work.

As discussed in Section 2.2.3, the study team employed a similar method for determining leakage in the test chamber using a calibrated duct blaster. An important difference is that ***absolute*** leakage can be more precisely estimated with the chamber technique because the chamber itself is extremely tight.

The study team identified insulation voids associated with the counterweight pockets surrounding the window frames as significant leakage areas; we explored these using the blower door to identify major air leaks and a single-axis infrared sensor to explore conductive losses. The primary aim of these measurements was to identify the *in-situ* thermal losses of the windows and their frames. This baseline data provided the basis for comparison to similar measurements taken post-retrofit to quantify savings.

2.2.3 Laboratory Testing Procedures

The study team designed and constructed a super-insulated, tightly-sealed 390 cubic foot test cell using six inch thick, urethane-based structurally insulated panels (SIPs) on all six sides. It is capable of testing window system samples of up to 20 cubic feet. The cell is heated with electric resistance radiant panels, controlled to maintain a constant warm temperature within a tenth of a degree F (e.g., 122°F). The test cell can be rolled into and out of a cold chamber built into the inside corner of a building. The cold chamber, which is insulated with 2 inches of polyisocyanurate and 3.5 inches of fiberglass (R-22), is accessed through a 280-pound door, weather sealed and insulated to R-25. The door opens and closes by means of a winch and pulley system suspended from steel roof rafters. The chamber is cooled by a modified room air conditioner to approximately 52F, thereby exposing fenestration samples to a temperature difference of 70 F. Figures 2-8 and 2-9 show the test cell and chamber during construction.

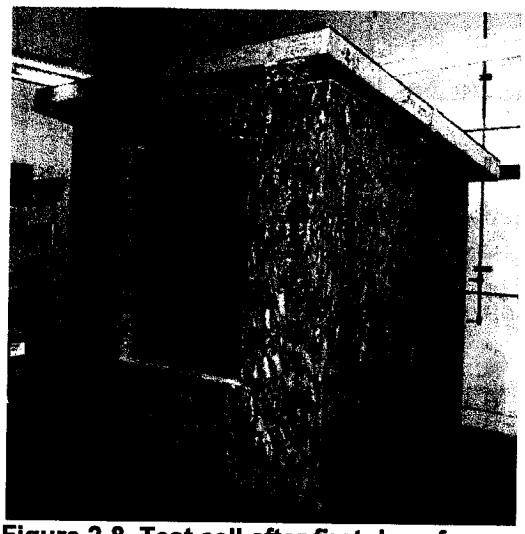

Figure 2-8. Test cell after first day of assembly

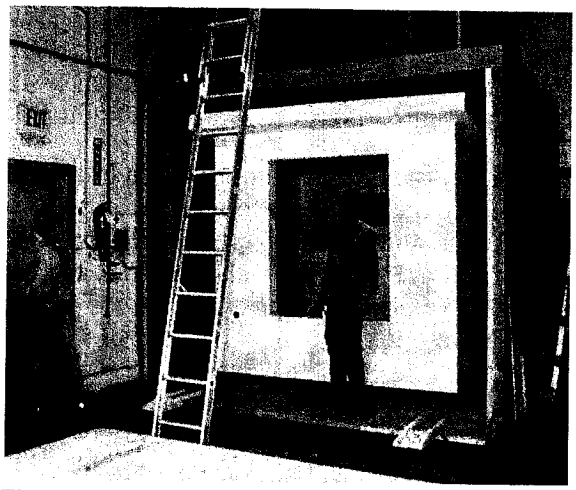

Figure 2-9. Completed test cell; outer chamber work nearing completion

The testing laboratory includes a controller designed and built by the project team (see Figure 2-10). The controller employs a WNB Series WattNode electric energy meter manufactured by Continental Control Systems, which produces pulses whose count per unit time is proportional to true watt hours used by the heaters in the chamber. It is calibrated to produce 53,333 pulses per kWh, 0.01875 watt hours per pulse. The electronics also measure temperature and control heaters in the test cell using an Omega Model CNi32 Temperature and Process Controller.

This industrial thermostat is used to operate a relay, which controls a pair of infrared heaters on either side of the test cell that can radiate up to 800 watts if needed, although a phase controller set at approximately 500 watts produces adequate heating for most fenestration system testing. The thermostat is set to have a zero dead band and upon reaching steady state routinely keeps the chamber to within a tenth of a degree F. A pair of EZ-8 data loggers manufactured by Simplified, Inc. is used to monitor eight temperature sensors inside and outside the test cell. These are sampled hundreds of times per minute and produce a time series data record that includes the average temperature of each sensor in the prior minute and the total watt hours of electrical energy used in the previous minute. As a check, the data loggers also record the number of times the heaters were actuated in the previous minute, and the duration of their "on" time.

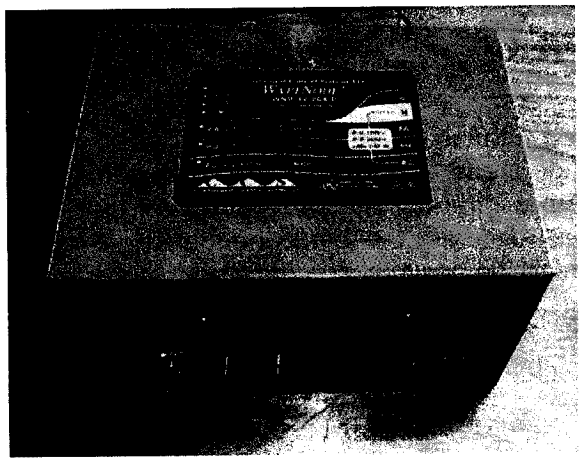

Figure 2-10. Controller, top view

Appendix B discusses the fabrication of the test chamber in more detail.

2.2.3.1 Determining Heat Transfer Coefficients

The heat transfer coefficient of the test cell as a whole (U-factor) is given by $U = Q/A\Delta T$, where U is in units of Btu/hour*ft2*F, Q is the quantity of energy in Btu/hour, A is the area of the chamber in square feet, and ΔT is the inside/outside temperature difference in degrees F. Electric energy used by the heater is gathered in watt hours by the data logger and converted to Btu at the rate of 3.412 Btu/watt hour. The area A is measured with a tape measure. ΔT is the average indoor air temperature differences over a measured time interval, less the average outdoor temperature differences over the same interval.

The team calibrated temperature sensors before setting up the chamber and periodically during its operation using an ice bath in a thermos bottle. Once a window is installed in the test cell, a plug made of the same material as the chamber is installed in the test sample space and is thoroughly sealed. Figure 2-11 shows the test cell with a window and plug installed; the plug is shown in blue. Finally, the doors are closed, the inner chamber is heated and the outer chamber is cooled prior to beginning a calibration run.

Typical calibration runs were conducted for 48 hours. The study team used a spread sheet to display and analyze one-minute data from the data loggers. The spreadsheet also calculates the U-value at the end of each 60 minute interval throughout the test. The analyst looks at the data after a run and notes when temperatures approach steady state and energy use is close to constant. This can take up to 12 hours since all of the mass associated with the chambers must come to temperature. Even if the chamber is already at steady state, the analyst routinely

discards the first and last hour's U-value calculation, then takes an average of the remaining computations for U-value and calculates the standard deviation of the distribution. Three to four decimal place repetitions in standard deviations are frequently achieved by this method and U-values for a given sample run are routinely within one percent of results achieved in subsequent runs. Particularly when a given sample being tested is subjected to retrofit, then tested again, such repetition gives confidence that ***changes*** in U-values by virtue of the retrofit can be determined with good accuracy.

The chamber is calibrated with a given plug via three runs of 24 to 48 hours each, which results in the overall U-value of the chamber with the particular plug installed. (The difference between the U-value of one plug and another is typically less than one percent.) A given plug is then used to "house" window samples, beginning with smaller window samples if practical. Under this circumstance, the energy required to maintain the chamber at a given delta T is the sum of (1) the known U-value of the chamber times the area of the chamber minus that of the sample and (2) the unknown U-value of the window sample times its area. Thus determining the U-value of the sample involves measuring its area carefully and ensuring it is completely sealed to the plug, then making another chamber run to gather temperature and energy consumption information.

Figure 2-11. Test cell configured to test small double hung window

2.2.3.2 Measuring Leakiness

The chamber was built to be extremely tight (see Appendix B), so leakage is very close to zero. The test cell has one access door (itself carefully weather-stripped and insulated to R-35) and the aforementioned 20 square foot opening for testing windows into which calibration plugs or plugs with sample windows are inserted. Two additional holes accommodate leakage testing (both of which are insulated with tight-fitting plugs of 7 inches of urethane and air sealed when not conducting leakage tests). Leakiness was measured using a custom-calibrated the duct blaster and two digital pressure gauges from the Energy Conservatory. One 12 inch diameter hole accommodates the duct blaster and allows for precise leakage measurement. The other hole is used to introduce leakage air of a known area (3.14 square inches) via a 2 inch diameter hole. This allows the fan to operate in the "sweet area" of its calibration curve to maximize accuracy.

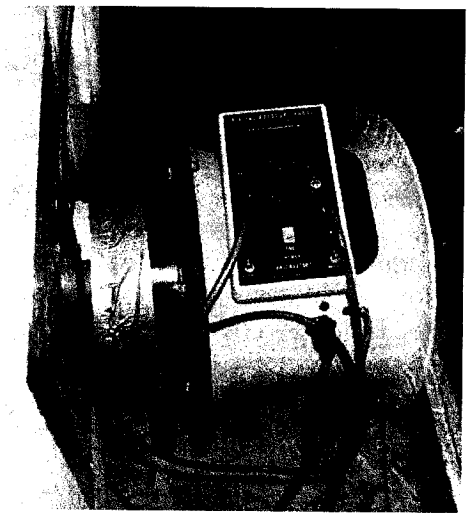

Figure 2-12. Duct blaster with manometer

When a sample window is installed, the duct blaster is used to pressurize the chamber, taking data points of inside/outside chamber pressure difference versus fan flow. In addition, the technician uses his hand to feel for leaks associated with fenestration system being tested. Then he depressurizes the chamber, again taking data. An analyst examines this data to quantify effective leakage area (ELA) using TECTITE 3.2 software by the Energy Conservatory, and then subtracts the measured leakage areas of the calibration hole and chamber as a whole with a calibration plug in place. The result is ELA in square inches of the sample window system under test. Figure 2-15 shows a screen shot of a plot of flow versus pressure difference.

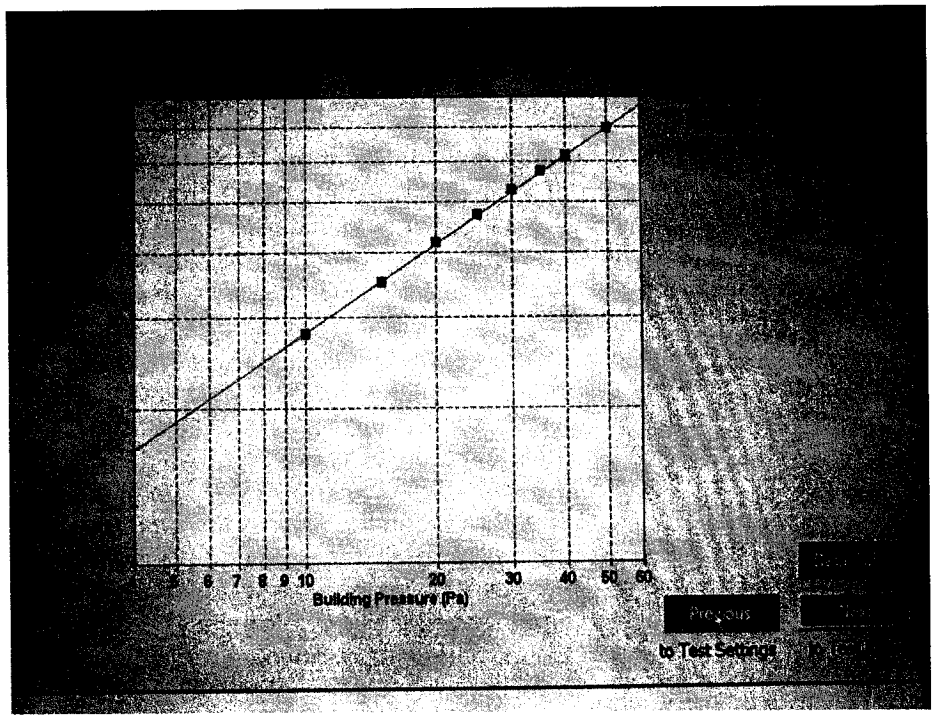

Figure 2-13. Screen shot of eight data points of leakage flow versus pressure difference.

As a final check before finalizing the analyses for this report, the team put a second calibration hole of 3.76 square inches into the chamber, then installed a new plug in the window-testing area and sealed the chamber tight, employing the same techniques used throughout the project. We then used the duct blaster to pressurize the chamber to 50 pascals to check for any leakage. Finally, we took a series of tests at five-pascal pressure increments while measuring flow to estimate the ELA of the chamber under conditions of different hole areas.

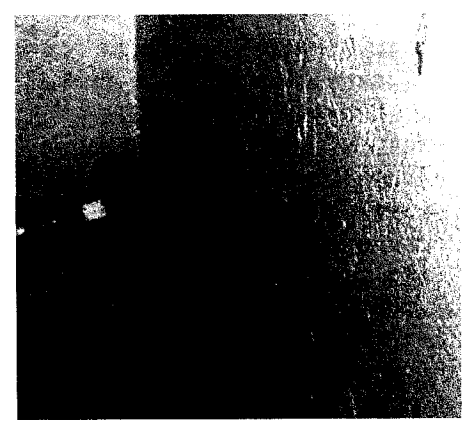

Figure 2-14. Drilling second calibration hole

The deviation of data points from the regression line is expressed by a correlation coefficient, where perfect agreement results in a correlation coefficient of 1. All of the data taken to produce the calculations resulting in Table 2-1 had correlation coefficients of greater than 0.999. Table 2-1 shows results of the tests.

2-1. Calculations of Effective Leakage Area

Mode	Physical hole size (in2)	Duct blaster measurement ELA (in2)	Difference (in2)	Difference (%)	Equivalent CFM@ 50 PA
Pressurizing	3.14	3.50	0.36	-11.4%	55
Pressurizing	5.02	4.80	-0.22	4.4%	73
Pressurizing	6.90	6.70	-0.20	2.9%	97
Average			0.0	-1.4%	
Depressurizing	3.14	4.90	1.76	-56.0%	71
Depressurizing	5.02	6.10	1.08	-21.5%	88
Depressurizing	6.90	7.70	0.80	-11.6%	110
Average			1.21	-29.7%	

Note that in pressurizing the chamber, the calculations of effective leakage area are remarkably close to the actual leakage area measured with a ruler, the difference being an average of 1.4 percent. This strongly suggests that: (1) the chamber is indeed quite tight, and (2) computations of ELA when pressurizing the chamber are close to the physical hole cross sectional areas. Accordingly, when testing a fenestration system with only the left calibration hole open, the technique of simply subtracting its actual area from the ELA as measured by the duct blaster when pressurizing the chamber appears sound.

When depressurizing, the difference between actual hole size and ELA is greater, particularly when calibration hole sizes are smaller. Given the accuracy of measured the data, it is possible to develop a calibration curve that produces a correction factor for measuring ELA when depressurizing. However, given both the absence of a clear physical explanation for deviations in the depressurized chamber and the excellence of results from pressurization, we elected to rely on pressurization tests for estimating leakage of the fenestration systems tested on this project.

2.2.3.3 Measuring Solar Heat Gain Coefficient

SHGC is the fraction of solar radiation admitted through a window that is directly transmitted and absorbed, and subsequently released inward. In this project, the team used a factory calibrated LICOR LI200S pyranometer and Keithley 485 digital picoammeter to take readings. The portion of SHGC directly transmitted is measured with a pyranometer that is responsive to the solar spectrum, both visible and invisible. A series of measurements is taken first with the pyranometer looking at the sky directly, then with the pyranometer looking at the sky through the glazing of the window being tested. The resulting ratio, a dimensionless number between 0 and 1, is multiplied by the glazing area portion of the whole window, including its frame. Then a factor is added that represents the portion of solar energy absorbed by the glazing and frame and subsequently released inward. By measuring SHGC and the size of the window, and using solar radiation data throughout a typical meteorological year, it is possible to determine the amount of radiant heat provided to a building through its windows.

2.2.3.4 Measuring Visual Transmittance

Vt is the fraction of visible radiation admitted through a window. The portion of visible light directly transmitted is measured with a digital light meter responsive to the visual specturm. In

this project, the team used a United Detector 351 digital light meter. A series of measurements is taken first with the light meter looking at the sky directly, then with the light meter looking at the sky through the glazing of the window being tested. The resulting ratio, a dimensionless number between 0 and 1, is multiplied by the glazing area portion of the whole window, including its frame. Visual transmittance is useful in estimating the daylighting performance of fenestration systems, but in the current project, no analytical use was made of the measurements.

2.2.4 Computer Modeling Procedures

Computer modeling is routinely used to evaluate window performance, particularly for new units. Most modeling techniques flow from engineering principles described in the Fenestration chapter of the *ASHRAE Handbook of Fundamentals*. This handbook was written by members of the American Society of Heating, Refrigeration, and Air Conditioning Engineers and is revised every four years.

Most window modeling software incorporates historic weather data available from NOAA to estimate window performance in different climate zones. Other parametric data for modeling comes both from the ASHRAE Handbook and its extensive library of technical literature, as well as national laboratories, universities, and other laboratories primarily associated with window manufacturers.[5]

The study team used RESFEN (for "Residential Fenestration"), a widely-used energy simulation modeling tool developed by the Lawrence Berkeley National Laboratory with funding the Department of Energy as part of a major performance simulation tool, DOE II. RESFEN is generally considered the most advanced windows simulation and modeling tool available for residential fenestration systems.

The RESFEN model includes historical weather data from over one hundred American cities. It runs a detailed hour-by-hour analysis of the energy flow through windows throughout a typical meteorological year to quantify heating and cooling energy and costs by façade. Key inputs, provided through field and lab testing, include window size, leakage, U-value, and SHGC. The team used RESFEN to predict with good precision the performance of the window systems (1) on the test home in Boulder (using TMY data from Denver, 30 miles distant) and (2) in a sample of cities in other climate zones, including Minneapolis, Anchorage Boston, Atlanta, Phoenix, and Sacramento.

RESFEN stores typical radiant flux and direction of the sun for each hour of the year at a given location. For each hour, this is multiplied times a factor expressive of the angle the sun makes with the window, a factor reflective of the shading on the window, and the SHGC to determine the radiant heat transfer through a window for a season, for example. The sum of radiant gains and conductive losses yields total heat loss/gain for the winter.

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[5] The Windows and Daylighting Group at the Lawrence Berkeley National Laboratory has a number of useful software tools available for free download. These include RESFEN for the analysis of residential fenestration systems and the International Glazing Database (IGDB) which contains spectral data used by other Optics and WINDOW programs. Users may register at **http://windows.lbl.gov/software/registration/register.asp**

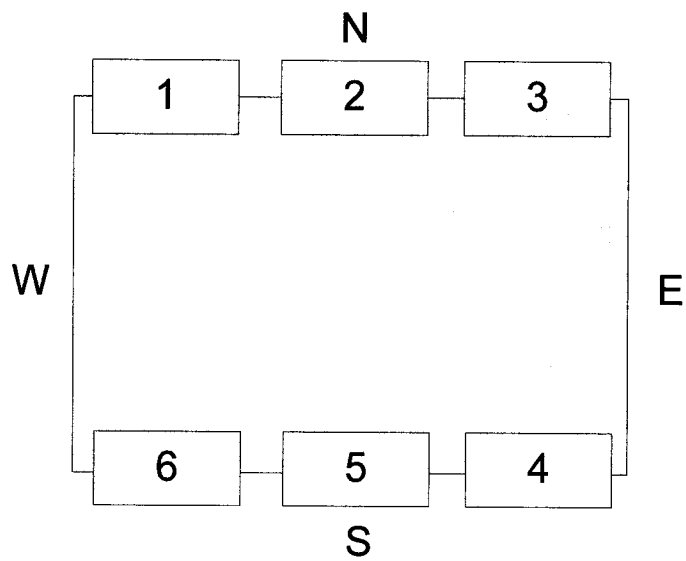
3. TESTING AND RESULTS

3.1 Field Work at Test Home

3.1.1 Initial Window Measurements

Three of the six windows studied in the test home are located on the north side; the other three are on the south. For the purposes of the analysis and reporting, the six windows are numbered clockwise, beginning on the west end of the north side and ending on the west end of the south side, as shown in Figure 3-1.

Figure 3-1. Orientation/numbering of study windows



Information on the test window sizes, SHGCs and Vts is provided in Tables 3-1 through 3-3.

Table 3-1. Window dimensions

Window	Window Height (in)	Window width (in)	Window area (ft2)	Glaz 1 h (in)	Glaz 1 w (in)	Glaz 2 h (in)	Glaz 2 w (in)	Glazed area (ft2)	Portion glazed
1	70.25	44.19	21.56	31.56	39.56	31.50	39.56	17.33	0.80
2	69.81	44.19	21.42	31.56	39.69	31.56	39.56	17.37	0.81
3	46.13	28.25	9.05	19.63	23.63	19.63	23.63	6.44	0.71
4	46.13	28.25	9.05	19.63	23.63	19.63	23.63	6.44	0.71
5	70.25	32.25	15.73	31.75	27.69	31.69	27.69	12.20	0.78
6	70.25	32.25	15.73	31.75	27.75	31.75	27.75	12.24	0.78

Note: Glazing 1 refers to upper and Glazing 2 refers to lower lite height and width

Table 3-2. Solar Heat Gain Coefficients

Window	Window alone		Storm alone		Screen alone		Window with Storm & Screen	
	Raw SHGC	Net SHGC	Raw SHGC	Net SHGC	Raw SHGC	Net SHGC	Raw SHGC	Net SHGC
1	0.81	0.73	0.884	0.92	0.62	0.64	0.58	0.55
2	0.81	0.74	0.884	0.92	0.62	0.64	0.58	0.56
3	0.81	0.68	0.884	0.96	0.62	0.64	0.58	0.53
4	0.81	0.68	0.884	0.96	0.62	0.64	0.58	0.53
5	0.81	0.73	0.884	0.98	0.62	0.64	0.58	0.58
6	0.81	0.73	0.884	0.98	0.62	0.64	0.58	0.58

Note: Raw SHGC refers to the fraction of solar heat transmitted through the center of a window immediately before any absorption or transfer takes place. Net SHGC includes absorbed energy that supplies heat inside.

Table 3-3. Visual Transmittance

Window	Window alone		Storm alone		Screen alone		Window with Storm & Screen	
	Raw Vt	Net Vt	Raw Vt	Net Vt	Raw Vt	Net Vt	Raw Vt	Net Vt
1	0.84	0.67	0.91	0.84	0.66	0.62	0.63	0.46
2	0.84	0.68	0.91	0.84	0.66	0.62	0.63	0.46
3	0.84	0.60	0.91	0.84	0.66	0.62	0.63	0.40
4	0.84	0.60	0.91	0.84	0.66	0.62	0.63	0.40
5	0.84	0.66	0.91	0.84	0.66	0.62	0.63	0.44
6	0.84	0.66	0.91	0.84	0.66	0.62	0.63	0.44

Note that the size and characteristics of windows 1 and 2, 3 and 4, and 5 and 6 are almost identical. These pairings facilitate measurements.

Second, all of the primary windows on the home appeared to be original as deduced by style of construction and (especially), the presence of wavy single glazing (save for Window 5). However they also had triple-track aluminum storm windows installed, whose glazing lites and screens could be moved up and down. Of course, the screen has a deleterious effect on both visual transmittance and SHGC, but it never covers more than half of the window. That fact was taken into account in calculating estimates of net SHGC and net Vt when all three elements are in place.

3.1 Window Retrofit

Following the audit, a team of craftsmen from Phoenix Window Restoration repaired the home's windows. Each of the energy efficiency treatments noted above were then applied to windows on the north and south elevations of the home, isolated from external influences to the extent

possible and new measurements were taken to quantify SHGC, Vt, and leakage using the same methodologies[6].

Retrofit work on the home was carefully coordinated so that windows slated to be measured in the chamber could be removed, tested in an "as is" condition in the chamber, then be retrofitted, tested again, and finally returned to the home.

Figure 3-2. Phoenix window's fully-equipped portable shop

Windows 1 through 3 and 5 and 6 each had weights removed from their pockets, the pockets air sealed and insulated, and spring systems installed to retain window functionality and replace counterweights. In addition, all six windows were carefully rebuilt to the extent necessary. This included removing layers of old paint, filling holes and cracks, repriming and sealing wood surfaces, installing new weather stripping, reglazing the windows, preparing fixed surfaces of the frame for the newly-retrofitted windows, and re-installing the windows.

In addition, a new window was designed and installed in the number 4 slot (the small window above the tub in the bathroom was deteriorated beyond repair), and a pair of energy efficient storm windows was installed in the areas formally occupied by triple track aluminum storm windows outside of the recently-repaired primary windows in slots 5 and 6.

Figure 3-2 shows the portable shop used by Phoenix for window retrofit work. Figures 3-3 through 3-7 show a sample of photos of retrofit work at the test home.

Figure 3-3. Starting work

[6] Although the size and characteristics of each of the pairs of windows on the north and south of the home are nearly identical, their in situ conditions differ. The simulations in Section 4, however, envision that the windows that were tested in both the home and the lab were on all four facades of homes exposed to the weather conditions discussed there. When leakage approaches zero, radiant and conductive heat transfer in windows predominate in determining their energy performance, as mentioned in the report.

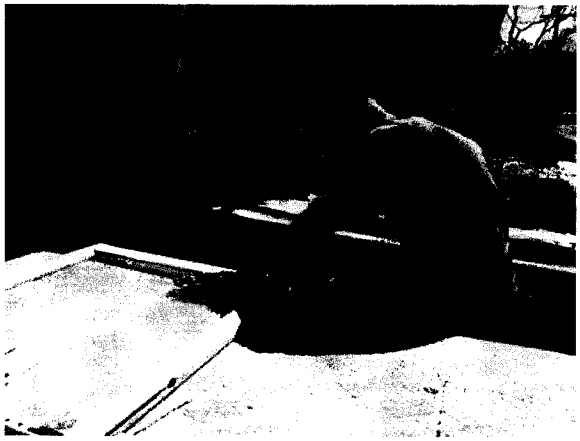


Figure 3-4. Sanding the window

Figure 3-5. Repairing rope system

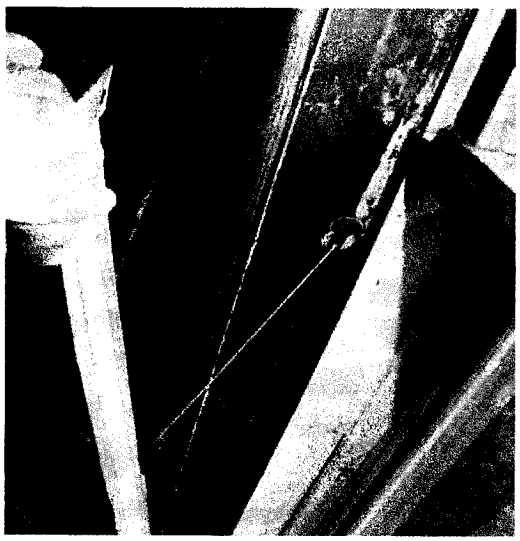


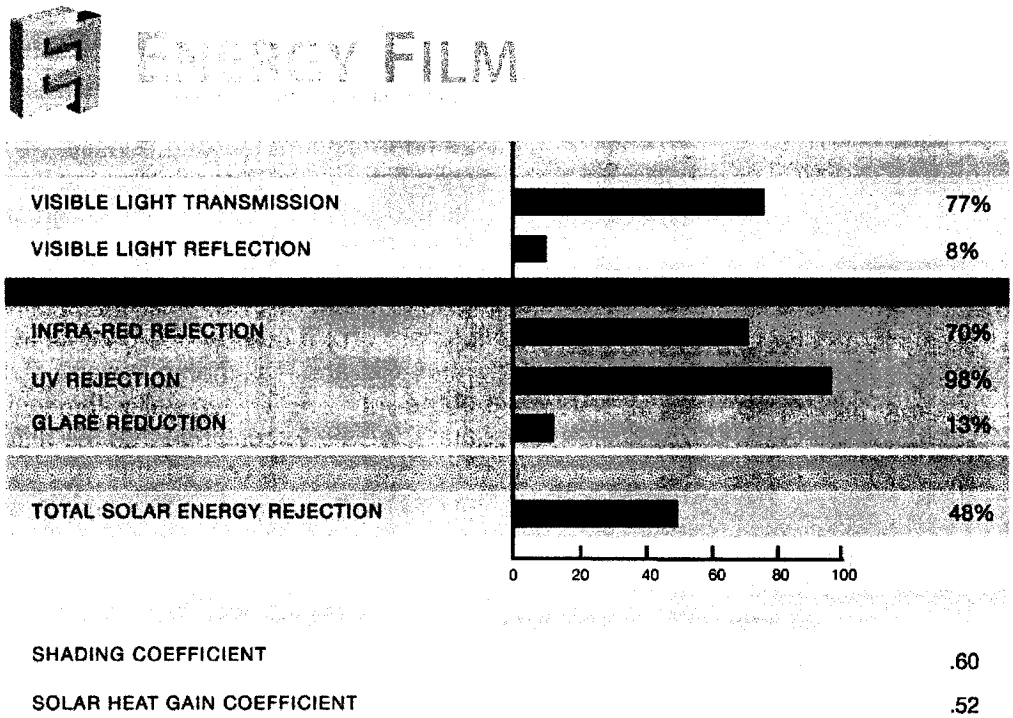
Figure 3-6. Installing spring

Figure 3-7. Retrofit of parting rail with weather strip

3.1.1 Energy Film Testing

Window films, which are adhered to existing glazing as a retrofit measure, are designed to improve window energy performance, enhance comfort, reduce glare, and diminish the fading effects of radiation in the ultraviolet spectrum. Some employ techniques that selectively transmit less of one band of radiant energy than another. For example, *Energy Film* has several products that substantially limit the amount of radiant energy from the sun in both the ultraviolet and infrared regions, while limiting visual transmittance only marginally. Figure 3-8, from *Energy Film's* web site gives information on one of the company's film products.

Figure 3-8. Characteristics of Energy Film



Source: www.energy-film.com

Energy Film's website states that their films improve energy performance in both the summer and the winter.

"Spectrophotometer tests prove in summer, both films block near infrared solar heat wavelengths at the window. This means solar heat rays that normally enter the room and heat its contents are stopped at the window and radiated back outside, reducing air conditioning costs. Laboratory chamber testing indicates in winter, both films allow the room to heat up faster and stay warm longer, reducing winter heating costs."

Figure 3-9. Energy Film installation

The team tested the heat transfer coefficient (U-value) of two types of Energy Film, a clear and a darker version, in relation to the U-value of a clear, single-glazed storm window. First, we installed the single-glazed storm window in the chamber with a wood frame. Its overall size is 15.89 SF and glazing area 12.93 SF, representing 81.4% of the window. We then ran a 24 hour test for U-value.

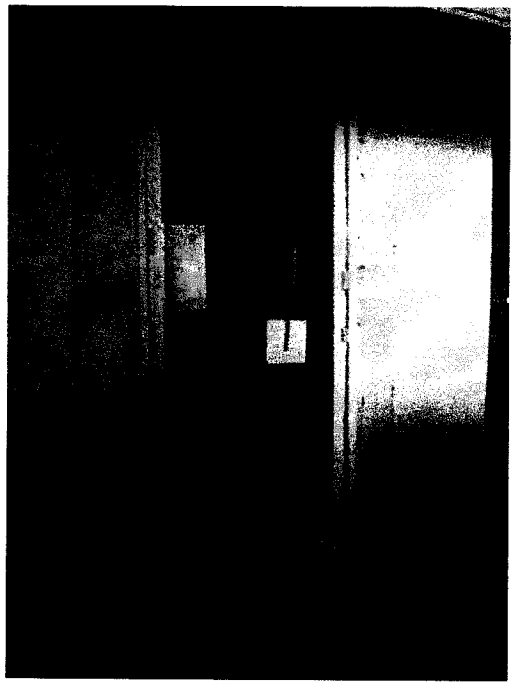


Figure 3-10. View of window with dark film installed from outside the chamber.

Next, we installed the darker film on the inside of the window without disturbing any other aspects of the window's configuration. (As shown in Figure 3-9, installation involves using water with several drops of liquid soap; then a squeegee is used to eliminate bubbles.) We then ran a pair of back-to-back 24 hour tests for U-value. Finally, we removed the darker film (a simple task since the film peels off from the corner), replaced it with the lighter film, and ran a 24 hour test on this film.

As shown in Table 3-4, the differences in measured U-values are only a quarter of a percent in the case of the dark film and less than one percent in the case of the light film. This is well within instrument error and it is safe to conclude that the differences are effectively zero. Of course, this tells us only that the film has no measurable effect on conductive and convective heat transfer as determined by testing in the chamber.

Nonetheless, there is a complex relationship between the actions of the film, the glazing, and the sun that a test of U-values does not reveal. Whenever radiation strikes a surface, some is transmitted, some is absorbed, and some is reflected. When radiation from the sun strikes a single-glazed clear window, almost 90 percent of it is transmitted. The result is that interior surfaces are heated, good news in the winter, not in the summer. A few percent of the sun's radiation is reflected into the exterior world and a few is absorbed by the glazing, raising its temperature. By virtue of this very slight extra heat, the window will radiate a bit more energy in the long IR wavelengths both to the outside and the inside. It will also heat the air by a modest amount on both the inside and outside.

Table 3-4. Results of chamber testing of U-value for three test cases

Description	*Number of test runs*	*Total test hours counted in calcs*	*Standard Deviation of hourly U-value*	*Weighted Average (U-value)*	*Weighted Average (R-value)*	*Increase in U-value from non-film case (%)*
Single glazed storm, wooden frame	1	18	0.00084	0.737	1.36	0.00%
Same single glazed storm, dark film	2	30	0.0008	0.739	1.35	0.27%
Same single glazed storm, clear film	1	14	0.0007	0.744	1.34	0.94%

If a film is mounted directly behind a single-glazed window, it will reflect, absorb and transmit some of the short wave radiation from the sun as well as some of the long wave radiation from the glazing. The energy it absorbs will raise its temperature, heating the air next to it (on both sides) and radiating in the longer wavelengths on both sides. That which goes inward helps during the heating season but not in the cooling season. That which goes outward is mostly transmitted by the single-glazed surface to which it is attached, but some of it is absorbed and thereby raises its temperature.

The sum of all of this is the effective solar heat gain coefficient of the glazing and film. We could not determine this with high accuracy with the instruments available. However, the film tested does not transmit very much radiation (our measurements indicate that approximately 48% is directly transmitted by the glass-plus-clear-film combination and 18% of the glass-plus-dark-film combination). Further, it does not reflect very much energy. Figure 3-8 indicates 8% reflection in the visible, which represents roughly half of all of the solar energy that strikes a surface after passing through the atmosphere. Accordingly, a substantial portion of solar energy is absorbed, particularly by the darker film. Around half of that ends up within the building's conditioned envelope where it tends to lower heating energy costs (though less so than glazing without film) and raise cooling costs (though less so than bare glazing).

We conclude that the retrofit of films is likely to be more cost effective in cooling-dominated climates that elsewhere. However, shading direct solar radiation outside the envelope is likely to be a better choice when practical.

3.1.2 Leakage Measurements

An initial energy audit of the home included depressurizing it to a canonical pressure difference of 50 pascals, approximately 0.2 of an inch of water pressure. This simulates the effect of a wind of about 22 miles per hour blowing on the home from every direction. The home was configured for winter and the blower door was placed in the front door. The flow was 3000 cubic feet per minute at 50 pascals, somewhat leaky for a 2700 square foot brick dwelling. After window work on the six windows in the study, the overall number dropped to 2884 cfm50, an improvement in overall house leakage of 3.9 percent.

Before and after window retrofit measurements were also taken of the three rooms associated with windows 4, 5, and 6 on the south side of the dwelling. Table 3-5 shows results.

Table 3-5. Blower door flow measurements before and after retrofit

Test Room #	*Retrofit*	*Configuration*	*Pressure (Pa)*	*Flow (cfm)*	*Pre-Post (cfm)*	*Heating savings (therms/yr)*
4	pre	storm only	50	427		
4	post	storm only	50	447	-20	
4	pre	primary only	50	421		
4	post	primary only	50	366	55	
4	pre	both	50	410		
4	post	both	50	366	44	3.92
5	pre	storm only	50	589		
5	post	storm only	50	513	76	
5	pre	primary only	50	502		
5	post	primary only	50	419	83	
5	pre	both	50	499		
5	post	both	50	415	84	7.48
6	pre	storm only	50	991		
6	post	storm only	50	972	19	
6	pre	primary only	50	991		

Test Room #	Retrofit	Configuration	Pressure (Pa)	Flow (cfm)	Pre-Post (cfm)	Heating savings (therms/yr)
6	post	primary only	50	923	68	6.06
6	pre	both	50	987		
6	post	both	40	914	73	

It is interesting to note that when storm windows only are closed in spaces 5 and 6, the post-retrofit blower-door-measured leakage diminishes in spite of no retrofit work on the storm window. This is likely to be due to air sealing work on the counter weight pockets. Weights were removed and the pocket areas were stuffed with fiberglass to high density. This retrofit was not performed on window 4 because the window was rebuilt and replaced.

Second, for window 6, the post-retrofit blower door reading was only 40 pascals of pressure difference, so it cannot be compared with the pre-retrofit flow since it was determined at 50 pascals of pressure difference. Accordingly, estimates of annual savings were made using the difference between readings looking at the primary window only. Accordingly, the estimate of convective savings for window 6 is likely to be conservative.

Third, the pre-post reading of the storm window by itself indicates that the post measurement is slightly higher than the pre measurement by 20 cfm, a modest number. The team did not apply any treatment to this window since it was not original to the home, it was in extremely poor condition, and was slated for removal. There is very little that can be done with such windows shy of permanently air sealing them, which is inconsistent with emergency egress. In the interest of the research project, the team elected to measure the storm by itself but in practice such window are routinely used only in conjunction with primary windows. The reading was anomalous but may have resulted because rust or other debris was disturbed in the process of opening and closing it in order to take other readings, thereby allowing slightly more air to pass through. The research team did not regard it as significant to the overall results.

The estimates of savings due only to lowering convective losses for the winter season assume that the heating degree days in Boulder are 5,500 and that the overall system efficiency of the natural gas-fired hydronic heating system at the test home is 80 percent. Annual savings of heating energy (natural gas) are by virtue of convective improvements alone.

3.2 Chamber Testing

The team tested various combinations of fenestration systems in the laboratory chamber, including windows removed from the test home and several other historic windows acquired from a salvage yard. A "test run" on a given fenestration system consists of configuring a calibrated plug to accept the unit and carefully air sealing its perimeter. After installation, the technical team used a duct blaster in the pressurization mode to test leakiness and to double check that the outer frame of the fenestration system is tightly sealed to the plug. This is accomplished by sliding a hand over all of the crack area with the chamber being pressurized to 25 pascals. Even tiny cracks can be detected because the Bernoulli effect causes small openings under high pressures to yield high velocity air flow. Finally, the team takes measurements with a duct blaster and records the results. Only fenestration systems with double hung or other moveable features showed leakage.

Next, the team removes the duct blaster, seals its hole and the calibration hole, and closes the main door to the chamber. The interior chamber continues to be heated and the exterior chamber cooled so that the masses in both do not drift very far from thermostatically set values. This shortens the time for the chamber to return to a steady-state condition where U-values from hour to hour are nearly uniform.

At this point, the technician leaves the automated equipment to heat the inner chamber and cool the outer chamber to maintain a constant difference in temperature of about 70F while electronic equipment gathers data on energy consumption and temperatures, writing time series data records each minute.

Roughly 24 to 50 hours later, an analyst downloads the data gathered by the data loggers onto a laptop computer, makes an entry into a log book of present circumstances, clears the data from the loggers, and initiates another run. The raw data is later put into an Excel spread sheet for analysis. After entering details on the fenestration system's characteristics, the technical team is able to produce graphs of temperatures and energy use at one minute intervals and calculations of U-values at hourly intervals. The analyst averages U-values over a continuous set of hours beginning with the hour after the chamber has reached steady state and ending an hour before the last computation of U-values. He then calculates a standard deviation of the set of U-values and records all data as shown in Table 3-6.

Table 3-6. Measurements of U and R-values

Description	Number of test runs	Total test hours counted in calcs	Standard Deviation of hourly U-value	Weighted Average (U)	Weighted Average (R-value)	Wind adjusted R	Wind adjusted U
Old double hung from window 5	4	102	0.000872	0.78	1.29	0.79	1.27
Single glazed original alum storm	2	39	0.000872	0.97	1.03	0.53	1.88
New Storm w/o insulated frame	2	32	0.00132	0.27	3.65	3.15	0.32
New Storm w insulated frame	1	16	0.00077	0.24	4.11	3.61	0.28
New Storm single glazed	2	40	0.001045	0.76	1.31	0.81	1.23
Old DH from 5 + new storm w/o Ins	2	39	0.000908	0.21	4.87	4.37	0.23
Old DH from 5 + new Storm w/ Ins	1	42	0.001054	0.19	5.18	4.68	0.21
Retrofitted double hung from wind 5	1	24	0.000862	0.48	2.07	1.57	0.64
Ret DH from 5 + new storm w/o ins	2	39	0.000958	0.19	5.32	4.82	0.21
Ret DH from 5 + new storm w/ ins	3	91	0.000958	0.17	5.83	5.33	0.19
Ret DH from 5 + sg wood storm w/o ins	3	116	0.000926	0.33	3.00	2.50	0.40
New Vinyl Window	3	110	0.000926	0.36	2.75	2.25	0.45

When several runs have been completed, weighted averages of U-values are calculated depending on the number of hours counted in each run. As shown in the table above, an R-value is also calculated (it is simply the inverse of the U-value). Since our chamber is not capable of producing a 15 mph wind across the outside of the sample, we subtracted a factor of R = 0.5 from the R-values to be consistent with canonical procedure from the Fenestration chapter of the ASHRAE Handbook, which counts the outside air film on a vertical window in 15 mph wind as having an R-value of 0.15. Still air has an R-value of 0.68, a differenced of 0.53. Since the flow from the air conditioner fan on the outside chamber produces a modest amount of air movement, we rounded to 0.5 in estimating the wind-adjusted R, and then took the inverse to produce the wind-adjusted U-values shown in the last two columns of Table 3-6. Table 3-7

shows results of duct blaster depressurization testing of the same fenestration configurations as those shown in Table 3-6.

Table 3-7. Effective leakage area estimates

Description	*Depress ELA*	*Net ELA*
Old double hung from window 5	5.2	2.06
Single glazed original alum storm	9.4	6.26
New Storm w/o insulated frame	5.2	2.06
New Storm w insulated frame	5.1	1.96
New Storm single glazed	4.9	1.76
Old DH from 5 + new storm w/o Ins	4.1	0.96
Old DH from 5 + new Storm w/ Ins	3.9	0.76
Retrofitted double hung from wind 5	4.7	1.56
Ret DH from 5 + new storm w/o ins	4.3	1.16
Ret DH from 5 + new storm w/ ins	4.3	1.16
Ret DH from 5 + sg wood storm w/o ins	4.5	1.36
New Vinyl Window	4.8	1.66

These tests were taken with the 3.14 square inch calibration hole open, so the net ELA reflects subtracting that known cross sectional area. In all cases save for the single-glazed aluminum storm window, the net ELA is small and within instrument error bands. The aluminum storm window was carefully sealed in the chamber, yet shows a high net ELA because of ill fitting lites in their tracks and a visible space where they should meet in the middle. In all events, the measurement of U-values reflects convective as well as conductive and radiative losses. Accordingly, computations of U-values are used in the comparisons shown in Section 4.

To further refine testing and confirm results, the study team removed a few of the windows from the test home for corroborative testing in the lab. This helped limit the number of difficult-to-measure variables, however; absolute numbers are more difficult to determine than relative numbers. There may be errors associated with a given measure of U-value (although a number of chamber tests of a standard window product were within a few percent of data listed on National Fenestration Rating Council labels.) However, measurements may be repeated with very small errors, typically less than one percent. Very small standard deviations were routinely achieved when looking at a set of hourly U-value measurements (based on one minute time series data records, themselves made up of averages of thousands of temperature measurements each minute). Thus, measuring a given window, then retrofitting it and measuring it again yields dependable (and often quite useful) relative changes, expressed as a percent change in U-value from the earlier configuration.

The team also used the test chamber to measure the performance of a number of historic and new windows, with various treatments applied, to provide a range of comparative data for the study. First, the study team obtained several used/recycled historic windows from a building materials recycling yard. These windows were of varying types and configurations, including the small double-hung window used in testing the efficacy of the "column" method of air sealing and insulating counter weight pockets (see Appendix D).

Second, we temporarily removed two windows from the historic test home, and installed them in the test chamber. Following baseline testing, the team applied window films, aluminum storm windows and new custom made, high-performance storm windows, measuring the same

parameters following each application. More than 200 tests for heat transfer (U-value) were run in the test chamber with an average length of 26 hours. Scores of tests for air leakage and a number of infrared scans were also conducted to identify areas of conductive and convective losses.

Finally, the team installed a new, high efficiency, double hung window to be able to compare the results of the various treatments applied to historic windows to the performance of a standard model new window. The new windows tested included a model with double glazing, interior film, and argon fill whose center of glass U-value is below 0.2 and whose SHGC is below 0.4; and another whose U-value is below 0.2 and SHGC is above 0.6.

4. ANALYSIS AND CONCLUSIONS

4.1 Window Performance in Seven American Cities

Using key tested parameters associated with ten of the window scenarios described in Section 3, the study team estimated energy and cost consequences in seven American cities: Anchorage, Minneapolis, Phoenix, Boston, Denver, Atlanta and Sacramento. Each city's weather patterns and energy costs differ from the others.

For purposes of the RESFEN-based simulation, we assume a 2700 square foot existing brick home with gas-fired heating, the circumstance of the test home. We further assume 100 square feet of window area for each system examined on each of four facades facing north, east, south, and west. This amounts to a window area that is 14.8% of the floor area. In addition to being close to the average total window area of a broad variety of housing stock, choosing 100 square feet per façade facilitates comparing modeled facades with facades of different areas by simply dividing the desired square footage by 100 and multiplying the result by the appropriate values in Tables 4-2 through 4-8. We also assume conventional electric powered compressor-based air conditioning for the modeled homes because this is far more common than is the evaporative cooler associated with the test home.

Almost all homes are shaded on some of their facades some of the time, which diminishes solar heat gain. Reductions in radiant energy entering the dwelling result from blinds, shades, screens, overhangs, and shadowing from fences, neighboring buildings, trees, and the like. Of course, it is important to take this shading into account in simulating window performance in both summer and winter. RESFEN software defines "typical" shading for generic dwellings as follows:

> *Typical...includes: Interior shades (seasonal SHGC multiplier, summer value = 0.80, winter value = 0.90); 1' overhang; a 67% transmitting same-height obstruction 20' away intended to represent adjacent buildings. To account for other sources of solar heat gain reduction (insect screens, trees, dirt, building & window self-shading) the SHGC multiplier was further reduced by 0.1. This results in a final winter SHGC multiplier of 0.8 and a final summer SHGC multiplier of 0.7.*
>
> *These assumptions are intended to represent the average solar heat gain reduction for a large sample of houses. A one-foot overhang is assumed on all four orientations in order to represent the average of a two-foot overhang and no overhang. A 67% transmitting obstruction 20 feet away on all four orientations represents the average of obstructions (such as neighboring buildings and trees) 20 feet away on one-third of the total windows and no obstructions in front of the remaining two-thirds of windows. An interior shade is assumed to have a Solar Heat Gain Coefficient multiplier of 0.9 during the winter and 0.8 during the summer. To account for solar heat gain reducing effects from other sources such as screens, trees, dirt, and self-shading of the building, the SHGC multiplier was further reduced by 0.1 throughout the year. This amounts to a 12.5% decrease in the summer and an 11.1% decrease in the winter. The final SHGC multipliers (0.8 in the*

winter and 0.7 in the summer) thus reflect the combined effects of shading devices and other sources.[7]

Given these considerations, Table 4-1 expresses U-values, SHGCs, SHGCs with typical shading in winter and SHGCs with typical shading in summer for each of the ten fenestration scenarios simulated.

Table 4-1. Key parameters modeled for each fenestration scenario

Window	U-value	SHGC	Typical Winter SHGC	Typical Summer SHGC
Old double hung	1.27	0.73	0.58	0.51
Old storm	1.88	0.98	0.78	0.69
Old double hung +old storm	0.76	0.58	0.46	0.41
New single-glazed storm	1.23	0.73	0.58	0.51
New low U storm	0.28	0.33	0.26	0.23
Old double hung with low U storm	0.21	0.27	0.22	0.19
Retrofit double hung	0.64	0.61	0.49	0.43
Retrofit double hung with single-glazed storm	0.4	0.55	0.44	0.39
Retrofit double hung with low U storm	0.19	0.25	0.20	0.18
New vinyl	0.45	0.43	0.34	0.30

4.1.1 Data

Tables 4-2 through 4-8 show results of seasonal costs in US dollars associated with energy gains and losses through each of these window systems. Results in energy units are expressed in therms of gas for heating and kilowatt hours (kWh) of electricity for cooling, with the total a common unit of a million British thermal units (MBtu). A therm has the energy equivalent of 100,000 Btus, so ten therms = 1 MBtu. A kWh of electricity is the equivalent of 3,412 Btu, so 293 kWh = 1 MBtu. A million Btus is the energy equivalent of about a person year of labor. In Colorado, one MBtu of natural gas costs residential utility customers about $10 while a MBtu of electricity costs $29.30.

[7] Page 6-3, Program Description of RESFEN 3.1, LBNL-40682 Rev August 1999.

Table 4-2. Energy performance of ten fenestration scenarios in Anchorage (Gas cost $0.440/therm; electricity cost $0.116/kWh)

Window	North heat (therms)	East heat (therms)	South heat (therms)	West heat (therms)	Total heat (therms)	Total heat ($)	North cool (kWh)	East cool (kWh)	South cool (kWh)	West cool (kWh)	Total cool (kWh)	Total cool ($)	Total annual energy (MBtu)	Total annual energy ($)
Old DH	290	238	180	243	951	$419	2	4	6	5	17	$2	95.2	$421
Old Storm	380	312	236	320	1248	$550	3	7	10	12	32	$4	124.9	$554
Old DH+Old Storm	195	154	107	156	612	$270	1	2	2	2	7	$1	61.2	$271
New Sing Glaz Storm	282	230	172	235	919	$405	2	4	6	5	17	$2	92.0	$407
New Lo U Storm	83	60	32	60	235	$104	0	0	0	0	0	$0	23.5	$104
Old DH w Lo U Storm	65	45	23	46	179	$79	0	0	0	0	0	$0	17.9	$79
Retrofit DH	165	122	73	125	485	$214	2	4	4	4	14	$2	48.5	$216
Retro DH w sing gl St	105	67	22	69	263	$116	2	3	3	3	11	$1	26.3	$117
Retro DH w Lo U St	59	41	20	42	162	$71	0	0	0	0	0	$0	16.2	$71
New Vinyl	127	96	60	97	380	$168	0	0	0	0	0	$0	38.0	$168

Table 4-3. Energy performance of ten fenestration scenarios in Minneapolis (Gas cost $1.00 /therm; electricity cost $0.10/kWh)

Window	North heat (therms)	East heat (therms)	South heat (therms)	West heat (therms)	Total heat (therms)	Total heat ($)	North cool (kWh)	East cool (kWh)	South cool (kWh)	West cool (kWh)	Total cool (kWh)	Total cool ($)	Total annual energy (MBtu)	Total annual energy ($)
Old DH	242	178	104	192	716	$716	138	278	241	327	984	$98	75.0	$814
Old Storm	324	239	140	261	964	$964	206	424	375	486	1491	$149	101.5	$1,113
Old DH+Old Storm	158	108	48	117	431	$431	105	206	178	242	731	$73	45.6	$504
New Sing Glaze Storm	234	172	97	185	688	$688	138	279	242	328	987	$99	72.2	$787
New Lo U Storm	63	37	2	40	142	$142	49	90	79	107	325	$33	15.3	$175
Old DH w Lo U Storm	50	27	-2	30	105	$105	36	64	57	77	234	$23	11.3	$128
Retrofit DH	132	82	18	90	322	$322	115	230	198	269	812	$81	35.0	$403
Retro DH w sing gl Stor	83	38	-21	44	144	$144	105	205	176	239	725	$73	16.9	$217
Retro DH w Lo U Storm	46	24	-3	27	94	$94	32	56	50	68	206	$21	10.1	$115
New Vinyl	101	64	18	69	252	$252	69	133	115	158	475	$48	26.8	$300

Table 4-4. Energy performance of ten fenestration scenarios in Phoenix (Gas cost $1.43 /therm; electricity cost $0.11/kWh)

Window	North heat (therms)	East heat (therms)	South heat (therms)	West heat (therms)	Total heat (therms)	Total heat ($)	North cool (kWh)	East cool (kWh)	South cool (kWh)	West cool (kWh)	Total cool (kWh)	Total cool ($)	Total annual energy (MBtu)	Total annual energy ($)
Old DH	37	13	-24	24	50	$72	804	1553	1337	1730	5424	$597	23.5	$668
Old Storm	48	19	-23	34	78	$112	1111	2135	1865	2377	7488	$824	33.4	$935
Old DH+Old Storm	25	5	-27	13	16	$23	616	1203	1022	1341	4182	$460	15.9	$483
New Sing Glaze Storm	37	12	-24	23	48	$69	800	1546	1330	1724	5400	$594	23.2	$663
New Lo U Storm	9	-3	-24	1	-17	-$24	333	662	542	735	2272	$250	6.1	$226
Old DH w Lo U Storm	7	-4	-21	0	-18	-$26	269	537	438	599	1843	$203	4.5	$177
Retrofit DH	20	0	-32	8	-4	-$6	619	1242	1052	1381	4294	$472	14.3	$467
Retro DH w sing gl Stor	12	-6	-34	1	-27	-$39	533	1097	921	1220	3771	$415	10.2	$376
Retro DH w Lo U Storm	7	-3	-20	0	-16	-$23	249	496	403	553	1701	$187	4.2	$164
New Vinyl	16	0	-26	6	-4	-$6	450	883	732	979	3044	$335	10.0	$329

Table 4-5. Energy performance of ten fenestration scenarios in Boston (Gas cost $1.51 /therm; electricity cost $0.17/kWh)

Window	North heat (therms)	East heat (therms)	South heat (therms)	West heat (therms)	Total heat (therms)	Total heat ($)	North cool (kWh)	East cool (kWh)	South cool (kWh)	West cool (kWh)	Total cool (kWh)	Total cool ($)	Total annual energy (MBtu)	Total annual energy ($)
Old DH	191	128	58	145	522	$788	106	226	184	228	744	$126	54.7	$915
Old Storm	261	174	82	201	718	$1,084	163	347	287	379	1176	$200	75.8	$1,284
Old DH+Old Storm	121	73	16	83	293	$442	82	167	136	186	571	$97	31.2	$540
New Sing Glaze Storm	185	122	52	139	498	$752	107	227	184	248	766	$130	52.4	$882
New Lo U Storm	47	20	-13	24	78	$118	37	73	59	82	251	$43	8.7	$160
Old DH w Lo U Storm	36	13	-14	16	51	$77	28	54	44	61	187	$32	5.7	$109
Retrofit DH	100	51	-9	60	202	$305	92	189	151	204	636	$108	22.4	$413
Retro DH w sing gl Stor	59	17	-38	23	61	$92	83	170	137	183	573	$97	8.1	$190
Retro DH w Lo U Storm	33	12	-13	15	47	$71	23	46	37	53	159	$27	5.2	$98
New Vinyl	75	39	-3	46	157	$237	58	111	92	123	384	$65	17.0	$302

Table 4-6. Energy performance of ten fenestration scenarios in Denver (Gas cost $1.00 /therm; electricity cost $0.10/kWh)

Window	North heat (therms)	East heat (therms)	South heat (therms)	West heat (therms)	Total heat (therms)	Total heat ($)	North cool (kWh)	East cool (kWh)	South cool (kWh)	West cool (kWh)	Total cool (kWh)	Total cool ($)	Total annual energy (MBtu)	Total annual energy ($)
Old DH	173	89	15	117	394	$394	132	318	230	303	983	$98	42.8	$492
Old Storm	228	119	21	158	526	$526	194	483	356	450	1483	$148	57.7	$674
Old DH+Old Storm	114	46	-1	68	227	$227	98	233	165	220	716	$72	25.1	$299
New Sing Glaze Storm	168	84	10	112	374	$374	131	318	230	302	981	$98	40.7	$472
New Lo U Storm	46	5	-3	18	66	$66	46	105	71	96	318	$32	7.7	$98
Old DH w Lo U Storm	35	1	-3	11	44	$44	34	79	54	73	240	$24	5.2	$68
Retrofit DH	94	25	-39	46	126	$126	107	258	183	242	790	$79	15.3	$205
Retro DH w sing gl Stor	57	-6	-64	13	0	$0	99	230	161	213	703	$70	2.4	$70
Retro DH w Lo U Storm	32	1	-26	10	17	$17	30	70	48	66	214	$21	2.4	$38
New Vinyl	72	21	-25	36	104	$104	66	153	105	142	466	$47	12.0	$151

Table 4-7. Energy performance of ten fenestration scenarios in Atlanta (Gas cost $1.196 /therm; electricity cost $0.071/kWh)

Window	North heat (therms)	East heat (therms)	South heat (therms)	West heat (therms)	Total heat (therms)	Total heat ($)	North cool (kWh)	East cool (kWh)	South cool (kWh)	West cool (kWh)	Total cool (kWh)	Total cool ($)	Total annual energy (MBtu)	Total annual energy ($)
Old DH	85	40	-11	50	164	$196	283	607	409	627	1926	$137	23.0	$333
Old Storm	113	56	-9	71	231	$276	397	847	581	879	2704	$192	32.3	$468
Old DH+Old Storm	54	18	-24	26	74	$89	230	483	321	501	1535	$109	12.6	$197
New Sing Glaze Storm	82	38	-13	48	155	$185	289	608	410	628	1935	$137	22.1	$323
New Lo U Storm	20	-2	-27	2	-7	-$8	136	271	177	280	864	$61	2.2	$53
Old DH w Lo U Storm	15	-3	-24	0	-12	-$14	111	221	144	228	704	$50	1.2	$36
Retrofit DH	43	7	-36	15	29	$35	253	522	353	534	1662	$118	8.6	$153
Retro DH w sing gl Stor	24	-9	-47	-2	-34	-$41	240	485	327	496	1548	$110	1.9	$69
Retro DH w Lo U Storm	14	-3	-23	-1	-13	-$16	104	204	133	210	651	$46	0.9	$31
New Vinyl	33	6	-27	11	23	$28	174	354	232	364	1124	$80	6.1	$107

Table 4-8. Energy performance of ten fenestration scenarios in Sacramento (Gas cost $0.917 /therm; electricity cost $0.122/kWh)

Window	North heat (therms)	East heat (therms)	South heat (therms)	West heat (therms)	Total heat (therms)	Total heat ($)	North cool (kWh)	East cool (kWh)	South cool (kWh)	West cool (kWh)	Total cool (kWh)	Total cool ($)	Total annual energy (MBtu)	Total annual energy ($)
Old DH	81	36	-8	46	155	$142	225	529	437	663	1854	$226	21.8	$368
Old Storm	107	50	-5	65	217	$199	319	762	637	946	2664	$325	30.8	$524
Old DH+Old Storm	53	16	-21	22	70	$64	173	409	330	511	1423	$174	11.9	$238
New Sing Glaze Storm	79	34	-10	43	146	$134	224	530	436	663	1853	$226	20.9	$360
New Lo U Storm	20	-3	-25	0	-8	-$7	91	209	160	265	725	$88	1.7	$81
Old DH w Lo U Storm	15	-4	-23	-2	-14	-$13	76	167	125	210	578	$71	0.6	$58
Retrofit DH	42	5	-34	11	24	$22	188	443	360	549	1540	$188	7.7	$210
Retro DH w sing gl Stor	23	-10	-46	-5	-38	-$35	174	406	325	494	1399	$171	1.0	$136
Retro DH w Lo U Storm	13	-5	-22	-3	-17	-$16	70	151	116	191	528	$64	0.1	$49
New Vinyl	33	4	-25	8	20	$18	128	289	229	365	1011	$123	5.5	$142

4.1.2 Discussion

Note that in Anchorage (Table 4-2) the weather is quite cold with almost no cooling load while Phoenix (Table 4-4) has very hot weather and very little heating. The cost of gas in Phoenix is 3.24 times that of gas in Anchorage. Nonetheless, double-hung windows with aluminum storms on all four facades in Anchorage result in window energy consumption of 61.2 MBtu, 3.8 times the consumption in Phoenix. The retrofit double hung plus Low U storm window in Anchorage lowers window energy use to 16.2 MBtu, a 3.78 factor of savings over the original system, and about the same relative percentage savings achieved in Phoenix. However, absolute savings (in millions of Btus) in Anchorage is greater by a factor of four.

Minneapolis (Table 4-3) has substantial heating and moderate cooling loads with middling energy costs for both gas and electricity. In this case, upgrading the original window and adding a low U storm results in an overall energy savings of four and a half fold, an annual energy savings of 35.5 MBtu and a cost savings of $389.

Boston's (Table 4-5) heating and cooling loads are typical of New England with energy costs for both gas and electricity well above national averages. Although storm windows are rarely employed as the only fenestration, it is instructive to look at the difference between the annual energy costs of a triple track aluminum storm window of the kind that was on the test home and that of the wood-frame low U storm window fabricated for this project. In Boston, the annual energy cost associated with the aluminum storm on its own is $1,284/yr versus $160 for the low U storm, a difference of $1,124. The same comparison in Denver (Table 4-6) yields a difference of $674/yr for the aluminum versus $98 for the wood-frame low U storm, a savings of $576. In Boston, the difference in energy performance of these two storm window systems amount to 67.1 MBtu, in Denver, 50.0 MBtu.

This illustrates that the cost of fossil-fuel-based energy used for space conditioning in most American homes remains quite modest, a fact that militates against short payback periods for many conservation measures. Where costs of energy are higher, savings associated with conservation retrofits are more attractive.

This point is made clearer by the comparisons shown in Tables 4-9 through 4-11 (which make use of the results shown in Tables 4-2 through 4-8). These illustrate savings from several different window treatments in each of the seven cities modeled. Absolute energy savings in MBtu per year and relative savings (percentage) are shown as well as annual dollar savings and costs of retrofitting 400 square feet of window area (100 square feet on each of four facades), and simple payback. Savings and payback calculations assume a retrofit cost of $25 per square foot. In practice, this number can vary widely depending on the condition of the existing windows and the customer's desires[8]. Labor tends to be the key element in most extensive window retrofit work.

Table 4-9 compares the double-hung historic window as found versus the same window after retrofit (including insulating and sealing, retrofitting counterweight pockets and replacing single glazing with an IGU).

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[8] Typical thorough retrofit practices are described and illustrated in Section 3.1 of this report.

Table 4-9. Savings from retrofitting existing double-hung windows

City	Old DH (MBtu/yr)	Retrofit DH (MBtu/yr)	Absolute Savings (MBtu/yr)	Relative Savings (%)	Savings ($/yr)	Retrofit Cost ($)*	Simple Payback (years)
Anchorage	95.2	48.5	46.6	49.0%	$206	$10,000	48.6
Atlanta	23.0	8.6	14.4	62.7%	$180	$10,000	55.5
Boston	54.7	22.4	32.4	59.1%	$502	$10,000	19.9
Denver	42.8	15.3	27.5	64.2%	$287	$10,000	34.8
Minneapolis	75.0	35.0	40.0	53.3%	$411	$10,000	24.3
Phoenix	23.5	14.3	9.3	39.4%	$202	$10,000	49.6
Sacramento	21.8	7.7	14.2	64.9%	$158	$10,000	63.1
Averages	48.0	21.7	26.3	54.8%	$278	$10,000	36.0

* Retrofit cost is based on $25 per square foot for 100 square feet of window area on each of four facades for a total of 400 square feet (400 x $25 = $10,000).

Average savings resulting from retrofit is 26.3 MBtu per year and 54.8%. However even though savings in Anchorage are twice as much as the average, paybacks are over twice as long than in both Boston and Minneapolis because natural gas costs in Anchorage are so low. Second, savings in this case are counted only from the change in U-value as measured in the test chamber which did not include leakage savings from sealing the weight pockets, but only from installing weather stripping in the parting rail between the upper and lower lites and the edges of the window frame.

Table 4-10 is analogous to Table 4-9 but compares the existing double-hung window with a new mid-grade vinyl window installed by a do-it-yourselfer. Savings and payback calculations assume a cost of $10 per square foot.

Table 4-10. Savings from replacing double-hung window with a new vinyl window

City	Old DH (MBtu/yr)	New Vinyl (MBtu/yr)	Absolute Savings (MBtu/yr)	Relative Savings (%)	Savings ($/yr)	Retrofit window cost ($)*	Simple payback (years)
Anchorage	95.2	38.0	57.2	60.1%	$254	$4,000	15.8
Atlanta	26.4	8.1	18.3	69.2%	$226	$4,000	17.7
Boston	56.1	17.7	38.4	68.4%	$612	$4,000	6.5
Denver	44.5	12.8	31.7	71.2%	$342	$4,000	11.7
Minneapolis	76.7	27.7	49.0	63.9%	$515	$4,000	7.8
Phoenix	33.1	15.4	17.7	53.6%	$339	$4,000	11.8
Sacramento	25.1	7.2	17.9	71.2%	$227	$4,000	17.6
Averages	51.0	18.1	32.9	64.5%	$359	$4,000	11.1

* Retrofit cost is based on $10 per square foot for 100 square feet of window area on each of four facades for a total of 400 square feet (400 x $10 = $4,000).

Here both average and relative savings are slightly higher and costs of the retrofit are lower, so paybacks are shorter than the other efficiency options evaluated for this study. However, the team used a relatively low-cost window of the type available in most home improvement stores

for this test. A higher quality window, installed by professional technicians would likely cost considerably more. Again, although absolute energy savings are three times higher than those achieved in Phoenix, paybacks are longer than in all cities save Atlanta.

Table 4-11 compares the existing double-hung window with the same window that has been supplemented with a low-U storm window. Savings assume a cost of $25 per square foot for the new storm window and 100 square feet of the fenestration systems installed on each of four facades.

Table 4-11. Savings from retrofitting double-hung window with new Low U-value storm

City	Old DH (MBtu/yr)	Old DH + New Lo U Storm (MBtu/yr)	Absolute Savings (MBtu/yr)	Relative Savings (%)	Savings ($/yr)	Retrofit window cost ($)*	Simple payback (years)
Anchorage	95.2	17.9	77.3	81.2%	$342	$10,000	29.2
Atlanta	26.4	1.2	25.2	95.4%	$297	$10,000	33.6
Boston	56.1	5.7	50.3	89.8%	$806	$10,000	12.4
Denver	44.5	5.2	39.3	88.3%	$424	$10,000	23.6
Minneapolis	76.7	11.3	65.4	85.3%	$686	$10,000	14.6
Phoenix	33.1	4.5	28.6	86.4%	$491	$10,000	20.4
Sacramento	25.1	0.6	24.5	97.7%	$311	$10,000	32.2
Averages	51.0	6.6	44.4	87.0%	$480	$10,000	20.8

* Retrofit cost is based on $25 per square foot for 100 square feet of window area on each of four facades for a total of 400 square feet (400 x $24 = $9600).

In this case, savings average 44.4 MBtu and 87%. Dollar savings are over $800 per year in Boston and average $480 overall. The savings in Anchorage are the energy equivalent of 77 person years of labor, yet paybacks are 28 years.

It is useful to note in the above analyses that:

- The assumed cost of a highly-energy-efficient storm window reflects no economies of scale and assumes a wood frame, which is labor intensive to manufacture and has an R-value that is three times less than that of fiberglass or vinyl.
- No local, state, federal, or utility incentives are taken into account.
- The analysis does not account for such benefits as increased comfort, yet many consumers count this factor as primary in decisions concerning their windows.
- There are many circumstances in the real world in which useful lifetimes of various window treatments may be less than payback periods. These factors are notoriously difficult to quantify and therefore have not been considered in payback calculations.
- The analysis does not account for the likely increase in the lifetime of the primary window resulting from either retrofit or adding an energy-efficient exterior storm window.
- Cost-benefit calculations assume the rate of inflation in energy costs is identical to the overall inflation rate. Accordingly, the analysis is likely to be conservative.

4.2 The Influence of Frame Size and Material on Window Efficiency

Before drawing inferences from the above findings, it is useful to note the key role played by frames in determining window energy performance. Historic window frames are typically made of wood; glazing is typically single. An inch of dry white pine has an R-value of one (1/Btu/ft2/F). Single glazing also has an R-value of approximately one owing primarily to a dead air space close to the surface of the inside whose R-value is 0.68 and an air space on the outside that varies with wind speed, but is conventionally assigned an R-value of 0.15, corresponding to a wind speed of 15 miles per hour. Accordingly, **when both the frame and glazing have roughly the same R-value** (the case of older single-glazed windows with wood frames), **conductive losses do not change much with the ratio of the cross sectional area of glazing to frame**.

IGUs have multiple glazings and sometimes films, either suspended between other elements or adhered to them. They frequently include an inert gas that enhances R-value. Of important energy consequence, they use spacers around their edges to hold the IGU together and ensure that the spacing between elements is maintained evenly. Generally, spacer material is made of thin, roll-formed metal that is strong enough to ensure good mechanical properties yet small enough to keep edge-of-glass conductive losses relatively low. However, as IGU techniques in achieving high center-of-glass R-values improve (R-values of over 10 are now readily achievable), edge-of-glass losses represent an increasing portion of overall losses through IGUs. Since spacers tend to be the same size for IGUs of all sizes, **edge losses are substantially more pronounced for smaller IGUs than for larger ones**. The window industry is working to develop edge materials that have lower conductive losses along with excellent strength. The problem is complicated by the fact that coefficients of linear expansion with temperature of glass tend to be much lower than expansion coefficients of plastics and other low conductivity materials, thereby increasing the risk of IGU leakage under conditions of large temperature swings.

Moderate size older double-hung windows with counter-weight boxes can have fixed plus moveable frame areas that are about the same cross section area as the glazed area. In such cases, if for example, the single glazing is replaced by a double glazed IGU with low-E hard coat and a U-value of 0.36 (R = 2.8), the overall window system is improved over single glazing from R-1 to only 1.46. Indeed, if an R-10 IGU is combined with an R1 frame whose area is half of the window system, improvement to the system is from R-1 to only R-1.8.

Frames made of either vinyl or fiberglass have R-values in the area of 3 per inch. The addition of urethane or related materials of substantially higher R-value can increase this value. (Urethane used as an insulation product has an R-value ranging from 7 to 11 depending on density.) In addition, adding even 25% of Styrofoam (R = 5 per inch) to cavities routed out from the inside of wooden frames can raise the overall R-values of window systems by 5 to 15%.

To illustrate the effects of frame material and percentage of window area on the U- and R-values of windows, Table 4-12 explores several combinations of frame and IGU R-values on windows with a glazing-to-total window area from 0.5 to 0.87 as a function of frame U-values of 1 and 0.33 with window U-values of 1 to 0.1.

Table 4-12. U-values and R-values on various glazing to window area ratios

Ratio glazing/ total window area	U frame	R frame	U glazing	R glazing	Total net U	Total net R
0.50	1	1.00	1	1.0	1.00	1.00
0.50	1	1.00	0.5	2.0	0.75	1.33
0.50	1	1.00	0.36	2.8	0.68	1.46
0.50	1	1.00	0.2	5.0	0.60	1.66
0.50	1	1.00	0.1	10.0	0.55	1.80
0.50	0.33	3.03	1	1.0	0.66	1.51
0.50	0.33	3.03	0.5	2.0	0.41	2.41
0.50	0.33	3.03	0.36	2.8	0.34	2.90
0.50	0.33	3.03	0.2	5.0	0.27	3.76
0.50	0.33	3.03	0.1	10.0	0.22	4.63
0.75	1	1.00	1	1.0	1.00	1.00
0.75	1	1.00	0.5	2.0	0.63	1.60
0.75	1	1.00	0.36	2.8	0.52	1.92
0.75	1	1.00	0.2	5.0	0.40	2.49
0.75	1	1.00	0.1	10.0	0.33	3.06
0.75	0.33	3.03	1	1.0	0.83	1.20
0.75	0.33	3.03	0.5	2.0	0.46	2.19
0.75	0.33	3.03	0.36	2.8	0.35	2.84
0.75	0.33	3.03	0.2	5.0	0.23	4.30
0.75	0.33	3.03	0.1	10.0	0.16	6.33
0.87	1	1.00	1	1.0	1.00	1.00
0.87	1	1.00	0.5	2.0	0.56	1.78
0.87	1	1.00	0.36	2.8	0.44	2.27
0.87	1	1.00	0.2	5.0	0.30	3.32
0.87	1	1.00	0.1	10.0	0.21	4.68
0.87	0.33	3.03	1	1.0	0.92	1.09
0.87	0.33	3.03	0.5	2.0	0.48	2.09
0.87	0.33	3.03	0.36	2.8	0.36	2.81
0.87	0.33	3.03	0.2	5.0	0.22	4.62
0.87	0.33	3.03	0.1	10.0	0.13	7.75

The above analysis results in a number of useful observations.

- Improving the R-value of frames is highly important. In particular, improving the R-value of a substantial portion of the fixed part of the frame of an older double hung window--like the counter weight box--can be very effective.
- Raising the glazing-to-frame ratio of any window system whose frames have an R-value of one or less makes good sense.
- Investing in high R-value IGUs is increasingly cost effective as frame portions become smaller and frame R-values higher.
- Retrofit storm windows with high R-value glazing are increasingly cost effective when frames are small and have good R-values.

4.3 Storm Windows for Historic and Other Homes

The strategy of adding an energy-efficient storm window to an existing fenestration system in an historic dwelling showed promising results. Even before upgrading the existing double hung window, the combination of a wood frame with a modern insulated glazing unit (IGU) and krypton gas resulted in an overall U value of 0.21 (SHGC 0.27). However, given the above discussion of the relative efficiency of wood versus vinyl or fiberglass frames, it is useful to estimate the storm window's energy performance if the wooden frame were replaced by fiberglass (retaining the same IGU).

Although PVC plastic is in wide use in windows and its insulating value is close to that of fiberglass (about R-3 per inch), we elected not to examine this option because of several shortcomings associated with vinyl. First, its coefficient of linear expansion with temperature is about 16 times that of fiberglass, so it tends to shift with temperature changes, which can weaken joints over time and result in leakage of both air and water. Second, even with the addition of ultraviolet inhibitors to the plastic during the extrusion process, the lifetime of vinyl windows is typically shorter than that of fiberglass or even well-maintained wood. The rate of deterioration is a direct function of the magnitude of long-term exposure to direct sunlight, so south-facing windows are more vulnerable to UV degradation than are those on other elevations. Lifetimes tend to be particularly short in sunny, high altitude regions like Colorado where clear skies and less atmosphere scatter the sun's direct beam UV radiation.

In addition, fiberglass is structurally much stronger than either wood or vinyl, so frames can be of smaller cross sectional areas than is possible with either of those materials. Since in this case, the IGU is even more insulative than fiberglass, the result of a smaller frame is a more energy-efficient window. This affords greater viewing area and solar heat gain, exposing more of the window's historic characteristics (while avoiding exposing it to the ravages of weather). Finally, pultruded fiberglass frames may be fabricated to closely resemble wooden frames.

Given these considerations, we analyzed results assuming a fiberglass frame. First, we took the chamber-measured U values of the low-U storm window with a wooden frame built for this project, as well as that of the old double hung before retrofit, and the combination of the two. We assumed an R value of 0.8 (U = 1.25) for the wooden frame which is 1.96 inches wide and an inch thick. (This is slightly less than the canonical R = 1 per inch because the frame houses the IGU whose R value at the edge is considerably less than at center of glass.) The net R value of the glazing was R = 5.33, U = 0.186. Next, we assumed a fiberglass frame that is an inch wide and de-rated the fiberglass from R= 3 to R = 2.4 to account for the glazing's edge effects. This allowed the study team to compare assumed conditions identical to those measured in the chamber, to examine specifically the effects of the fiberglass frame. The R value for the storm window estimated by this procedure is 5.05, U = 0.198. With the old double hung, the R value of the fenestration system is 6.l25, U value 0.16. Owing to the larger opening (yet low secondary heat effect due to the better insulated frame) we increased the estimate of SHGC from 0.27 to 0.28. Finally, we ran RESFEN with this window system making the same assumptions that were made in producing the analyses shown in Tables 4-2 through 4-8.

The results by city are shown in Table 4-13.

Table 4-13. Energy Performance of Double Hung window with Low U, Fiberglass Frame Storm Window (U = 0.16; SHGC = 0.28)

City	North heat (therms)	East heat (therms)	South heat (therms)	West heat (therms)	Total heat (therms)	Total heat ($)	North cool (kWh)	East cool (kWh)	South cool (kWh)	West cool (kWh)	Total cool (kWh)	Total cool ($)	Total annual energy (MBtu)	Total annual energy ($)
Denver	23	-11	-41	-1	-30	$(30)	36	83	56	77	252	$25	-2.1	$(5)
Boston	24	1	-27	4	2	$3	31	63	52	71	217	$37	0.9	$40
Minneapolis	35	11	-19	14	41	$41	43	79	68	96	286	$29	5.1	$70
Phoenix	4	-7	-24	-3	-30	$(43)	268	546	443	609	1866	$205	3.4	$162
Atlanta	9	-9	-31	-7	-38	$(45)	119	234	153	239	745	$91	-1.3	$45
Sacramento	8	-11	-30	-9	-42	$(39)	76	167	126	209	578	$58	-2.2	$19
Anchorage	46	26	3	26	101	$45	0	0	0	0	0	$0	10.1	$45
Averages	21	0	-24	3	1	$(10)	82	167	128	186	563	$64	2	$54

4.3.1 Discussion

Note that in all cases, the system using a fiberglass frame saves substantial energy over a wood-framed window system; the average across seven cities modeled is 70%.

The product modeled for the study is not yet available in the marketplace, so estimating costs to the consumer is inexact. However, by applying the costs of energy-efficient IGOs and fiberglass pultrusions, which are increasingly widespread in the window industry, we are able to estimate costs to the end user with the following assumptions:

- Economies of scale. Manufacturing windows in batches is substantially more cost effective than building individual windows to precise measurements. Thus, we assume that "bulk" purchases are defined as orders of 20 units or more.
- The costs of taking window measurements, installation, and shipping are not included in the cost estimates.

Given these considerations, we estimate costs of $14 to $18 per square foot for a fiberglass frame, low U storm window discussed above. In the case of the relatively large (15.73 square feet) windows in the historic home that is the subject of this report, the cost would be about $236 per window.

Table 4-14 assumes a cost of $15 per square foot for purposes of calculating paybacks.

Table 4-14. Double Hung with Fiberglass Low U Storm @ $15/ft2

City	*Old DH (MBtu/yr)*	*Old DH + New Lo U Fiberglass Frame Storm (MBtu/yr)*	*Absolute Energy Savings (MBtu/yr)*	*Relative Energy Savings (%)*	*Savings ($/yr)*	*Retrofit window cost ($)*	*Simple payback (years)*
Anchorage	95.2	10.1	85.1	89.4%	$377	$6,000	15.9
Atlanta	26.4	-1.3	27.6	104.8%	$287	$6,000	20.9
Boston	56.1	0.9	55.1	98.3%	$875	$6,000	6.9
Denver	44.5	-2.1	46.6	104.8%	$497	$6,000	12.1
Minneapolis	76.7	5.1	71.6	93.4%	$745	$6,000	8.1
Phoenix	33.1	3.4	29.7	89.8%	$506	$6,000	11.9
Sacramento	25.1	-2.2	27.3	108.9%	$349	$6,000	17.2
Averages	51.0	2.0	49.0	96.1%	$519	$6,000	11.6

The table reflects 100 square feet of window area on each of four facades for the cities analyzed. Note that in three cities savings are over 100%. This means that the window systems become net producers of energy on a full-year basis.

4.4 Final Conclusions

Tightening windows helps lower convective losses and contributes to improving energy performance and comfort, but if leakage is modest to begin with, savings are likely to be small. Of course, if work is being done on the weight box, it makes sense to undertake tightening, sealing, and other improvements on existing windows at the same time. Painting and adjustments, plus good hardware also improve comfort and extend lifetimes. The level of improvement achievable is a function of how leaky windows were before the retrofit.

The work of carefully rebuilding old windows is practiced primarily by professional craftsmen who work with specialized tools and equipment. Some, like Phoenix Windows, employ a portable shop which they bring on site to enable rebuilding multiple windows in several days time. This process can breathe new life into old windows and dramatically improve comfort and energy efficiency. However, because the work is painstakingly conducted by a skilled craftsman, the cost is very different from window systems manufactured off site and left to a homeowner or local technician to install.

Adding a more efficient IGU to windows in combination with air sealing and insulating the existing window and its weight pocket showed good improvements in this study. Empirical data from chamber measurements were consistent with the computations in Table 4-12. In particular, if a wooden frame dominates a window, the only way to achieve excellent savings while retaining the historic window is to install an energy-efficient storm window.

Adding storm windows was quite successful and has aesthetic advantages as well as significant thermal ones. Even with a wooden frame (whose proportions were modest while being consistent with traditional historic aesthetics), energy efficiency was on the order to four times that of the original window. Switching to an energy-efficient fiberglass frame would improve the performance a great deal, probably raising the overall efficiency of the window system by a factor of six or more over an existing single-glazed wooden window. It is possible to fabricate fiberglass frames to appear to be virtually identical to wooden frames. This would result in a storm window that could be manufactured at a lower cost than a wooden storm window. It would also achieve better comfort, longer life, and greater energy savings than wood. This type of frame is not currently commercially available; however, a mass-produced, semi-custom fiberglass frame solution may find strong commercial demand among historic homeowners and others. Because storm windows are modular and removable, it is assumed that such a product would pass muster with most historic preservation communities.

In a recent look at the prices of storm window produced by four manufacturers offering bulk purchase pricing, the study team found that canonical 10 square foot storm windows may be purchased in bulk (20 or more windows) for $10 (i.e., for storm windows with aluminum frames and single glazing) to $28 per square foot (i.e., storm windows with a vinyl frame, double glazing and a low-E coating on an interior surface). Based on current window technology, bulk purchases of similar-size storm windows with fiberglass frames and lower U value glazing than any storm windows currently available could cost from $14 to $18 per square foot. Assuming a cost of $15 per square foot, such a product would lower paybacks to an average of 11 years for most of the areas of the country examined in this report and last considerably longer than any other storm windows now available. This simple payback is similar to that achievable by a new low-end vinyl window, although lifetime and aesthetic considerations highly favor the storm window approach.

Along with appropriate insulation and high-quality air sealing (of envelopes as well as duct systems), using window systems such as these would open the way to improvements of 60% to

80% over historic buildings that are leaky, have little insulation, and are equipped with wood-framed windows with single glazing.

In general, improvements in U-value result in lower SHGC. Sometimes this is desirable, particularly in cooling-dominated climates, especially on west and east elevations. When designing appropriate storm windows for historic buildings, matching U-values and SHGC to facades is quite important. In Boulder and other climates with good sunlight for much of the year but also substantial heating loads, ensuring high SHGC for south-facing window systems that are not substantially shaded is much more important than achieving the lowest possible U.

Adding window film that adheres to existing glazing had no effect on U-value but did lower radiant heat transfer from the sun. However, since the film is mostly absorptive rather than reflective, glazings are heated by the film, causing them to transmit more heat (to both the inside and outside of the envelope) via the heat transfer mechanisms of long-wave radiation, convection, and conduction.

The most important conclusion flowing from this research is that it is possible to improve the overall energy performance of existing window systems by over four fold without altering their historic character through repairs, sealing, and the installation of an excellent storm window. This retrofit will also raise comfort substantially. The cost impacts of such measures vary depending on climate, materials used, and local fuel and labor rates. While the cost and payback of good quality retrofit work and storm windows exceeds the cost of new windows, in many areas replacing historic windows is not permitted under historic and landmark rules. Accordingly, such measures offer the only viable option for homeowners seeking greater comfort and efficiency from their windows.

Air temperature on the inside surface of a single-glazed window on a cold and windy day can be 40F or even lower. Assuming the efficient storm window retrofit developed in this project, applied in a climate akin to Boulder's, and an indoor room air temperature of 70F, the window surface exposed to the inside will rarely drop below 65F. This halves mean radiant temperature losses from human beings through windows, thereby improving comfort dramatically.

The result also protects the original window, improves its functionality, and likely provides for another century of life while retaining the home's aesthetic charm.

APPENDIX A. ANNOTATED BIBLIOGRAPHY

***ASHRAE 2005 Handbook of Fundamentals*, Chapter 31 on Fenestration, 69 pp.**

The ASHRAE 2005 Handbook includes a bibliography of 200 + technical papers on recent research in window technology. It is broadly considered the definitive text of currently-known energy science associated with fenestration.

Carmody, J., S. Selkowitz and L. Heshong. *Residential Windows: A Guide to New Technologies and Energy Performance*. W.W. Norton & Company. 1996.

This book is a useful primer on modern window technology, how specularly-selective surfaces work to optimize glazing performance in different climate zones, and educated projections on what the future holds for the development of more effective fenestration systems.

Fisher, Charles. *"Installing Insulating Glass in Existing Wooden Sash Incorporating the Historic Glass."* Preservation Tech Notes: Windows No. 3. Historic Preservation Education Foundation. 1985.

In this case study, Charles Fisher examines alternatives to upgrading 102 wooden windows in an historic Chicago office building. While the windows were in relatively good condition, there was considerable air leakage due to lack of weatherstripping, cracked putty seals around the glass, and shrinkage and cracks in the caulk around the outside frame. As part of the rehabilitation of the building, the windows were repaired, weatherstripped and retrofitted with an additional sheet of glazing using a technique that permitted creation of sealed insulating units in each sash. No alternative techniques to achieving efficiency gains were evaluated as part of this project and actual energy savings were not evaluated.

James, Brad, Andrew Shapiro, Steve Flanders, and Dr. David Hemenway. *"Testing the Energy Performance of Wood Windows in Cold Climates."* Report to The State of Vermont Division of Historic Preservation Agency of Commerce and Community Development. August 30, 1996.

This study, conducted by energy and environmental engineers, was undertaken to test the assumption that historic windows can be retained and upgraded to approach the thermal efficiency of replacement sash or window inserts. In the study, non-infiltrative losses (conduction, convection and radiation) were modeled using a computer simulation of thermal fenestration performance. Infiltration was measured by field testing 151 windows in various stages of repair, mostly in Vermont. The results were used to model three window infiltration scenarios: typical, tight and loose. Estimated annual energy costs of these assumed windows were used to estimate energy cost savings associated with various efficiency treatments. This study revealed several interesting results – among them the multitude of environmental and site specific factors that can impact energy savings results associated with a given treatment. Because the authors evaluated a large sample of windows in different stages of upgrade, rather than measuring the "before" and "after" efficiency gains of renovated windows, their results required a high degree of "normalizing" the data to achieve anecdotal results.

Kinney, Larry. "Windows and Window Treatments," Prepared for the USDOE's Building America Program. September 2004.

This report details a study of energy efficient window options with an orientation to the Southwest. It defines a number of technical terms in layperson language and discusses window system applications in new and retrofitted residential structures in a six state region that includes Colorado. It includes an extensive discussion of the importance of matching window characteristics to facades to optimize energy performance. Results of simulations using RESFEN software are given in both tabular and graphic form.

McGrew, Dr. Jay L., David P. McGrew and George P. Yeagle. *"Integrated Heat Flow in Windows."* A report to the Energy Research Foundation. July 1978.

This study, conducted in Denver Colorado, looks at the heat flow characteristics of historic windows. The study authors argue that evaluation of U-value – the primary element of structural heat flow evaluated in studies up to that time – offered a poor estimate of heat flow in most cases. They sought to develop a more theoretically sound and accurate estimation of heat flow. Towards this end, the study authors developed a computer model that considers the transient nature of window heat flow, and includes all relevant variables such as geographical location, window orientation, geometry, eave overhang, and environmental effects such as sun, wind and cloud cover as well as the component temperatures. The authors' research compared the heat flow properties of single pane versus double pane windows, (add comma) and used experimental measurements to verify their theoretical model. Finding that the two did not match, they made corrections to compensate in the model. This study was quite innovative for its time, however its relevance today is limited. The study relies entirely on computer modeling circa 1978, which may well have been a precursor to today's RESFEN, which is based on DOE2 models, but with less sophistication, a smaller range of potential variables and a lower degree of accuracy. Additionally, the study does not utilize residential site measurements in historic structures or isolated laboratory measurements to verify and refine the models findings. Finally, the study looks only at the addition of a pane of glazing as an alternative efficiency scenario and ignores other possible treatments such as various coatings that may provide valuable solutions for historic structures.

Park, Sharon C. *"Thermal Retrofit of Historic Wooden Sash Using Interior Piggyback Storm Panels."* Preservation Tech Notes: Windows No. 8. Historic Preservation Education Foundation. 1980.

This report, by architect Sharon C. Park, AIA, is a case study that looks at several alternatives to improving the energy performance of 506 windows in an historic office building in downtown Oklahoma City. The following approaches were investigated: 1. Repairing the existing windows; 2. Adding weather stripping to the existing units; 3. Adding a second layer of glazing to the existing windows, either as a separate storm window or as applied storm panels; 4. Replacing the existing windows with new double-glazed thermal windows. The need to maintain the visual integrity of the historic structure and to stay within budget eliminated two of the four options, as reported in the case study:

> "The need to seek a cost-effective and yet compatible solution quickly eliminated two common options. The first was the use of an exterior storm window since it would have altered the deep setback which was a character-defining feature of

the building. The second alternative was the use of a modern replacement window. The cost of replicating 507 double-hung windows out of wood and installing thermal glazing was beyond the budget of the owner. A much less expensive solution, which was investigated, involved the replacement of all windows with a metal frame, fixed sash and solar grey heat absorbing insulating glass. While the cost estimate of $300 per unit was within the budget, the architect felt that such a solution was unacceptable since it would have drastically changed the building's historic appearance."

After careful evaluation, the decision was made to fit a new storm panel to the existing sash in a manner that was cost-effective and also preserved the window's distinctive qualities. The project resulted in a cost-effective solution for the building owner, however, this study did not involve any direct measurement of the resulting thermal gains of the applied window treatments.

Sedovic, Walter and Jill H. Gotthelf. *"What Replacement Windows Can't Replace: The Real Cost of Removing Historic Windows."* APT Bulletin: Journal of Preservation Technology. 36:4, 2005.

Mr. Sedovic and Ms. Gotthelf argue that replacing historic windows is inherently less sustainable that preserving them. This conclusion is based on several arguments: 1. the embodied energy associated with materials used in most replacement windows is high, 2. since restoration relies on labor more than materials, restoration contributes to local economies, supporting economic sustainability, 3. the materials used in most window replacements degrade and are difficult to reuse or recycle while historic windows can last up to 100 years with minimal maintenance, 4. window manufacturers' efficiency claims are often skewed or misrepresented, and 5. addressing the primary sources of energy waste in historic homes, namely air leakage and insufficient insulation can be cost-effectively accomplished without replacing windows. While many of these arguments are valid, Mr. Sedovic and Ms. Gotthelf make several massive generalizations that are patently designed to influence the reader toward their opinions with no data provided to back up their claims.

Trissler, Wayne and Charles Fisher. *"Exterior Storm Windows: Casement Design Wooden Storm Sash."* Preservation Tech Notes: Windows No. 3. Historic Preservation Education Foundation. 1984.

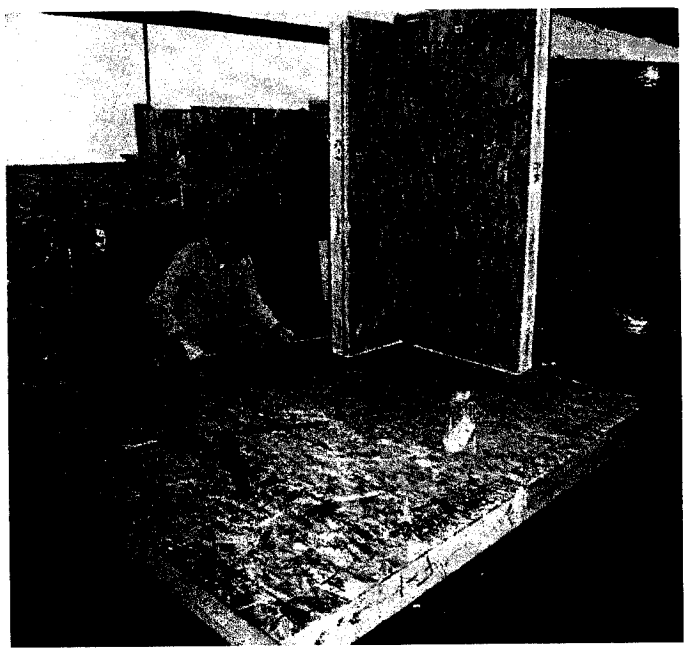
This case study looks at efforts to upgrade the efficiency of historic windows in a two-story historic gatehouse in New York. The windows are prominent features of the building, and although in good condition were energy inefficient. Although careful consideration was given to restoration methodology and the need to meet specific historic considerations, design and energy efficiency goals, no consideration was given to alternative approaches to achieving these goals. The windows on this structure were fitted with custom-made exterior storm windows that meet specified performance criteria and yet minimize both damage and visual obstruction to the historic windows.

APPENDIX B. WINDOW TEST FACILITY CONSTRUCTION

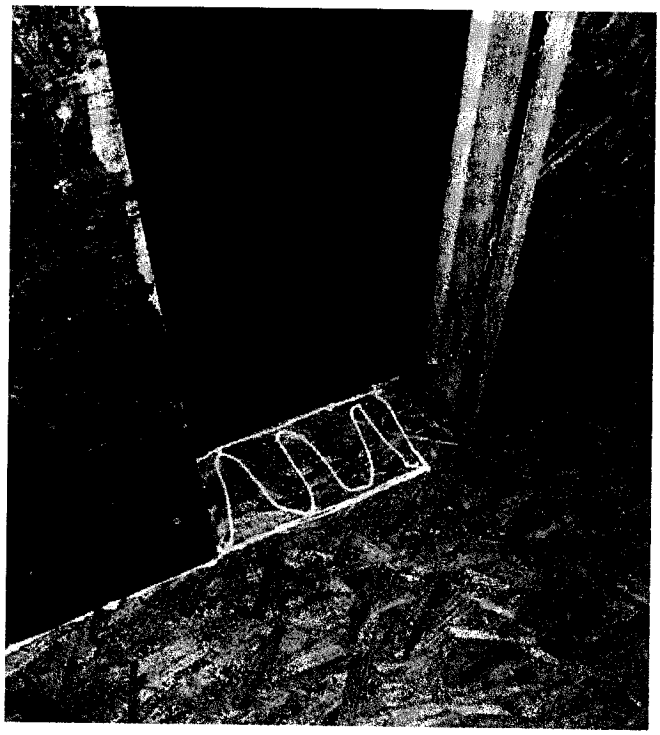
In order to isolate and study the efficiency properties of window units, the study team constructed a super-insulated, tightly-air-sealed window test facility chamber. The facility was calibrated with no windows in place, which allowed the team to determine the chamber's heat transfer coefficient (U factor) with an insulated plug in place of a sample window. Then, when a window is tested, the difference in U can be assigned to the window. Once U factor is known, heat loss (Q) can be determined for any difference in temperature or cross sectional area of the window. So, for example, if one has data for a typical meteorological year for a given locus, one can calculate winter heat losses by summing up hourly heat losses.

For this project, we used techniques that are sound but cost effective. A considerable amount of labor, materials, and instrumentation were donated to help the study achieve its goals.

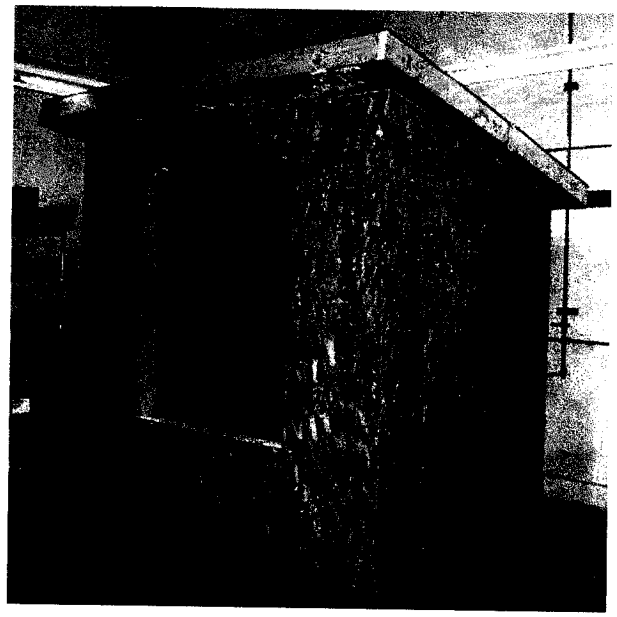
The following pictorial depiction follows construction and testing of the chamber.



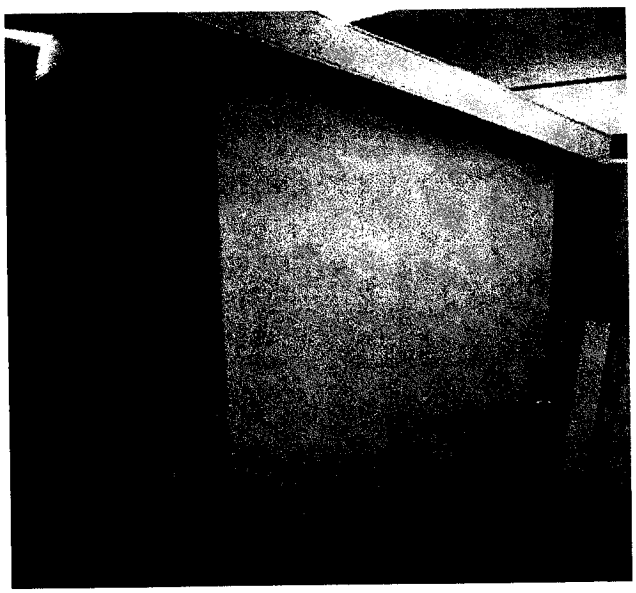
The test cell was constructed using structural insulated panels composed of oriented strand board on either side of urethane insulation. The photo on the left shows the first corner of the test cell being set into place.

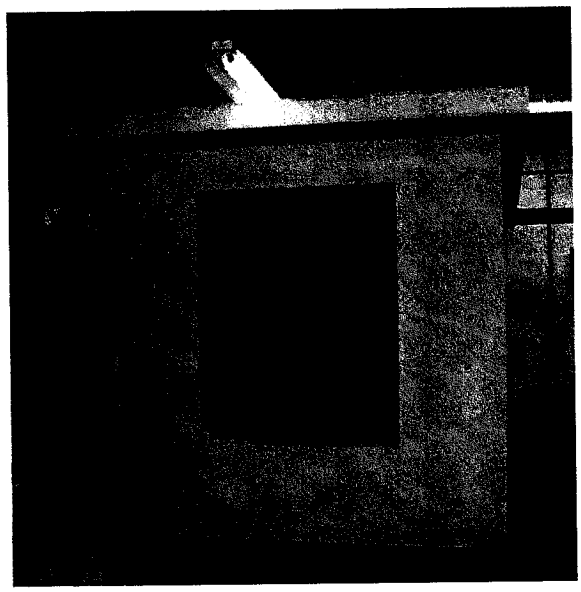


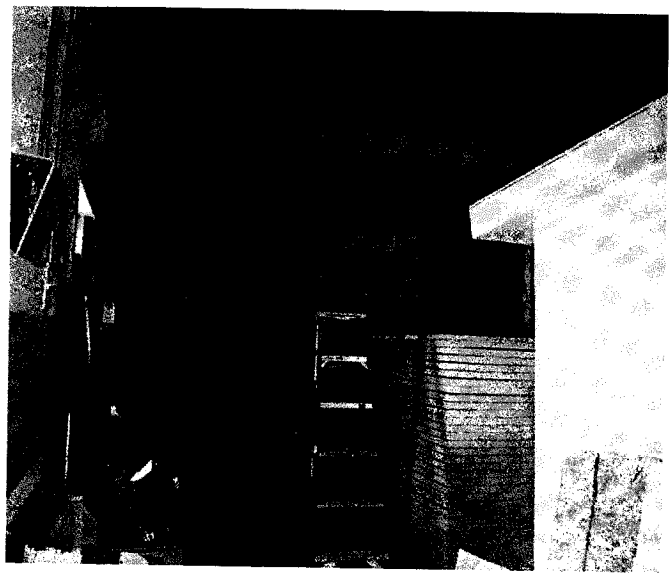
Each joint was sealed using urethane foam insulation and caulk to ensure joints were well sealed. The team used clamp hooks to snug the walls together. Then, wheels were installed to roll the test cell in and out of the chamber. The photo below shows the constructed test cell following a day's work.

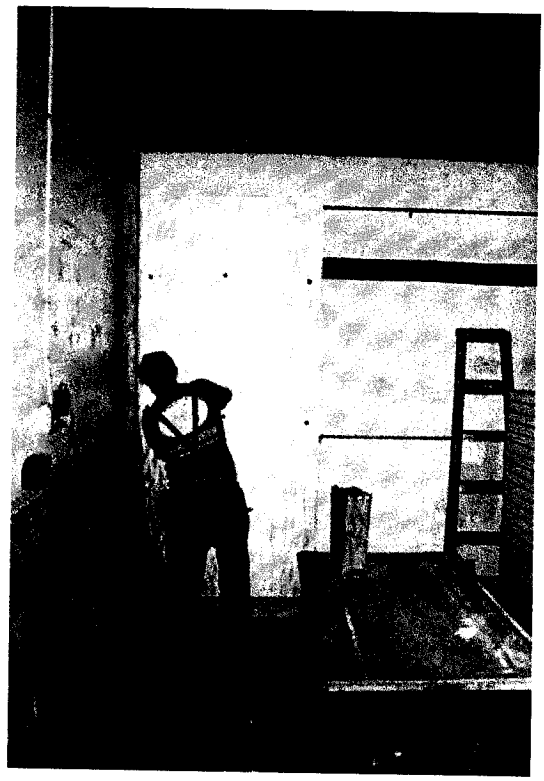


Fourteen tubes of caulk were applied to the post-assembly test cell. Three coats of vapor barrier paint were then applied inside and out to ensure well-sealed construction.

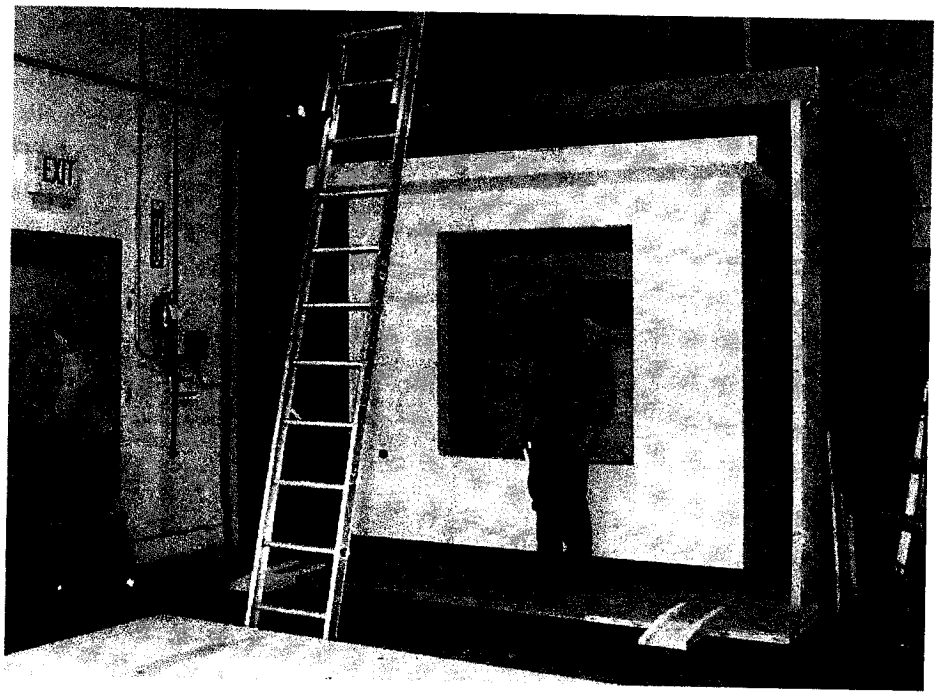






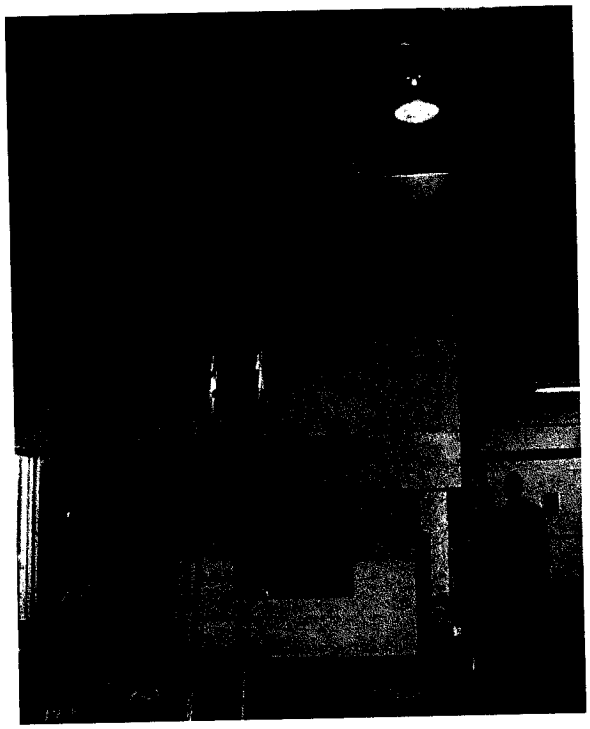


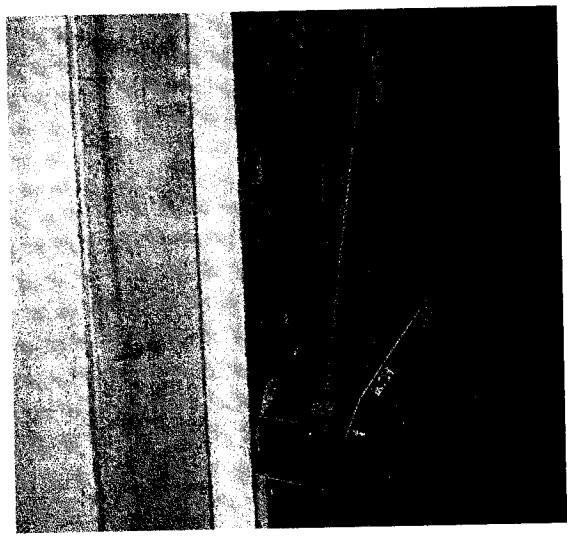
The chamber was framed into the corner of a warehouse. The existing walls were first covered in two inches of polyisocyanurate (R-13).

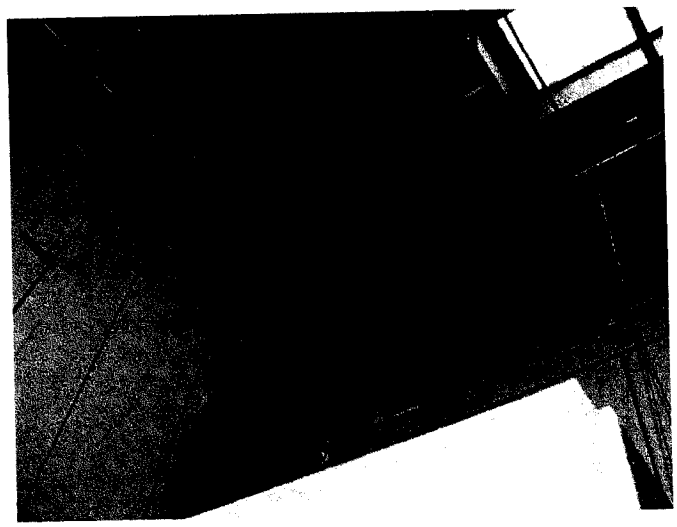


The photo on the left shows three walls of the chamber completed with the test cell inside. The outer chamber, likewise well insulated and sealed, is cooled while the test cell is heated to test U values.

The technical team constructed a 380 pound door (see photo at left), insulated with both fiberglass and polyisocyanurate to R-25. The photos below show a winch and pulley system, suspended from steel roof rafters, used to open and close the chamber door.



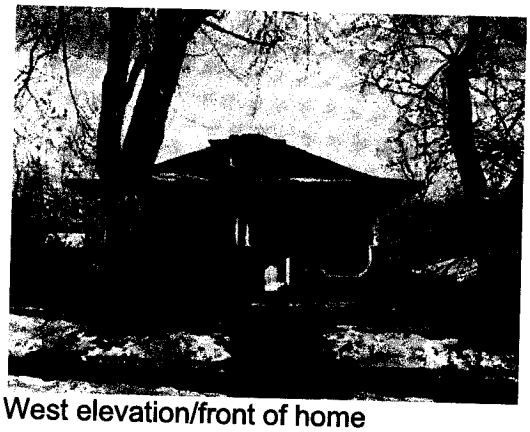




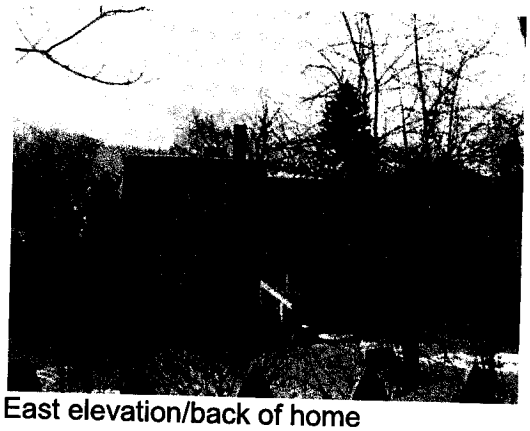
APPENDIX C. FIELD WORK DETAILS

Part of the process of preparing this research design included examining approximately ten potential homes and interviewing homeowners. The result of this process was the selection of a 108 year home in a historic district in Boulder owned by Gretchen Lang and Michael Wilkins. The Synertech team performed an extensive energy audit of the home on January 4, 2008. This appendix consists of a selection from the 75 photographs taken during the audit.

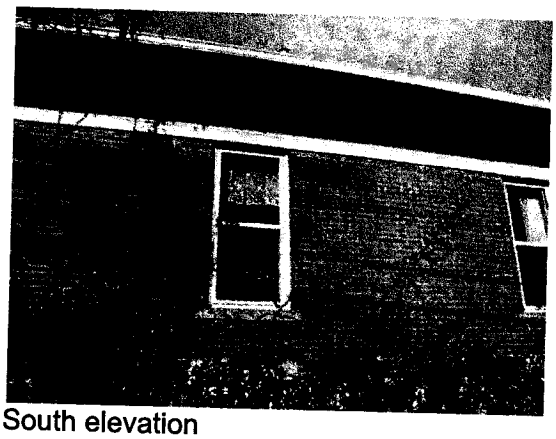
The following are exterior views of the home and its windows.



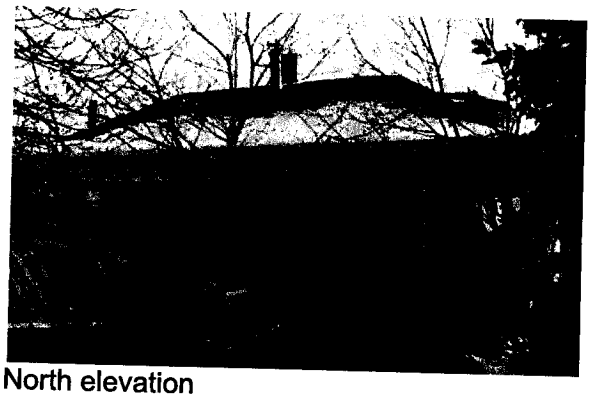
West elevation/front of home



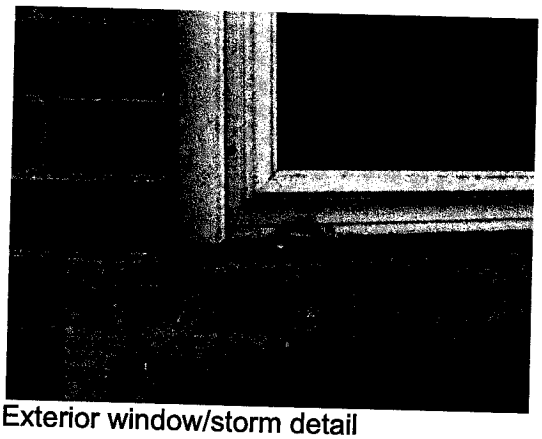
East elevation/back of home



South elevation



North elevation

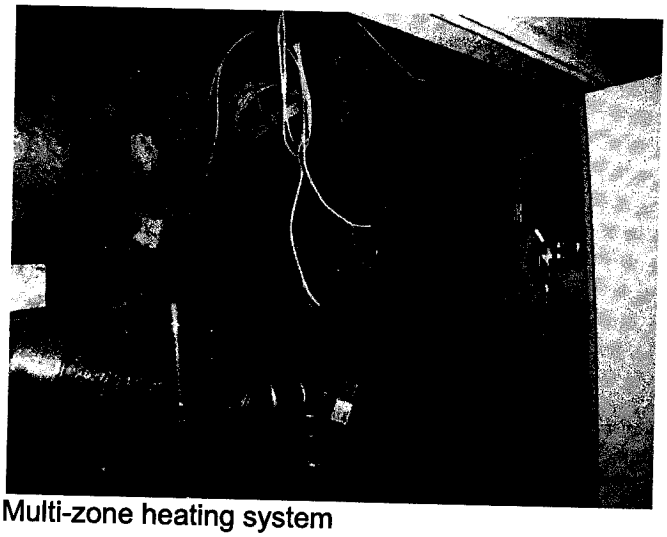


Exterior window/storm detail

Blower door test

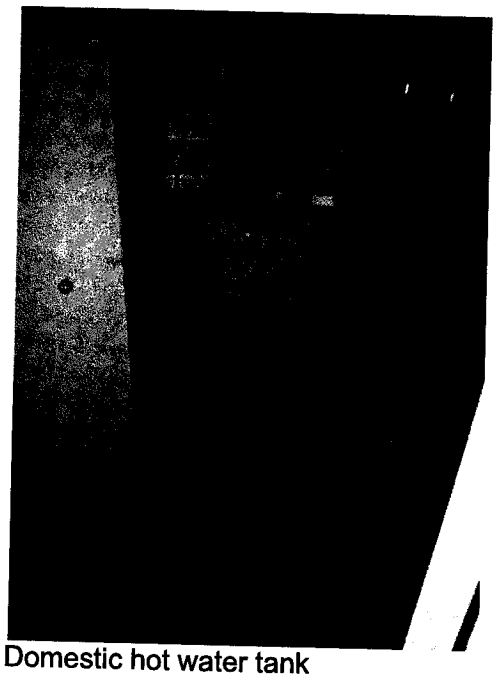
The two-story 2700 square foot home is quite leaky; the blower door reading showed 3500 cfm of leakage when the conditioned envelope was depressurized to 50 pascals of pressure. (Between the audit and the retrofit of the home, the homeowners undertook a number of air sealing measures—none of which had to do with windows—which resulted in lowering the blower door reading to 3000 cfm at 50 pascals. As reported in Section 3, the window work resulted in bringing the leakage down to 2860 cfm at 50 pascals.)

In spite of spotty insulation in the attic (see photos at left and below) and none in the walls of the old portion of the home (there's a newer addition on the back—east—façade of the home), air leakage accounts for approximately half of the heating load on the home. Such leakage causes energy waste and discomfort, and can shorten the lifetime of beautiful old homes like this one.

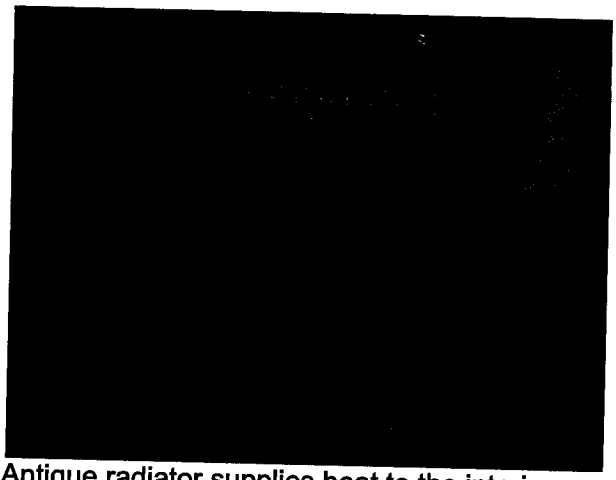


Multi-zone heating system

The home is heated by a multi-zoned, gas-fired boiler expertly installed by the homeowner. One zone, controlled by an aquastat, heats water in a "side arm" tank which supplies the home's needs for domestic hot water.

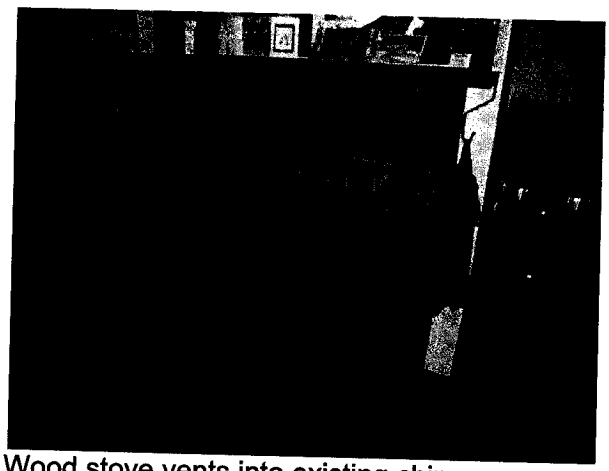


Domestic hot water tank



Antique radiator supplies heat to the interior

In addition, a good deal of the heating load is met by a wood-burning stove mounted in front of a chimney centrally located in the home's living room. The modest cooling load is met by an evaporative cooler on the roof. Of consequence to the window retrofit, distribution of cool air from the evaporative cooler involves opening a number of windows to direct cool air to spaces that need it.



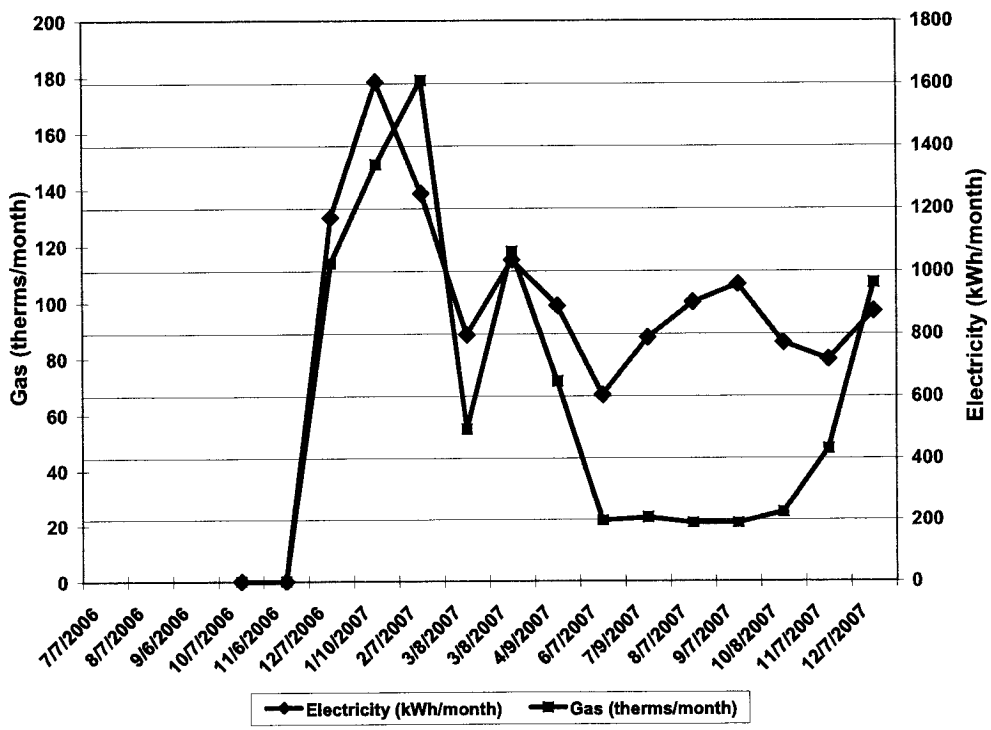
Wood stove vents into existing chimney

Table C-1 summarizes the use of gas and electricity in the home broken down by baseload, heating and cooling. Heating energy is normalized to home size and weather. Figure C-1 shows fossil fuel energy consumption by month.

Table C-1. Annual Energy Consumption

Annual Energy	Total	Heating	Cooling	Baseload	Air leakage
Gas (therms/yr)	840	677.5	na	162.5	341.7
Gas ($/yr)	$781	$630	na	$151	$318
Electricity (kWh/yr)	11,194	1,591	248	9,356	922
Electricity ($/yr)	$896	$127	$20	$748	$74
Total (MMBtu/yr)	122.2	73.2	0.8	48.2	36.9
Total ($/yr)	$1,677	$757	$20	$900	$392
Estimated portion of heating and cooling costs due to air leakage					50%
Normalized annual consumption (Btu/ft^2/heating degree day)					3.8

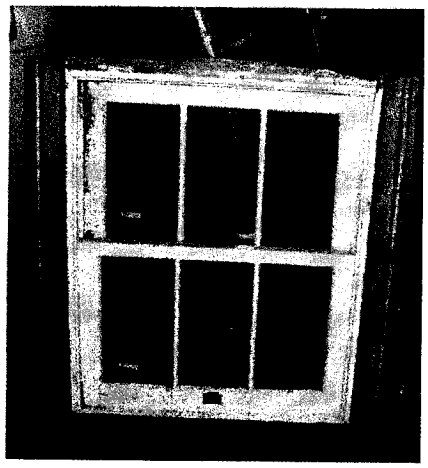
Figure C-1. Gas and Electric Consumption by Month



APPENDIX D. ALTERNATIVE APPROACH TO AIR SEALING AND INSULATING COUNTERWEIGHT POCKETS

Introduction

Unlike newer windows, older double-hung window systems routinely include un-insulated boxes on their sides that contain iron weights, ropes, and pulleys. The ropes connect weights to the frames of moveable lites of the window systems, thereby providing counter-balancing forces that aid in opening the windows. Such boxes constitute a large portion of the fixed part of the window frames. A combination of visual inspection, blower door testing, and infrared scanning reveal that these boxes are frequently the source of substantial convective and conductive energy losses in summer and (especially) winter. Thus, the combination of large cross sectional area and thermal leakiness of the frame means that even if glazing is replaced with excellent insulating glass, the overall performance of the window system is doomed to be modest at best.



Old window with closed counter weight pockets

The study team explored two options for retrofitting counter-weight pockets. What we call "the spring solution" eliminates the function of the box, replacing its weights with a spring mechanism and stuffing the box with fiberglass insulation. This solution was employed on the test home, as illustrated in Section 3. What we call "the column solution" retains the function of the box and its weights, replaces old rope with new, inserts a plastic column inside of which the weights may slide, and adds urethane foam to the remaining spaces within the box. In both cases, air sealing and insulating are achieved. If carefully done, finished retrofits are invisible to the naked eye.

This appendix consists of an annotated set of photographs aimed at illustrating the problem and showing details of the column approaches to solving it.

The problem

Counter weights are heavy solid iron cylinders attached to the windows via ropes. These weights slide up and down in uninsulated vertical boxes on each side of the window. These boxes are frequently leaky to the outsides of homes. Cold air can enter the home through pulley holes and other cracks. Both conductive and convective energy waste are the unhappy results (along with discomfort).

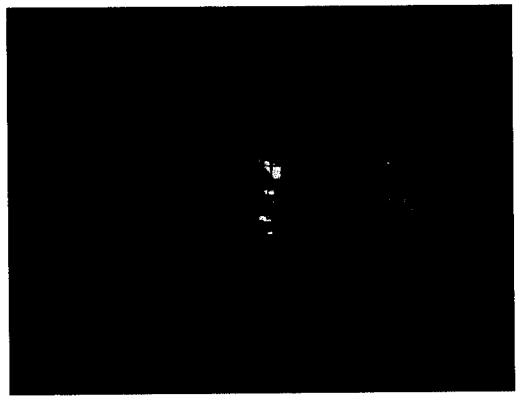
Open pocket with counter weight

Ropes connected to these weights pass over pulleys and down the inside edge of the window frame and sash. The sash is usually equipped with a hole drilled in

both its vertical outer edges to accept a knot tied in the ends of the ropes thereby securing the weights to the sash.

With the column solution, the aim is to retain the virtues of the old counter weights without suffering their problems.

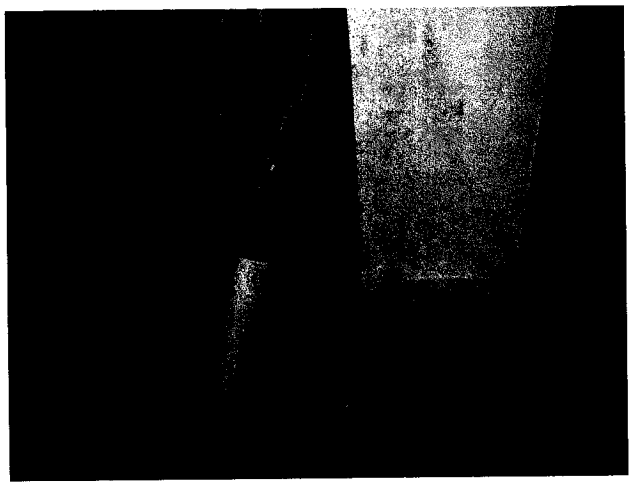
First, we tested the window "as is" in the test chamber. A 4 x 5 foot insulated plug was adapted to fit the window. The plug was fitted in the chamber and tested for air leakiness, then U value.



Window in the test chamber

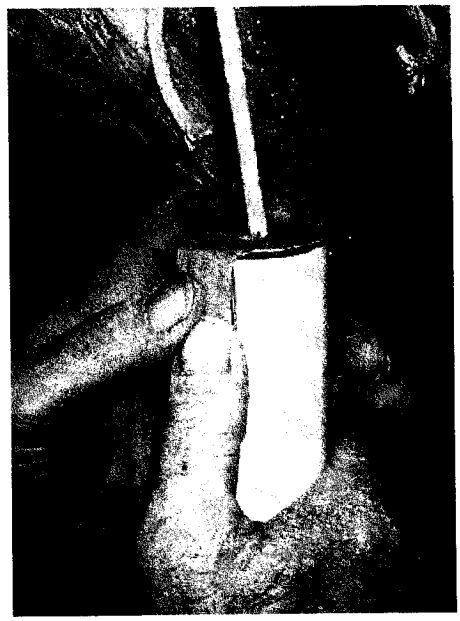
The column solution

Inserting a plastic pipe, whose inside diameter is just larger than the outside diameter of a counter weight is the key to the solution. The weight slides inside the pipe while the rest of the open space in the counter weight box is sealed with expanding foam insulation such as urethane.



Sliding counter weight into PVC tube

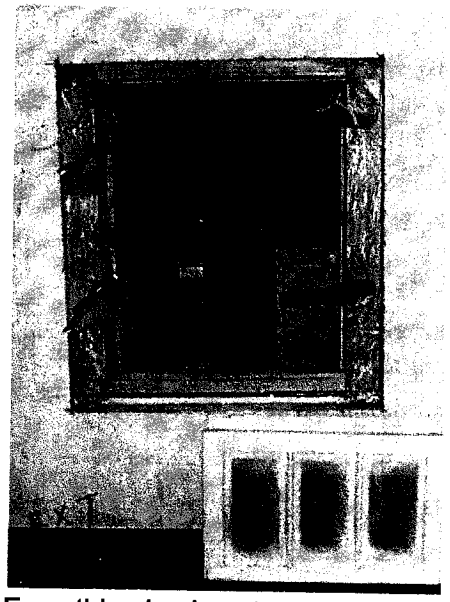
New weight ropes are installed and cardboard and packing tape is used to seal up both ends of the PVC tubes to prevent urethane from penetrating the area where the weight slides.



Cardboard in place over PVC tube

Adding urethane to pocket

Urethane is applied in layers to ensure weight tubes are completely surrounded – foam (shown), 1st tube inserted, foam, second tube, and still more foam. Foam expands several fold while curing.



Everything in place to cure.

Urethane sticks to almost everything, but not plastic sheeting. Technicians wrap boards covering the box in plastic to facilitate post-cure inspection, then clamp them down and test the movement of the ropes.

Cure is complete in a few hours. Clamps are removed, rope functionality is verified, and the cracks are sealed.

Post-retrofit testing indicates an eight percent improvement in window performance. No doubt it would be more under windy conditions.

APPENDIX E KEY MEMBERS OF THE PROJECT TEAM

Amy Ellsworth, Project Manager. Ms. Ellsworth has 17 years of project management and practical experience in the energy efficiency, renewable energy, and climate change arenas. Her experience includes a broad range of project analysis, program design, and policy work. Currently a Senior Associate with the Cadmus Group, Ms. Ellsworth works with utilities and local governments to design energy efficiency, demand reduction and conservation programs. Ms. Ellsworth provided broad oversight for the project and led reporting and facilitation between the technical team, historic homeowners, funding partners, and stakeholders.

Larry Kinney, Technical Team Leader. Larry is the cofounder and president of Synertech Systems Corporation, a Boulder-based energy efficiency research and development firm founded in 1984. Active in energy conservation research for over 35 years, he has broad experience in weatherization program operations, fenestration systems, lighting and daylighting technologies, energy-efficient refrigeration, air handling and conditioning systems, and controls. He did undergraduate work in Physics and Philosophy at Davidson and Rhodes colleges and holds a PhD in Philosophy from Syracuse University. Larry has authored over 200 publications and reports to clients and is the co-holder of three patents in the daylighting area. He led the technical research of the present study and is the principal author of this report.

Gerald (Gary) Cler, Technical Team. Gary is an independent consultant specializing in energy efficiency, daylighting, renewable energy, and combined heat and power (CHP) applications. He did undergraduate work in Mechanical Engineering at the University of Illinois and holds a Masters Degree in Mechanical Engineering from Colorado State University. Gary was the principal designer and assembler of the window test lab, developed the analytical spreadsheet, and played key roles in laboratory testing and data analysis.

In addition to these team members, the study benefitted greatly from volunteer labor that contributed both expertise and enthusiasm to the work of the project.

Conservation Services Group

Residential Retrofit

Conservation Services Group (CSG) is the market leader in the movement to optimize energy efficiency in residential buildings. Residential retrofitting is designed to reduce a home's energy consumption by using cost-effective measures without extensive remodeling work. This work defines CSG's core competency since our inception.

We specialize in designing and implementing mid-to large-scale programs that provide in-home audits, contractor training and certification, and quality assurance, and which promote comprehensive energy improvement packages. CSG also often handles incentive processing for diverse program designs. These creative, cost-effective programs ensure measurable and ongoing energy savings resulting in economic, environmental, and other important benefits.

From new program design to measurable results, our established internal processes and best practices enable streamlined start-up, training, implementation, marketing, quality control, and reporting functions. We work with utilities and state and federal agencies to build successful home energy assessment programs nationwide. We also partner with our clients to establish networks of trained contractors that use the latest building science techniques and standards, including:

- Safety testing of combustion appliances
- Blower door — to evaluate building leakage
- Duct blaster — to test duct system performance
- Infrared camera — to detect deficiencies in insulation & air sealing

Why is Residential Retrofit Important?

Energy conservation is often referred to as the "least-cost" energy strategy, and for good reason. Reducing consumption of energy does more than just save money; it also reduces the costs associated with today's environmental and social challenges. CSG collaborates with partners and other stakeholders to develop and implement effective programs that help reduce energy demand and educate consumers on the benefits of energy efficiency.

Key to Success:

The "Whole House" Approach

CSG uses the "whole house" approach to the extent possible within any program. This means that we consider, along with health and safety measures, the following:

- Thermal envelope — air leakage and insulation improvements
- Mechanical systems — HVAC upgrades, renewable electricity generation, solar thermal and domestic hot water
- Appliances and lighting
- Occupant behavior

The whole house approach is a framework to view these interactions given energy usage rate, building site, and climate to assess a home's overall performance. We can then make the most effective targeted recommendations for improvements to ultimately reduce residential energy demand.

About CSG

CSG is the leading provider of residential energy efficiency programs in North America, providing proven expertise to utilities, state agencies, trade allies and homeowners looking not only to save money but also to improve home durability, safety and comfort.

Comprehensive, high quality programs that deliver lasting and measurable results have been CSG's sole focus for nearly thirty years. We pioneered residential energy efficiency in North America, and conti[illegible] to deliver our unique b[illegible] expertise and innovation [illegible] and every client and program.

What People Are Saying...

"Without CSG's expertise and their data management system this program would not be as successful as it is today. Thanks again and I look forward to working with CSG in the future!"

—Contractor, Southwest Region

Contact Us

For more information contact CSG at: info@csgrp.com or 508.836.9500, or visit www.csgrp.com.

Conservation Services Group

Measuring & Scoring Home Energy Performance

Think of an energy performance score as an asset based "miles-per-gallon" type of metric for single family homes, based on modeled energy consumption. CSG is both an architect of the software algorithms used to deduce scores, and also is helping to secure essential information about how these systems can act as a tool for strategic customer engagement nationally. An energy performance score:

- Enables homeowners to understand whether their home was designed and built efficiently
- Allows homeowners to visualize potential energy savings from recommended improvements
- May be used to help homeowners compare their usage with similar homes
- May be used in a real estate transaction by the seller to showcase the home's energy improvements
- Enables a home buyer to compare their annual energy use and associated carbon emissions with a home of similar size

Our Programs Deliver Results

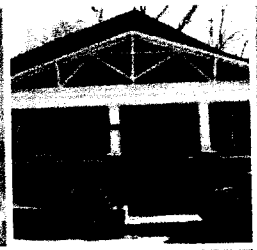
CSG contributed to the completion of nearly 40,000 residential efficiency projects in just one year with an average 30% per-project reduction in energy use, all due to our work delivering energy efficiency programs. Residential retrofit programs we design and implement have included direct installation of measures, walk-through and online audits, tiered audit programs, and comprehensive whole house audits, including Home Performance with ENERGY STAR®.

When home assessments/audits and energy evaluations lead residential customers to act on recommendations and invest in energy efficiency improvements, we count the results as "completions" (as shown in the table). The results are many thousands of MBTUs saved every year, and multiple benefits for our clients, homeowners and the environment.

*Measurable Results, Program To Date**

	Savings in MBTU	Completions
Arizona (APS/Salt River Project)	18,728	2,959
Oregon (Energy Trust of Oregon)	46,054	2,480
Illinois (Ameren ActOnEnergy)	34,226	904
Maine (Efficiency Maine)	183,922	3,211
Massachusetts	854,401	47,305
New York (NYSERDA, LIPA)	1,487,702	45,055
New Jersey	121,463	7,872
Ohio (Columbia Gas of Ohio)	193,368	6,225
Tennessee Valley (TVA)	95,863	17,574

*Selected programs implemented in whole or part by CSG. Totals exclude multifamily, direct install, new construction and renewables completions.



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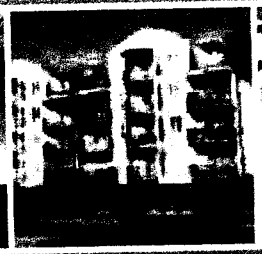

2011 National Weatherization Training Conference

Advanced Diagnostics: Duct Leakage Testing

Adam Harris, Dale Sherman – NYSWDA

Michael Stahl – Environmental Management Consultants

Marquam George - UAS

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Why Duct Leakage Testing?

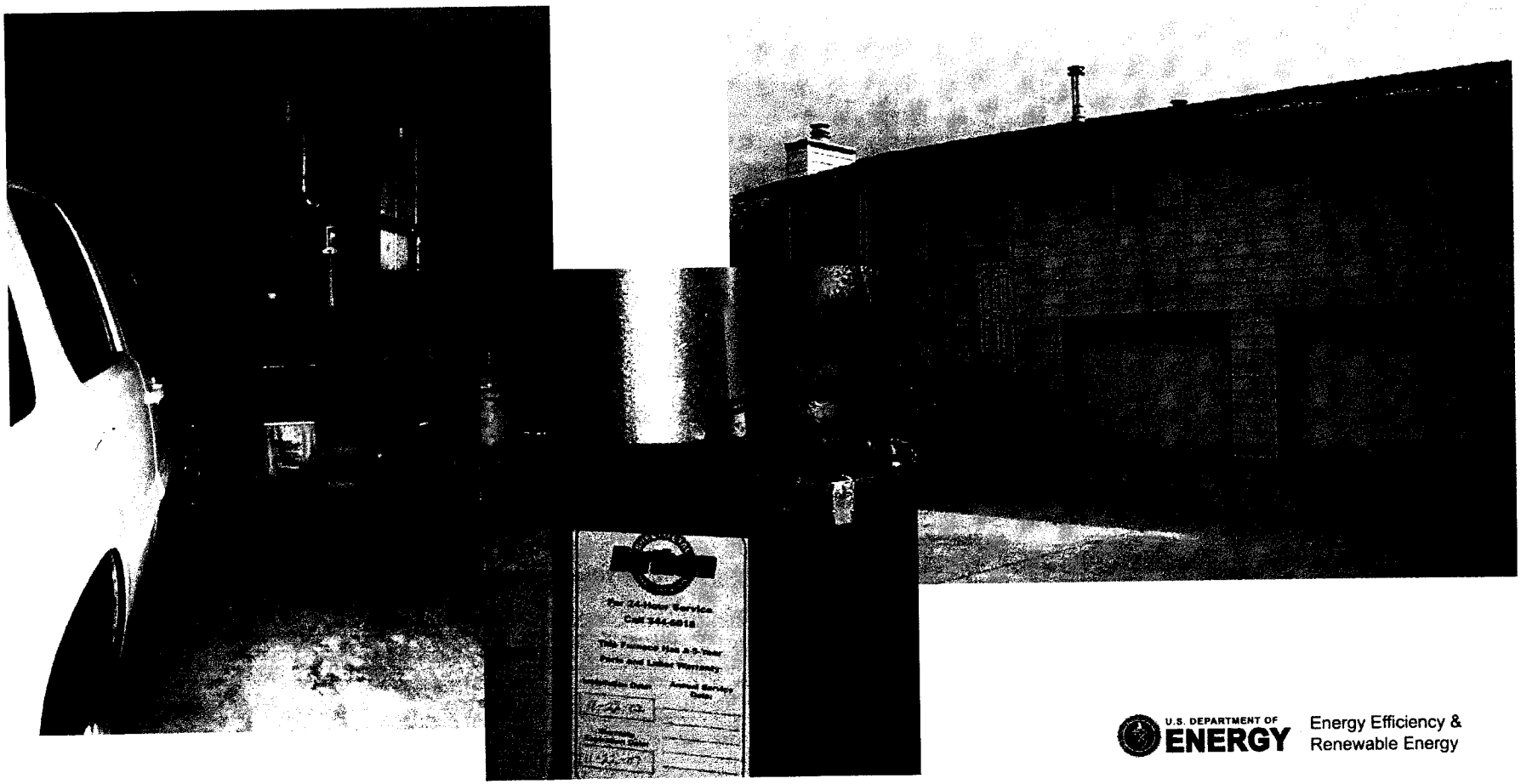
- Studies indicate that duct leakage can account for as much as 25% of total house energy loss

Why Test & Utilize Diagnostics?

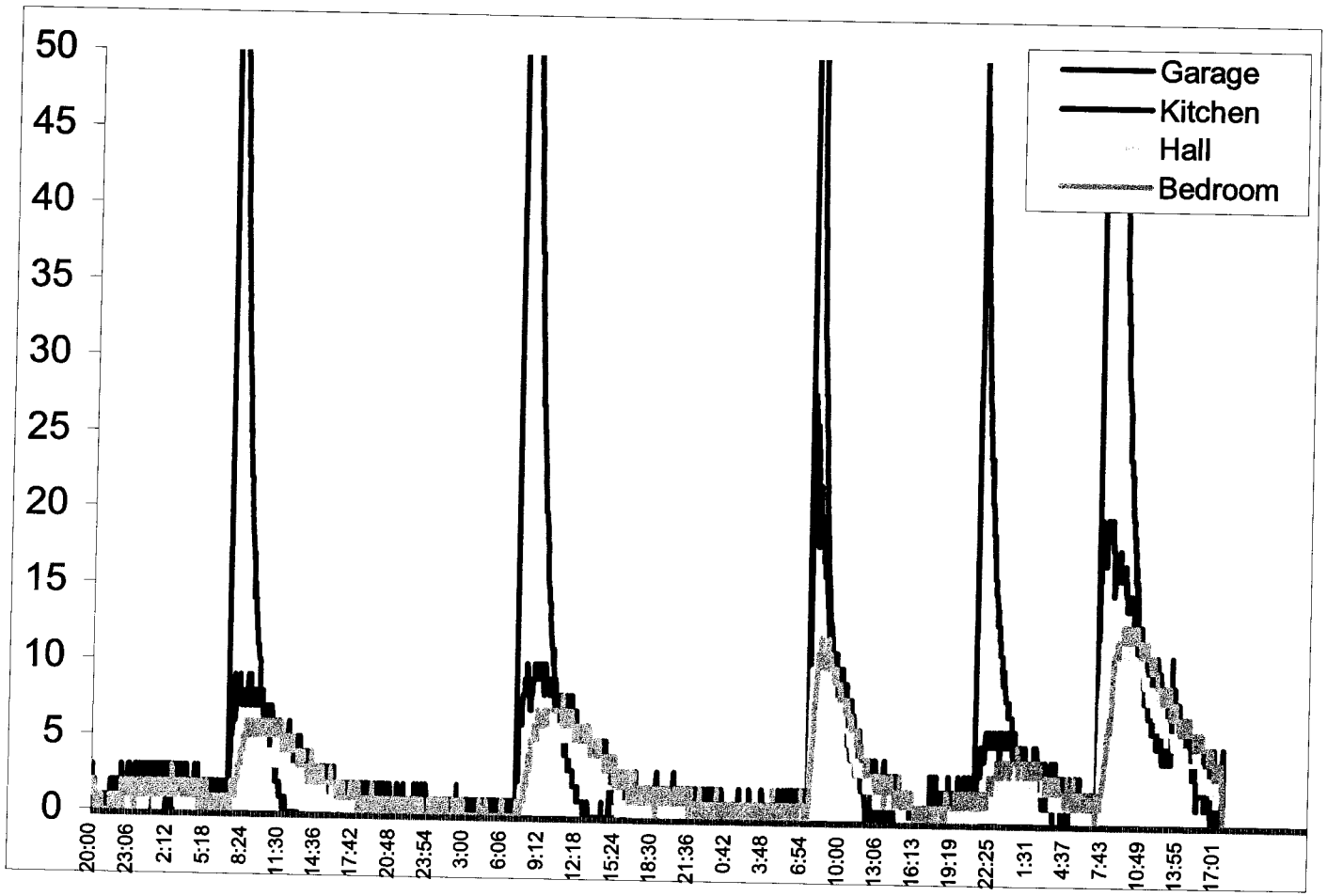
- Troubleshooting comfort and performance complaints
- Measure effectiveness of duct sealing
- Estimate annual HVAC system losses from duct leakage
- Certifying compliance

Why? Building Durability

Why? Compliance



CO[illegible] 2011 National Weatherization Training Conference

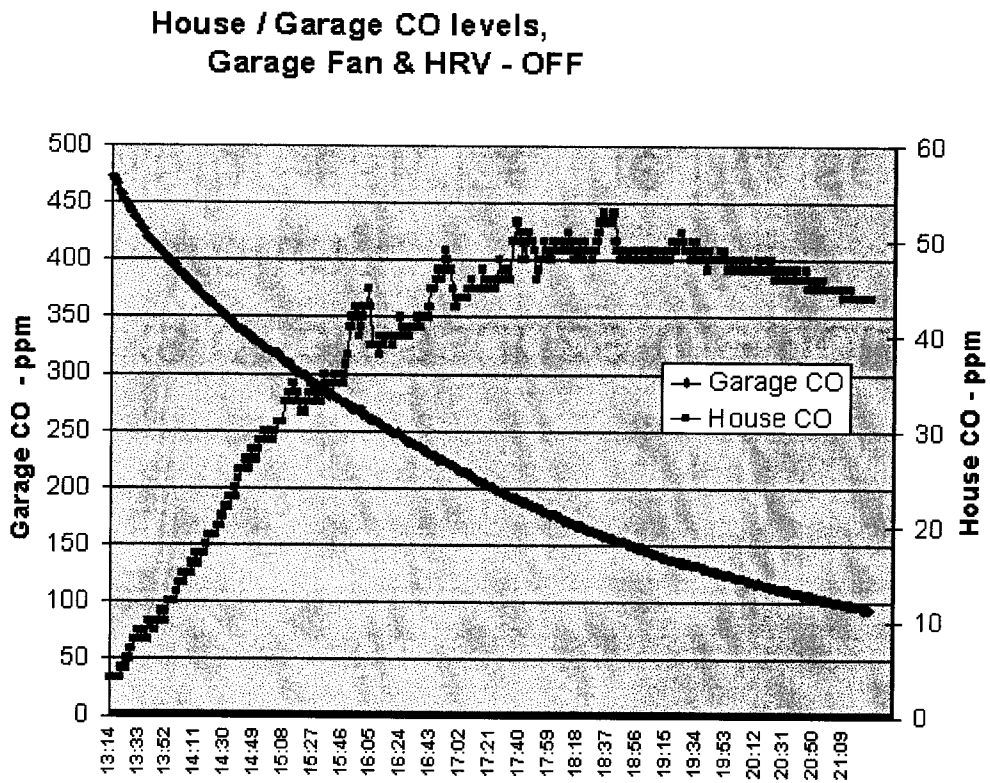


Why? Unplanned Airflows

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

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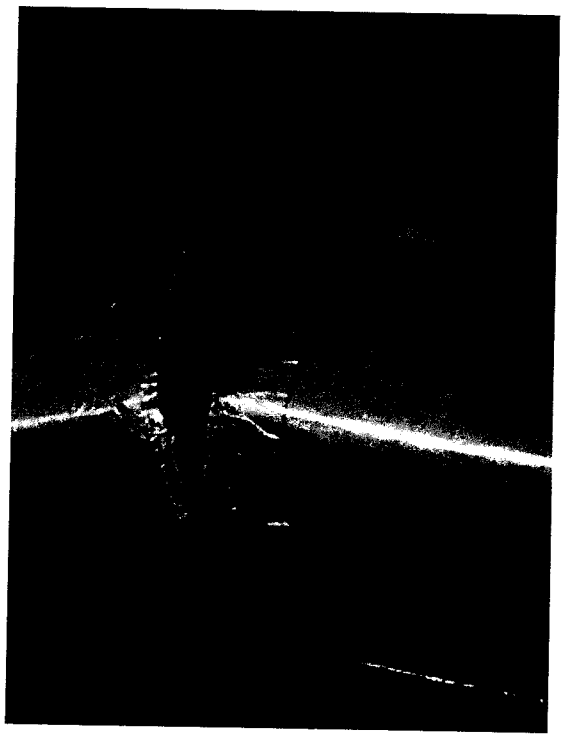

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Pressure pan testing

- 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

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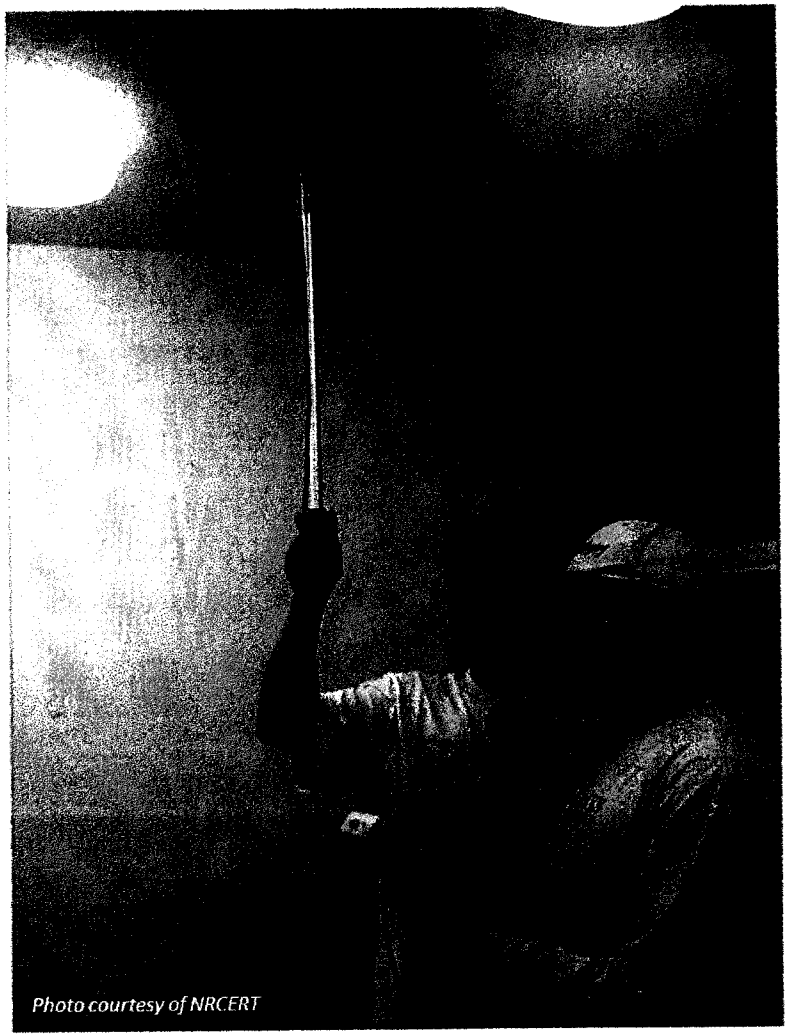

Photo courtesy of NRCERT

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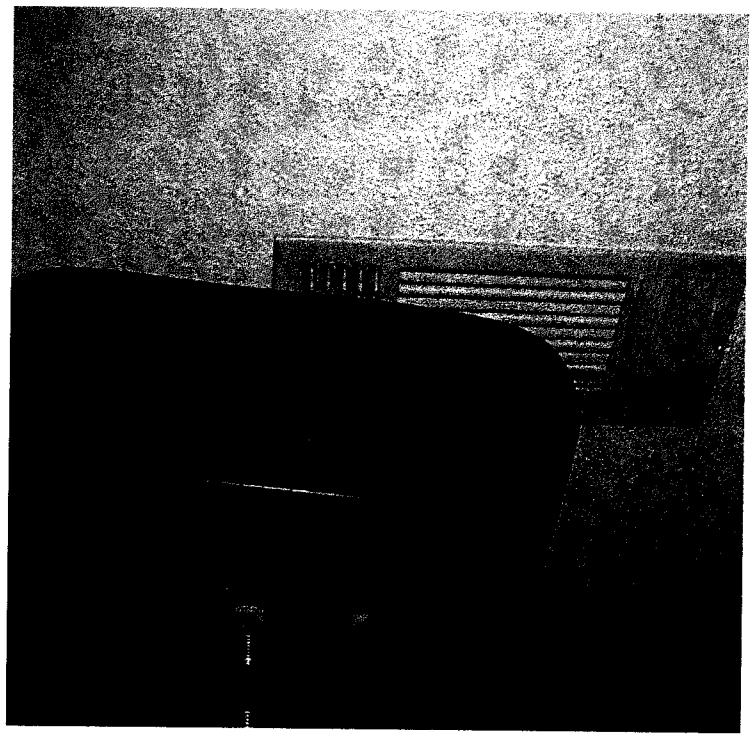
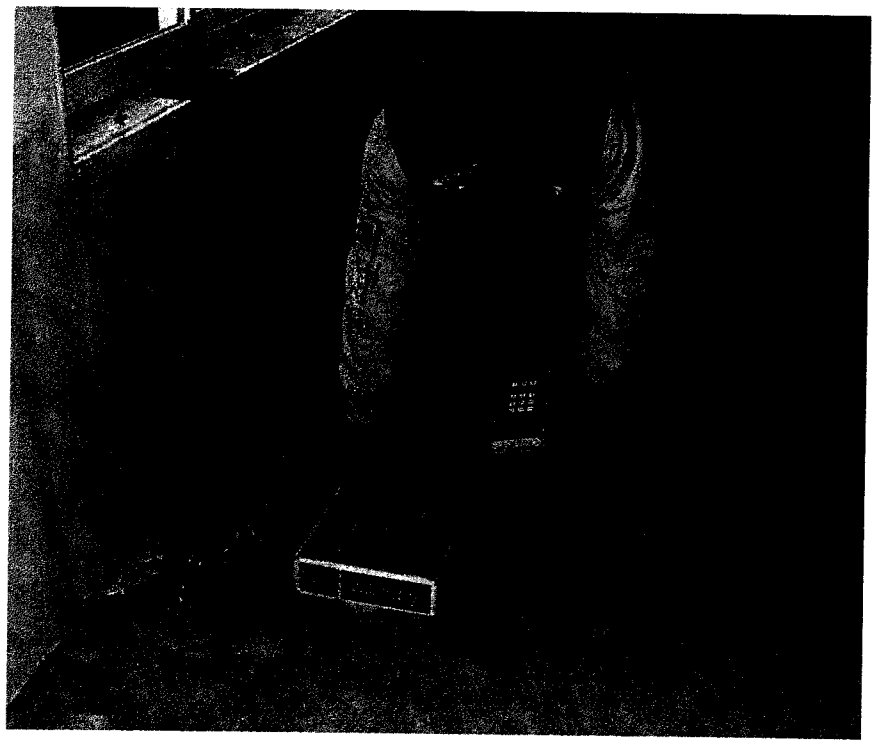
Pressure Pan





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

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"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

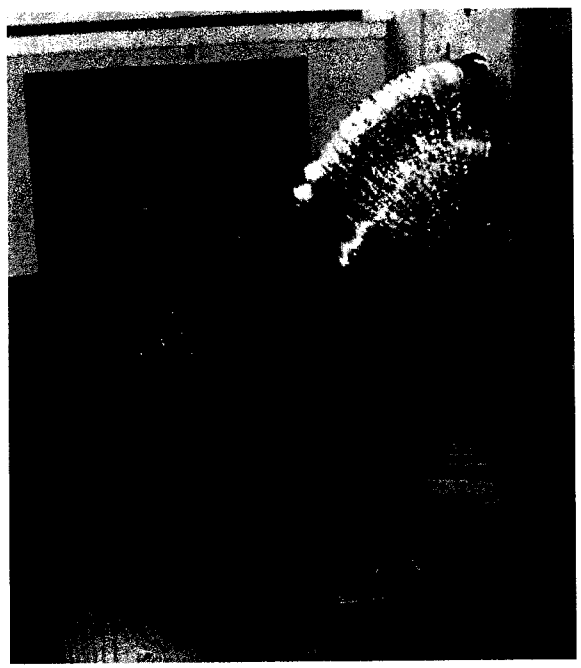
Total Duct Leakage Procedure

- 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

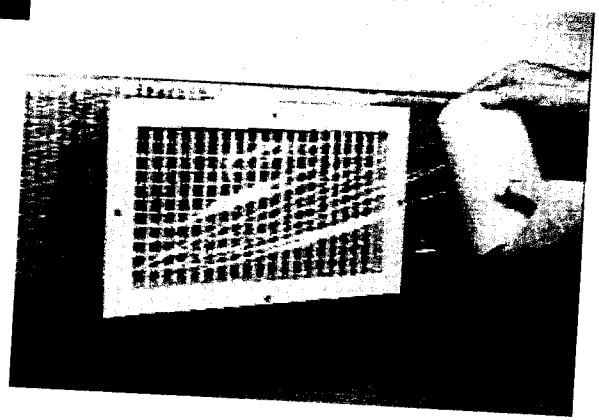
Equipment



Prepare ducts and house

Courtesy: Retrotec

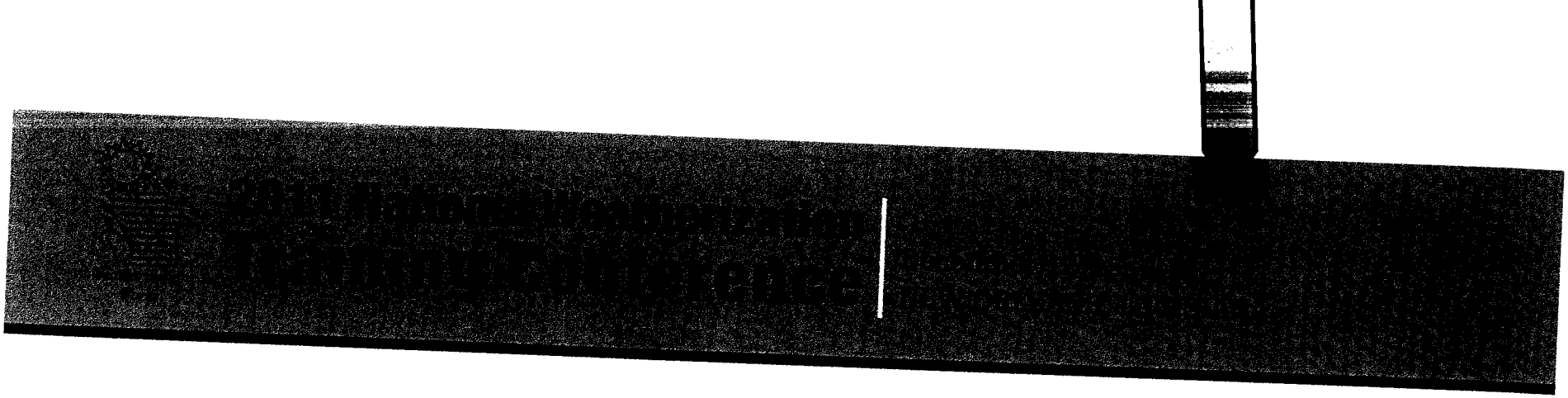
Sealing Ducts



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

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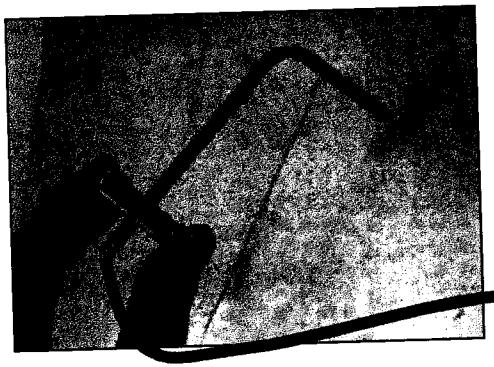
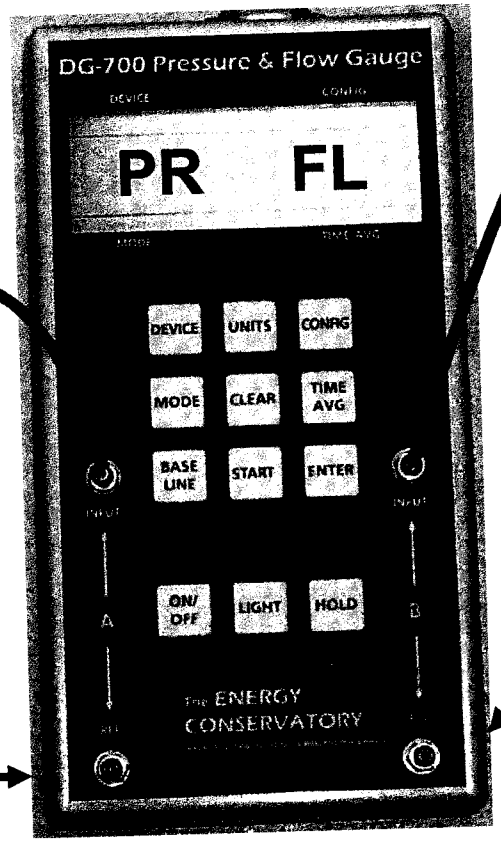
Duct Blasting - Pressurization





Connect pressure probe to the duct system

Connect to the Brass tap on duct blaster fan

Should be connected to Space where the duct blaster fan is installed

Should be open to inside of building if duct blaster is installed In the building

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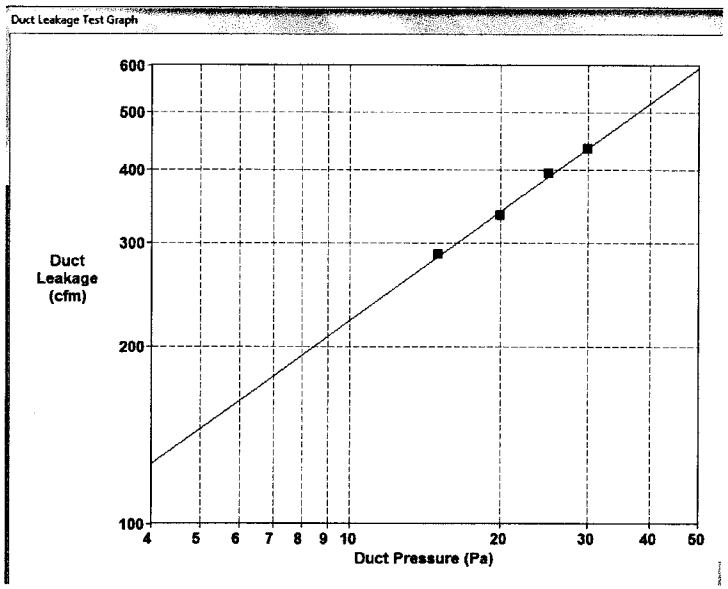
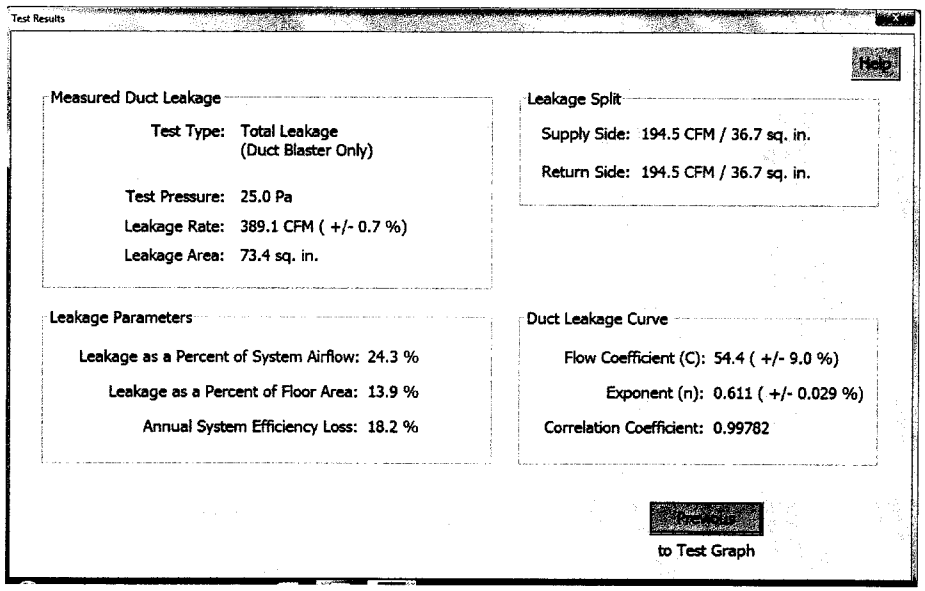
Troubleshooting

- 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
600
500
400
300
200
100
Duct Leakage (cfm)
4
5
6
7
8
9
10
20
30
40
50
Duct Pressure (Pa)


Test Results
Help
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

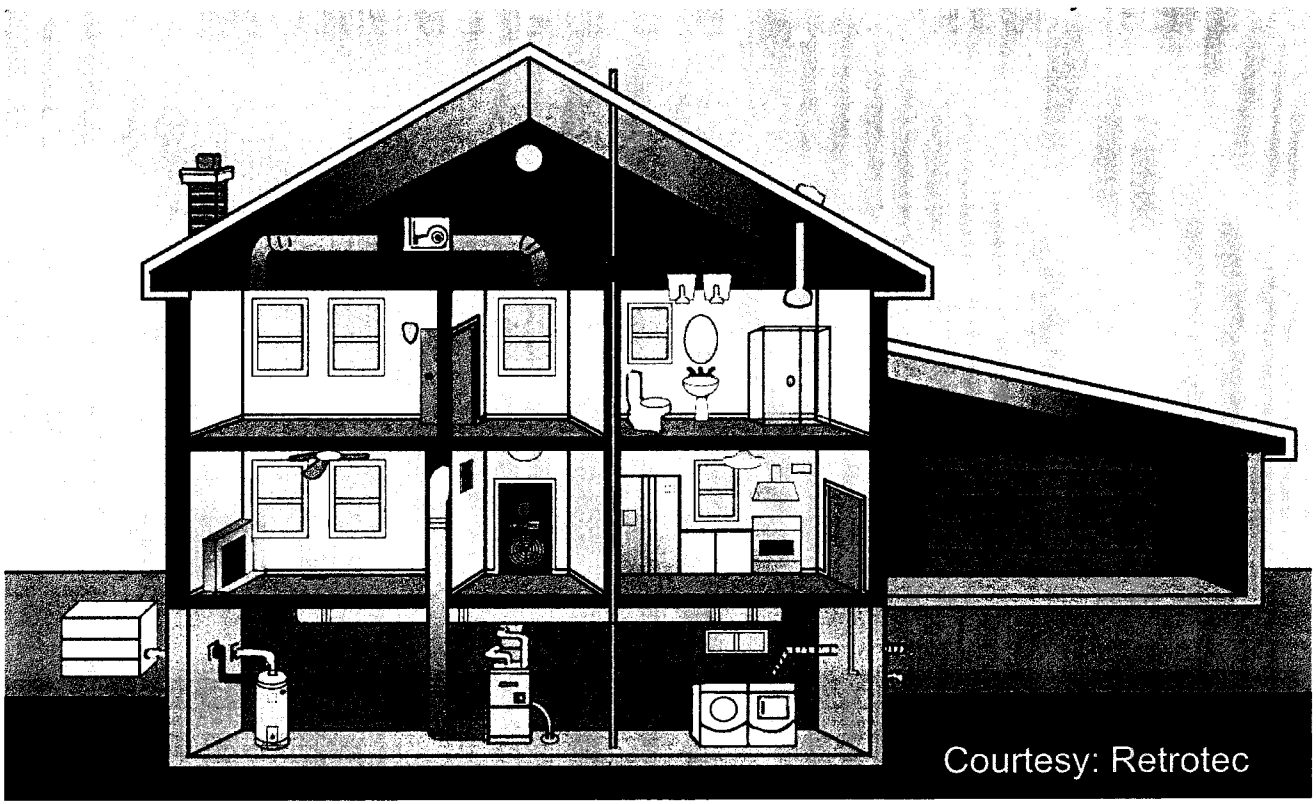
Delta-Q Testing

- 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

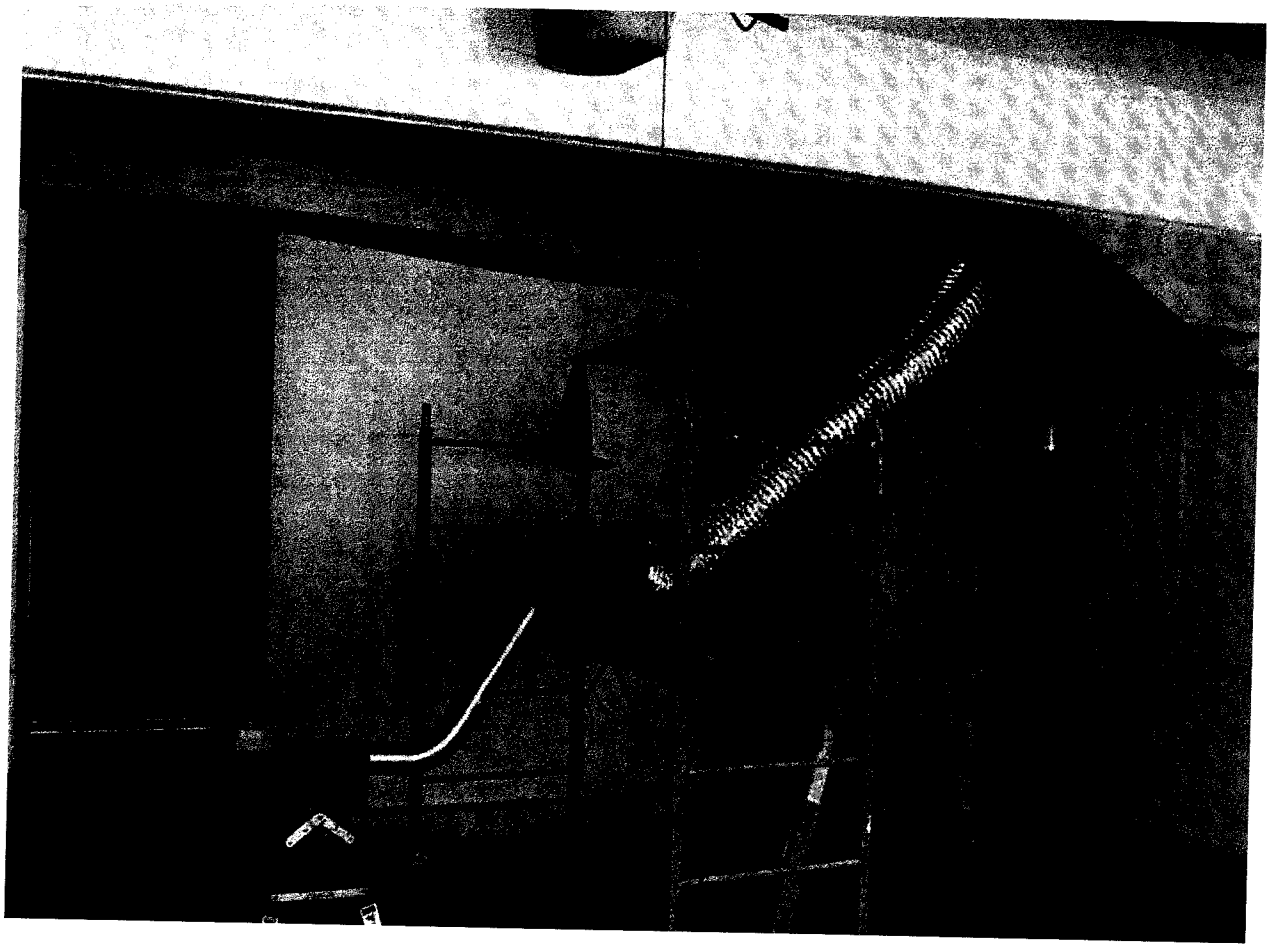
Delta-Q Testing

- 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 National Weatherization Training Conference



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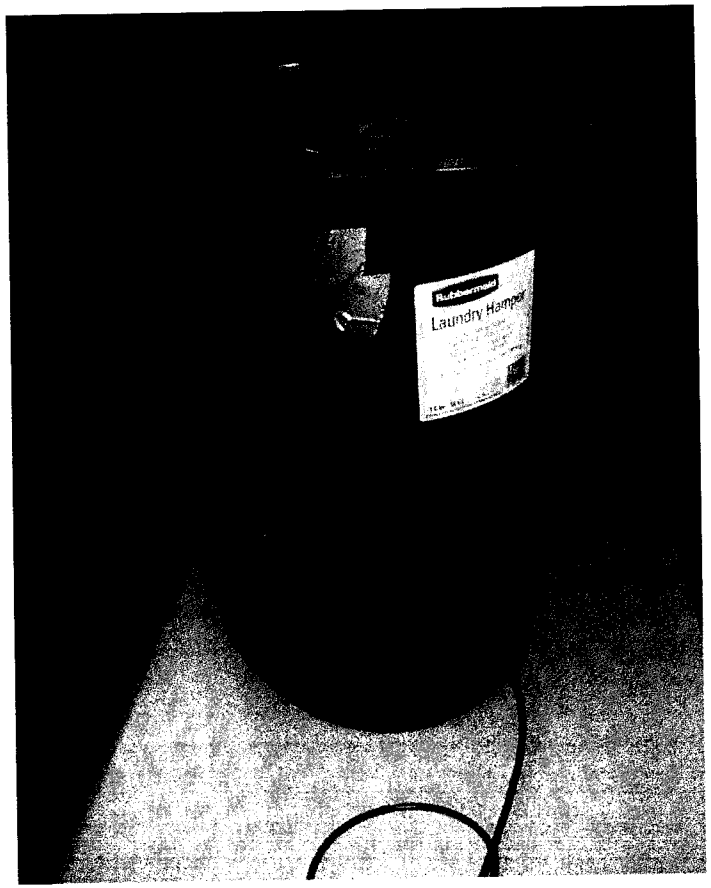
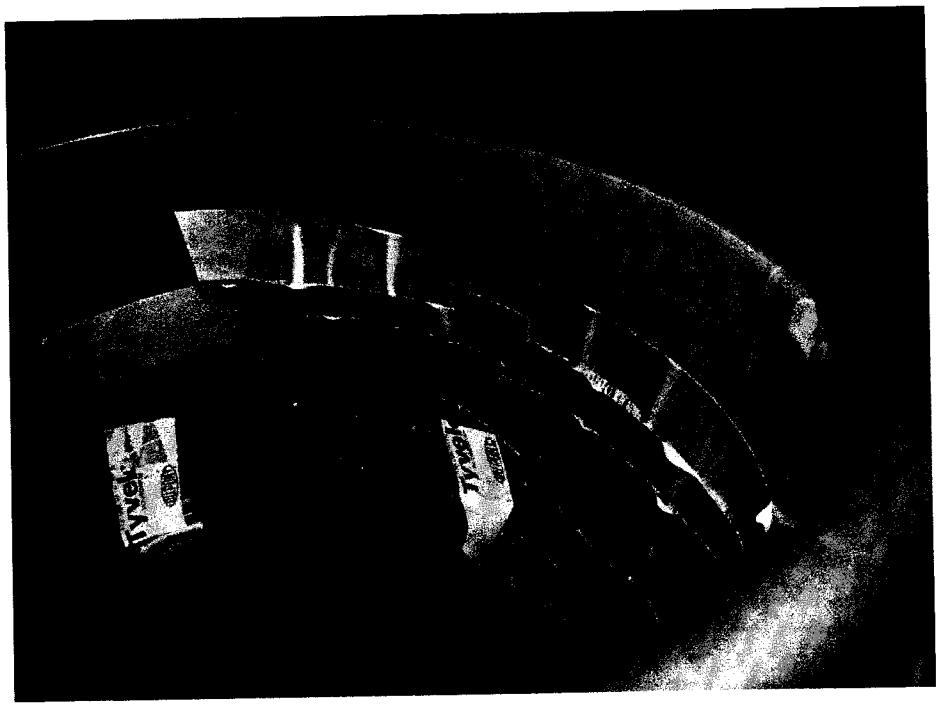
Energy Efficiency & Renewable Energy

2011 National Weatherization Training Conference

December 12-15, 2011
NEW ORLEANS, LOUISIANA





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

HOME ENERGY AUDIT SERVICES

ECI REC offers home energy audits. These audits identify areas where members can make home improvements or perform maintenance tasks that result in energy savings.

ECI REC is able to offer energy audits through a partnership with Consumers Energy Cooperative in Marshalltown. To help make the audits affordable for all members, ECI will waive the charge normally associated with a trip to the members' residence or business.

CONSUMERS ENERGY

Below are the energy audit options and applicable fees from which members may choose. Members are responsible for the noted fee for corresponding services For more information regarding these services contact our member services director, Frank Weber.

Thermal Imaging – ***Insulation Check:* $150**

- Checks for thermal problems related to insulation of a home.
- Checks heat loss/gain around windows and doorways.
- Can help identify moisture problems in structure of a home.
- Provides color photos of problem areas.
- Recommend combining with Blower Door Test.

Blower Door Test – ***Air Infiltration of Home*: $200**

- Checks for areas where air leaks into or out of the home.
- Identifies locations to tighten up the home with caulk or weather strip.
- Evaluates exterior doors and windows for leaks.
- Good to combine with Thermal Imaging and/or Duct Blaster Test.

Duct Blaster – ***Furnace Ductwork Integrity Test:* $200**

- Checks for leaks in furnace ductwork which results in lost energy.
- Great for new homes still under construction where ducts are accessible.
- Evaluates ductwork in "unconditioned" space, such as crawl spaces and attics, where any leaks are considered 100% lost energy.
- Good to combine with Blower Door Test.

HERS® – ***Home Energy Rating System:* $500**

- Consumers Energy has one of the few certified raters in Iowa.
- Provides a review of technical specifications of a home.
- Used to qualify for Energy Tax Credit (ETC)– Builders only.
- Used to qualify for utility rebates/incentives for non -conventional home construction such as icynene foam insulation, vaulted ceilings, etc.
- Provides home improvement analysis (REM-Rate).
- HERC (Home Energy Rating Certificate)—used to help sell a home.

ENERGY STAR® Rating – ***E★ Star:* $550**

- Nationally recognized energy efficiency certification.
- Used to qualify for utility rebates or incentives.
- Used to qualify for EE & EI mortgages.
- ENERY STAR® certificate can be an asset in selling a home.
- New home must be inspected prior to drywall for thermal bypass checklist.
- Blower Door and Duct Blaster Test after completion of construction.

Energy Tax Credit – ***(ETC):* $500**

- HERS rating using REM-Rate software that provides certificate for Builder's Tax Credit that is available through 2008.
- Home construction must be completed and audit performed prior to filing taxes for year of construction.
- Other Home Energy Check-Up options may also be recommended.

ECI REC
Energy Wise, Community Connected

2400 Bing Miller Lane | PO Box 248 | Urbana, IA 52345-0248
Toll Free: 877-850-4343 | Email: ecirec@ecirec.coop | Web: www.ecirec.coop
A Touchstone Energy® Cooperative

Energy Check

health comfort safety energy efficiency

Energy Check Services and Rates

Home Performance Contracting Services

We are licensed and insured contractors. Our well trained crew has extensive experience in energy efficiency retrofit projects and is a vital part of the process that leads to true improvement in your home's performance.

We offer free estimates to our Energy Audit clients as well as others seeking input for post-energy audit work or energy related remodeling and home improvement projects. Let us know how we can help.

Home Performance Assessment Services

Comprehensive Residential Energy Audit: *as low as $350.00*

Highly recommended to get the most out of your energy audit. An assessment of your home's performance, including analysis of your building envelope, insulation adequacy, air leakage, moisture, comfort issues, energy loss through air infiltration and duct work, and combustion testing. At base price of $550.00, services to include:

- ✓ **Blower Door Testing**
- ✓ **Infrared Imaging Scan**
- ✓ **Duct Blaster Testing, one system**
- ✓ **Moisture Content (MC) Testing**
- ✓ **Relative Humidity (RH) testing**
- ✓ **System and Appliance Combustion Testing ***
- ✓ **Physical inspection**
- ✓ **Health and Safety Check, including ambient CO analysis when applicable**
- ✓ **Same-day comprehensive written report, including photographs and prioritized recommendations based on analysis of your home's testing results, comparative study of those results, as well as your home's specific needs and optimal performance expectations.**
- ✓ **Educational meeting to fully explain the report and recommendations.**

Apply discounts based on your home's needs

- ✓ **Discount $100 for homes without forced** no Duct Blaster Testing required
- ✓ **Discount $50 for homes without gas or combustion appliances.**
- ✓ **Discount $50 for homes less than 1800 total (incl. unfinished) square feet.**

Additional Services

Depending on each your circumstances and the systems in your home, the following services are also available

- ✓ **Additional Duct Blaster Testing**, add $100 per system
- ✓ **Utility Analysis** – add $25
- ✓ **Return on Investment Analysis** – add $50
- ✓ **Consulting and Hourly Diagnostic Work** - $75/hour

Travel Fee:

* Energy Check serves the entire New River and Roanoke Valleys and surrounding localities, Prices quoted for homes within 40 mile radius of downtown Blacksburg. **Past 40 miles: add .85/mile**, (all mileage in excess of 80 mile round trip)

* Custom designed assessments can be done to suit your needs.

P.O. Box 355 Blacksburg, Virginia 24063-0355 540-443-9966 www.wecheckenergy.com wecheckenergy@wecheckenergy.com

EfficiencyFirst FOUNDING MEMBER
BPI
ENERGY STAR PARTNER

2005 City of Lodi Electric Utility
High Efficiency & Duct Repair Rebate Program Protocols

Background

- The City of Lodi Electric Utility has contracted with the Energy Doctor, Inc. to implement the 'House- As-a-System Home Inspection Program,' utilizing state of the art diagnostic technologies, such as Minneapolis Blower Door, and Honeywell Enalasys eScanAF™ equipment. The purpose of this inspection is to:
  1) identify, educate and direct City of Lodi Electric Utility customers on cost-effective energy saving home improvement opportunities based on the existing condition of their home;
  2) improve the overall performance of the central heating & air conditioning system.
- The Honeywell Enalasys eScanAF™ technology has been selected for this pilot program because of its advanced technology and its ability to diagnose hidden problems with the HVAC systems.

Eligibility

- *Qualified Homes*
  1) homes that are 10 years or less in age, are **not eligible** for the eScanAF™ airflow portion of the City of Lodi Electric Utility 'House-As-a-System Home Inspection Program,' and therefore not eligible for duct replacement rebates. These newer homes will be tested using the Duct Blaster, measuring tight ducts, and not the air flow, as the inspection program is focused on repairing older housing stock;
  2) duct systems that are 10 to 15 years in age, are **not eligible** for the duct replacement rebates as the ductwork is considered to be in useable condition, *unless*:
     - your load calculation and duct design proves the existing ductwork to be inadequate;
     - you advise the City of Lodi Electric Utility and obtain prior authorization to replace the delivery system;
  3) duct systems over 15 years in age **are eligible** for the duct replacement rebates;
  4) all homes **are eligible** for the duct repair rebates, unless-
     - the home was built using tight duct methods for energy compliance;
     - the home owner has already received funding under a previous City of Lodi Electric Utility rebate program for duct repair;
  5) in order to qualify for the duct replacement rebate, 100% of the accessible ductwork (supply and return) must be replaced (with a reasonable improvement in air flow);
  6) in order to qualify for a tight duct rebate the pre CFM25 must be greater than 151 CFM and the post CFM25 must be at or below 150 CFM25 using Minneapolis Duct Blaster with a reasonable reduction in CFM air loss;
  7) duct systems over 10 years in age must meet the proper system air flow @ 400 CFM per ton + or - 15% using eScanAF™ when qualifying for duct repair, replacement, or high efficiency rebates;
  8) the central air conditioner must be a minimum of 12 SEER (before a rebate will be paid the Building Permit must have been signed off by the City of Lodi Building Department);
  9) a customer may receive a rebate for either duct repair or duct replacement;
  10) customers that have previously used the tight duct rebate program may qualify for additional duct replacement rebates.

Design Requirements

- The following conditions must be met for the air flow and/or equipment efficiency rebates:
  1) air flow design (eligible for rebate without changing equipment):
     - Manual J load calculations or equivalent must be performed in order to-
       - verify proper equipment tonnage for the home's square footage and heat gain characteristics;
       - verify proper system air flow @ 400 CFM per ton + or - 15% using eScanAF™;
       - provide a Certificate of Compliance (see attachment A), completed and signed by the contractor or his legally authorized representative. This form must be submitted (not required if using eScanAF™) with every rebate application showing that the system was properly designed and that the air flow & leakage measurements were taken to verify appropriate supply and return air balance for the equipment that is being used;
     - Duct leakage-
       - must not exceed 150 CFM25 using Minneapolis Duct Blaster;
     - Multiple returns-

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- design returns so they do not create a positive or negative pressure zone when doors are closed;

2) equipment efficiency (must correct air flow to qualify for rebate):
   - 12 SEER minimum equipment is required (if changing out the equipment)-
     - duct design & air flow leakage corrections are required when qualifying for any high efficiency equipment rebate that may be available.

Performance Testing

- *Diagnostic Testing*
  1) contractors are required to verify their results using the Honeywell Enalasys eScanAF™ airflow & Minneapolis Duct Blaster testing equipment or equivalent (for other testing equipment and procedures you plan to use, you must first prove the results to the City of Lodi Electric Utility). Your method must be proven and verified to be as good as, or better, than the results achieved using the eScanAF™ equipment;
  2) the heating and cooling system must be fully operational, as air flow testing and compliance verification is to be done under heating and air systems own operating power;
  3) all registers must be fully open in order to verify maximum air flow;
  4) all supply and return register grills or air diffusers must be in place as they affect air flow;
  5) all filters must be in place for final verification test (system must be designed to handle a highly restrictive filter);
  6) **negative pressures** on the main body of the home due to the central heat and cooling systems supply and return air delivery **are not allowed;**
  7) **negative pressures** in any room location that could have an adverse effect on any combustible appliance flue gasses or chimney flues due to the central heat and cooling systems supply and return air delivery **are not allowed.**

Pre-Testing Protocol

- **Follow Honeywell Enalasys eScanAF™ test procedures** except as noted below. (Again, for other testing equipment and procedures you plan to use, have the procedure first approved by the City of Lodi Electric Utility). Quality Assurance, third party verification will be performed using eScanAF™ equipment-
  1) turn air handler on high speed (air-conditioning speed);
  2) make sure all supply and return registers are fully open and not taped or restricted;
  3) test return air flow following eScanAF test procedures (with existing filter in place), & record results;
  4) remove filter from the system and re-test the return air flow (record results); this will show your customer what the air flow drop is over a dirty or a highly restrictive filter **(however, the system must be designed to meet air flow test with the filter in place; this is important if you plan to use a highly restrictive filter);**
  5) re-install non-restrictive filters and continue testing with filter in place. If, however, the filter is restricted do to dirt or filter type, leave it out in order to obtain maximum air flow and proceed with the supply and return air test. **(Again, be sure that your design takes into consideration the filter when post testing, as the system needs to pass the eScanAF™ air flow test with the filter in place.)**

Duct Replacement Protocol

- Verify home's eligibility and replacement rules under item 2 (Eligibility);
- If the system fails the air flow test (system is not working to design CFM):
  1) perform Manual J load calculations to determine-
     - proper equipment tonnage (Certificate of Compliance will be provided to confirm you have done this);
     - proper duct sizing (supply and return) to match equipment tonnage @ 400 CFM per ton + or - 15% using eScanAF™;
  2) take static pressure readings to determine if the coil is restricted and, as necessary, provide the customer with a complete service of the equipment (if not new) to include cleaning the cooling coil and the condenser coil. (Keep in mind a restricted cooling coil can reduce air flow, so you should be sure this is not part of the air flow problem prior to replacing or repairing any part of the air delivery system);

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3) verify that there are not structural design issues that would hinder a successful retrofit of the new ductwork;
4) replace all supply and return ductwork following any & all manufacturer installation specifications, along with any state and local codes that may apply (*note:* whenever a code discrepancy is noted, to ensure compliance, follow the most stringent code);
5) Verify duct leakage is at or under 150 CFM using the duct blaster.

Repair Protocol

- If the system fails air flow test (system is not working to design CFM):
  1) perform Manual J load calculations to determine or verify-
     - proper equipment tonnage (Certificate of Compliance will be provided to confirm compliance);
     - proper duct sizing (supply & return) to match equipment tonnage @ 400 CFM per ton + or - 15% using eScanAF™;
  2) existing supply and return air delivery ductwork size and/or design flaws;
  3) if sizing appears to be correct, check entire system (supply and return) for disconnected, leaky, restricted or deteriorating ductwork;
  4) take static pressure readings to determine if the coil is restricted, and as necessary, provide the customer with a complete service of the equipment (if not new) to include cleaning the cooling coil and the condenser coil. (Keep in mind, a restricted cooling coil can reduce air flow, so you should be sure this is not part or all of the air flow problem prior to replacing or repairing any part of the air delivery system);
  5) correct air flow & leakage as necessary with appropriate repairs using UL181 tapes and mastics;
  6) replace any ductwork following any/all manufacturer installation specifications, along with any state and local codes that may apply (*note:* whenever a code discrepancy is noted, to ensure compliance, follow the most stringent code);
  7) verify duct leakage is at or under 150 CFM using duct blaster.

Post-Testing Protocol

- **Follow Honeywell Enalasys eScanAF™** post test procedures (for other testing equipment and procedures you plan to utilize, first have those procedures approved by the City of Lodi Electric Utility). Quality assurance to be performed using eScanAF™:
  1) turn air handler on high speed (air-conditioning speed);
  2) make sure all supply and return registers are open and not taped or restricted;
  3) test air flow following eScanAF procedures (with existing filter in place);
  4) if air flow fails-
     - check your design and any repairs made and make necessary changes;
  5) if air flow passes-
     - complete the Certificate of Compliance (see attachment "A") **Not required if you are using eScanAF™;**
     - white copy for the customer;
     - green copy for the utility (leave with customer);
     - goldenrod copy for the contractor;
  6) using a Digital Manometer or equivalent measure house pressures to ensure that no negative pressures are created by the return ductwork in the main body of the home or in any room location that could have an adverse effect on any combustible appliance flue gasses or chimney flues due to the central heat and cooling systems supply and return air delivery;
  7) Verify duct leakage is at or under 150 CFM using the duct blaster.

Customer Education/Health & Safety

- Inform the customer of the following:
  1) closing doors to rooms in the home, thus isolating the supply air from the return air ducts, can cause the home to experience negative pressure and may cause combustible gas appliances or chimney flues to back-draft, causing hazardous indoor air quality and safety issues;
  2) recommend multiple returns where this may be an issue; design returns so they do not create positive or negative pressures zones when doors are closed;

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3) recommend to customer that if they have any gas, combustible appliances (ranges, water heaters, furnace, etc.) located in the conditioned space of the home, serviced on a regular basis to avoid causing hazardous indoor air quality and safety issues.

Maintenance

- Service Checks:
  1) recommend annual service/maintenance checks to keep the system operating at peak efficiency.

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Attachment "A"

Contractor Certificate of Compliance

To be completed by the installing contractor and left with the customer

Contractor Name: _____ SCL # _____
Address _____ Age of Home _____
City _____ State _____ Zip _____
Phone # _____ Fax # _____
City Permit # _____ Date Issued _____

In order to be eligible for the City of Lodi Electric Utility High Efficiency Rebate program, I have determined that the following components must be installed and have been verified to meet the design airflow of 400 Cubic Feet (CFM) per ton:

System designed Tonnage [Tons] System Designed air flow (400 CFM per ton) [CFM]

Design Method used _____

Measured post airflow [Supply CFM] [Return CFM] What verification method was used? _____

Register Location (use additional paper if necessary)	Supply Designed CFM	Return Designed CFM
1.)		
2.)		
3.)		
4.)		
5.)		
6.)		
7.)		
8.)		
9.)		
10.)		
11.)		
12.)		
13.)		
14.)		
15.)		
16.)		
17.)		
18.)		
Total Airflow's (should equal system design airflow above to within 15% under real time operating conditions).		

I _____ a legally authorized agent of _____;
Print Name Company name
hereby certify the above information to be true and correct to the best of my knowledge.

_____
Signature Date (mm/dd/yy)

Form L1204 version Nov. 11, 2004 all rights reserved Energy Doctor, Inc. 800-564-8189 Note changes to section Eligibility, items 5, 6, 7 and 8

energylogic ACADEMY

HERS Rater Training
Field Syllabus

Part 1: Course Information

Instructor Information

Instructor(s): EnergyLogic Staff or a Qualified Proxy Trainer
Location: Various Please check with EnergyLogic Schedule
Class Hours: 8:00am – 5:30pm daily
E-mail: eve.owen@nrglogic.com

Prerequisites

In order to join EnergyLogic or a proxy trainer for the field portion of training you must complete:

- EnergyLogic Online HERS Rater Training
- Pass the National Exam*
- Complete an Equivalent Training*

*These prerequisites may require additional training from EnergyLogic at your expense. EnergyLogic will evaluate your prerequisites on a case by case basis.

Course Description

The field portion of HERS Rater Training is 3 days of field training designed to introduce the HERS Rater inspection processes and diagnostic testing. There will be an optional 4th half day for students to prepare for and take the RESNET National Rater exam.

During the field training we will complete 2 practice ratings according to the RESNET training standard. Practice ratings will be performed on an existing and new home. In addition, students will have an opportunity to complete a pre-drywall inspection.

This is an instructor facilitated course. Students will have one-on-one instruction on the testing equipment. Much of the field work will be done in a group setting where peer to peer interaction is used to complete the practice ratings.

The course will provide each student ample time to have hands on

experience with the diagnostic equipment. By the end of the course each student will receive equipment certification for the Blower Door system and Duct Blaster system. This will be a one-on-one evaluation with an instructor to measure the students' competence with the testing equipment.

Textbook & Course Materials

Required Materials

- EnergyLogic Field Workbook
- Tape Measure
- Hard Hat & Respirator
- Clipboard
- Architect Scale or Ruler
- Pencil
- Shoe Cover(s)
- Computer

Recommended Text

- Energy Auditor Field Guide – John Krigger and Chris Dorsi
  - http://srmi.biz/bookstore/field-guides/
- Builder's Guide "to your climate" – Joseph Lstiburek
  - http://www.buildingsciencepress.com/%2FBuilders-Guide-to-Cold-Climates--P1.aspx
- Insulate & Weatherize – Bruce Harley
  - http://www.tauntonstore.com/build-like-a-pro-insulate-and-weatherize-bruce-harley-070649.html

Course Requirements

Students are required to attend every class for the entire scheduled time. Students will be evaluated in one on one session with the course instructor for competency using the diagnostic equipment. To successfully pass the course students must receive the certification on the equipment.

Course Structure

This course will be delivered using a combination of classroom presentations and field work. In addition, students will have access to the EnergyLogic Academy. The EnergyLogic Academy will have online lessons, course materials, and resources.

Course Structure (Continued)

The course will be delivered over 3 days with an optional fourth day to prepare for and take the RESNET National Rater Exam. Please make sure to review the schedule posted on the EnergyLogic Academy course page for details on dates and times.

The first day of training will be dedicated to labs. We will do a brief classroom presentation on the principles of diagnostic testing. That will be followed by a blower door lab where the instructor will demonstrate proper use of the blower door system. Next will be a pressure diagnostic lab followed by a duct blaster lab. In each of the lab sessions students will get an opportunity to have hands on time with the equipment.

The second day will be our first practice rating. This will be completed on an existing home. Students will gather data in groups during the morning session. While students are gathering data the instructor will have one-on-one coaching sessions with each of the participants in the course. During this one-on-one session the student will setup and run the blower door and perform pressure diagnostics. The student will then interpret the data provided by the diagnostic test with the instructor.

In the afternoon of day one the group will work together to perform take-offs from their field sketches and create a REM/Rate file for the house. During this group session each participant will be tested and certified using the blower door system.

During the third day we will complete a practice rating on a new home. In the morning we will perform a pre-drywall inspection. This will be followed by an identical structure to day 2, except the equipment coaching and certification will be for the duct blaster system.

There will be an optional fourth day of training. This will be a half day in the morning. During this session we will have a study group discussion followed by the RESNET National Rater Exam.

The EnergyLogic Academy

HERS Rater Training
Field Syllabus

Part 2: Course Objectives

The field portion of HERS Rater Training is designed to give participants in depth training on the processes and diagnostic equipment required to complete a home energy rating.

Objectives:

1. To develop a full understanding of measuring and inspecting a home for home energy ratings.
2. To develop competency using the manometer.
3. To develop competency using the blower door system.
4. To develop competency using the duct blaster system.
5. To complete 2 practice ratings.

You will meet the objectives listed above through a combination of the following activities in this course:

- Review the blower door, duct blaster, and pressure diagnostic modules prior to attending class
- Participate fully in the labs.
- Engage in the one-on-one coaching with the instructors
- Assume a leadership role when necessary: voluntarily help other students when you have knowledge they don't have.
- Approach the course with a desire to learn
- Complete the practice ratings.

The EnergyLogic Academy

HERS Rater Training
Online Syllabus

Part 3: Topic Outline/Schedule

Important Note: Refer to the course calendar for specific meeting dates and times. If you have any questions, please contact your instructor.

Diagnostic Labs	
Day 1	**Instruction**
8:00:00 AM	Classroom -- Week outline, expectations, introductions
9:00:00 AM	Classroom -- Principles of Diagnostic Testing
10:00:00 AM	Blower Door Lab
11:00:00 AM	Blower Door Lab
12:00:00 PM	Lunch
1:00:00 PM	Duct Blaster Lab
2:00:00 PM	Duct Blaster Lab
3:00:00 PM	Pressure Diagnostic Lab
4:00:00 PM	Pressure Diagnostic Lab
5:00:00 PM	Wrap-up

Existing Home	
Day 2	**Instruction**
8:00:00 AM	Final Inspection & BD/PD Testing Practice
9:00:00 AM	Final Inspection & BD/PD Testing Practice
10:00:00 AM	Final Inspection & BD/PD Testing Practice
11:00:00 AM	Final Inspection & BD/PD Testing Practice
12:00:00 PM	Lunch
1:00:00 PM	Take offs & REM Input & Blower Door Certification
2:00:00 PM	Take offs & REM Input & Blower Door Certification
3:00:00 PM	Take offs & REM Input & Blower Door Certification
4:00:00 PM	Take offs & REM Input & Blower Door Certification
5:00:00 PM	Wrap-up

The EnergyLogic Academy

Part 3: Topic Outline/Schedule (Continued)

New Home	
Day 3	**Instruction**
8:00:00 AM	Rough Inspection
9:00:00 AM	Field -- Practice Rating 2, DB Practice
10:00:00 AM	Field -- Practice Rating 2, DB Practice
11:00:00 AM	Field -- Practice Rating 2, DB Practice
12:00:00 PM	Lunch
1:00:00 PM	Take offs & REM Input & Duct Blaster Certification
2:00:00 PM	Take offs & REM Input & Duct Blaster Certification
3:00:00 PM	Take offs & REM Input & Duct Blaster Certification
4:00:00 PM	Take offs & REM Input & Duct Blaster Certification
5:00:00 PM	Wrap up

Testing (Optional)	
Day 4	**Instruction**
8:00:00 AM	Test Review
9:00:00 AM	Test Review
10:00:00 AM	RESNET National Exam
11:00:00 AM	RESNET National Exam
12:00:00 PM	
1:00:00 PM	
2:00:00 PM	
3:00:00 PM	
4:00:00 PM	
5:00:00 PM	

HERS Rater Training
Field Syllabus

Part 4: Grading Policy

Successful Completion of Course

Successful completion of the field training portion of Rater training is two parts. First, you must pass the equipment certification process with an instructor. This will be a one-on-one session to demonstrate your proficiency with the equipment.

The second part of completing your field training is submitting your practice ratings to your instructor. The instructor will evaluate your rating for accuracy and provide feedback on improvements. Once the practice ratings meet the satisfaction of the instructor you will have met this requirement.

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April 23 - 27, 2012 • Boise Centre • Boise, ID

TUTORIAL DESCRIPTIONS

IN THE FIELD • Monday • April 23rd • Full Day

TIME	TRACK	TUTORIAL	PRESENTER
8:30AM - 4:30PM LUNCH INCLUDED	Installer	**GET 'ER SEALED!** This hands on session will focus on getting duct system, repaired and sealed with a focus working efficiently	Bruce Manclark & Vince Pacheco
	Auditor/Assessor	**CONDITIONING CRAWLSPACES WITH CLOSED CELL SPRAY FOAM** This course will cover the pros and cons of conditioning crawlspaces, situations best suited for them in retrofit applications, and the basics of conditioning the crawl. This course will present a live demo of a conditioned crawl space wall with a spray foam application. This will be followed by a field trip out to a local Senior center in which two conditioned crawl spaces with closed cell spray foam were completed.	Hans Berg & Dave Crawford
	Crew Chief	**EVALUATING AND APPLYING THE ASHRAE 62.2-2010 RESIDENTIAL VENTILATION STANDARD** ASHRAE Standard 62.2-2010 is the residential ventilation standard. The Standard is a complete system from definitions to system sizing to system design options. This in-field session will apply the standard to an actual house. The process of applying all parts of the standard and facilitate its application to real world situations. As houses get tighter, the need for mechanical ventilation to insure indoor air quality increases and the interaction with other air hungry equipment like combustion appliances becomes more critical. Recognizing these converging issues, building codes are increasing their mandate to require and scrutinize effective, mechanical ventilation systems in both new and existing homes. This Session is focused on ASHRAE Standard 62.2-2010 and how to comply. • Evaluate the details of the house and determine the best solutions for the whole building ventilation requirement; • Apply the existing house Appendix A to adjust the required flow rate; • Select the best solution for the local ventilation requirements; • Demonstrate how to test the installed systems; • Create the documentation; • Determine the interaction between the ventilation system and other systems including	Paul Raymer & Paul Fransisco

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TUTORIAL DESCRIPTIONS

IN THE FIELD • Monday • April 23rd • Full Day

TIME	TRACK	TUTORIAL	PRESENTER
8:30AM - 4:30PM LUNCH INCLUDED	Installer	**THE FUNDAMENTALS OF RETROFITTING WITH SPRAY POLYURETHANE FOAM** New to SPF or need a refresher on the basics? Then this one is for you! Develop a solid foundation for more advanced learning. We'll talk about everything SPF, from what it is made of to how to spray and what to not spray. Join us for classroom discussion and then follow us to the field for an on-site demonstration. Stick around after lunch and we'll show you a Full Mobile Home Roof Spray!	Rito Reynoso, Jessie Lumbreras & Mike Figueredo
	Crew Chief	**BASIC AUDIT & ASSESSMENT** By attending this session, participants will learn to perform a home energy audit by calculating square footages; determining existing insulation levels; and providing basic diagnostic readings from the blower door, duct blaster and furnace testing equipment. Participants will calculate basic heat loss to determine simple payback in energy savings, perform technical testing procedures, and do basic measurement and assessment.	Rod Burk, Ed Campos & Randy Wright

IN THE CLASSROOM • Monday • April 23rd • Full Day

TIME	TRACK	TUTORIAL	PRESENTER
8:30AM - 4:30PM LUNCH INCLUDED	Installer	**OSHA 10, PART 1 • CERTIFICATION PROGRAM** *(You must attend Part 1 & 2 to receive certificate—Part 2 is Half Day on Tuesday)* This OSHA 10 class will provide weatherization program workers with an OSHA 10 course custom designed to address health and safety issues typically found at weatherization jobs, along with the mandatory OSHA 10 course requirements. Included is an overview of OSHA rules and regulations, "Focus Four" topics which include falls, electrocutions, struck-by hazards, and caught in/between hazards, understanding MSDS sheets, spray foam safety, personal protective equipment use, ladder safety, and heat stress prevention. Completion of this session will satisfy DOE's new OSHA 10 requirement .	Jon Martin

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TUTORIAL DESCRIPTIONS

IN THE CLASSROOM• Monday • April 23rd • Half Day • Morning

TIME	TRACK	TUTORIAL	PRESENTER
8:30AM - NOON NO LUNCH PROVIDED	Program Management	**THE PRINCIPLES OF ADULT LEARNING** This interactive workshop will introduce several effective adult learning concepts, including the ADDIE and ARCS models, to assist participants in the development, implementation, and assessment of training events for program staff and/or participants. Session participants will also create a training plan based on real world case studies.	Christina Zamora
	Auditor/Assessor	**BASELOAD ELECTRICITY END USE** End use electrical energy management relies on efficiency, conservation and monitoring. Effective management depends on reducing electric baseload which requires recognizing opportunities through assessments, intentional prioritizing, efficiency technologies and changing behaviors. Participants learn the fundamentals in performing an on-site electric baseload energy audit. Practices include understanding residential operations, interviewing occupants, inspecting a premise, analyzing energy usage statements, reviewing diagnostics tools, using collected information and developing goals, action plans and follow-up performance. Various evaluation tools, techniques and protocols that help probe appliances, lighting, plug loads, electric water heating and other electric energy usage in the home are considered. Attendees learn how to separate electric baseload from total whole house electric use, how occupants, equipment, and behavior use patterns affect electricity consumption, how to incorporate and prioritize opportunities for electric baseload reduction and budgeting. Application of electric baseload analysis to sizing renewable energy generation systems is briefly reviewed. The ½-day session is designed for weatherization coordinators, assessors, and crews interested in learning more about household electric baseload usage and understanding.	Todd Hoener & Dan Berube

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TUTORIAL DESCRIPTIONS

IN THE CLASSROOM• Monday • April 23rd • Half Day • Afternoon

TIME	TRACK	TUTORIAL	PRESENTER
1:30PM - 4:30PM NO LUNCH PROVIDED	Auditor/Assessor	**AIR TIGHTNESS TESTING OF MULTIFAMILY BUILDINGS** This session will cover common testing standards used when testing multifamily buildings and the different testing methods and equipment options for testing individual units, multiple units at a time, or the whole building. Case studies will be presented showing row house type buildings, low rise apartments, as well as a high rise building. A demonstration will be presented using the TECLOG2 software to control multiple Blower Door fans.	Paul Morin & Anthony Cox
	Auditor/Assessor	**CONDENSATION & MOLD: UNDERSTANDING & PREVENTION** In the pursuit of energy savings we have to be very watchful for side effects of moisture that WE CAN CREATE. In this session you will learn the causes and remedies for moisture problems and how to troubleshoot these situations. More importantly, you will learn how to avoid contributing to moisture/mold problems. The presentation will include a variety of slides and case studies from "live & learn" weatherization projects.	Jim Lee & Aaron Tisdell

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TUTORIAL DESCRIPTIONS

IN THE FIELD• Tuesday • April 24th• Full Day

TIME	TRACK	TUTORIAL	PRESENTER
8:30AM - 4:30PM LUNCH PROVIDED	Crew Chief	**PRESSURE BALANCING** This Tutorial will show how to conduct the pressure diagnostics tests that verifies a pressure balance problem exists. We will discuss and show the best techniques used to correct pressure problems and how to determine the best practice for correcting problems. The class will install measures to relieve the pressure problems and ensure there are no worst-case problems, combustions appliance zone concerns and combustion appliances draft issues. We will use best practices Pressure Diagnostics testing procedures to ensure correct and balanced air flow in the HVAC system. The presenter will explain how these problems could be related and how the fixes, in many cases, are the same. Understand the tools used for testing and the different materials used to fix the pressure problems. **By attending this Tutorial, participants will:** • Lean the Good, Bad and Ugly of different Airflow measurement methods • Understand the issues and concerns related to Pressure Balancing • Get hands on experience at installing measures to correct Pressure Balancing problems • Understand the testing to identify Pressure Problems and the tests to ensure the problem is corrected properly.	Tom Brodbeck
	Crew Chief	**EVALUATING AND APPLYING THE ASHRAE 62.2-2010 RESIDENTIAL VENTILATION STANDARD** *REPEAT - FROM MONDAY SESSION*	Paul Raymer & Paul Fransisco
	Auditor/Assessor	**CONSTRUCTION TECHNIQUES FOR ACHIEVING DEEP ENERGY REDUCTIONS THROUGH RETROFITS** Warm represents dry, good. Cold represents wet, bad. As we alter conventional building assemblies with increased insulation levels we jeopardize the moisture balance and tolerance of the structure. Increased energy performance and improved durability are readily achievable. Depending on climate and existing housing stock achieving a 50% reduction in energy usage is very doable.	Marquam George

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TUTORIAL DESCRIPTIONS

IN THE FIELD • Tuesday • April 24th • Full Day

TIME	TRACK	TUTORIAL	PRESENTER
8:30AM - 4:30PM LUNCH PROVIDED	Installer	**MOBILE HOME WEATHERIZATION** Hands on! Clackamas County Weatherization Crew from Oregon will guide you in the installation of mobile floor insulation, infiltration measures, duct sealing, window install and more. The crews will be happy to answer questions regarding all phases of mobile home weatherization including those you do not see every day.	April Richey
	Auditor/Assessor	**WARM WEATHER AUDITING** Field demonstration on how a Weatherization Audit is performed in Arizona. Learn what information is needed and why. Learn what tools are utilized in gathering and diagnosing the information gathered.	Ken Pancost & Vinnie Pedalino
	Auditor/Assessor	**HOME PERFORMANCE DIAGNOSTICS** This session will cover all aspects of diagnostics testing from Blower Door and Zonal Pressures, to Pressure Pan , Duct Blaster, Dominant Duct Leakage, Room Pressures and Exhaust Fan Flows.	Anthony Cox
	Beyond Weatherization	**STRAW BALE TOUR** This program will focus on the energy efficiencies associated with strawbale buildings. We will be presenting energy modeling of strawbale homes, energy use performance and temperature analyses of existing strawbale buildings, as well as information concerning construction details associated with building energy efficient strawbale buildings. There will be in class powerpoints as well as visits to two existing strawbale homes with blower door and thermal imaging, If possible, there will a hands-on component involving building using strawbales.	Mark Lung

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TUTORIAL DESCRIPTIONS

IN THE CLASSROOM• Tuesday • April 24th• Half Day

TIME	TRACK	TUTORIAL	PRESENTER
8:30AM - NOON NO LUNCH PROVIDED	Beyond Weatherization	**WORKING IN INDIAN COUNTRY** The Purpose Of This Workshop is to provide participants with the basic principles of developing effective partnerships with American Indian Tribes and organizations (associations, coalitions, etc.). Participants will leave with a basic understanding of – A new leadership paradigm when working in Indian country – American Indian history as it relates to relationship building today – How to communicate in a culturally diverse environment – The basic principles to building trust, relationships, and partnerships.	Larry Keown
	Beyond Weatherization	**WEATHERIZATION ASSISTANCE PROGRAM TECHNICAL TOOLS & RESOURCES** The Department of Energy's Weatherization Assistance Program (WAP) is currently developing a comprehensive set of tools and resources aimed at enhancing the training and work quality standards to be utilized throughout the home energy upgrade industry. These efforts are supported by the WAP National Training and Technical Assistance (T&TA) Plan. As these projects move to completion, the Weatherization Assistance Program is seeking input from the professionals in the field to ensure that these resources are finalized and disseminated in a way that is useful to the technicians and program managers on the ground. Please join us for this interactive workshop during which participants will receive updates on the current status of the Weatherization Assistance Program tools and resources and participate in a dialogue with the project leads about how to further enhance the products to meet the needs of the Weatherization and Home Performance industry. Topics for discussion will include: • The Standard Work Specifications for Home Energy Upgrades • The Accreditation of Energy Efficiency Training Programs • The Certification of Energy Efficiency Technicians • The Multi-Family Energy Audit Tool • The National Weatherization Training Platform	Jen Somers & Josh Olsen

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TUTORIAL DESCRIPTIONS

IN THE CLASSROOM• Tuesday • April 24th• Half Day

TIME	TRACK	TUTORIAL	PRESENTER
1:30 - 4:30PM NO LUNCH PROVIDED	Installer	**INSULATION BEST PRACTICES: RETROFIT & NEW CONSTRUCTION** The Purpose Of This Workshop is to provide participants with the basic principles of developing effective partnerships with American Indian Tribes and organizations (associations, coalitions, etc.). Participants will leave with a basic understanding of – A new leadership paradigm when working in Indian country – American Indian history as it relates to relationship building today – How to communicate in a culturally diverse environment – The basic principles to building trust, relationships, and partnerships.	Loren Christopher
	Installer	**OSHA 10, PART 2 • CERTIFICATION PROGRAM (CONT. OF PAR 1)** *(You must attend Part 1 & 2 to receive certificate—Part 1 is a Fully Day on Monday)*	Jon Martin
	Beyond Weatherization	**UTILITY PARTNERSHIPS** How do you identify utility partners to leverage funds and support for your Weatherization program? What techniques have been utilized to advocate for low-income populations with Investor Owned Utilities, rural cooperatives, and municipalities? How can aligning with other advocacy groups help fulfill the mission of your organization? This tutorial will feature presentations by two of the Northwest's experienced low-income advocates who will share challenges and successes when partnering with utility companies. Session attendees will also participate in a facilitated brain storming exercise to identify where they are in the partnership process and the 'next steps' they can take in order to build, strengthen, and maintain utility partnerships.	Nancy Hirsh & Chuck Eberdt

IC3 International CODE COMPLIANCE CALCULATOR

City of Austin

Energy Systems Laboratory
Texas A&M University

SECO
State Energy Conservation Office
Texas State Energy Conservation Office

US Department of Energy

Texas HERO
Home Energy Raters Organization
Texas Home Energy Rating Organization

US Environmental Protection Agency

TEES
Texas Engineering Experiment Station

Texas A&M University System

v3.12.2 Builder's Guide – April 2012

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1 Introduction

The International Code Compliance Calculator (IC3) software is a web-based, software tool that builders, inspectors, architects, engineers, and others use to demonstrate the performance of proposed single family residences according to the Texas Building Energy Performance Standards. The software is intended to cover the majority of site built houses being produced in Texas. IC3 targets homes using wood framing, conventional systems, one or two stories, and under 10,000 square feet of conditioned space per floor. Other types of residential construction may not be candidates for this software and the User should contact their local Building Official for other Energy Code compliance options. Repairs and remodels of existing construction are not addressed with this software.

IC3 does more than calculate the above code performance of a new home. It also calculates how much pollution has been reduced (emissions reductions) through the home's energy efficiency. Energy Systems Laboratory (ESL) is working with the different Councils of Government in Texas to develop a verification mechanism in order to maximize SIP Credits.

1.1 Background

The United States Environmental Protection Agency (EPA) has designated four areas in Texas as having unacceptable ozone levels in excess of the National Ambient Air Quality Standard (NAAQS) limits, leading to a designation as non-attainment areas. In response, the 77th Texas Legislature's Senate Bill 5 (2001) established the Texas Emissions Reduction Plan (TERP). This legislation directs the Energy Systems Laboratory (ESL) at Texas A&M University to develop a series of programs to assist the State in reducing air pollution through Building Energy Efficiency.

The Energy Systems Laboratory (ESL) has developed several web-based energy efficiency and emissions reduction calculators. IC3 is used to benchmark the estimated energy performance of new construction single family homes in Texas, and is freely available to all through the internet

1.2 Requirements

1. Browser: Internet Explorer v7/8/9 or Firefox v3/4/5
2. Adobe Acrobat Reader 6.x or greater (to view/print/save the certificates)
3. Google Chrome – partial support due to a confirmed bug in the Chrome PDF print routine as of July 2010 so you can use the calculator, but will not be able to view/print the certificates nor the checklist. You can do a "Save As" and use a Adobe products to print the certificate.
4. Apple Safari (Mac/iPad/iPhone)– not fully tested. Please report any issues to us (ic3_support@esl.tamu.edu Please include a screen shot showing the problem.

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5.

1.3 What's New!

In Version 3.12 (January 2012)

1. Deprecated IECC 2001 and IECC 2006 Houston codes.
2. Added Energy Report w/ signature to generate an Energy Report with a signature line present.

In Version 3.11 (December 2011)

1. Added support for IECC 2009 Austin Amendments

In Version 3.10 (September 2011)

1. Three IECC 2009 compliant reports (i.e. energy, inspection list, and certificate)
2. Paging enhancements on "My Page" to help organize large quantities of projects.
3. Multifamily usability increased with Plan/Unit information being displayed on pages.
4. Elimination of flash animation (so we will *become* iPad compatible).
5. Updated/expanded help text.
6. Updated illustrations.
7. Tweaked min/max values on duct insulation, water heaters.

In Version 3.9.x (October 2010)

8. Added slab insulation
9. Updated the manual

In Version 3.8.x (September 2010)

1. Fixed default of Multifamily Units to be "Ducts in Conditioned Space" to YES
2. Fixed wrong IECC code version on certificate
3. Enhanced input screens by moving several fields from Units to Floor Plans

In Version 3.7.x (June 2010)

1. Simple multi-family code compliance
2. Updated model
   a. Floor Insulation R-Value
   b. Four foundation types
3. Updated illustrations
4. Updated manual

In Version 3.6.2 (April 2010)

1. Fixed defect in 2nd Floor, Back Window issue
2. Reference A\C tonnage matches the proposed A\C tonnage.
3. Updated model
4. Updated illustrations

In version 3.6.1 (December 2009)

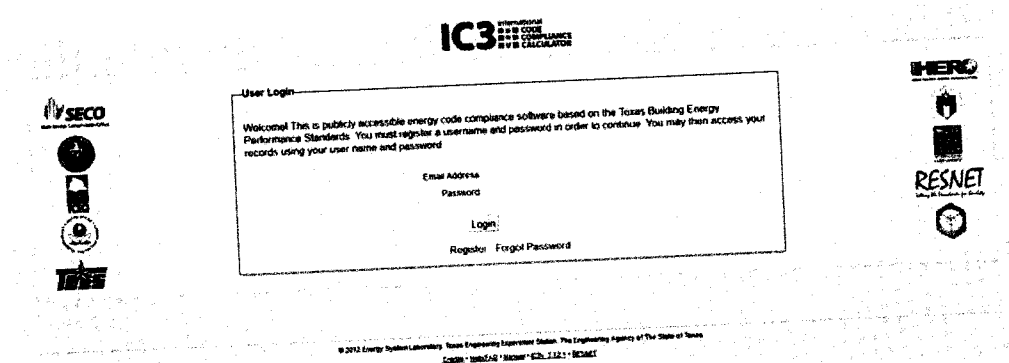
1. Foundations
2. Opt out of emails
3. Copy a project
4. Moved orientation from Floors tab to Project Information

In version 3.5.2 (November 2009)

1. Three code choices: IECC 2009, IECC 2006 (with Houston Amendments) and IECC 2000/2001.
2. Duct insulation values
3. Improved input of overhang values to allow for just inches

2 Common Screens

2.1 User Login Screen



Users who have registered on the current version of IC3, simply enter their Email Address and [illegible]ord in the spaces specified and left-click on the **Login** tab.

If the user has forgotten or needs to change their password, they press the "**Forgot Passwor**[illegible]ugh the secure process of changing their password. ***(See Section 2.2)***

A User who has ***not*** registered on the current version of IC3, presses the "Register" link and is redirected to the "**User Registration**" Page. ***(See Section 2.3).***

Users who have an account and enter their password correctly are led to "**My Page**". ***(See Section 2.4)***

Note:
The current version of the software is found here.

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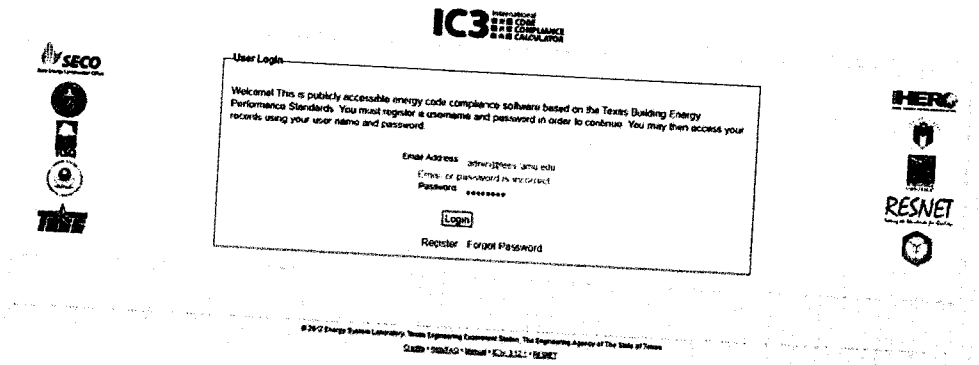
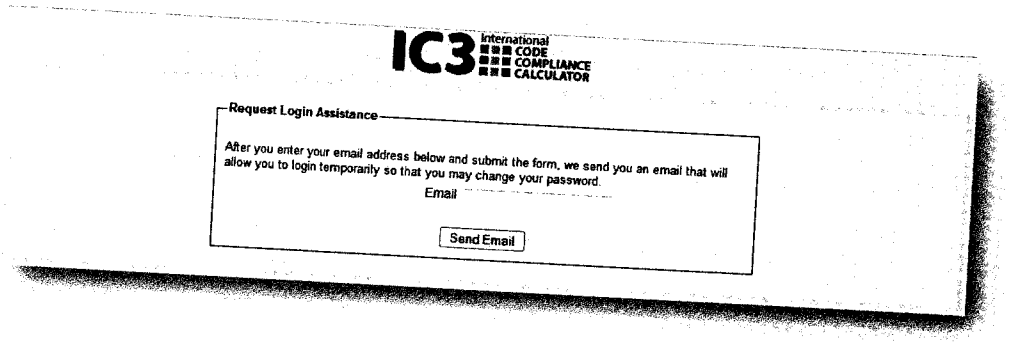
2.2 User Resets Password



Users who enter the wrong password, see the screen above.

Users who have forgotten or want to change their password, enter their email address and left-click on the **"Forgot Password"** link.



The userenters their email address in the space provided and then left-clicks on the **"Send Email"** button. The system then sends an email with a special link for finishing the reset process and then redirects the user to the login screen.
This is a sample of the email message the user will receive.

```
From: ic3_support@esl.tamu.edu [mailto:ic3_support@esl.tamu.edu]
Sent: Monday, March 24, 2008 3:12 PM
To: someone@tamu.edu
Subject: IC3: Password Reset Request

A password request has been submitted from this address.  If you did not request a new password, you may simply
discard this message and continue using IC3 as you normally do.  If you did request a new password, please visit
the following link, or copy and paste it into a browser.

http://ic3.tamu.edu/authenticate/cd75dd50-1fde-4965-98b0-d8496dfd91f0

If you have any questions about IC3, please visit our help page at

http://esl.eslwin.tamu.edu/software/iccc.html
```

The email address you entered above will appear here.

Copy and paste this link into your internet browser, or click on the link to reset your password. This will allow temporary access to your profile.

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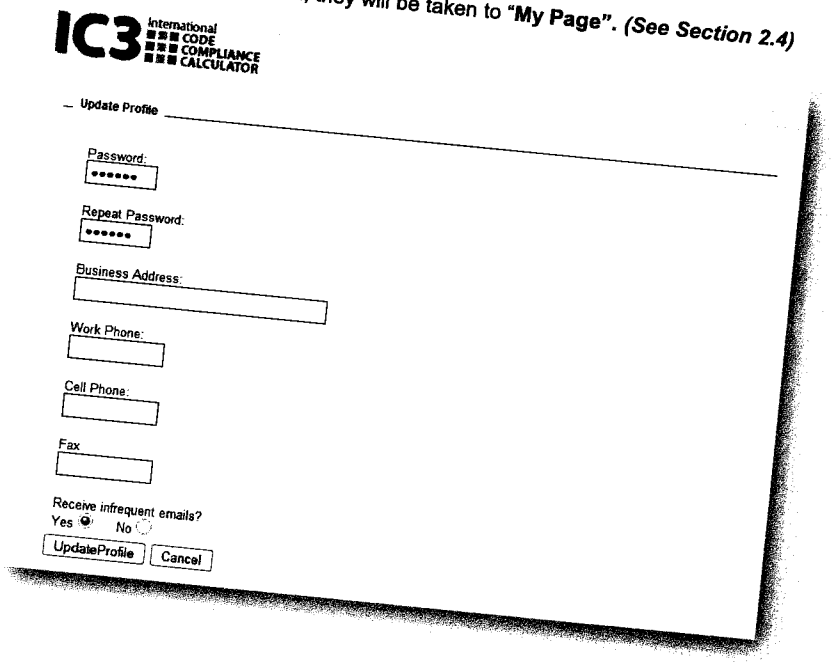
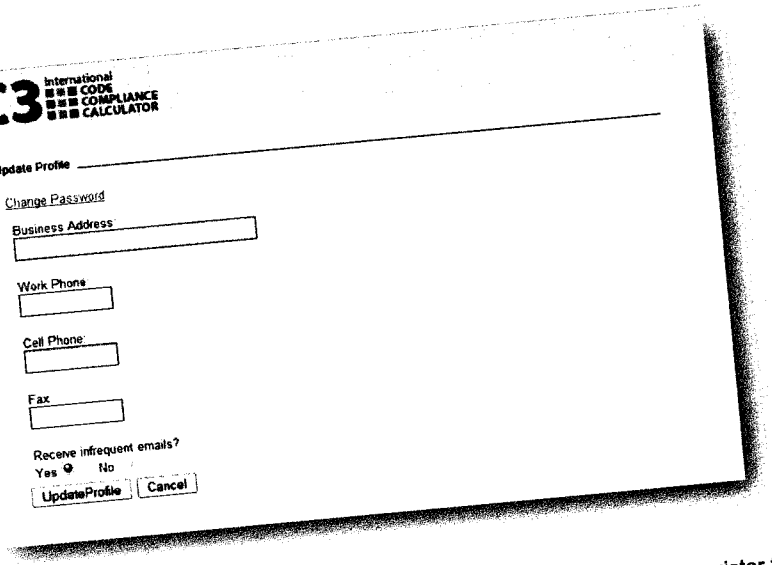
The user simply enters their password twice, and if they match, they will be taken to **"My Page"**. ***(See Section 2.4)***



2.3 User Registration



After clicking on the **"Register"** tab on the **"User Login"** *(See 2.1 User Login Screen)* page, a new User may register the first time they use IC3. The user may specify if they want to receive informational emails about new versions or planned outages. ESL reserves the right to send critical emails as necessary.

Once the page is successfully completed, the user is taken to **My Page**. *(See 2.4 My Page).*

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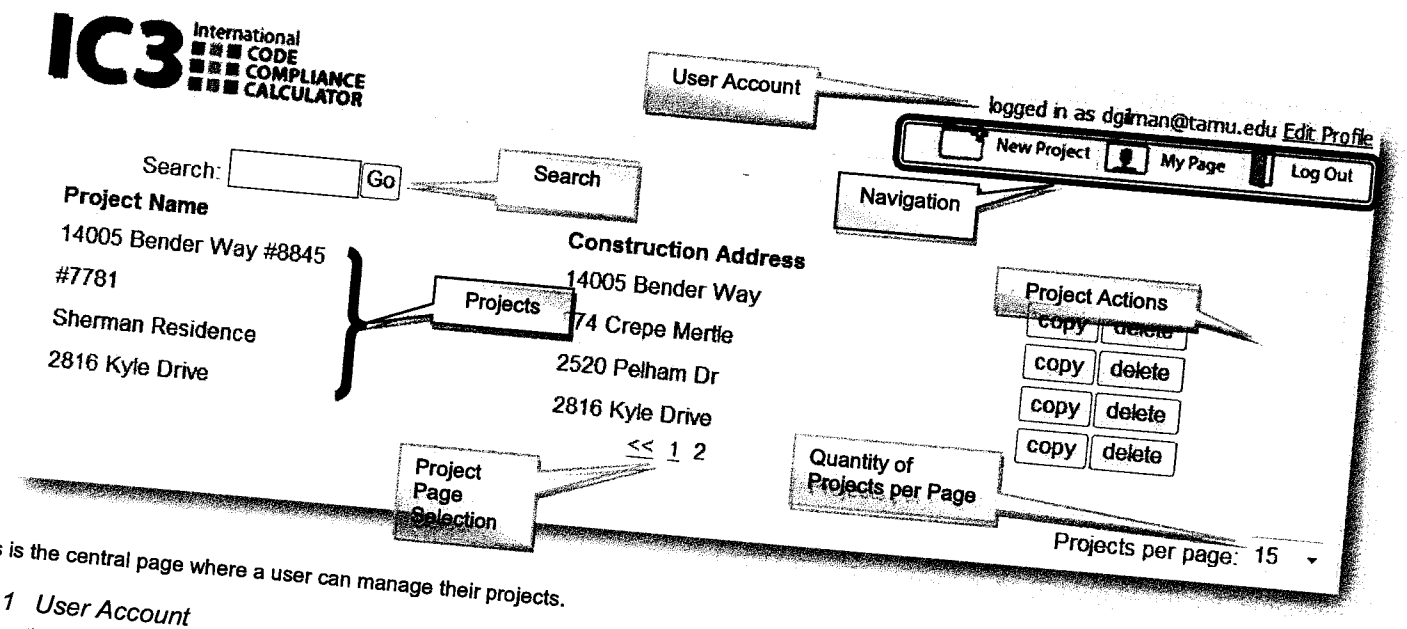
2.4 My Page



This is the central page where a user can manage their projects.

2.4.1 *User Account*

Shows the user login (useful if you are in a larger inspection company on a shared computer) and a link to edit your user profile.

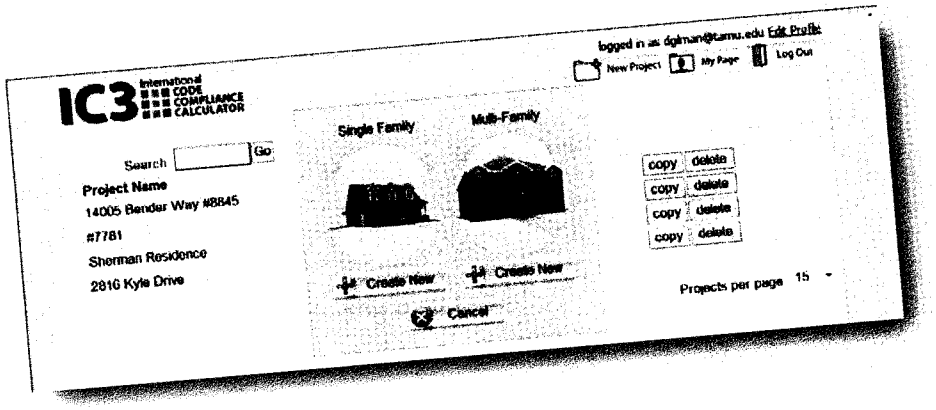
2.4.2 *Navigation*

On this page there are three buttons in the upper right hand side of the screen:

New Project – creates a new Multi Family or Single family project.
My Page – brings the user back to this page (**My Page**) from anywhere in the program.
Log Out – the preferred way to leave the system when a user finishes.

The system **does** save incomplete projects

New Project: "New Project "Button allows a user to select either **Single family** project or **Multifamily** project.



2.4.3 *Search*

The "Search for Construction Address Street Name:" allows the user to search on any part of an address and all matches will appear. Entering "Smithstone" will return all houses on any street with "Smithstone" in the name entered under this account. Likewise, entering "Smith" will result in "Granny Smith Lane" as well as "Smithstone Ct" and "Smithstone Ln". To clear the search, simply press "Go" again and the last ten projects will re-appear.

The grey area displays your last set of projects, or those selected by the Search feature.

IF YOU HAVE MORE PROJECTS THAN YOU CAN SEE, Simply press the "GO" button without any text in the search field. This will bring up all of the projects, and may take a while if you are a frequent user of the system!

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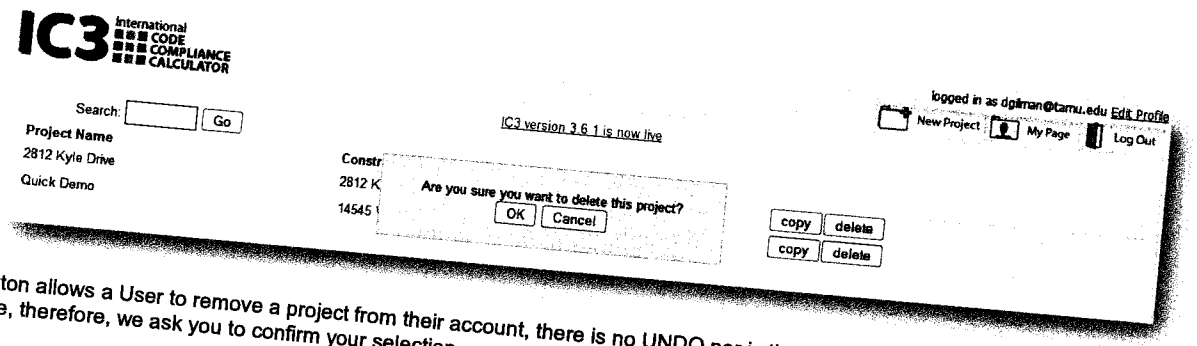
2.4.4 *Project Actions*

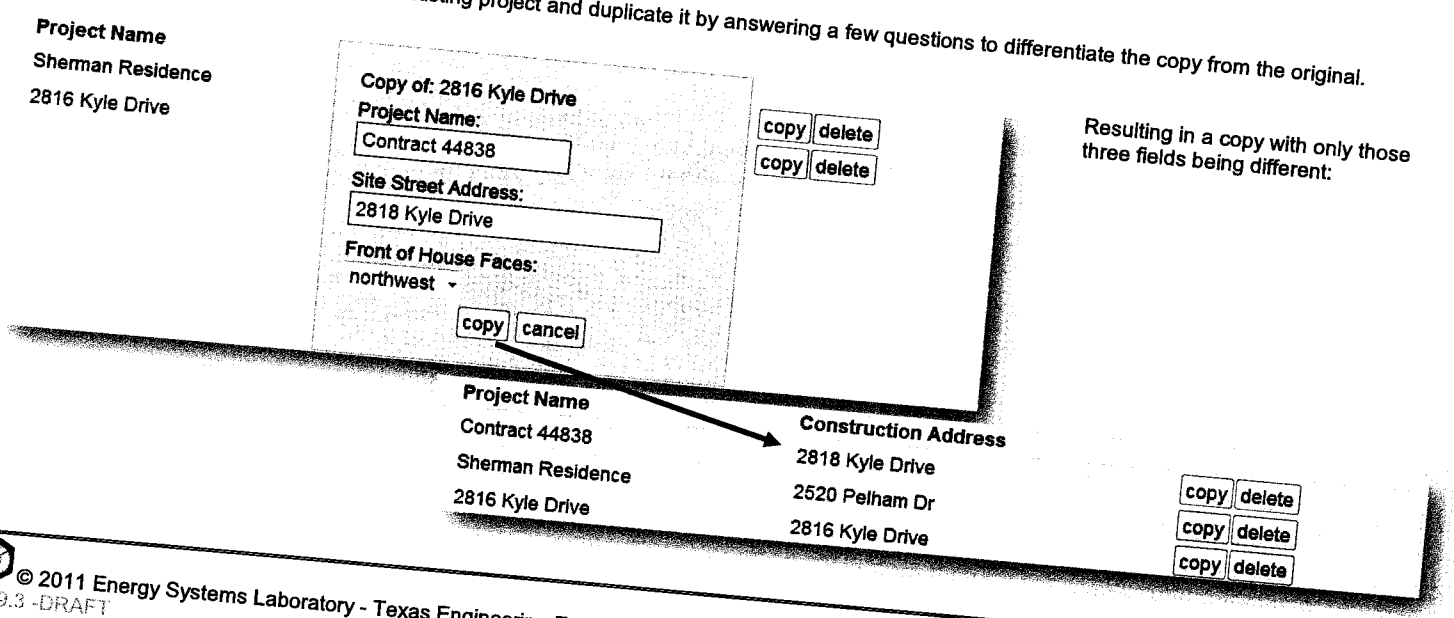
2.4.4.1 The Delete button



The "**Delete**" button allows a User to remove a project from their account, there is no UNDO nor is there any way for ESL to retrieve the project. This is a permanent delete, therefore, we ask you to confirm your selection.

2.4.4.2 The Copy button

The copy feature allows a user to take an existing project and duplicate it by answering a few questions to differentiate the copy from the original.



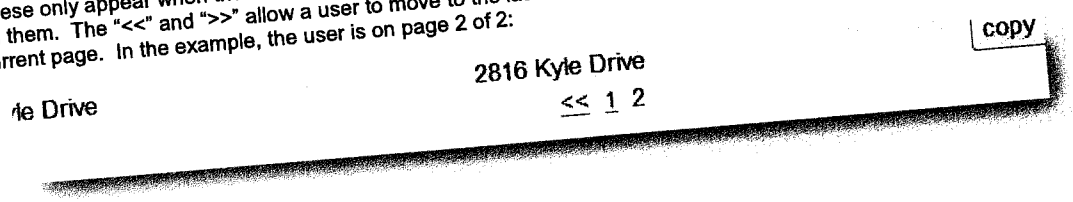
Resulting in a copy with only those three fields being different:

2.4.5 *Projects*

One project per line is displayed. The Project name field is intended to capture the builder or inspector's project number (which is often the street address). However, the actual street address is also shown to facilitate searching.

2.4.6 *Project Page Selection*

These only appear when the user has more projects than can fit on a single page. The numbers allow the user to jump to a specific page by simply clicking on them. The "<<" and ">>" allow a user to move to the last or next page on the list. If the number is not underlined then it is the page number of the current page. In the example, the user is on page 2 of 2:



2.4.7 *Quantity of Projects per Page*

Some users prefer to see more of their projects on a page, others less. Here the user can select 15, 25, 50, or 100 projects per page. The Project Page Selection will re-calculate when the new value is selected and the page refreshes (which may require the user to refresh the page using the browser's tool bar, right clicking the mouse or pressing the F5 key at the top of the keyboard.

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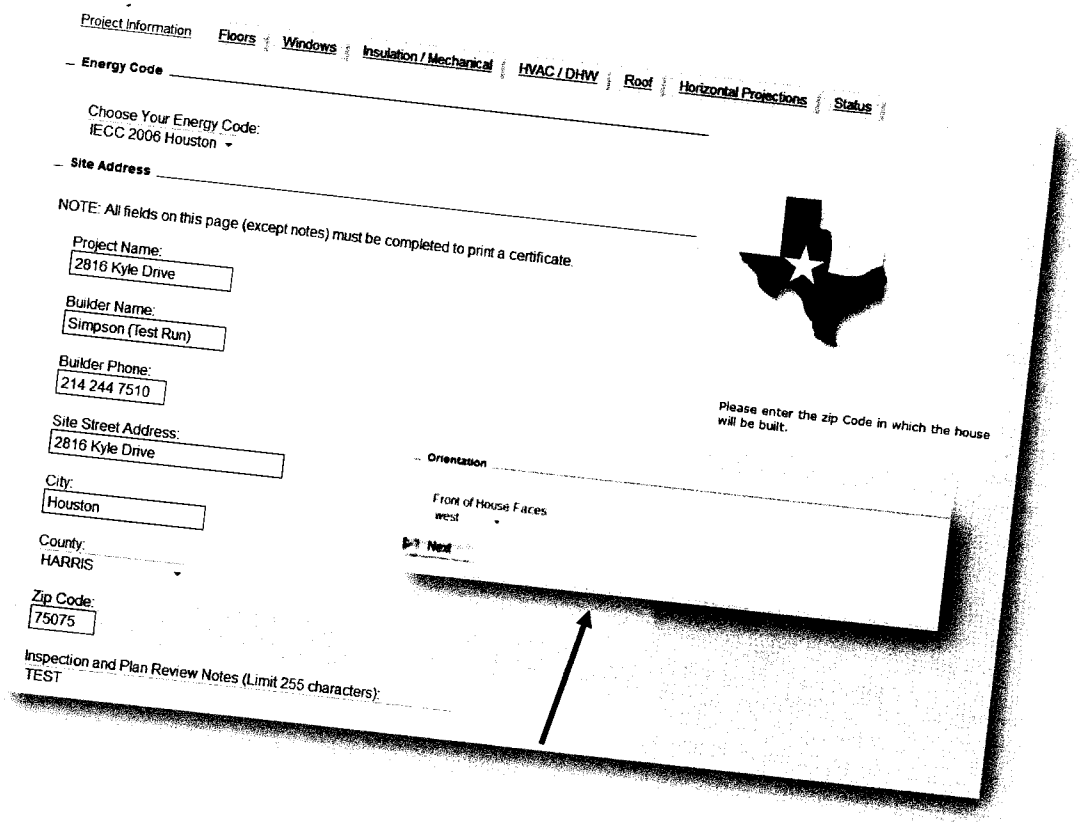
3 Single Family Specific

3.1 Project Information



Note that the screen is longer than displayed, with the "Front of House" faces being superimposed.

The **"Project Information"** screen allows a User to enter the details of the current project. The address entered is the address where the house will be built. Notes are shown on the certificate. This is a great place to document specific information that the inspector or others may need to know in the future. (i.e.; information such as duct trade-off)

Title	Picture	Range	Guidance	Notes
Energy Code		• IECC 2006 Houston * • IECC 2000/2001 * • IECC 2009 • IECC 2009 Austin	Please select the applicable energy code. **Only select Austin if you are in Austin!**	Choose the Energy Code Version accepted by the Authority Having Jurisdiction for the location of construction.
Project Name		n/a	Please enter a unique name for your proposed project. (Preferably a name not used by any other project.)	
Builder Name			Please enter the name of the client.	
Builder Phone			Please enter the phone number of the client.	
Site Street Address			Please enter the address of the house.	
City			Please enter the city in which the house will be built.	
County			Please select the county in which the house will be built.	Note that the choices are limited to the counties in Texas. IECC 2006 Houston defaults to Harris County.
Zip Code			Please enter the zip Code in which the house will be built.	
Notes			Please add any other notes about the house you would like to add.	If you are just playing, please add "TEST" to the notes section.
Front of House Faces		Eight compass points	Please select the orientation of the house from the drop-down menu. The front of the house is the direction the front door faces. The right side of the house is to the right of the house when facing it.	

*As of January 1, 2012, the State of Texas has depreciated all energy codes prior to 2009. These codes are available to view legacy projects, but you cannot print an energy report or certificate for them.

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3.2 Floors

2816 Kyle Drive

Project Information | Floors | Windows | Insulation / Mechanical | HVAC / DHW | Roof | Horizontal Projections | Status

– Floors

Number of Floors:
1

– 1st Floor

Conditioned Floor Area (sq ft):
2686

Perimeter of Conditioned Area (ft):
261

Average Ceiling Height (ft):
9.4

– Bedrooms

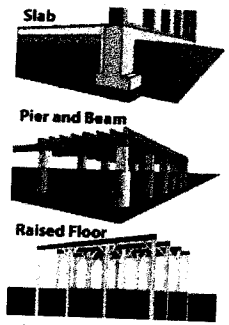
Number of Bedrooms:
4

– Foundation

Foundation Type:
Slab On Grade

Add Slab Insulation

Next



Please select the type of foundation the house will have.

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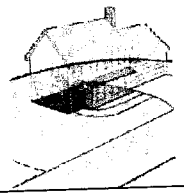
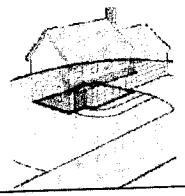
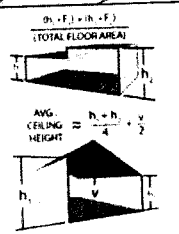
Title	Picture	Range	Guidance	Notes
Number of floors?		1-3	Please select the number of floors the house will have.	Choosing two or three floors, the page expands to show fields for second story entries. Split level homes are not modeled at this time.
1st floor displays regardless of selection of the number of floors.				
Conditioned Floor Area (sq. ft.)*		100-10,000 sq ft	Please enter the square-footage of conditioned space on this floor.	This excludes the garage or any porches.
Perimeter of Conditioned Area (Linear ft.)*		45-800 ft	Please enter the total length of the walls separating conditioned space from unconditioned space on this floor.	The perimeter wall length is the total linear length of the walls surrounding conditioned space. This includes wall lengths between unconditioned garages or porches and the conditioned interior of the structure.
Average Ceiling Height (ft)*		6.67-40 ft	Please enter the average ceiling height for this floor.	This value should be a weighted average of the ceiling heights. The impact from averaging is not large relative to the other fields the Builder is providing. **Note:** A two-story house where a foyer or a room on the first floor has a ceiling as high as those on the second floor, the ceiling height input for the tall foyer or room will be the same as the input value for the rest of the average ceiling height.

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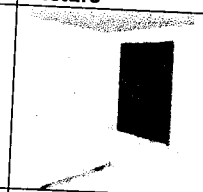
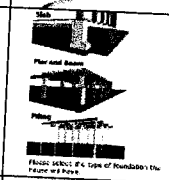
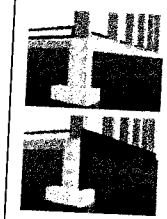
Title	Picture	Range	Guidance	Notes
Number of Bedrooms		1-10	Please enter the number of bedrooms the house will have.	A room without an external window and closet is not to be counted towards this value. This software uses this value to statistically determine domestic hot water usage.
Foundation Type		**Menu:** • Slab On Grade • Pier and Beam • Piling	Please select the type of foundation the house will have.	If "Slab On Grade" is selected than "Add Slab Insulation" appears in lieu of the Slab Insulation Field. **IC3 doesn't model basements at this time.**
Floor Insulation		0-20	Please input the R-Value of the floor insulation.	Automatically appears for Pier and Beam;, and Piling options.
Slab Insulation**		0-20	Please input the R-Value of the slab insulation.	Will appear for Slab if user selects "Add Slab Insulation" link (as shown above). **Do not use "0" to remove slab insulation, use the "Remove Slab Insulation" link!!** Not recommended for use in areas with a high likelihood of termite infestation. Please refer to your local building code office if you are unsure whether your project requires slab insulation.

**** Note that these fields are repeated for the each floor selected.***
***** Will not appear for "Slab on Grade" unless user selects "Add Slab Insulation", and replaces "Floor Insulation"***

3.3 Windows

Project Information | Floors | Windows | Insulation / Mechanical | HVAC / DHW | Roof | Horizontal Projections

Glazing Properties

Solar Heat Gain Coefficient:
0.36

U-factor:
0.45

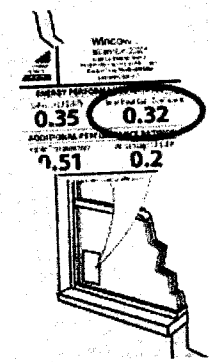
1st Floor Windows

Front (sq ft):
132.5

Right (sq ft):
145.5

Back (sq ft):
147.4

Left (sq ft):
46



Please enter the Solar Heat Gain Coefficient (SHGC) for the fenestrations (e.g., windows and doors). (This information should be provided on the construction documents to be verified at the time of inspection.)

In v3.x of the software, in smaller houses, or houses with LOTS of glazing, there are some restrictions on window sizes to meet code. The software will tell the user if they have exceeded an effective window to wall ratio.

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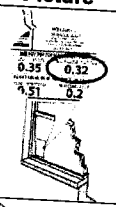
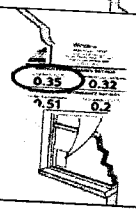
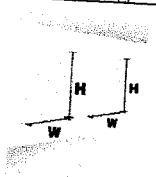
Title	Picture	Range	Guidance	Notes
Solar Heat Gain Coefficient		.20 - .50	Please enter the Solar Heat Gain Coefficient (SHGC) for the fenestrations (e.g., windows and doors). (This information is provided on the construction documents verified at the time of inspection.)	In the event of the home having different values, one enters the worst value or one calculates a weighted average based on square footage.
U-factor		.25-1.22	Please enter the U-Factors of fenestration products (e.g., windows and doors). (This information is provided on the construction documents verified during inspection.)	In the event of the home having different values, one enters the worst value or one calculates a weighted average based on square footage.
*Front/Right/Back/Left Window area (sq. ft.)		Must be equal to or greater than 0.	Please enter the total combined area of all windows and glass doors; measured using the rough opening and including the sash, curbing or other framing elements. For doors where the daylight opening is less than 50% of the door area, the glazing area is the daylight opening area only. For glass doors, the glazing area is the rough opening area for the door including the door and frame.	Make sure your directions (front, back, left, and right) are correspond to the orientation of the house. For doors where the daylight opening is less than 50% of the door area, the glazing area is the daylight opening area only. For glass doors, the glazing area is the rough opening area for the door including the door and frame.

*** Note: These fields will be duplicated for a home that has a 2nd or 3rd story (as shown above).**

3.4 Insulation/Mechanical

Project Information | Floors | Windows | Insulation / Mechanical | HVAC / DHW | Roof | Horizontal Projections | Status

Mechanical

Mechanical in conditioned space?:
Yes ○ No ◉

Measurements for Blower Door:
Not Tested

Measurements for Duct Blaster:
Not Tested

Insulation

Wall Cavity Insulation R-Value:
13

Insulated Wall Sheathing R-Value:
2

Exterior Wall Finish:
Brick

Total Roof/Ceiling Insulation R-Value:
30

Supply Duct Insulation R-Value:
8

Return Duct Insulation R-Value:
8

Next

Stucco

Vinyl

Brick

Cement Board

Wood Siding

Please select the exterior wall finish from the drop-down menu.

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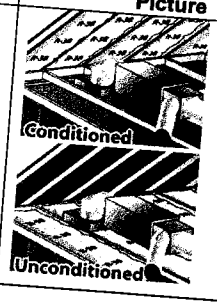
Title	Picture	Range	Guidance	Notes
Mechanical in conditioned space?		**Radio Button** • Yes • No	Please mark your answer according to the location of the mechanical equipment and its duct-work.	When the insulation is applied on the underside of the roof decking we can consider the attic space a conditioned space.
Measurements for Blower Door are:		**Menu:** • Not Tested • Estimated* • Tested*	If project will not have a Blower Door Test, answer "Not Tested". If you want to estimate the project's results for the Blower Door Test, answer "Estimated" If the Blower Door test has been performed, answer "Tested".	The measurements or results from a Blower Door test are considered untested if no blower door test were performed. If Estimated* or Tested* is selected, then the following Input appears as shown on the next line. "Estimated" Blower Door measurements or results are those expected before construction. "Tested" measurements or results are those actually measured or verified after construction. Blower Door tests are required in IECC 2009 and later.
Blower Door (in ACH50) *Only appears for Estimated/Tested choices above.*		Values are typically 0 -20.	Please enter the expected results from the Blower Door test for the proposed house.	Typical Blower Door ACH50 test ranges fall between 0 and 20 ACH with respect to indoors or outdoors. [1]

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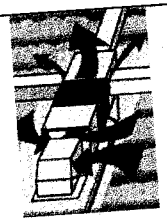
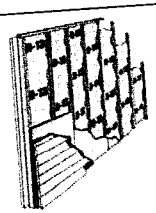
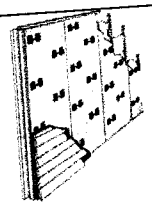
Measurements for Duct Blaster are:		**Menu:** • Untested • Estimated* • Tested*	Please specify whether measurements for Duct Blaster test are untested, estimated, or tested.	If Estimated* or Tested* is selected, then the following Input appears as shown on the next line.
Duct Blaster (in CFM25) *Only appears for Estimated/Tested choices above.*		• Values are typically 0-50.	Please enter the expected results from the Duct Blaster test for the proposed house. Typical Duct Blaster CFM25 test ranges fall between 0 and 50 CFM with respect to outdoors.	Duct Blaster Tests are used to determine if the air handler and leaks in the duct system affect the pressure inside the house with respect to the outside. Generally speaking, the ducts are pressurized to ΔP=25Pa and the flow rate into the ducts is recorded.
Wall Cavity Insulation Value		5-50	Please enter the R-Value for the wall cavity insulation. Insulation R-Values are verified during inspection.	This is the value of the insulation installed between the studs.
Insulated Wall Sheathing R-Value		0 or 2-50	Please enter the R-Value for insulated wall sheathing if applicable. If none is used, please enter "0".	This is the value of the insulated sheathing applied to the exterior of the wall assembly. If no sheathing is used, enter 0. If sheathing is used, then the minimum value is R-2.

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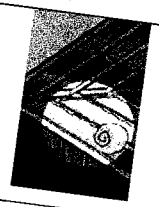
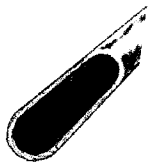
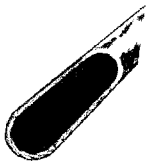
Exterior Wall Finish	Stucco Vinyl Brick Cement Board Wood Siding	**List of:** • Stucco • Vinyl Siding • Brick • Fibrous Cement Board • Wood Siding	Please select the exterior wall finish from the drop-down menu.	If your siding type is not listed, please choose the closest material for an approximation.
Total Roof/ Ceiling Insulation R-Value		13-60	Please enter the weighted average R-Value for the roof/ceiling cavity insulation. Insulation R-values are verified at inspection.	Regardless of the *type* of insulation, the value here reflect the cavity insulation installed at the ceiling, or the top of the thermal envelope. (Possibly the roofline).
Supply Duct Insulation R-Value		6+	Please enter the R-Value of the supply duct insulation.	Depends on the IECC Code selected. IECC 2009 for Austin requires R8
Return Duct Insulation R-Value		6+	Please enter the R-Value of the return duct insulation.	Depends on the IECC Code selected. IECC 2009 for Austin requires R8

**** KEY NOTES ****

1] Blower Door Tests measure the flow rate (cfm) through the fan by measuring the ΔP (difference in pressure) through the fan pressure sensor.

ACH50 = CFM50 x 60/ Volume of the house

In a single-point Blower Door Test, the house is de-pressurized to ΔP=50Pa (inside with respect to outside.)

3.5 HVAC/DHW (Climate Control)

2816 Kyle Drive

Project Information | Floors | Windows | Insulation / Mechanical | HVAC / DHW | Roof | Horizontal Projections | Status

Heating

Heating Type:
Natural Gas

Heating Efficiency (AFUE):
0.8

Cooling

A/C Efficiency (SEER):
14

A/C Size(tons):
5

Water Heater

Water Heater Type:
Natural Gas

Energy Factor:
0.62

Next

Please enter the tonnage of the air conditioning equipment. Equipment must be sized according to method acceptable to the building official or authority having jurisdiction.

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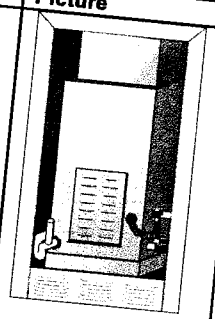
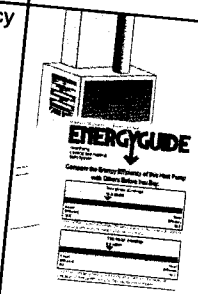
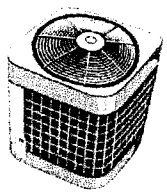
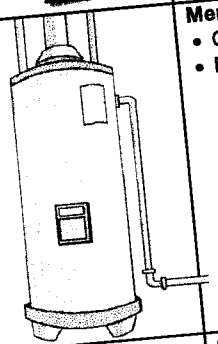
Title	Picture	Range	Guidance	Notes
Heating Type		The simulation supports three heating types. • Gas Furnace • Heat Pump • Electrical Resistance (not allowed in 2009 Austin)	Please select the heating type for the house (e.g., heat pump, natural gas).	The software assumes the HVAC is electric. All Natural Gas indicates the furnace and DWH are gas fired. Heat Pump and Electric assumes that the HVAC is an electric Heat Pump, probably with backup electric strip heating, and the DWH is electric.
Heating Efficiency (AFUE)		The value range and label depends on the Heating Type (above): • AFUE: 0.6 -1 • HSPF 7.7-12	Please enter the Annual Fuel Utilization Efficiency (AFUE).	Note that the label changes based on your Heating Type, and that if you enter an AFUE value, and change the heating type, you will see a reminder that the factional AFUE isn't an acceptable HSPF value! **NOTE: The system sets the efficiency of the furnace if it is electric.**
A/C Efficiency (SEER)		13-28	Please enter the Seasonal Energy Efficiency Ratio (SEER).	This applies to Heat Pumps too!

A/C Size (tons):		1.0-15.0	Please enter the tonnage of the air conditioning equipment. Equipment must be sized according to method acceptable to the building official or authority having jurisdiction.	
Water Heater Type		**Menu:** • Gas • Electric	Please select the type of fuel the water heater uses in the house (e.g. electric or, natural gas).	
Energy Factor		0.93– 1.0	Please enter the Energy Factor (EF) for the water heating equipment to be installed in the proposed house.	The software works with both tank-type and tank-less water heaters. If you have more than one water heater, please do a weighted average of the units, or use the efficiency rating of the least efficient water heater here.

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3.6 Roof

Project Information | Floors | Windows | Insulation / Mechanical | HVAC / DHW | Roof | Horizontal Projections | Status

Roof

Roof Covering Material:
Comp Shingle

Uses Radiant Barrier:
Yes ○ No ◉

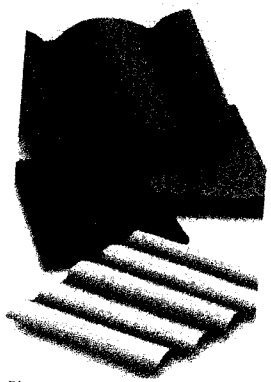
Ceiling Area

Flat Roof Area:
0

Cathedral Ceiling Area:
1253

Attic Floor Area:
2003

Area of Wall Adjacent to Unconditioned Attic Space:
416



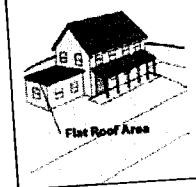
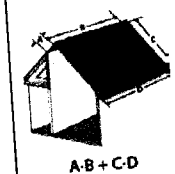
Please select the type of roof covering for the proposed house.

Ceiling Area Explained

Current Ceiling Area: 3256 sq ft

Minimum Ceiling Area: 2686 sq ft

Ceiling Area over:
1st Floor: 2686 sq ft

Title	Picture	Range	Guidance	Notes
Roof Covering Material		Pull Down Menu: • Clay or Concrete Tile • Composite Shingle • Metal • Slate • Wood Shingles • Other	Please select the type of roof covering for the proposed house.	This field uses the type of roof covering material to estimate the reflectivity and absorbance of the roof.
Radiant Barrier		Radio Button: • Yes • No	Please check the radio control according to your proposed house.	This field uses the type of roof covering material to estimate the reflectivity of the roof.
Flat Roof Area		0-30,000 ft	Please enter the square footage of the ceiling area covered by a flat roof.	
Cathedral Ceiling Area		0-30,000 ft	Please enter the square footage of the cathedral ceilings.	

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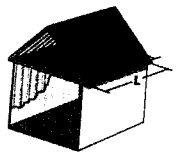
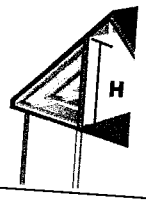
Attic Floor Area (sq ft)		0-30,000 ft	Please enter the square footage of the attic area (measured horizontally).	
Area of Knee Wall Adjacent to Attic (sq ft)		0-30,000 ft	Please enter the square footage of any walls adjacent to unconditioned space.	

3.7 Horizontal Projections

Project Information | Floors | Windows | Insulation / Mechanical | HVAC / DHW | Roof | Horizontal Projections | Status

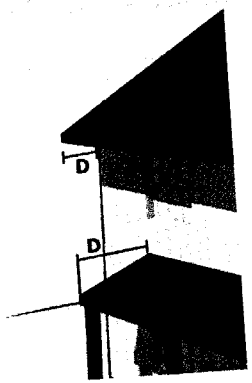
1st Floor Horizontal Projections

Front: (feet and inches i.e.: 4' - 6")
3' 0"

Right: (feet and inches i.e.: 4' - 6")
1' 6"

Back: (feet and inches i.e.: 4' - 6")
8' 0"

Left: (feet and inches i.e.: 4' - 6")
1' 6"



Please enter the distance measured from the wall to the outer edge of the projection.

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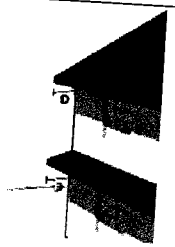
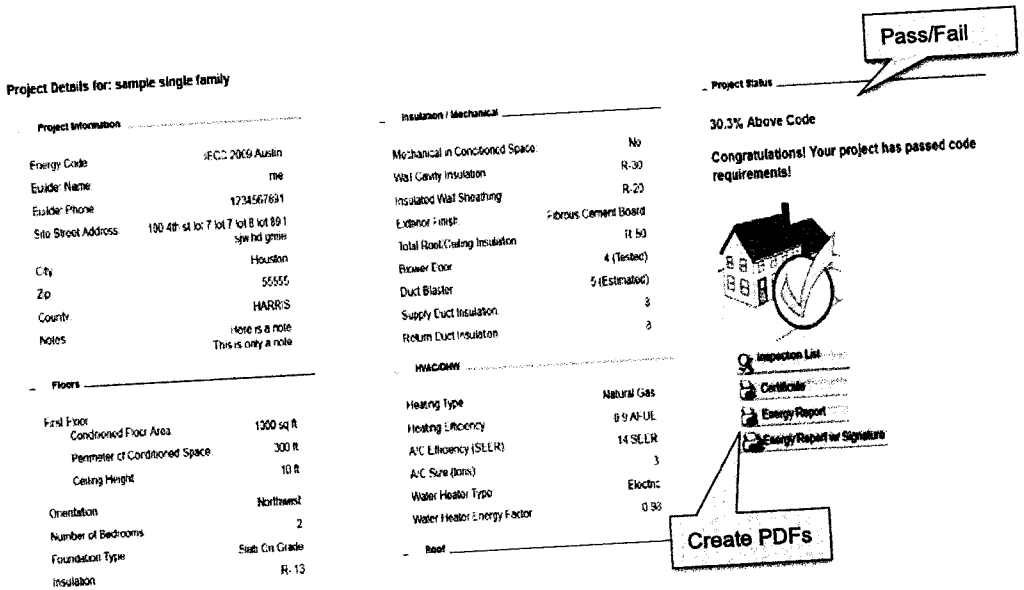
Title	Picture	Range	Guidance	Notes
*Front/Right/Back/Left (ft)		0-40 ft	Please enter the distance measured from the wall to the outer edge of the projection.	This is located at the roof level, and provides shade to both the windows (very important) and to the building itself. It is ok to enter values here as well as the Conditioned over non-Conditioned question on the Floors Tab. These are focused on shading of the windows; the other is focused on thermal loss through the exposed floor. Enter the horizontal distance (ft) from the wall to the edge of the overhang, eave, or permanently attached shading device on this side of the house for this floor. **NOTE: That if you enter just inches, the software will convert to feet and inches.**

Note that these inputs are repeated for any 2nd or 3rd floors.

3.8 Status



Please note that if you want the Certificate to appear in its own window, Right Click on any print button. Then select ***"Open in New Window."***

The project may pass or fail. The level at which it passes or fails is detailed at the upper right of the screen.

Several Documents are available on a passing project. These include the Energy Report, Certificate, and Inspection List. They are detailed below. These reports will only be available for a passing project.

If a project fails, it can be from one of three reasons.

1) If a specific reason is given below the failure messages, it means that your project has failed to meet a mandatory requirement. The error message will detail the exact reason for the failure.
2) If the project is incomplete, one or more sections in the Project Details portion of the screen will state this fact. Clicking on the link in this section will take you back to the appropriate tab.
3) Otherwise, if the only information given is' XX.X% Below Code', then the project has failed inspection. This means that the entered house uses more energy than the code house for the given energy code. You will need to go back and improve the efficiency in one or more areas to generate a passing score. The best candidates are usually improving the windows (SHGC and/or U-Value) or adding more insulation.

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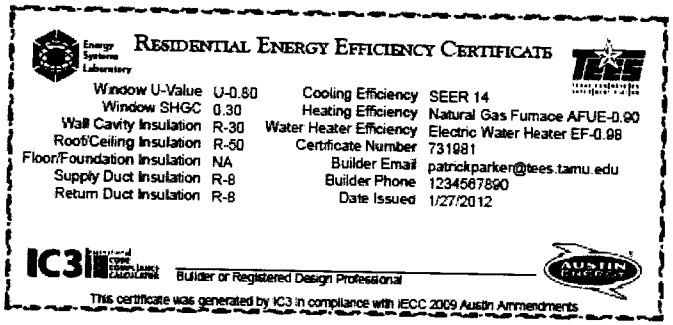
3.9 Certificate



RESIDENTIAL ENERGY EFFICIENCY CERTIFICATE

Window U-Value	U-0.80	Cooling Efficiency	SEER 14
Window SHGC	0.30	Heating Efficiency	Natural Gas Furnace AFUE-0.90
Wall Cavity Insulation	R-30	Water Heater Efficiency	Electric Water Heater EF-0.98
Roof/Ceiling Insulation	R-50	Certificate Number	731981
Floor/Foundation Insulation	NA	Builder Email	patrickparker@tees.tamu.edu
Supply Duct Insulation	R-8	Builder Phone	1234567890
Return Duct Insulation	R-8	Date Issued	1/27/2012

Builder or Registered Design Professional

This certificate was generated by IC3 in compliance with IECC 2009 Austin Ammendments

Certificates are small documents that are to be placed in the electrical panel of the inspected house. They are to be signed by the builder or 'registered design professional'.

3.10 Energy Report

The energy report is a multipage document detailing the results of the analysis run on the project. There are 2 versions available: normal or with signature. The signature version includes a signature line of the first page of the report. Although IECC standards do not require these reports to be signed, some municipalities do require a signature. Please check with your local government to determine what their exact requirements are.

3.11 Checklist

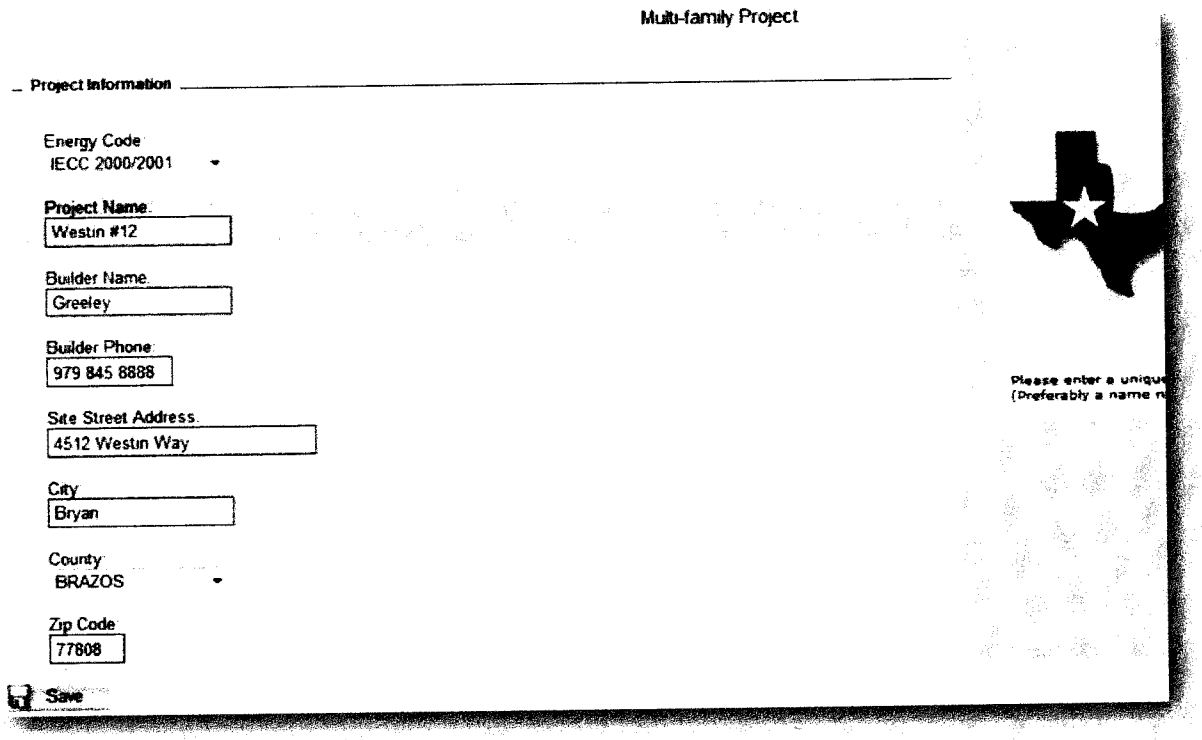
IECC standards require that an inspection checklist be provided by our software. This checklist is specific to your local Climate Zone. Note that these are given because the IECC code requires that we provide them, but are almost never used. Each municipality generally has their own procedures and checklists to use for energy inspections. This checklist may be used for self-inspection in those counties which allow for it.

4 Multi Family Specific

In this release of IC3, you can run simple multi-family simulations. As each building **Project** is made up of **Units**, which can have different **Floor Plans**, the calculator has to gather some information so it can properly model the building appropriately.

4.1 Project Information:

Allows the user to enter Project information



Title	Picture	Range	Guidance	Notes
Energy Code		• IECC 2006 Houston • IECC 2000/2001 • IECC 2009	Please select the applicable energy code	Choose the Energy Code Version accepted by the Authority Having Jurisdiction for the location of construction.
Project Name		n/a	Please enter a unique name for your proposed project. (Preferably a name not used by any other project.)	
Builder Name			Please enter the name of the client.	
Builder Phone			Please enter the phone number of the client.	
Site Street Address			Please enter the address of the house.	
City			Please enter the city in which the house will be built.	
County			Please select the county in which the house will be built.	Note that the choices are limited to the counties in Texas. IECC 2006 Houston defaults to Harris County.
Zip Code			Please enter the zip Code in which the house will be built.	

Pressing **"OK"**, brings you to a summary page and allows you to start a new Unit Floor Plan.

Westin #12

Energy Code:	IECC 2000/2001
Builder Name:	Greeley
Builder Phone:	979 845 8888
Site Street Address:	4512 Westin Way
City:	Bryan
County:	BRAZOS
Zip Code:	77808

edit

You will need to create a floorplan before entering individual units.

New Unit Floor Plan

To enter a multi-family project, first you must create a new floor plan. Units in multi-family structures often share common characteristics (i.e. square footage, ceiling height, etc.). A floor plan is just a way to collect those common characteristics between units with an identical or "mirrored" layout.

Press **"New Unit Floor Plan"**

4.2 Geometry Information

The first tab that displays for entering a Floor Plan is Geometry

Multi-family Project

Geometry | Windows | Insulation / Mechanical | HVAC / DHW | Horizontal Projections

Plan Name

Plan Name:
Long B

Geometry

Conditioned Floor Area:
850

Linear Feet of All Walls:
85

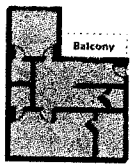
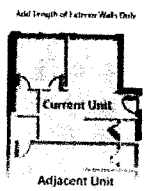
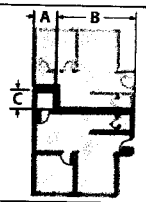
Linear Feet of Common Wall(s):
15

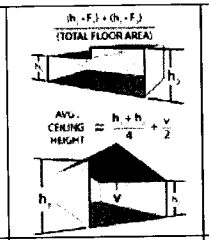
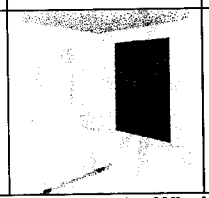
Average Ceiling Height:
9

Number of Floors:
1

Number of Bedrooms:
2

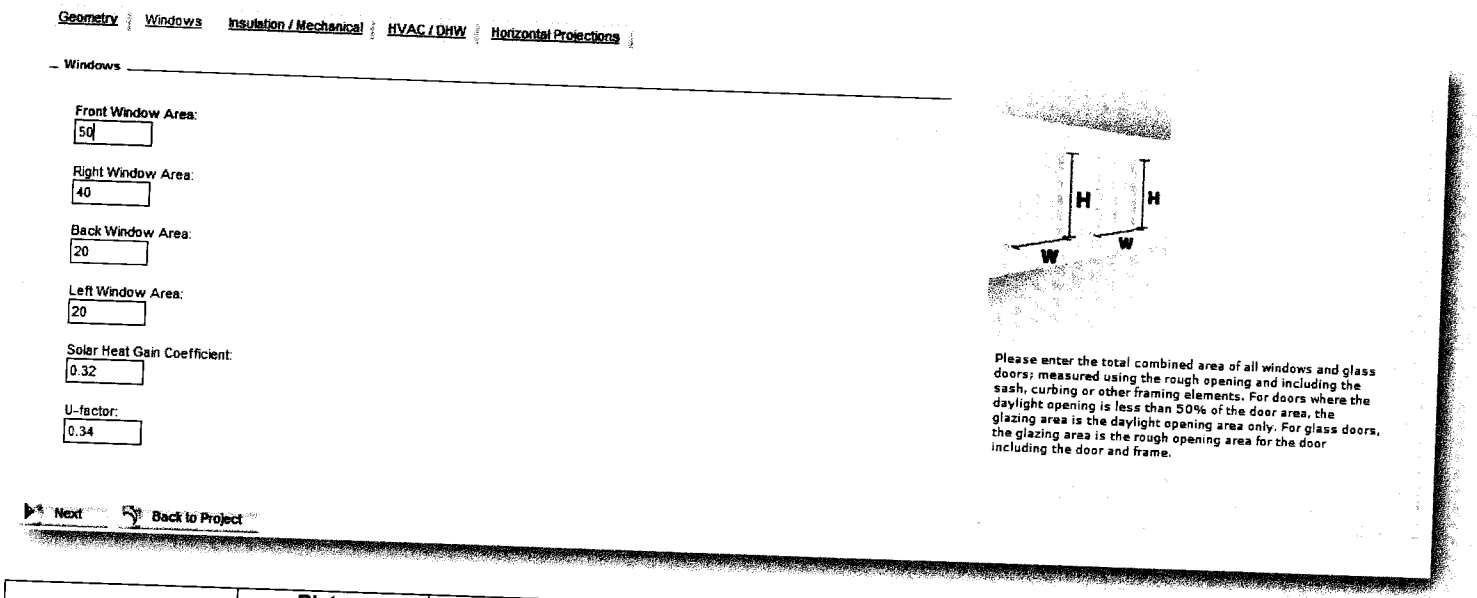
Next | Back to Project

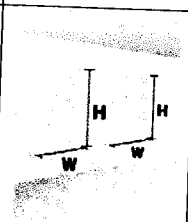
Title	Picture	Range	Guidance	Notes
Plan Name		30+ char	n/a	You can use a very long name if you wish.
Conditioned Floor Area		100-10000	Please enter the square-footage of conditioned space on this floor.	
Linear Feet of All Exterior Walls		45-800	Please enter the total length of the walls separating conditioned space from unconditioned space on this floor.	
Linear Feet of Common Wall(s)		At least 0	Please enter the total length in feet wall area shared between units.	*?

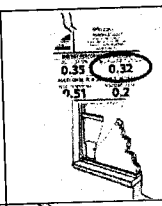
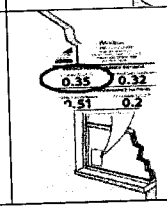
Average Ceiling Height:		6.67—40	Please enter the average ceiling height for this type of unit.	
Number of Floors		1,2,3	Please select the number of floors the house will have.	
Number of Bedrooms:		1-10	Please enter the number of bedrooms this type of unit will have.	

The **"Next"** button takes you to the **Windows** tab, while the **"Back To Project"** button returns you to the Project.

4.3 Windows



Title	Picture	Range	Guidance	Notes
*Front/Right/Back/Left Window area (sq. ft.)		Must be equal to or greater than 0.	Please enter the total combined area of all windows and glass doors; measured using the rough opening and including the sash, curbing or other framing elements. .	The directions are relative to the location of the front door. Make sure your directions (front, back, left, and right) are correspond to the orientation of the house. For doors where the daylight opening is less than 50% of the door area, the glazing area is the daylight opening area only. For glass doors, the glazing area is the rough opening area for the door including the door and frame

Solar Heat Gain Coefficient		At least 0.2	Please enter the Solar Heat Gain Coefficient (SHGC) for the fenestrations (e.g., windows and doors). (This information is provided on the construction documents and verified during inspection.)	In the event of the home having different values, one can enter the worst value or one can calculate a weighted average based on square footage.
U-factor		.25-1.22	Please enter the U-Factors of fenestration products (e.g., windows and doors). (This information is provided on the construction documents and verified during inspection.)	In the event of the home having different values, one can enter the worst value or one can calculate a weighted average based on square footage.

*** Note: These fields will be duplicated for a unit that has a 2nd or 3rd story (as shown above).**

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4.4 Insulation

Comment [DG1]:

Comment [DG2]:

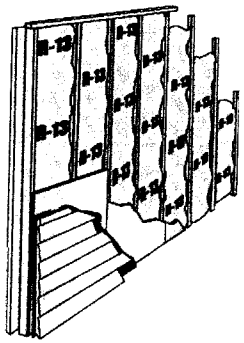
Geometry | Windows | Insulation | HVAC / DHW | Horizontal Projections

Insulation

Exterior Wall Cavity Insulation:
38

Insulated Wall Sheathing R-Value:
2

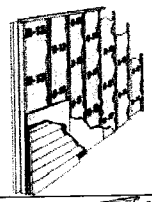
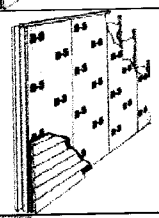
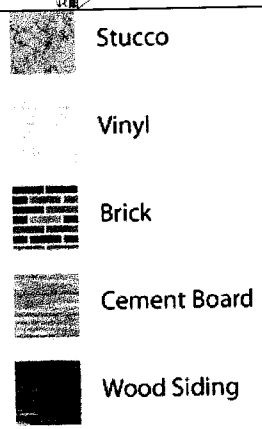
Exterior Wall Finish:
Stucco



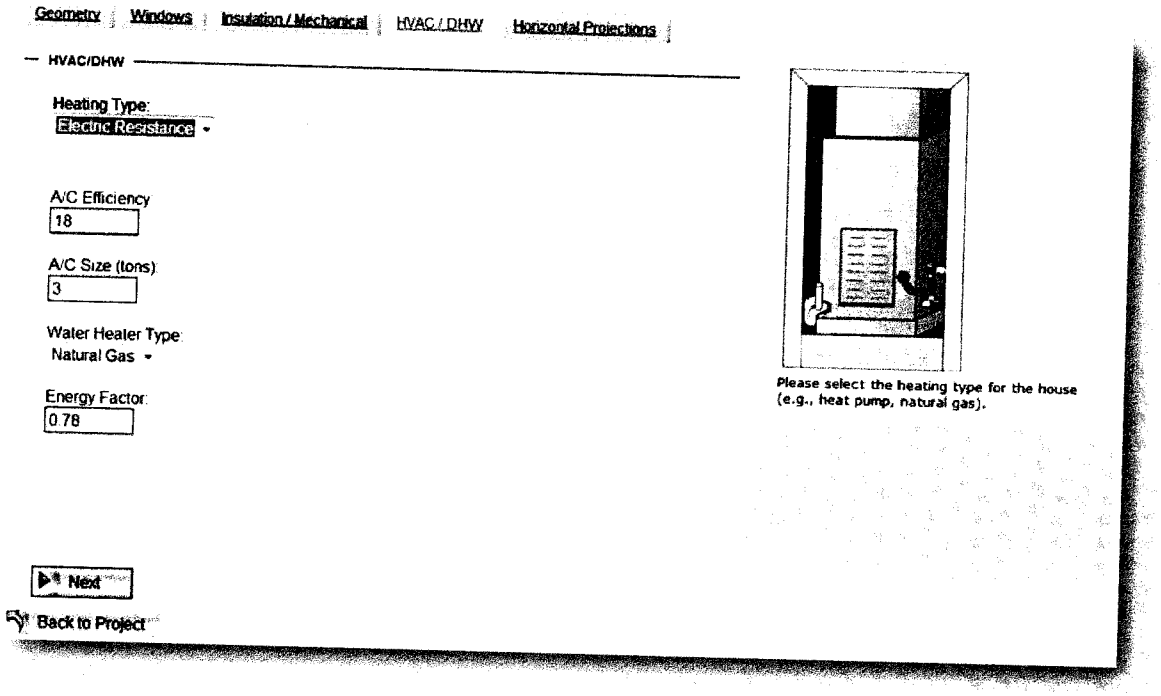
Please enter the R-Value for the wall cavity insulation. Insulation R-Values are to be verified during inspection.

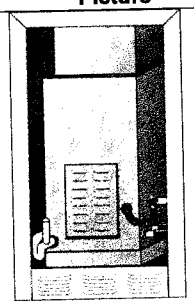
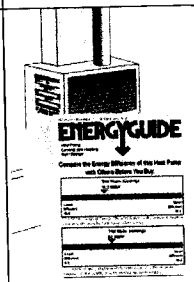
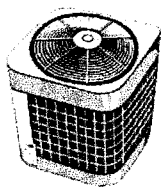
Next

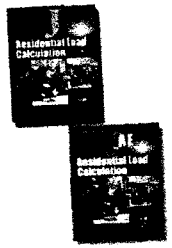
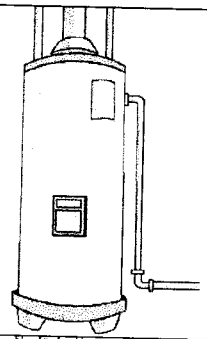
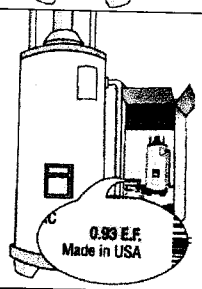
Back to Project

Title	Picture	Range	Guidance	Notes
Exterior Wall Cavity Insulation		5-50	Please enter the R-Value for the wall cavity insulation. Insulation R-Values are verified during inspection.	This is the value of the insulation installed between the studs.
Insulated Wall Sheathing R-Value		0 or at least 2	Please enter the R-Value for insulated wall sheathing if applicable. If none is used, please enter "0".	This is the value of the insulated sheathing applied to the exterior of the wall assembly. If sheathing is used, it must be of at least R-2 rating.
Exterior Wall Finish		**List of:** • Stucco • Vinyl Siding • Brick • Fibrous Cement Board • Wood Siding	Please select the exterior wall finish from the drop-down menu.	If your siding type is not listed, please choose the closest material for an approximation.

4.5 HVAC / DHW


Geometry
Windows
Insulation / Mechanical
HVAC / DHW
Horizontal Projections
HVAC/DHW
Heating Type:
Electric Resistance
A/C Efficiency
18
A/C Size (tons)
3
Water Heater Type:
Natural Gas
Energy Factor:
0.78
Please select the heating type for the house (e.g., heat pump, natural gas).
Next
Back to Project

Title	Picture	Range	Guidance	Notes
Heating Type		The simulation supports three heating types. • Gas Furnace • Heat Pump • Electrical Resistance (not allowed in 2009 Austin projects)	Please select the heating type for the house (e.g., heat pump, natural gas).	The software assumes the HVAC is electric. All Natural Gas indicates the furnace and DWH are gas fired. Heat Pump and Electric assumes that the HVAC is an electric Heat Pump, probably with backup electric strip heating, and the DWH is electric.
Heating Efficiency (AFUE)*		The value range and label depends on the Heating Type (above): • AFUE: 0.6 -1 • HSPF 7.7-12	Please enter the Annual Fuel Utilization Efficiency (AFUE).	Note that the label changes based on your Heating Type, and that if you enter an AFUE value, and change the heating type, you will see a reminder that the factional AFUE isn't an acceptable HSPF value! **NOTE: The system sets the efficiency of the furnace if it is electric.**
A/C Efficiency (SEER)		13-28	Please enter the Seasonal Energy Efficiency Ratio (SEER).	This applies to Heat Pumps too!

A/C Size (tons):		**1.0-15.0**	**Please enter the tonnage of the air conditioning equipment. Equipment must be sized according to method acceptable to the building official or authority having jurisdiction.**	
Water Heater Type		**Menu:** • **Gas** • **Electric**	**Please select the type of water heater used in the house (e.g. tank-less, natural gas).**	
Energy Factor		**0.93– 1.0**	**Please enter the Energy Factor (EF) for the water heating equipment installed in the proposed house.**	**The software works with both tank-type and tank-less water heaters. If you have more than one water heater, please do a weighted average of the units, or use the efficiency rating of the least efficient water heater here.**

**Heating Efficiency (AFUE) only appears if the heating type is Natural Gas*

4.6 Horizontal Projections

Geometry | Windows | Insulation / Mechanical | HVAC / DHW | Horizontal Projections

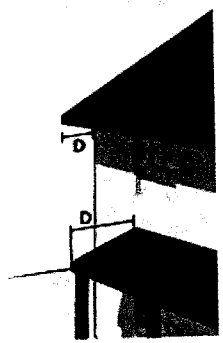
Horizontal Projections

Front Horizontal Projection:
0' 1"

Right Horizontal Projection:
0' 0"

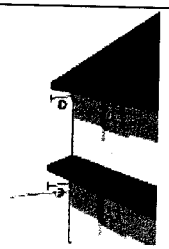
Back Horizontal Projection:
0' 1"

Left Horizontal Projection:
0' 1"

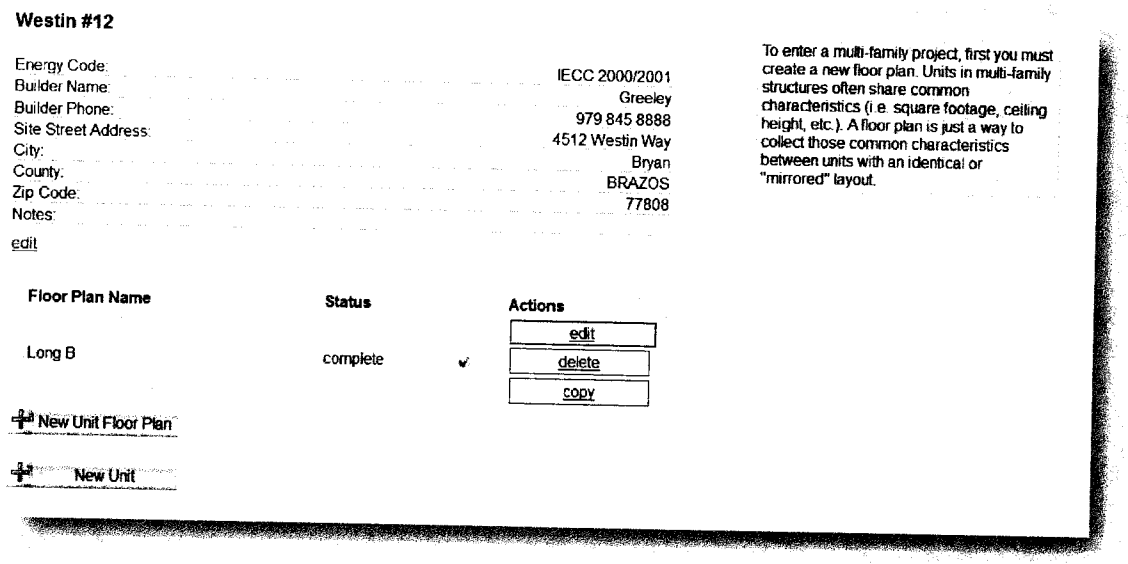


Please enter the distance measured from the wall to the outer edge of the projection.

Back to Project

Title	Picture	Range	Guidance	Notes
*Front/Right/Back/Left (ft)		0-40 ft	Please enter the distance measured from the wall to the outer edge of the projection.	This is located at the roof level, and provides shade to both the windows (very important) and to the building itself. It is ok to enter values here as well as the Conditioned over non-Conditioned question on the Floors Tab. These are focused on shading of the windows; the other is focused on thermal loss through the exposed floor. Enter the horizontal distance (ft) from the wall to the edge of the overhang, eave, or permanently attached shading device on this side of the house for this floor.

Hitting **"Back to Project"** will return you to the **Project Screen** where you will see your Project with the first Floor Plan created.



Now you can enter another Floor Plan (simply repeat from 4.2to 4.6 above) or a Unit…

4.7 New Unit – Unit Properties

Multi-family Project->New Unit

Properties | Orientation

Unit Properties

Unit Name:
A

Floor Plan:
Long B

Conditioned Floor Area Overhanging Unconditioned Space:
0

Floor Type:
Bottom Floor

Remove Slab Insulation

Slab Insulation R-Value:

Not recommended for use in areas with a high likelihood of termite infestation. Please refer to your local building code office if you are unsure whether your project requires slab insulation.

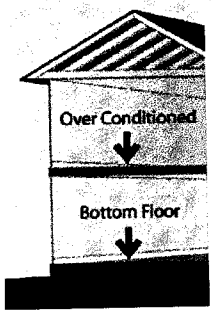
Ceiling Type:
Under Conditioned

Mechanical in Conditioned Space?
Yes No

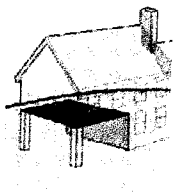
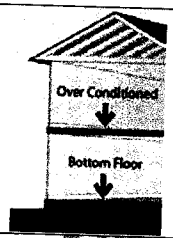
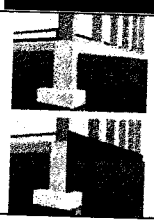
Measurements for Blower Door are:
Not Tested

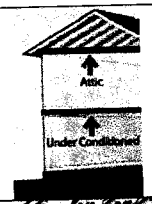
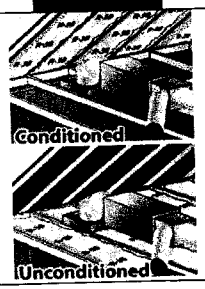
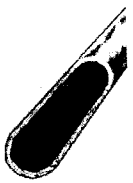
Measurements for Duct Blaster are:
Not Tested

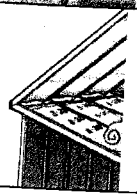
Next | Back to Project



Floor type.

Title	Picture	Range	Guidance	Notes
Unit Name		Text input	The name of the unit, probably the unit number or letter.	
Floor Plan		Pull down menu of the Floor Plans previously defined.	The type of floor plan the unit is built from.	
*Conditioned Floor Area Overhanging Unconditioned Space		0-10,000 sq ft	Please enter the total square-footage of conditioned space of this floor overhanging ambient (unconditioned) air. (i.e.-2nd floor overhanging an unconditioned porch or garage.)	This does not negate or replace the overhang values to be entered on the Overhang tab. This entry is to allow the simulation to calculate heat loss/gain via the exposed floor. The Overhang tab is to collect information on shading on the windows. The area of this value must be less than the floor area. So if you have a 500sq ft 2nd floor, you may only enter 499 for the overhang. This is a modeling limitation.
Floor Type		• Bottom Floor • Over Conditioned	Floor Type	If you select "Bottom Floor", you will see a link for adding Slab Insulation.
Slab Insulation**		0 - 20	Please input the R-Value of the slab insulation.	Will appear for Slab if user selects "Add Slab Insulation" link (as shown above). **Do not use "0" to remove slab insulation, use the "Remove Slab Insulation" link!!**

Ceiling Type		• Attic • Under Conditioned	Ceiling type	
Mechanical in conditioned space?		**Radio Button** • Yes • No	Please mark the radio control according to your proposed house.	This entry is referring to the location of the mechanical equipment and its duct-work. When the insulation is applied on the underside of the roof decking we can consider the attic space as a conditioned space.
Supply Duct Insulation R-Value*		8+	Please enter the R-Value of the supply duct insulation.	*** Only appears if Mechanical in Conditioned Space is "No"**
Return Duct Insulation R-Value*		8+	Please enter the R-Value of the return duct insulation.	*** Only appears if Mechanical in Conditioned Space is "No"**

Blower Door (in ACH50) *Only appears for Estimated/Tested choices above.*		Values are typically 0 -20.	Please enter the expected results from the Blower Door test for the proposed house. Typical Blower Door ACH50 test ranges fall between 0 and 20 ACH with respect to indoors or outdoors. For further information on this topic, please refer to the IC3 User Manual.	Blower Door Tests measure the flow rate (cfm) through the fan by measuring the ΔP (difference in pressure) through the fan pressure sensor. ACH50 = CFM50 x 60/ Volume of the house. In a single-point Blower Door Test, the house is de-pressurized to ΔP=50Pa (inside with respect to outside.)
Measurements for Duct Blaster are:		• Untested • Estimated* • Tested*	Please specify whether ducts are untested, estimated, or tested. For further information on this topic, please refer to the IC3 User Manual.	If Estimated* orTested* is selected, then the following Input appears as shown on the next line. Duct blaster and Blower Door tests are required for IECC 2009 and later codes..
Total Roof/Ceiling Insulation R-Value ***		13-60*	Please enter the weighted average R-Value for the roof/ceiling cavity insulation. Insulation R-values are verified at inspection.	*Provisional range

***** Will not appear for Slab unless user selects "Add Slab Insulation", and replaces "Floor Insulation"***
****** Only appears for top unit.***

Pressing the **Next** button brings you to the Orientation Screen:

4.8 New Unit – Unit Orientation

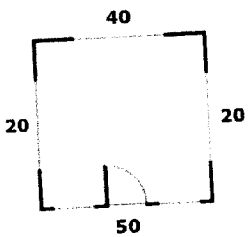
Multi-family Project

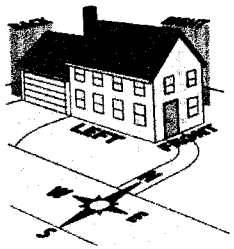
Properties | Orientation

Unit Orientation

Orientation:
south

Mirror:
Yes ○ No ◉





Please select the orientation of the unit from the drop-down menu. The front of the unit is the direction the front door faces. The right side of the unit is to the right of the unit when facing it.

Back to Project

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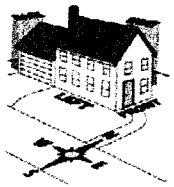
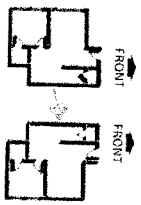
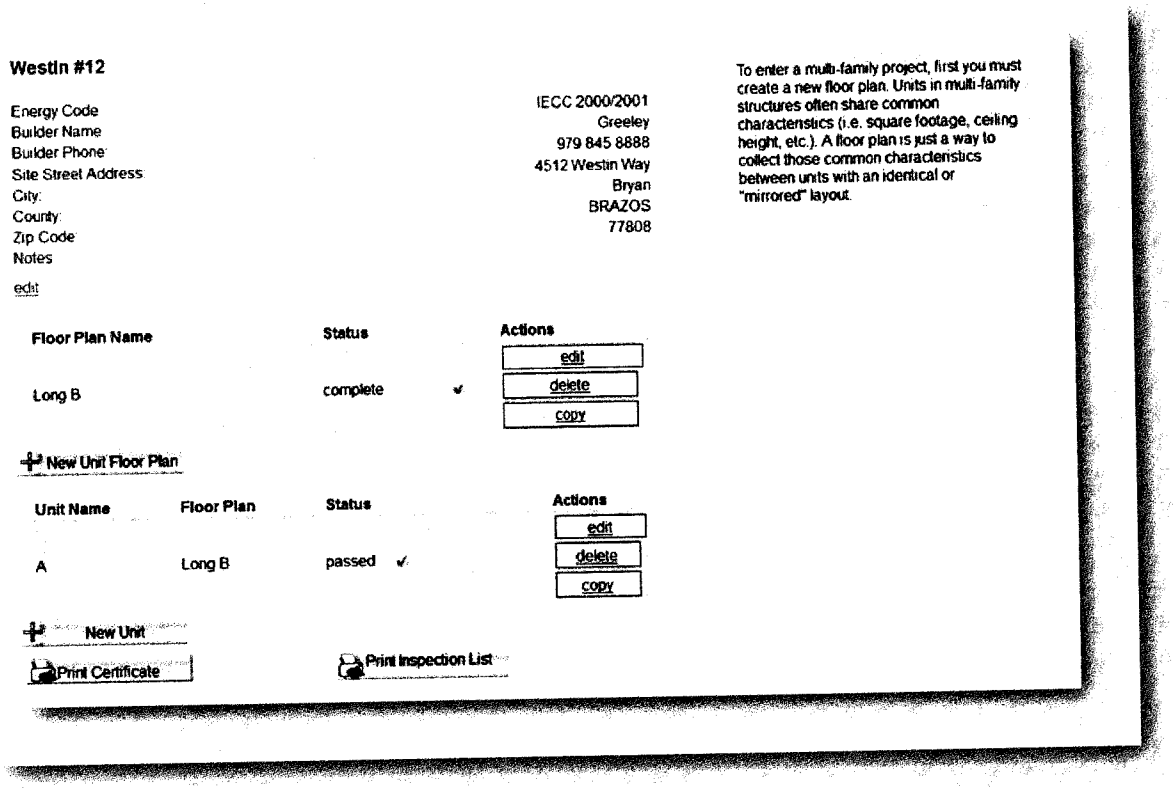
v3.9.3 -DRAFT

Title	Picture	Range	Guidance	Notes
Orientation		Eight compass points	Please select the orientation of the unit from the drop-down menu. The front of the unit is the direction the front door faces. The right side of the unit is to the right of the unit when facing it.	
Mirror		• Yes • No	The unit is mirrored from the specified floor plan if the properties of the sides of the unit (i.e. window properties) are swapped.	

Pressing the **Back to Project** button will return you to the Project screen where you will see that this Project has one Unit and one Floor Plan.



In this case we have pressed the **Print Certificate** option which causes the simulation to execute and a certificate to be generated.
New Unit begins the **Unit** definition process

5 Other Information

5.1 FAQ

Q – Can I use REScheck to show compliance with the 2006 IECC in Texas?

A – No. ResCheck is a "prescriptive" based computer software tool addressing building envelope effectiveness. The 2006 version is meant to be used with the 2006 version of the IECC.

The state charged the Energy Systems Laboratory (ESL) with verifying stringencies between the 2000 version of the International Energy Conservation Code with 2001 Amendments and any versions published afterward. In comparison, the 2006 residential provisions were determined to be less stringent. To address this situation, the North Central Texas Council of Governments (NCTCOG) developed a package of amendments that redefine climate zones and provide the correct insulating values for building performance according to those climate zones. The recommended amendments to the 2006 International Energy Conservation Code compensate for the differences.

If a municipality adopts the 2006 IECC along with the NCTCOG amendments, they are in compliance with state law. IC3 is a software tool designed to be used with the 2006 IECC and NCTCOG amendments combined. IC3 is a "performance" based computer software tool which addresses specific performance values of construction including the envelope but also including efficiencies of equipment, different power sources, location of equipment, etc. It allows you to compare your "proposed" design to the "standard" design already simulated in the calculator. Using IC3 allows you see how much above code or below code your "proposed" construction would be.

Q – Where is the 2006 IECC w/ NCTCOG amendments in the drop down tool?

A –In terms of stringency, Energy Systems Laboratory (ESL) determined that the 2006 International Energy Conservation Code (IECC) is less stringent than the 2000 IECC with the 2001 Supplement. Therefore, the laboratory worked closely with the North Central Texas Council of Governments (NCTCOG) to develop a set of amendments to the 2006 IECC. The 2006 IECC w/ NTCOG amendments is the same as the 2000 – 2001 IECC option.

Q – I am confused. How do I know which code option to choose?

A – "IECC 2009" is your choice to show compliance with the 2009 IECC. The "IECC 2009 Austin" code should be used to show compliance with the 2009 amendments published by Austin Energy.

Q – How does an IC3 User access older projects in IC3?

A – You should be able to access your older projects from "My Page". Initially, IC3 displays the last ten projects entered into IC3. If you need to find projects that are being stored that are older than the last three projects, then simply click on the "Search" button (with nothing typed in the search field). This will open the "project scroll function" and the ability to scroll through all of the projects that you have access to. If there you are still unable to locate your project, it could be that IC3 has undergone an enhancement that affected the status of your project. In this case, you may use the "Help/FAQ's" link at the bottom of every page in IC3. From the web page that opens up, simply select the "Contact Us" option and send us your request and we can help by retrieving the information for you.

Q – How do I use the "Texas A&M Duct Trade-Off Option" in IC3?

A - The "Duct Trade-Off Option" cannot be used with the "IECC 2009" or later code selections.

Q – Why won't the software calculate an addition on the back of a house?

A – IC3 isn't presently configured to do additions, only new single family residences.

Q – IC3 allows Solar Heat Gain Coefficient and U-Factors greater than what is allowed for the climate zone where my project is located. Is this a defect with the software?

A – No, this is not a defect. IC3 has been developed to allow the user to enter the values for SHGC and U-factor that would comply with the State of Texas energy code requirements. It is also intended to demonstrate our interpretation of the simulated performance approach. IC3 allows the user to enter SHGC and U-factor values that may not meet the minimum for a certain area, but will allow the user to see how the entire building will perform according to the users' input. Minimum values for SHGC and U-factor may be dictated by a jurisdiction's currently adopted energy code, or by amendments that the jurisdiction has adopted. It is the responsibility of the jurisdiction and its inspectors and plan reviewers to ensure that current minimums are being met; both at the plan review stage and during construction/inspection stage.

Q – How does the emissions calculator work?

A – The version that we use, utilizes an allocation of power providers for the county selected, and then does a series of "look-ups" from the EPA's eGrid database. The results are then applied to the energy savings and are displayed.

Q – What does a reduction in tons of CO2 emissions mean?
A – Perform a web search on "reduction in carbon dioxide equivalent" at the website, http://www.epa.gov/cleanenergy/energy-resources/calculator.html . The search yields some good explanations from a variety of source. Comparing CO2 reductions to cars being taken off of the road is a poor example sometimes, but works for some.

5.2 Getting Help

The following are provided in the order of the quickest response time to you!

1. See the FAQ here: http://esl.eslwin.tamu.edu/software/iccc.html#FAQ
   Remember:
   - Your window to floor ratio. There are some situations where our model will not calculate window to floor ratios over ~ 80%
   - Think about your overhanging non-conditioned space. The model requires at least 1 ' of the overhang to be over the floor below. So if you have an 800sq ft garage apartment, either simulate it separately OR enter 799 for the overhang (assuming all other construction is the same and it is on a common HVAC system).

2. Please look on this page for the latest updates: http://esl.eslwin.tamu.edu/software/iccc.html and in particular the **RELEASE NOTES**

3. Please send an email to: ic3_support@esl.tamu.edu and in it please put:
   - SUBJECT: IC3 HELP
   - The question
   - The type of browser you are using (Fire Fox, Internet Explorer 6 or 7)
   - A screen shot if you are asking about something specific on the screen.

5.3 General Process

- specific on the screen.

5.4 General Process

The user enters a house and the system performs two simulations. One for the house as entered, and another for the house as if it was built exactly to code. The difference in total energy usage is the % above code as shown. The software allows a user to make changes to the proposed house, but each time a new certificate **(with unique certificate number)** is generated. Only ONE certificate will be accepted by the Inspector and only that certificate will provide for any emissions reduction credit. This final design then becomes the house of record for the purposes of the inspection.

The software has been, and continues to be, benchmarked against other code-compliant simulation systems. The effective maximum size of the house is 10,000 sq ft. Houses larger than this typically require custom simulations due to the use of construction materials, geometry, and systems that are not common.

For more detail, please refer to the IC3 Technical Notes found at: http://esl.eslwin.tamu.edu/software/iccc.html

Development of a Texas Building Registry

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ABSTRACT

The Texas Building Registry (TBR or Registry) provides data collection, storage, and analysis of above-code residential housing construction in Texas. The original system was developed to support the Texas Emissions Reduction Plan (TERP). Since 2005, the Energy Systems Laboratory (The Laboratory) has provided web-based, above code energy efficiency calculators for public use. The Registry can accept single entry and batch loading of data describing Energy Star™ homes, low-income weatherization programs, or data from municipal code enforcement systems. The Registry is independent of, and respectful of, other rating systems used by partners, thus it can accept data for homes measured against Energy Star, IECC 2000/2001, 2006, 2009, and specially amended Codes. Reports can be given summarized geographically against weather zones, county or cities, and even displayed on a map (i.e., thematic mapping). Additional reports on building characteristics can be analyzed and reported such as: HVAC tonnage per sq. ft; or average SHGC. Data provided by partners is kept secure database server located at the Texas A&M University. Individual results from the Registry will not be displayed to further respect the privacy of individuals who have provided the data.

BACKGROUND

Since 2001, Texas has been proactive in initiating clean air and energy efficiency-in-buildings policies. The Texas Emissions Reduction Plan (TERP) Legislation (SB 5, 77TH Leg., 2001), mandates state-wide adoption of energy codes, creates a 5% annual energy savings goal for public facilities in affected counties through 2007 and provides approximately $150 million in cash incentives for clean diesel emissions grants and energy research among other measures. Texas was the first state in the nation to create emissions reduction credits for energy efficiency and renewable energy through the State Implementation Plan under the Federal Clean Air Act.

In 2008, the 81st Texas Legislature amended the Texas Administrative Code (TAC .§388.008 2009) to develop a Registry of Above-Code homes. The Laboratory built the first version of the Registry in 2009. This preliminary version allowed The Laboratory to provide basic metrics on usage of the Laboratory's above code calculators, *IC3*[1] and *TCV*[2]. By running reports against the calculator's databases, The Laboratory could determine calculator usage by month for Texas' Cities and Counties. These reports allowed a better understanding of how builders were adopting the calculators across the State so the Laboratory could improve the calculators.

Residential energy standards help create more energy-efficient homes and thus reduce air pollution from electricity generation. Texas programs have partially transformed the housing market in Dallas/Fort Worth and Houston with 30,000 Energy Star homes (approximately 27 %) in 2006, which have reduced emissions from

[1] International Code Compliance Calculator, a web based, above code calculator for single family, detached, new construction in Texas.

[2] Texas Climate Vision, a web based, above code calculator for single family, detached, new construction in Austin Energy's service area.

building energy-efficient homes, and have created new manufacturing jobs for energy-efficient equipment and windows. In 2008, the figures were 32,000 units or 41% Texas market penetration (US Department of Energy 2009), just as the recession was taking hold.

METHODOLOGY

Each year the Registry adds data and reporting capability.

REGISTRY (2009 EDITION)

The 2009 edition allows The Laboratory to provide basic metrics on usage and overall energy consumption of the proposed houses from the laboratory's above code calculators, *IC3* and *TCV*.

As illustrated below and a *"Report on the Development of the Format for a Texas Residential Registry* (Gilman, et al. 2008), the underlying database was optimized for supporting the *IC3* and *TCV* calculators and therefore needed a transformation to allow for seamless reporting. Consequently, The Laboratory has been steadily adding reporting capability and has been making software changes to reflect the new reporting requirements and analysis capabilities.

The underlying technology of the *IC3* and *TCV* calculators was Microsoft SQL Server 2005[3]. This product offered reporting capabilities through various tools.

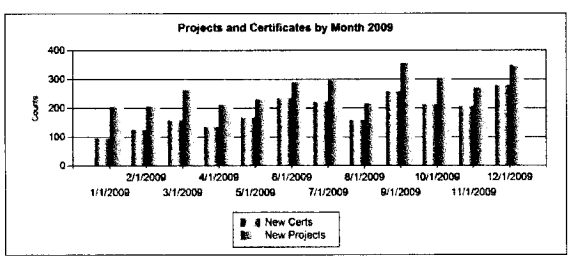

Figure 1: *IC3* 2009 Certificates and Projects

Figure 1 shows the Projects and Certificates issued each month since January 2009. A Project is a house plan, Certificates are printed reports given to the building official - assuming that the house is at or above code. In 2009, some users entered a basic floor plan and re-cycled it to generate more certificates. Figure 1 shows that more projects were entered (and presumably did not pass) than certificates created.

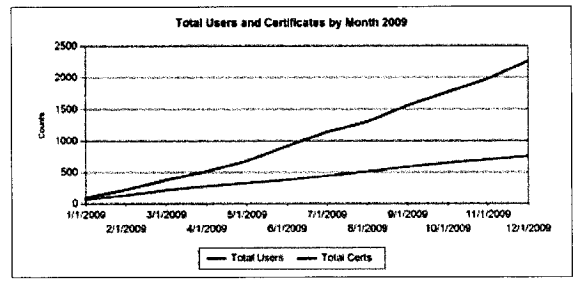

Figure 2: *IC3* 2009 Users vs. Certificates

Figure 2 shows the cumulative Users and Certificates since January 2009. The divergence between the two lines emphasizes the difference between the projects completed and certificates issued.

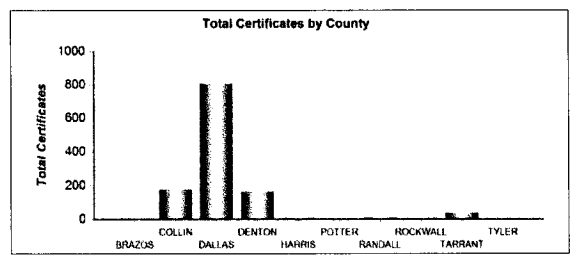

Figure 3: *IC3* 2009 Certificates - Top 10 Counties

Figure 3 shows that the earliest adopter of the *IC3* software was the North Central Texas Council of Governments (NCTCOG) area, specifically, users building in Dallas, Collin, Denton, and Tarrant Counties.

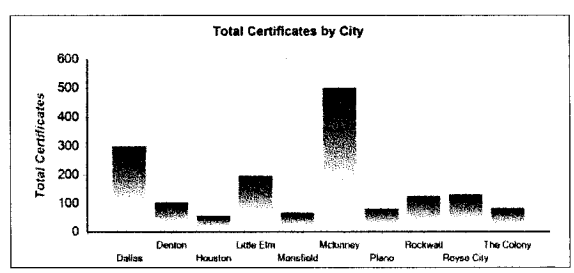

Figure 4: *IC3* 2009 Certificates - Top Ten Cities

Figure 4 shows the certifications issued by city (excluding Austin). Figure 4 shows that the City of McKinney leads the way with 500 certificates, followed by the City of Dallas, then

[3] The system is being updated to SQL Server 2008 R2 in the Fall of 2010.

Little Elm, and the other cities located in the NCTCOG area.

Since the City of Austin and much of Travis County use the *TCV* software, their usage is presented in Figure 5, below.

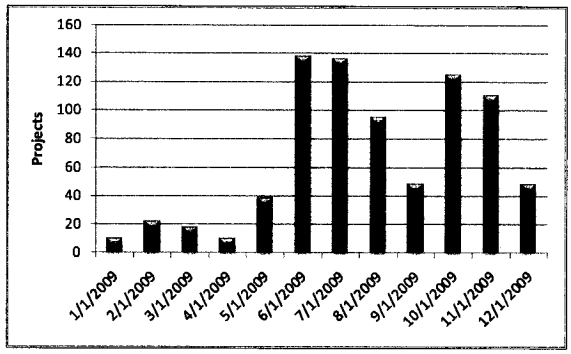

Figure 5: *TCV* 2009 Annual Energy Reports

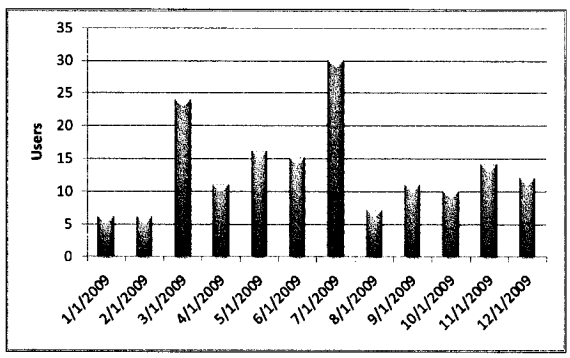

Figure 6: *TCV* 2009 New User Counts

Figure 6 shows the new users counts from the *TCV* software. The City of Austin conducted beta testing in March 2009, training sessions in the summer of 2009 and then went live with version 1.1 of the *TCV* software in July of 2009. The *TCV* software also has the capability of capturing "as built" and the results of third party testing of the homes.

REGISTRY (2010 EDITION)

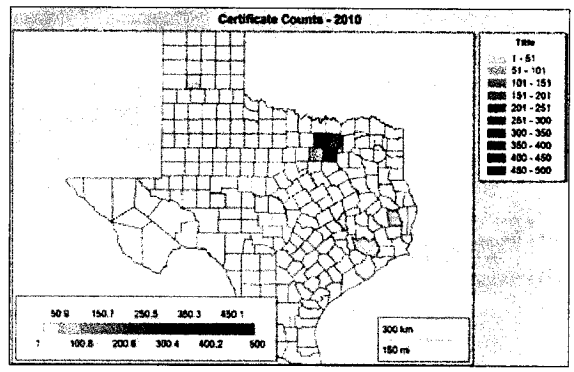

Figure 7: *IC3* 2010 Year to Date Certificate Map

The current version of the Registry is part of a broader TERP Data Repository that also contains NOAA weather data, data from building sensors, a solar test bench data, and utility bills. This newer version will have the capability to perform weather normalization of utility bill data as well as report in terms of both energy and emissions reductions.

NOAA weather data is being automatically collected for all Texas locations going back to the year 2000. Server based procedures are being developed based on Baltazar's work (Baltazar and Claridge 2002) to condition the data and flag data that requires human intervention, filling, or interpolation.

Utility bill analysis is a key part of the Laboratory's Continuous Commissioning® [4] services. Several database systems have been built to facilitate analysis of utility bill data from a variety of building types. For example, the Laboratory's original *eCalc* (Gilman, Don; Haberl, Jeff; Culp, Charles; Marshall, Kyle; Yazdani, Bahman; Liu, Zi 2004) also provided utility bill analysis and weather normalization using ASHRAE's Inverse Model Tool Kit [5]. The Laboratory will leverage this knowledge to allow

[4] Continious Commissioning® is a Service Mark of the Energy Systems Laboratory and Texas A&M University.

[5] ASHRAE's Inverse Model Toolkit (Kissock, Haberl and Claridge 2002) (IMT) a software that uses linear and change-point linear algorithims. IMT was funded under ASHRAE Project RP-1050.

the Registry to analyze electric, natural gas and water utility billing data.

Avg User/Avg Code expressed in MMBtu												
	2009.10			2009.11			2009.12			2009 Q4 Averages		
	Avg User	Avg Code	% Above	Avg User	Avg Code	% Above	Avg User	Avg Code	% Above	Avg User	Avg Code	% Above
ORANGE	41.7	53.8	22.5				67.5	91.6	26.3	54.6	72.7	24.4
COMAL	63.6	76.6	17.0							63.6	76.6	17.0
SAN PATRICIO							115.6	138.3	16.4	115.6	138.3	16.4
LUBBOCK							111.5	132.6	15.9	111.5	132.6	15.9
ELLIS							46.1	54.7	15.7	46.1	54.7	15.7
KING	90.3	108.3	16.6	103.2	121.1	14.8				96.8	114.7	15.7
HUTCHINSON	81.5	95.9	15.0							81.5	95.9	15.0
IRION				83.7	97.2	13.9				83.7	97.2	13.9
WILSON	97.2	111.1	12.5							97.2	111.1	12.5
TYLER	63.0	74.9	15.9	74.5	80.5	7.5				68.8	77.7	11.7
HOOD	201.3	234.2	14.1				390.0	429.1	9.1	295.6	331.7	11.6
KLEBERG							70.1	79.2	11.6	70.1	79.2	11.6

Figure 8: 2009 4th Qtr – Energy Prototype Report

Figure 8 shows an additional report is being developed that will give average MMBtu for both the as designed and code versions of the home and % average above code by County.

During 2010, the Laboratory is upgrading the IT infrastructure. The servers supporting TERP are being replaced with modern systems that are ten times more powerful and use 1/3 less electricity than the systems they replace. This new hardware will allow the Laboratory to update key reports automatically each day. This functionality is provided by the new Microsoft *SQL Server 2008 R2* software.

REGISTRY ORGANIZATION

INTENDED DATA FLOWS

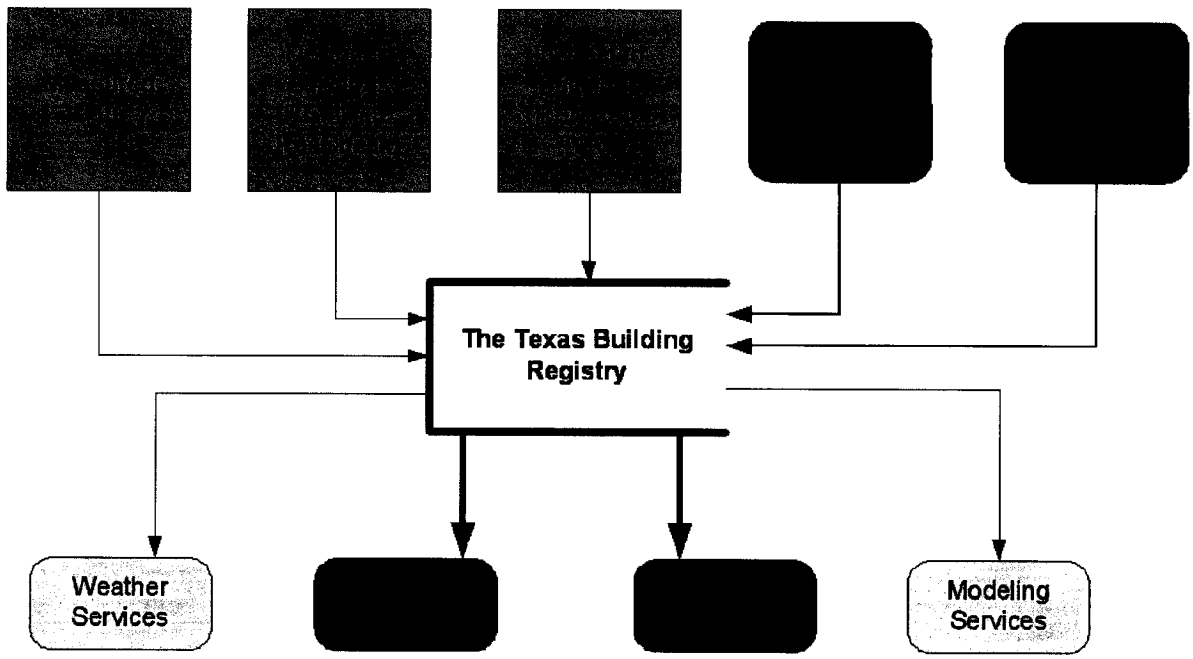

Figure 9: High Level View of Data Flows

Figure 10 shows a very high-level view of the major functional blocks of the Registry. The top level push data into the system and the bottom level draw data out. Data cleaning, flagging, and

quality assurance routines are not separated in this diagram. Dark blue coloring indicates functionality that is in place, light blue indicates functionality being actively assembled. The following sections describe several of the functional blocks of Figure 10.

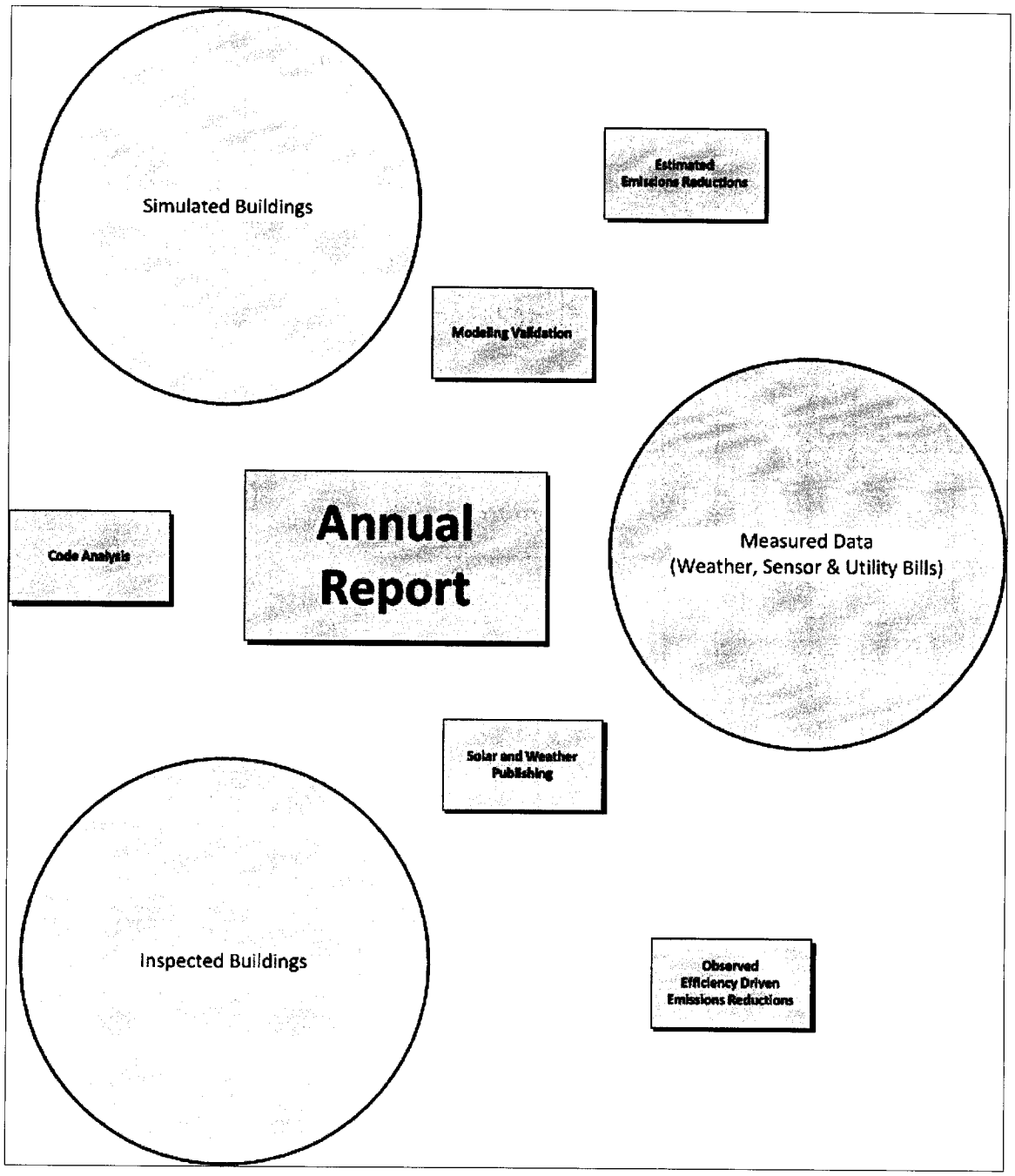

Figure 10: Registry Components

Figure 9 shows the current Registry components. There are three functional areas of the Registry. Each functional area will consist of at least one database. Raw data is typically kept in segregated areas, either as raw ASCII data or as simple SQL Server "loading tables".

SIMULATED BUILDINGS

This will be a collection of building descriptions. In the 2009 version, this was specifically the *IC3/TCV* data structure.

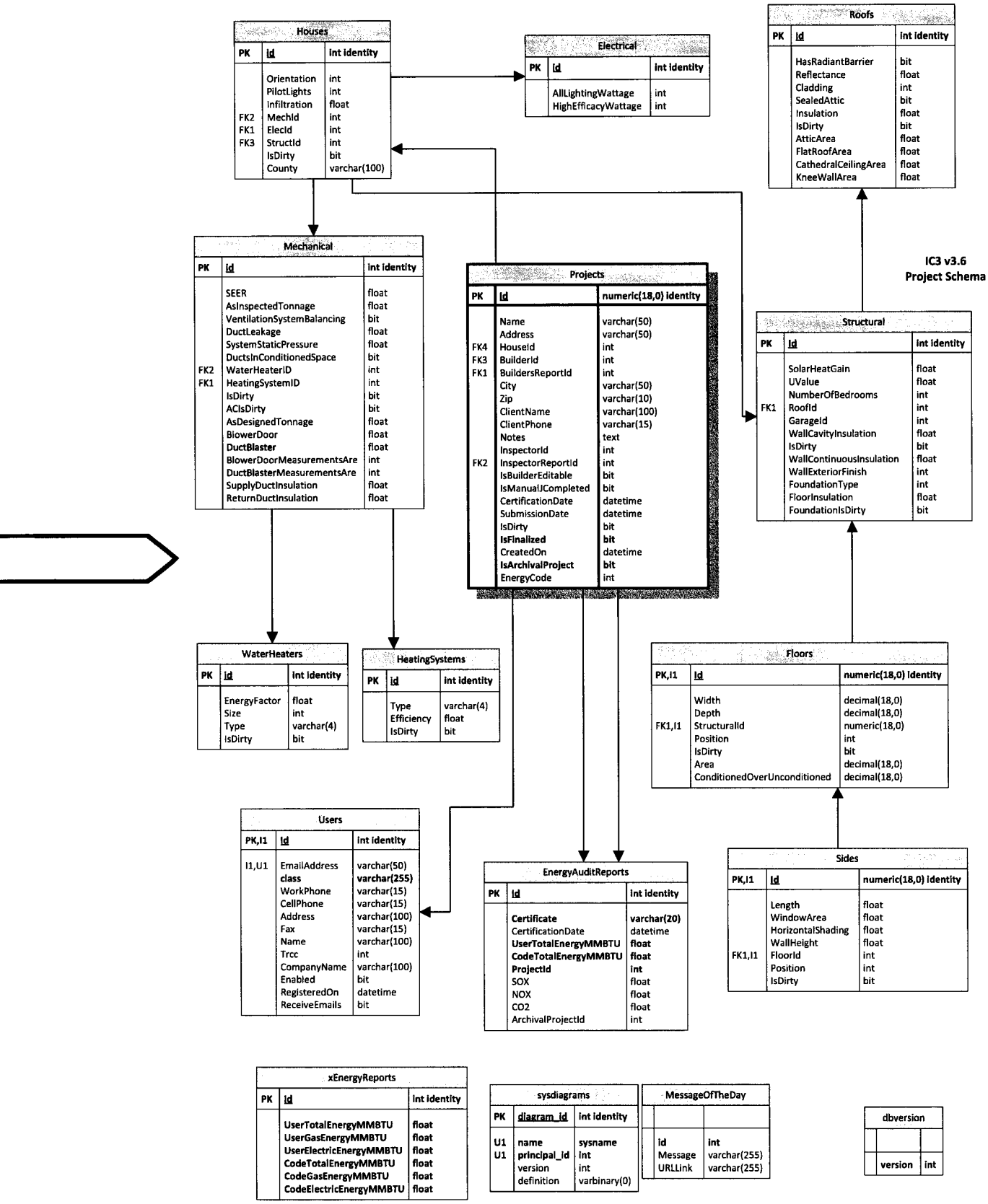

Figure 11: *IC3/TCV* Database Layout

Figure 11 shows the "schema" of the IC3 (v3.6) and TCV[6] (v1.1) databases. It gives a rough overview of the different tables (called "entities") found in the *IC3* database. The entities are linked together using "foreign keys" which allows the database to maintain a higher quality through "database integrity". The center entity is the Project, which is the center of the *IC3* software's abstraction of a house. The other tables are linked in via the foreign keys, which include floors, walls, electrical, and systems.

With the addition of future data sources (in 2010 or 2011) with building design data (i.e. *ResCheck™* or *REM/Rate™*) a new generalized schema (layout) will be created and a loading function will be added to transfer each of the unique new building descriptions to a common description. Existing reports will be saved, and new reports added to the broader and more general data. The minimum data elements are listed below:

Attribute	Purpose
Bldg_id	Unique registry id
Address	To locate the building for weather, jurisdiction, and potentially utility providers.
Status	New, addition, renovation, re-inspection
Square footage	Size
Energy code	Which efficiency measure applies
Year	Date of status
*floors	The number of floors.
*orientation	The direction that the front of the building faces.

* Preferred but not required.

[6] The *TCV* v1.1 database has different fields due to the built-in inspection module and the fact it was completed two years earlier than the described *IC3* v3.6.

MEASURED DATA

These will be a collection of data measures optimized for huge numbers of sensor readings from devices such as varied as portable temperature/humidity matchbook loggers to building control systems. The Laboratory's Solar Test Bench data will be collected in this section of the Registry. Finally, utility bills are a form of measured data that will be kept in the collection of linked tables.

INSPECTED BUILDINGS

Another functional module from Figure 11, the following table provides a subset of data:

Attribute	Purpose
Id	Unique inspection id
Bldg_id	The building id for this inspection
Inspection	Type of inspection recorded (i.e. Energy Star, IECC, local, etc)
Date	Date of inspection
Scoretype	HERS index or % above code or pass/fail
Scorevalue	The numeric value specified in scoretype
Blower door	Optional value for blower door reading
Duct blaster	Optional value for duct blaster reading

REGISTRY REPORTS

EMISSIONS REDUCTIONS ESTIMATED FROM MODELING

Estimated SOx NOx CO2 Per County from IC3 Runs

	2009.10			2009.11			2009.12			
	SOx	NOx	CO2	SOx	NOx	CO2	SOx	NOx	CO2	TOTAL
DENTON	61	113	93,841	53	100	81,395	183	346	287,910	464,002
DALLAS	107	193	156,051	121	218	175,494	81	142	115,525	447,932
COLLIN	93	170	137,682	93	173	140,808	98	178	143,331	422,626
TARRANT	79	148	121,160	53	101	83,166	94	173	140,204	345,179
ROCKWALL	29	51	40,233	21	39	32,075	46	83	67,643	140,222
RANDALL	0	1	773	15	27	21,698	25	50	42,499	65,089
BEXAR	9	18	14,643	2	3	2,676	9	15	12,118	29,493
HARRIS	2	4	3,121	7	13	10,805	11	18	14,300	28,281
TYLER	17	31	24,266				(2)	1	2,884	27,197
WICHITA	2	3	2,459				16	28	22,729	25,236
HUTCHINSON				11	22	18,246				18,278

Figure 12: *IC3* 2009 Preliminary Emissions Report

Figure 12 shows an *IC3* Emissions report that provides EPA approved emission calculations of SOx, NOx, and CO2 for the top ten counties for the last quarter of 2009.

MODELING VALIDATION

The Registry will provide the ability to validate simulated energy savings and emissions reductions by comparison with measured utility bills with weather corrections.

BUILDING CODE ANALYSIS

Having a large database of simulated and measured homes allows new code revisions (which occur every three years) to be evaluated for their impact across Texas. Historically, the Laboratory has provided this service by creating "typical" homes for a location (i.e., Houston) and simulating hundreds of variations. That activity would be enhanced considerably if actual homes, preferably with utility bills, were available for verification and validation purposes.

PUBLICATION OF SOLAR AND CONDITIONED WEATHER DATA

The Laboratory currently publishes weather data sets on its' website (Energy Systems Laboratory 2010) for use by architectural and engineering professionals who do their own modeling. The data provided includes Daily, Hourly, Daily Time Series, Hourly Time Series, TRY Format and TRY packed data formats. Presently, this data is manually processed and published using spreadsheets. The new system would allow a user to pick a location, a data format, and a date range for dynamic generation of the data from the database. This would allow custom date ranges and allow for continuous data quality improvements on the server to become available to the end user.

EMISSIONS REDUCTIONS FROM OBSERVED EFFICIENCIES

Estimating SOx, NOx, and CO2 emission reductions from simulated houses is an effective way to guide energy efficiency measures as realized in the current Code and in actual construction. However, to compare the actual values versus estimated values allows the Laboratory to maximize potential SIP[7] credits.

THE LABORATORY'S ANNUAL REPORT

Each year the Laboratory generates an Annual Report for the Texas Legislature and the Texas Commission on Environmental Quality. This report quantifies the results of the Laboratory's work to quantify credible NOx emissions because of energy efficiency and renewable energy. It provides stakeholders, government and academic researchers with a creditable basis for their emissions reduction activities for energy efficiency and renewable energy projects.

[7] State Implementation Plan (SIP) – is a Federally mandated plan for states to account for a net reduction in SOx, NOx, and CO2 emissions through energy efficiency measures.

SUMMARY

In summary, a Texas Building Registry has been created to provide data about above-code housing in Texas. The registry captures and displays projects and certificates as part of The Laboratory's *IC3* code-compliant calculator. The information and analysis from the Registry will be used to improve *IC3* and provide improve the level of detailed information about new residential construction in Texas.

ACKNOWLEDGMENTS

This work was funded by the Texas Legislature through the Texas Emissions Reduction Program (TERP).

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Tabor Commons Green Jobs Training Program

The U.S. Environmental Protection Agency selected the Tabor Commons site and the Oregon Tradeswomen as one of the brownfields sustainability pilot projects. Working under contract with SRA International, ICMA coordinated the development of a green jobs training curriculum. The training curriculum is designed to inform entry level tradeswomen about the green job opportunities in areas such as deconstruction, weatherization, eco or solar roofing, stormwater systems and more. This curriculum is the result of the work conducted largely by Flying Hammer Productions—a green building and green jobs consulting organization, with support from the Oregon Tradeswomen. For more information on this effort, contact Tad McGalliard, Director of Sustainability, ICMA (202/962-3563 or tmcgalliard@icma.org).

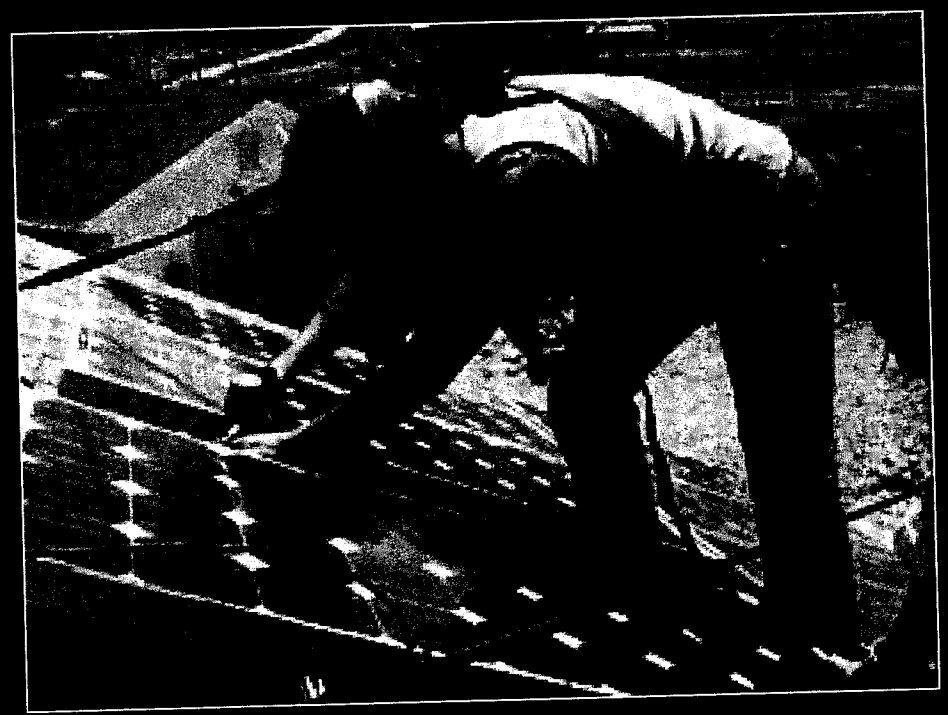
ICMA
Leaders at the Core of Better Communities

Flying Hammer Productions
http://www.theflyinghammer.com

Oregon Tradeswomen, Inc.
http://www.tradeswomen.net

Green Jobs

Introduction to Green Building
and green jobs



What is Green Building?

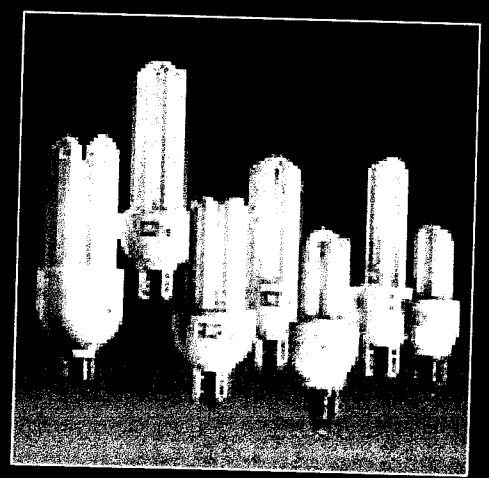
- **Green Building** is an approach to construction that focuses on energy efficiency, resource conservation for the life cycle of a building and has positive benefits both ecologically and socially.

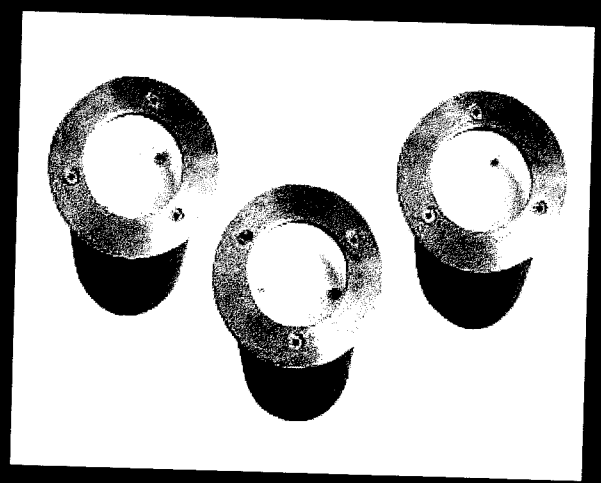
Energy Efficiency

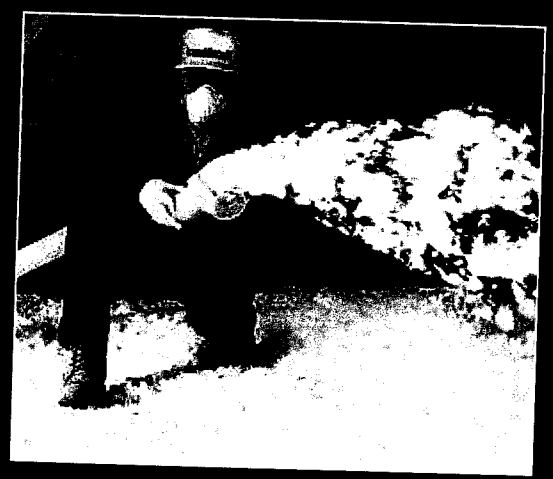
- Energy efficiency is using less energy to provide the same level of energy service. Efficient energy use is achieved primarily by means of a more efficient technology or process rather than by changes in individual behavior. Energy efficiency can also be achieved via the design of a project.

Examples of energy efficiency

- Insulating a home so that less heating and cooling energy is required to achieve the same temperature
- Installing fluorescent lights or use of natural lighting fixtures (such as skylights, solar tubes, etc.) in place of incandescent lights to attain the same level of illumination.

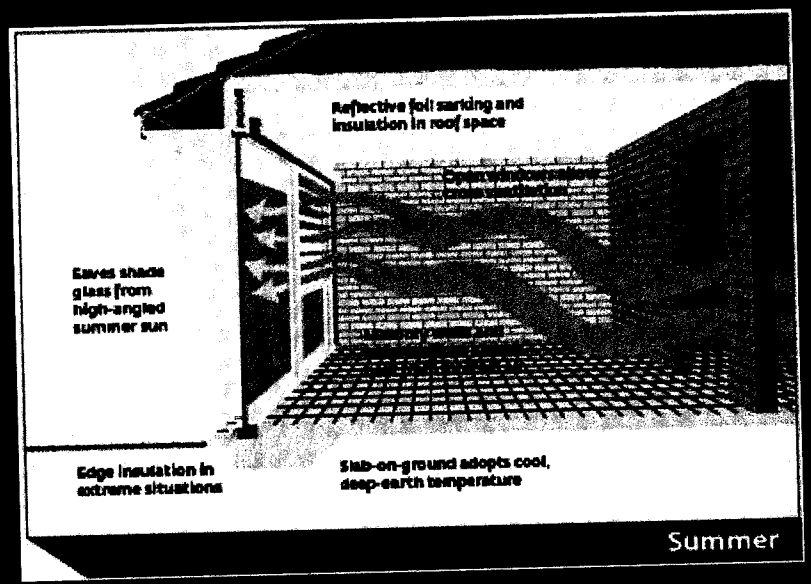


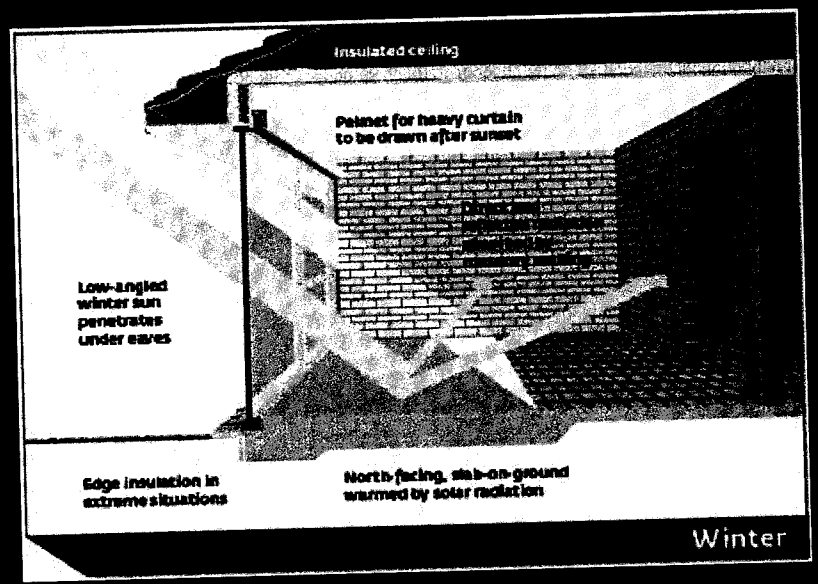




Passive solar

- Building design and orientation can greatly effect its efficiency





Images from MidlandBrick co.

Natural Resource Conservation

- The management of natural resources (land, water, soil, plants and animals) with a particular focus on how the management or uses of those resources affects the quality of life for both present and future generations.
- Using lumber that has been certified by the Forest Stewardship Council is one example of resource conservation. By not using lumber from unsustainable harvesting practices. Using materials that have a high recycled content, are re-useable or biodegradable are all ways to practice resource conservation.

Natural Resource Conservation

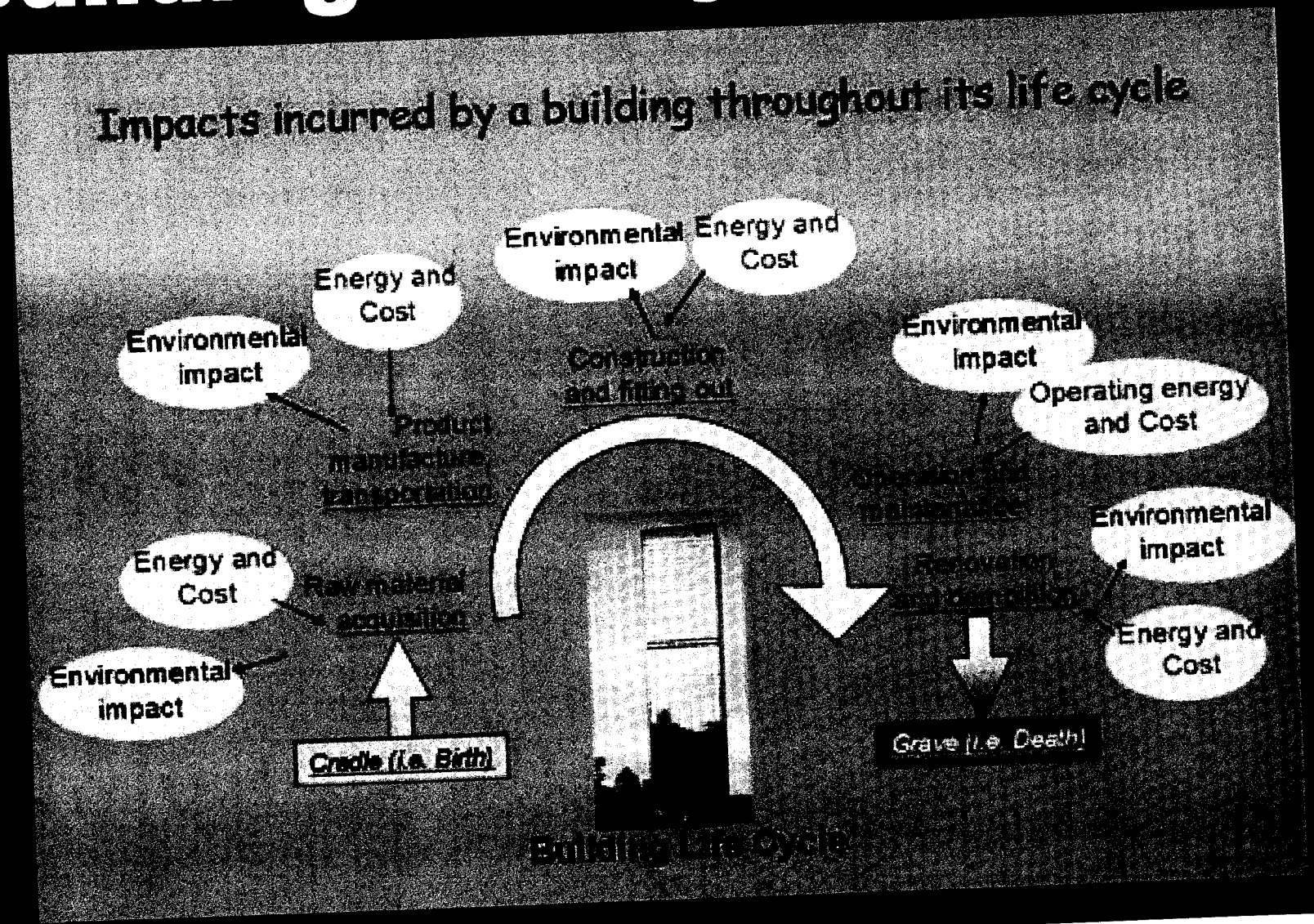
U.S. GREEN BUILDING COUNCIL MEMBER

FSC

Building Life Cycle

- Refers to the environmental impacts of the building from the production of the products that go into its construction, its performance and maintenance while in use and what happens to the building and its parts once it is no longer in use.

Building Life Cycle

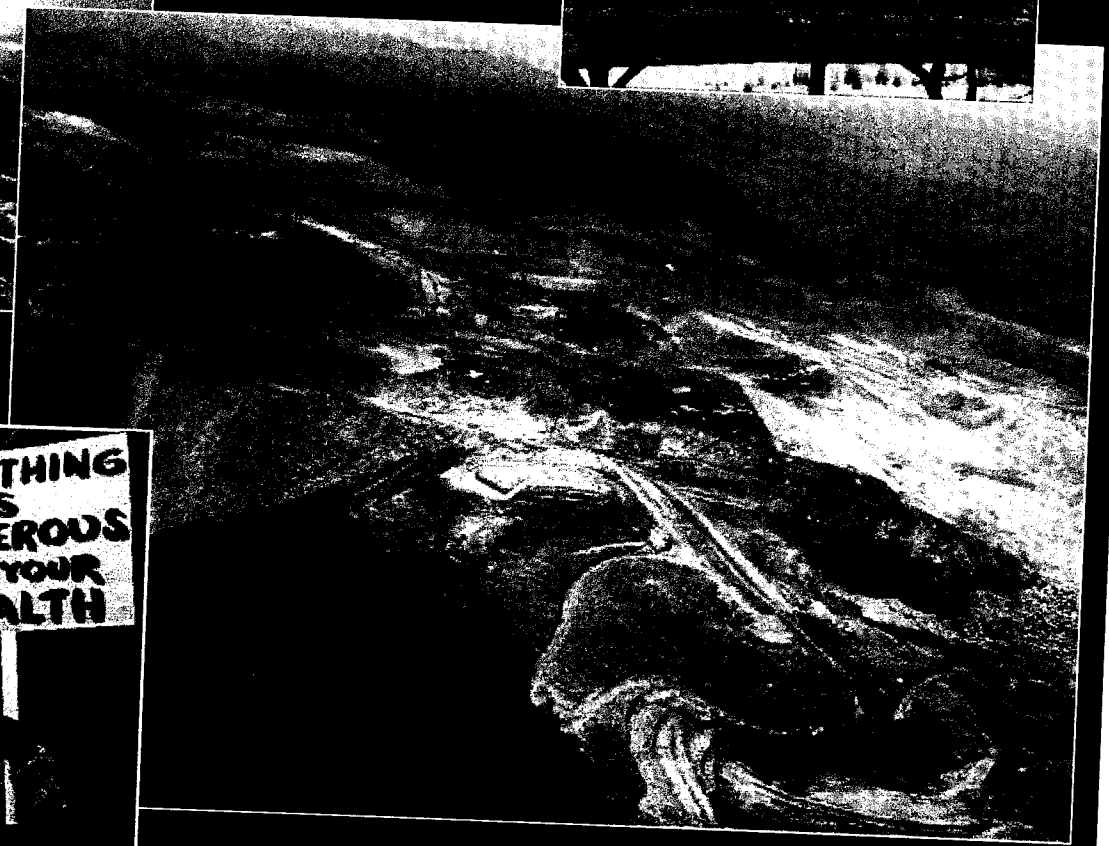


Positive Social and Human Impact

- This refers to the positive systemic impacts of green building on the people who process and work with the materials to the people who work or live in green buildings to the greater social implications of a healthier society. This includes building with indoor air quality in mind, using materials that are non or less toxic throughout their whole life cycle, improving water quality via conservation, grey water reuse, storm water management etc.
- Building green encourages a broad spectrum approach to construction. In stead of just looking at construction via the 'bottom line' (how much a project costs or profit to be made) it looks at it through a much broader lens referred to as the 'triple bottom line' (people, planet, profit) which expresses an expanded spectrum of criteria for measuring success: environmental/ecological and social and economic.

Positive Social and Human Impact

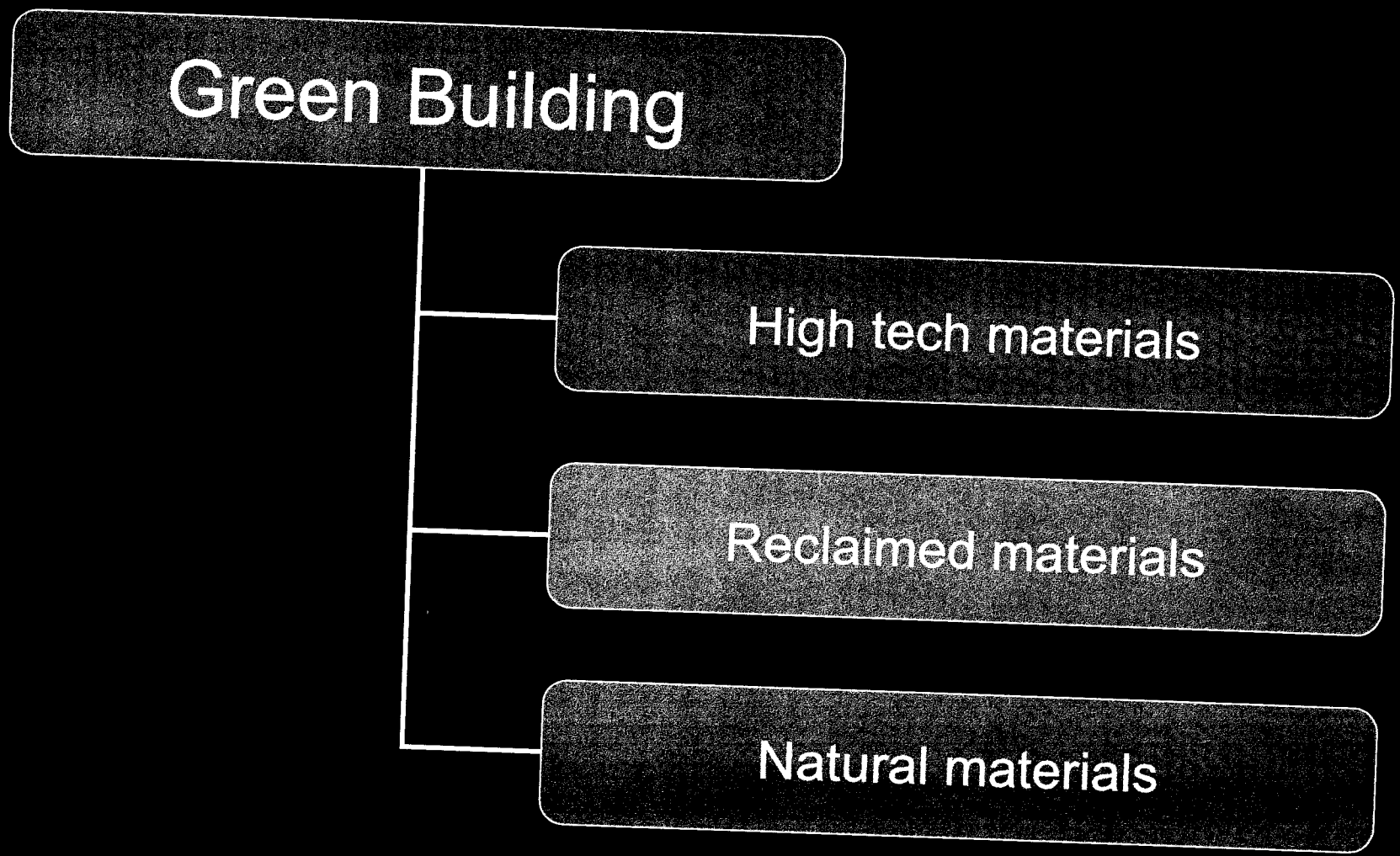
Why Build Green?



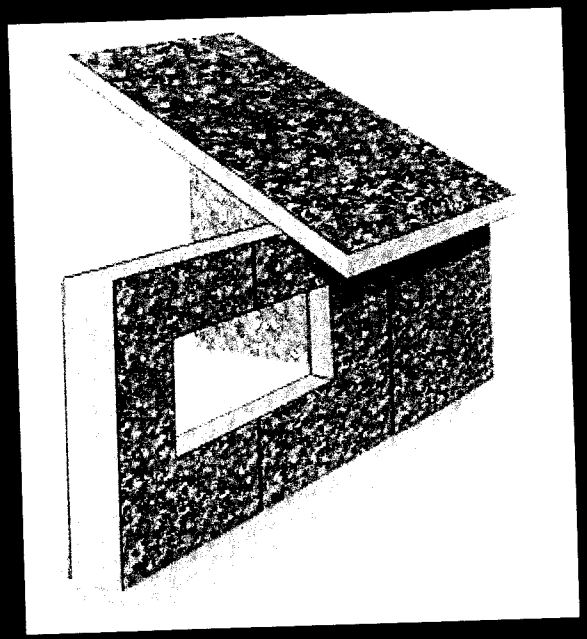
Why is Green Building Important?

- Less embodied energy
- Healthier workers
- Healthier spaces
- Creates more jobs (example: deconstruction, recycling, and reuse) + niche markets and alternative economies
- More sustainable future
- Less reliance on fossil fuels and more energy independent structures
- Less reliant on virgin materials and finite resources
- Creates a sense of connection and pride in work
- Less greenhouse gasses
- Helps support more stable local economies
- Provides materials for future generations
- Longer term employment via jobs where resources are better managed
- Same sustainable building philosophies applied to work environment as are applied to resource management: healthy happy long term employment

Green Building Umbrella

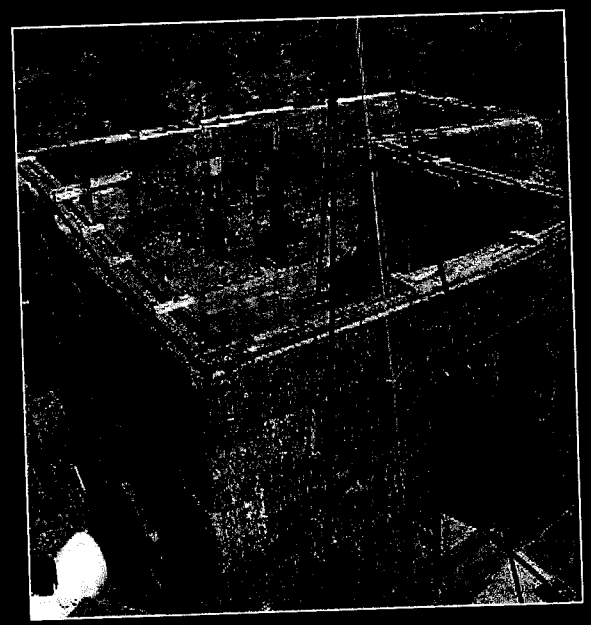


Green Building Umbrella



High tech materials

Reclaimed materials



Natural materials

U.S.G.B.C.
United States Green Building Council

- The **U.S. Green Building Council** is a 501(c)(3) non-profit community of leaders working to make green buildings available to everyone within a generation.
- In the United States alone, buildings account for:
  - 72% of electricity consumption,
  - 39% of energy use,
  - 38% of all carbon dioxide (CO2) emissions,
  - 40% of raw materials use,
  - 30% of waste output (136 million tons annually),and
  - 14% of potable water consumption.

L.E.E.D

Leadership in Energy and Environmental Design

- Construction activity pollution prevention
- Site selection
- Development density
- Brownfield redevelopment
- Alternative transportation
- Restoring habitat
- Stormwater design
- Heat island effect
- Light pollution reduction
- Water efficient landscaping
- Innovative waste water technologies
- Water use reduction
- Minimum energy performance
- Refrigerant management
- Onsite renewable energy
- Green power
- Recycled content
- Certified wood
- Material reuse
- Regional materials
- Ventilation
- Low-Emitting Materials
- Indoor chemical pollutant control
- Thermal comfort
- Daylight and views

Earth Advantage

- At minimum, an Earth Advantage® home is designed to improve energy efficiency by 15 percent over a conventionally built home. The incorporation of products such as energy-efficient windows, appliances, mechanical systems and light fixtures can add up to lower energy usage and greater comfort year round.

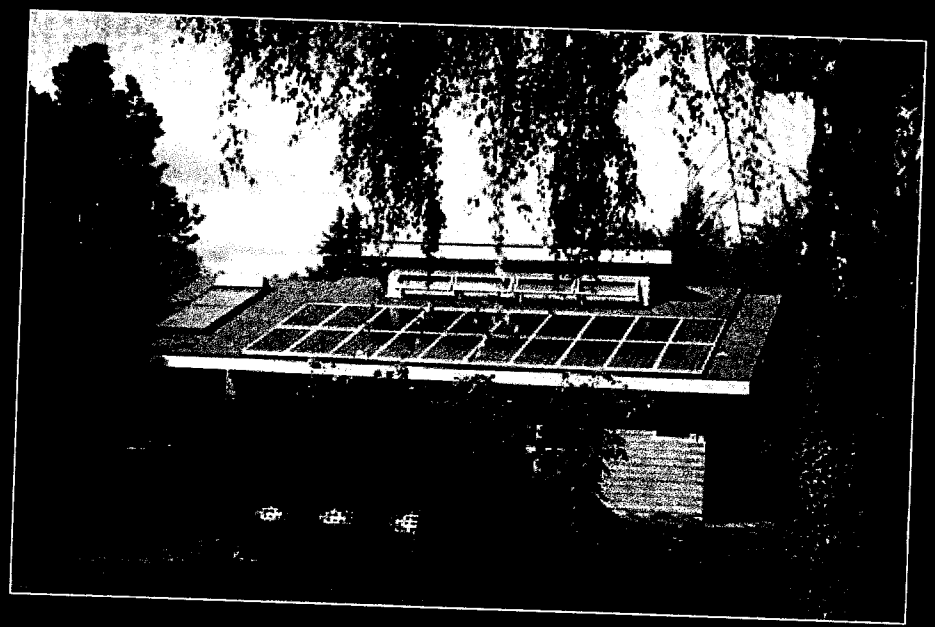
earth® advantage

Energy Star

- ENERGY STAR is a joint program of the U.S. Environmental Protection Agency and the U.S. Department of Energy helping consumers save money and protect the environment through energy efficient products and practices.

Net-Zero Energy Home

- A net-zero energy house is designed to produce as much energy as it consumes on an annual basis.



Living Building Challenge

- generate all of its own energy with renewable resources
- capture and treats all of its water on site
- use resources efficiently and for maximum beauty

Living

Types of Green Building Techniques

- Smart Framing
- ICFs
- Formaldehyde free materials
- No VOC materials (Volatile Organic Compounds)
- Recycled materials (Trex, gluelams, blue jean insulation)
- High efficiency windows
- Tight thermal envelope
- Recyclable materials
- Energy efficient heating and cooling systems
- Reclaimed materials

What assumptions does Green Building make?

Humans play an important role in the health of the planet.

Finite resources are worth using wisely.

Sustainability is an achievable goal.

Environmental health is an important part of economic health.

Green Collar Jobs

- What are Green Collar Jobs?
- Pays decent wages and benefits that can support a family
- Inclusive and diverse workforce
- Provides upward mobility
- Reduces waste and pollution
- Benefits the environment
- Meets the triple “bottom line” of People, Planet and Profit

GREEN JOBS:

Green Building

- An approach to construction that focuses on energy efficiency, resource conservation for the life cycle of a building, and ideally has positive benefits both ecologically and socially

Green Remediation

Using earth friendly technologies to repair and reduces damages to an area or building from toxic practices

Examples:

Lead Abatement

Brownfields Remediation and Revitalization

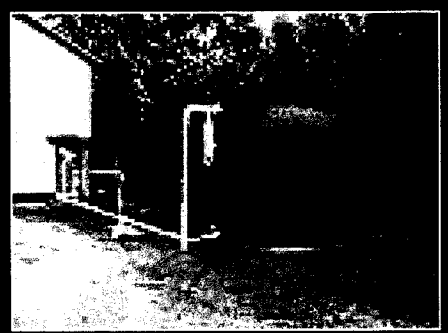
Deconstruction

- Deconstruction is an alternative to the commonly practiced demolition of buildings by carefully removing reusable materials from a no longer needed building and making them available for reuse.

- The Rebuilding Center, Portland, OR
- Lovette Deconstruction, Portland, OR
- Urban Ore, Oakland, CA

Stormwater Management

- The management of stormwater runoff, often using water retention facilities, to provide controlled release into receiving streams

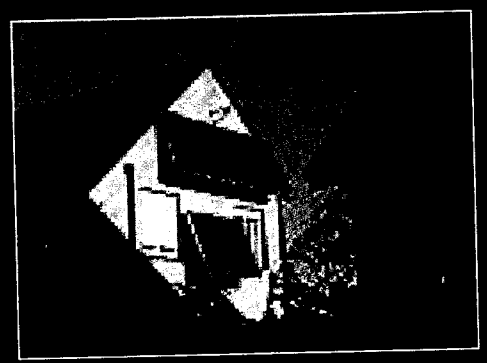


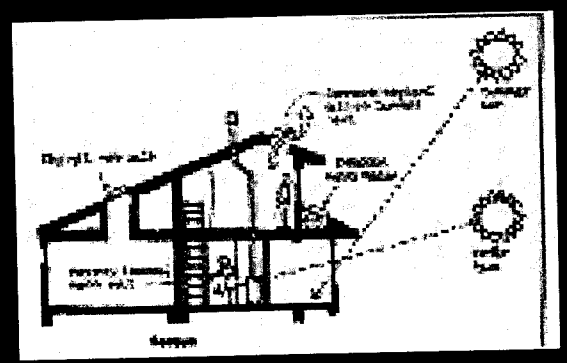
Eco-Roofs

- A green roof, or eco-roof, is a living, breathing vegetated roof system that provides a sustainable alternative to conventional roofing. An eco-roof is a lightweight system of soil and vegetation designed to be as self-sustaining as possible. A successful eco-roof is synergetic. It not only manages stormwater by slowing the run off via slow draining soil, it calms what is known as 'heat island effect' provides habitat and beauty, lasts a long time and aids in insulating a building.

Solar Roofing

- Solar roofing refers to using the suns energy that strikes the roof of a structure for generation of electricity, heating water or passively heating or cooling a building via a variety of technologies: photovoltaic, solar thermal and passive solar design.





Weatherization

- Weatherization is the modifying of a building to reduce energy consumption and optimize energy efficiency.
- Examples: Insulating, replacing windows, fixing air leaks, upgrading heating and cooling systems

Case Study: Tabor Commons

- Brownfields remediation
- Deconstruction
- Green building
- Passive solar

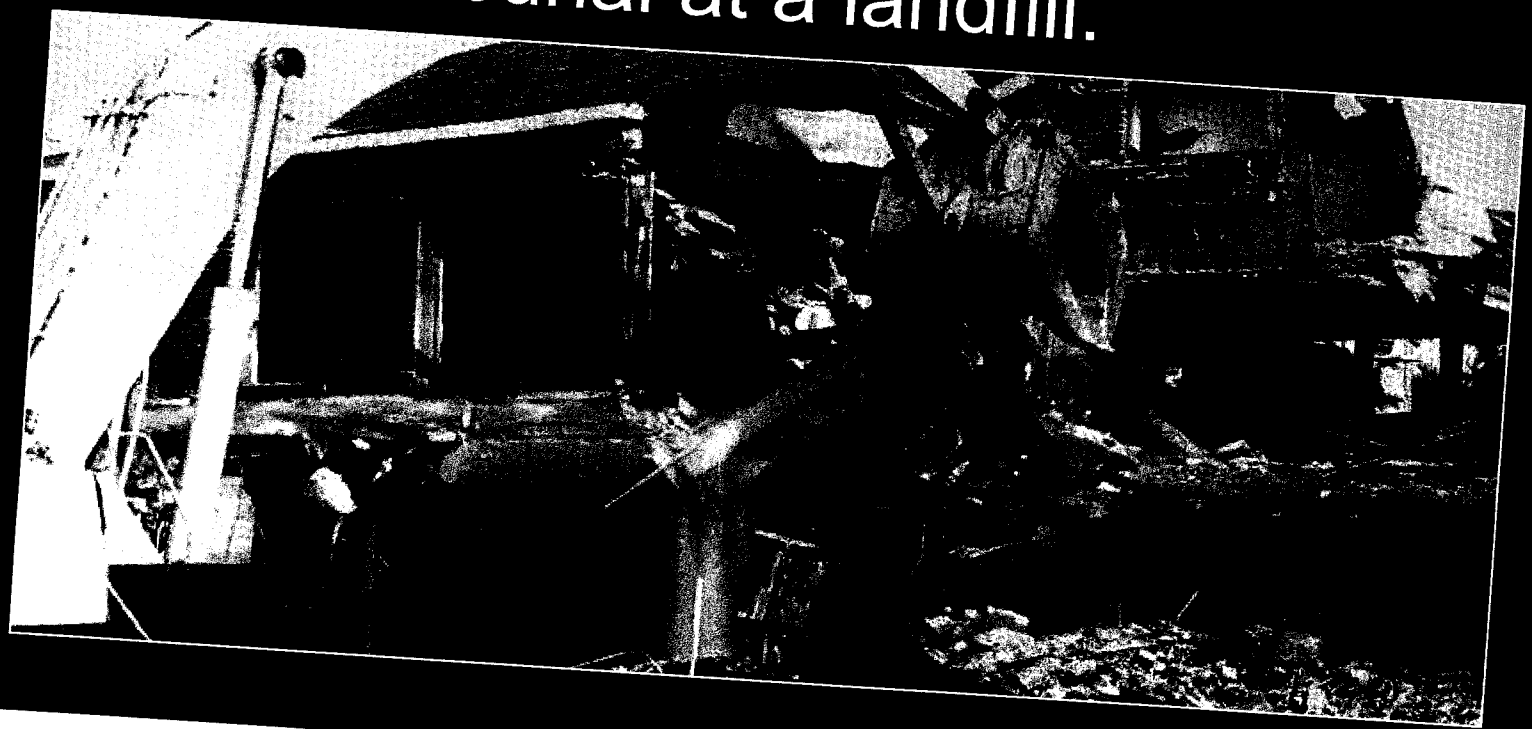
Deconstruction and Materials Reuse

What is deconstruction?

- Deconstruction is the dismantling of a structure into components that can be reused or recycled. Deconstruction is a viable alternative to demolition.

What is demolition?

- Demolition is the removal of a structure by crushing it and hauling away the debris for burial at a landfill.

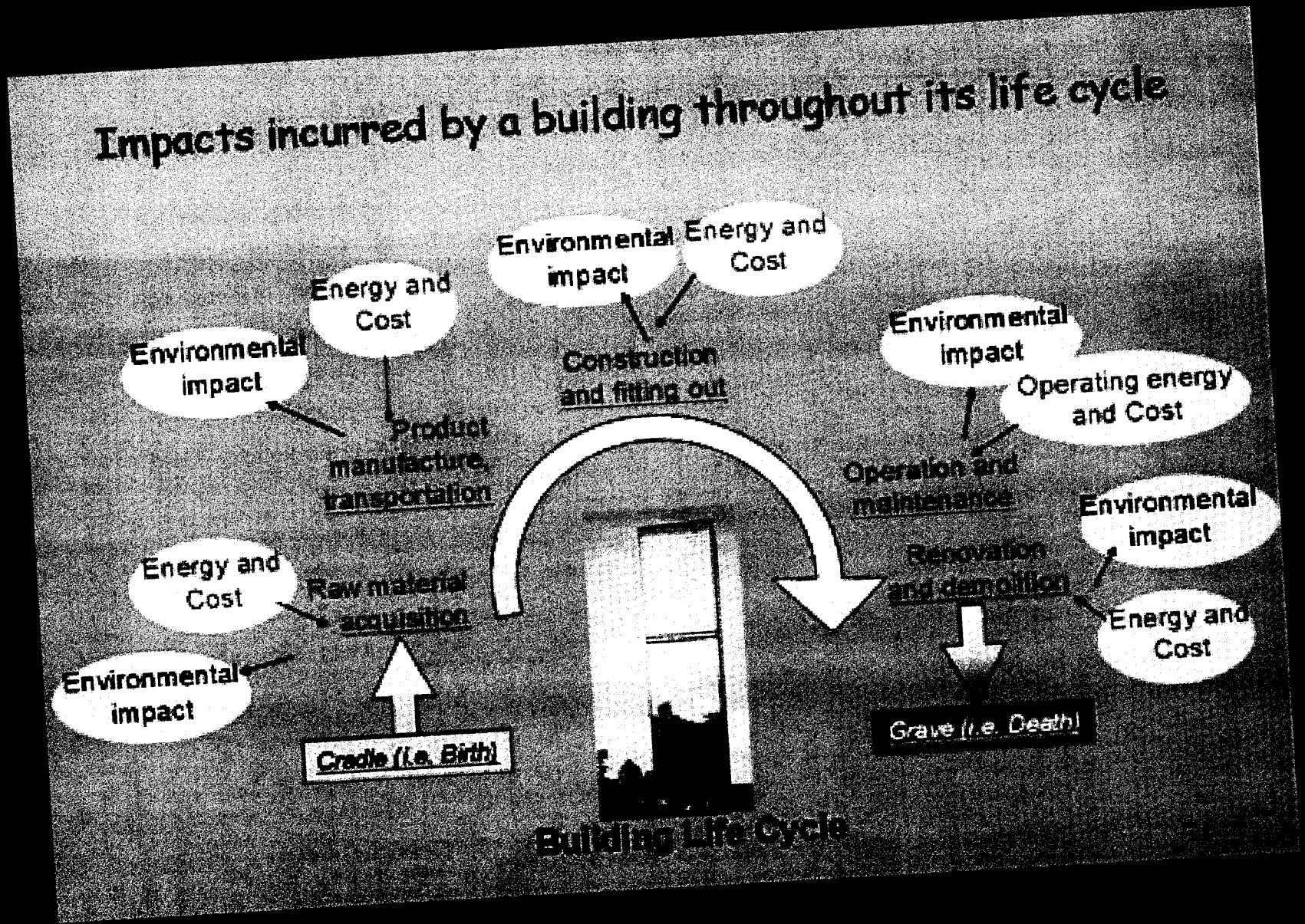


Reduce, Reuse and Recycle

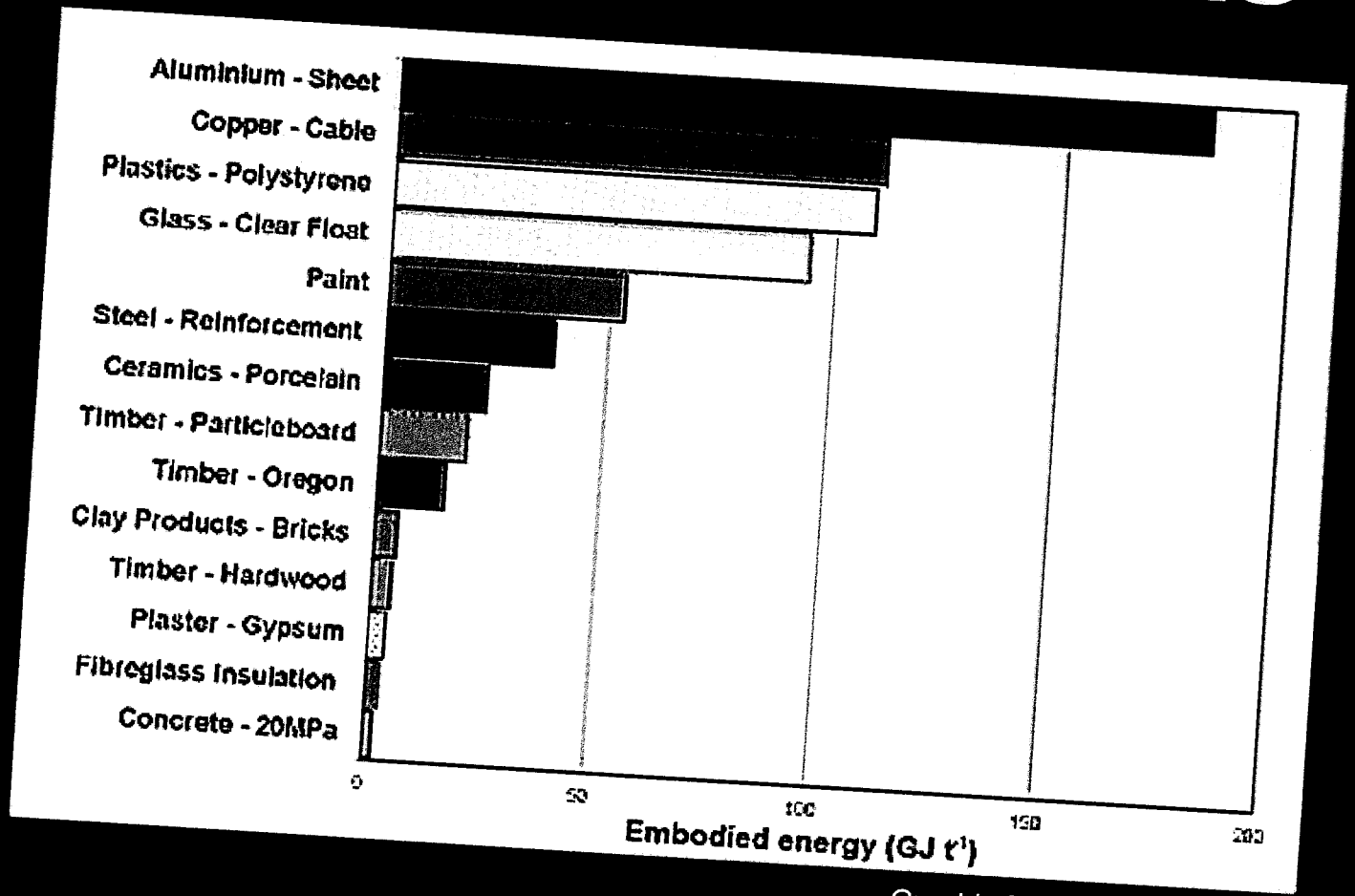
1. REDUCE: reduce waste or the need to recycle by not generating waste in the first place
2. REUSE: reuse materials before recycling or discarding
3. RECYCLE: transform material into another usable material

What is embodied energy?

- Embodied energy is a way of describing all the energy required to create a material throughout the whole life cycle of its production.

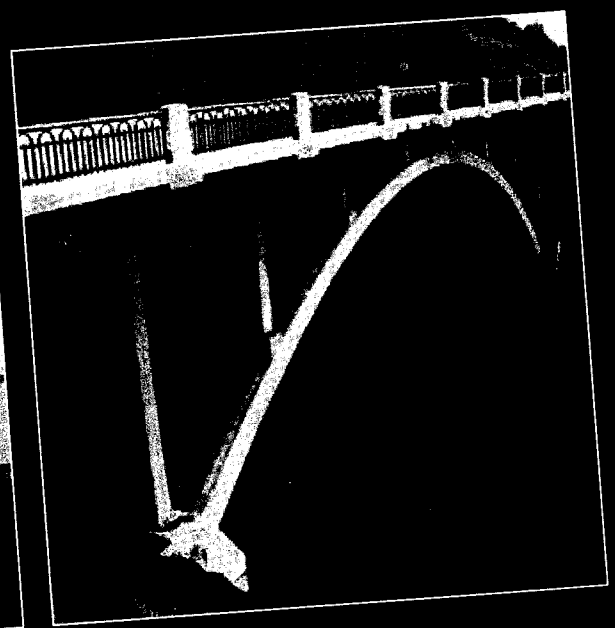

Impacts incurred by a building throughout its life cycle
Environmental impact
Energy and Cost
Product manufacture, transportation
Energy and Cost
Raw material acquisition
Environmental impact
Cradle (i.e. Birth)
Environmental impact
Energy and Cost
Construction and fitting out
Environmental impact
Operating energy and Cost
Operation and maintenance
Environmental impact
Renovation and demolition
Energy and Cost
Grave (i.e. Death)
Building Life Cycle

Embodied Energy in construction materials

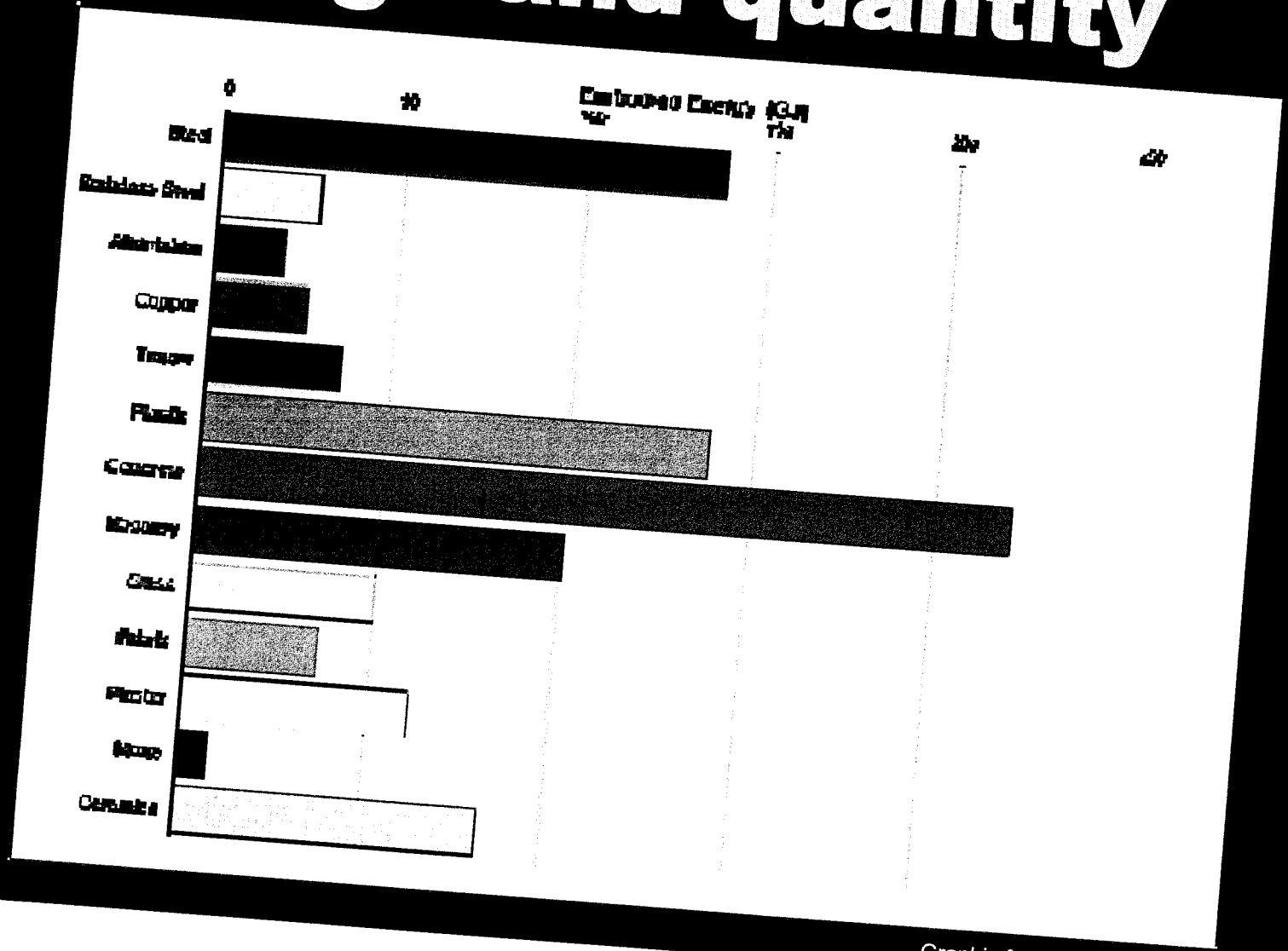


Graphic from TecEco Pty.Ltd

- Concrete is the most widely used material on earth with over two tons per person on the planet being used. Associated high usage in construction results in higher total emissions than any other material.



Embodied energy based on usage and quantity

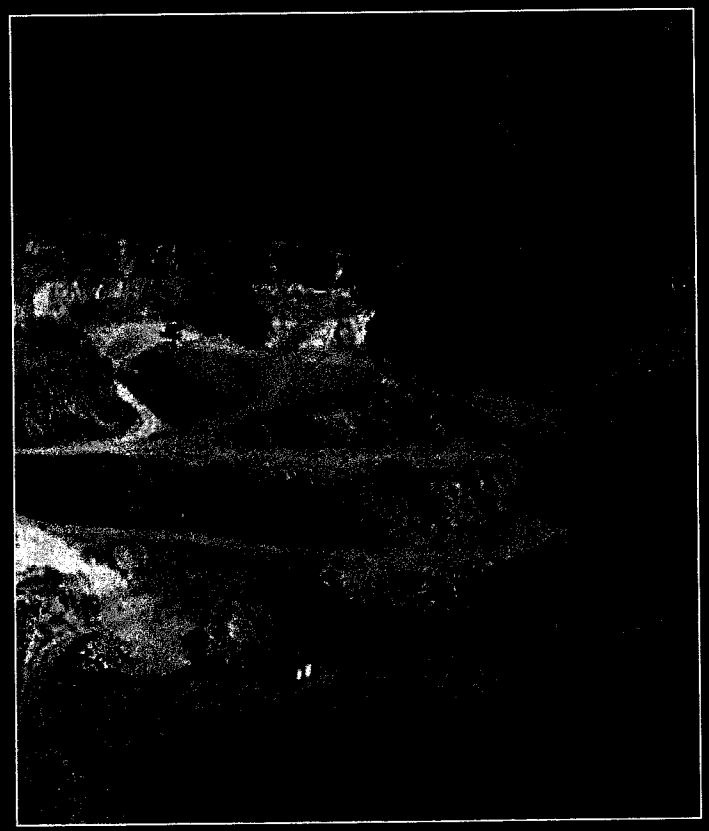


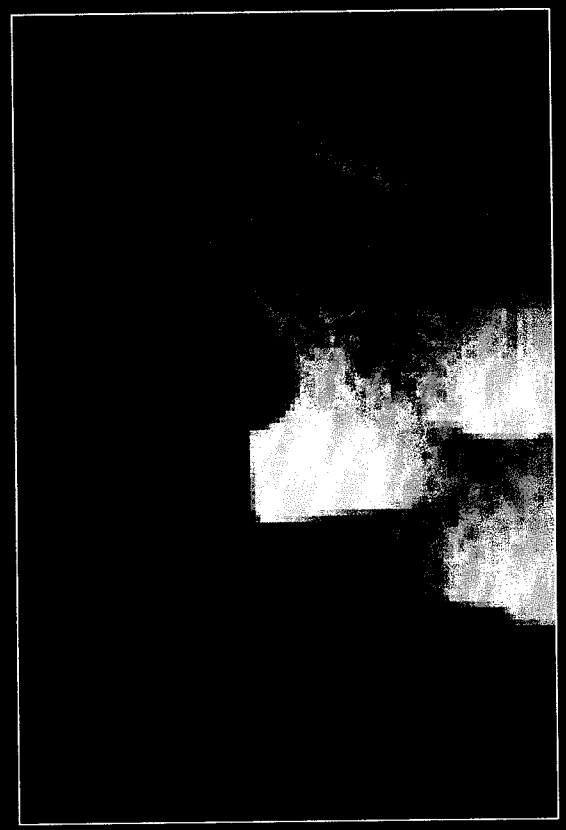
Graphic from TecEco Pty.Ltd

Deconstruction is positive for the environment, for the planet and for job creation

- Reduces reliance on raw materials
- Keeps useable materials out of landfills
- Creates jobs
- Reduces energy consumption

Reducing the use of raw materials ensures less negative impacts on the environment

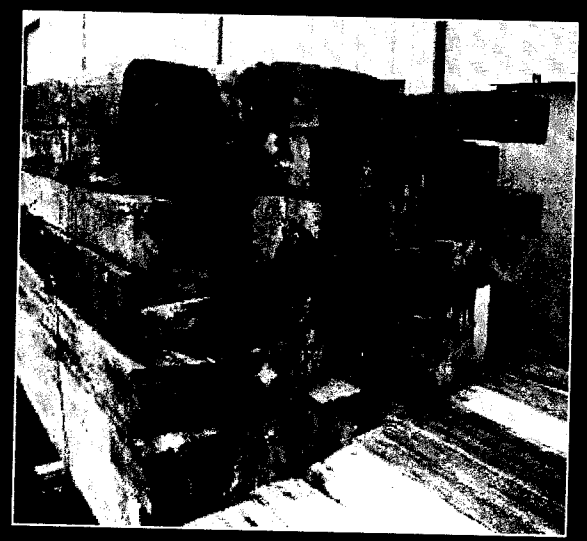




Deconstruction keeps usable materials out of landfills

Reclaimed doors

Crushed concrete as aggregate in new concrete



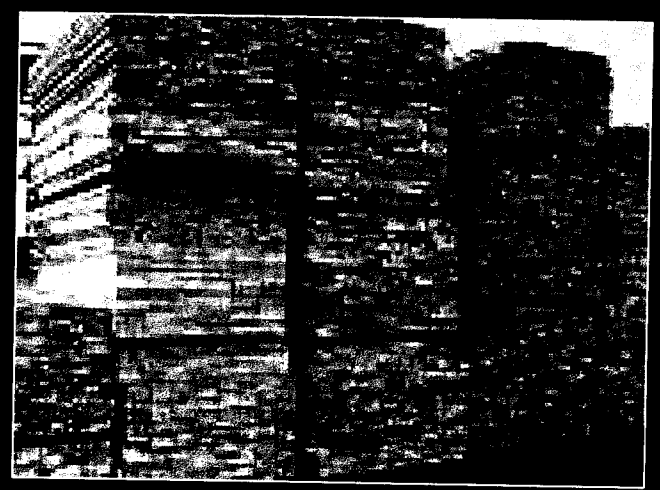
Reclaimed timber that can be milled into wood products

What is materials Reuse?

- Materials can be reused for their original function or used in an innovative way. This is referred to as 'reclaiming materials' or 'repurposing'. Because there is minimal reprocessing, as in recycling, these materials have a lower embodied energy. Whenever possible, reuse should take priority over recycling which may mean taking more time to remove items carefully to ensure a undamaged product.

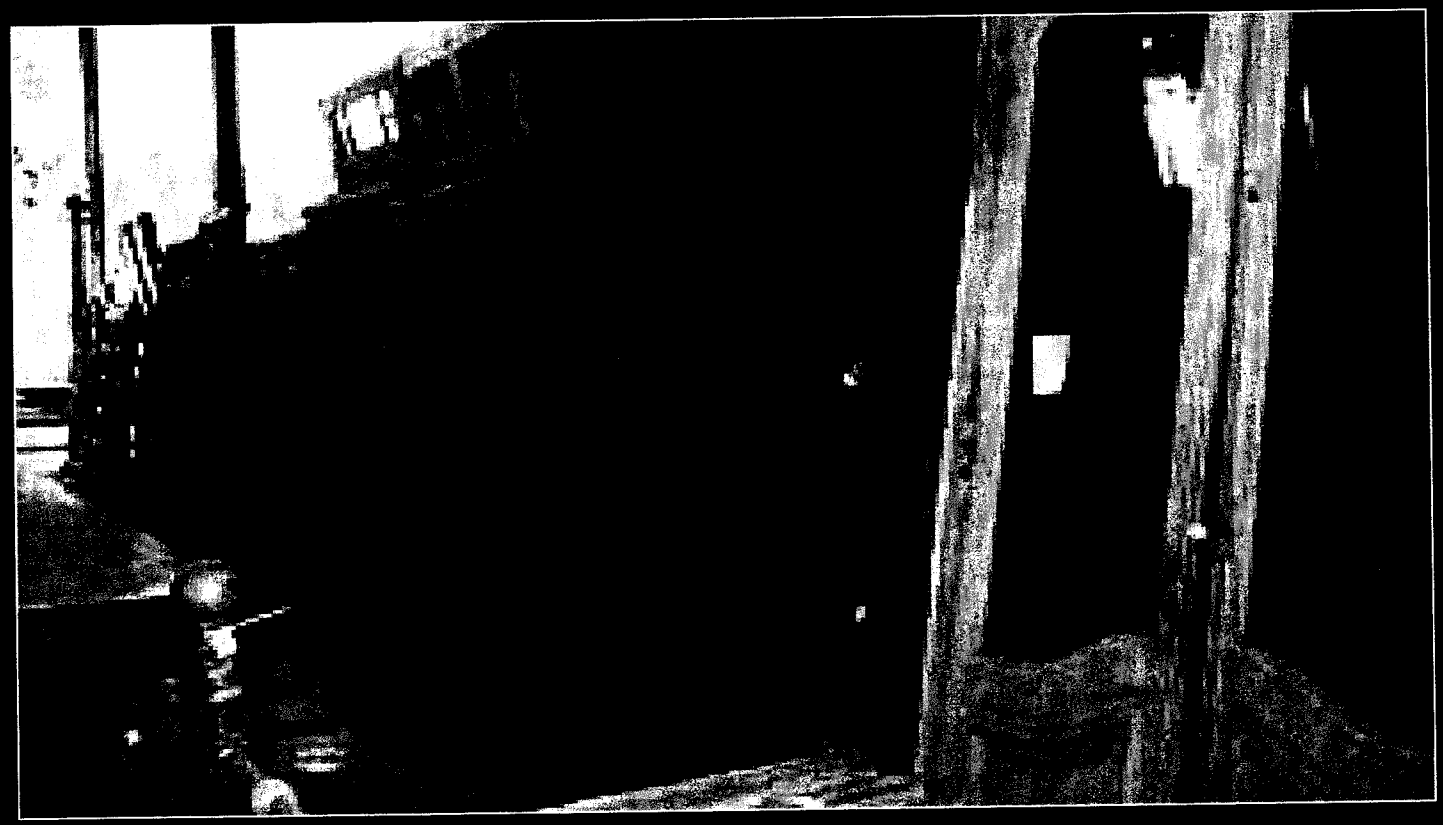
What materials can typically be reused?

- Wood- one of the largest waste product from deconstruction. With only 5% of old growth forests left in the United States recovering old growth wood from deconstruction sites slows the cutting of forests and reclaims higher quality wood.

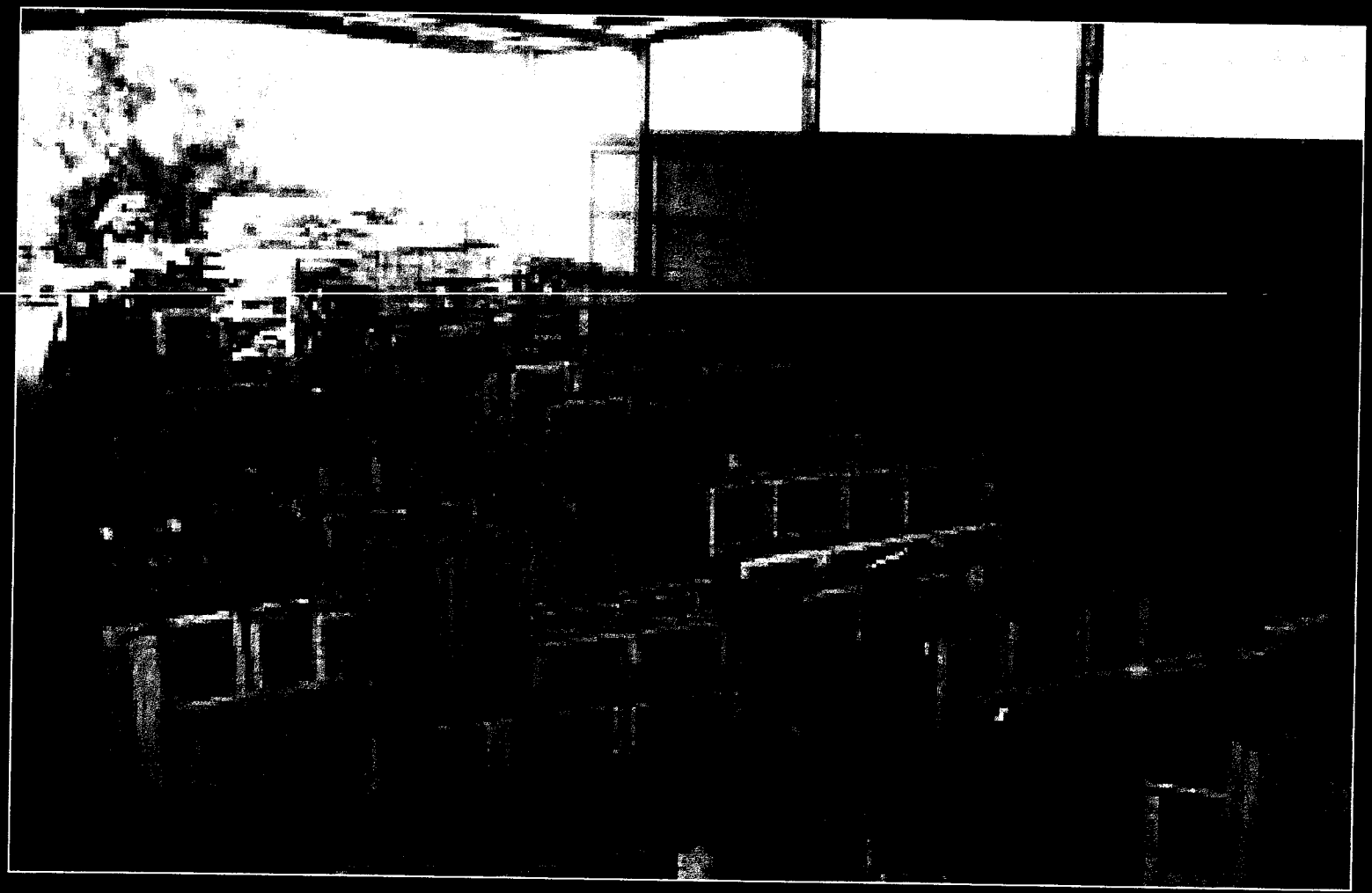


Doors

- Doors are very easily reused.

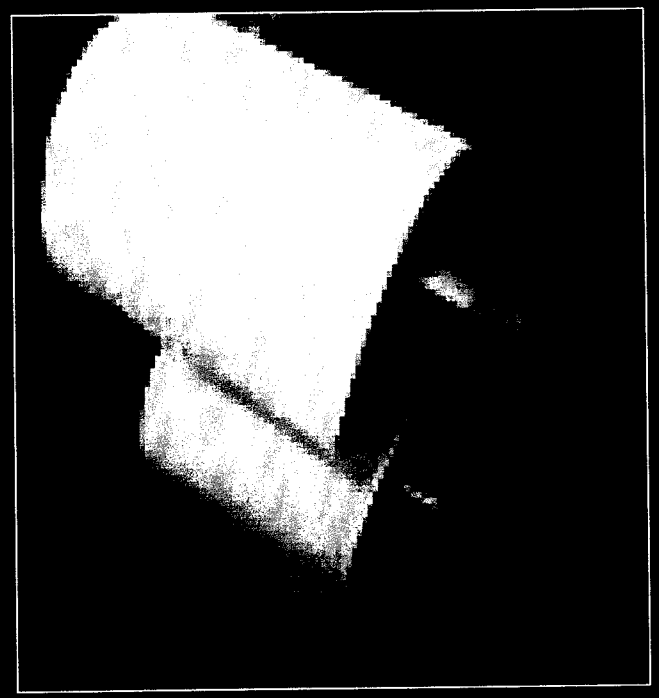


Windows



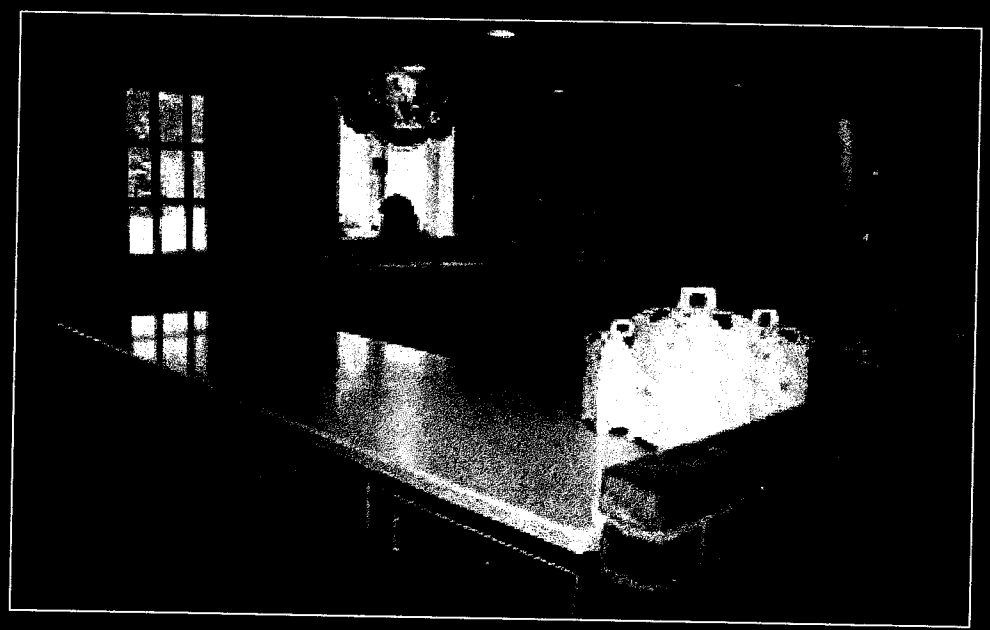
Pipes

- Pipes can be reused or repurposed



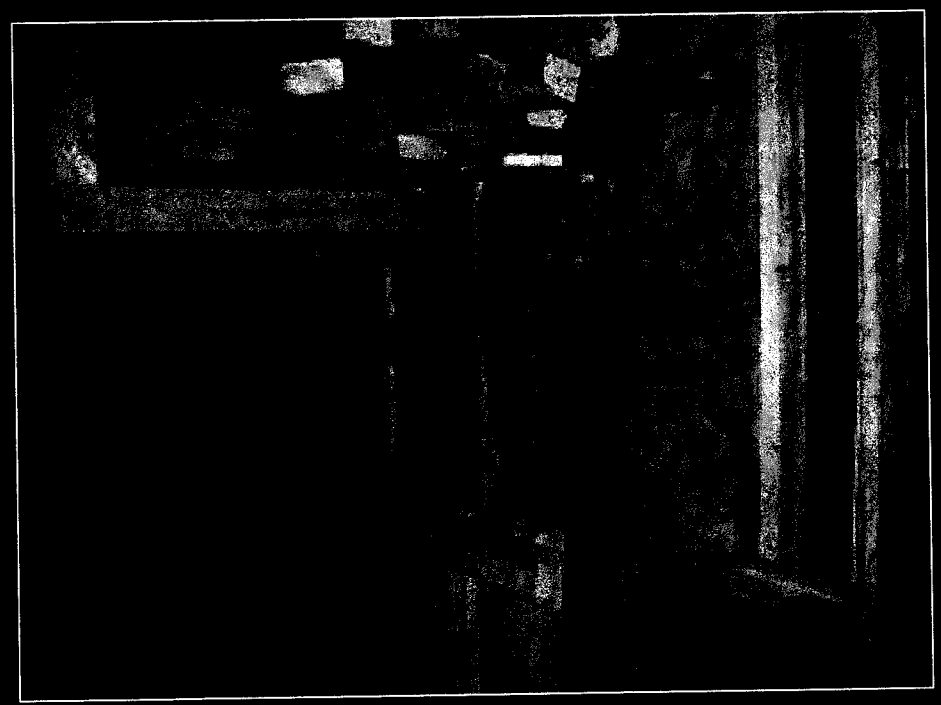
Cabinets and shelving

- Cabinet grade wood can be remade in to cabinets as well as the reuse of cabinets themselves.



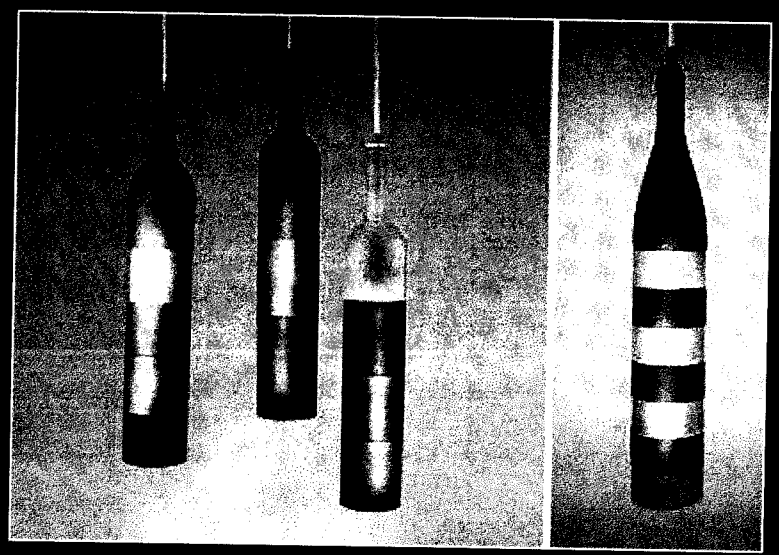
Insulation

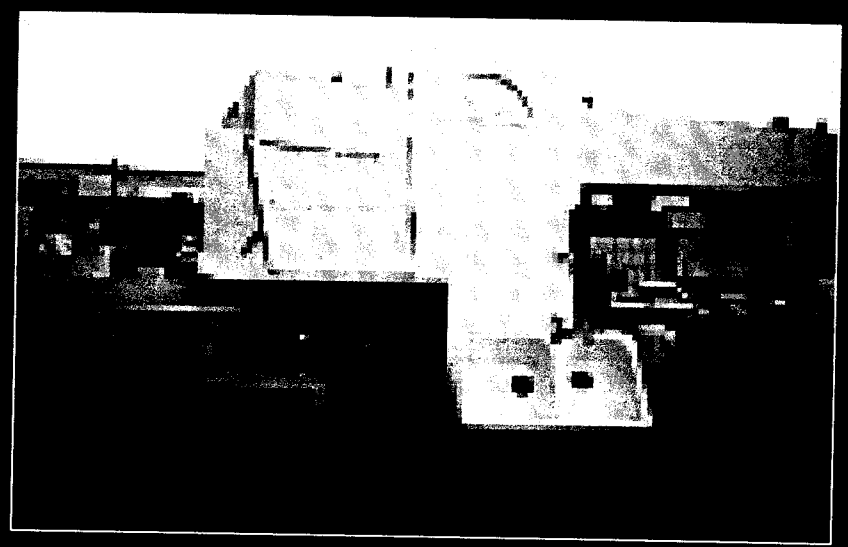
- Fiberglass insulation can be removed and reinstalled



Fixtures

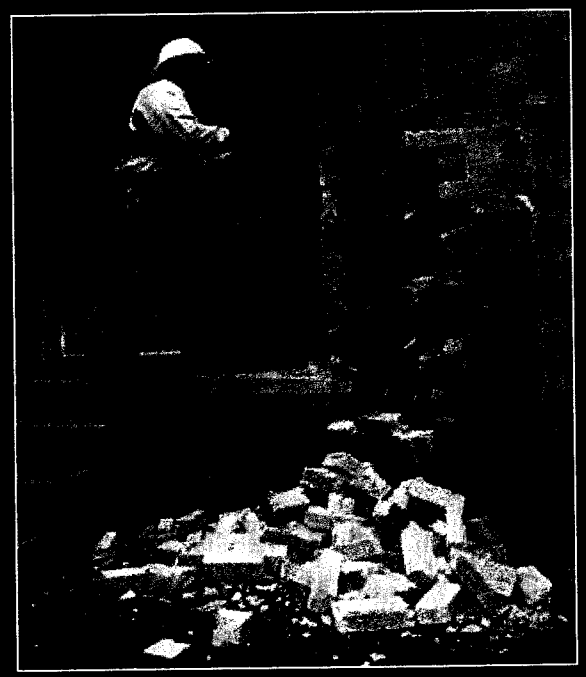
- There is no limit to how materials, particularly fixtures, can be reusued



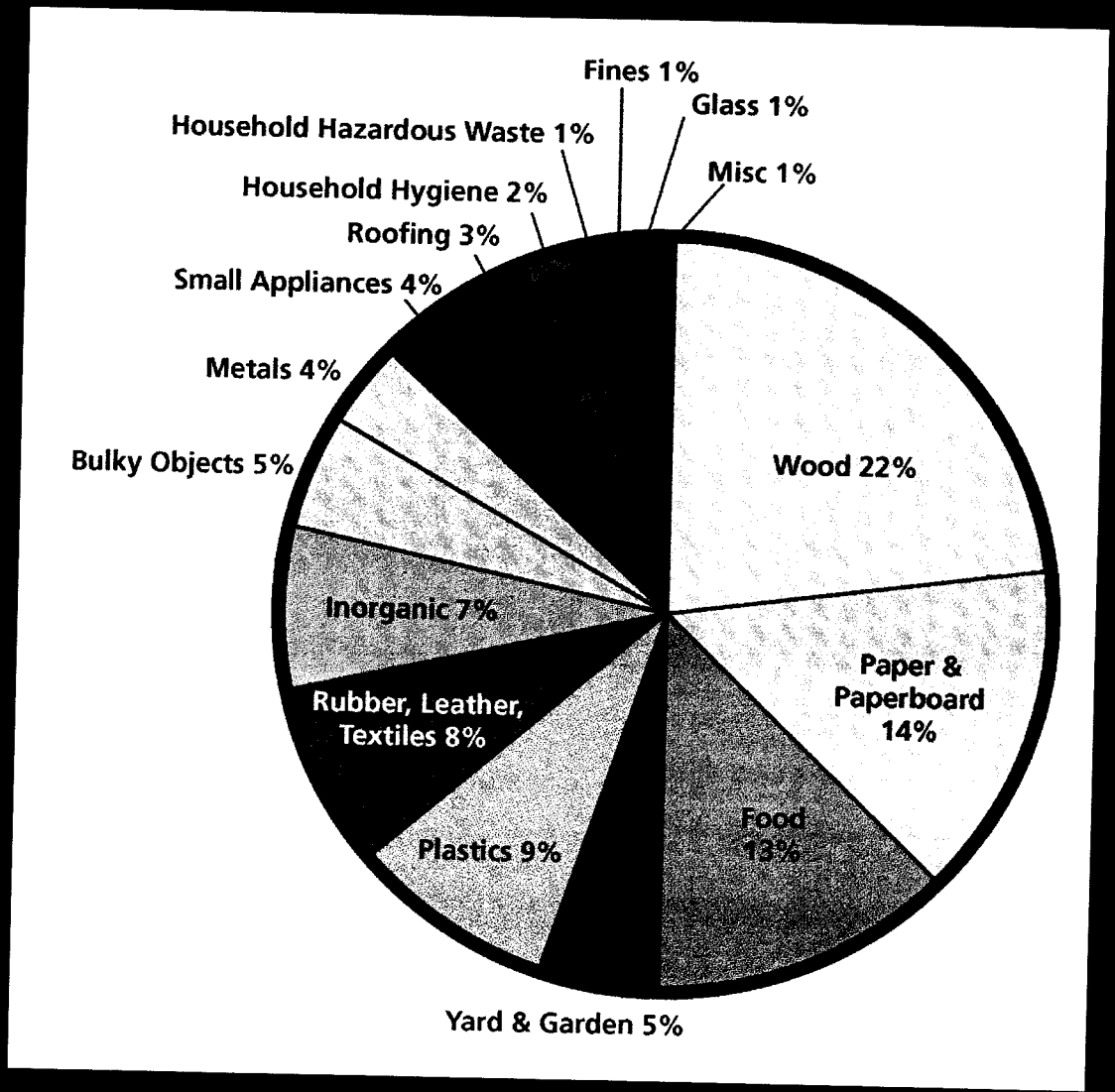


Bricks

- Bricks can be reused for pavers or patios



What materials are considered solid waste?



What kinds of materials can be recycled?

- Metals
- Paint
- Concrete
- Asphalt
- Drywall
- Glass
- Plastic
- Carpet

Tabor Commons Deconstruction

- Much effort was put into deconstructing part of the existing building for reuse and saving on waste

Students from Oregon Tradeswomen dismantle an awning and remove siding.

The Future of Deconstruction

- This is a growing field and as the demand for 'green' products that are reclaimed or recycled there will be more and more desire for deconstruction services.
- Buildings that are designed for future deconstruction.

Weatherization

What is Weatherization?

- Modification of a building to reduce energy consumption and optimize energy efficiency
- Protection of a building from the elements of nature that can damage the life expectancy of the building.

How to Conserve? Energy Efficiency!

Create and implement systems that use ***less energy*** to achieve the ***same level of energy service*** that is currently in use.

- Use more efficient technology
- Install this efficient technology through the lens of nature
- Educate Occupants on their energy-use choices and behavior in their home

These are all jobs of a Weatherization Technician

How to Protect? Moisture Control!

- In certain climate zones, moisture can deteriorate a building very quickly through rot and mold.
- Protection is also important from extreme wind, sun, snow

Black Mold Damage

Dry Rot

Weatherization Job Demand High and still Growing

Housing Market Bubble Burst

↓

New Home Construction Crashed

↓

Many Construction Workers Lost Jobs

↓

Federal Stimulus Bill Created to:

↓

Reduce Energy Use

↓

Reduce Energy Bills, Tax Credits, and Offer Rebates

↓

And Create Jobs for Weatherization Workers

Federal Stimulus Stats

- $5 billion to weatherize houses of low-income families
- $2.25 billion to retrofit Section 8 housing with energy-efficient products
- The Existing Homes Tax Credit increases from 10% to 30% for the cost of energy-efficient windows, HVAC equipment, and insulation, up to $1,500 per qualifying household through 2010.

Alliance to Save Energy

City of Portland Clean Energy Fund

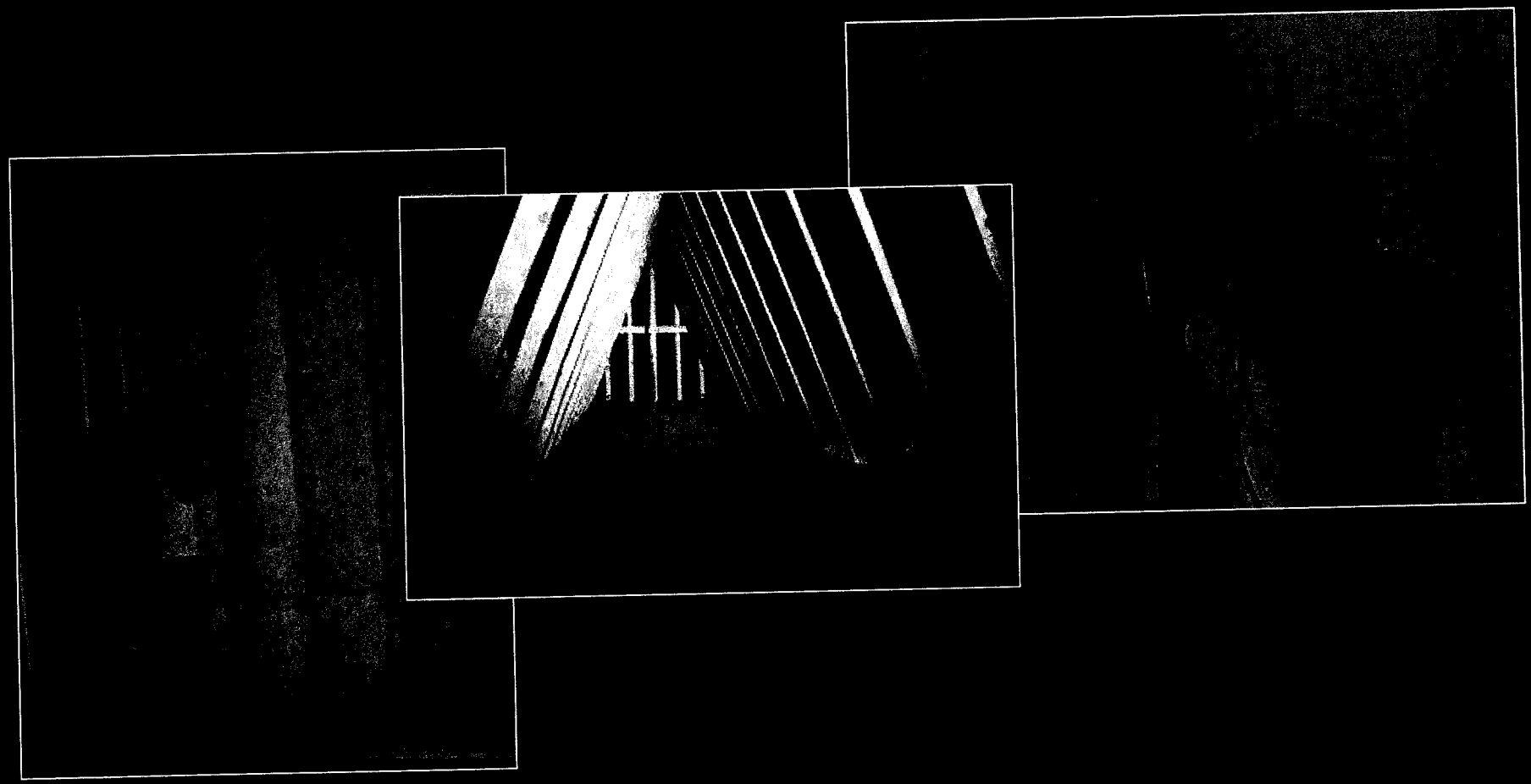
- City of Portland will fund energy improvements for 500 homes through federal stimulus funds
- Payments of energy improvements will be integrated into monthly utility bills that will be offset by the costs of energy saved after the improvements
- More to Come? Program model was created as a test run and could be used for the Climate Action Plan, which calls for the energy retrofits of 10,000 homes per year

Portland Tribune: 5/17/2009, *City to use stimulus for energy programs*

Weatherization Practices

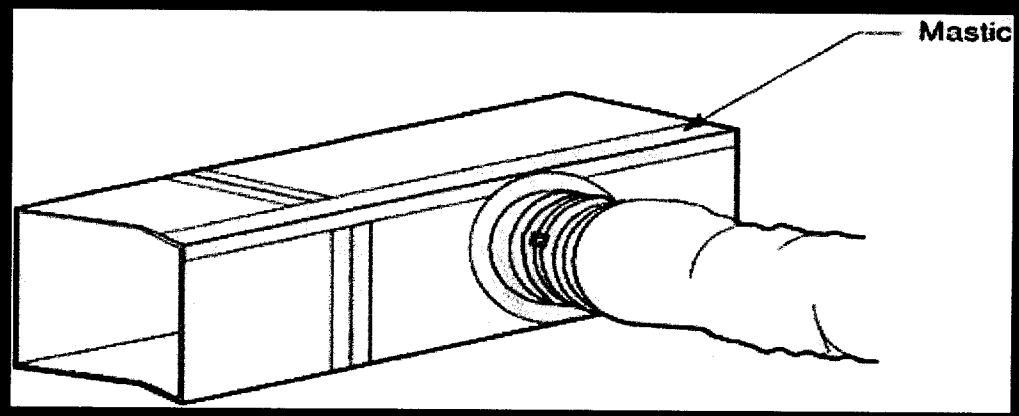
Insulation Installation:

Attic, Floors, Foundations, and Walls



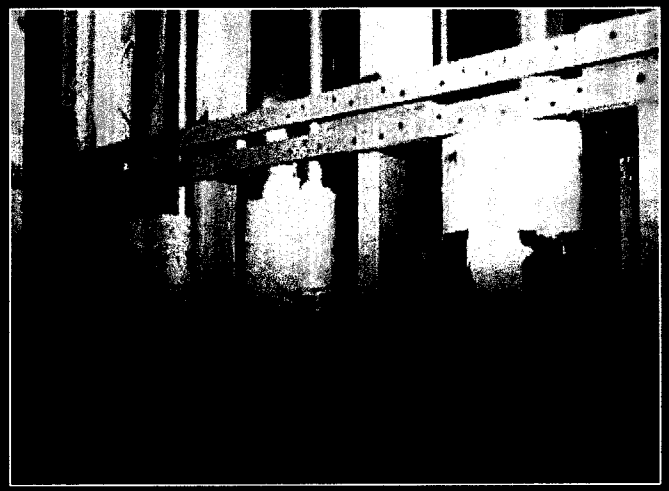
Duct Sealing: Prevents Heat Loss Ductwork

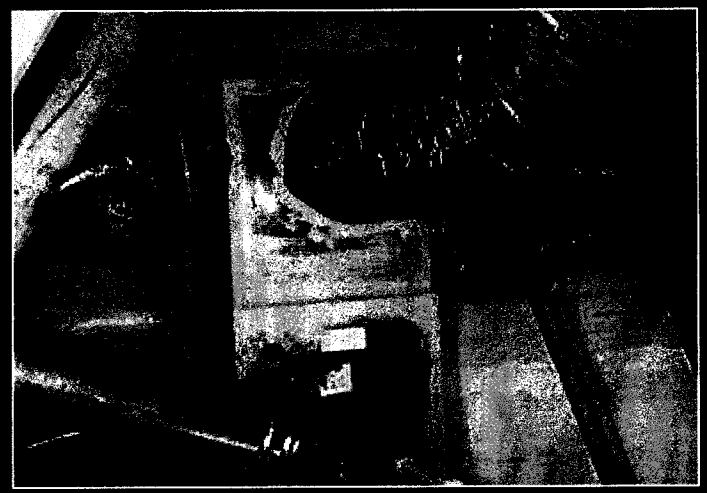
Ductwork: Pink indicates where to seal



Critical Duct Sealing directly above furnace where majority of heat escapes from ducts

After Duct Sealing: The Results





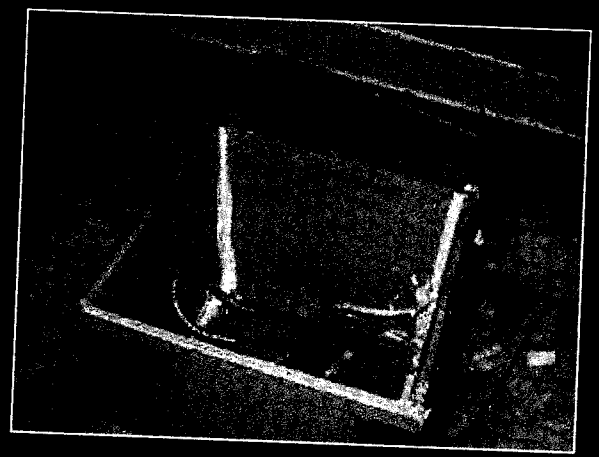
- Throughout the U.S, duct leakage typically wastes 10% - 30% of the heating or cooling energy purchased by a homeowner

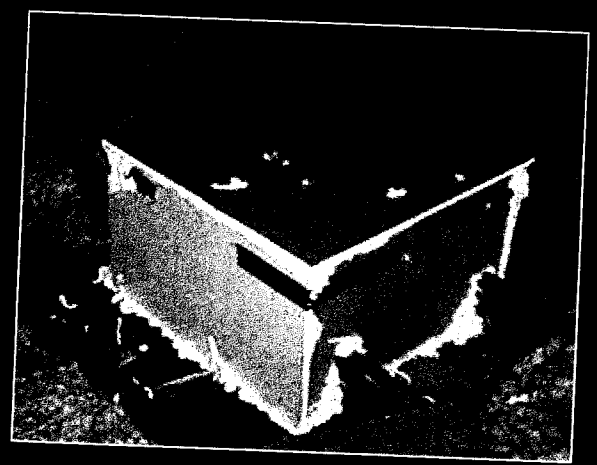
Residential Energy: by Krigger and Dorsi, in Duct Leakage Section

Air Sealing

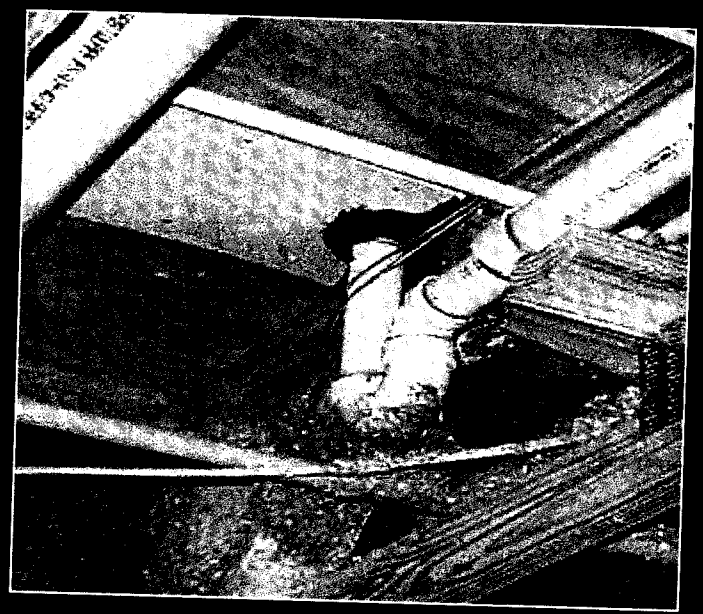
- Seal cracks, gaps, holes in the building shell to remove drafts and prevent heat loss from building
- Red Arrows indicate where heated typically escape, and Blue indicates where air typically leaks in

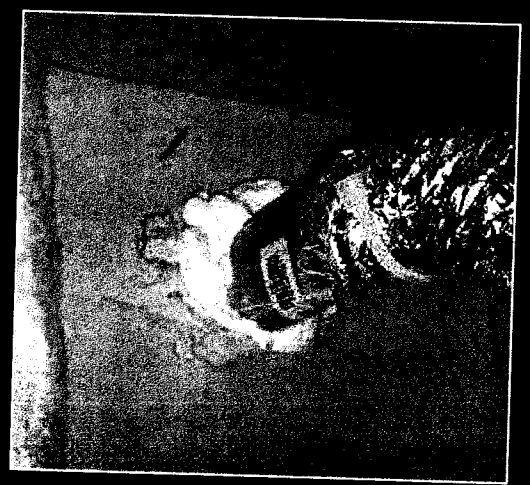
Air Sealing Recessed Lights





Air Sealing
Wire, Plumbing, Venting
Penetrations



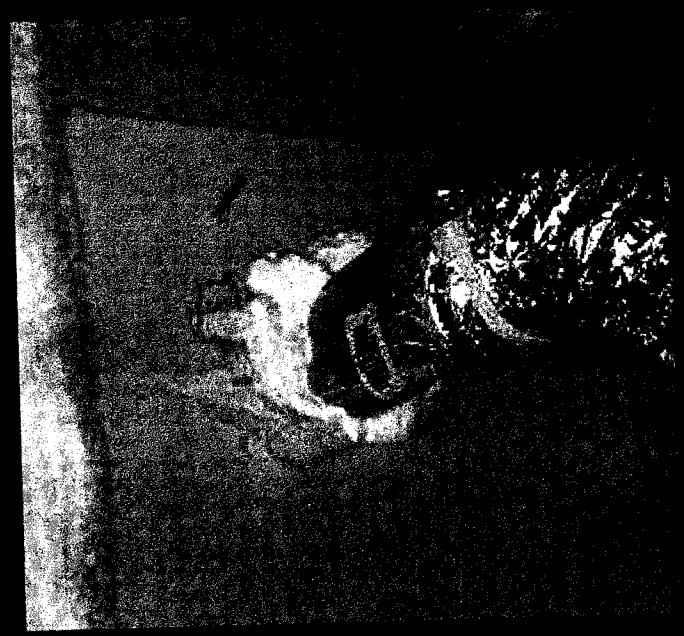


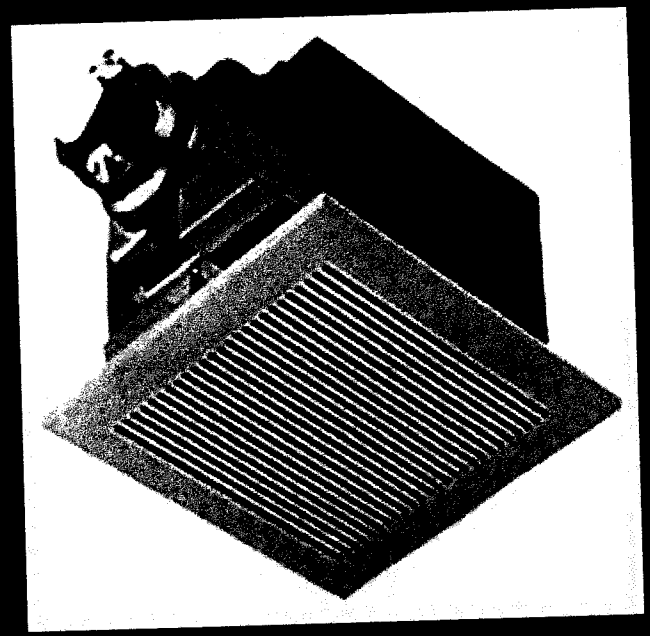
Other Air Sealing Measures

- Weather-stripping and caulking doors and windows
- Sealing chimney bypasses with flashing and and heat resistant caulking
- Replacing chimney dampers
- Sealing Rim Joists along Foundation walls
- Blocking and Sealing Knee walls
- And many, more, innumerable spots…

Moisture Control

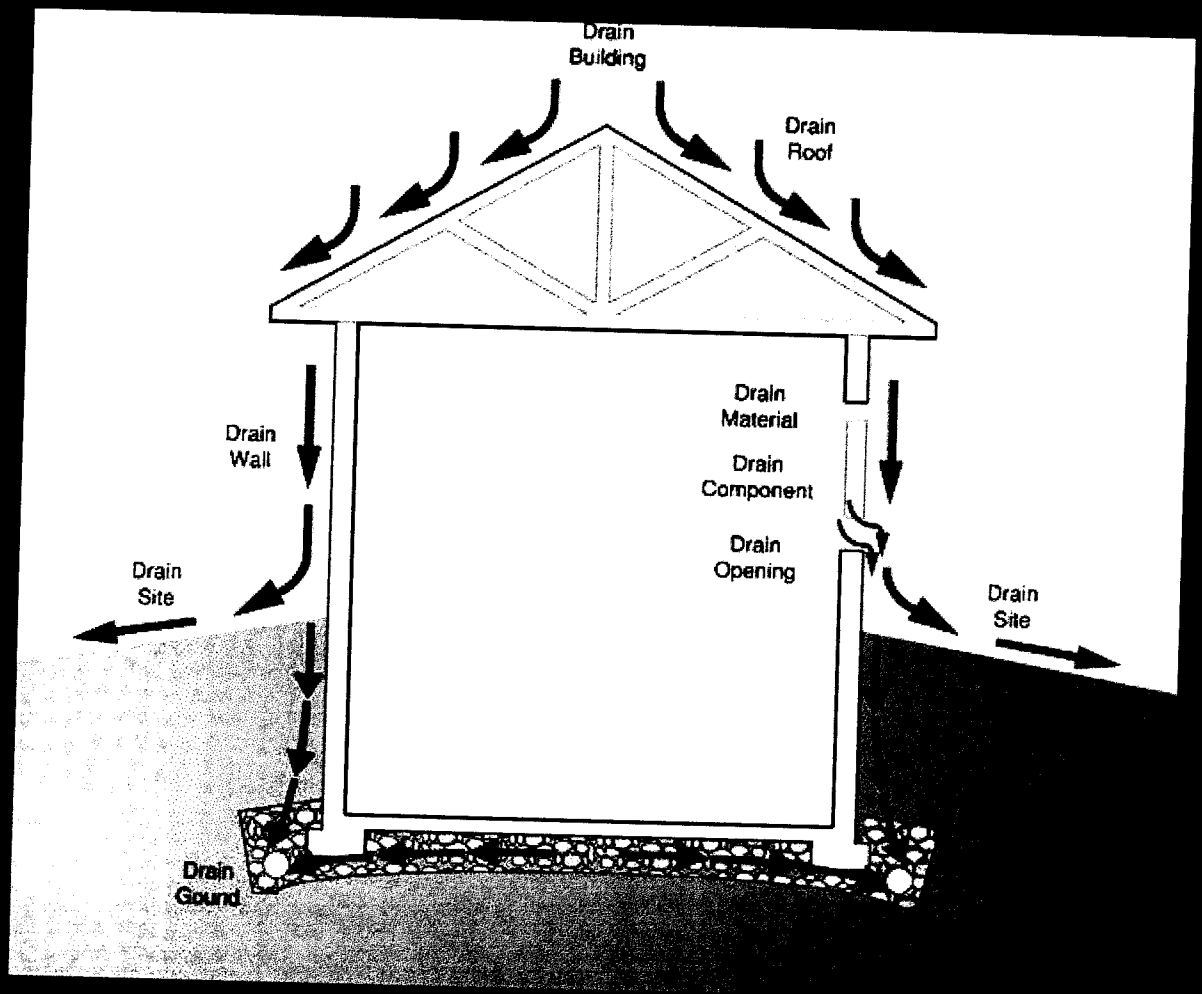
Ventilating Out Moisture From Inside the Home





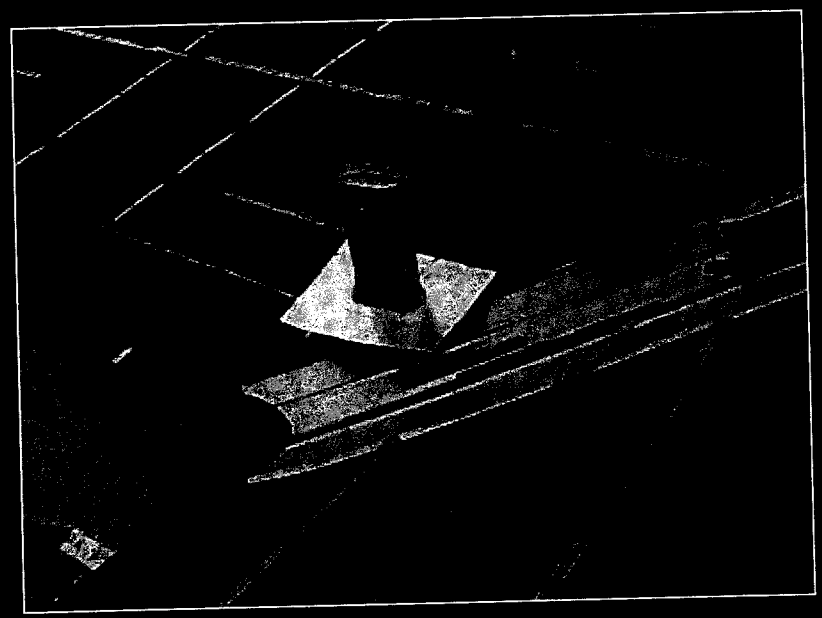
- Per Person Per Day, Showering, housecleaning and cooking can exude up to 3 pints per day + the average person evaporates 4 pints (Residential Energy, Krigger and Dorsi)
- Installing dryer vents and bath fans are basic examples which help remove moisture within the home.

Moisture Control: Directing Water On the Outside



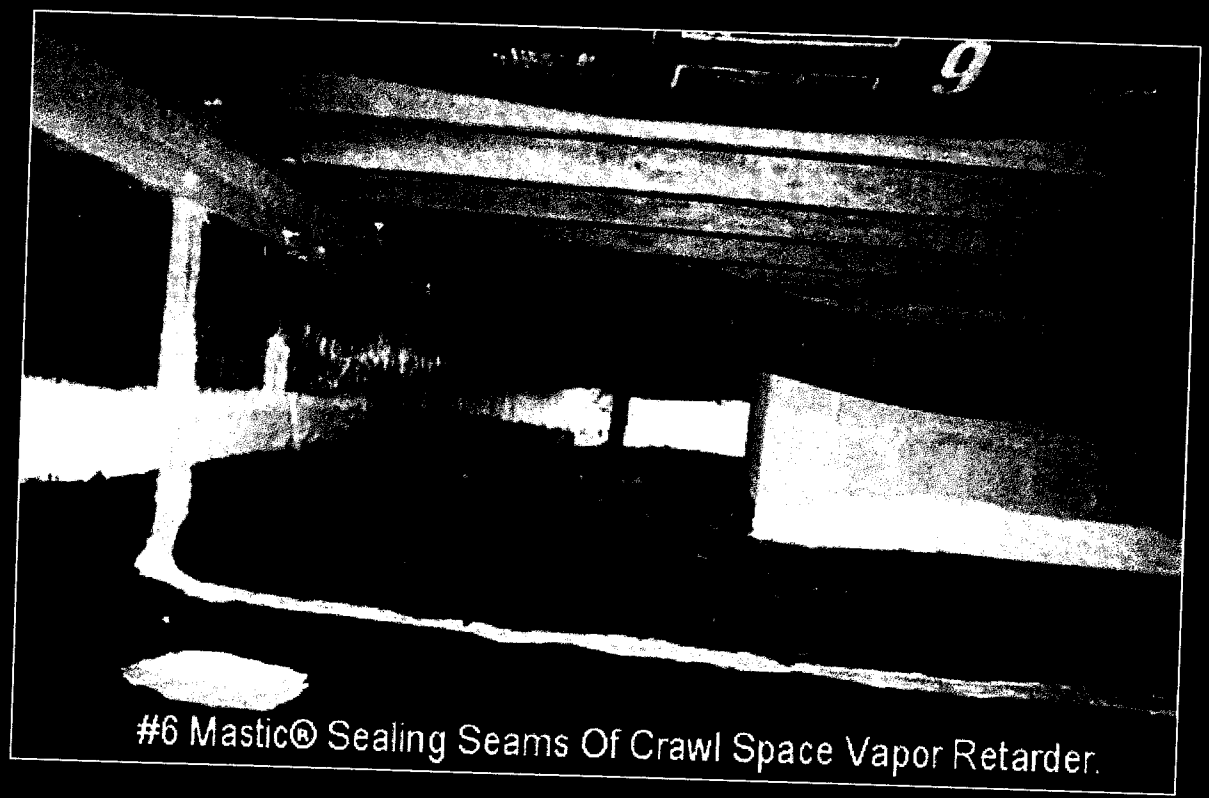
Moisture Control in Roofing Construction

- Placement and design of flashing, tar paper, shingles, and ALL other roofing membrane materials are essential to create a lasting healthy building.



Crawlspace Moisture Control

- Laying down Plastic Groundcover will prevent gallons of water everyday from rising up from the soil and through the floor.



#6 Mastic® Sealing Seams Of Crawl Space Vapor Retarder.

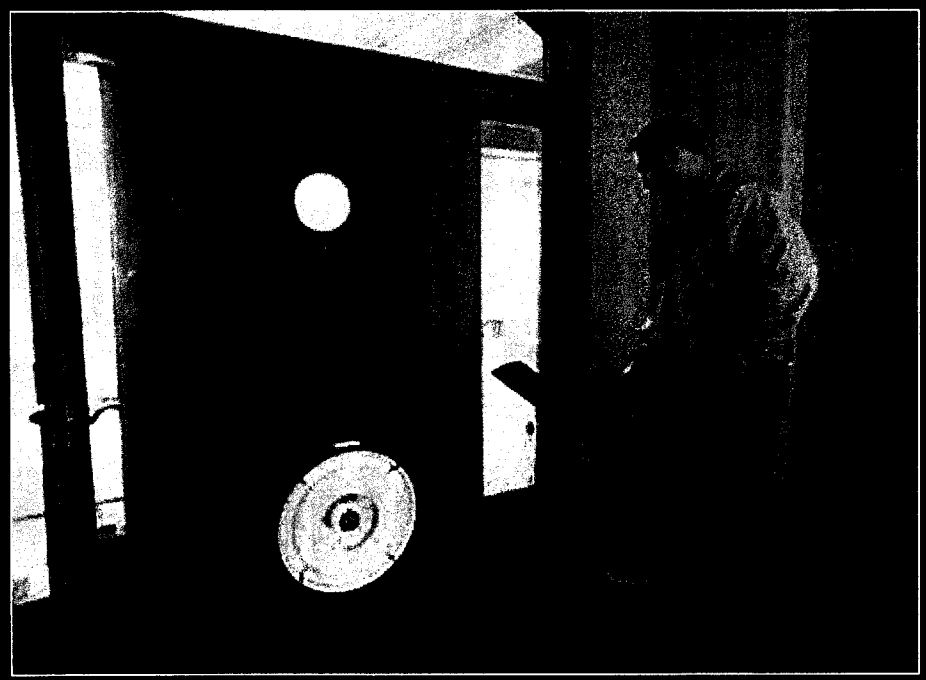
RD Mastics: www.rcdmastics.com

Other Weatherization Procedures

- Insulating Ductwork
- Clean and Install Furnace Filters
- Insulating Water Pipe
- Installing storm doors / Windows
- Replacing Windows with efficient, low emissivity, Double-glazed windows
- Installing Footing Drains, or other techniques to protect the building from surface water runoff or groundwater
- Ventilating Crawl Spaces and Attics

Testing Weatherization Work

- Weatherization Installers who are certified in testing can test air leakage rate of homes
- Test are administered before and after work is completed to see how installation improved the home
- Blower Doors like the one shown below are used to measure air leakage



Testing Continued:

- Duct Leakage can tested with a Duct Blaster shown on the left. The Manometer on the right digitally shows you the air leakage rate

Job Skills Needed:

- Ability to work in dark confined spaces; Crawl Spaces and attics are common
- Agility is needed to crawl under floors and in attics over water pipes, ducts, wiring, etc
- Comfortable with Heights: If roof insulation or vents are needed
- Carry and lifting heavy materials
- Operating power tools typical in carpentry
- Building Science background is helpful
- Basic Electrical and Carpentry is helpful

List of Businesses that offer Weatherization Employment and Services:

- County Governments – Low Income Weatherization Programs: State/County Referral List
- Energy Trust: Contractors Trained in Energy Efficiency are called Trade Allies. The referral list: http://www.energytrust.org Click For Homes>Existing Homes>Choose a Trade Ally

Green and Solar Roofing Systems

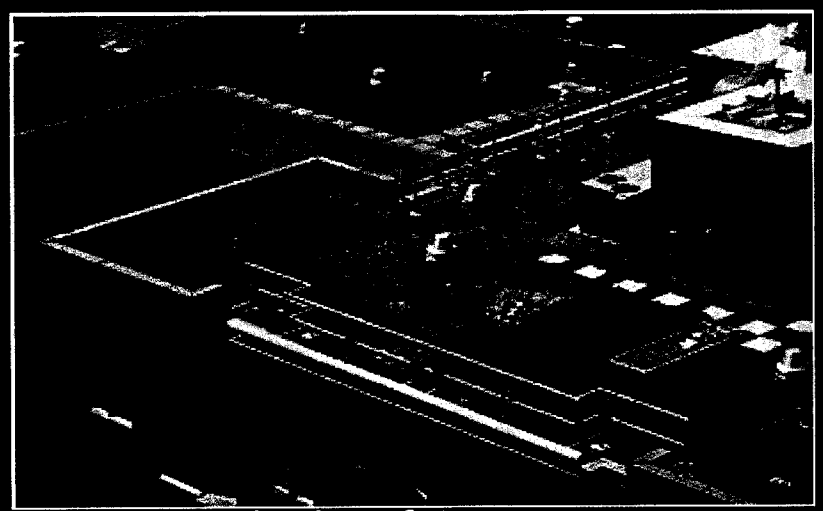


Photo from Oregon State University

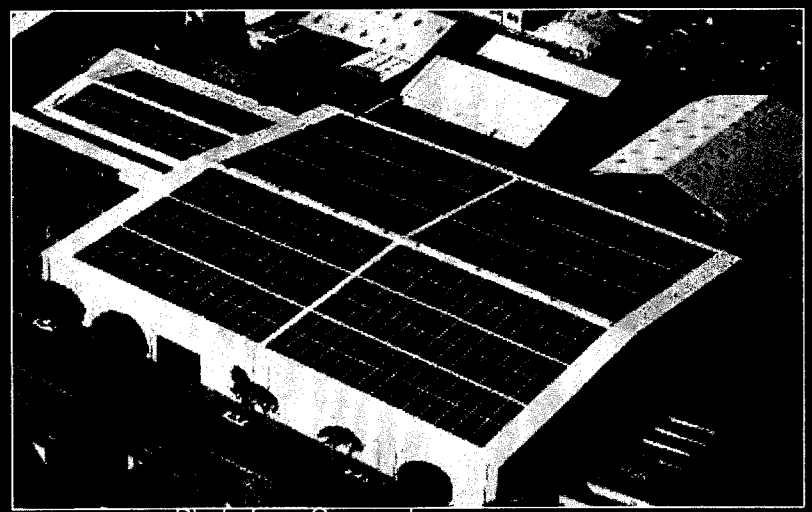
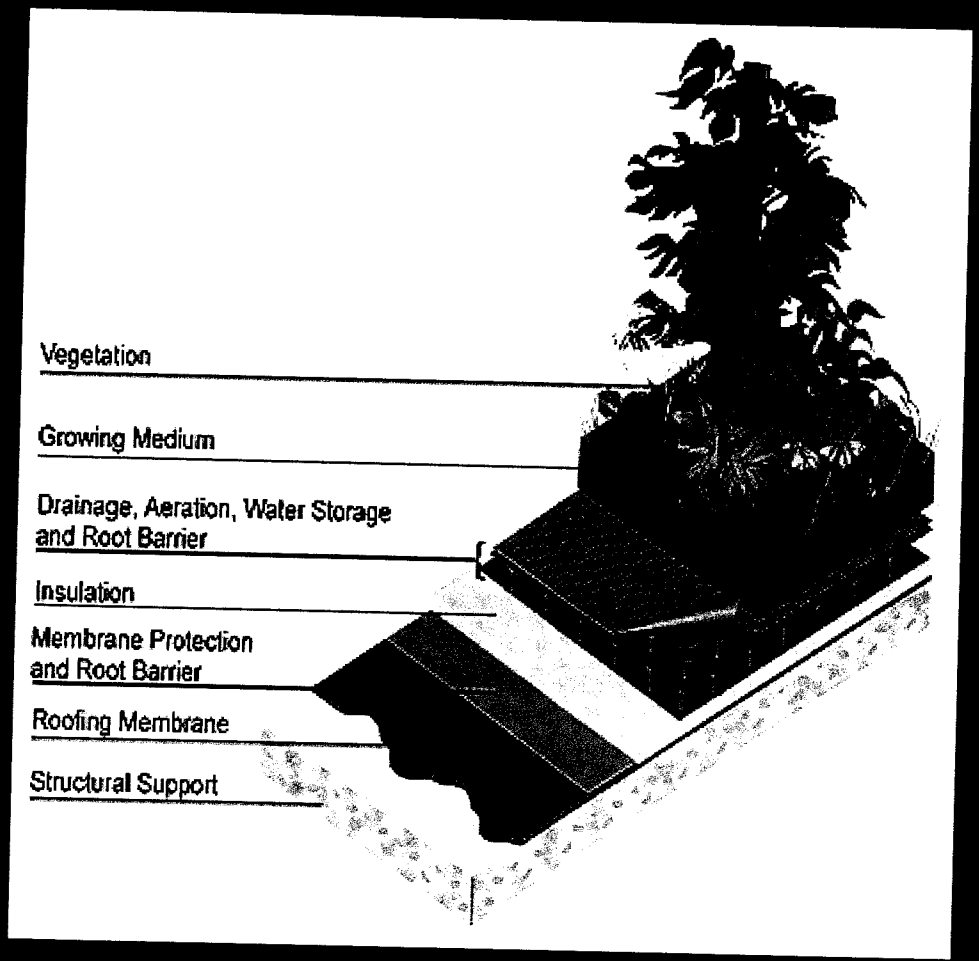


Photo from Coca-cola

What is a Green Roof?

- A green roof, (also known as an eco-roof, living roof or sod roof) is a living, breathing, vegetated roof system that provides a sustainable alternative to conventional roofing.



(Source: American Wick Drain Corp.)

- An eco-roof is a lightweight system of soil and vegetation designed to be as self-sustaining as possible.
- A successful eco-roof is synergetic. The soil anchors the plant roots and supports plant growth. The plants protect the soil from erosion and heat gain. Water and sun feed the soil and plants. Plants photosynthesize and produce food for other species, which produce waste matter that helps improve the soil.

What is a Solar Roof?

- A solar roof is a roofing system that has photovoltaic panels built into the roofing membrane, shingles or tiles.

Solar Integrated Roofing

- Traditionally photovoltaic panels have either been mounted onto roofs via metal racks, or to a pole adjacent to the building. Solar Roofing allows for two systems to be installed at once.

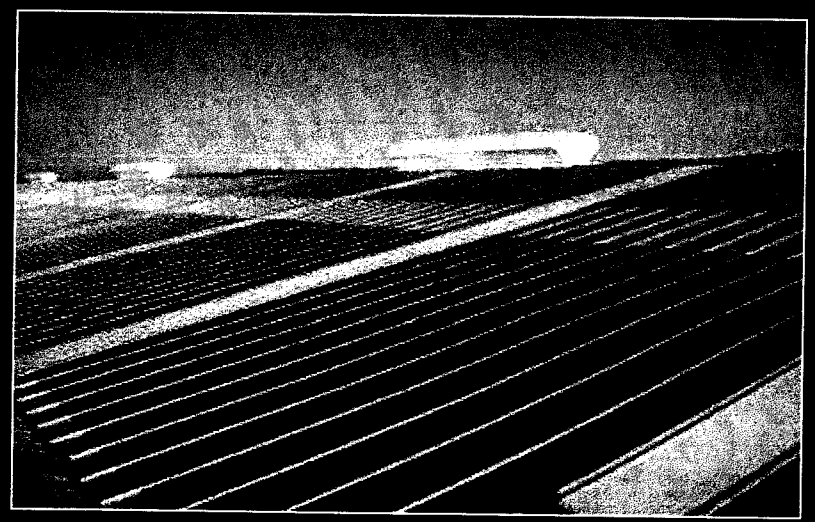
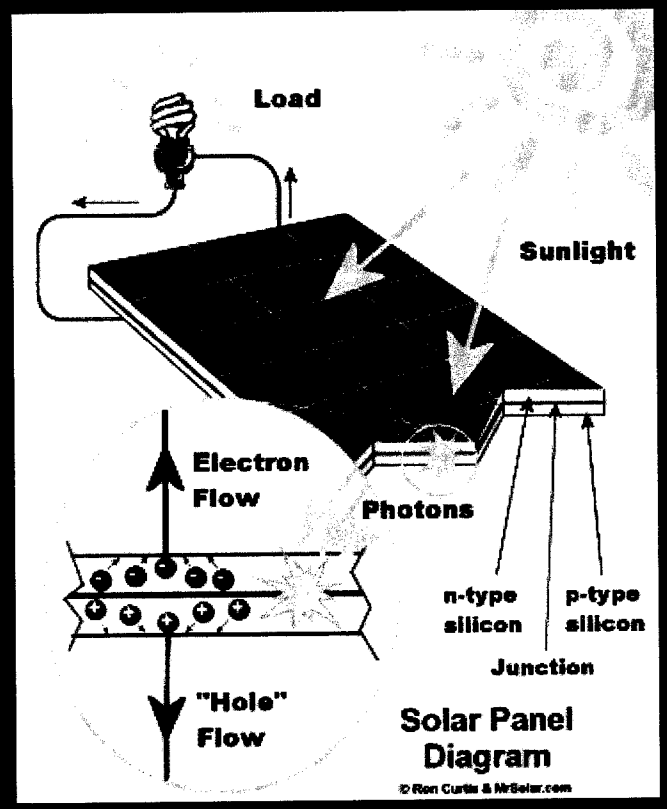


Photo from General Motors

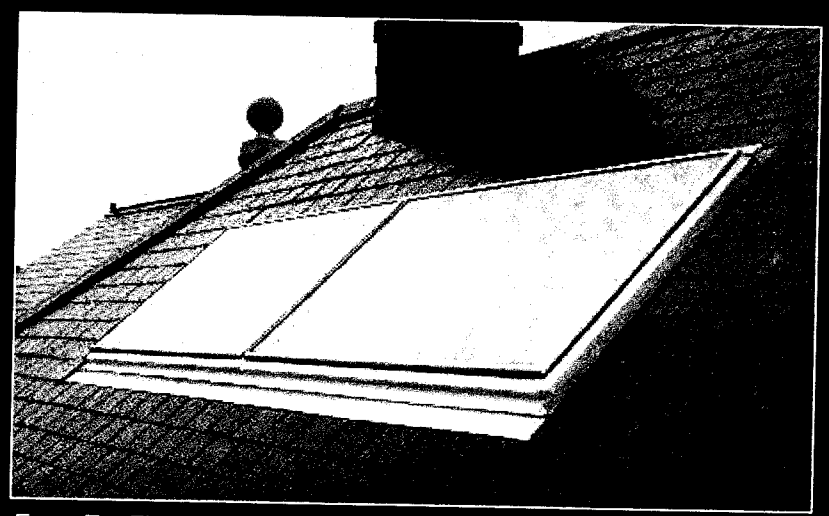
What are Photovoltaic Panels?

- Photovoltaic (or PV) panels, otherwise known as 'solar panels,' are panels that convert solar energy (photons) in to electricity (volts). Photo+volts = photovoltaic.



What is Solar Thermal?

- A solar thermal panel is a panel that harnesses the sun's energy to store heat.



From EcoFirst.net

Greenpeace/Langrock/Zenit

Solar Thermal Panels

-are shallow flat panels containing tubing that is filled with a fluid (water or glycol) that collects heat and transfers the heat to a tank of water for domestic or commercial use.

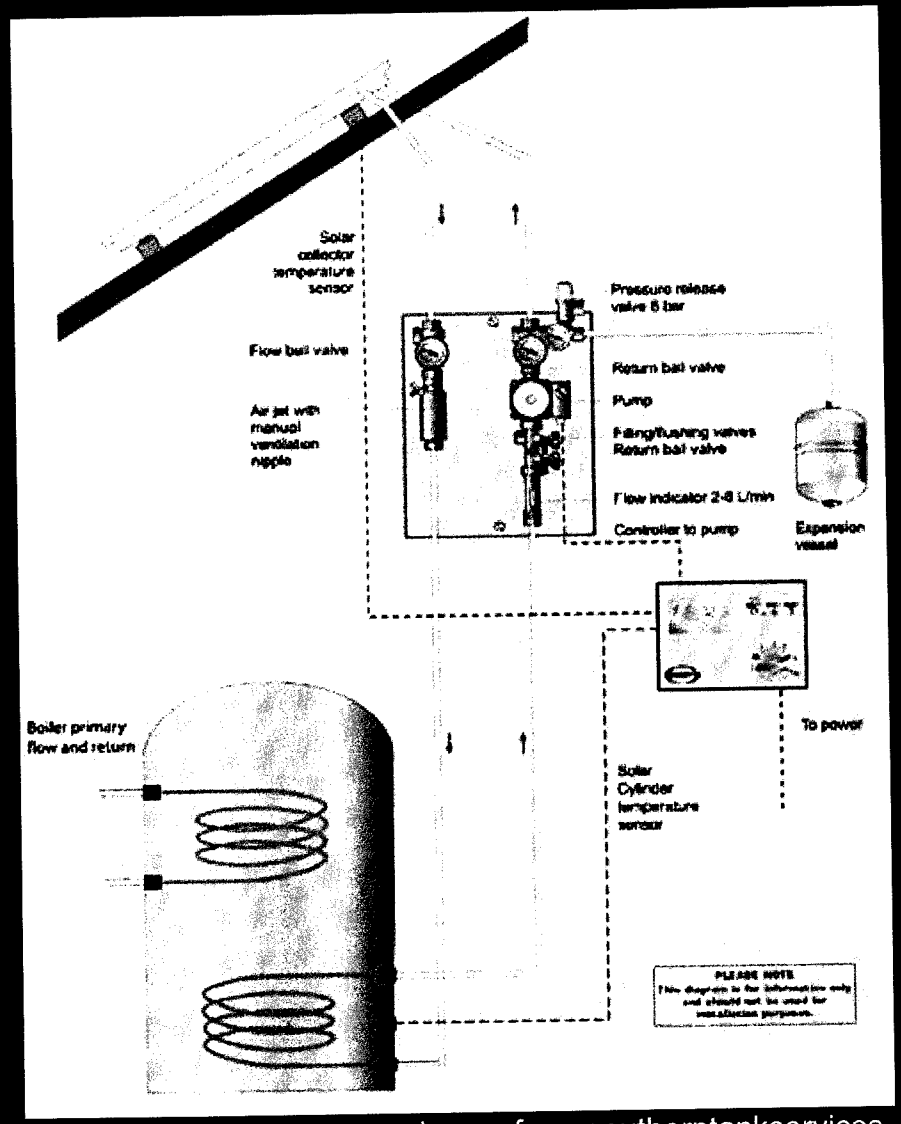
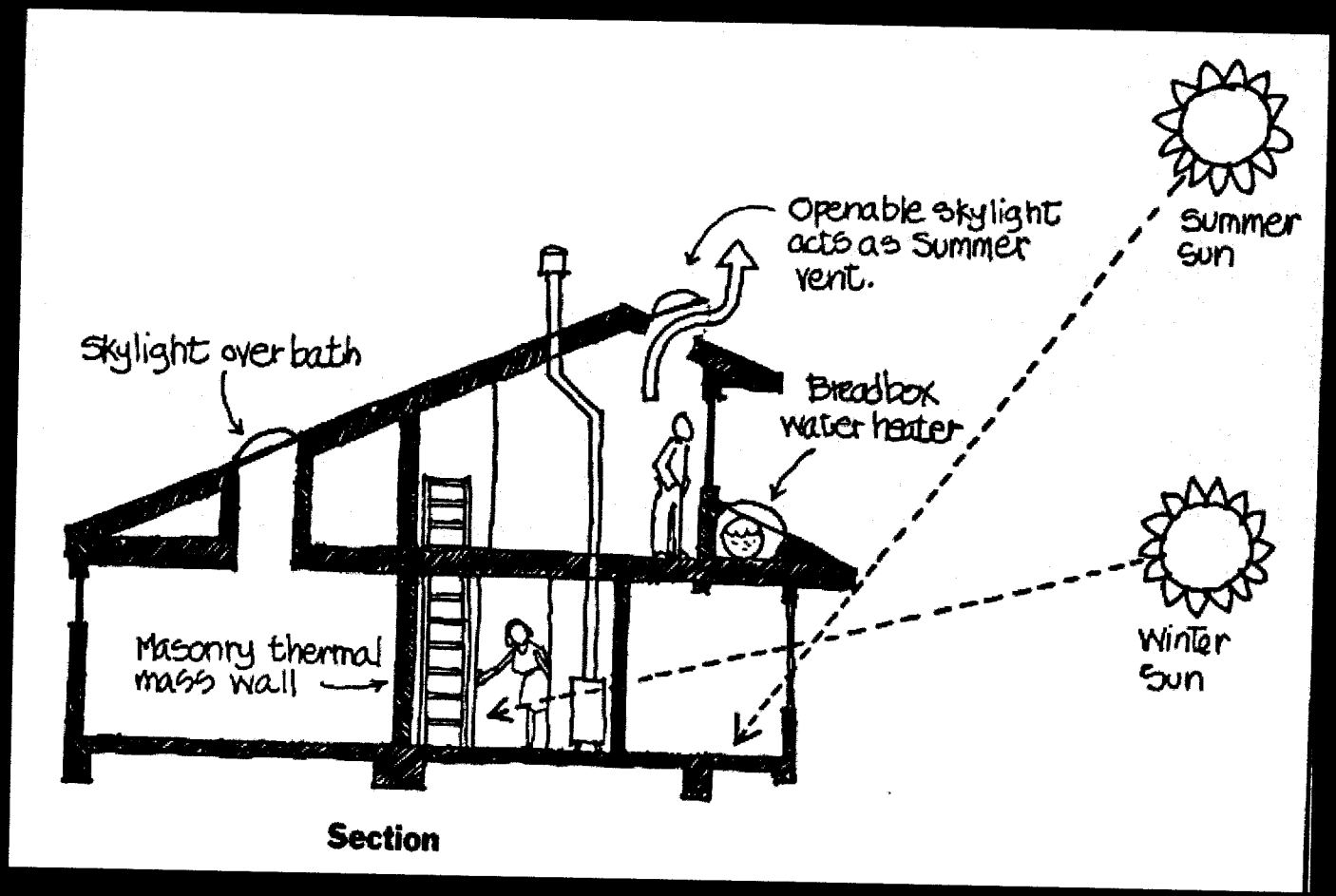


image from southerntankservices

What is Passive Solar?



(Hibshman, 1983, p.71)

Tabor Commons Passive Solar Design

- South facing glass
- Minimal glazing on West
- Concrete floor to retain heat

Designing for Passive Solar

- Location
- Orientation
- Native or planted vegetation
- Seasonal use of building
- Glazing
- Roof overhangs or trellises
- Thermal Mass

Considerations for planning and designing an eco-roof

- Location and orientation
- Type of vegetation
- Live and dead loads
- Climate
- Anticipated levels of operations and maintenance
- Aesthetics
- Access
- Drainage

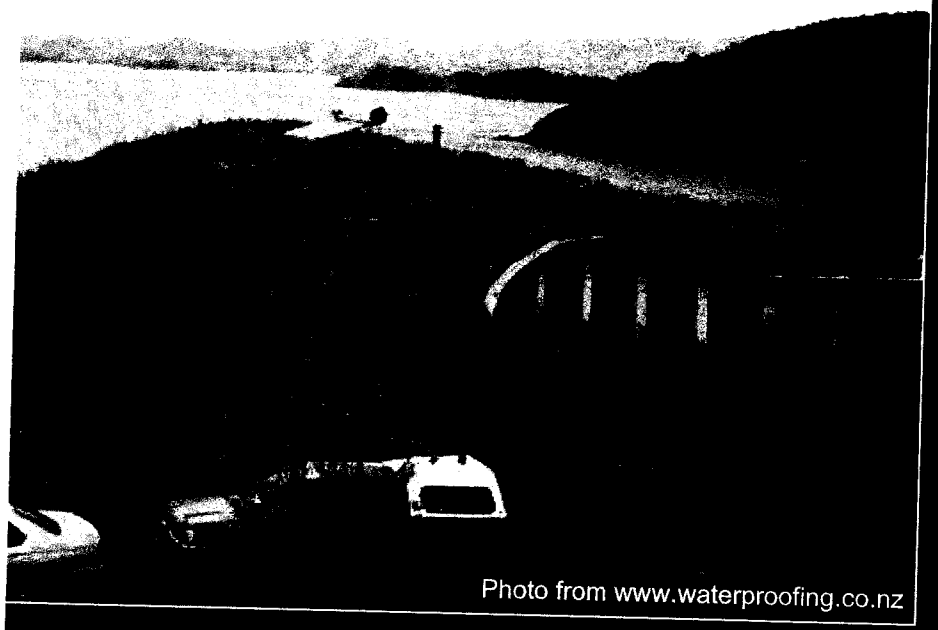


Photo from www.waterproofing.co.nz

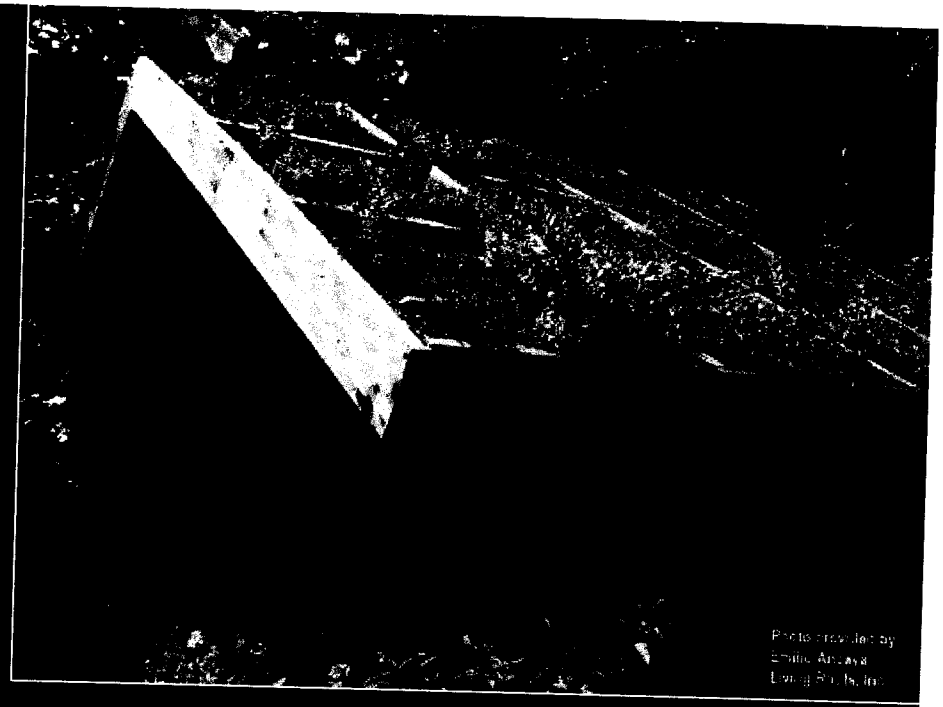
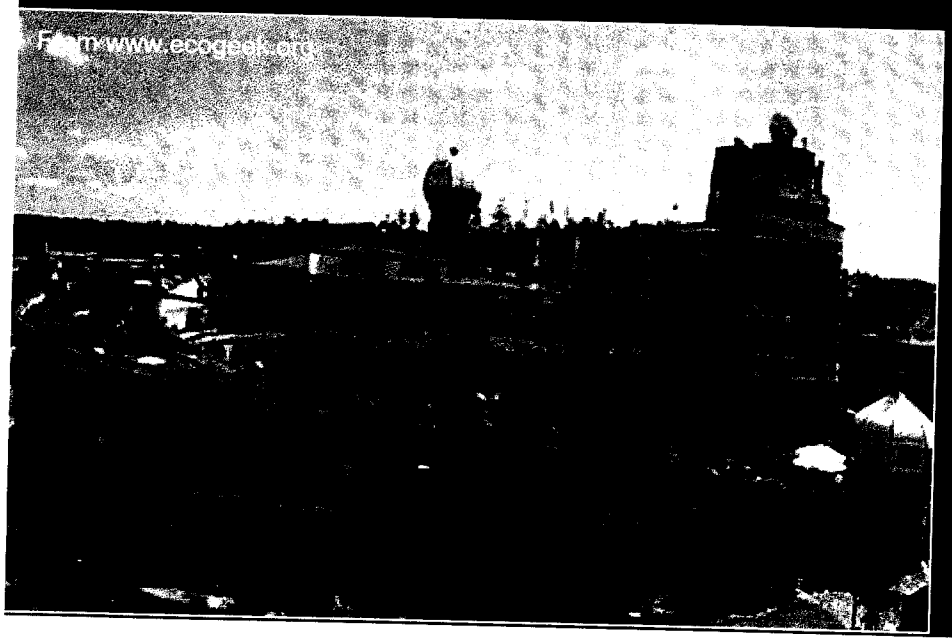
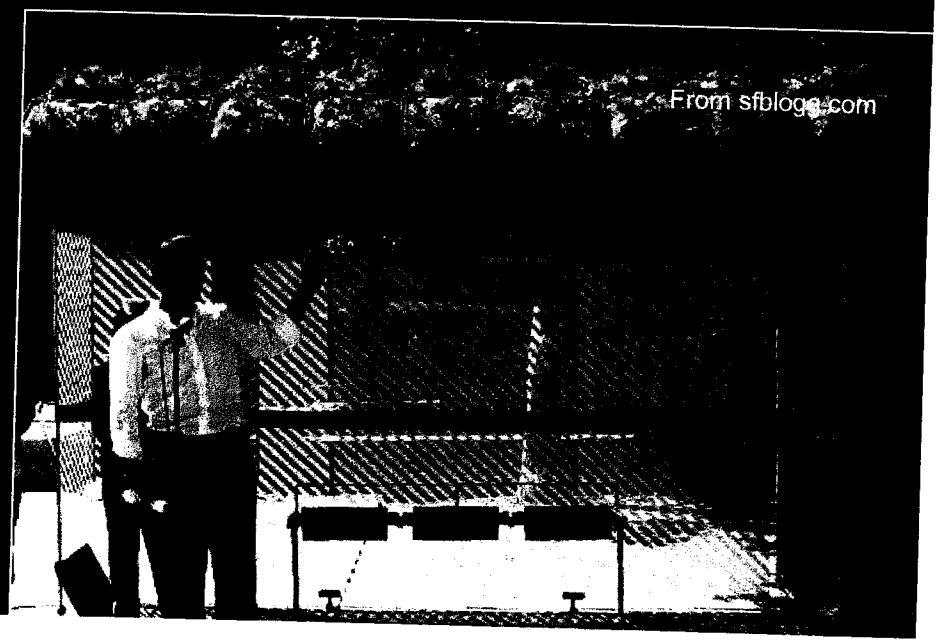


Photo provided by
Emilio Ancayal
Living Roofs, Inc.



From www.ecogeek.org



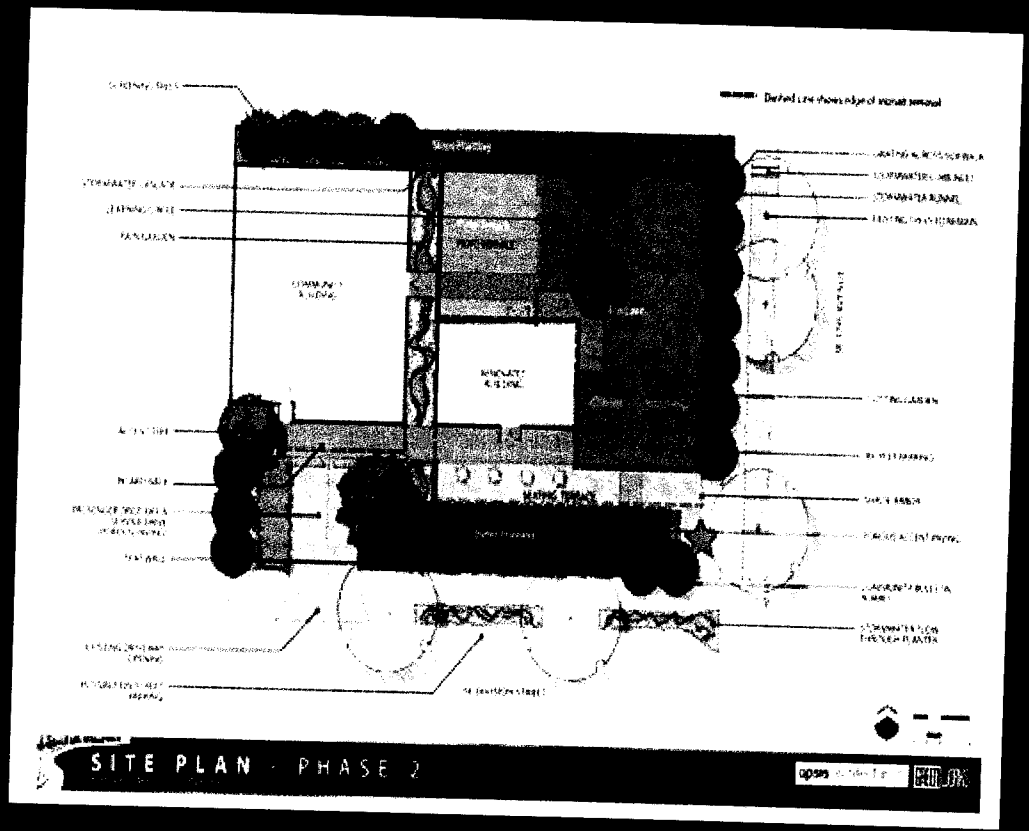
From sfblogs.com

Considerations for planning and designing a solar roof

- Location and orientation
- Climate
- Local flora
- Amount of energy consumed by occupants
- Type of roofing

Case Study: Tabor Commons

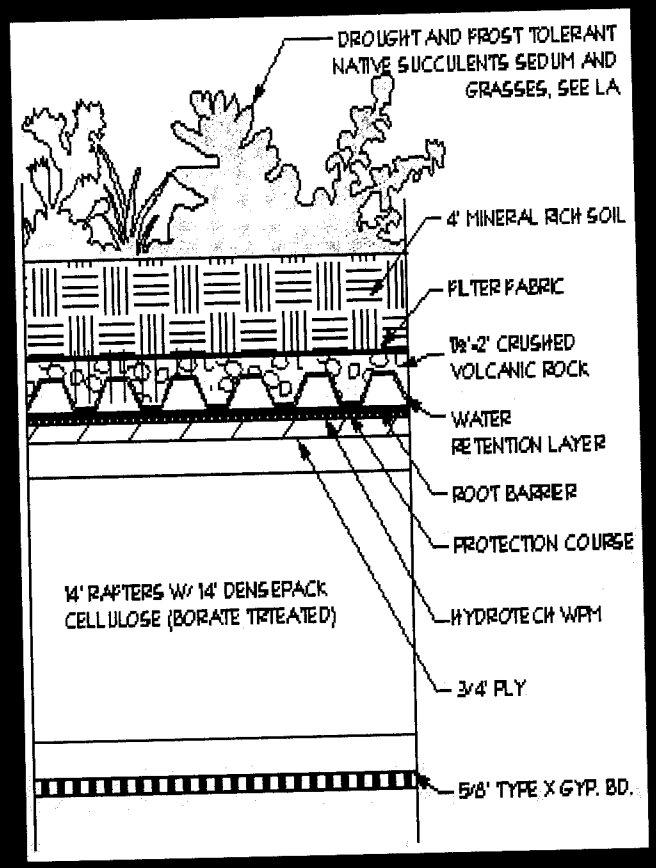
- "We just found out that we needed a new roof on the building. The metal roof is 50 years old; the project is going to be challenging. We wanted to do an eco-roof; this is our opportunity."
- "Eco-roofs are heavy. We need to reinforce the building to be strong enough to carry the additional weight. We're working with our volunteer engineers and advisory people to figure out what that would cost, and how we would do that."
- -Paul Liestner



Text from The Bee April 30th, 2008

Construction and installation of green roofing systems

Photo from Greenforall.org



From www.presentationcenter.org

Construction and installation of solar roofing systems

- *Traditional installation of rack and panel systems attaching the racking and mounting the panels*

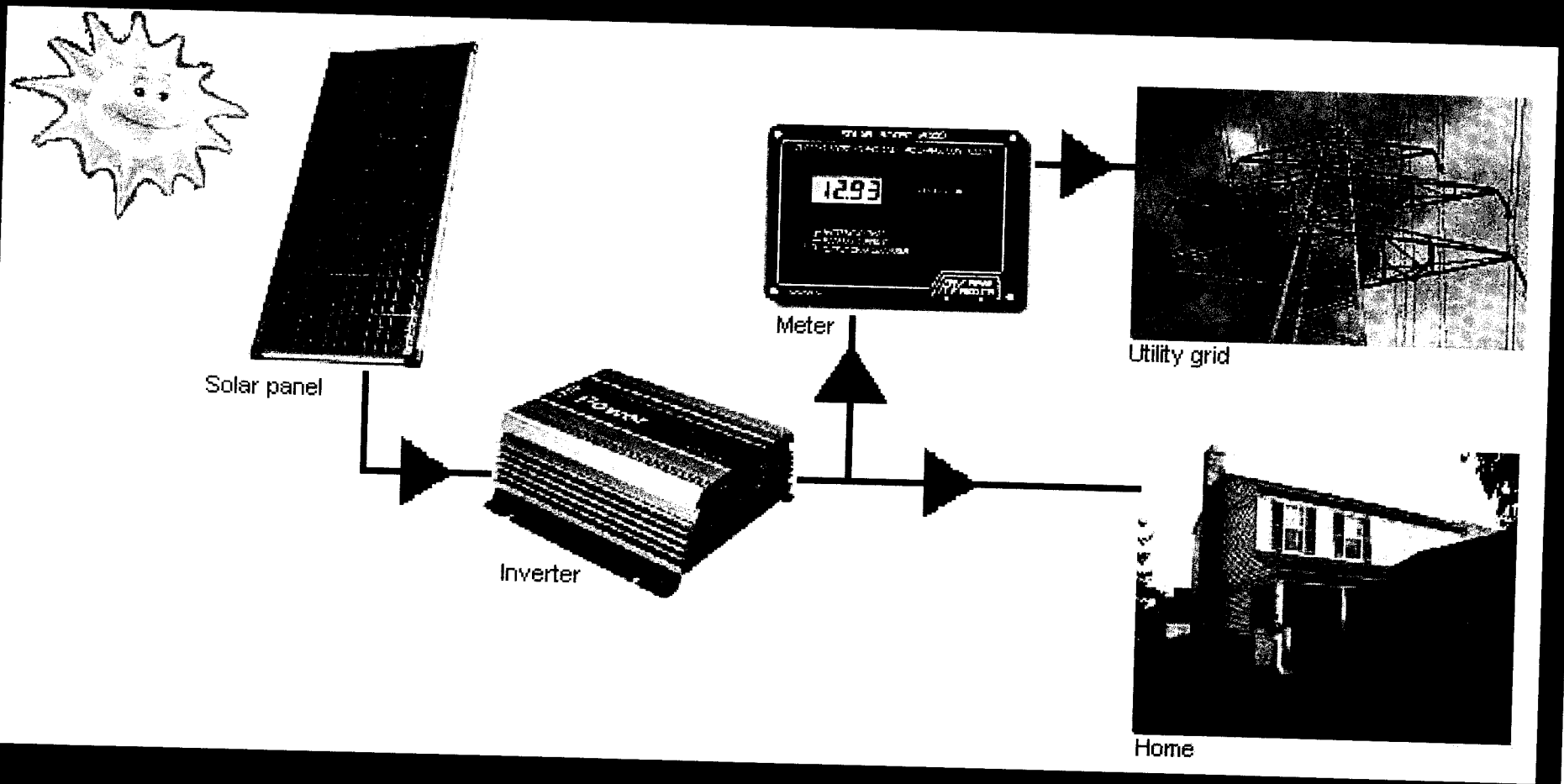
Photo from Solar Richmond

Solar Panel Installation

- Mounting racks to roof surface
- Locating panels on roof
- Mounting
- Wiring
- Control panels

Photo from silverbacksolar.com

Grid-Tied Solar System



From easy-solar-power.com

Stand Alone Solar System

Block Diagram of PV System

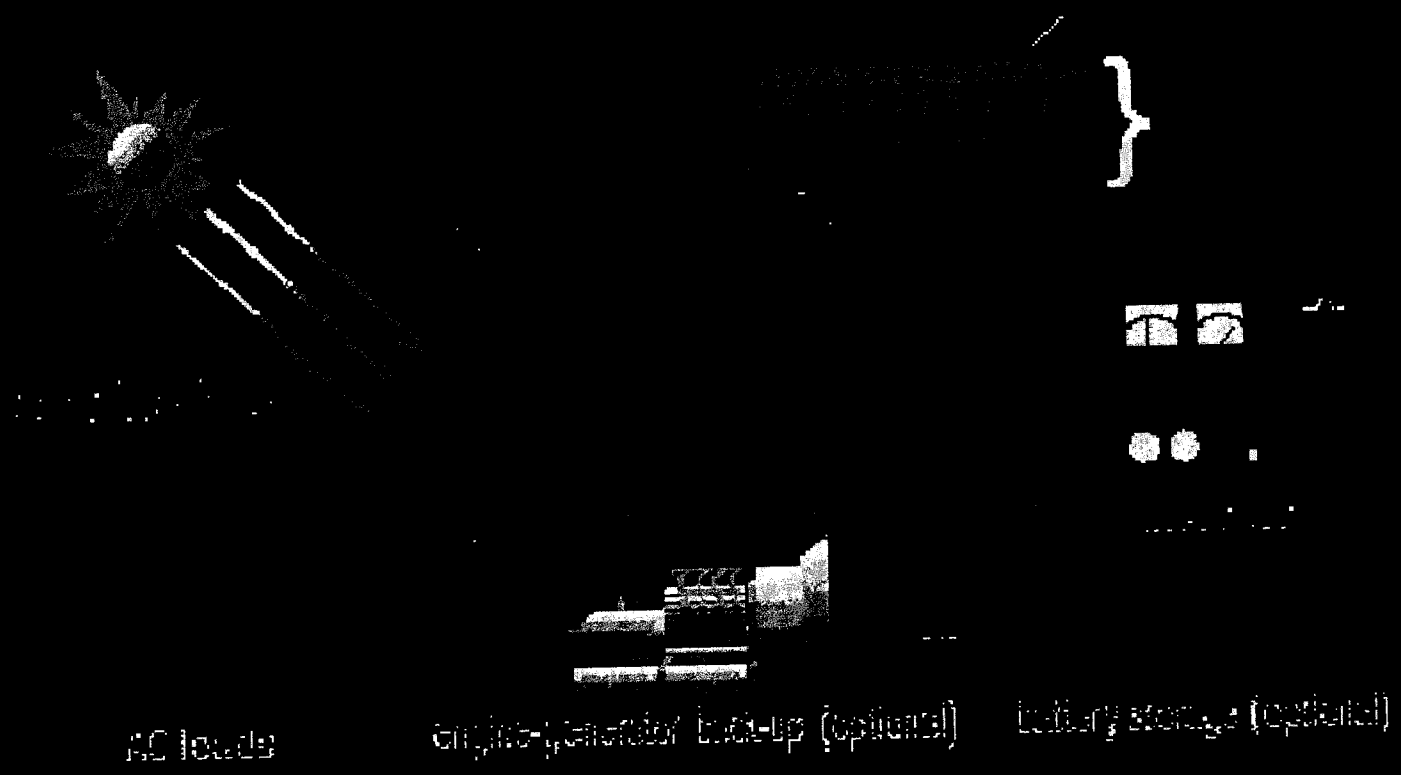


Diagram from cogeneration.net

Pole mount systems

- Systems for locations where roof orientation is oriented poorly, shaded or inaccessible

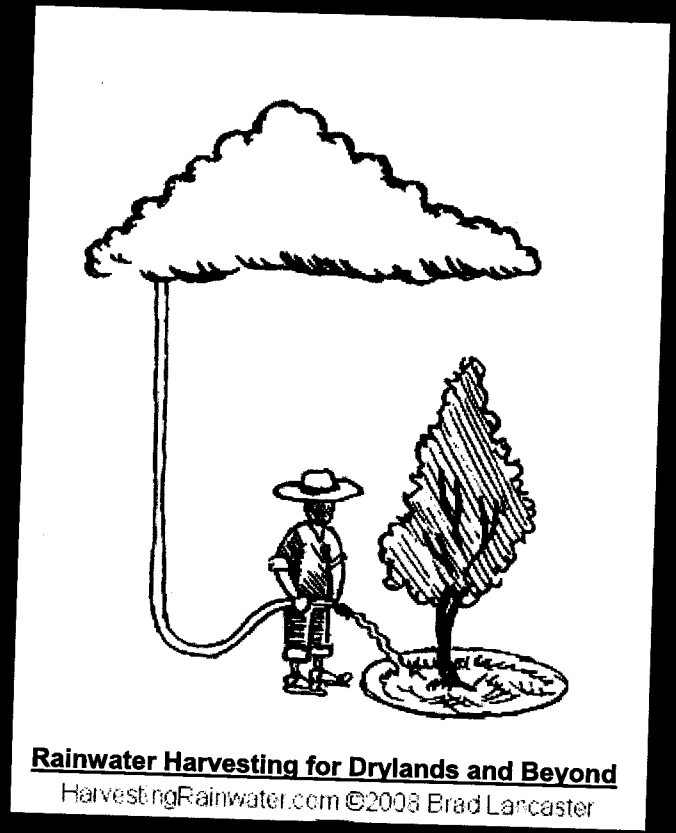
Photo from KEETSA

Solar integrated roofing installation

- There are many different styles of integrated solar roofing
- Each system is unique and must be designed to fit in with planned roofing (new construction and roofing remodels)
- Designed to simplify wiring

Photo from sweetsolarhome.com

Stormwater Management



Introduction to Green Jobs in Stormwater Management

What is Stormwater?

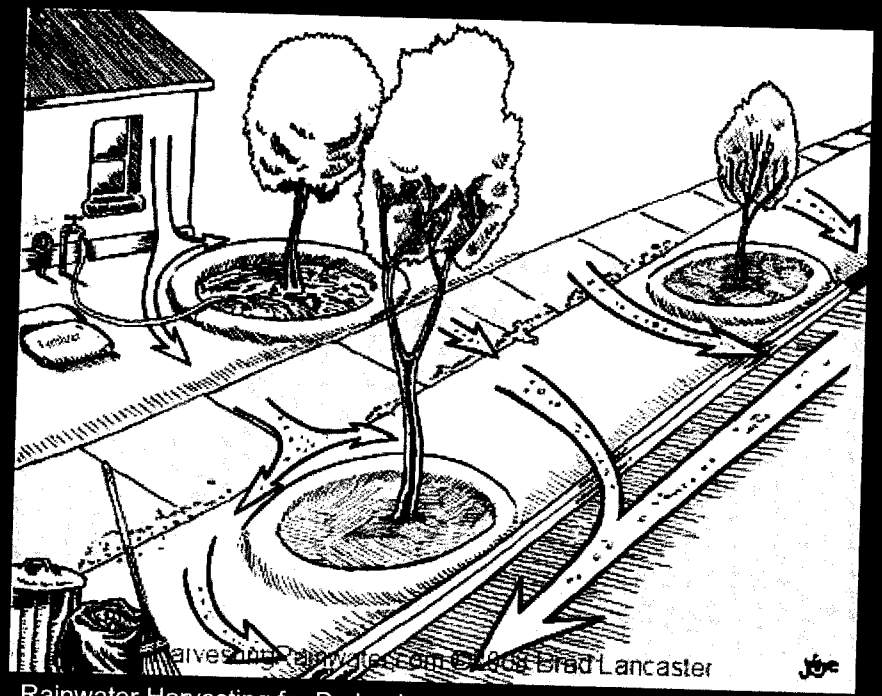
- Rainwater that flows across an impervious surface on its way to a natural body of water

What is Stormwater Management?

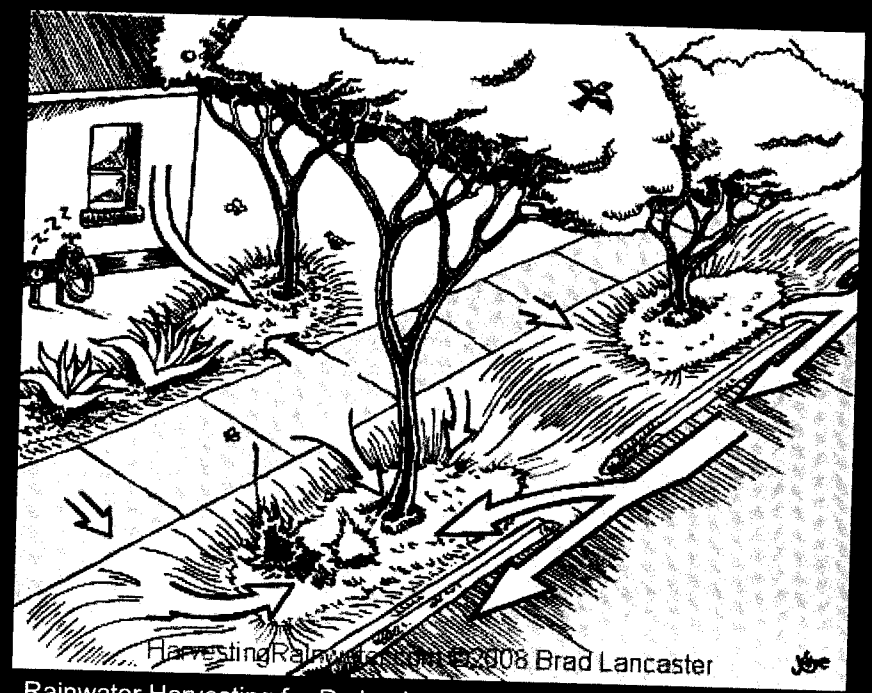
- The management of stormwater runoff that provides water retention facilities that control the release for stormwater to flow into receiving streams.

Defined in www.water-technology.net in glossary

Why manage stormwater?



Rainwater Harvesting for Drylands and Beyond



Rainwater Harvesting for Drylands and Beyond

When buildings, roads, parking areas and lawns dominate the landscape, rainfall becomes stormwater runoff.

Why Stormwater Management continued...

- Much less water is able to be infiltrated by plants and soil,
- Less water evaporates back to the atmosphere
- Instead, more water (about 20-30 percent in a suburban neighborhood) becomes surface runoff or stormwater runoff.

(Puget Sound Partnership http://www.psp.wa.gov/stormwater.php

Why Stormwater Management continued...

The excess volume of water and increased flow rate can cause the following problems:

- Flooding hazard potential
- Stream erosion, which destroys certain fish habitat
- Combined Sewer Overflows

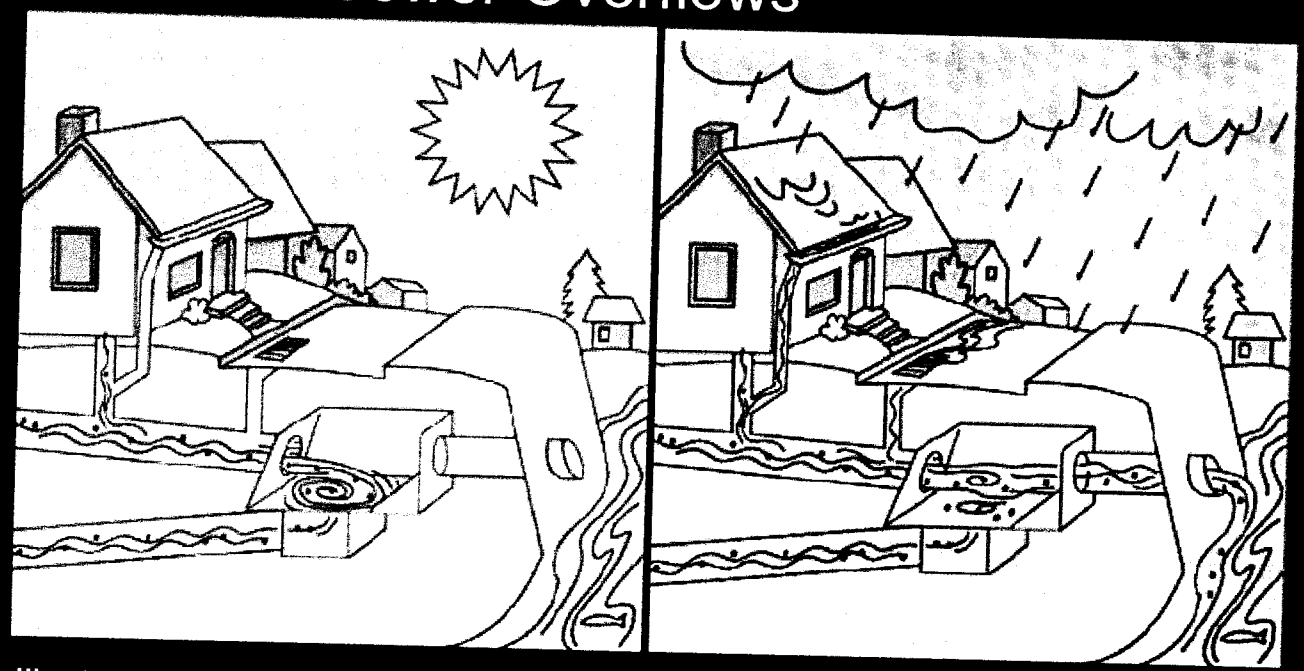


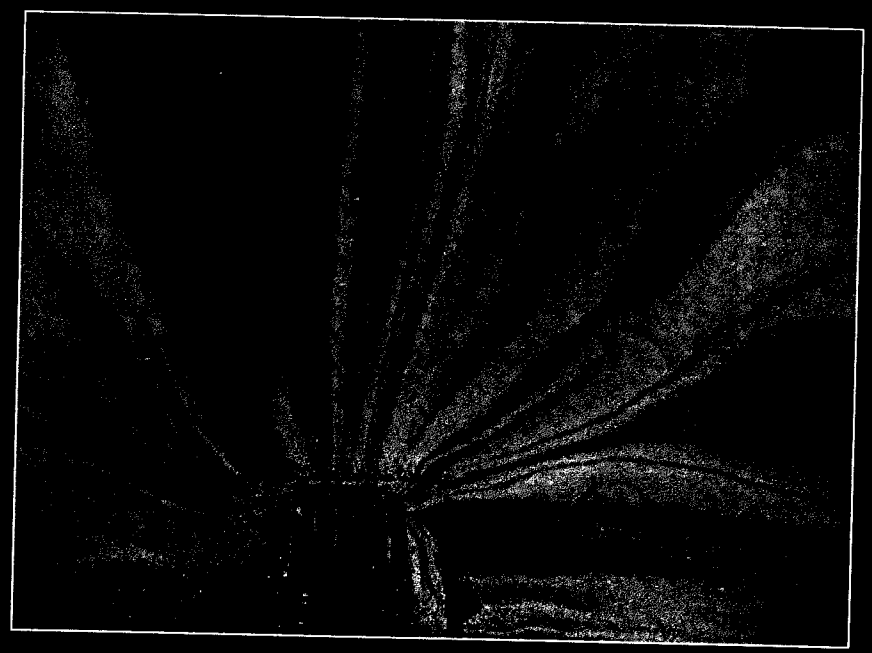
Illustration by City of Portland

Combined Sewer Overflows in Portland, OR

- Stormwater from downspouts and from storm drains combine with sewage in underground pipes, which normally flow to a wastewater treatment facility.
- During most rain events in Portland, the pipes to the treatment facility exceed capacity, and trigger a built in automatic overflow recovery system that transfers the excess polluted mixture of stormwater and sewage directly into the Willamette River
- About half of Portland neighborhoods are connected to the Combined Sewer Overflows system. The city has been working to reduce these overflows since 1991

Stormwater Carries Other Pollutants:

- Heavy Metals
- Animal waste
- Petroleum Products
- Sediments from construction sites, roads, highways, parking lots, lawns and other developed lands



Colorado Department of Transportation

(Puget Sound Partnership http://www.psp.wa.gov/stormwater.php

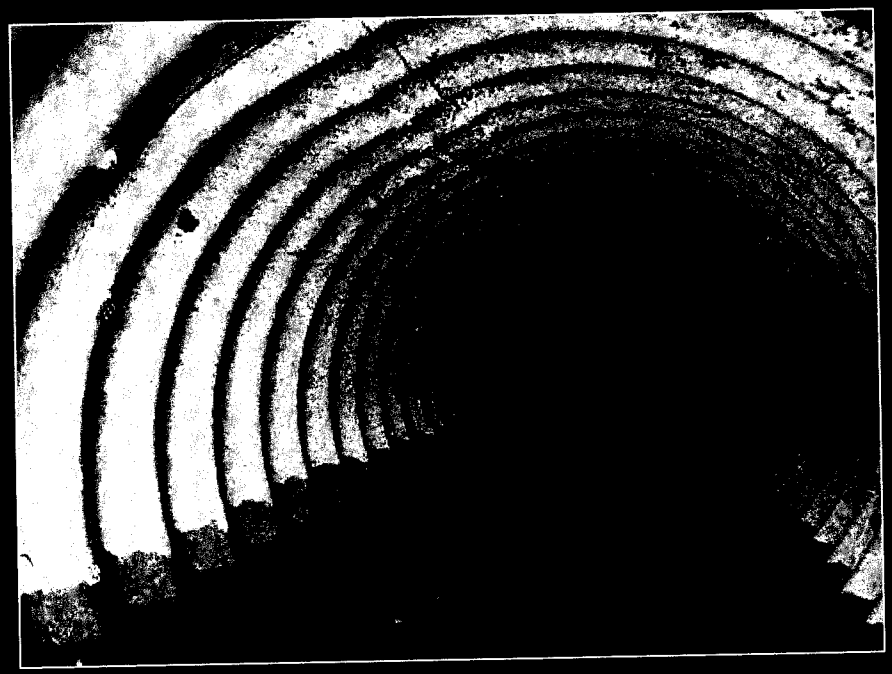
Effects of Stormwater Pollution:

- Water quality degradation requiring filtration and restoration.
- Loss of habitat in riparian areas
- Economic losses from damage to marine species such as fish and shellfish

Puget Sound Partnership http://www.psp.wa.gov/stormwater.php

All of these reasons outline why **sustainable stormwater management** is gaining more recognition and opening up more green job opportunities.

Standard Practices



What has been the common stormwater management practice BEFORE sustainable stormwater became an accepted practice in stormwater construction?

The Standard Solution to Stormwater was Get rid of it QUICKLY, and OUT OF SITE.

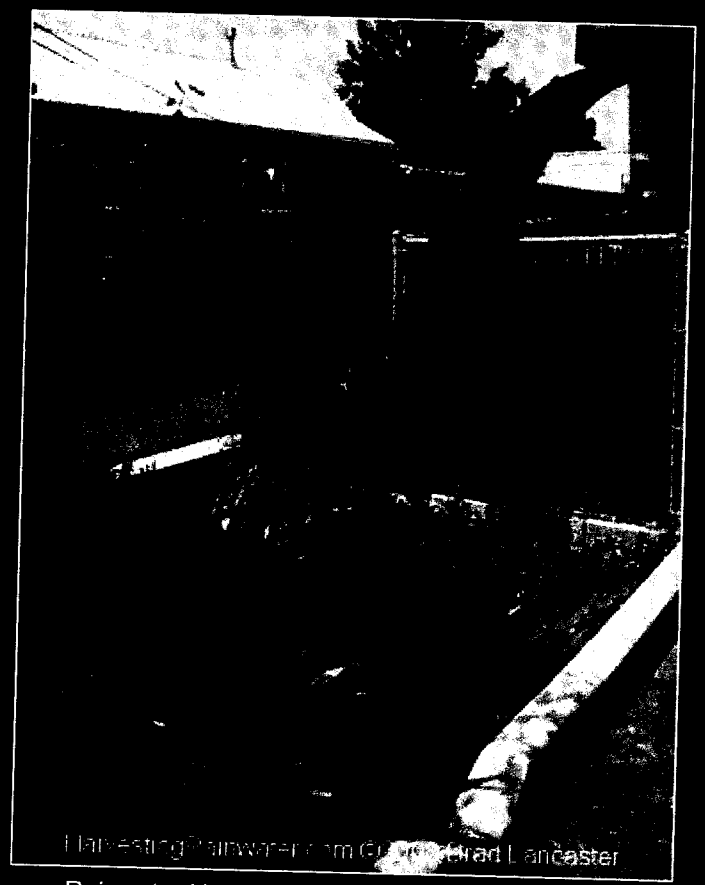
- Street, parking lot, or sidewalk grading that direct stormwater into piping systems underground that flow directly into our waterways
- Rooftop materials such as asphalt shingles and increased Roof pitch that direct stormwater into downspouts and away from buildings
- Gutters and downspouts that guide water into concrete inlets that lead directly to the stormwater pipe drainage systems mentioned above.
- Combined Sewer and Stormwater drains that mix and pipe into the river after large rain events

Innovative Practices

Rainwater Harvesting for Drylands and Beyond

Downspout Disconnection

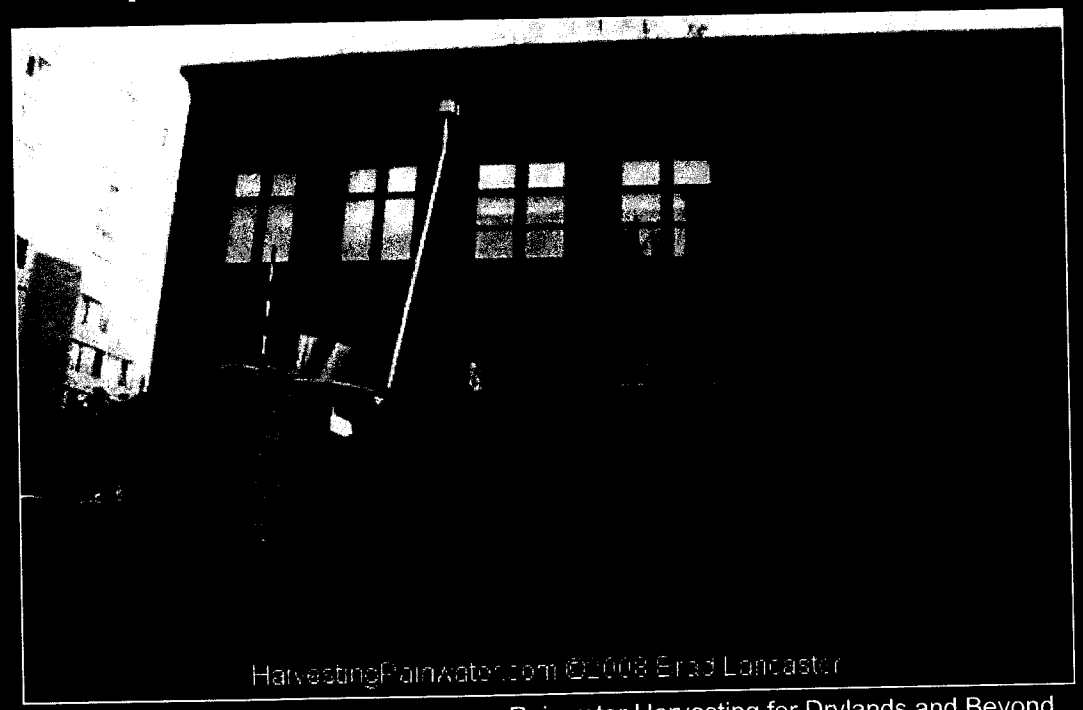
- Redirecting roof runoff from the sewer system by directing water from downspouts onto the surrounding landscape.
- Related Job type: Sheet metal worker, Pipefitter, Landscaper, City of Portland Downspout Disconnection Program



Rainwater Harvesting for Drylands and Beyond

Rain Barrels

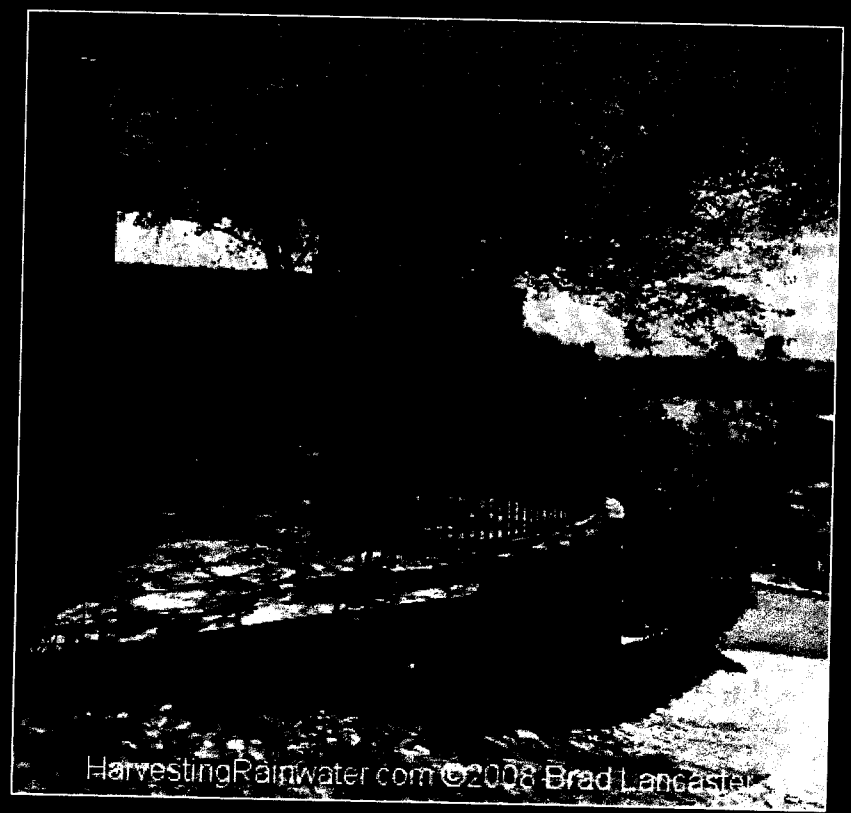
- Using rain barrels to collect roof runoff for re-use in Seattle.
- Related Job Type: Plumber, Pipe fitter, Landscaper



Rainwater Harvesting for Drylands and Beyond

Cisterns

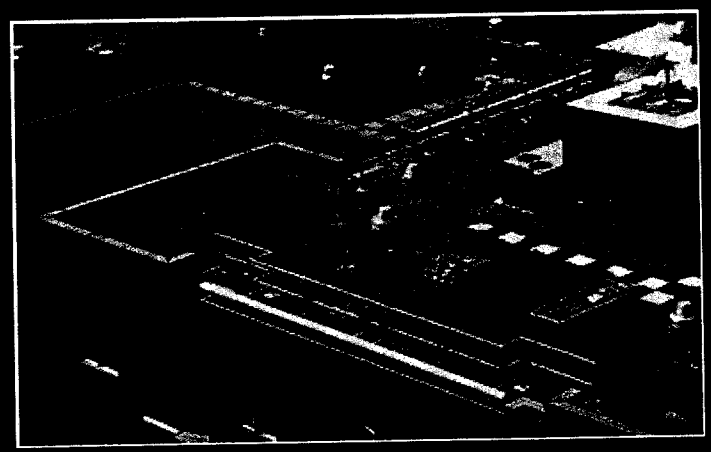
- Larger storage for stormwater runoff for reuse.
- Related Job Type: Plumber, Pipe fitter, Landscaper
- This image shows a innovative example of a dual-purpose rock-walled cistern and patio structure



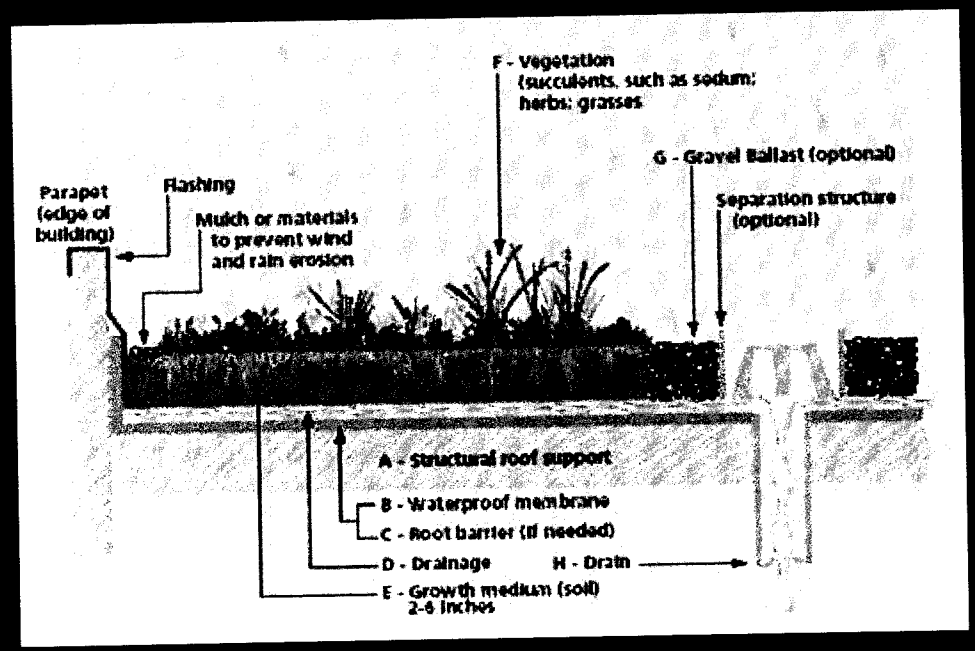
Rainwater Harvesting for Drylands and Beyond

EcoRoofs

- Managing stormwater with lightweight vegetated roof systems.
- Related Job Type: Carpenter, Landscaper, Framing Construction, Roofing Contractor

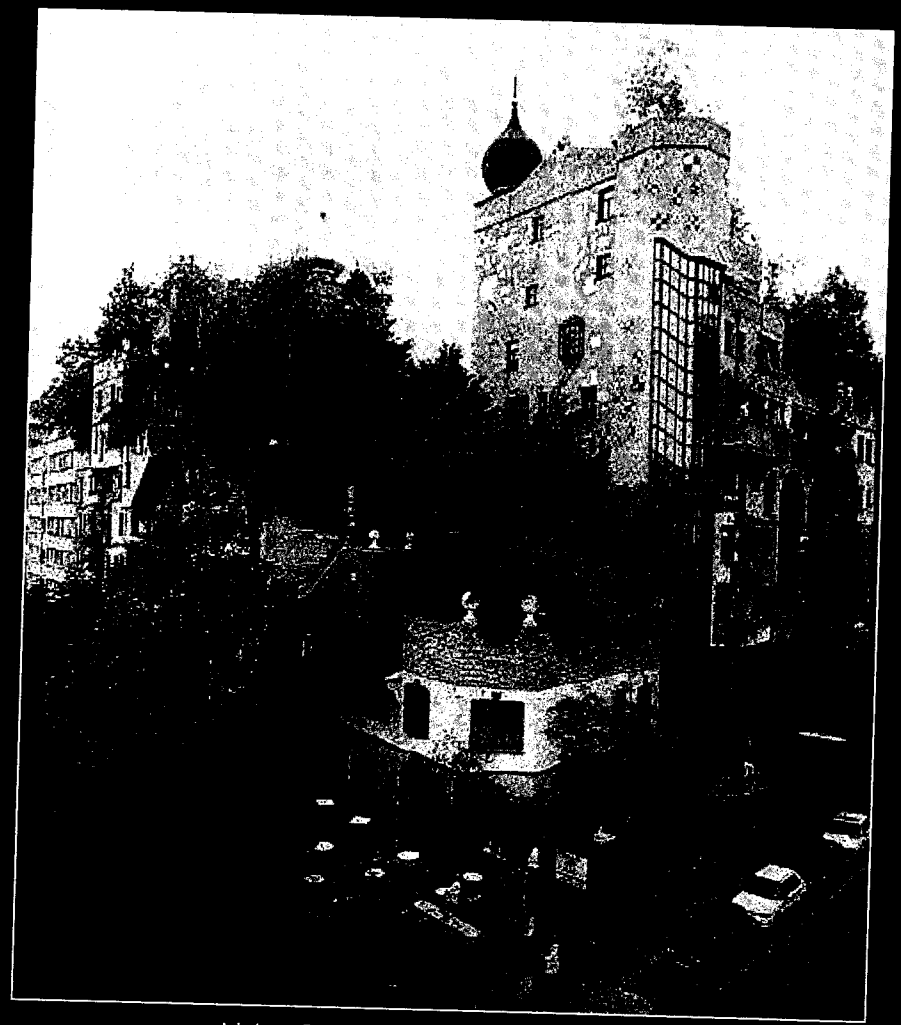


Photos from the University of Oregon and luxury property blog



Roof Gardens

- Heavyweight roof systems that manage stormwater.
- Related Job Type: Carpenter, Landscaper, Framing Construction, Roofing Contractor



Living On The Edge - Balcony Rooftop Designers Guild
http://permaculture.org.au/2006/03/13/living-on-the-edge-the-balcony-garden-designers-guild/

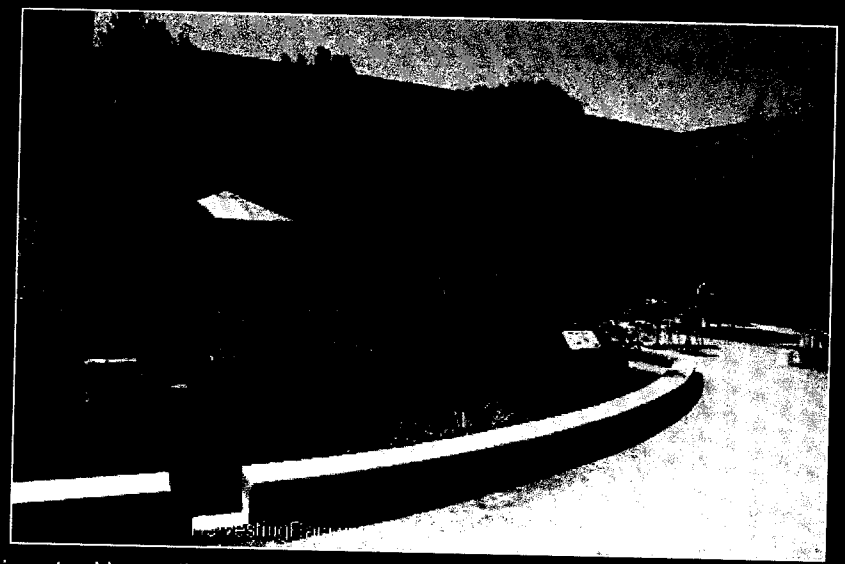
Trees

- Increase vegetation and places to slow runoff through soil infiltration.
- Related Job Type: Landscaper

Rainwater Harvesting for Drylands and Beyond, HarvestingRainwater.com

Contained Planters

- Increase vegetation and places to slow runoff through soil infiltration.
- Related Job Type: Landscaper, Concrete Worker



Rainwater Harvesting for Drylands and Beyond, HarvestingRainwater.com

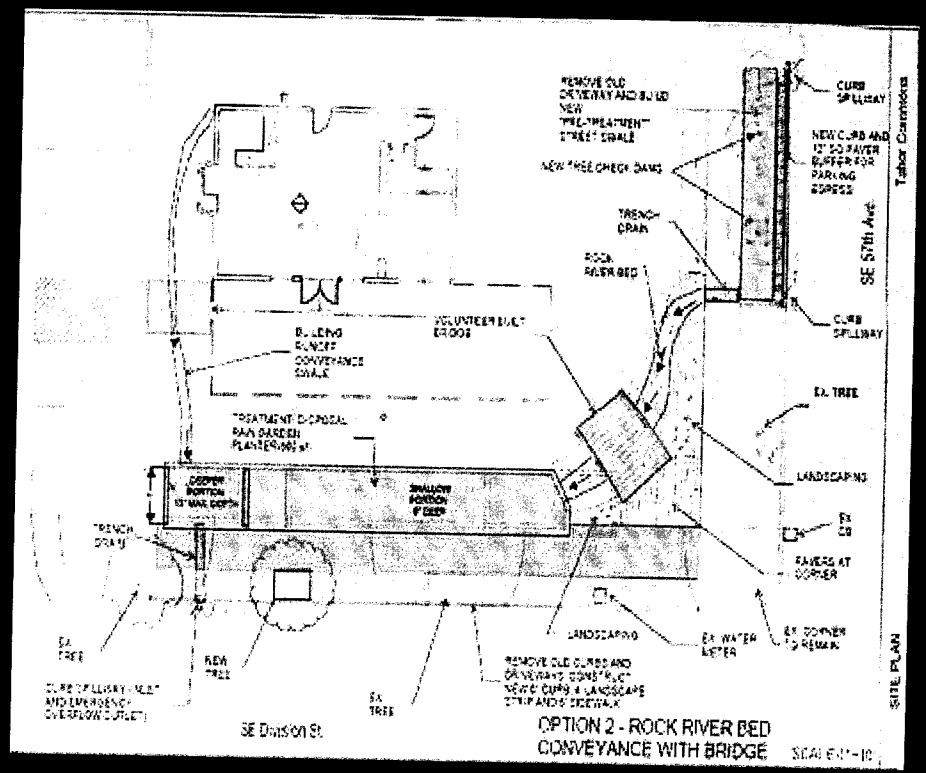
Vegetated Swales

Rainwater Harvesting for Drylands and Beyond,

- Gently sloping, vegetated depressions that collect and treat stormwater runoff.
- Related Job Type: Landscaper, Surveyor

Tabor Commons innovative stormwater management

- This is the layout design of the water garden that will be funded by Portland Bureau of Environmental Services. It will take runoff water from 57th street and redirect it to an onsite water garden retention facility. New curbs and bump outs will be constructed as part of the project.



Curb Extensions

- Manage stormwater runoff from streets, slow traffic, improve pedestrian safety, and bring a natural element to the hardscape.
- Related Job Type: Landscaper, Surveyor, Laborer, Road Construction

Rainwater Harvesting for Drylands and Beyond.

Pervious Pavers

Rainwater Harvesting for Drylands and Beyond.

- Pervious pavers allow stormwater to soak into the ground and reduce runoff.
- Related Job Type: Landscaper, Concrete worker, Road Construction, Surveyor

Soakage Trenches

- Shallow lined trenches treat stormwater runoff from hard surfaces.
- Related Job Type: Landscaper, Road Construction

Rainwater Harvesting for Drylands and Beyond.

Other Innovative Stormwater Practices:

- Infiltration Planters Small planting containers work well in space limited sites with good drainage.

  Related Job Type: Landscaper
- Pervious Pavement resembles conventional paving material but allows stormwater to infiltrate.

  Related Job Type: Landscaper, Concrete worker, Road Construction, Surveyor
- Turf Block allows rain to infiltrate parking areas, driveways and walkways.

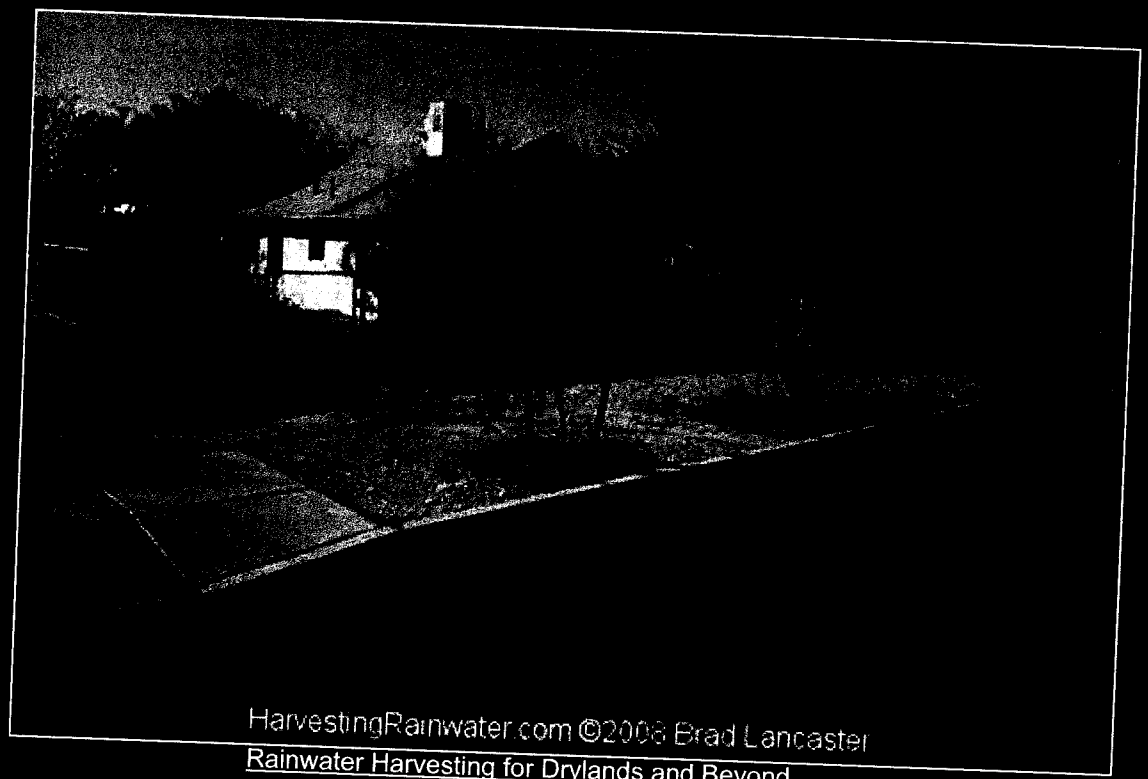
  Related Job Type: Landscaper, Concrete worker, Road Construction, Surveyor
- Drywells Underground perforated pipes collect stormwater and allow it to soak into the ground.

  Related Job Type: Concrete worker, Road Construction, Surveyor

Constructing Stormwater Projects

- Example is the ROW Project in Tucson, Arizona
- Converting a sidewalk median into a stormwater catchment garden
- Neighborhood-Driven Project
- Photos Provided by Brad Lancaster

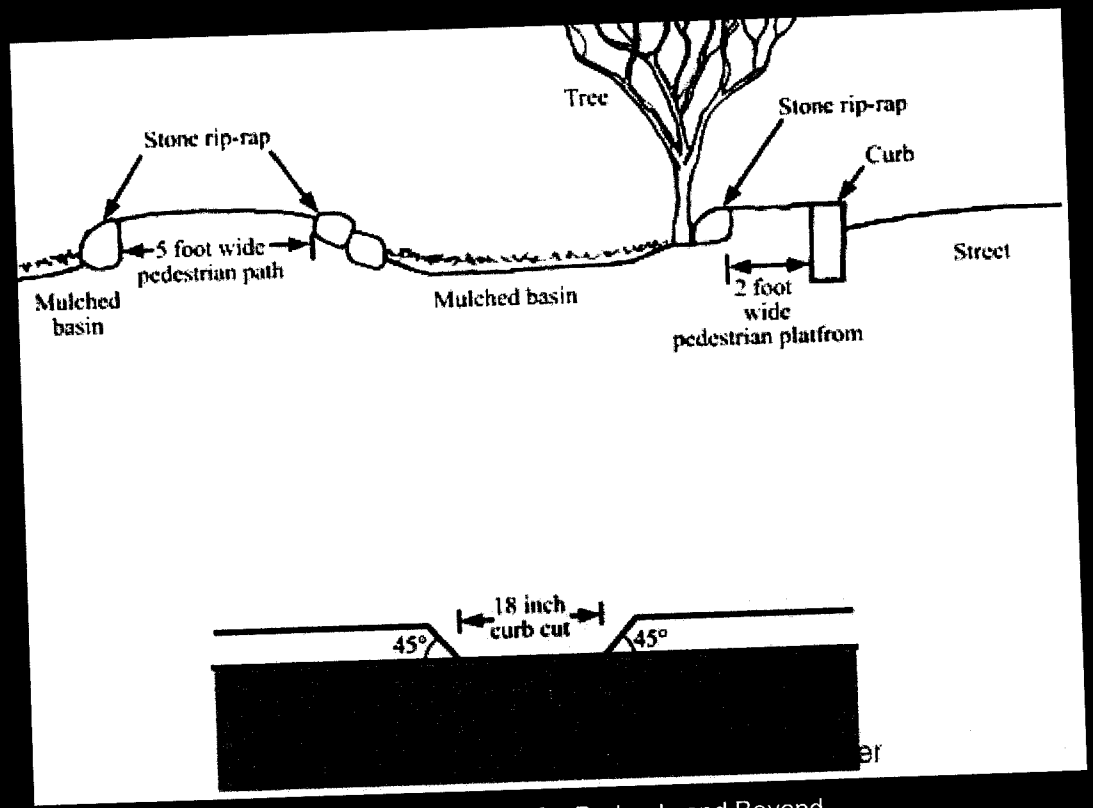
The ROW Project – The Site



Rainwater Harvesting for Drylands and Beyond,

- The median between sidewalk and roadway

The Plan



Rainwater Harvesting for Drylands and Beyond.

- Create basins for rainwater collection and a curb cut to direct road stormwater runoff into the basins from the street surface

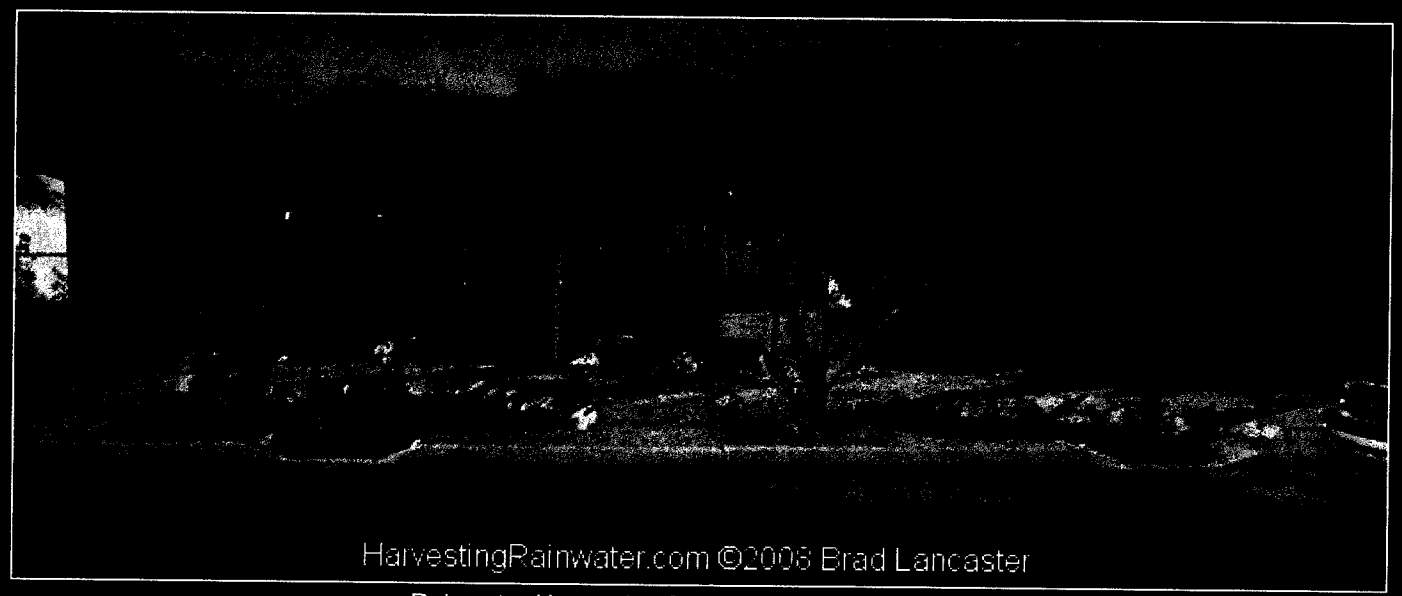
Construction:

Rainwater Harvesting for Drylands and Beyond.

Curb Cutting:

Rainwater Harvesting for Drylands and Beyond,

The End Result



Rainwater Harvesting for Drylands and Beyond,

- Curbs Cut and Basins mulched

Businesses in Stormwater Construction

- City of Portland Stormwater Professionals In Stormwater List
- City of Portland EcoRoof Contact List
- Women On Water: Career Networking Group In Portland. Monthly gathering and Job Listserv: womenonwater@lists.onenw.org

ACHIEVING AIRTIGHT DUCTS IN MANUFACTURED HOUSING

Janet McIlvaine
Research
Analyst

David Beal
Project
Engineer

Neil Moyer
Principal
Research Engineer

Dave Chasar
Senior
Research Engineer

Subrato Chandra
Program
Director

Florida Solar Energy Center
Cocoa, Florida

ABSTRACT

This Florida Solar Energy Center (FSEC) study, conducted under the auspices of the U.S. Department of Energy's Building America Industrialized Housing Partnership (BAIHP), compares mastic sealed duct systems to tape sealed systems by showing measured *total* duct leakage ($CFM25_{TOTAL}$ and Qn_{TOTAL}) and/or measured leakage *to the outside* ($CFM25_{OUT}$ and Qn_{OUT}) in 190 manufactured home floors or home sections.

All manufacturers were considering or actively working toward achieving duct leakage below 3% of the conditioned floor area (Qn_{OUT}=0.03), consistent with Energy Star Manufactured Homes criteria.

Previous field tests suggest that $CFM25_{OUT}$ accounts for about half of $CFM25_{TOTAL}$.

These data show that achieving $CFM25_{TOTAL}$=6% during production was generally correlated with achieving $CFM25_{OUT}$=3% in mastic sealed systems, but less reliably with taped systems. Cost for achieving duct tightness goals range from $4 to $8 including duct testing on the assembly line

INTRODUCTION TO BAIHP

Over the past 10 years, researchers at the Florida Solar Energy Center (FSEC) have worked with the Manufactured Housing industry under the auspices of the U.S. Department of Energy (DOE) funded Energy Efficient Industrialized Housing Program and the Building America (BA) Program (www.buildingamerica.gov). FSEC serves as the prime contractor for DOE's fifth Building America Team: the Building America Industrialized Housing Partnership (BAIHP) (www.baihp.org).

This Building America research builds on the work of FSEC's Buildings Research Division, which has conducted energy efficiency research, produced technical guidelines, and provided training for the various sectors of the construction industry for the past 25 years (http://www.fsec.ucf.edu/bldg/).

FACTORY VISITS

Data and findings presented here were gathered during 39 factory visits to 24 factories of six HUD Code home manufacturers interested in improving the energy efficiency of their homes. Researchers conducted tests on 101 houses representing 190 floors[1].

During initial factory visits, BAIHP researchers typically meet with factory managers for an introduction to Building America and the systems engineering approach to building better houses. Factory managers explain their objectives (eg achieve Energy Star), challenges they are facing (call backs, reoccurring moisture problems, etc), and conduct a factory tour for BAIHP researchers. During the tour, researchers observe assembly techniques and identify areas of potential improvement.

Researchers test completed duct systems in the factory and in finished houses, if available, to assess initial duct tightness. This creates a benchmark for gauging progress.

After the factory visit, BAIHP researchers provide a Trip Report detailing the findings of the visit, including test results, and recommendations for improvements.

After manufacturers have implemented BAIHP recommendations, researchers may return to the factory for reassessment. Depending on the success of implementation, additional recommendations and reassessment are sometimes needed.

---

[1] Unless specifically called out as a "floor assembly" or "floor system", the term "floor" in this document refers to a single wide manufactured home or one section of a multi-section manufactured home. Floors are typically 12-14' wide and up to 60' long.

CHARACTERISTICS OF DATA SET

During factory visits and fieldwork with new manufactured homes between 1996 and 2003, researchers tested 132 floors with mastic sealed duct systems and 58 floors with taped duct systems (Table 1). Depending on the stage of production and the objective of the testing, researchers measured total leakage only, leakage to the outside only, or both.

Table 1 Characteristics of Data Set

	Taped	Mastic	Total
Factories Visited			24
Total Visits			39
Manufacturers			6
Total Floors	58	132	190
Number of Tests			
$CFM25_{TOTAL}$ Tests	56	124	180
$CFM25_{OUT}$ Tests	30	86	116
Type of Test Conducted			
$CFM25_{TOTAL}$ Only	30	44	74
$CFM25_{OUT}$ Only	4	6	10
Both $_{TOTAL}$ and $_{OUT}$	26	80	106

DUCT TIGHTNESS GOAL

Standard testing procedure calls for measuring the air flow rate through a calibrated fan used to eliminate the pressure difference between the duct system and the house while the house is held at either natural conditions ($CFM25_{TOTAL}$) or in a steady state at -25pascals (pa)[2] with respect to the outside ($CFM25_{OUT}$) (Energy Conservatory, '93 and '96.)

The ratio of $CFM25_{OUT}$ to conditioned area can be expressed as *normalized duct leakage,* Qn. (Florida Department of Community Affairs, '98.) Qn is useful for comparing the relative tightness of duct systems in houses of dissimilar area.

$Qn_{OUT} = CFM25_{OUT}$ / conditioned area

BAIHP recommendations recommends reducing normalized duct leakage to the outside, Qn_{OUT}, to a number less than or equal to 3%.

Qn_{OUT},target = 3%

[2] Though test protocols can use pressurization to measure duct leakage, all the CFM25out and $CFM25_{TOTAL}$ tests discussed in this paper were conducted using depressurization.

The $CFM25_{OUT}$ test cannot be performed until the house is nearly finished. Researchers and factory staff need to assess duct system tightness during production, when the duct system is still accessible for repair, if needed. However, the $CFM25_{TOTAL}$ test can be conducted after the duct system is completed before it is concealed. Leaks can still be repaired without disturbing any finishes.

Thus, duct tightness goals for manufactured housing are set in terms of total leakage, $CFM25_{TOTAL}$, typically at 6% or less of conditioned floor area (Qn_{TOTAL}).

Qn_{TOTAL}, target = (Conditioned Area) X 0.06

The following equations can be used to determine the $CFM25_{OUT}$ and $CFM25_{TOTAL}$ targets for meeting these goals:

$CFM25_{TOTAL}$,target = (Qn_{TOTAL}, target)(Cond. Area)
$CFM25_{OUT}$,target = (Qn_{OUT}, target)(Cond. Area)

Example:
Let, Qn_{TOTAL},target = 6%
Qn_{OUT},target = 3%
Cond. Area = 900

$CFM25_{TOTAL}$,target = (Qn_{TOTAL}, target)(Cond. Area)
= (6%)(900)
= **54**

$CFM25_{OUT}$,target = (Qn_{OUT}, target)(Cond. Area)
= (3%)(900)
= **27**

The duct leakage targets for a 900 ft^2 floor are $CFM25_{TOTAL}$ = 54 and $CFM25_{OUT}$ = 27.

Rationale for Duct Tightness Goal

A compilation of findings from field studies around the country shows average savings from airtight duct construction in new and existing homes to be 15% cooling energy savings and 20% heating energy savings (Compilation of findings in Cummings, et al, '91 and '93, Davis '91, Evans, et al, '96, and Manclark, et al '96.) Field repairs in these studies were usually made using UL181 listed tape and/or mesh and mastic.

These savings are achieved at relatively low first cost (see Economics of Duct Tightening for Manufactured Housing below) compared to other energy improvements such as equipment efficiency and window upgrades. However, changes or refinements in the production process are often required.

Duct Tightness Goal Achievability

Among the earliest BAIHP data, four houses built by the same manufacturer in 1997 exemplify the achievability of duct tightness in the manufactured housing setting. Two were standard homes used as control homes for comparison to an "energy improved" model and a "health improved" model (Chandra, et. al., '98.) Standard manufacturing methods were changed to mastic and the 3% Qn_{OUT} leakage target was easily met (Table 2).

Table 2 Demonstration of Duct Tightness Achievability: Standard Production compared to 2 Improved Models 1997

	Area (ft^2)	$CFM25_{TOTAL}$	$CFM25_{OUT}$	Qn_{TOTAL}	Qn_{OUT}
Control Home	1600	118	84	7%	5%
Control Home	1280	126	89	10%	7%
Energy Home	1494	51	25	3%	2%
Healthy Home	1920	79	36	4%	2%

CHALLENGES TO ACHIEVING DUCT TIGHTNESS GOAL

The challenges most often encountered mirror those identified by BAIHP staff during fieldwork with moisture and uncontrolled airflow damaged manufactured homes (Moyer, et al, '01).

- Leaky supply and return plenums
- Misalignment of components, for example, floor boots not reaching or not being lined up with trunk ducts (in-line floor ducts)
- Free-hand hole cutting in duct board and sheet metal without templates, often with fabricated tools or utility knives
- Insufficient connection area at joints
- Mastic applied to dirty (sawdust) surfaces
- Insufficient mastic coverage
- Mastic applied to some joints and not others
- Loose strapping on flex duct connections
- Incomplete tabbing of fittings
- Poor tape application

RECOMMENDATIONS FOR ACHIEVING DUCT TIGHTNESS GOAL

- Apply tapes per manufacturer recommendations for surface prep, temperature, and application pressure applied with a squeegee.
- Seal joints with mastic and, when needed, fiberglass mesh
- Accurately located and cut holes for duct connections
- Fully bend all tabs on collar and boot connections
- Trim and tighten zip ties on flex duct connections to sheet metal collar with a strapping tool
- Institute quality control measures, such as pressure testing ducts during production, in addition to visual inspection.
- Provide return air pathways from bedrooms to main living areas.

IMPROVING DUCT TIGHTNESS

Researchers found variation among manufacturers related to duct system materials, layout, fabrication, assembly, sealing, equipment type, quality control and air handler position. The primary variable analyzed here is the duct sealing method.

Duct Materials

Manufactures typically install ducts made of sheet metal, duct board, and flex duct.

Duct board components, which are generally assembled in the factory, include supply ducts, return plenums, ceiling boots, distribution boxes, etc.

Flex ducts are used in conjunction with prefab sheet metal collars to connect duct board components. Flex ducts are secured to collars with plastic zip ties. Collars are secured to duct board with built in tabs that fold out around the edge of the duct board.

Sheet metal components, such as supply boots, are generally pre-fabricated by suppliers in standard sizes. Sheet metal trunk ducts are fabricated in the factory. Table 3 summarizes the duct materials represented in the data set.

Table 3 Duct Materials in Data Set

	Tape Sealed	Mastic Sealed
Undocumented	5	0
Sheet Metal (some with Flex Components)	24	22
Duct Board (some with Flex Components)	29	110
Total Systems Tested	58	132

Recommended Duct Sealant

Regardless of duct material, BAIHP recommends sealing with mastic, an elastomeric material specifically made for permanently sealing the fabricated joints and seams in heating, cooling, and ventilating ducts and duct insulation. This is consistent with other building scientists. (Lstiburek, '93. Cummings, et al, '93. Andrews, '01. MHRA, '03.) The elastomeric properties of mastic (RCD, '03.) allow it to expand and contract as the dimensions of the duct system change slightly during each cycle of heating or cooling.

The longevity of mastic yields a performance advantage over tape, the traditional material used for duct sealing. Whereas taped systems may perform well initially, they may become leakier over time if the adhesive fails due to material movement at the joints surface and/or temperature differences and changes. Mastic, on the other hand, tolerates the temperatures differences between inside and outside duct surfaces as well as the frequent temperature changes over the life of the system.

Quality Control: Tangible Success

An objective quality control strategy is essential to achieving tight duct construction. If air were visible to the naked eye, a visual inspection would reveal leakage sites in any given duct system. In the absence of visible air, managers and line workers will need to learn a way to evaluate their duct construction quantitatively using pressure-testing equipment common to building science.

Initially, a standardized duct test on the factory floor provides an objective evaluation of current practice, repairs, and process improvements. Ultimately, pressure testing all duct systems replaces subjective evaluation with a tangible, objective measure of success: total duct leakage, $CFM25_{TOTAL}$ or a ratio of duct leakage to conditioned area, Qn_{TOTAL}. These surrogate measurements are shown by this data and other field studies (Cummings, et al, '02. MHRA, '02) to substantially correlate with duct leakage to the outside of completed houses, the factory's ultimate quality goal.

Manufacturers often cite the support of BAIHP as objective, third party experts as a major benefit. Some manufacturers have already adopted the test procedure into their production process to conduct their own in-house verification of duct system tightness. This leads to a higher quality product as well as accountability of both the factory and field work force.

Examination of a Single Factory's Progress

BAIHP found duct tightness improvement to be an incremental process. For example, in one factory, the duct leakage measured during the first visit was Qn_{TOTAL}=10% in the floor mounted systems and 5% in the ceiling mounted systems (Table 4). BAIHP made recommendations for improving the floor systems and the factory managers set out to achieve the Qn_{TOTAL} = 6% goal, in preparation for building homes under the Energy Star Manufactured Homes Program.

Problems with the floor systems included misalignment of the trunk duct with the floor risers/boots cutouts; free hand hole cutting; insufficient mastic application to seal the floor boots, crossover collars, and furnace plenum; and loose straps.

Researchers recommended: circle cutting and strap tightening tools (for flex duct zip ties), improving placement of trunk ducts under riser holes precut in the sub-floor, using templates for cutting holes in the trunk duct to improve dimensional matching with the risers, and increasing the size of the bead of mastic applied to joints.

During the second factory visit, researchers found that alignment had improved. Other issues were still unresolved: holes were still being cut free hand, leading to a host of assembly difficulties, workers were confused about where to seal the furnace plenum, not all joints were being sealed, and some were not sealed completely.

Researchers tested two randomly selected sections with floor systems (Table 4) which did not meet the Qn_{TOTAL} = 6% goal. A trip report

reemphasized the recommendations that had not been implemented.

The third visit to the factory found substantial improvement to the assembly of the floor duct system. Three randomly selected houses were tested: All three met the Qn_{TOTAL} = 6% goal (Table 4). This factory's experience echoes that of other factories that BAIHP has worked with.

Table 4 Test Results of 3 Visits to Same Factory

Visit #	Duct Location	Floors Tested	Qn_{TOTAL} (Goal=6%)
1	Flr/Belly	1	10%
1	Ceiling	1	5% •
2	Flr/Belly	1	7%
2	Flr/Belly	1	6.3%
3	Flr/Belly	2	5.4% •
3	Flr/Belly	2	4% •
3	Flr/Belly	2	3.8% •

MEASURED DUCT TIGHTNESS IMPROVEMENTS FROM IN-FACTORY REPAIRS

Of the 190 floors in this data set, 9 test results show improvements from repairs made to initially leaky systems (Table 5). Maximum improvement was a reduction of Qn_{TOTAL} from 11.7% to 5.5%. The least improved system was tightened from Qn_{TOTAL} of 8.1% to 7.1%. Qn_{TOTAL} was reduced an average of 3.5%, representing a 43% improvement in duct tightness. This is a very persuasive method of training factory personnel when conducted with a freshly produced duct system on the factory floor.

Table 5 Duct Repair Test Results

House ID#	Initial Duct Joint Sealant	Before Repair Qn_{TOTAL}	After Repair* Qn_{TOTAL}
AL5R	Tape	11.7%	5.5%
68	Tape	11%	4.9%
84	Tape	8.0%	4.8%
85	Tape	8.1%	7.1%
88	Tape	4.5%	3.3%
14	Mastic	6.4%	2.6%
47	Mastic	6.5%	4.4%
51A	Mastic	8.0%	2.6%
52A	Mastic	6.0%	3.6%
Average		7.8%	4.3%
Average Reduction to Qn_{TOTAL}			**3.5%**

*All system repairs made with mastic, not tape.

The duct systems in Houses 14, 47, 51A, and 52A were assembled with mastic. However, the production was marred by problems such as inaccurate cutting, inaccessible joints, and misalignment of components. These problems occurred in other mastic sealed systems that failed to make the target Qn_{TOTAL} as described next in Duct Tightness Findings.

DUCT TIGHTNESS FINDINGS

Duct tightness data presented have been gleaned from BAIHP Trip Reports with some supplementary data from the preceding program, the Energy Efficient Industrialized Housing Project.

All duct systems tested were in newly manufactured homes using industry standard methods as delineated in the Minneapolis Blower Door and Duct Blaster User Guides (Energy Conservatory, '93 and '96.) and augmented by the Florida Home Energy Rating requirements where appropriate. (Florida Department of Community Affairs, '93.)

Average, maximum, and minimum duct leakage data are presented in Table 6, which also includes similar data from a study published by the Manufacture Housing Research Alliance for comparison (MHRA, '03.) Figures 1 and 2 show all data points for Qn_{TOTAL} and Qn_{OUT}.

For mastic sealed systems (n=132), average Qn_{TOTAL}=5.1% (n=124) with 85 systems achieving the Qn_{TOTAL} = 6% target (Fig. 4). Average Qn_{OUT}=2.4% (n=86) with 73 systems reaching the Qn_{OUT} = 3% goal (Fig. 5).

For taped systems (n=58), average Qn_{TOTAL}=8.2% (n=56) with 19 systems reaching the Qn_{TOTAL} = 6% target (Fig. 2). Average Qn_{OUT}=5.7% (n=30), more than double the mastic average, with 5 systems reaching the Qn_{OUT} = 3% goal (Fig. 3).

The average Qn_{OUT} found in this data for mastic sealed systems was 2.4%. This correlates with the Manufactured Housing Research Alliance's study, which found an estimated average Qn_{OUT} of 2.5% in 59 floors, tested after duct repairs at 16 factories (MHRA, '03). MHRA did not report the measured total leakage used to estimate leakage to the outside, leakage for taped systems, or leakage for systems before repair.

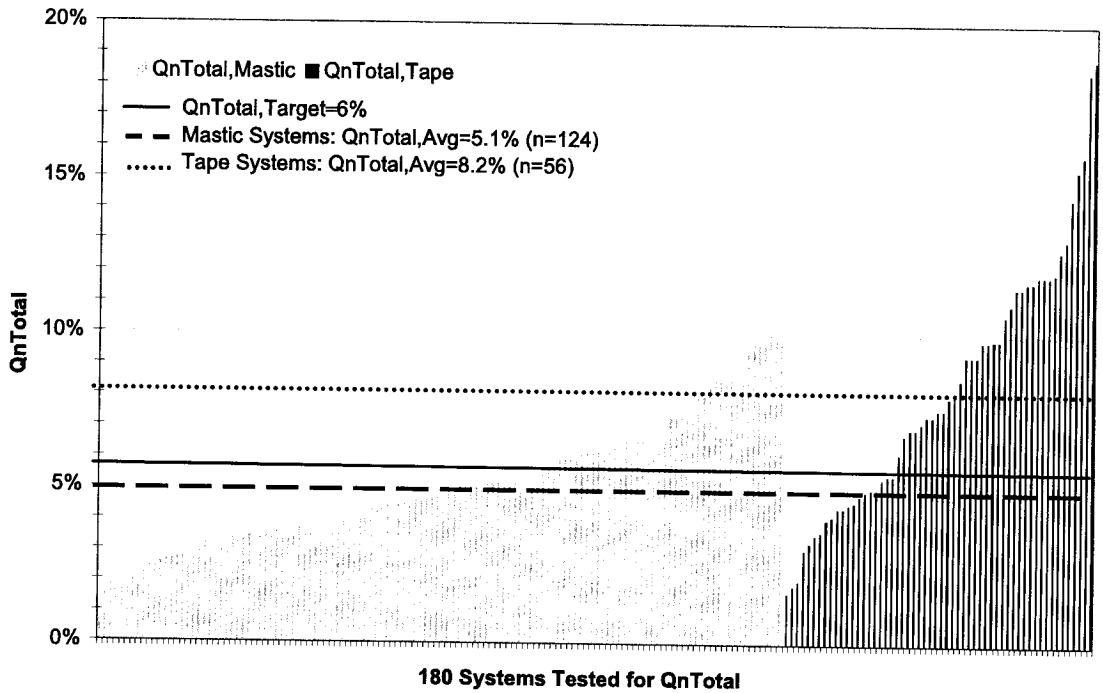


Figure 0 All 180 Qn_{TOTAL} data points. Qn_{TOTAL},Avg for taped systems (dotted line) was 8.2, well above the Qn_{TOTAL}=6% target (solid line) whereas for mastic systems Qn_{TOTAL},Avg=5.1%. Mastic data points exceeding the target are listed in Tables 7and 8.

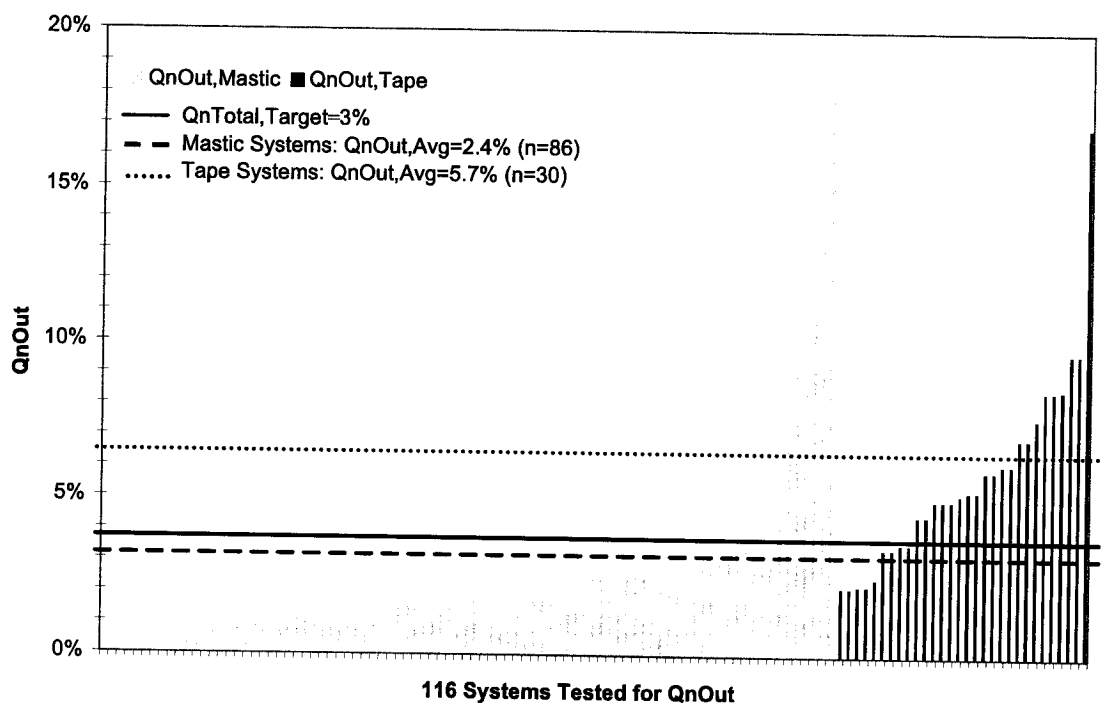


Figure 2 All 116 Qn_{OUT} data points. Five taped systems met the 3% Qn_{OUT} goal (solid line); however the Qn_{OUT},Avg = 5.7%, significantly exceeding the target. For mastic systems, the Qn_{OUT},Avg = 2.4%. Mastic systems exceeding the 3% Qn_{OUT} target are listed in Tables 8 and 9. Twelve mastic systems had $CFM25_{OUT}$ measurements below the threshold of instrument accuracy. (Energy Conservatory, '96.) These are reported as Qn_{OUT} ~ 0% and do not register on this scale (note blank area on the far left portion of the X axis.)

Table 6 Summary of Findings With MHRA Findings

	BAIHP		MHRA
	Tape	Mastic	Mastic, Repaired
Floors Tested	58	132	59
$CFM25_{TOTAL}$ (cfm)	71 avg (n=56) 210 max 13 min	43 avg (n=124) 90 max 16 min	NA
$CFM25_{OUT}$ (cfm)	49 avg (n=30) 186 max 13 min	23 avg (n=86) 216 max 0 min	NA
Qn_{TOTAL}	8.2% avg (n=56) 18.9% max 1.7% min	5.1% avg (n=124) 10.2% max 1.6% min	NA
Qn_{TOTAL} = 6%	19	85	
Qn_{OUT}	5.7% avg (n=30) 17% max 2.2% min	2.4% avg (n=86) 18.9% max NA min	2.5%** avg (n=59)
Qn_{OUT}=3%	5	73	
Ratio of Qn_{OUT} to Qn_{TOTAL}	56% avg (n=30) 80% max 20% min	36% avg (n=80) 80% max 0% min	50% (apprx) avg (n=59) 60% max 24% min
Source	See References, Data Sources		(MHRA, '03)

*MHRA estimated Qn_{OUT}. See Qn_{OUT} compared to Qn_{TOTAL} below.

Mastic Sealed Duct Systems

Of the 190 floors tested, 132 had mastic sealed duct systems. Researchers conducted 124 $CFM25_{TOTAL}$ tests and 86 $CFM25_{OUT}$ tests.

Only total duct leakage was measured in 44 mastic sealed systems. Of those, 17 did not meet the Qn_{TOTAL} = 6% goal (Table 7). Problems centered on dimensional coordination of duct components and misaligned pre-cut register holes in sub-floor assemblies, incomplete mastic application, imprecise cutting, and incomplete joints (eg not all tabs bent).

Table 7 Mastic Sealed Systems Exceeding Target Leakage Rates

ID #	Floors	Qn_{TOTAL}	Problems Identified
27	2	10.1%	Holes in main trunk oversized boots
28	2	7.5%	Leakage at registers, furnace plenum, and joints. Many make-shift tools
51	1	8.0%	Leakage at registers, furnace plenum, and joints.
25	2	8.3%	No mastic on supply plenum
13	1		No mastic on furnace plenum
45	1	6.7%	Mastic applied incorrectly
26	2	7.3%	No mastic on furnace plenum
29	2	6.8%	Make-shift tools; poorly fitted holes
60	2	6.4%	Register installed under interior wall (inaccessible for sealing). Gaps in mastic application.
47	1	6.5%	Tab-over boots not in contact with trunk line. Gaps in mastic application.
50	1	6.1%	Leakage at registers, furnace plenum, and joints. Gaps in mastic application and boot connections.

Both total and outside leakage tests were conducted on 80 mastic sealed systems, of which 58 floors met both the Qn_{TOTAL}<=6% and Qn_{OUT}<=3% goals. The remaining 22 floors were divided into three groups (Table 8):

- Group 1: 14 Floors Met the Qn_{OUT} goal but not the Qn_{TOTAL}. The Qn_{TOTAL} range: 6.1% to 9.7%
- Group 2: 1 Floor that met the Qn_{TOTAL} but not the Qn_{OUT} goal. Qn_{OUT}=4.1%
- Group 3: 7 Floors that met neither goal.

Six of the seven floors that met neither goal were tested during two initial factory visits. One of the factories did not pursue BAIHP recommendations and the other is working toward achieving the Qn_{TOTAL} = 6%.

Table 8 Mastic Systems Exceeding Leakage Goals			
Group 1 (n=14) Achieved Qn_{OUT} =6% *but not* Qn_{TOTAL}=3%			
ID#	Floors	Qn_{TOTAL}	Qn_{OUT}
24	2	9.0% (Fail)	1.6% (Pass)
43	3	6.5% (F)	2.5% (P)
87	2	9.7% (F)	1.0% (P)
91	3	6.6% (F)	2.6% (P)
97	2	6.5% (F)	1.5% (P)
98	2	6.1% (F)	1.2% (P)
Group 2 (n=1) Achieved Qn_{TOTAL}=6% *but not* Qn_{OUT}=3%			
ID#	Floors	Qn_{TOTAL}	Qn_{OUT}
67B	1	6.0% (P)	4.1% (F)
Group 3 (n=7) Achieved Neither Qn_{TOTAL}=6% *nor* Qn_{OUT}=3%			
ID#	Floors	Qn_{TOTAL}	Qn_{OUT}
100	2	8.9% (F)	3.4% (F)
39	2	9.7% (F)	3.4% (F)
54A	1	9.1% (F)	3.3% (F)
99	2	6.3% (F)	3.1% (F)

Leakage to the outside *only* was measured in seven mastic sealed systems. One floor had leakage too low to measure. The six remaining floors failed to meet the Qn_{OUT} goal. This illustrates that mastic application alone will not ensure a tight duct system. Various problems in construction, installation, and sealing occurred in these systems as described in Table 9.

Qn_{OUT} compared to Qn_{TOTAL}

The MHRA study estimates Qn_{OUT} (Table 6) using a measured Qn_{TOTAL} multiplied by the ratio of Qn_{OUT} to Qn_{TOTAL} for a completed house from the same factory.

For example, if a completed house for Factory A was found to have Qn_{TOTAL}=7% and Qn_{OUT}=3.5%, then the Qn_{OUT} estimation factor for incomplete houses at Factory A would be 0.5 (7%/3.5%). The value of Qn_{OUT} to Qn_{TOTAL} ratios found by MHRA ranged from 24%-60% (MHRA, '03).

Field measurements in new site built homes (Cummings, et al, '02.) and many of MHRA's field measurements in new manufactured homes show Qn_{OUT} is often approximately half of Qn_{TOTAL}, and in the absence of measured data from a factory, MHRA used 50% as the multiplier to estimate Qn_{OUT} from the measured Qn_{TOTAL} (MHRA, '03.) As mentioned earlier, the goal of Qn_{TOTAL}<= 6% originates from applying the 50% rule of thumb multiplier to obtain a Qn_{OUT}<=3% goal, which is the BAIHP recommended duct leakage level corresponding to the most stringent duct leakage level in the Manufactured Home Energy Star program.

Table 9 Mastic Sealed Systems Exceeding Target Leakage Rates			
ID#	Floors	Qn_{OUT}	Problems Identified
124 125	1 1	18.9% 13.3%	No mastic on return or supply plenum. Holes cut with large knife described Misalignment of components throughout
127 128 129 130	1 1 1 1	11.5% 9.8% 9.3% 7.2%	Tested in field shortly after set-up. All same manufacturer who is still in pursuit of Qn_{OUT} <=3% goal.

BAIHP data includes 26 taped systems that researchers tested for both total and outside leakage. The average ratio of outside leakage to total leakage was 56%, roughly agreeing with the rule of thumb. However, in the 80 mastic sealed systems, the average ratio of outside leakage to total leakage was somewhat lower than expected at 36%. There were 13 mastic sealed systems that met the Qn_{OUT} = 3% goal without meeting the Qn_{TOTAL} = 6% goal.

This lower than expected ratio is perhaps due to the improved sealing at joints between duct components but not between the house envelope and the air distribution system (e.g. joint of supply boots and subfloor or ceiling). Leakage at that joint is part of the total leakage, but tends to be eliminated when measuring leakage to outside.

Though the average ratio of outside leakage to total leakage in the mastic sealed systems was slightly lower than expected (36%), the range spanned 0% (no leakage or leakage too small to measure accurately) to 80%. The data strongly supports that achieving a Qn_{TOTAL} of 6% signifies that

the Qn_{OUT} will be less than 3%. Only one exception was documented (Qn_{OUT}=4.1%).

ECONOMICS OF DUCT TIGHTENING IN MANUFACTURED HOUSING

Costs for implementing tight duct recommendations were reported by Palm Harbor Homes (Kessler, '03.) and Southern Energy Homes.

Mr. Bert Kessler, VP of Engineering, reported, "Based on research with BAIHP, Palm Harbor Homes implemented duct system testing and increased return air pathways from bedrooms to 50in2 per 100cfm supply air company-wide. Since this implementation started, PHH has manufactured 35,000 homes and has had no incidents of moisture related issues in homes installed in hot-humid climates. Additionally, air flow issues have been all but eliminated."

Kessler comments that, "The benefits of testing and return air requirements far exceed the cost, both to the consumer and the manufacturing facility." The target leakage level is Qn_{TOTAL}<=3% and return air requirements adopted by the manufacturer based on 50in2 for every 100cfm of supply air delivered to the space. Excluding the 1 time cost for duct blaster equipment, Kessler estimates average mastic materials cost at $2.90 and labor cost for the duct sealing and testing at $12.42, totaling $15.32 for a 28 X 76, 2026 ft2, 3 bedroom, double wide home. Per floor cost equaling half that or $7.66

Kessler notes that all duct systems manufactured by Palm Harbor Homes are pressure tested on the production line and that costs for implementing the tight duct procedure vary significantly from plant to plant based on when during the production process the duct testing takes place, the system layout, and previous production standards. This is illustrated in the following information from Craig Young of Palm Harbor's Florida Division (Young, '03.) who reports lower labor costs but higher material costs than Mr. Kessler reports for the company at large.

Mr. Young reported production department supervisor estimates to BAIHP, finding that the labor cost of applying the mastic to the duct system is $3.47 per floor and the labor cost of testing the duct system including setting up the equipment (Minneapolis Duct Blaster) is also $3.47 per floor. The incremental material cost compared to tape is estimated at $1 per floor for a total of $8 per floor.

Correspondence from Michael Wade, Director of Quality Assurance & Code Conformance, Southern Energy Homes (Wade, '03.)

Mr. Michael Wade Director of Quality Assurance & Code Conformance, Southern Energy Homes reported projected production of 8,000 homes in 2003. They test their duct systems to evaluate if their goal of Qn_{TOTAL} <= 3% has been achieved. Mr. Wade says, "The test procedure is so quick that we don't take testing labor cost into consideration." Material costs were stated to be $6 per floor compared to $2 per floor for tape, a total incremental cost of $4 per floor.

CONCLUSIONS

Reduced duct leakage has been proven to reduce homeowner utility bills while improving comfort, durability, and indoor air quality (Compilation of findings in Cummings, et al, '91 and '93, Davis '91, Evans, et al, '96, and Manclark, et al '96.) Duct leakage prevalence has been documented among site built homes (Cummings, et al, '91, '93, '03), new manufactured homes (Tyson, et al, '96. MHRA, '03), and manufactured homes in failure due to moisture and air flow control issues (Moyer, et al, '01).

BAIHP researchers measured total duct leakage ($CFM25_{TOTAL}$, Qn_{TOTAL}) and duct leakage to the outside ($CFM25_{OUT}$, Qn_{OUT}) in 190 new manufactured homes or sections between 1996 and 2003. Taped (58) and mastic sealed (132) duct systems are included. The data set is further characterized in Tables 1 and 3.

Factories implementing duct tightening recommendations showed steady progress and were able to consistently produce duct systems that met the target tightness of Qn_{TOTAL}<=6%.

80 floors with mastic sealed duct systems were tested for both total and outside leakage. 58 achieved both the Qn_{TOTAL} = 6% and the Qn_{OUT} = 3% goals. Only one system achieved Qn_{TOTAL} = 6% but not Qn_{OUT}<=3%. This exception had a Qn_{OUT}=4.1%. An additional 14 mastic sealed systems met the Qn_{OUT} = 3% while exceeding the Qn_{TOTAL} >6% goal. Duct leakage measurements and findings are further summarized in Tables 6-9 and Figures 1 and 2.

BAIHP researchers will continue to use the Qn_{TOTAL}<=6% target with manufacturers. The average ratio of outside leakage to total leakage in the mastic sealed systems was slightly lower than expected at

36%. This helps explain how some manufacturers not meeting the Qn_{TOTAL} = 6% goal still met the Qn_{OUT} = 3% goal.

Though measuring duct leakage to the outside is the only positive way to verify that the Qn_{OUT} goal has been met, BAIHP feels confident recommending the approach documented here for assisting home manufacturers with meeting the Qn_{OUT}<=3% goal. Of the 24 factories discussed in this paper, 22 were able to achieve the Qn_{TOTAL} = 6% and/or the Qn_{OUT} = 3% goals they set for duct tightness.

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Trip Reports produced by the Building America Industrialized Housing Partnership for the following factory visits:

Testing and Factory Reviews		
Location	**Date(s)**	**Manufacturer**
Albemarle (NC)	April 2000, June 2000	Palm Harbor Homes
Alma (GA)	December 2002, May 2003	Fleetwood Homes
Auburndale (FL)	December 2002, May 2003	Fleetwood Homes
Austin	August 2001	Palm Harbor
Austin Plant 5	May 2003	Palm Harbor Homes
Austin Plant 7	February 2000	Palm Harbor Homes
Boaz (AL)	April 2000	Palm Harbor
Buda (TX)	May 2003	Palm Harbor
Burleson (TX)	February 2000, May 2003	Palm Harbor Homes
Casa Grande (AZ)	April 2000	Palm Harbor Homes
Douglas (GA)	December 2002, May 2003	Fleetwood Homes
Fort Worth	February 2000, April 2000, July 2000, May 2003	Palm Harbor Homes
Moultrie (GA)	April 2002	Oakwood Homes
Pearson (GA)	September 2000, December 2002, May 2003	Fleetwood Homes
Plant City (FL)	July 1997	Palm Harbor Homes
Safety Harbor (FL)	December 1999	Jacobson Homes
Seiler City (NC)	April 2000, May 2000	Palm Harbor Homes
Tempe	April 2000	Palm Harbor Homes
Waycross (GA)	July 2001	Clayton Homes
Willacoochee (GA)	December 2002, May 2003	Fleetwood Homes

FLORIDA SOLAR ENERGY CENTER®

Energy Star Manufactured Homes: The Plant Certification Process

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Energy Star Manufactured Homes: The Plant Certification Process

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ABSTRACT

In an on-going collaboration over the last ten years, researchers have worked with the manufactured housing industry offering building science advice and conducting diagnostic testing (Chandra et al 2002). This partnership resulted in the first two HUD code ENERGY STAR homes in 1997 and the development of standardized, in-plant Duct Blaster testing in 2001. One manufacturer is currently testing duct leakage on every home in 12 factories, representing over 8,000 homes per year.

In 2001, the U.S. Environmental Protection Agency (EPA) introduced the ENERGY STAR label for manufactured homes. Guidelines for this program focus on certification of the HUD-code plant and award the ENERGY STAR label to any homes manufactured to prescriptive design requirements. The primary hurdle to certification is consistent production of tight duct systems. Other important aspects of the program include verification of prescriptive design packages and energy related site installation details.

An outline of the certification process at 10 plants in six states is presented, including Blower Door and Duct Blaster test results from over 40 homes. Duct test data taken by researchers from site-installed homes is compared with corresponding, in-plant test data. Photos, specifications and cost data are used to illustrate certification with an emphasis on achieving targeted duct leakage. Duct system design and installation details are also presented along with in-plant testing protocols.

Background

The HUD Code

Since June 15, 1976, all Manufactured homes are constructed in accordance with the Federal Manufactured Homes Construction and Safety Standards, administered by the U.S. Department of Housing and Urban Development (HUD). Known as the HUD code, these standards regulate home design and construction including strength, durability, fire resistance and energy efficiency (Title 24 CFR 2001). The code was revised to enhance energy efficiency, ventilation standards and wind resistance in the early 1990's.

Manufactured homes are similar in many respects to modular homes. Both are built in a factory and transported to a site for installation. The difference is that manufactured homes are regulated by the HUD code, whereas modular homes must follow the building code enforced in the jurisdiction where the home will be located.

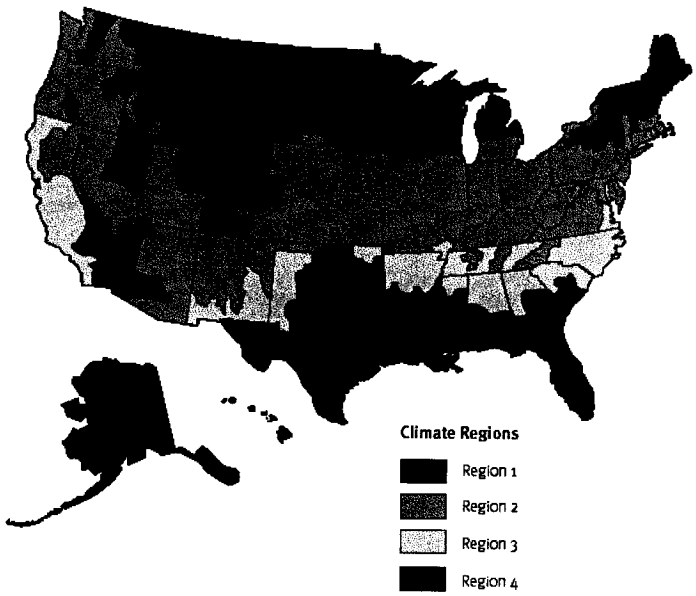
Energy Star Requirements

Prescriptive Design Packages

The Energy Star guidelines for manufactured homes (MHRA 2003) are very similar to the guidelines for site-built homes. As with a site-built home, an ENERGY STAR labeled manufactured home must be at least 30% more energy efficient in its heating, cooling and water heating than a comparable home built to the 1993 Model Energy Code (MEC). The 30% efficiency specification can be met either through prescriptive design packages or through the performance-based approach using approved software. While achieving Energy Star through software analysis is identical for both site-built and manufactured homes, there are a few differences in the prescriptive packages.

Pre-approved Energy Star packages for HUD code manufacturers diverge from the Builder Option Packages (BOPs) used by site-builders in several ways. Unlike BOPs, which are based on climate zones defined in the International Energy Conservation Code, HUD code packages are based on a four zone climate region map (Figure 1). Within each climate region, manufacturers can choose from maximum duct leakage targets of 3, 5 and 7%.[1] Once a duct leakage target is chosen, HUD code packages become increasingly similar to site-built BOPs, including trade-offs between heating, cooling and hot water equipment efficiency and window solar heat gain coefficient (SHGC).

Figure 1. Energy Star Climate Region Map for Manufactured Homes



Source: Energy Star Labeled Manufactured Homes Procedures, 2nd Ed. 2003

[1] Values based on cubic feet per minute of leakage to outside at 25 pascals divided by conditioned floor area.

Another difference between manufactured and site-built guidelines is use of the whole-house U_o (coefficient of heat transmission) as outlined in NFPA 501: Standard for Manufactured Housing (NFPA 2003). This property is routinely used by HUD code manufacturers and provides a single measure of heat conductance through the entire building envelope, including floor, walls, ceiling, doors and windows. Whereas BOPs specify individual R-values or U-values for walls, floors, attics and windows, manufactured housing packages specify only the whole-house U_o.

Site Installation Checklist

HUD code home construction takes place primarily in a controlled factory setting however an additional obstacle to ensuring Energy Star efficiency occurs when the completed home is installed at its final on-site destination. The advantages of building energy efficient homes in a factory environment are quickly undermined if certain critical tasks are not properly performed during setup. For this reason a home site installation checklist must be signed-off on every Energy Star manufactured home.

The checklist primarily focuses on field connections critical to building and duct airtightness but also ensures the installed HVAC equipment meet efficiency specifications. Most manufactured homes are composed of at least two sections that must be mated on site at the marriage line. The marriage line seal is crucial to achieving a tight envelope and must consist of a continuous, non-porous, insulating gasket where the ceiling, floor and end walls come together. Penetrations through the bottom board are routinely required for utility hook-ups and must be sealed with a durable patch to prevent air leakage.

Multi-section homes require a duct connection to join systems between floors. This is often done with a crossover duct, which are typically large (12-14 inch diameter) flex-ducts connected during setup and located either in the attic or crawlspace. The checklist specifies that crossover connections be secured in a permanent fashion with adequate insulation and a continuous vapor barrier to prevent condensation.

Sampling Protocol

A final distinction between manufactured and site-built Energy Star guidelines involves the random sampling of completed homes. Initial procedures are similar in that three consecutive homes must meet the guidelines as determined by a 3rd party verifier. Once it is determined that the builder or manufacturer can consistently produce homes that meet the guidelines, a sampling protocol is followed in which the 3rd party Energy Star certifier randomly selects and tests homes to verify envelope and duct leakage requirements. The sampling rate is set at 15% for site-builders and 2% for HUD code manufacturers.

Implementing Energy Star

Meeting Energy Star requirements, whether for manufactured or site-built homes, relies on a combination of a better performing envelope and higher efficiency equipment. Duct leakage however, is arguably the single most important factor in the home energy efficiency equation. Prevalence of duct leakage has been documented among site built homes (Cummings, et al, 1991, 1993, 2003) and new manufactured homes (Tyson, et al, 1996.

MHRA, 2003), as well as in manufactured homes in failure due to moisture and air flow control issues (Moyer, et al, 2001). Duct repair studies from the 80's and 90's show average savings of 15% cooling energy and 20% heating energy (Cummings 1991 and 1993; Davis 1991; Evans et al 1996; Manclark et al 1996.). Other benefits resulting from tight duct systems include first cost savings from smaller equipment sizes improved comfort, better indoor air quality and in many cases improved durability (Moyer 2001).

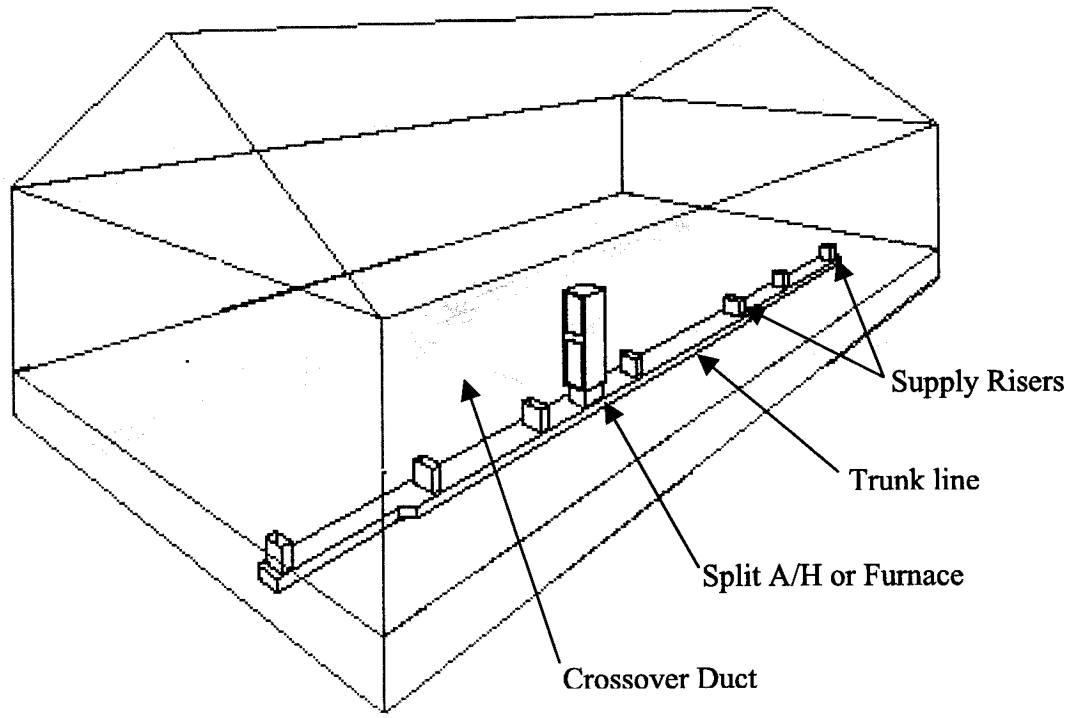
While the potential for energy loss is great, preventing leakage is relatively simple and inexpensive when approached in a systematic manner. The problem however, is that air leakage is difficult to determine without sophisticated testing equipment. Unlike other aspects of home energy efficiency, air leakage represents the only performance test currently required for Energy Star certification. All other characteristics that differentiate an Energy Star home from a standard home such as equipment efficiency and insulation levels are verified by visual inspection.

Duct System Design

Duct systems in manufactured homes are, by nature, very simply designed. The two basic types are overhead systems installed in the attic space and under-floor systems installed in the belly space between the floor deck and the bottom board. Floor duct systems are composed of rectangular sheet metal or fiberglass duct board, which runs down the center of each home segment. The simplest floor system is the inline type that has metal supply risers tied directly to the trunk line as shown in Figure 2. The perimeter floor duct system takes this design one step further with flex duct supply branches emanating from the trunk line and terminating at points near the exterior walls. Ceiling duct systems on the other hand are constructed entirely of flex duct with distribution boxes built of fiberglass duct board.

Multi-section homes have an additional section of ductwork that is connected during the setup operation. A flexible duct is used to connect the supply sections together in the attic or in the crawlspace. Also called the crossover duct, this connection is usually made with a tie strap.

Figure 2. Inline Duct System in a Two-section Manufactured Home



Source: Improving Air Distribution System Performance in Manufactured Homes. 2003

Sealing with Mastic versus Tape

Researchers collected duct leakage data during factory visits to 24 different plants on behalf of 6 HUD-code manufacturers. The data, dating back to 1996, illustrates the advantages of duct systems sealed with mastic over those sealed with tape (McIlvaine et al 2003). Duct leakage was measured in 101 houses representing 190 floors (single wide equals one floor, double wide equals two floors, etc.) and includes more recent data taken during factory certification for Energy Star. Throughout this testing the duct leakage goal was Qnout $\leq 3\%$.[2] Researchers tested homes at sales lots and home sites, as well as partially constructed homes in the factory setting, however home sections in the factory cannot be sealed enough to perform a CFM25out test. Past field tests suggest that CFM25out will be roughly 50% of total leakage (CFM25total). Thus, to achieve a Qnout of less than 3%, it was recommended that manufacturers strive for a CFM25total of less than 6% of the conditioned area (Qntot). Duct leakage data gathered from 1996 to 2003 is summarized in Table 1 and Figure 3.

[2] Qnout is the ratio of duct leakage to outside at 25 pascals (CFM25) to conditioned floor area (square feet).

Table 1. Number of Home Sections Tested by Sealing Method, Duct Location and Duct Material (1996-2003) 39 factory visits to 24 plants run by 6 different manufacturers			
	Tape	**Mastic**	**Total**
Duct System Location			
Undocumented	1	0	1
Overhead Systems	25	44	69
Floor Systems	32	88	120
Total	**58**	**132**	**190**
Duct Materials			
Undocumented	5	0	5
Sheet Metal with Flex	24	22	46
Duct Board with Flex	29	110	139
Total	**58**	**132**	**190**

Figure 3. Average Duct Leakage: Tape vs Mastic Sealed Ducts

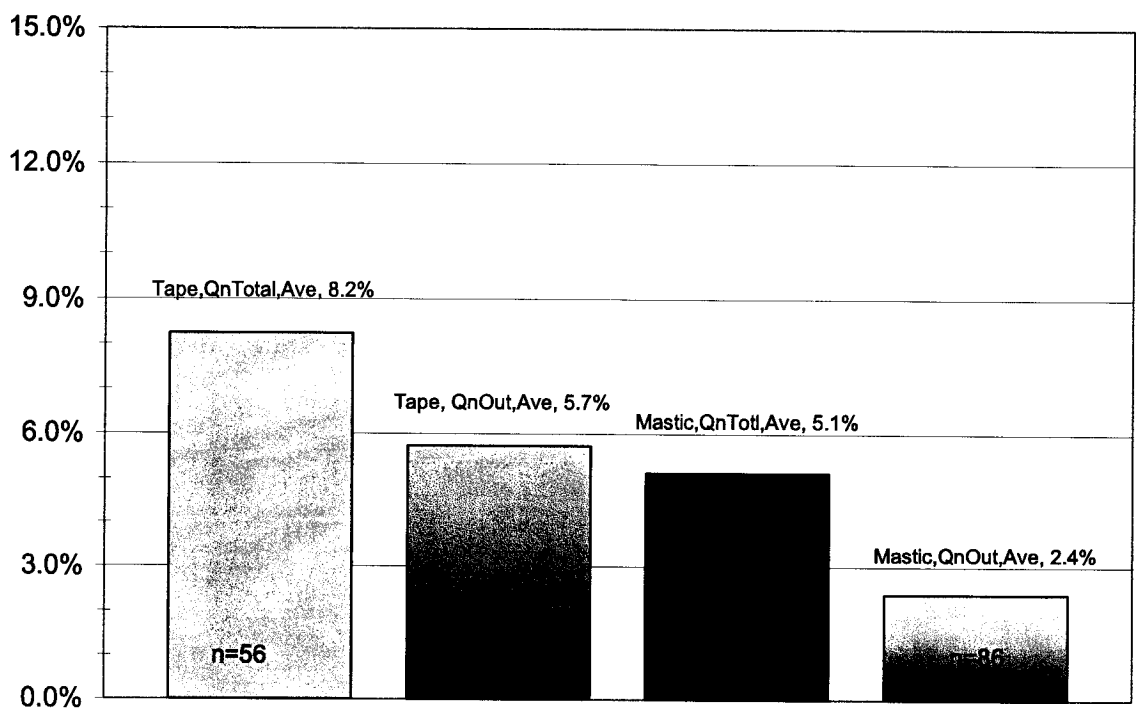


Figure 3 indicates that mastic provides a superior seal over what can be accomplished with tape. The average taped system did not meet either of the duct leakage targets, Qntot ≤ 6% and Qnout ≤ 3%, while the average mastic system met both. Cost information from two manufacturers indicates that the added cost of implementing a duct sealing program using mastic ranges from $4 to $8 per floor, including in-plant quality control procedures (testing) critical to meeting duct tightness goals.

Energy Star Plant Certification Data

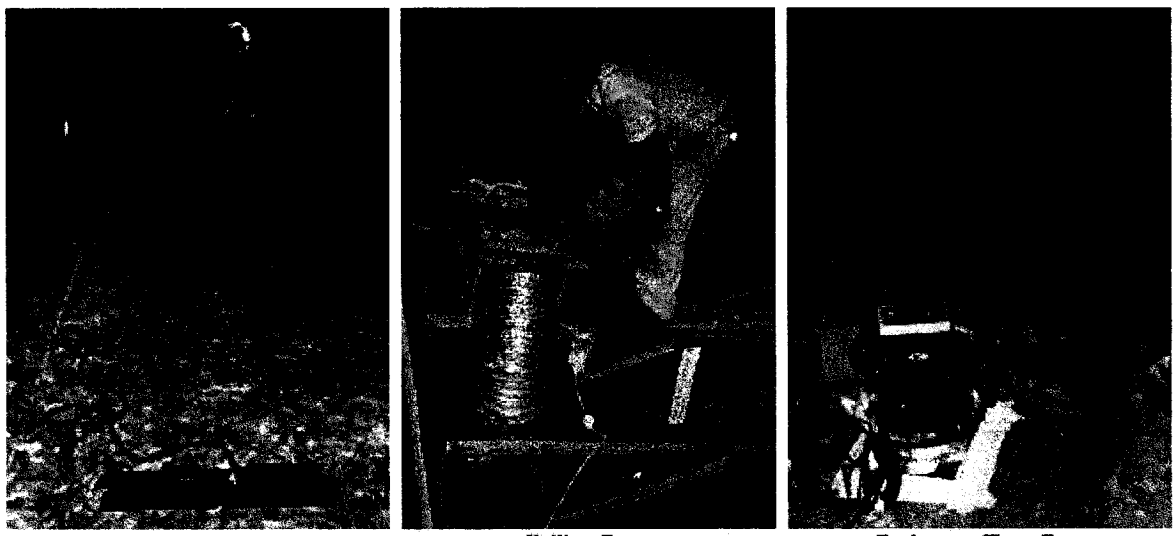
Researchers, acting as third party verifiers, visited 10 HUD-code plants for a single manufacturer in 2002 and 2003 to certify them for Energy Star production. Energy Star procedures call for three consecutive homes under production to be tested at the plant to determine whether duct leakage requirements are being met (in this case Qnout ≤ 3%). Prior to these visits, the manufacturer began voluntarily testing all duct systems in all homes throughout the company.

In-plant Duct Blaster Testing

During 2001, plant personnel at 10 facilities were outfitted with a duct blaster and digital manometer and trained in their use with assistance from researchers. Training focused only on those points essential to completing a reliable leakage test and avoided in-depth instruction to keep the test as uncomplicated as possible. Basic duct testing such as this typically adds only a few minutes of time to the production process unless excessive leakage is detected.

Duct leakage guidelines were set at Qnout ≤ 3% company-wide but beyond that each plant was allowed to develop its own duct testing protocol. In most plants the preference was toward early testing, soon after the ductwork was installed. Three such strategies are shown in Figure 4, each of which takes place on the production line while the home is being constructed. The first two photos of Figure 4 (left and center images) show inline and ceiling systems being tested by depressurizing the ducts. In the last photo (right image) a perimeter system is tested by pressurization. The duct blaster is taped to the air handler plenum with the fan blowing into the ducts, which allows for a simple, compact test setup without the need for a flex connection.

Figure 4. In-plant Duct Blaster Testing – Incorporated into Production Line



Inline Floor Ducts | Ceiling Ducts | Perimeter Floor Ducts

A few factories performed duct testing at the end of production as shown at two plants in Figure 5. All plants perform function testing on HVAC, electrical and plumbing systems upon completion of construction, at which time a temporary crossover duct is installed offering an ideal time to test duct leakage for the home as a unit. While duct leaks are more difficult to correct at this stage, the testing conditions are far more controlled and less apt to cause damage to sensitive test equipment.

Figure 5. In-plant Duct Blaster Testing – Performed upon Product Completion

During factory certification, researchers observed duct testing by line workers to ensure proper technique and offered advice on possible improvements to test methodology. Tests were sometimes repeated with researcher equipment.

Field Testing

Energy Star factory certification procedures also call for duct leakage and blower door testing of at least three site-installed homes per plant. Researchers tested 42 homes as part of this effort. Some of these homes were completely installed and occupied, but more often they were located at sales lots where setup was only partially completed. All tested homes were produced after implementation of in-plant duct blaster testing, which offered an opportunity to compare field test results with those recorded in the plant as shown in Table 2.

Table 2. Field-Measured Duct Leakage as Part of Manufactured Home Energy Star Plant Certification
Results from 42 homes built in 10 factories

	Area (ft^2)	ACH50	Qntot	Qnout	Qnfactory[3,4]
38 Homes Passed					
Average	1,774	5.66	4.62%	1.39%	2.28%[3]
Maximum	3,116[1]	8.14	9.60%	3.00%	3.48%
Minimum	1,093[2]	3.94	2.44%	0.00%	0.78%
4 Homes Failed					
Average	1,465	5.65	10.30%	4.59%	N/A[4]
Maximum	2,052	6.38	11.50%	5.86%	N/A
Minimum	1,140	4.32	9.05%	3.77%	N/A

Notes: 1. Largest homes were triple-wide models (3 included in data set)
2. Smallest homes were single-wide models (2 included in data set)
3. Factory duct leakage records were available for only 30 of 38 passing homes
4. Not applicable as only 2 of 5 failing homes had factory duct leakage data available

Similar to the other Qn quantities, Qnfactory represents the ratio of duct leakage measured at 25 pascals with respect to floor area. Technically this is a measure of total duct leakage as duct testing is performed on detached home sections that cannot be tested for leakage to out. Depending on the point during production that the test is performed however, the Qnfactory quantity can nearly achieve the same measure as leakage to out. The majority of factory test data collected for this report was done early in the production process when supply and return outlets are easily accessed and can be sealed relatively tightly and is reflected in the data showing factory leakage as being much closer to the field-measured leakage to out than to total leakage. This goes contrary to past studies that estimate duct leakage to out to be 50% of total leakage (MHRA 2003). In this case the manufacturer requires Qnfactory $\leq$ 3%.

Details on the four field-tested homes that failed the Qnout $\leq$ 3% duct leakage requirement are provided in Table 3. These homes originated from one of two factories and missed the leakage target by only 1% to 3%. In all but one case, leakage was concentrated on side A, which has additional sealing requirements as that is where the air handler is mounted. These four homes were on average 17% smaller than the typical home that passed and 3 out of 4 were nearly 30% smaller, one being a singlewide unit. This illustrates the increasing difficulty of meeting Energy Star duct leakage criteria as unit size shrinks.

Table 3. Duct Leakage Details on Four Failed Homes						
	Total Duct Leakage			Duct Leakage to Out		
Area (ft^2)	Side A[1]	Side B	Qntot	Side A	Side B	Qnout
1,370	100	24	9.05%	44	10	3.94%
1,296	125	24	11.50%	62	14	5.86%
2,052	145	66	10.28%	50	48	4.78%
1,140[2]	118	N/A	10.35%	43	N/A	3.77%

Notes: 1. Side A has air handler installed
2. singlewide unit

Conclusion

Ten years of collaboration with the manufactured housing industry has yielded useful information on how this important housing sector can continue to improve the quality and efficiency of its product. HVAC systems in general and ducts in particular have proven to be a key element in providing a safe, durable and energy efficient manufactured home. The Energy Star label for manufactured homes provides individual recognition for this housing type, offering building packages tailored specifically for HUD-code construction and allowing certification at the factory level.

Sealing duct systems in manufactured housing comes at a relatively low cost with the proper use of mastic. Duct Blaster test data taken since 1996 on 190 manufactured home sections show the superiority of mastic over tape for sealing ductwork, with the average mastic-sealed system allowing only 2.4% leakage to out at 25 pascals compared to 5.7% for the average taped system. Use of mastic has proven to be very cost effective as the added cost of implementing a duct-sealing program using mastic ranges from $4 to $8 per floor according to two manufacturers.

One manufacturer has incorporated Duct Blaster testing into its daily operations at 12 plants in six states representing over 8,000 HUD-code homes in fiscal year 2003 (SEC 2004). The testing has proved cost effective toward efforts to consistently provide an energy efficient home that meets Energy Star requirements. Researchers collected duct leakage data during factory certification for Energy Star on 42 homes and found field measurements consistent with leakage measurements obtained by factory personnel.

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Title 24, Code of Federal Regulations Part 3280, 2001 Department Of Housing And Urban Development [Docket No. FR-4376-P-01] Manufactured Home Construction and Safety Standards

EarthCents® Home Energy Improvement Program
Individual Improvements Approach

Individual Improvements Process

1. Property owner visits http://www.georgiapower.com/earthcents/residential/home.asp to establish whether the Whole-House or Individual Improvement approach is most appropriate for their project.
2. If the Individual Improvements approach is chosen, the http://www.georgiapower.com/earthcents/residential/home-improvement-program/pdf/GPHomeImprovementImprovementsRebates.pdf document needs to be reviewed to ensure that the preconditions for the home are met.
3. The energy efficiency improvements are made.
4. If the improvements were completed by a contractor, an itemized invoice should be obtained. If the improvements were completed by the homeowner, all receipts for materials should be available. Receipts and/or invoices must accompany the rebate application.

Duct Sealing Individual Improvement Rebate Process

1. Homeowner identifies and contacts a Program Participating Contractor or Duct and Envelope Tightness (DET) verifier at http://www.georgiapower.com/earthcents/residential/home-improvement-program/participating-contractors.asp.
2. Prior to improvements, the Contractor performs a duct blaster test-in on the home. The results are recorded on page 5 (Test-Out Form for Air and Duct Sealing Improvements and BPI Assessments) of the attached rebate application.
3. The duct sealing improvements are made.
4. The Contractor performs a duct blaster test-out to determine if the 30 percent minimum improvement is met. If 30 percent reduction is not achieved, then the duct sealing process can be continued until the minimum requirement is met.
5. The Contractor records the final CFM 25 readings and percent improvement for the home on page 5 (Test-Out Form for Air and Duct Sealing Improvements and BPI Assessments) of the attached rebate application.
6. A **Test-Out Form for Air Sealing Improvements and BPI Assessments** must be included with the rebate application.

Air Sealing Individual Improvement Rebate Process

1. Homeowner identifies and contacts a Program Participating Contractor at http://www.georgiapower.com/earthcents/residential/home-improvement-program/participating-contractors.asp.
2. Prior to improvements, the Contractor performs an initial assessment (test-in) on the home. The resulting CFM 50 values are recorded on page 5 (Test-Out Form for Air and Duct Sealing Improvements and BPI Assessments) of the attached rebate application.
3. The air sealing improvements are made.
4. The Contractor performs a final assessment (test-out) to determine if the 20 percent minimum improvement was achieved. If 20 percent improvement is not achieved, then the air sealing process can be continued until the minimum requirement is met.
5. The Contractor records the final CFM 25 reading and percent improvement for home on page 5 (Test-Out Form for Air and Duct Sealing Improvements and BPI Assessments) of the attached rebate application.
6. A Test-Out Form for Air Sealing Improvements and BPI Assessments must be included with the rebate application.

Information Needed Prior To Submitting a Rebate Application

Home improvements must be completed prior to applying for rebates and rebates will be paid on qualifying improvements only. The following information needs to be collected and included as part of the rebate application:

1. Meter or Georgia Power account numbers associated with the home.
2. Itemized invoices (showing improvements performed and specific pricing for measures installed).
3. General information about the property being improved (contact information and address).
4. Homeowner mailing information if the mailing address is different from the premises address.
5. General Contractor information (name, company name, and BPI certification number).
6. Completed Georgia Power Home Energy Improvement Program Single Family Individual Improvements Rebate Form including Test-Out Form for Air Sealing Improvements and BPI Assessments if air and/or duct sealing improvements were made to the home.

Documents That Need To Be Submitted To Georgia Power

1. Completed **Georgia Power's EarthCents Home Energy Improvement Program Single Family Individual Improvements Rebate Form.**
2. Detailed copy of invoices; must show specific costs for all improvements made to the home.

Where to Submit Application

The application can be submitted by:

E-mail: HomeImprovements@southernco.com
Fax: 1-877-768-9017
Mail: Georgia Power's EarthCents Home Energy Improvement Program
c/o ICF International
3 Corporate Square NE, Suite 370
Atlanta, GA 30329

Please call 1-877-310-5607 for assistance.

Rebate applications take between six and eight weeks to be processed.

GEORGIA POWER
A SOUTHERN COMPANY
earthcents

EarthCents Home Energy Improvement Program
Single Family Individual Improvements Rebate Form

NOTE: Please email, fax, or mail this form only after the improvements have been satisfactorily completed to program requirements. For information on program requirements, please refer to http://georgiapower.com/homeimprovements/pdf/GPHomeImprovementImprovementsRebates.pdf.

Rebates will be paid on qualifying improvements ONLY. Rebates are 50 percent of the improvement cost up to the individual rebate cap. The maximum rebate for all improvements is $700 annually. Receipts for equipment/material must accompany request for payment. Please keep a copy of the form and receipts for your records.

Section 1: Contact Information	
Homeowner/Premises Information (location where work was performed; rebate check will be sent here unless mailing address is provided.)	
Homeowner Name:	Homeowner Email:
Premise Address:	
Premise City, State, ZIP:	Georgia Power Account #:
Homeowner's Daytime Phone:	
Homeowner Mailing Information (if different from premises)	
Mailing Street Address:	Mailing City, State, ZIP:
Renter Information (if Georgia Power account is in a renter's name, please provide information below). Please note rebate will be paid to owner unless previous consent is obtained.	
Renter Name:	Georgia Power Account #:

Section 2: House Information				
Home Square Footage:			Approx. Year Built:	
Heating Fuel Type:	☐ Electric	☐ Natural Gas	☐ Oil	☐ Propane
House Type:	☐ Single Family	☐ Townhome/Duplex Interior	☐ Townhome/Duplex End Unit	

Section 3: Home Energy Improvement Rebates Requested[1]

Heating and Cooling Improvements

(Improvements in this section can be performed by a program participating BPI-certified contractor or an industry-specific licensed contractor.)

Eligible Improvements	Rebate Cap (per unit)	Total Units Installed	Requested Rebate Amount ($)[3]	Total Installed Cost ($)5	Tons	AHRI Reference Number	Make/ Brand	SEER/ EER/ HSPF	Outdoor Model Number	Indoor Model Number	Install Date
High-Efficiency Central Air ≥ 16 SEER	$50										
Replace Heat Pump with High-Efficiency Heat Pump ≥ 15 SEER	$100										

Heating and Cooling Improvements Converting From Natural Gas

(Improvements in this section can be performed by a program participating BPI-certified contractor or an industry-specific licensed contractor.)

Eligible Improvements	Rebate Cap (per unit)	
High-Efficiency Heat Pump Replacement ≥ 15 SEER	$100	*The rebate application for heat pump conversions from natural gas is handled separately from this application by the installing heating and cooling contractor. A list of qualified heating and cooling dealers is listed on the Georgia Power website, http://www.georgiapower.com/dealers/hvac_metro.asp., or installation may be performed by a licensed heating and cooling contractor of choice. Additional rebate incentives from Georgia Power may be available during other periodic offerings separate from the EarthCents Home Energy Improvement Program. All rebate payments for heat pump conversions will be mailed separately from EarthCents Home Energy Improvement Program rebates. The $100 rebate is applied to the $700 total rebate eligibility cap for the program.*

Water Heating Improvements Converting From Natural Gas

(Improvements in this section can be performed by a program participating BPI-certified contractor or an industry-specific contractor.)

Eligible Improvements	Rebate Cap (per unit)	Total Units Installed	Requested Rebate Amount ($)[3]	Total Installed Cost ($)[5]	Make/Brand	Model Number	Energy Factor (EF)	Install Date			
Solar Water Heater from a Steel-tank Electric Water Heater	$250										
Heat Pump Water Heater from a Steel-tank Electric Water Heater	$250										

Insulation and Other Improvements

(Improvements in this section can be performed by participating BPI-certified program contractor[2], industry-specific contractor and/or homeowners.)

Eligible Improvements	Rebate Cap	Total Units Installed	Requested Rebate Amount ($)[3]	Total Installed Cost ($)5	Make/Brand	Install Date			
Attic Insulation[4]	$300	_____# bags /_____ sq.ft.							
Knee Wall Insulation[4]	$150	_____# bags /_____ sq.ft.							
Floor/Foundation Wall/Unvented Crawlspace Insulation[4]	$200	_____# bags /_____ sq.ft.							
Rim Joist Insulation[4]	$100	_____# bags /_____ sq.ft.							
Programmable Thermostat	$100								
Electric Water Heater Tank Wrap	$50								

1. *Rebate applications for home energy improvements must be submitted within 60 days from the purchase date of the materials/equipment installed, as documented by the purchase receipt.*
2. *Program Participating Contractors are required to be certified BPI Building Analysts unless otherwise noted above.*
3. *Itemized invoices that show costs per improvement must accompany this rebate application.*
4. *BPI assessment and air sealing improvements must be performed by a Program Participating Contractor (Assessor) who is a certified BPI Building Analyst to be eligible for the rebate.*
5. *The Test-Out Form for Air Sealing Improvements and BPI Assessments must be completed if Air Sealing Improvements and/or BPI Assessments were completed. Application for these rebates must include Georgia Power's EarthCents Home Energy Improvement Program Single Family Individual Improvements Rebate Form.*
6. *Fifty percent of the installed cost up to the rebate cap may be requested. Total rebates requested (including Assessment) may not exceed individual rebate cap or overall annual cap of $700.*
7. *Dense pack or wet cellulose and spray foam insulation must be installed by a Building Performance Institute (BPI) certified contractor according to BPI standards.*
8. *Receipts for equipment/material installed must accompany this rebate application.*
9. *The rebate application for heat pump conversions from natural gas is handled separately from this application by the installing heating and cooling contractor. A list of qualified heating and cooling dealers is listed on the Georgia Power website, http://www.georgiapower.com/dealers/hvac_metro.asp., or installation may be performed by a licensed heating and cooling contractor of your choice. Additional rebate incentives from Georgia Power may be available during other periodic offerings separate from the EarthCents Home Energy Improvement Program. All rebate payments for heat pump conversions will be mailed separately from the EarthCents Home Energy Improvement Program rebates. These heat pump rebates do not affect the $700 cap.*
10. *The rebate application for water heating conversions from natural gas is handled separately from this application. An additional rebate for the conversion is available of up to $200. The Standard Electric Steel-Tank program requires that the gas water heater be the last remaining gas appliance in the home to qualify. Rebate applications may be found on the Georgia Power Web site: http://georgiapower.com/residential/waterheater.asp. All rebate payments for these programs will be mailed separately from the Home Energy Improvement Program rebate. These rebates do not affect the $700 cap.*

Air and Duct Sealing Improvements***

(Improvements in this section can be performed by participating BPI-certified program contractors)

Eligible Improvements	Rebate Cap	Requested Rebate Amount ($)*	Improvements Contractor	Total Installed Cost ($)	Install Date
BPI Assessment	$200				
Air Sealing*	$400				
Duct Sealing**	$400				

**Air sealing improvements and BPI Assessment must be performed by a BPI-Certified Building Analyst.*
*** A licensed conditioned air contractor with Duct and Envelope Tightness (DET) Verifier certification can seal and test ducts.700*
**** The Test-Out section of this form for Air and Duct Sealing Improvements and BPI Assessments must be completed if any of these improvements are made.*

Section 4: Signatures

Terms and Conditions: All installations and rebates under this program are subject to visual verification by the Georgia Power Corporate Compliance Organization. If the field audit discovers the equipment has not been installed, or any other non-conforming condition exists, the customer is not eligible for the rebate and Georgia Power will assess reimbursement for rebate on the customer's monthly bill. By signing this contract, applicant acknowledges and agrees that Georgia Power's liability and responsibility in connection with any rebate program shall be strictly limited to the making of certain rebate payments to eligible applicants, and that Georgia Power is not making, will not be providing and specifically disclaims any representations, warranties, covenants or guaranties whatsoever, expressed or implied, in connection with the equipment or the program itself, including, without limitation, those regarding merchantability or fitness. Warranties with respect to the equipment are strictly manufacturer's warranties, and applicant shall not make, nor have the right to make, any claims against Georgia Power relating to any such warranty. Georgia Power shall in no way be liable or responsible for any equipment installed or any act or omission of any other entity or individual, including, without limitation, any contractor, technician or other service provider. Georgia Power reserves the right to cancel or modify the rebate program at any time in its sole discretion.

Homeowner's Signature _____ Date _____

If you have questions about this form, please call 1-877-310-5607 to reach Georgia Power's EarthCents Home Energy Improvement Program's customer service center. Completed forms with all other documentation for improvements may be submitted by e-mail to homeimprovements@southernco.com; fax to 1-877-768-9017; or mail to Georgia Power's EarthCents Home Energy Improvement Program, c/o ICF International, 3 Corporate Square NE, Suite 370, Atlanta, GA 30329.

Test-Out for Air Sealing Improvements

Test-Out Date: _____	Test-Out Standards Met? Yes / No (circle one)
Air Sealing (ACHnatural):	
Test-In Results:_____ACHnatural	Test-Out Results: _____ACHnatural
Ventilation Requirements (CFM 50):	
Building Airflow Standard (min. CFM 50): _____CFM 50	Measured Airflow (actual CFM 50): _____CFM 50
Combustion Safety Testing:	
Appliance 1: _____ =	Pass / Fail (circle one)
Worst Case Depressurization - Measured:_____pa, Limit:_____pa	Spillage - stops within 60 sec? Yes / No (circle one)
Draft - Measured: _____pa, Limit: _____pa	CO - Measured: _____ppm, Limit: _____ppm
Appliance 2: _____ =	Pass / Fail (circle one)
Worst Case Depressurization - Measured:_____pa, Limit:_____pa	Spillage - stops within 60 sec? Yes / No (circle one)
Draft - Measured: _____pa, Limit: _____pa	CO - Measured: _____ppm, Limit: _____ppm
Appliance 3: _____ =	Pass / Fail (circle one)
Worst Case Depressurization - Measured:_____pa, Limit:_____pa	Spillage - stops within 60 sec? Yes / No (circle one)
Draft - Measured: _____pa, Limit: _____pa	CO - Measured: _____ppm, Limit: _____ppm
Appliance 4: _____ =	Pass / Fail (circle one)
Worst Case Depressurization - Measured:_____pa, Limit:_____pa	Spillage - stops within 60 sec? Yes / No (circle one)
Draft - Measured: _____pa, Limit: _____pa	CO - Measured: _____ppm, Limit: _____ppm

Test-Out for Duct Sealing Improvements	
Duct Sealing/Replacement (Percent Leakage = CFM 25 / ft2 floor area served):	
UNIT 1 - Test-In Results: _____% Leakage	**Test-Out Results: _____% Leakage**
UNIT 2 - Test-In Results: _____% Leakage	**Test-Out Results: _____% Leakage**
UNIT 3 - Test-In Results: _____% Leakage	**Test-Out Results: _____% Leakage**

1. *Program participating Building Performance Institute (BPI) analyst or a licensed conditioned air contractor with Duct and Envelope Tightness (DET) Verifier certification can seal and test ducts.*

Accurate Rater Network

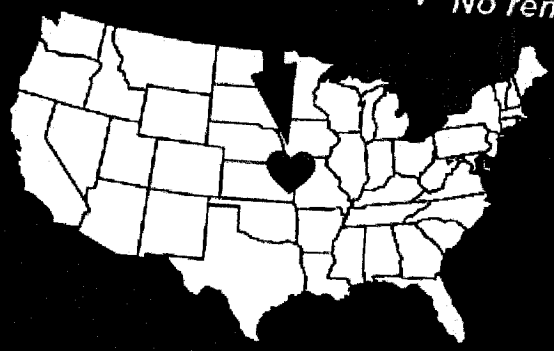
Training for Your Future.
Partnering for Your Success.

Our Services Include:

- ✓ RESNET Accredited Provider
- ✓ QA Provider
- ✓ Training Provider
- ✓ Sampling Provider
- ✓ BOP (Builder Option Package) Provider
- ✓ Building Performance Institute (BPI) Training Affiliate
- ✓ Green Training
- ✓ Contractor Training
- ✓ LEED® for Homes Provider
- ✓ NAHB Green Verifier Training
- ✓ Rater Mentoring Services
- ✓ HERS Rater Equipment Rentals

We are in the heart of the action

- ✓ Affordable hotels in walking distance to training site
- ✓ Restaurants in walking distance
- ✓ Shuttle from Kansas City International Airport, 25 minutes
- ✓ ***No rental car needed!!***



Check our training calendar!!

Call us today:
1-888-RATER-04
(1-888-728-3704)
Green@AccurateRater.com
www.AccurateRater.com
Greater Kansas City Area

Who We Are

The Accurate Rater Network (ARN) is a Training, Certification, and Quality Assurance Provider organization, nationally accredited by:

- Residential Energy Services Network (RESNET)
- Building Performance Institute (BPI)
- U.S. Green Building Council (USGBC) LEED® for Homes
- National Association of Home Builders (NAHB) Green Verifier Program

ARN works for our network members providing a one-stop-shop for training, certification, quality asurance support, continuing education, review and archiving services for multiple energy and environmental programs.

Our high quality assurance standards and ongoing support and education help the members of our network set themselves apart as highly qualified, highly trained professionals. Builders, homeowners, and other industry professionals have confidence that their choice of an Accurate Rater Network member will provide them the highest quality results from expertly trained professionals.

Raters and Rater Services

Membership Benefits

The Accurate Rater Network (ARN) invites Independent Certified HERS Raters, Green Raters, Green Verifiers, HERS Rating Companies, Energy Auditors and BPI Certified Building Analysts to join our network. At ARN we have a large staff of extremely knowledgeable building scientists and energy geeks ready to answer your questions and assist you in your work. Our staff has decades of experience providing testing and certification services for national energy and environmental programs such as ENERGY STAR, NAHB Green Build, LEED® for Homes, American Lung Association Health House, and State and Federal Energy Tax Credits. ARN is ready to put that knowledge to work for you. Joining the Accurate Rater Network gives you a team of experts just a click or a call away. Membership benefits include:

- Phone and email support
- Access to our members-only library of forms and training videos
- Access to our members-only discussion forum and FAQ listing
- Builder referrals
- Discounts on advanced training classes

Certified Home Energy Raters

Under the Uniform Accreditation Standard set by the Residential Energy Services Network (RESNET), a Home Energy Rating System (HERS) Rater must report to a HERS Provider for their Quality Assurance and certification process. Accurate Rater Network (ARN) can be your Provider. See our ARN Quality Assurance Program on the back cover.

ARN's home energy rating program has two categories of raters that are differentiated by the number of ratings the rater has successfully completed:

- **Probationary Rater** – Completed the rater classroom training and passed the course's examination or has passed a challenge test. We have a program available to guide individuals through the probationary period. See our ARN Mentoring Program below.
- **Certified Rater** – Satisfactorily conducted five field ratings, two during training and three in the field

For more information, see www.AccurateRater.com.

ARN Mentoring Program

The Accurate Rater Network (ARN) Mentoring Program has been developed to aid those starting rating businesses or those expanding their businesses for the ENERGY STAR, LEED® for Homes, and/or NAHB Build Green Programs, local, state or federal tax credits, and/or IECC code compliance.

This program is designed for individuals who have already passed the National RESNET HERS Rater test. It helps the rater gain knowledge from ARN's expert staff, such as performing ratings, inspections, and numerous other skills addressing building science issues.

The program guides individuals through their probationary rating period. Members of the ARN Mentoring Program also receive discounts on our wide variety of training and refresher courses.

Our Mentoring program includes the following:

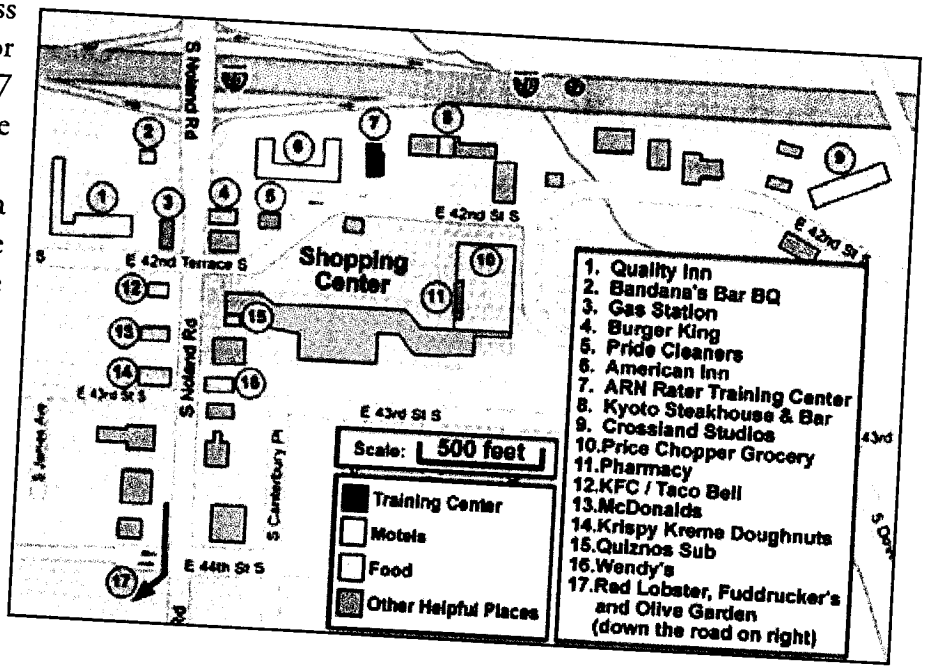
- Coordination and oversight of two required trainer mentored ratings. (Note: This support is provided at ***no charge*** to participants of the ARN Rater Training Class.)
- Telephone, Email Support and Quality Assurance Review of required Probationary Ratings.
- Rental of Equipment and Supplies. Includes Blower Door, Duct Blaster, Manometers, Hoses, Duct Mask, and Measuring Wheel.
- Rental of Tablet PC Loaded with Tectite and REM/Rate Software with Cabling for Automated Testing.
- Onsite Training and Assistance. A Certified HERS Rater will work with you at your jobsite.

Trainees Have Great Accommodations

We have a brand new first-class training facility. One of our criteria for the selection of this building (number 7 on the map to the right) was that it be perfect for our trainees.

Once you arrive, there are hotels a stone's throw, literally, from our Accurate Rater Training Facility. We have made arrangements for discounted rates with three very nice and inexpensive hotels for you to stay within walking distance. You will have multiple choices for eating, also very close at hand (such as Bandanas, Wendy's, Quizno's, Fuddruckers, Red Lobster, Olive Garden, and the Price Chopper Grocery Store). You are a quick 25 minute shuttle ride from the airport.

Yep, this is the perfect location.



Training Information

Accurate Rater Network is a RESNET Accredited Training Provider conducting home energy rater certification training and a BPI Accredited Affiliate conducting Building Analyst certification training. We offer advanced training and business development classes for energy professionals. Accurate Rater Network is also a LEED® for Homes Provider and offers training to those wanting to expand their business into this and other "Green" programs.

For Energy Auditors, we offer diagnostic training sessions including hands-on combustion safety testing and training in identifying and working with HVAC systems, water heaters, insulation, and other items that prove difficult for the energy specialist just starting out.

We have training sessions dedicated to specialized equipment use, maintenance and interpretation. Our training curriculum gives you the flexibility to learn and practice a little at a time, or to jump right in and cover a wide range of material all in one session.

Accurate Rater Network Training Classes:

- ***Basic HERS Rater Training*** - Training Preparation Course for the RESNET HERS Rater Test
- ***Advanced HERS Rater Training*** - Training aimed at the experienced Certified HERS Rater
- ***BPI Building Analyst*** - Home energy diagnostics, combustion equipment safety training and preparation course for the BPI Building Analyst test
- ***BPI Building Analyst Certification for the Certified HERS Rater*** - Shortened BPI course
- ***Field Inspector Training*** - Preparation course for the RESNET Field Inspector Test
- ***Running a Home Energy Rating / Home Energy Auditing Business*** - Marketing, bookkeeping, paperwork, oh my!
- ***Advanced Energy Auditor Training*** - Focused training on HVAC systems and construction practices and materials
- ***Green Rater Training*** - Preparation for the LEED® for Homes Third-Party Certification Role
- ***Green Verifier Training*** - Preparation for the NAHB Green Verifier Test

the dead space above on the attic side of the ceiling. That often creates an air leak, and it also makes it hard to keep the insulation in contact with the drywall air barrier. We fix those situations by installing rigid foam or drywall at the attic floor level and air-sealing the joints before blowing insulation.

Once the air-pressure boundary is sealed, insulation can be blown into the space. The key is to keep the insulation aligned with the air-pressure boundary and in contact with it. That way, the insulation can perform at its full rated value.

Houses with complicated rooflines and tight attic spaces offer the greatest challenge. On the cape shown in (**Figure 4, page 5**), we lined the knee-wall crawlspace with Typar, then blew the walls and the sloped portion of the ceiling with dense-pack cellulose. Above, in the attic, we sealed the air leaks individually, then installed loose-blown cellulose over the floor. The result is a continuous insulated boundary and a continuous air-sealed plane, both in contact with each other.

In houses that lack wall insulation, we blow dense-pack cellulose into the walls (**Figure 5, page 6**). This improves airtightness and boosts the wall's R-value.

Figure 7. The technician verifies the correct operation of a new furnace and water heater (left) and documents the safety of the new kitchen range (below left). A final blower-door test (below) indicates the increase in house airtightness, from 3,600 CFM-50 to just over 1,900 CFM-50.

Testing Out

I don't have space in this article to go into window replacements or hvac upgrades. Instead, I want to emphasize the crucial quality-control process — testing out after the work is done (**Figure 6, page 7**). The final tests are always performed by different technicians than the advisors who test in; that way, there's no unconscious bias in favor of fudging the numbers.

At the end of the test, our technicians hand the homeowners a certificate documenting the work that was done and the energy savings predicted — including the reduction in their "carbon footprint," in tons of carbon dioxide per year that their house will no longer contribute to the atmosphere. We want to make clear in the homeowners' minds the link between the improved comfort they'll be noticing, the money they're saving on their energy bills, and the good they are doing for the planet (**Figure 7**).

Onward. Then it's on to the next home — and we're not about to run out of candidates. Even with today's economy, I fear that, as somebody once phrased it, "they're building them faster than we can fix them."

I also believe that if you're going to sell this kind of service to homeowners, you ought to be willing to buy it yourself. I recently sold a house in Burlington, Vt., to which I gave the same complete makeover that we're giving to houses in Syracuse (and then some). My new house is a 1920s-vintage home with no insulation in the walls and just 3½ inches of insulation in the attic; my plan is to make it into a net zero-energy home. What I've discovered with these upgrades is that, completely apart from the money you save and the good you're doing, once you've experienced the comfort of that well-lit, comfortable, healthy indoor environment, you never want to go back.

***Mike Rogers** is senior vice president for business development at GreenHomes America; he's based in Burlington, Vt.*

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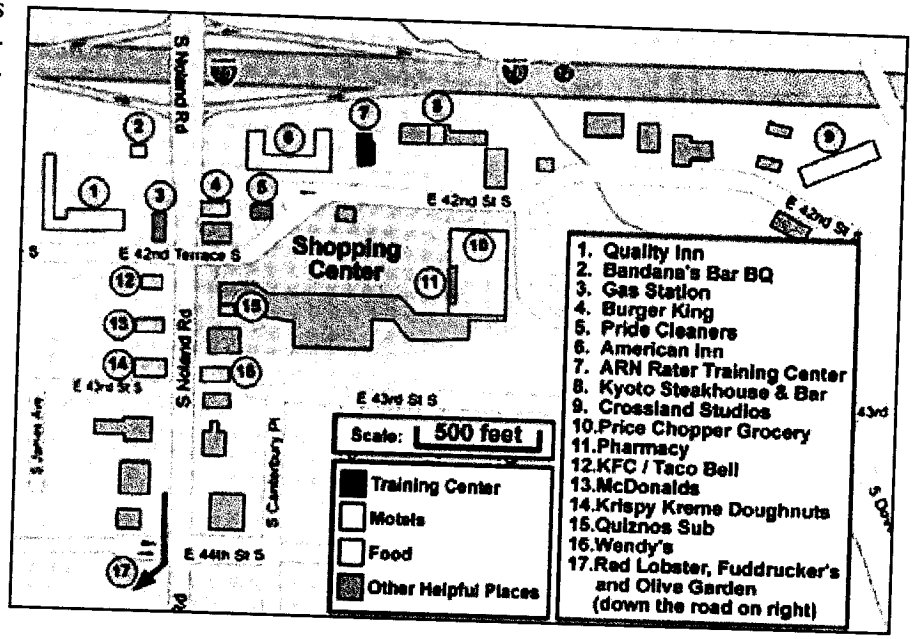

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ARN Quality Assurance Program

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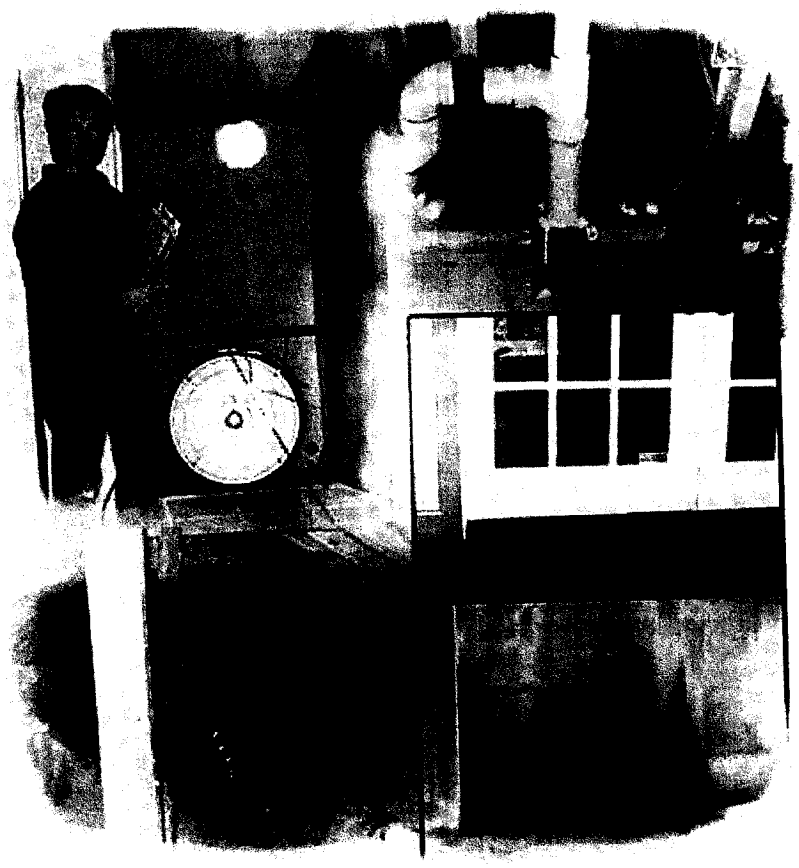
ARN personnel will perform the on-site visits for inspection verification required by RESNET.

- You submit your rating file to ARN once a rating of a home is complete. ARN reviews the rating and contacts you via email with any questions or corrections needed.
- Once the file is finalized, ARN will set print permissions allowing you to create final reports from the REM/Rate file for your clients and will mail you a Certification Sticker if applicable.
- ARN then archives the rating with the appropriate program.

To join the ARN network, you will need to sign the Annual Rater Agreement and return it to ARN along with the annual fee. You must also sign the REM/Rate Sub-License Agreement. Upon receipt of this signed agreement, you will receive the software along with a user ID and password for the software.



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Home Performance Contracting

Careful diagnostic testing is the key to cost-effective energy upgrades

by Mike Rogers

If you were to ask the average American to define "home performance contracting," you'd probably get a blank look. In fact, I doubt that most professional remodelers really know what it is. In coming years, though, I believe we're going to see home performance contracting become a household term. My own company, GreenHomes America, is betting on it: After three years fine-tuning our business model in Syracuse, N.Y., we're planning to go nationwide with company-owned branches and franchises, starting this year. What we've proven in Syracuse, we hope to repeat in every state.

Home performance contractors use a comprehensive "house as a system" approach to upgrading the energy systems in existing homes. We start with a complete battery of diagnostic tests and a careful analysis of the house's energy efficiency, comfort, and indoor environment. We call this "testing in." Then we apply the upgrades that make sense. After the work is done, we test the house again — "testing out" — to make sure that the measures we have installed are going to perform the way we intended and that we're leaving the home in a safe condition.

We're not consultants — we do most of the work ourselves. Our crews blow insulation, seal attics, put in doors and windows, and install furnaces and water heaters. We even put up solar water heaters and, occasionally, photovoltaic solar panels.

The way we work, homeowners get the benefit of "one-stop shopping" for the whole package of energy and comfort upgrades. More important, we take one-point responsibility for the way all the systems in the house will interact. It's not the usual situation, where one trade

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acuse, we have ads under
Windows, Insulation Contractors, and Heating and Cooling Contractors. And yet we're not a window company, or an insulation company, or an hvac contractor — instead, we're all three, but we're also more than that. So when we get sales leads from various sources — TV and radio advertising, print ads, the Yellow Pages, our Web site, or people who have noticed our phone number on our fleet of trucks — our first challenge is to explain to the caller what it is that we really do.

Energy efficiency is our focus, and we deliver energy savings every day. However, many people who call us are not necessarily looking for savings on their energy bill. Most Americans don't even know that a typical house can easily save 25 percent or more on its energy bills with a modest investment. So our typical customer is calling about something else — usually a comfort or performance issue, like a chilly draft or a room that's too hot or too cold all the time, or some durability problem like ice on the roof or moisture-related paint failure.

No matter what the reason for the call, we always provide the same service first: One of our advisors (we don't call them "salesmen") visits the house for a comprehensive inspection. We visually inspect the building, inside and out. We check airtightness with a blower door, we test the furnace and water heater for combustion efficiency and safe operation, we use infrared imaging cameras to find insulation voids or thermal bypasses, and we use smoke pencils to locate air leaks. We "sniff" the gas piping for leaks. Depending on the situation, we may measure duct system airtightness and airflows. Then, once we know exactly what's going on and how the house works, we recommend the upgrades that we predict will save the

Figure 1. After drilling holes to insert sensor probes in the appliance flues (top left), the advisor uses a combustion analyzer to check for complete combustion in the furnace and water heater (top right). With doors and windows shut and all exhaust fans in the building operating, he uses a manometer to check the draft (bottom left); he is also required to check gas piping for leaks (bottom right).

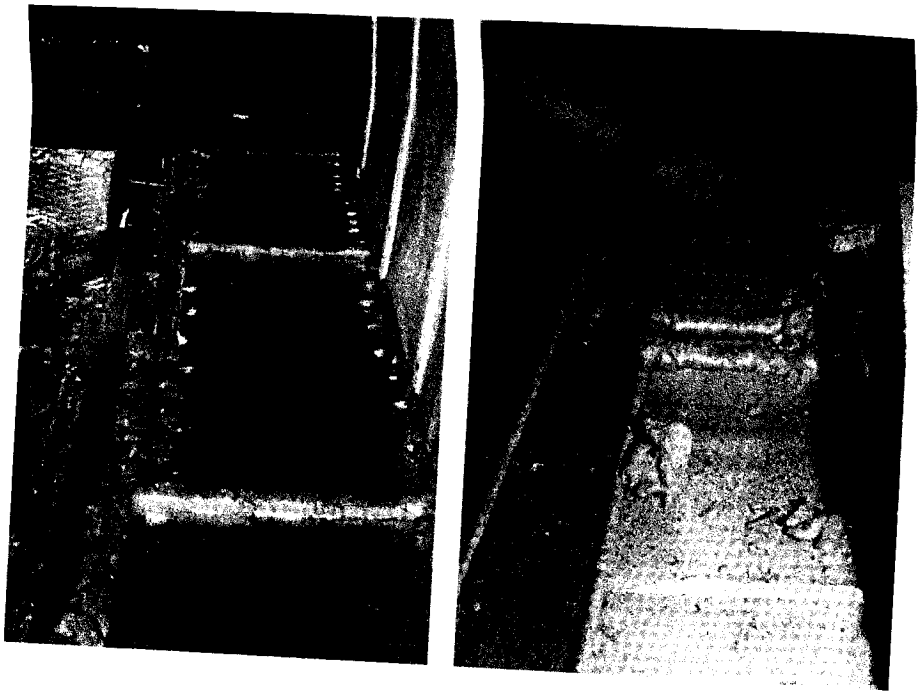


Figure 2. Crews seal spaces over cabinet soffits by installing rigid insulation across the opening at attic floor level and sealing the joints with foam (far left). Gaps where wall plates meet the attic floor must also be sealed (near left).

most energy most cost-effectively while also improving the safety and durability of the building.

Safety is one of the critical reasons for testing. We can't come in and tighten up a house that already has a carbon monoxide problem or a gas leak — we don't want to expose our crews to the hazard, and we clearly don't want to risk the homeowners' safety or incur legal liability. So without combustion testing and air-quality testing, we won't touch the house.

We also never quote prices before we've determined what the house needs. Ultimately, of course, it's the homeowners who will decide what to buy. After all, it's their investment and their budget. We might recommend insulating and air-sealing the attic as a first step, and they might decide they want new windows instead. But they don't have to make that choice blindly, because we give them good information to work from.

We occasionally lose customers. There are those who say, "I just want new windows, I don't want you going down into my basement," or "Joe said he would put in a new 95,000-Btu furnace for X dollars, I just want to know what your price is." But most of the time, customers appreciate our need to know what we're looking at before we start trying to sell them a product. And our goal is to have a lifetime relationship with every customer (in fact, one good reason to install the hvac systems ourselves is that it means we will visit that house again every year for routine maintenance).

Testing In

Our advisors are the primary point of contact with the homeowner. They need a lot of training to be ready for this work, because they do a lot: Each advisor is a diagnostician and a salesperson rolled into one. It's quite technical — the advisor has to know how to operate the blower door, use the combustion testers, run the duct blaster, operate the infrared camera, visually inspect the house, and interpret all the results. But he also needs good sales and communication skills, because he has to make our analysis of the house understandable to a layperson — and at the end of the day, he has to put together a scope of work, sign the agreement with the customer, and get that deposit check.

Combustion testing. Furnace and water-heater efficiency are key elements of a home's energy efficiency, and their safe operation (and that of the gas range in the kitchen) is important for the safety of the home. So our advisor checks flue gases with a combustion analyzer to measure the system's baseline performance (**Figure 1, page 2**).

Appliance vent draft. The advisor also assesses the ability of heating appliances to draft properly. Flue draft and room air pressures are related: If the draft is weak, and there's also negative pressure in the basement, the unit could backdraft and send combustion products into the living space. We need to know what might happen in the worst case. So the advisor closes all the windows and doors, turns on all the exhaust fans in the house — the range hood, bath vent fans, the clothes dryer — and checks the pressure difference between indoors and outdoors. He compares his reading with a standard set by BPI, the Building Performance Institute (bpi.org). Whatever change we make to the home must correct any pressures that fall outside recommended levels.

Sniffing for gas leaks. GreenHomes is "accredited" by the Building Performance Institute — a contractual relationship that means all our personnel must earn BPI certification. It also means we agree to correct certain deficiencies in any house we work on: We're required to test for leaks on any accessible gas piping and

repair any leaks we find (or, if they are on the gas company's side of the meter, call the utility in to fix them).

Blower-door testing. We use the blower door to measure the total air leakage of the house. If the house leaks too much, it costs too much to heat and cool. On the other hand, if it's too tight, it may need mechanical ventilation for fresh air and will require direct-vented combustion equipment. Most houses we work on start out too leaky. So the "test-in" blower-door values provide us with a baseline; after we do our work, we'll test again to make sure we accomplished the air-tightening we set out to achieve.

To run the test, the advisor shuts all the windows and doors, blocks off the fireplace, and installs his equipment in the door. He runs an air line from his manometer to the outside, then runs the blower-door fan and records the airflow required to bring the house to -50 pascals of pressure compared with outdoors. That number can be used to estimate the air-leakage area of the house envelope, which gives us an idea of how much air-sealing work will be needed.

The blower door gives you an aggregate airtightness number, but you still need to run around and locate the leaks, using smoke pencils. (The attic, by the way, is typically where most of the leaks are.)

Infrared imaging. The infrared camera lets us locate areas where there's not enough insulation or voids — where somebody missed a spot, the batts are compressed, or blown insulation has settled.

The IR camera is also helpful for educating the homeowner. Rather than try to explain all the science, we can bring the homeowner along as we inspect, and show them the cold or hot spots on the screen. When the blower door is operating, those spots show up even better on the camera display, as the suction pulls outdoor air in through leaky uninsulated spaces.

Infrared cameras are getting better and cheaper as technology advances. The best new equipment will reveal insulation defects when there's just a 5°F difference from inside to outside (it doesn't matter whether the outside is warmer or colder than the inside, as long as they're different). And prices for the equipment have come down, too: Ten years ago a good camera might have cost more than $20,000, while today you can get a camera with better resolution, a better sensor, and a lot more functions for around $5,000.

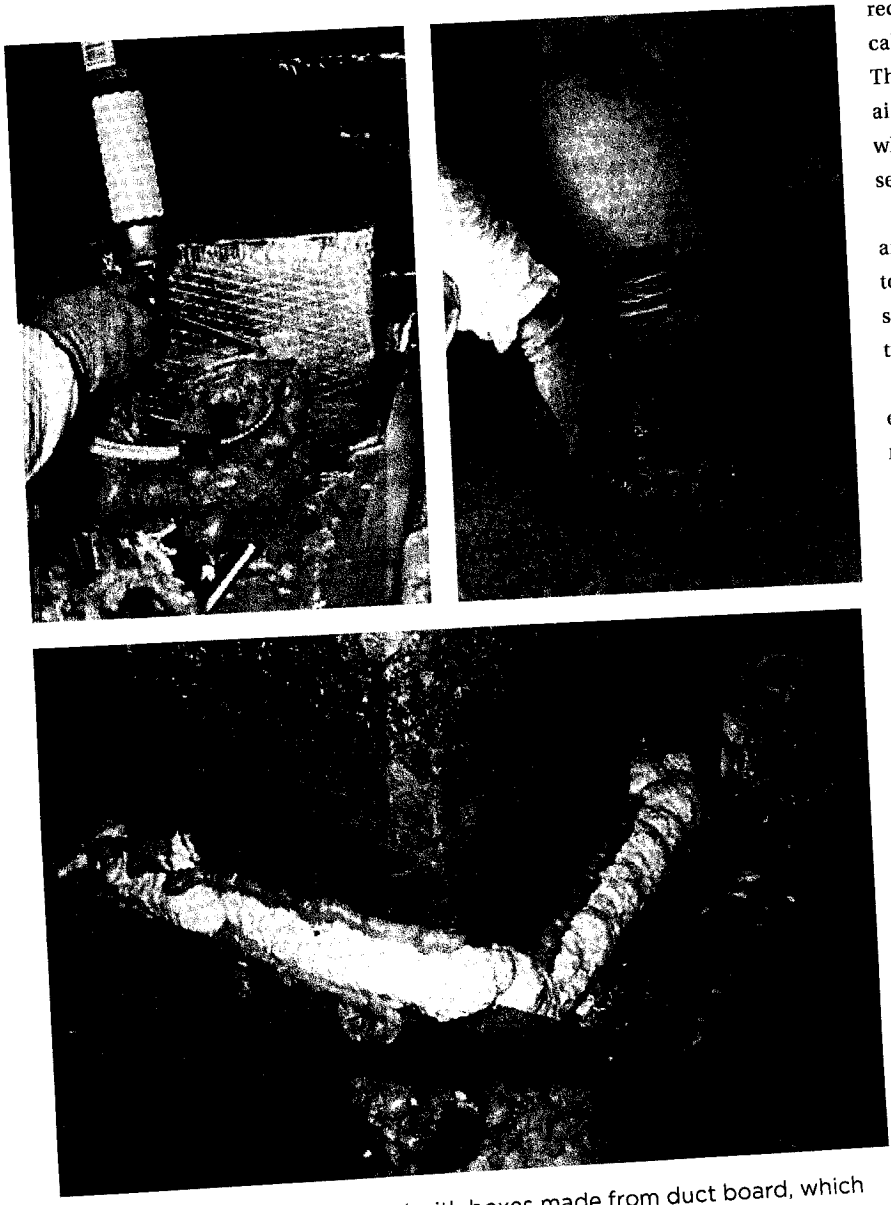


Figure 3. Can lights are covered with boxes made from duct board, which are foamed in place (top left); hvac boots are also sealed (top right). This chimney (above) was decommissioned when a direct-vent furnace was installed, so the crew has sealed around it with foam; air gaps around active chimneys are sealed using sheet metal and high-temperature silicone caulk.

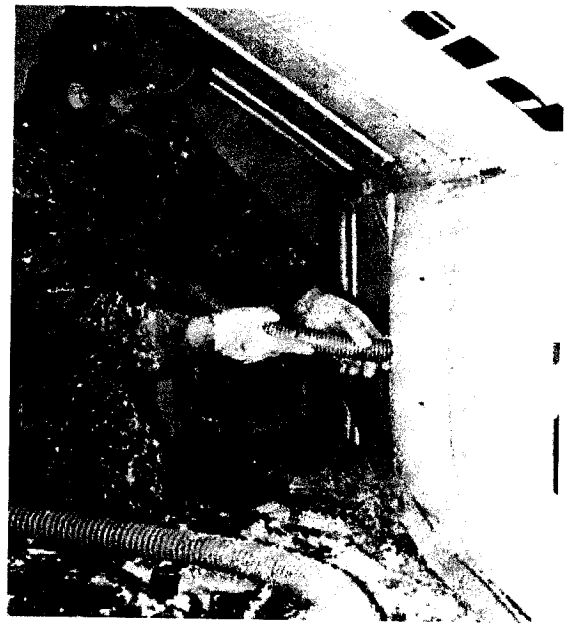


Figure 4. Here, a crew has applied housewrap to the inside face of a knee wall and low roof and is dense-blowing cellulose into the wall cavities (right) and the short sloped section of ceiling (above).

Testing ductwork. We test ductwork when we need to. Purists may insist that you should do a duct-blaster test on every house you work on. But if the ducts are all inside the conditioned space, testing them is a low priority for us. We're more concerned that the pressures and airflows are balanced.

In predominantly heating climates, where the ducts are in the basement, research and our own experience both show that duct leakage is not very important — it's all within the conditioned space anyway. So we focus our efforts on the envelope instead.

In the South, on the other hand, where air-conditioning ducts typically run through an unconditioned hot attic, it's critical that you take a close look at duct leakage and do a very thorough job of sealing any leaks you find. But even then, duct blasting when you're testing in may be superfluous. If you can see at a glance that the ductwork needs to be torn out and redone, you shouldn't spend hours on a duct-blaster test first — moving the furniture around, sealing registers, and so forth. The important thing is to test after the work is done, to verify the performance of the new ducts. (For more on duct testing, see "Pressure-Testing Ductwork," 4/03.)

Evaluating the Data

We always give the homeowner an estimate of how our upgrades will affect the home's energy bills. We offer a 25 percent energy-savings guarantee, whether there's a government program involved or not, if the customer chooses to install the entire package of measures we recommend. In our experience, you can achieve that degree of improvement in almost any house. Even a brand-new code-compliant house can usually cut its energy bills 25 percent — after all, code is the legal minimum, not some kind of high-performance ideal.

We don't rely on computer models; among energy practitioners, they're notorious for overestimating the savings. If we're working in a local or state program that requires us to model the house, we'll do it — but I'd be terrified to use a computer model as the basis for our own energy-savings guarantees. Instead, we use our own in-house methods, based on experience, to predict energy savings. However, you can get pretty close with publicly available methods that anyone can use. The EPA has a useful tool for analyzing utility bills posted on its Home Performance with Energy Star Web site. BPI also has a statistical database of before-and-after home energy bills that you can use to make a fair estimate of how an upgrade will change a house's performance.

Assessing utility bills. We start by taking a careful look at the utility bills. We "dis-aggregate" the utility bill, breaking it down to figure out where the major loads are and how the energy is being used. And based on the improvements we recommend, we do a very conservative estimate of the savings we want to see.

Here's a simplified example. Let's say you have all the gas bills for a house that is heated with gas. You can track the usage month by month for the past year. July 1 is a good starting point, because we know the house isn't being heated. So the gas bill that month reflects what the occupants use for everything else: cooking, water heating, and maybe a gas clothes dryer. When fall comes, that number starts to rise. It climbs through November and December and on into the dead of winter. Then in February or March it starts to decline again. If you graph it, you get a bell-shaped curve.

From the summer bills, we know the home's baseline usage for nonheating needs. Now we can figure out what portion of the midwinter bill goes for space heating. With that, we can pretty well figure out how much we stand to save if we improve the insulation by so much, if we reduce the

building air leakage by so much, or if we change from an 80 percent efficient furnace to a 94 percent efficient furnace.

In the same way, we can pick apart the electric bill. We figure out how much each appliance is responsible for: the refrigerator, the air conditioner, the blower motor on the furnace, lighting, and so on. And we can guess pretty accurately how much the owners will save if we improve each of those elements.

It takes experience to make accurate estimates. But once that experience is acquired, a careful house-by-house analysis is more reliable than any software on the market today.

Of course, the homeowners make the final call on what we do — it's their money, and they get to decide. Naturally, they often make their decisions based on things other than energy savings. They may choose a furnace because they like the easy controls, or buy insulation and air-sealing to make their home office more comfortable. Still, the energy savings are always a plus. We like to show customers that with the financing we can help them get and with other available incentives — plus the reduction in energy use they'll achieve — they could end up with extra cash in their pocket every month.

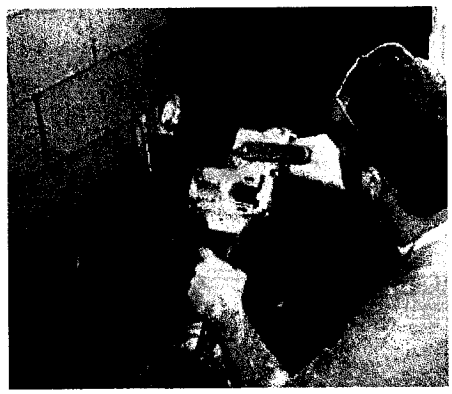
Upgrading the House

Once we've reported our assessment and the homeowners have made choices, we move to the next phase of the job, implementation. As I mentioned above, energy efficiency is not always the customer's only objective. But when reduction in energy use is in fact the main goal, the most cost-effective upgrade is almost always air-sealing and insulation.

I'm continually amazed at how many houses in the cold Northeast are underinsulated. Many old houses still have no wall insulation and just a few inches of attic insulation. Even houses built in the last three years typically offer major opportunities to improve the air-sealing and insulation. Crews may miss spots when they insulate, and most builders still pretty much ignore air-sealing in the attic. So a good air-sealing job is usually our top recommendation.

The next step is typically to upgrade the heating and cooling system. There are lots of 80 percent efficient furnaces out there, but in heating climates it's usually worthwhile to upgrade to a 95 percent efficient unit or better, and to replace old air handler motors with new variable-speed ECM (electronically commutated) motors.

When it comes to cooling systems, our



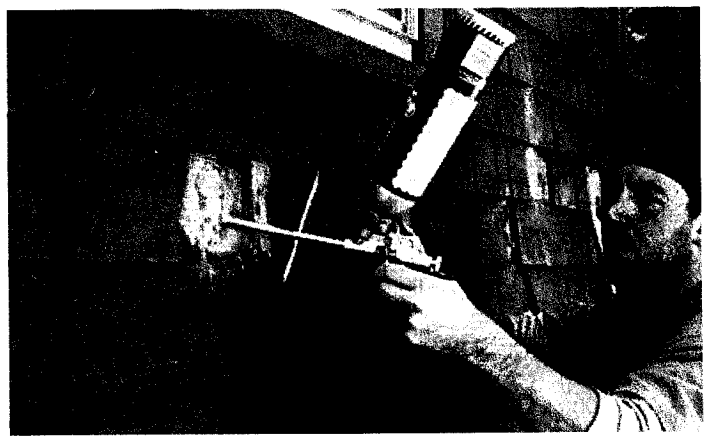


Figure 5. A GreenHomes wall-insulation crew carefully cuts off wood shingle siding to expose the sheathing (far left), then drills holes for the insulation blower hose (left). After blowing in the cellulose (below left), they seal the holes in the sheathing with closed-cell expanding foam (below), then carefully renail the shingles.

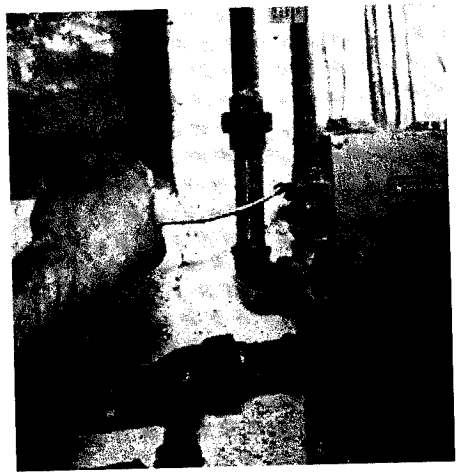


Figure 6. "Testing out" is a key element in quality assurance and customer service. In the house shown here, the technician saw the need to touch up the mastic on the basement ducts (far left). More important, he discovered a previously unnoticed gas leak (left) — a leak that probably became evident after other fittings in the piping were tightened.

recommendation depends on the climate. In Syracuse, where most houses don't even have air conditioning, installing anything higher than SEER 14 or 15 doesn't make much sense. But in Houston or Dallas, you'd want to consider a SEER in the high teens or twenties.

Windows, typically, are not high on our list. Almost all homeowners think they can get big improvements from high-performance windows — the window industry has done a great job of selling that idea. But in reality, windows are usually the least cost-effective energy upgrade.

Homeowners may have good reasons to get new windows — the old ones may be in bad condition or painted shut. And if they're getting new windows anyway, it always makes sense to choose energy-efficient units, because the difference in cost is trivial. But getting new windows just for energy-performance reasons doesn't usually pay. We're careful to be clear with homeowners about that. (This doesn't hurt us, by the way. We still sell and install a lot of replacement windows.)

Although they seldom accept our entire package of recommendations, homeowners usually decide to adopt several measures. Sometimes it makes more economic sense to upgrade the furnace and air conditioner than to buy new windows. But if the plan is to do both, we upgrade the windows before replacing the hvac equipment. Shell upgrades — like windows or insulation — let you reduce the size of the hvac system, which saves upfront cost as well as the expense to operate the equipment.

In our experience, solar thermal panels — rooftop water heaters — typically turn out to be a smarter investment than new windows when considered individually. This is true even in a northern market like Syracuse. We're very excited about the potential market for solar water heating. The new systems are much simpler and more reliable than those of the 1970s or '80s, when you had to be a master plumber and a mechanical engineer and build the whole thing from scratch yourself. These days, a solar thermal installation is essentially an appliance that you mount on the roof. You may still need a licensed plumber to tie it in, but it's no more complicated than tying in a standard water heater or any other appliance.

Upgrading the lighting is also usually cost-effective. On most houses, we offer a basic lighting upgrade for free — we just walk around with a 12-pack of compact fluorescent bulbs and replace every incandescent bulb we see. For a few important high-use fixtures, we may recommend replacing the whole fixture with an advanced unit.

Air-Sealing and Insulating

The attic is usually the gold mine of opportunity (**Figure 2, page 3**). Even today, builders rarely give it the attention it deserves. The stack effect places the boundary between the living space and the attic under a lot of pressure, and the ceiling is a large area. In most houses, air constantly flows across that plane.

The goal is to keep the indoor air that you've paid to heat or cool down in the living space where it belongs. So our crew goes through the attic and finds every hole that connects to downstairs (**Figure 3, page 4**) — plumbing chases, chimneys, vent pipes, electric wiring, duct penetrations, whatever — and seals them. They also look for joints where dissimilar materials meet. Partition walls often communicate with the attic, at cracks and gaps between the drywall and framing.

In a one-story home, kitchen cabinet soffits are a major point of leakage. In new construction, a good approach is to install drywall on the ceiling before you build the soffit, creating a continuous air barrier at the ceiling level. But in most existing houses, those soffits were framed before the drywall was installed, leaving

the dead space above on the attic side of the ceiling. That often creates an air leak, and it also makes it hard to keep the insulation in contact with the drywall air barrier. We fix those situations by installing rigid foam or drywall at the attic floor level and air-sealing the joints before blowing insulation.

Once the air-pressure boundary is sealed, insulation can be blown into the space. The key is to keep the insulation aligned with the air-pressure boundary and in contact with it. That way, the insulation can perform at its full rated value.

Houses with complicated rooflines and tight attic spaces offer the greatest challenge. On the cape shown in (**Figure 4, page 5**), we lined the knee-wall crawlspace with Typar, then blew the walls and the sloped portion of the ceiling with dense-pack cellulose. Above, in the attic, we sealed the air leaks individually, then installed loose-blown cellulose over the floor. The result is a continuous insulated boundary and a continuous air-sealed plane, both in contact with each other.

In houses that lack wall insulation, we blow dense-pack cellulose into the walls (**Figure 5, page 6**). This improves airtightness and boosts the wall's R-value.

Figure 7. The technician verifies the correct operation of a new furnace and water heater (left) and documents the safety of the new kitchen range (below left). A final blower-door test (below) indicates the increase in house airtightness, from 3,600 CFM-50 to just over 1,900 CFM-50.

Testing Out

I don't have space in this article to go into window replacements or hvac upgrades. Instead, I want to emphasize the crucial quality-control process — testing out after the work is done (**Figure 6, page 7**). The final tests are always performed by different technicians than the advisors who test in; that way, there's no unconscious bias in favor of fudging the numbers.

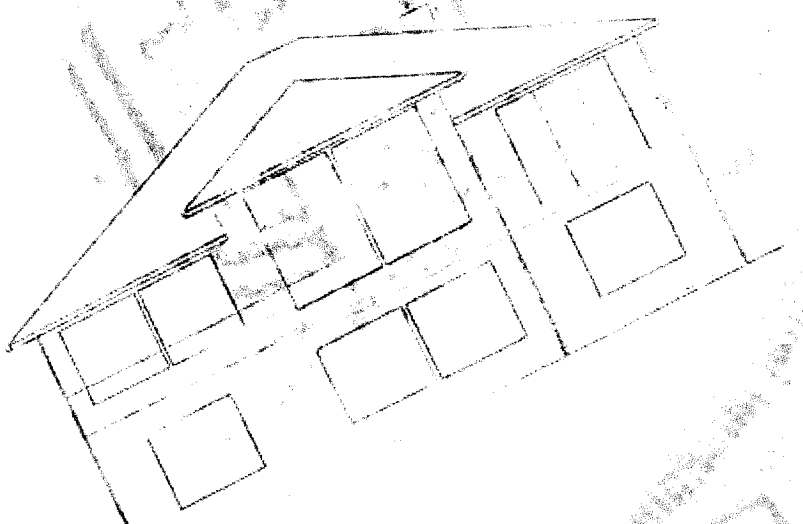
At the end of the test, our technicians hand the homeowners a certificate documenting the work that was done and the energy savings predicted — including the reduction in their "carbon footprint," in tons of carbon dioxide per year that their house will no longer contribute to the atmosphere. We want to make clear in the homeowners' minds the link between the improved comfort they'll be noticing, the money they're saving on their energy bills, and the good they are doing for the planet (**Figure 7**).

Onward. Then it's on to the next home — and we're not about to run out of candidates. Even with today's economy, I fear that, as somebody once phrased it, "they're building them faster than we can fix them."

I also believe that if you're going to sell this kind of service to homeowners, you ought to be willing to buy it yourself. I recently sold a house in Burlington, Vt., to which I gave the same complete makeover that we're giving to houses in Syracuse (and then some). My new house is a 1920s-vintage home with no insulation in the walls and just 3 1/2 inches of insulation in the attic; my plan is to make it into a net zero-energy home. What I've discovered with these upgrades is that, completely apart from the money you save and the good you're doing, once you've experienced the comfort of that well-lit, comfortable, healthy indoor environment, you never want to go back.

***Mike Rogers** is senior vice president for business development at GreenHomes America; he's based in Burlington, Vt.*

Building Affordable ENERGY STAR® Qualified Homes



HAC

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HAC, founded in 1971, is a nonprofit corporation that supports the development of rural low-income housing nationwide. HAC provides technical housing services, loans from a revolving fund, housing program and policy assistance, research and demonstration projects, and training and information services. HAC is an equal opportunity lender.

Building Affordable ENERGY STAR® Qualified Homes

Housing Assistance Council

2009

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INTRODUCTION

Rising energy prices have forced many low-income households—the majority of which pay a much greater share of their income on energy costs—to make tremendous sacrifices. Studies show that more families are now choosing between heating their homes and buying groceries, paying their utilities or refilling a prescription (American Gas Association 2007). Although the challenges faced by these households are many, proven methods do exist for improving the energy efficiency and reducing the operating cost of their homes. Many affordable housing developers have incorporated these methods and are building energy efficient housing in order to protect low-income households from further economic hardship.

The United States Department of Housing and Urban Development (HUD) has also developed new energy strategies for affordable housing, which has led to some increases in minimum efficiency requirements. For example, under the Energy Policy Act of 2005, public housing authorities are now required to purchase ENERGY STAR® qualified products. The Self-Help Homeownership Opportunity Program recently established ENERGY STAR® certification as a minimum requirement for all newly constructed units, and several HUD competitive grant programs award points for energy efficiency. HUD also stated in the 2007 SuperNOFA that ENERGY STAR® certification may soon be established as a requirement for all HUD competitive grant programs (HUD 2008).

HUD Implements New Energy Efficiency Standards

Program offices may now award points for energy efficiency in competitive applications for:

- Section 202 Supportive Housing for the Elderly
- Section 811 Supportive Housing for Persons with Disabilities
- HOPE VI
- Rural Housing and Economic Development
- Housing Opportunities for Persons with AIDS (HOPWA)
- Indian Community Development Block Grants
- Housing Counseling
- University Partnerships Program

Source: *U.S. Department of Housing and Urban Development www.huduser.org/publications/pdf/EnergyReport_08.pdf*

These new requirements and incentives are helping to fuel the transition to energy efficient affordable housing. However, this transition is difficult for many organizations that now must navigate a new world of construction modifications, home energy raters, and unfamiliar requirements. This guide serves as a tool for rural nonprofit organizations building ENERGY STAR® qualified homes, outlining the basic steps, providing advice from home energy raters, and sharing best practices from affordable housing developers in the field.

ENERGY STAR® Qualified Homes

The energy efficiency of today's homes continues to improve as a result of new policies, innovative technologies, and effective programs such as ENERGY STAR®. ENERGY STAR® is a joint program of the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Energy

(DOE), helping consumers save money and protect the environment through energy efficient products and practices (EPA 2009a).

Since its introduction in 1992, the ENERGY STAR® blue label has been awarded to products in over 60 categories, becoming a recognizable indicator of energy efficiency. In addition to products, any single- or multi-family structure of up to three stories can earn the ENERGY STAR® rating by complying with high efficiency performance guidelines and passing an inspection by a certified home energy rater. Units in four and five story buildings can also earn the ENERGY STAR® rating if the units are permitted as residential structures and each unit has its own heating, cooling, and hot water systems separate from other units. (EPA 2009a).

According to the EPA, ENERGY STAR® qualified homes have energy efficient features that make them at least 15 percent more efficient than homes built to the 2004 International Residential Code, and 20 to 30 percent more efficient than standard homes. Further, the rigorous building standards of an ENERGY STAR® qualified home improve durability and comfort with better indoor air quality and more even temperatures throughout the house (EPA 2009b).

Features of an ENERGY STAR® Qualified Home

- Effective Insulation
- High Performance Windows
- Tight Construction Ducts
- Efficient Heating and Cooling Equipment
- Efficient Lighting and Appliances
- Third-Party Verification

Additional information on the ENERGY STAR® program and ENERGY STAR® qualified homes is available online at www.energystar.gov/homes.

Building an ENERGY STAR® qualified home is a realistic goal for any developer. However, successful certification of the unit requires a high degree of planning, coordination, and the use of a certified home energy rater. For those developers preparing to take on the additional requirements of ENERGY STAR® certification, the first step is to find a certified home energy rater excited about the project and willing to take an active role.

Choosing A Home Energy Rater

Residential Energy Services Network (RESNET®)—a national nonprofit organization whose mission is to ensure the success of the building energy performance certification industry, set the standards of quality, and increase the opportunity for ownership of high performance buildings—has trained and certified a network of home energy rating providers across the country. These home energy rating providers are, in-turn, authorized to train and certify home energy raters, all of whom must pass a national test and abide by RESNET® standards and procedures (RESNET® 2009a).

To connect housing developers with nearby certified home energy raters, ENERGY STAR® and RESNET® both maintain directories which are found on the websites below. Raters on the ENERGY STAR® website have joined ENERGY STAR® as partners and have experience doing ratings specifically for homes earning the ENERGY STAR® label. In addition to searching online,

Locate a Home Energy Rater

Residential Energy Services Network (RESNET®)
www.resnet.us/directory/raters.aspx

ENERGY STAR®
www.energystar.gov/index.cfm?fuseaction=new_homes_partners.showHomesSearch

developers may also find it beneficial to seek recommendations from partner architects, builders, engineers, city code officials, or other affordable housing developers. It is also recommended that developers building their first ENERGY STAR® qualified project interview a number of raters to compare rates, services, and experience or interest in affordable housing.

"Ratings of single-family homes typically run in the $800 to $1,200 range, depending on size," says Art Paterson of AJP Development LLC, a HERS rater in New Mexico. Many raters charge a set fee that includes an initial rating of the construction plans and two onsite visits; one pre-drywall and one post-construction. As described in one of the following case studies, some raters may also inspect the home before insulation is installed to examine the framing and ductwork.

Home energy raters are often knowledgeable in other aspects of green building, such as water efficiency, environmentally preferred products, renewable energy options, waste reduction and recycling, smart growth, and improved indoor environments. If interested in incorporating these elements into the project, the developer should ask potential raters about their experience and/or interest in green building. Raters who have received additional training in green building techniques are certified by RESNET® as Green Raters and are identified by the Green Rater icon in RESNET's® online directory (RESNET® 2009b).

Unfortunately, it is often difficult for home energy raters to discount their services as it requires the same effort and resources to rate an affordable project as it does a market rate project. However, opportunities do exist for reducing home energy rating costs. For example, housing developers building multiple units can take advantage of the sampling method, under which the rater conducts a random onsite inspection and rating on one out of every seven housing units in the development. There are strict guidelines for the sampling protocol and not all providers are accredited in this method, so developers should check with their rater. Home energy rating providers trained and accredited to oversee sampling ratings are listed online at www.natresnet.org/programs/sampling_providers/default.htm.

Important Questions for Home Energy Raters

- Is the rater certified by RESNET®?
- How many units has the rater tested?
- Where was the rater trained?
- How far will the rater travel?
- Is the rater's provider local or out-of-state?
- Does the rater have any experience in affordable housing?
- Is the rater willing to work hands on to improve the home's energy efficiency while still keeping it affordable?

CHOOSING A PATH: PRESCRIPTIVE OR PERFORMANCE

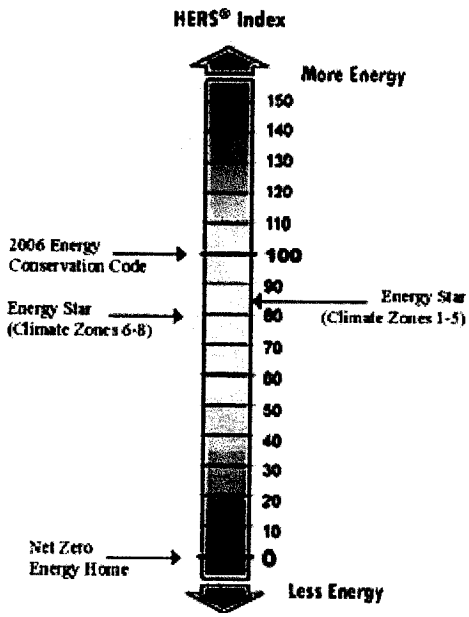
In most states, housing developers may follow either the prescriptive path or the performance path to ENERGY STAR® certification. However, developers in Washington, Oregon, California, Hawaii, and Florida[1] should review state and region-specific ENERGY STAR® requirements with their certified home energy rater. Developers in Idaho and Montana may use either the national ENERGY STAR® program or the regional Northwest ENERGY STAR® program. More information on ENERGY STAR® certification in these states may be found on the websites below (EPA 2009d).

Regional and State ENERGY STAR® Guidelines

Washington and Oregon
www.northwestenergystar.com

California, Hawaii, and Florida
www.energystar.gov/index.cfm?c=bldrs_lenders_raters.homes_guidelns

The *performance path*, which is generally preferred among affordable housing developers, allows for the flexibility to accommodate conditions unique to the locality and project. Projects following this path must receive a passing score on the HERS® Index, a standard measurement of energy efficiency created by RESNET® (RESNET® 2009d).



Provided by RESNET.

An energy rater calculates a home's score on the HERS index by entering the home's construction features as well as onsite testing results into a RESNET®-approved software program. As illustrated in the graphic, a zero-energy home[2] scores 0 on the HERS Index, a home built to the 2006 International Energy Code scores 100, and each 1 point decrease on the Index is equal to a 1 percent increase in energy efficiency. To earn the ENERGY STAR® label, a home must score ≤85 on the HERS Index in climate zones 1-5 or score ≤80 in climate zones 6-8 (EPA 2009e). *(See map on page 5)*

The *prescriptive path* requires the builder to follow a Builder Option Package (BOP) and does not utilize the HERS Index. BOPs—which are searchable by climate zone and county on the ENERGY STAR® website—contain construction specifications for the home's heating and cooling equipment, thermostat,

1 Homes permitted in Florida after June 1, 2009 must achieve a HERS Index of 77 or better to earn the ENERGY STAR.

2 A zero-energy home is an energy-efficient home that produces at least as much energy as it consumes.

ENERGY STAR® Qualified Homes 2011

ENERGY STAR® has released a proposed new specification for homes. Once finalized, it will replace current requirements. The new specification is proposed to go into effect on January 1, 2011, and is posted on the ENERGY STAR® website: www.energystar.gov/index.cfm?c=bldrs_lenders_raters.nh_2011_comments

ductwork, envelope, windows, water heating, lighting, and appliances. Homes built to BOP specifications consistently meet ENERGY STAR® guidelines.

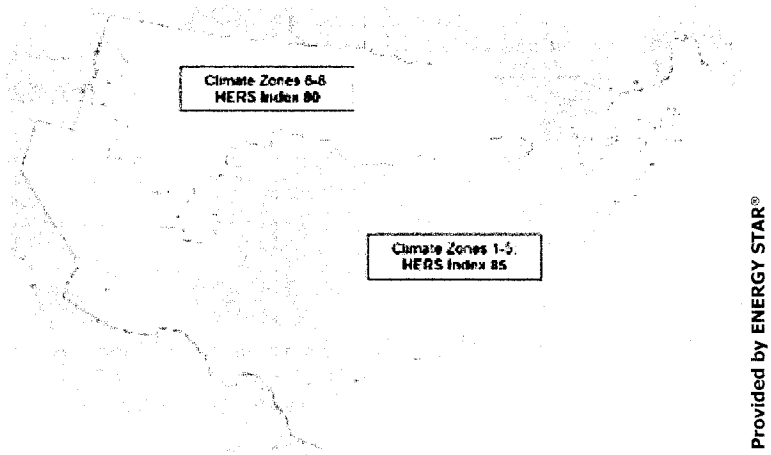
All ENERGY STAR® qualified homes, regardless of the path taken to certification, must pass onsite testing and inspections by a certified home energy rater (EPA 2009d).

Designing For ENERGY STAR® Certification

"Home energy raters are excited about saving energy," says David Mann of Energy Matters LLC, a HERS provider in New Mexico. "They should be brought in at the design stage if possible to offer energy-relevant input and perform a projected rating based on the plans." A projected HERS report, which assesses the planned insulation levels, window efficiency, wall-to-windows ratio, heating and cooling systems, solar orientation of the home, water heating system, and other energy related elements, provides an accurate indication of whether the completed home will earn the ENERGY STAR® rating (RESNET® 2009c).

The home energy rater produces the report with the use of a RESNET®-approved software program, which, if necessary, provides recommendations and suggestions to bring the projected rating within ENERGY STAR® performance levels (≤85 or ≤80 depending on the climate zone). The report also provides an estimate of the annual energy costs of the home as well as any energy savings that would result from specific design modifications or upgrades.

Not consulting with a home energy rater during design can create delays and obstacles down the road. If brought into the project after the design phase, the home energy rater may tell the project



Provided by ENERGY STAR®

Note: Due to the unique nature of some state codes and/or climates. EPA has agreed to allow regionally-developed definitions of ENERGY STAR in California, Hawaii and the Pacific Northwest to continue to define program requirements. The States of Montana and Idaho may use either the requirements of the national program or the regionally-developed program in the Pacific Northwest.

manager to make adjustments, such as redoing the furnace or upgrading the insulation. These types of modifications may result in additional architectural and design fees or other unexpected costs. If the home energy rater is consulted after construction has begun, it may be too late for ENERGY STAR® certification altogether.

Home Energy Rating System (HERS) Report

A HERS report is similar to a miles-per-gallon rating on a car. HERS reports, which are prepared by a trained energy rater, provide an evaluation of an individual home's energy efficiency. Factors such as insulation, appliance efficiencies, window types, local climate, and utility rates are used to rate the home and calculate energy costs.

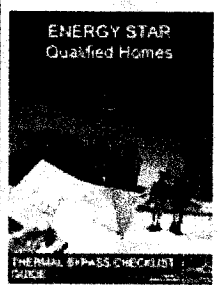
A HERS Report Includes:

- Overall Rating Index of the house as it is
- Recommended cost-effective energy upgrades
- Estimates of the cost, annual savings, and useful life of upgrades
- Improved Rating Index after the installation of recommended upgrades
- Estimated annual total energy cost for the existing home before and after upgrades

Source: U.S. Department of Housing and Urban Development www.hud.gov/offices/hsg/sfh/eem/eemhog96.cfm

Developers interested in the prescriptive path to ENERGY STAR® certification should consult with their certified home energy rater and refer to the climate specific builder option packages available on the ENERGY STAR® website. To earn the ENERGY STAR®, the project must follow the correct BOP and pass an onsite inspection by a certified home energy rater.

Thermal Bypass Resources for Builders



Thermal Bypass Checklist: www.energystar.gov/index.cfm?c=bldrs_lenders_raters.thermal_bypass_checklist

ENERGY STAR® Guide: www.energystar.gov/ia/partners/bldrs_lenders_raters/downloads/TBC_Guide_062507.pdf

RESNET® Guide: www.natresnet.org/rater/checklist/Thermal_Bypass_Checklist.ppt#886,1

Preparing for an ENERGY STAR® Build: Both Paths

As the designs are finalized, it is critical that the project manager and home energy rater discuss the timeline with the builder and contractors, explaining the onsite inspections and the importance of communication. During the construction of the home, the builder, contractors, and laborers should communicate any changes, regardless of how small or insignificant, to the home energy rater. Not doing so could jeopardize ENERGY STAR® certification.

Before construction, the builder should also review the requirements for the thermal bypass checklist and discuss any concerns or questions with the home energy rater. The Thermal Bypass Checklist is available in Spanish and English on the ENERGY STAR® website. Guidance for building to the thermal bypass checklist is found on both the ENERGY STAR® website and the RESNET® website.

Before construction, the builder should also register as an ENERGY STAR® partner on the ENERGY STAR® website. Becoming an ENERGY STAR® partner gives builders the opportunity to use the ENERGY STAR® partners-only logos (www.energystar.gov/logos) in promoting ENERGY STAR® qualified homes. Partners are listed on the ENERGY STAR® partner locator tool, a searchable tool for locating and contacting builders, raters, lenders, and program sponsors who are directly involved in the construction and sale of ENERGY STAR® qualified homes.

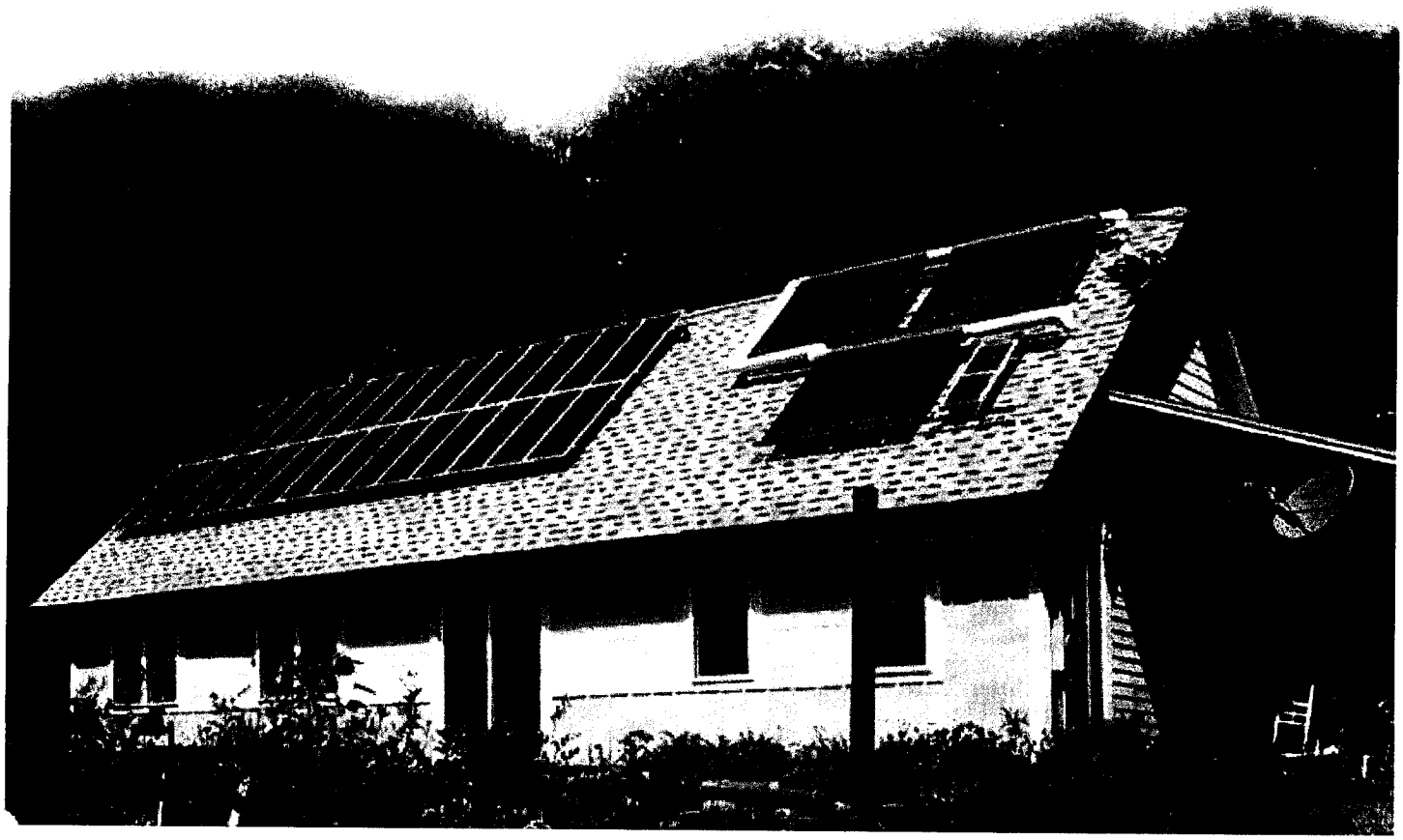


Photo courtesy of Rural Development Inc.

BUILDING AN ENERGY STAR® QUALIFIED HOME

After the plans have been finalized, the rater will clear the construction team to begin the framing and insulation of the home. While framing and insulating, it is important that the team be mindful of the thermal bypass checklist, which the rater will use to conduct the first onsite inspection. During the first inspection, the rater will examine the insulation, overall air barrier, thermal barrier alignment, walls adjoining exterior walls or unconditioned spaces, floors between conditioned and exterior spaces, shafts, attic and ceiling interfaces, and common walls between dwelling units (EPA 2009c). The home energy rater may also conduct a duct blaster test at this time to measure the air-tightness of the ducts.

Photo provided by CHP.

Construction crew members insulate a duplex for Community Housing Partners. Successful ENERGY STAR® certification requires that a HERS rater inspect the home after insulation has been installed and before drywall is hung.

Raters recommend that these tests be scheduled while the HVAC contractor is still onsite. If the rater detects any problems with the duct system, the HVAC contractor can repair them immediately and the home energy rater can test or inspect again. By planning ahead, the project manager can prevent the need for additional visits from the rater and HVAC team, saving both time and money.

Organizations may request that the home energy rater perform an inspection before insulation is installed. At this point in the project, the rater can examine the HVAC system and the air sealing of the building, identifying any areas that need to be corrected before insulation is installed.

Only after the home energy rater inspects the insulated home and gives approval should the construction team continue forward. It is very important that these inspections be conducted before any drywall is hung.

Testing And Inspecting An ENERGY STAR® Qualified Home

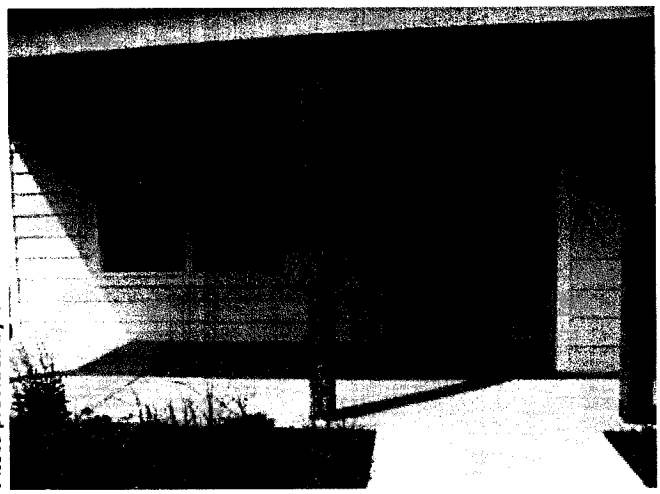


Photo provided by CHP.

A blower-door test measures the air-tightness of a Community Housing Partners home.

Upon completion of the home, the home energy rater will perform a final inspection to verify the air-tightness of the home. Proper building tightness reduces energy consumption, prevents moisture condensation, reduces draftiness, and improves indoor air quality (DOE 2009). To test the air-tightness of the home, the home energy rater will conduct a blower door test, duct blaster test, and will complete the thermal bypass

checklist. The results of these tests help to determine if the finished home meets the high energy efficiency specifications of an ENERGY STAR® qualified home.

A home energy rater performs the blower door test by covering one of the home's exterior doors with the blower door. The blower door is equipped with a fan, a pressure gauge, and a device to measure airflow. When turned on, it will create a pressure difference of 50 Pascals between the inside and outside of the home. In a leaky home, the fan must move more air to maintain the pressure difference. The home energy rater will measure the amount of air passing through the fan and will use this number to determine the air-tightness of the home (Southface 2009).

While the blower door test measures the air-tightness of the home, the duct blaster test measures the tightness of the ductwork. As seen in the photo, the rater attaches the duct blaster to the air handler or central return grille and pressurizes the duct system to 25 Pascals. While pressurizing the ductwork, the rater takes a measurement of the air passing through the duct blaster fan. More air must pass through the fan to pressurize a leaky duct system. If leaks are detected, the home energy rater may inject a non-toxic fog into the duct system to locate deficiencies in the system (Southern California Gas Company).

A duct-blaster test pressurizes the duct system to measure the air-tightness of the system.

Photo provided by CHP.

For homes certifying via the performance path, the rater will enter the results of these tests into a RESNET®-approved software program along with additional information about the home's general structure, mechanical systems, building shell, light and appliance features, as well as information about local climate and utility rates. Based on this information, the program will produce a confirmed rating report. The rating report will include the HERS score, which must be ≤85 on the HERS Index in climate zones 1-5 or ≤80 in climate zones 6-8 for the home to certify as an ENERGY STAR® qualified home (RESNET® 2009c).

Home Energy Rating Certificate

If the home meets or exceeds ENERGY STAR® requirements, the developer will receive an official Home Energy Rating Certificate as well as a blue ENERGY STAR® label to attach to the home's utility box. In addition to the HERS score, the certificate will include a star rating of 1-5 and a summary of estimated annual energy costs.

CASE STUDIES: AFFORDABLE ENERGY STAR® PROJECTS

"It just doesn't make sense to build an affordable home if it comes with high monthly utility bills," says David Mann. "That's building failure into the homeownership dream." Mann and others working in the field have seen how higher up-front construction costs for energy efficiency are usually offset by decreased utility costs. Cutting costs at construction may lower the purchase price, but the higher utility bills can result in a higher combined monthly expense.

As highlighted in the following case studies, earning the ENERGY STAR® label is an attainable goal for rural affordable housing developers and will guarantee a home's energy efficiency, durability, and sustainability for years to come.

Community Housing Partners and ENERGY STAR®[3]

Energy efficiency has long been a priority for Community Housing Partners (CHP), a nonprofit community development organization based in Christiansburg, Virginia. In 1976, CHP first created an in-house energy services division to provide energy and weatherization assistance to low-income households. Since then, CHP has strived to provide sustainable green housing for low- and moderate-income households in the southeast, receiving several awards for their efforts.

Among CHP's award-winning projects is Roanoke-Lee Street, a 14-unit duplex project in Blacksburg, Virginia. CHP completed this project in collaboration with its in-house design team, Community Design Studio, LLC (CDS). CDS followed the performance path to certification, which allowed for more flexibility in the overall design of the units. The firm also worked with CHP's Energy Service division and an in-house certified home energy rater throughout the design, construction, and final ENERGY STAR® certification. Upon completion in 2006, the 14 units of this project received an average score of 75 on the HERS Index.

Photo provided by CHP.

The fourteen ENERGY STAR® qualified units of the Roanoke-Lee Street project received an average score of 75 on the HERS Index.

<u>Before Construction</u>

When CDS completed the housing designs for the Roanoke-Lee Street project in 2004, the home energy rater conducted a preliminary analysis using Residential Energy Analysis & Rating software V12.3, a RESNET®-approved software program. The CDS designs scored very well with an average preliminary score of 74. The home energy rater approved the major design components, such as the insulation level, mechanical system, and water heater. However, the rater did recommend that

3 All information for this case study was derived via an interview with Colin Arnold on March 23, 2009.

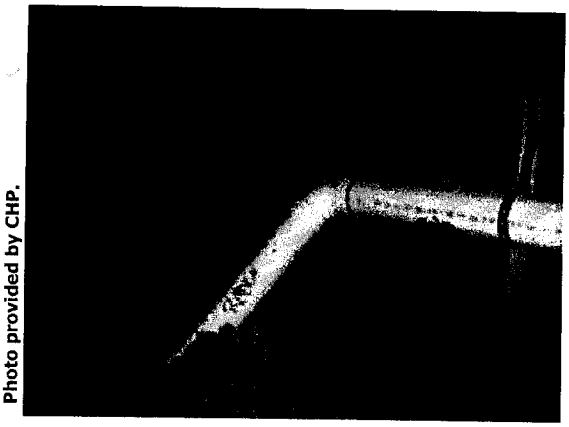


Photo provided by CHP.

Not only is a tightly sealed and insulated home more energy efficient, but it is also healthier and more comfortable.

CDS change the lighting package. Although this was not difficult, it did add to the overall cost of the project. However, CDS was able to minimize the increase in cost by using attractive and affordable ENERGY STAR® lighting products in heavily used rooms while installing less expensive fluorescent lighting in places such as closets.

During Construction

The home energy rater conducted the first thermal bypass checklist inspection and duct blaster test on the project during the rough-in stage and prior to drywall. The rater did find one deficiency, which was fixed by making a change to the air sealing on the air handler. After this was corrected, the home energy rater approved the project to move forward.

"Before hanging drywall, it is important to ensure that all of the appropriate inspections have been made and that no issues need to be addressed," explains the director of CDS, Colin Arnold AIA/LEED AP. "These inspections should be given the same consideration and importance as inspections for plumbing and electrical and should be incorporated into the construction timeline."

After Construction

In 2006, CHP completed the Roanoke-Lee Street projects and awaited approval from the home energy rater. The home energy rater visually inspected the homes and completed the final thermal bypass checklist, duct blaster, and blower door test. The blower door test did locate a few failures to the envelope where band joists were not properly sealed. However, these deficiencies did not prevent the project from earning the ENERGY STAR® label.

After final inspections and calculations, the home energy rater sent the completed paperwork to a third party home energy rating provider that approved the projects as ENERGY STAR® qualified. *(See page 17 to view certificate.)*

The Roanoke-Lee Street project earned several honors, including the 2007 ENERGY STAR® Award for Excellence in Energy Efficient Affordable Housing, the Home Depot Foundation's Award for Excellence in Affordable Housing Built Responsibly, a 2007 Best in American Living (BALA)/HUD Secretary's Award for Excellence, and a 2008 Silver EnergyValue Housing Award (EVHA) in the Affordable Home/Cold Climate category. CHP has monitored the energy consumption of the units, finding that they are even more efficient than expected.

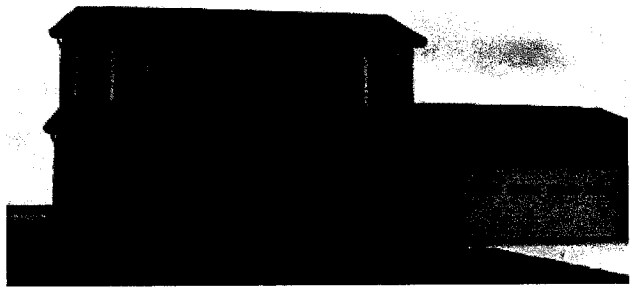
4 EarthCraft House,™ is a regional green building program that serves as a blueprint for healthy comfortable homes that reduce utility bills and protect the environment. More information is available at www.earthcrafthouse.com.

Moving Forward

After the Roanoke-Lee Street Project, CHP began building EarthCraft House™[4] homes, which require other green building criteria in addition to ENERGY STAR® certification. In building sustainable affordable housing, CHP has learned that just as every home is different, so are the ways to incorporate energy efficiency into the construction process. Colin Arnold advises project managers to work with builders who share the goal of energy efficiency and believe that it is an important part of the project. "The construction superintendent needs to make sure the trades are doing the work correctly, because when you are building ENERGY STAR® qualified homes, you can get to a point when you can not fix it."

YouthBuild McLean County and ENERGY STAR®[5]

Photo provided by YBMC.



This ENERGY STAR® home built by YBMC's self-help program earned a 75 on the HERS Index.

YouthBuild McLean County (YBMC), an accredited member of the YouthBuild USA Affiliated Network, is a nonprofit community development corporation located in Bloomington, Illinois. YBMC provides low-income youth aged 17-24 with the opportunity to earn their high school diplomas, gain job skills, and serve low-income families in their community by constructing affordable housing. Since opening its doors in 1994, YBMC has worked with hundreds of youth while building and rehabilitating more than 50 local units of housing. The organization also incorporates energy efficiency into its projects and in 2008 received ENERGY STAR® certification for seven self-help homes in Stoneman Gardens, a 53-acre subdivision in Carlock, Illinois.

Before Construction

In 2000, YBMC's Vice President of Construction and Development, Brian Fitzgerald PMP/LEED AP, visited Austin, Texas to learn more about the innovative green building techniques used by the YouthBuild affiliate in that city. Brian had hoped to find replicable ideas and techniques to incorporate into YBMC projects. However, upon returning to Bloomington, he found that many of the materials used by the YouthBuild program in Austin were not available on the local market. He also found that some local contractors were not enthusiastic about trying new techniques or stepping out of their comfort zone. Despite these challenges, which are common in many rural areas, YBMC has found ways to incrementally incorporate green practices into its projects.

Although training opportunities are limited in Bloomington, many who work in the construction industry have responded to the increased demand for energy efficiency and sustainable building by enrolling in workshops and trainings in nearby Normal, Illinois. With more contractors receiving this

5 All information for this case study was derived via an interview with Brian Fitzgerald on April 21, 2009.

training, YMBC has found it easier to find those who are not afraid to incorporate new techniques or try suggestions from the design team. YBMC makes it a point to work with progressive thinking contractors who are also willing to work with the students and self-help families.

In 2007, YBMC began construction on its first ENERGY STAR® qualified project consisting of seven self-help homes, each with three bedrooms and approximately 2500 square feet. YBMC chose the performance path and used the ENERGY STAR® program as a tool to improve upon the organization's already energy efficient building techniques. YBMC staff also viewed ENERGY STAR® certification as a good first step towards other green building programs that focus on energy efficiency in addition to other sustainable features such as materials reuse, land use, and water efficiency.

YBMC contracted with a home energy rater from Thermal Imaging Services, a company based in Lewiston, Illinois. Staff had spoken with the home energy rater at various trainings and information sessions in Normal and was confident in the rater's knowledge and ability. The rater had extensive experience rating homes and was able to discuss best practices as well as answer questions, both complex and simple, on topics ranging from insulation, air sealing, moisture control, weatherization, and the thermal bypass checklist.

While still in the pre-design phase, YBMC sent the project's plans to the home energy rater to get his initial thoughts as well as a bid on the project. The home energy rater responded with a set fee, which YBMC was able to pay for with a grant from the Wal-Mart Foundation.

The home energy rater entered the initial plans into the RESNET®-approved software program, REM/Rate™ 12.6, which approved the overall designs for the homes. The home energy rater did, however, recommended that YBMC change the homes' proposed fiberglass insulation to either dense pact cellulose or Icynene® Insulation, both of which have a higher R-Value. YBMC staff ultimately decided that changing the insulation would be beneficial.

As with all of its self-help projects, YBMC conducted 15 meetings with the participating families to provide information and training on the upcoming build. Staff explained to the participants that a number of professionals had been involved in the project's design and that it was important to follow directions, as even small changes can be costly. Before stepping foot on the construction site, the families knew exactly what to do and successfully stuck to the plan.

In preparing for the build, YBMC staff and the home energy rater finalized the schedule, giving the home energy inspections a high priority.

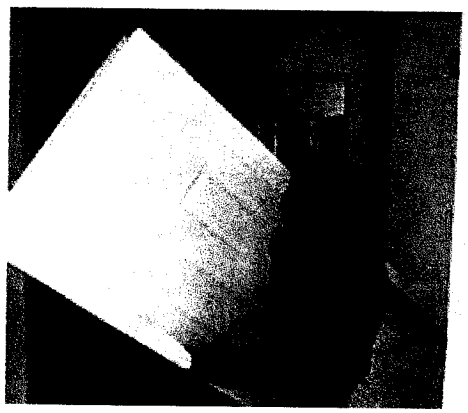


Photo provided by YBMC.

A YBMC student puts the finishing touches on a Stoneman Gardens home. YBMC students gain useful skills, earn their high school diplomas, and help build affordable housing for their community.

During Construction

The home energy rater was fairly involved throughout the construction process, conducting an initial onsite visit after the homes had been framed and a second after the mechanical installation, each time inspecting the caulk work and verifying that the homes had been properly sealed. After insulation, the home energy rater conducted the first mandatory inspection, which included the thermal bypass checklist. The rater approved the duct work and the building teams began the drywall and final phases of construction.

After Construction

As part of the process for verifying a home's energy efficiency, the home energy rater performed a blower door test, duct blaster test, and final thermal bypass checklist on the completed units. With the results of these tests, the home energy rater calculated the homes' scores on the HERS Index, which ranged from 75-84. Within a few weeks of the final onsite inspection, YBMC received its final home energy rating certificates and ENERGY STAR® labels. *(See page 16 to view certificate.)*

Moving Forward

YBMC is currently constructing six additional self-help ENERGY STAR® qualified homes which are scheduled for completion in June 2009. The organization is also in the pre-design phase on six new homes with the goal of attaining LEED for Homes certification or higher. Fitzgerald acknowledges that it is a learning process and they hope to continue to aggressively improve the energy efficiency of their homes.

CONCLUSION

YouthBuild McLean County, Community Housing Partners, and numerous other affordable housing developers across the nation have persistently found ways to overcome the challenges of building energy efficient housing. Driven by the ultimate goals of reducing monthly utility costs, providing healthier living areas, and protecting the environment, these developers continue to provide housing that is both affordable and sustainable for low- and moderate-income homeowners. Their accomplishments should serve as motivation and remind us that we can no longer afford *not* to build energy efficient affordable housing.

Other Resources for Affordable Housing Developers

The ENERGY STAR® Bulk Purchasing Tool is an online tool that allows organizations looking to purchase ENERGY STAR® products and appliances to negotiate prices with multiple suppliers: www.quantityquotes.net.

A comprehensive listing of incentives for energy efficiency and renewable energy is available at: www.dsireusa.org. Information on federal tax credits can be found at www.energystar.gov.

ENERGY STAR® has a webpage containing tools and resources specifically for affordable housing stakeholders. The website can be accessed by going to www.energystar.gov/homes.

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APPENDIX I
Home Energy Rating Certificate - YouthBuild

Home Energy Rating Certificate

101 Poston Dr.
Carlock, IL 61725

5 Stars
Confirmed Rating

Uniform Energy Rating System — **Energy Efficient**

1 Star	1 Star Plus	2 Stars	2 Stars Plus	3 Stars	3 Stars Plus	4 Stars	4 Stars Plus	5 Stars	5 Stars Plus
500-401	400-301	300-251	250-201	200-151	150-101	100-91	90-86	85-71	70 or Less

HERS Index: 75

General Information

Conditioned Area:	2574 sq. ft.	HouseType:	Single-family detached
Conditioned Volume:	20592 cubic ft.	Foundation:	Conditioned basement
Bedrooms:	3		

Mechanical Systems Features

Heating:	Fuel-fired air distribution, Natural gas, 73.0 AFUE.
Cooling:	Air conditioner, Electric, 13.0 SEER.
Water Heating:	Conventional, Natural gas, 0.64 EF, 40.0 Gal.
Duct Leakage to Outside:	15.00 CFM.
Ventilation System:	None
Programmable Thermostat:	Heating: Yes Cooling: Yes

Building Shell Features

Ceiling Flat:	R-45	Exposed Floor:	NA
Vaulted Ceiling:	NA	Window Type:	U:0.33, SHGC:0.40*
Above Grade Walls:	R-13	**Infiltration:**	
Foundation Walls:	R-6.1	Rate:	Htg: 0.21 Clg: 0.12 ACHnat
Slab:	R-0.0 Edge, R-0.0 Under	Method:	Blower door test

Lights and Appliance Features

Percent Fluorescent Pin-Based:	0.00	Clothes Dryer Fuel:	Natural gas
Percent Fluorescent CFL:	100.00	Range/Oven Fuel:	Natural gas
Refrigerator (kWh/yr):	775.00	Ceiling Fan (cfm/Watt):	0.00
Dishwasher Energy Factor:	0.46		

The Home Energy Rating Standard Disclosure for this home is available from the rating provider.

REM/Rate - Residential Energy Analysis and Rating Software v12.6

This information does not constitute an warranty of energy cost or savings.
© 1985-2008 Architectural Energy Corporation, Boulder, Colorado.

Rating Number: Youthbuild #1 6/18/08
Certified Energy Rater: Brian Kumer
Rating Date: 6/18/08
Rating Ordered For: Jackie Crawford

Estimated Annual Energy Cost
Confirmed Rating

Use	MMBtu	Cost	Percent
Heating	72.8	$356	31%
Cooling	2.9	$74	6%
Hot Water	18.1	$126	11%
Lights/Appliances	25.4	$456	39%
Photovoltaics	-0.0	$-0	-0%
Service Charges		$154	13%
Total		**$1165**	**100%**

This home meets or exceeds the minimum criteria for all of the following:

Brian Kumer
Thermal Imaging Services, Inc.
198 N. Robinson St.
Lewistown, IL 61542
309-547-5000
309-547-5005

APPENDIX II
Home Energy Rating Certificate - Community Housing Partners

Home Energy Rating Certificate

Roa & Lee 202
202 Prospect St
Blacksburg, VA 24060

5 Stars
Confirmed Rating

Uniform Energy Rating System

1 Star	1 Star Plus	2 Stars	2 Stars Plus	3 Stars	3 Stars Plus	4 Stars	4 Stars Plus	5 Stars	5 Stars Plus
500-401	400-301	300-251	250-201	200-151	150-101	100-91	90-86	85-71	70-0

Energy Efficient

HERS Index: 73

DRAFT

General Information

Conditioned Area: 1038 sq. ft.
Conditioned Volume: 8300 cubic ft.
Bedrooms: 2
House Type: Duplex, single unit
Foundation: Slab

Mechanical Systems Features

Air-source heat pump: Electric, Htg: 8.1 HSPF. Clg: 15.0 SEER.
Water Heating: Conventional, Electric, 0.91 EF.

Duct Leakage to Outside: Total: 40.00 CFM @ 25 Pascals.
Ventilation System: Supply Only: 90 cfm, 150.0 watts.
Programmable Thermostat: Heating: Yes Cooling: No

Building Shell Features

Ceiling Flat: R-38
Vaulted Ceiling: NA
Above Grade Walls: R-21
Foundation Walls: NA
Slab: R-7.5 Edge, R-7.5 Under
Exposed Floor: NA
Window Type: U: 0.34,SHGC: 0.33
Infiltration:
Rate: Htg: 784 Clg: 784 CFM50
Method: Blower door test

Lights and Appliance Features

Percent Fluorescent Pin-Based: 20.00
Percent Fluorescent CFL: 77.00
Refrigerator (kWh/yr): 412.00
Dishwasher Energy Factor: 0.58
Clothes Dryer Fuel: Electric
Range/Oven Fuel: Electric
Ceiling Fan (cfm/Watt): 0.00

The Home Energy Rating Standard Disclosure for this home is available from the rating provider.

REM/Rate - Residential Energy Analysis and Rating Software v12.32

This information does not constitute any warranty of energy cost or savings.

© 1985-2006 Architectural Energy Corporation, Boulder, Colorado.

Rating Number:
Certified Energy Rater: Anthony Cox
Rating Date: 11-3-2006
Rating Ordered For: To Be Determined

Estimated Annual Energy Cost
Confirmed Rating

Use	MMBtu	Cost	Percent
Heating	8.0	$187	22%
Cooling	1.9	$45	5%
Hot Water	10.6	$248	29%
Lights/Appliances	13.1	$307	36%
Photovoltaics	-0.0	$-0	-0%
Service Charges		$60	7%
Total		**$847**	**100%**

This home meets or exceeds the minimum criteria for all of the following:
EPA Energy Star Home
2003 International Energy Conservation Code

Lee O'Neal
NSPECTS Ltd.
PO Box 221704
Chantilly, VA 20153-1704
Phone: (866)-218-9055 Toll Free
Fax: (703) 988-0839
Website: www.nspects.org

The Housing Assistance Council (HAC) has created the Green Building/Healthy Homes Initiative with generous support from the Home Depot Foundation. The initiative is a comprehensive program of capacity building grants, research, training, and technical assistance activities to promote the incorporation of a "greener" approach to affordable rural housing development.

ISBN: 978-1-58064-161-6

ENERGY EFFICIENCY REPORT

VERDUZCO PROPERTY
2129 FAIRFAX AVENUE
EVERETT, WA 98203

PREPARED BY

integrated renewable energy

SEATTLE, WA
206-517-2875
PBIRKELAND@INTEGRATEDRENEWABLEENERGY.COM

XX, 2008

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INTRODUCTION

The clients are applying for an Energy Efficient Mortgage on their home, and requested a HERS rating to determine eligibility. In addition, the clients seek advice on the best use of funds for energy efficiency upgrades.

The property currently has a natural gas furnace and a natural gas water heater to supply the one-floor, 1150 square foot home.

SUMMARY OF FINDINGS

A HERS rating was conducted on the property, including a Blower Door Test to determine infiltration, and a Duct Blaster Test to determine duct leakage to the ambient.

Infiltration (air leakage) was determined to be the single largest cause of energy loss, both warm air leaking out and cool air leaking in. The third largest contributor was **Duct Leaks**. (In between the two, but only slightly greater than **Duct Leaks** was conduction through the above-grade walls. The above –grade walls are built of 2x4 lumber with fiberglass batt insulation all around, and there is little that can be done to reduce this source of energy loss.)

Analysis concluded that **Infiltration** is occurring through an effective leak area of 144.5 sq in, or the equivalent of a one-foot square hole. The **Duct Leaks** were caused by an effective leak area of 29.7 sq. in. in the ductwork.

During the blower door test, dust and debris were observed rising from the supply registers. This would indicate that duct leaks contribute, not only to the loss of warm air into the crawlspace, but the introduction of cold air (from the crawlspace) into the living area between furnace cycles.

In addition, removal of several supply registers revealed duct boots that were poorly seated in the floor resulting in the direct supply of warm air into the (unheated) crawlspace.

Finally, the supply registers in the unheated crawlspace are poorly insulated. The floor itself bore fiberglass batt insulation that was poorly secured and falling down in several locations. The blown-in cellulose attic insulation was uneven, and the flextube return duct was barely embedded in the insulation.

Taken together, this analysis and observations indicate a clear energy upgrade strategy. In summary:

1. Duct Upgrade – A program to seal the existing ducts with mastic, properly seat and seal the ducts in each cutout in the floor, and better insulate the ductwork will pay off greatly. Alternatively, the contractor may decide to simply replace the ductwork to achieve the same effect.

2. Floor Insulation Upgrade – The insulation under the floor is nominally R-11, but as a Grade III installation, it is likely performing far below that level. Floor insulation should be repaired and upgraded, preferably to R-33.

3. Attic Insulation Upgrade – Attic insulation was uneven, although nominally R-19. An upgrade to R-50 should be easily accomplished and would pay off in savings.

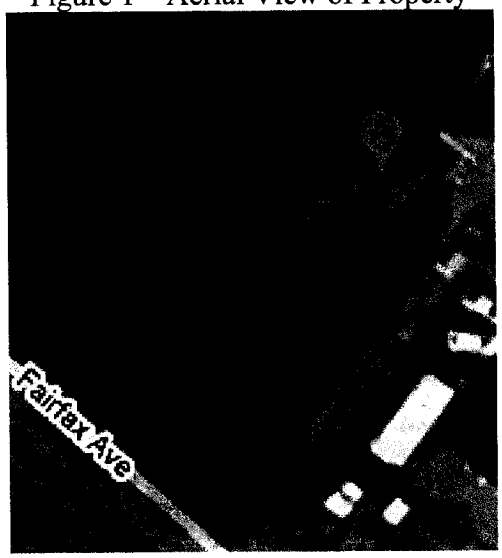
Physical Characteristics

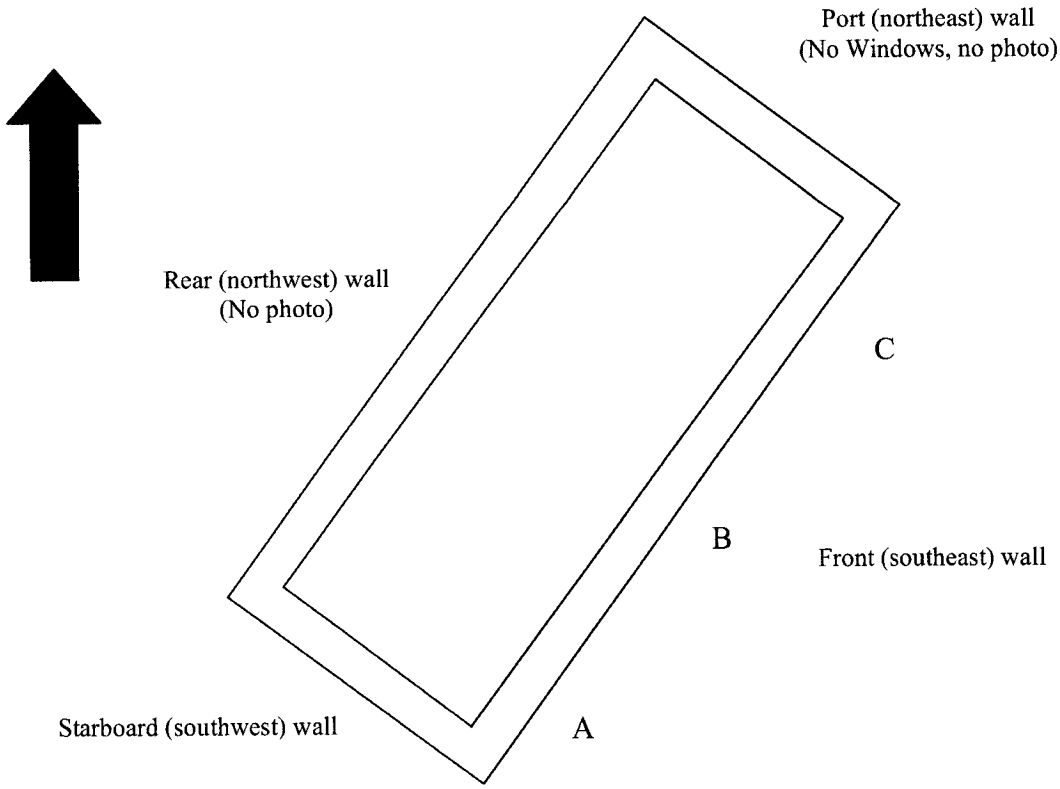
The home is located in Everett, WA at approximately 47°56'40.7" N and 122°12'9.1" W and an elevation of 380 feet. Figure 1 shows an aerial view of the property.

The residence is placed in the center of the property and faces an azimuth of 130 degrees (SE). The home is well shaded from three sides.

The home itself is a simple rectangular design 25 feet by 46 feet in dimension, with the front/rear of the home being the long dimension. A simple overhang approximately 3 feet in depth encircles the house. The northeast wall of the home has no windows. It was not possible to take photos of the northwest wall due to a fence and vegetation.

Figure 1 – Aerial View of Property



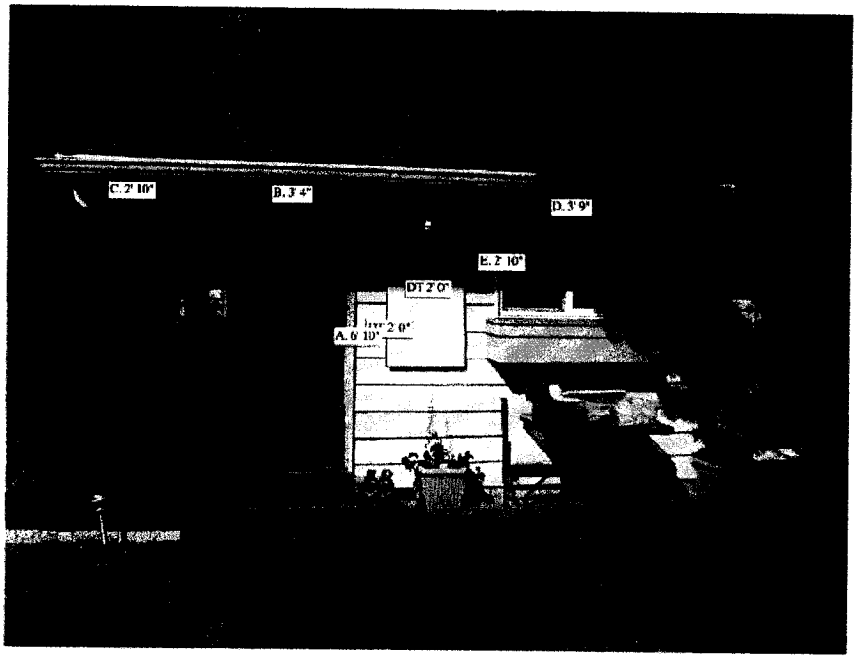


Plan View Schematic

U MEASURE

Project: Verduzco-1

Customer:

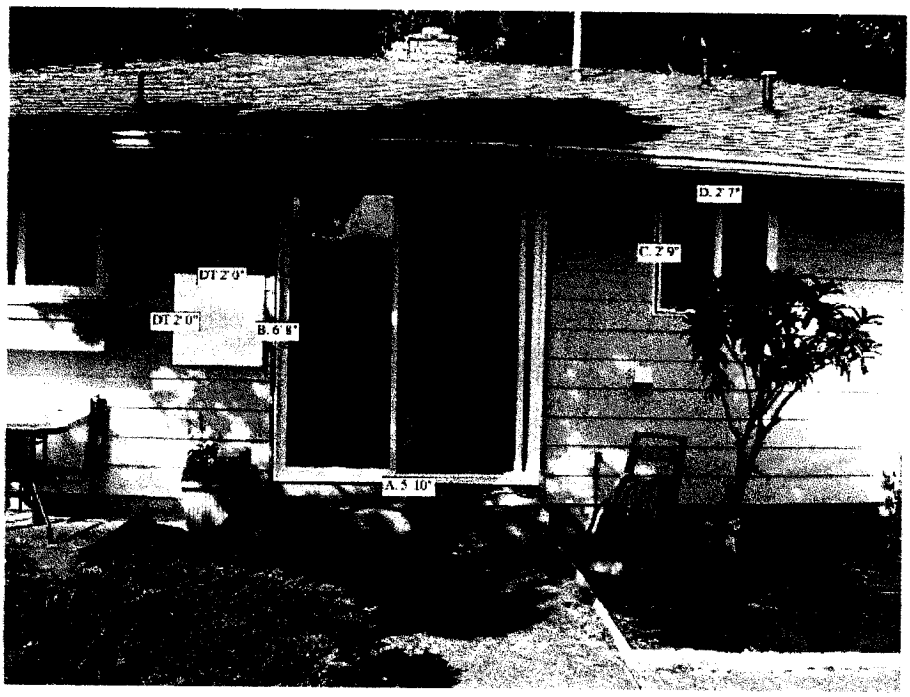


Front (Southeast) wall, southeast corner (segment A)

U MEASURE

Project: Verduzco - 2

Customer:

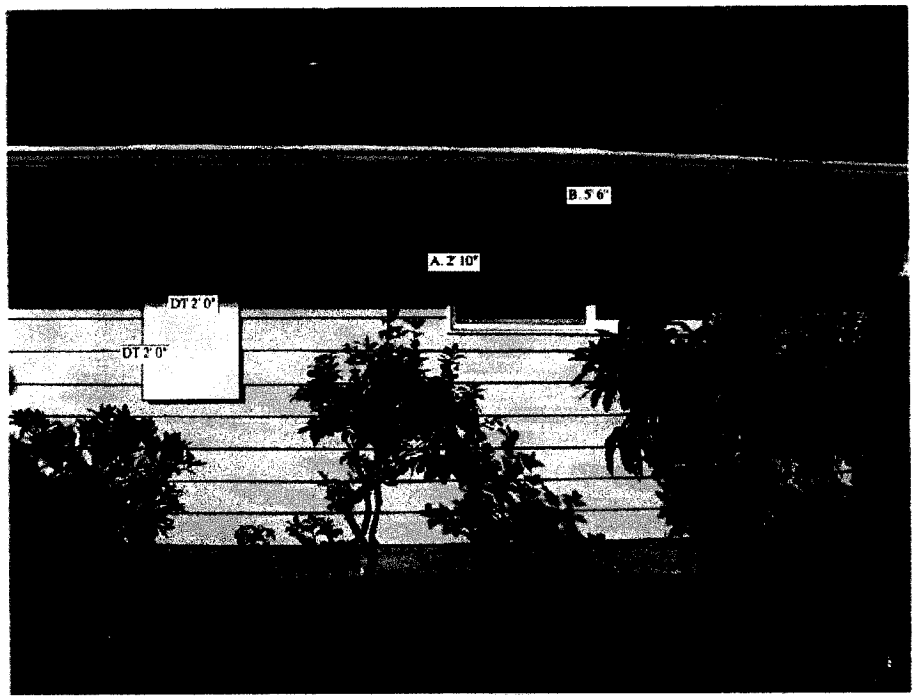


Front (Southeast) wall, center segment (segment B)

U MEASURE

Project: Verduzco-3

Customer:



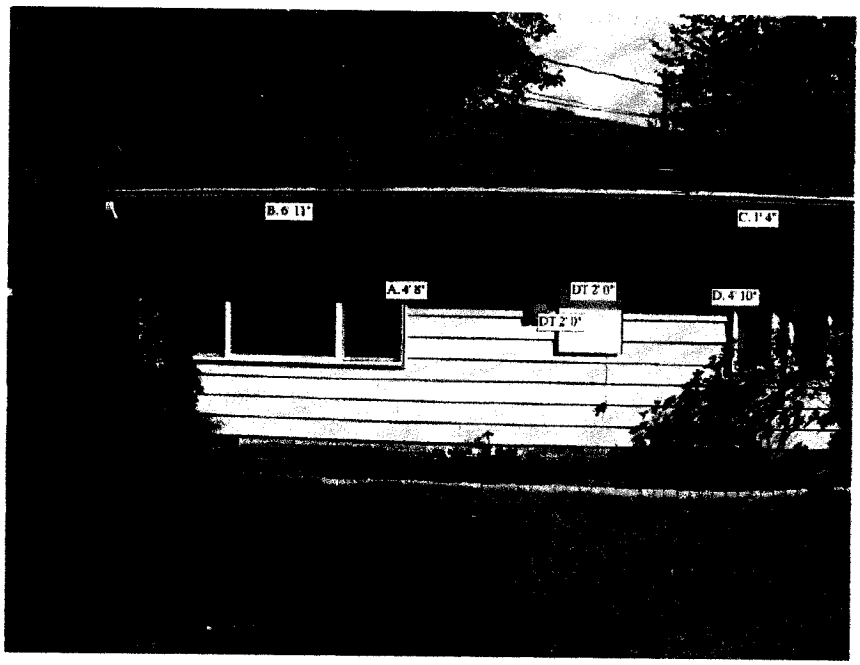
Front (Southeast) wall, northeast segment, segment C

integrated renewable energy

U MEASURE

Project: Verduzco-4

Customer:



Starboard (Southwest) wall

Home Energy Auditor Training (HEAT)

LEED COUNCIL

LEED Council and eZing, Inc. are offering **Home Energy Auditor Training (HEAT)**, a FREE job-skills training program designed to prepare trainees to perform a variety of residential energy auditing services. Successful graduates will have the opportunity to become a **"Building Analyst"** certified by the nationally recognized **Building Performance Institute (BPI)**.

Funded by the Illinois Department of Commerce and Economic Opportunity, this program is intended to serve unemployed and underemployed individuals who have a strong desire to begin a career in the field of Home Performance. The HEAT curriculum is based on current building-science principles and best practices in home energy auditing and weatherization. **Classroom-, workshop- and field-based training** will include:

The Environment, Building Science and Energy Efficiency:

- Green building principles, residential architectural styles and implications for auditing and weatherization
- Building science principles and the "whole house" approach to home-performance analysis
- Building envelopes, with an emphasis on the performance of air and thermal barriers
- Mechanical systems and home appliances: energy rating, installation, operation and performance
- Building "tightness" and air quality; minimum ventilation standards; compliance measures and costs

Home Energy Auditor Practices:

- Initial (exterior) photos, safety checks and consultation with the home owner on building performance
- Diagnostic testing **(blower door, infra-red camera and duct blaster)**: principles, demonstration and practice
- Envelope improvements: cost effectiveness of component replacements, materials and methods of installation
- HVACR equipment and home appliances: combustion safety testing, specifications, performance and controls
- Energy-auditing software: calculating, reporting and recommending home performance improvements

TRAINEE ELIGIBILITY CRITERIA:

- **Must live in the City of Chicago.**
- **Must demonstrate respect for homes of others**—occupants, contents, and structures. Must dress and behave appropriately for in-home consultations and inspection work.
- **Must be capable of reading and doing math at 10th grade level or higher,** in order to:
  - review utility data; measure and calculate volumes of spaces; and estimate costs
  - learn computer software programs related to the work of a home energy auditor
  - apply safety regulations, as required for BPI certification
- **Must be able to perform the physical work** required for home energy auditing:
  - work in challenging conditions: extreme weather, high/low interior temperatures, poor building condition, poorly lit and ventilated areas
  - lift up to 75 lbs; carry, hoist and climb ladders; carry and position blower door equipment
  - get in and out of crawl spaces and attics, work in physically awkward or demanding positions
- **Must be determined to successfully complete the HEAT training and BPI certification processes. Must be committed to auxiliary components of the training program, as required, including:** adult education, computer skills training, career exploration, and job search.
- **Must be determined to secure job placement** in a related trade or occupation.

DETAILS:

Training Period:	February 27 (Monday) – April 20, 2012 (Friday)
Training Length:	8 weeks
Training Days/Times:	Monday - Friday, 8:30 a.m. – 4:00 p.m.
Location:	LEED Council (address below)
Contact:	**Ebony McLaurin, Client Services Coordinator, 773-929-5552, ext. 228**
Enrollment:	Must call to reserve slot at information session. No walk-ins.

Local Economic and Employment Development (LEED) Council
1866 N. Marcey, Chicago, IL 60614
(773) 929-5552 phone, (773) 929-6162 fax
www.leedcouncil.org

Weatherization Installer Occupation Profile
Compiled by the Regional Economic Development Institute
Division of Workforce and Economic Development @ Los Angeles Trade-Technical College

SOC Code & Title 47-4099.03
See document: 47-4099.03 Weatherization Installers and Technicians

Work Description
Perform minor envelope repair necessary to stop air infiltration such as door replacements, attendant hardware, threshold, door shoes, wall patching, caulking and other applicable/feasible measures; Install weather stripping, carbon monoxide detectors, switch/outlet gaskets, low flow showerheads, aerators, window/glass replacements, compact fluorescent light bulbs, touchier lamps and microwave ovens; Install energy efficient refrigerators and remove old refrigerator for disposal; and operate diagnostic equipment like Duct Blaster and/or Blower Door per program requirement and complete reports.

Salary Range
$14.00 - $20.00/hr

Job Outlook
See document: 47-4099.03

Competency Model Framework

Eligibility
- ***Age***
  - 18 or older
- ***Physical***
  - Stooping, crawling, squatting Has physical capacity to stoop, crawl, squat, and maneuver on hands and knees
  - Working in small/confined spaces - Has capacity to work and maneuver in small and confined spaces.
  - Walking and standing - Has physical capacity to walk 5 to 7 miles per day and stand for extended periods of time
  - Agility - Able to climb ladders (no fear of heights)
- ***Prior Education***
  - High school diploma - Meets minimum educational requirements of a high school diploma, GED, or equivalency
- ***Legal***
  - No felonies
- ***Proof of identity and the legal right to work in the United States***
- ***Drivers license, driving record, transportation - Valid driver's license with an acceptable driving record, a personal owned vehicle that is safe and reliable, proof of automobile insurance***

Tier 1: Personal Effectiveness
- ***Interpersonal Skills***
  - Working with diverse people, social, and cross-cultural skills
    - *Is flexible and open-minded when dealing with a wide range of people; listens to and considers others' viewpoints and alters opinion when it is appropriate to do so; works well and develops effective relationships with highly diverse personalities*
  - Respecting diversity

        - *Demonstrates sensitivity and respect for the opinions, perspectives, customs and individual differences of others; promotes and strives to create a workforce and environment that represents and values diversity of people and ideas*
- ***Professionalism***
    - Professional appearance
        - *Maintains a professional demeanor; dresses appropriately for work requirements; maintains appropriate personal hygiene*
    - Substance abuse
        - *Is free from substance abuse*
    - Maintains a positive attitude
    - *Projects a professional image of oneself and the organization; demonstrates a positive attitude towards work; takes pride in one's work and the work of the organization*
- ***Initiative***
    - Persisting
        - *Pursues work with energy, drive, and a strong accomplishment orientation; persists and expends extra effort to accomplish tasks even when conditions are difficult or deadlines are tight; persists at a task or problem despite interruptions, obstacles, or setbacks*
    - Achievement motivation
    - *Intrinsically driven to succeed and excel; strives to exceed standards and expectations; exhibits confidence in capabilities and an expectation to succeed in future activities*
- ***Dependability & Reliability***
    - Fulfilling obligations
        - *Behaves consistently and predictably; is reliable, responsible and dependable in fulfilling obligations; diligently follows through on commitments and consistently meets deadlines*
    - Productivity and accountability
        - *Demonstrates sense of accountability for producing products/services to required standards and beyond*
    - Showing up on time
        - *Demonstrates regular and punctual attendance; rarely is late for work, meetings, or appointments*
    - Complying with policies
        - *Follows written and verbal directions; complies with organizational rules, policies and procedures, ability to take and follow directions*

Tier 2: Academic Competencies

- ***Reading***
    - Comprehension
        - *Locates, understands, and interprets written information in documents such as manuals, reports, memos, letters, forms, graphs, charts, tables, calendars, schedules, signs, safety notices, applications and directions*
    - Application
        - *Integrates what is learned from written materials with prior knowledge; applies what is learned from written material to follow instructions and complete specific tasks*
- ***Business Writing***
    - Organization and development
        - *Creates documents such as reports and other written information, which may contain technical material, in a logical, organized and coherent manner*
    - Mechanics
        - *Uses standard syntax and sentence structure; uses correct spelling, punctuation, and capitalization; uses appropriate grammar (e.g., correct tense, subject-verb agreement, no missing words)*

LOS ANGELES TRADE-TECH COLLEGE
WORKFORCE
& ECONOMIC DEVELOPMENT

- ***Mathematics***
  - Quantification
    - *Reads and writes numbers; counts and places numbers in sequence; recognizes whether one number is larger than another*
  - Computation
    - *Adds, subtracts, multiplies, and divides with whole numbers, fractions, decimals, and percents; calculates averages, ratios, proportions and rates; converts decimals to fractions; converts fractions to percents; solves basic algebraic equations*
  - Measurement and estimation
    - *Takes measurements of time, temperature, distances, length, width, height, perimeter, area, volume, weight, velocity, and speed; uses and reports measurements correctly; converts from one measurement to another (e.g., from English to metric), reads maps and diagrams with an understanding of symbols, scales, keys and legends (e.g., an ability to read gas layouts, company maps, blueprints, etc.)*
  - Application
    - *Performs basic math computations accurately; translates practical problems into useful mathematical expressions and uses appropriate mathematical formulas and techniques*
- ***Basic Computer Skills***
  - Entering data
    - *Ability to fill out forms online (e.g. safety data sheets and benefit packages), ability to type at least 30 words per minute*
- ***Communication - Listening & Speaking***
  - Listening
    - *Receives, attends to, interprets, understands, and responds to verbal messages and other cues; picks out important information in verbal messages*
- ***Locating & Using Information***
  - Information literacy
    - *Ability to read/interpret maps*

Tier 3: Workplace Competencies

- ***Teamwork***
  - Acknowledging team membership and role
    - *Accepts membership in the team; shows loyalty to the team*
- ***Marketing & Customer Focus***
  - Understanding customer needs
    - *Demonstrates a desire to understand customer needs; listens to what customers are saying and asks questions as appropriate; demonstrates awareness of client goals*
  - Providing personalized service
    - *Provides prompt, efficient and personalized assistance to meet the requirements, requests, and concerns of customers; provides thorough, accurate information to answer customers' questions and inform them of commitment times or performance guarantees; actively looks for ways to help customers by identifying and proposing appropriate solutions and/or services; establishes boundaries as appropriate for unreasonable customer demands*
  - Acting professionally
    - *Is pleasant, courteous and professional when dealing with internal or external customers; develops constructive and cooperative working relationships with customers, and displays a good-natured, cooperative attitude; is calm and empathetic when dealing with hostile customers*
- ***Problem Solving & Decision Making***

- Identifying the problem
  - *Anticipates or recognizes the existence of a problem; identifies the true nature of the problem by analyzing its component parts; uses all available reference systems to locate and obtain information relevant to the problem; recalls previously learned information that is relevant to the problem*
- Locating, gathering, and organizing relevant information
  - *Effectively uses internal resources to locate and gather information*

- ***Planning & Organizing***
  - Completing forms
    - *Selects and completes appropriate forms quickly and completely; attends to and follows through on important information in paperwork*
  - Maintaining logs
    - *Keeps logs, records, and files that are up-to-date and readily accessible; updates logs, files, and records*
- ***Applied Technology***
  - Selecting tools
    - *Basic understanding and use of hand/portable power tools, selects and applies appropriate tools to frequently encountered problems; carefully considers which tools are appropriate for a given job, and consistently chooses the best tool for the problem at hand, understand use of tools, understanding of the clockwise and counter-clockwise princples (e.g., righty-tighty, lefty-loosy)*

Tier 4: Industry-Wide Technical Competencies

- ***Standard Safety Procedures***
  - Knowledge of relevant equipment, policies, procedures, and strategies for safe operations
  - 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
  - Knowledge of Material Safety Data Sheets
  - Knowledge of Occupational Safety and Health Act (OSHA) standards including: ladder safety, fall protection, personal protective equipment, respiratory protection, motor vehicles, power-operated hand tools, fire prevention, permit-required confined spaces, and other worker-related OSHA standards
  - 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; and work Lead Safe; identify serious mold conditions; and assess work area safety hazards
- ***Mechanical Aptitude***
  - Knowledge of machines and tools, including their designs, uses, repair, and maintenance; ability to manipulate machines and tools
- ***Realistic View of Industry***
  - Understanding of physical demands and nature of work in the utilities industry
- ***Test-Taking***
  - Ability to pass exams for entry level and incumbent positions

Tier 5: Industry Sector Competencies

- ***Mathematics***
  - Ability to solve problems and perform calculations using algebra
- ***Basic Construction Knowledge***

Tier 6: Occupation Specific Knowledge Areas (O*Net, OPM Mosaic Taxonomies)

- ***Tasks***

- Inspect buildings to identify required weatherization measures, including repair work, modification, or replacement.
- Recommend weatherization techniques to clients in accordance with needs and applicable energy regulations, codes, policies, or statutes.
- Test and diagnose air flow systems, using furnace efficiency analysis equipment.
- Apply insulation materials such as loose, blanket, board, and foam insulation to attics, crawl spaces, basements, or walls.
- Explain energy conservation measures, such as the use of low flow showerheads and energy efficient lighting.
- Install and seal air ducts, combustion air openings, or ventilation openings to improve heating and cooling efficiency.
- Install storm windows or storm doors and verify proper fit.
- Make minor repairs using basic hand or power tools and materials, such as glass, lumber, and drywall.
- Prepare and apply weather-stripping, glazing, caulking, or door sweeps to reduce energy losses.
- Prepare cost estimates or specifications for rehabilitation or weatherization services.

Tier 7: Occupation Specific Technical Competencies

- ***Basic Weatherization - DOE WAP***
  - Airsealing
    - *Knowledge*
      - *Proper materials selection based on location of leakage areas*
      - *Minimum ventilation rates*
    - *Skills and Abilities*
      - *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)*
      - *Modify or install mechanical ventilation to ensure acceptable indoor air quality for post-air-sealing conditions*
  - Duct Sealing
    - *Skills and Abilities*
      - *Properly seal duct connections with mastic and fiberglass mesh tape or other approved material*
      - *Repair or modify duct systems as specified in a work order*
  - Insulation
    - *Knowledge*
      - *Properties and appropriate application of different insulation materials*
      - *Potential hazards of insulating around knob-and-tube wiring*
    - *Skills and Abilities*
      - *Install blown and batt attic insulation;*
      - *Access closed wall cavities and properly install dense-packed cellulose wall insulation including removing and replacing siding;*
      - *Install blown insulation and batt insulation in a floor;*
      - *Install water heater installation blankets;*
      - *Install insulation on ducts, hydronic distribution pipes, and domestic hot water pipes*

- Base-Load Measures
- ***Basic Weatherization - CA LIEE (gas only)***
  - Skills and Abilities
    - *Caulking Gaps*
    - *Install low-flow shower head*
    - *Install cover plate gasket*
    - *Seal ducts with mastic and tape*
    - *Check gas pipes for leaks*
    - *Cut glass*
    - *Replace broken glass*
    - *Install water heater insulation*
    - *Install pipe installation*
    - *Install jamb weather stripping on a door*
    - *Repair Drywall*
    - *Door Replacement*
    - *Attic Insulation*
    - *Set Duct Tester and Blower door*
    - *Install threshold and door bottom*
    - *Install GFCI outlet*
    - *Install hard wired CFL fixture (Electrical Measure)*

Certifications & Licensure

- **Required**
  - *For weatherization work conducted utilizing LIHEAP programs, installer must obtain California Community Services Department (CSD) certification*
- **Desirable**
  - *OSHA 10*
  - *EPA Lead Safe Renovator*
  - *EPA Lead Safe Worker*
  - *Industrial First Aid, CPR*

Related Occupations

Construction Laborers: 47-2061.00
See document: 47-2061.00
Laborers: 53-7062.00
See document: 53-7062.00
Helpers Construction Trades-All Other: 47-3019.00
See document: 47-3019.00
Helpers-Installation, Maintenance, and Repair Workers: 49-9098.00
See document: 49-9098.00
Helpers-Carpenters: 47-3012.00
See document: 47-3012.00
Construction and Related Workers-All Others: 47-4099.00
See document: 47-4099.00
Helpers-Electricians: 47-3013.00
See document: 47-3013.00
Insulation Installer: 47-2131.00
See document: 47-2131.00
Insulation Workers, Mechanical: 47-2132.00
See document: 47-2132.00
Home Appliance Repairers: 49-9031.00
See document: 49-9031.00

Installation, Maintenance, and Repair Workers-All Other: 49-9099.00
See document: 49-9099.00
Heating and Air Conditioning Mechanics and Installers: 49-9021.01
See document: 49-9021.01

McCREA
HEATING & AIR CONDITIONING SERVICES

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4463 Beech Road
Temple Hills, MD 20748
mdservice@McCreaway.com
301.423.4585
1.800.597.0091

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5083 Lee Highway
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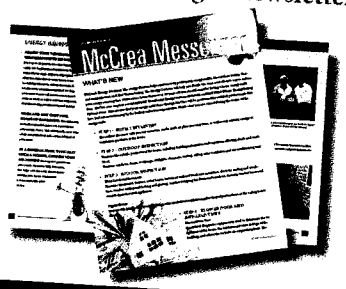
vaservice@McCreaway.com
540.341.8812
1.800.788.6216

Pennsylvania
151 Commerce Avenue
Greencastle, PA 17225
paservice@McCreaway.com
717.597.7044
1.866.446.2001

POSTAGE

McCrea Messenger Newsletter Inside!



www.mccreaway.com

celebrating 75 years

COUPONS/CURRENT PROMOTIONS

The McCrea team is extremely proud to have celebrated our 75th anniversary in 2011. Now in our 76th year of service, we decided that many of our great promotions ran during our anniversary year were so well received by our customers, we would offer them again this year. In addition, McCrea has partnered with Trane to offer an incredible promotion valid for the 2012 year only. See below for promotion details.

$75.00 off

Any Indoor Air Quality Product

Expires 12/31/2012

Must be presented at time of the purchase, offer not valid on prior purchases. Restrictions apply. Call for details

$75.00

Service Call

Expires 12/31/2012

Must be presented at time of the purchase, offer not valid on prior purchases. Restrictions apply. Call for details

TRANE COMFORT SPECIALIST

TRANE
It's Hard To Stop A Trane.

Free 10 year parts and labor warranty on ANY complete Trane heating and air conditioning system installed by McCrea. Now that is PEACE OF MIND.

Promotional dates
3/1/2012 thru 12/31/2012

Fold

SPRING EDITION 2012

McCrea Messe

WHAT'S NEW

McCrea's Energy Division! The energy division helps customers by performing energy audits, blower door testing, thermal imaging scans, and duct blaster testing. The Energy Division will help you decide the most cost effective way to reduce your energy consumption. If you own a home that is over 10 years old you should consider having a home energy audit done. McCrea now employs several RESNET (Residential Energy Services Network) certified HERS (Home Energy Rating System) raters. This ensures that your energy audit completed by McCrea will be performed by certified professionals that have had extensive training by the leading industry organization. Here's what you can expect during the course of the energy audit:

- **STEP 1 - INITIAL INTERVIEW**
  The auditor discusses with you any concerns, needs, goals or plans you may have, as well as any existing energy or ventilation problems in the house.

- **STEP 2 - OUTDOOR INSPECTION**
  Examine the outside perimeter of the home, including building orientation and vegetation affecting shade and windbreak.
  Examine windows, doors, overhangs, skylights, chimneys, roofing, siding, attic ventilation and air-conditioning unit.

- **STEP 3 - INDOOR INSPECTION**
  Main Level and Basement
  Examine thermostat, furnace, water heater, basement wall and band joist insulation, ducts for sealing and insulation, window sealing and locking and glazing, weather stripping for doors and windows, flooring, washer hoses and overall character of all appliances.

  Upper Floors
  Inspect attic hatch seals, cann[illegible]lighting, attic insulation/ventilation and sealing of perforations in the ceiling below the a[illegible]

- **STEP 4 - BLOWER DOOR AND INFRARED TESTS**
  Blower Door Test
  Specialized diagnostic equipment is used to determine the air tightness of the house, the total amount of air leakage of the building, and where the air leaks are originating from. The

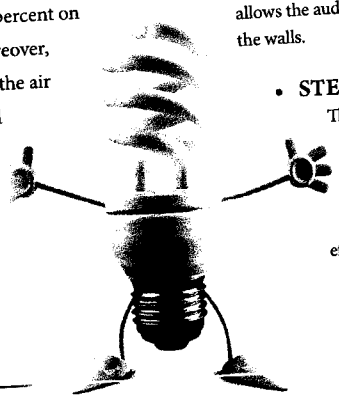
(Continued on page 2)

ENERGY SAVING TIPS

ADJUST YOUR WATER HEATER'S TEMPERATURE TO 120 DEGREES (save up to 10 percent on water heating costs; verify this by placing a thermometer below some of your taps). Majority of people don't realize that their electric water heater is essentially running constantly to heat the water. If you set the water temperature around 120 degrees your water heater will not have to re-heat the water as much as it does at hotter temperatures therefore saving you electricity and money.

WASH AND DRY ONLY FULL LOADS OF GARMENTS. Use cold water as much as possible which will (save 2 to 4 percent on your energy costs). This additionally saves time when you plan ahead and wash a full load of your items.

AS A GENERAL RULE, TYPICALLY ONCE A MONTH, CHANGE YOUR AIR FILTERS (save up to 5 percent on your yearly electricity bill). Moreover, this helps with dust and dirt in the air making your house cleaner and a more enjoyable place to live.



(Continued from page 1)

blower door test also identifies moisture condensation problems and tests the indoor air quality. During the test, a powerful fan depressurizes the entire house and examines the rate that air re-enters the building through unsealed cracks and other openings in the building envelope.

Infrared Thermal Image Scan
Using an infrared thermograph, a special infrared camera which is also called a FLIR (Forward Looking Infrared) camera, the auditor can identify where the building is better insulated, and where opportunities exist to improve insulation or air sealing. By capturing temperature variations of the building's surfaces using wavelengths that are invisible to the naked eye, the camera identifies "hot" and "cold" spots in the building envelope, which allows the auditor to see what's going on behind the walls.

- **STEP 5 - REVIEW RESULTS**
  The auditor reviews the initial findings with you. A more detailed report is emailed to you within one week, with specific recommendations to make your home more energy efficient.

COMMUNITY INVOLVEMENT

McCrea is proud that we are able to help those that are less fortunate than most. McCrea recently finished working on a project with Home-Aid, and our trade partner Stanley Martin Homes. The project entailed renovating the Christian Relief Services Center Transitional Shelter in Alexandria. McCrea proudly partnered with Goodman Manufacturing to donate all the equipment, material, and the labor needed to complete this project for such a great cause.

Left to right Brian Hamilton (General Manager), Jim Birch Sr. (Senior Vice President), Steve Alloy (President Stanley Martin Homes).

Meanwhile, the Greencastle office donated supplies and equipment to the Franklin County Career and Technology Center to aid in the learning of future HVAC apprentices. McCrea has committed to hiring the top students from the HVAC Program under their CO-OP Program, which stands for "cooperative opportunity". This technical school is made up of only high school students from the Franklin County school district.

McCrea's next project will be in Warrenton, VA where we will be working with Habitat for Humanity. This summer, Habitat will build a duplex unit that will be certified by Earth Craft for energy effectiveness. These units will provide homes for needy families in Fauquier County. In addition to providing shelter, these earth craft certified homes will reduce the families energy costs making the units more affordable to live in.

PRESSURE-TESTING Ductwork

A pressure test with telltale fog will keep your duct installers on their toes

by Michael Uniacke

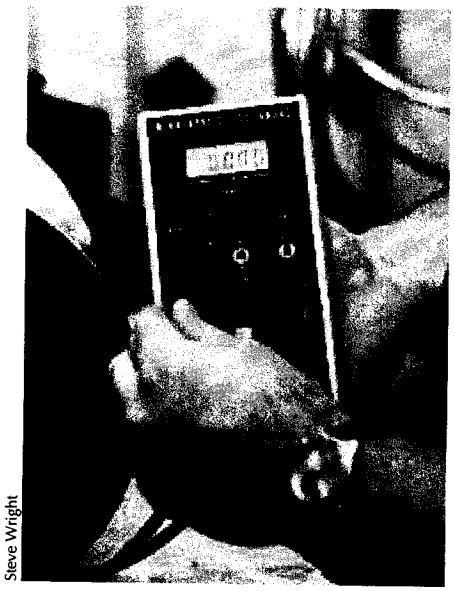
Airtight ductwork is one of the keys to a quality heating and cooling system. It helps to make a home more healthful, more comfortable, and more energy efficient. By reducing the load on the equipment, it also reduces wear and tear.

There is only one way to make sure that the ductwork has been thoroughly sealed: Test it. A simple pressure test can measure the airtightness of the air distribution system and helps you hold your installers to a high standard of quality.

Of course, airtight ductwork is only one of the keys to quality hvac. A *Manual J* load analysis and *Manual D* duct design, proper refrigerant charge, and correct airflow over the evaporative coil are all just as vital. But poorly sealed ductwork can negate good work in all those other areas: You can properly size the unit, lay out the distribution system correctly, tune the compressor perfectly, and set the fan just right, but if leaky ductwork blows most of your conditioned air into the attic, or pulls most of the system's return air from the crawlspace, you'll have a system that costs too much to run and doesn't do its job.

Pressure testing is not a new concept in home construction. Plumbers have their work pressure tested on every job, and the test forces them to get it right — meaning no leaks, period. But when plumbing leaks, there is an immediate consequence: Things get wet. Air leakage, on the other hand, is invisible and seldom causes immediate trouble. Instead, homeowners gradually become

Figure 1. The Minneapolis Duct Blaster is a calibrated variable-speed fan that's tied into the heating or cooling air distribution system at a supply plenum, return grille, or air handler compartment (right). The digital pressure gauge (below) calculates air leakage rates from pressure and fan speed data.



Steve Wright

aware of comfort problems, high utility bills, and decreasing indoor air quality over time. The test is the only way to identify the defects in advance.

In ten years of testing ductwork before drywall is hung, I've seen some excellent ductwork installations and some atrocious ones. I've learned that if you want consistently good results, you have to test consistently. All tradespeople do better work when they know they face inspections. As one local mechanical contractor's lead man put it to me, "There are three kinds of air distribution systems: regular, sealed, and sealed and tested." If you test your installer's work, it will get better. And realistically, until you start testing, and showing your installers the results, they won't even know that their system leaks. They certainly won't know where it leaks. The test makes them face reality, but it also helps them learn.

The duct airtightness testing system I use is called Minneapolis Duct Blaster, from the Energy Conservatory (612/827-1117, www.energyconservatory.com). It consists of a calibrated variable-speed fan, a fan speed control, and a digital pressure-reading gauge called a digital manometer (see Figure 1). The test itself is pretty simple: We attach the Duct Blaster fan to the air distribution system at a return grille, a supply plenum, or the blower compartment on the air handling unit. We temporarily seal off all the registers and grilles. Then we turn on the Duct Blaster fan and apply pressure. The Duct Blaster system measures the airflow needed to create a test pressure of 25 pascals (a 0.10-inch water column) in the duct system. This airflow rate is our duct leakage measurement. We compare the duct leakage reading with a recognized standard, and we give the system either a pass or a fail. The whole process takes less than two hours (mostly for setup and takedown) and typically costs around $220.

Over the years, my company has headed off a lot of potential problems by testing ductwork before the drywall is hung. When the drywall is up, we can

still gain access to the ducts, but the problems are harder to locate and assess.

Vhy Airtight Ductwork Matters

Good duct sealing makes a major contribution to the healthfulness, safety, comfort, and efficiency of a new home. Sealing the ducts is even more important than sealing the building envelope, because when the air handler is running, the pressures in the air distribution system are much greater than in the building or the outside air. Pressure differences are what drive infiltration; a hole or crack in the building envelope is not an air leakage point unless it sees a pressure. Ducts always operate under pressure, so a hole in the ductwork is always a leak.

To clarify the importance of pressure, let's look at some numbers. Wind, stack effect, exhaust fans, and the like generate air pressures across the building shell that range from 0.5 to 10 pascals. On average, a house is usually in the low end of this range. (A pascal is a very small metric unit of pressure. here are 25 pascals in 1/10 inch of water column. If you were to put a straw into a glass of water and suck the water up the straw 1 inch, you'd create an inch of water column pressure, or 250 pascals.)

Pressures created in air distribution systems when the air handler is running range from 10 to 125 pascals, tens of times greater than the ordinary pressures acting on the house envelope. And these pressures, unlike the wind, are continuous when the air handler is running. That is why house infiltration rates can double or triple when the equipment is active.

Temperatures. Remember, too, that leaks in supply ductwork involve conditioned air, not room air. The air that escapes from supply ductwork has been heated to 140°F or cooled to 58°F, and it is not getting to the room it was meant for. If most of the ductwork is in the attic or crawlspace which is often the case), all this heated or chilled air is now leaking straight to the outdoors. The resulting energy loss is much greater than the loss that occurs when 70°F room air leaks out around a window, for example. That's why simple duct tightening may cut heating and cooling costs by 15% to 30% in many homes.

Researchers at the Florida Solar Energy Center found that sealing ductwork in existing homes cut cooling bills by about a third

Duct leaks also typically affect comfort, because the system doesn't deliver the intended amount of conditioned air to satisfy the design load for a room. Rooms at the end of long duct runs suffer the most: The farther away from the fan a room is, the greater the likelihood that air will find its way out of a leak instead of going where it's meant to.

On the return side of the air distribution system, leaks pull ambient air or even hot attic air into the system, further compromising efficiency. Leaks also threaten indoor air quality: Air from a crawlspace may carry pesticides, moisture, radon, and mold spores, all of which can get sucked into the return leak, then sent through the supply side to every room in the house.

Energy penalty. How much do these leaks affect energy consumption? A 1999 summary report of 19 separate studies from around the country (www.aceee.org/pubs/a992.htm) suggests that the average annual energy savings potential in a typical house from sealing the ductwork is around 17%. These studies include both heating and cooling climates. Anywhere ductwork can leak outside of the house, there is the potential for a large energy penalty. In one study, researchers at the Florida Solar Energy Center found that sealing ductwork in existing homes cut cooling bills by about a third.

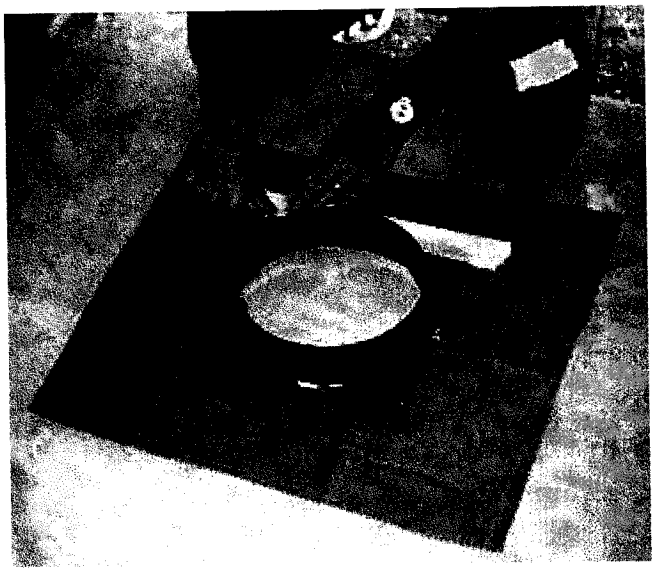
Locating the Leaks

Where are these leaks happening? Basically, leaks are possible at any joint or seam in the system, from the air handlers supplied by manufacturers, right on through to the sheet-metal supply boots your installer brings to the job. If you look at all the joints, you'll find the leaks.

There are leaks on sheet-metal trunk ducts every 48 inches, where the trunk sections connect. Every collar attached to the trunk, where flex duct branches take off, represents a possible leak. So does every adjustable elbow. We also find leaks where flex duct connects to supply boots, in the boots themselves, and around the plaster grounds. I'm often surprised by how leaky some of the manufacturers' mechanical units are. I've tested units that leaked 40 to 45 cfm right out of the box.

I used to commonly find flex ducts that either had never been connected or had been accidentally disconnected by another trade. During the early to mid 1990s, most framed return cavities were major leakage sites. Disconnected ducts and framed cavities still tend to be the biggest culprits, but practices have improved significantly.

Stud and joist bays used as returns are still common in my part of the country and often present a lot of problems. All framed cavities should be lined with OSB, plywood, duct board, drywall, or sheet metal and then sealed with mastic at every joint. Hvac contractors sometimes blame the framers for not lining the cavities, but we don't accept that excuse — if it leaks, you fail.



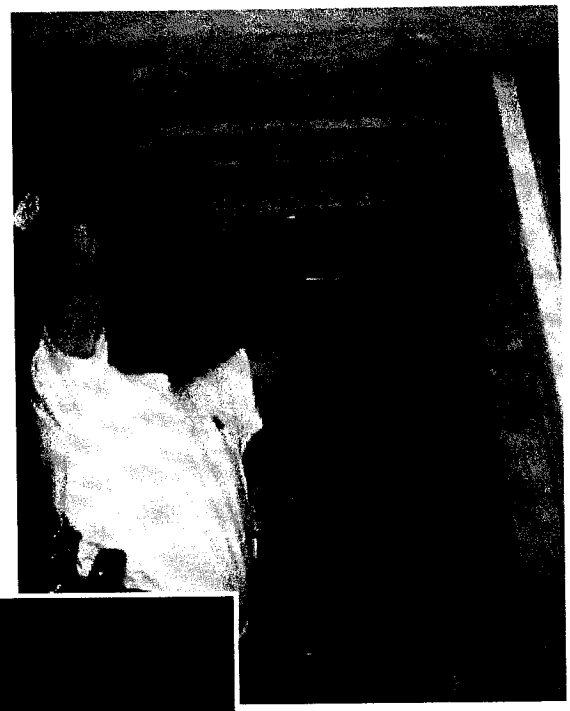


Figure 2. The author tapes a plastic transition fitting to a piece of cardboard cut to fit the opening in the air distribution system (above), then places the assembly in the opening (above right) and connects the fan to the opening with a length of flex duct (right). It's best to test the system with the air handler installed, because the air handlers are often a leakage point. If the air handler has not been set, the author hooks up the Duct Blaster [redacted] trunk line where the air [redacted]er will go. The equipment can also be attached to a return grille (below).

The most frustrating leaks are where the hvac installer tried to seal the system and failed — where someone did the sealing but didn't get it right. For example, it hasn't yet dawned on everyone that each joint and seam have to be sealed on four sides, not just three. If a crew hasn't had the benefit of some training, and has never seen a system tested and fogged, it's a good bet the system won't pass. Installers just can't picture the consequences of an average duct sealing job.

Running the Test

A Duct Blaster test on a single air distribution system takes about 45 minutes to $1^1/_2$ hours to perform. Most of that time is spent sealing off registers and grilles and setting up the equipment. Once a system is prepared, it takes only about 2 minutes to perform the test.

The first step is to attach the Duct Blaster fan to the air distribution system (Figure 2). We can attach it to the blower compartment on the air handler or to a return grille. If the air handler is not set when I arrive to test, I connect the Duct Blaster directly to the trunk lines in the mechanical room where the

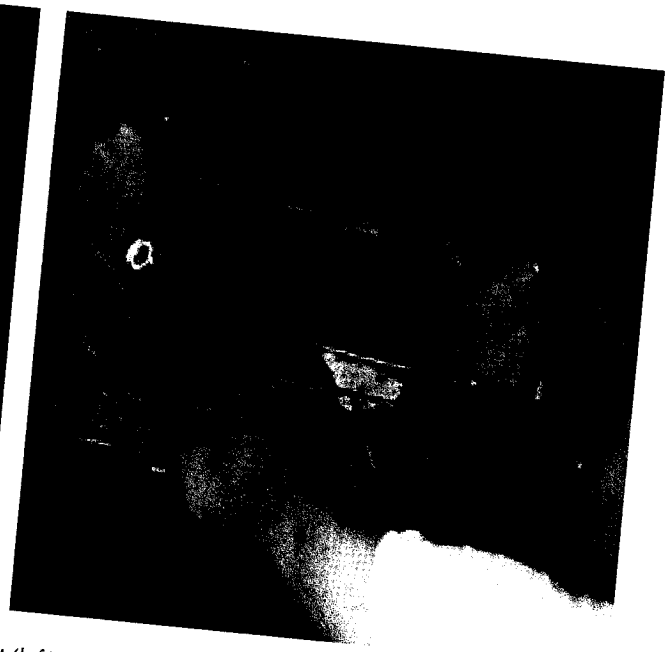


Figure 3. The author carries a roll of adhesive poly Duct Mask on his belt (left) and uses the material to seal registers and grilles (right).

handler will eventually be set. But prefer to test with the air handler talled, because of the leakage we've n in even brand-new units.

he second step is to seal off the air ribution registers with a poly prod- called Duct Mask (Figure 3). It es on a roll (also from the Energy servatory), so I simply run a belt ugh the roll and wear it around waist. Duct Mask is perforated 4 inches and has adhesive on ide. It makes sealing up the sys- uch a simple task that I consider ential. But I now have some nical contractors who seal all pply registers that are installed rs with sheet metal and mastic. eeps construction debris and of the ductwork and also pre- e system for testing.

st piece of equipment to hook digital manometer, which is set up and operate. The digi- meter I use both measures the in the duct system and isplays air flow through the ster fan in cubic feet per hich is convenient and cuts rrors.

I can often tell how leaky a duct system is simply by turning on the Duct Blaster and seeing how quickly or slowly the duct reference pressures respond. A leaky system will require that I ramp up my Duct Blaster fan speed to overcome the numerous leaks in the system. In fact, in some homes the ducts are so leaky that I can't pressurize the air distribution system at all. In a system with a return that leaky, it's very possible that more air is being drawn into the system from the crawlspace or attic than is being pulled from the house.

Once the air distribution system is pressurized to 25 pascals, I read the air flow through the Duct Blaster fan from my digital manometer.

It's important to recognize that the Duct Blaster measures the air leakage at a test pressure of 25 pascals, not the actual duct leakage when the system is running. The actual duct leakage under normal use depends on where the leaks are located and what pressures they see. The closer the duct leaks are to the air handler fan, the higher the pressures. The typical leaks where refrigerant lines enter the coil, for example, will see much higher pressures than the leaks around the supply boots at the end of branch runs, and thus will leak more air.

The tests are performed at a uniform pressure of 25 pascals because that represents a typical average operating pressure in residential systems and gives us a quick way to compare the measured leakage rate to accepted standards.

The Fog Machine

The shortcoming of a digital manometer readout is that tradespeople can't picture the leakage; in their minds, that number is not associated with anything. Also, we still don't know just where the leaks are. By introducing theatrical fog into the system through the Duct Blaster, we can make most of the leaks visible (Figure 4, next page).

The fog pouring out of duct leaks is a real eye opener. No one argues with this part of the test. Even after ten years of using a fog machine out in the field, I'm shocked sometimes that so much fog can leak out so fast. It is truly telling.

In my experience, installers really

Streamline A/C

Streamline A/C

Streamline A/C

Figure 4. When a system exceeds the allowable air leakage standard, the author uses a theatrical fog generator to introduce visible vapor into the Duct Blaster fan intake. The fog makes it easy to find the leak locations.

appreciate being on hand when their work is tested and fogged. It's often the first time they've seen their work tested, and the fog drives home the importance of paying attention.

Sealing the system. Fortunately, duct leakage problems are simple to eliminate during new construction if you know where to look for leaks and how to seal them. The cost varies depending on the system's size and complexity, but most systems can be sealed for somewhere between $150 and $600. Research has shown that the cost is recovered within one to five years; after that, the savings go to the homeowner's bottom line. And of course, the greatest benefit is a more healthful and comfortable home.

The products of choice are water-based mastic, accompanied by a fiberglass mesh on larger holes. The mastic has the consistency of mashed potatoes. It is easily spread over joints in the ductwork with an inexpensive paintbrush or one's hand. On cracks and gaps wider than 1/4 inch, a 2-inch fiberglass mesh tape is placed in a be

of mastic to reinforce the seal. The advantage of mastic over duct tape is that it provides a long-term durable eal. The water-based mastic cleans up easily with water.

Duct Tightness Standards

The goal of duct sealing is to ensure that the system is sufficiently airtight. That does not mean submarine airtight or hermetically sealed. We aim not to eliminate leakage entirely (although some contractors come close) but to reduce the leakage to an acceptable threshold. I use one of two standards for duct system airtightness, and each generates a "not to exceed" duct leakage number.

One standard is 3% of the livable quare footage. For example, a 2,000-quare-foot home should have no ore than 60 cfm of leakage in the air stribution system. The other common standard is based on the size of e air-conditioning unit, which you n read off the unit's label (or the taller can tell you). It's common ctice to assume 400 cfm per ton, so -ton unit would be rated at 1,600 ; the air leakage should not exceed of the total airflow capacity, or in example, 80 cfm.

ese levels are realistic on the job; cientious workers can easily sathem. In my experience, if a crew meet these criteria routinely, they don't have enough training xperience, or they aren't trying nough.

Should Test?

are a growing number of third-sting companies like mine. A list g contractors by state is avail- the Energy Conservatory web- w.energyconservatory.com).

e that hvac companies should in-house testing of air distrib- tems. If your hvac contractor wns a Duct Blaster and other tools, that tells you that the truly wants to do quality npanies that don't own a r have to ask someone else to test their work, as well as show them their mistakes.

I've worked with architects who make the builder pay for the first test and the hvac contractor pay for the second test if he fails the first one. If a system fails, as a part of my fee, I'll spend up to an hour on the job helping the crew find the leaks with my Duct Blaster and fog machine.

Reaping the Benefit

On most jobs, there is a tug of war between quality and profit, and profit routinely wins. This means ductwork is often not sealed, or it's sealed but not tested. When customers have a comfort, air quality, or utility bill problem, it adds to their distress to learn that no one bothered to implement a simple quality-control step. They begin to wonder what other corners the builder cut.

I always advise my builder and hvac customers to at least offer sealed ductwork and testing. If you offer it and the customer turns you down, there's a record, in case of later complaints, that the customer chose low price over quality.

For builders who do test, we file a test report, which becomes a record for the house. I encourage my builder customers to use this report as evidence that they are truly committed to quality behind the drywall. If you seal and test ductwork and the contractor across the street doesn't, you have a better product, and you can use our documentation to build your reputation.

Satisfied customers also provide a marketing advantage. A customer who moves into a new home that is more healthful, comfortable, and energy efficient is more likely to tell friends that you are someone who builds a home that works.

Michael Uniacke runs Advanced Insulation, Inc., an Arizona company that supplies insulation, energy auditing, diagnostics, testing, and consulting services.

Sources of Supply for Duct-Sealing Mastic

AM Conservation Group, Inc.
908/852-6464
www.amconservationgroup.com

Biddle Company
800/878-7876
www.trustsm.com

Carlisle Coatings & Waterproofing, Inc.
800/527-7092
www.hardcast.com

Carrier Aeroseal, LLC
800/772-6459
www.aeroseal.com
(aerosol duct sealing franchiser)

Ductmate Industries
800/245-3188
www.ductmate.com

Duro Dyne Corporation
800/899-3876
www.durodyne.com

Foster Products Corporation
800/231-9541
www.fosterproducts.com

McGill AirSeal Corporation
800/624-5535
www.unitedmcgill.com

Mon-Eco Industries, Inc.
800/899-6326

RCD Corporation
800/854-7494
www.rcdmastics.com

Rectorseal Corporation
800/231-3345
www.rectorseal.com

Shelter Supply
800/762-8399
www.sheltersupply.com

MEEA
Midwest Energy Efficiency Alliance

The Source on Energy Efficiency

Midwest Energy Codes Needs Analysis Report

Prepared for
Battelle Memorial Institute
Pacific Northwest Division

Prepared by
Isaac R. Elnecave; Senior Policy Manager

Midwest Energy Efficiency Alliance

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1. Introduction

MEEA is pleased to submit the following needs analysis on behalf of Midwest states. Part of the deliverables for Grant No. 135069 includes the submittal of a needs analysis to the Pacific Northwest National Laboratory that aims to identify state specific needs with respect to code adoption, implementation, enforcement and compliance to help PNNL better target assistance and resources.

In terms of energy code adoption and development, the Midwest is in a unique position. First, it contains a huge disparity in terms of code adoption, implementation and enforcement. The region contains some of the most advanced states in the country (Minnesota and Wisconsin), states that have begun serious efforts (Illinois, Indiana and Michigan) and states that have not even adopted a state energy code. Consequently, the needs within states will vary and any analysis should take that into account.

This paper will describe needs on two levels:

1. Regional needs.
2. Individual State Needs

For the regional analysis, this paper will briefly look at:

- Specific region wide issues that should be addressed.
- The needs related to those issues.

For the individual state needs section, the paper will give:

- Brief overview of state status including statutory requirements, current code, status of code enforcement activities.
- Describe state specific barriers to code adoption, implementation and compliance.
- Detail state needs based on discussions with key stakeholders and general understanding of the state.
- Recommendations that can address the needs.

2. Regional Needs

Before entering a discussion of specific state needs, Section 2 will briefly go over problems and needs that extend across the region. These three items act in a complementary manner to frustrate progress on energy codes. Within this environment, energy codes get progressively less attention which inevitably results in an underperforming building.

2.1. Lack of Resources

Jurisdictions at every level, state, county and municipal, suffer from a lack of funds. Typically, local jurisdictions are funded through building fees, state funds or a combination of both. Without exception, over the last few years, funds directed toward building energy code enforcement have decreased. Much of this is due to decreasing building activity but it also arises from decreasing contributions from the state (which inevitably has its own budgetary problems). Due to lack of resources, local and state code officials are increasingly unable to fully discharge their duties resulting in underperforming energy codes.

Need: Development of a steady funding source for local and state code offices.

2.2. Increasing Complexity of the Energy Code

Over the last few code cycles, as the energy code has become more energy efficient, it has also become more complex. Because of this emerging complexity, building practitioners must spend more time and effort in learning the code, moreover, more time has to be devoted to meeting its requirements (both from the point of view of the practitioner and the building official). This compounds the first issue. First, practitioners are receiving lower fees for design and construction; second, building officials have less time than they had before to review and inspect buildings.

Need: Development of multiple levels/pathways of training materials. Sufficient funding of training that can reach all affected stakeholders. Reducing the cost and barriers to effectively training practitioners.

2.3 Prioritization of Energy Codes:

Both practitioners and building officials, because of legal issues, tradition and general concern for welfare, prioritize health and safety over energy. This prioritization goes on top of the first issue. Building practitioners and officials have less and less time and with the prioritization of health and safety, it is most likely that energy codes will have disproportionately less time devoted to them.

Need: Education program for building practitioners that emphasizes the direct and indirect benefits of the energy code.

3. State Needs

3.1 Illinois

Current Status

The State of Illinois enacted HB 3987 in February 2010 which established a statewide energy code initially set at the 2009 IECC for both residential and commercial buildings. Prior to this action, the state had adopted a commercial code (ASHRAE 90.1-2004), and some local jurisdictions had adopted a residential code in addition. The statute includes the following requirements:

1. Automatic Update of the energy code every three years.
2. Residential code is "min-max," meaning that it cannot be amended in any way.
3. Commercial code can be made more stringent but cannot be weakened.
4. Local jurisdictions that had adopted a code prior to XXX can strengthen the residential code.
5. Jurisdictions over 1,000,000 people can also amend code to make it more energy efficient.

The Illinois Department of Commerce and Economic Opportunity (DCEO) has embarked on an aggressive effort to train officials and practitioners on the energy code. It has contracted with the International Code Council to run a number of trainings across the state. DCEO is working with the Building Codes Assistance Project to conduct Phase 1 of the BCAP gap analysis project. Additionally, DCEO received funding from the Department of Energy to conduct its own gap analysis run by the Metropolitan Mayor's Council (which will cover different jurisdictions than those covered by BCAP) and to do a baseline compliance analysis based on the PNNL protocol (much like the work being done through the pilot studies).

Code Barriers

- Illinois has just recently adopted a statewide code
- Illinois remains fragmented in the way that codes are adopted, implemented and enforced.
- Certain part of the state, for example, Chicago and some of the surrounding suburbs have enforced energy codes for years; others have not. Within this latter group, there will be significant resistance to enforcing energy codes.
- Second, as local jurisdictions still have discretion in adopting a code, problems arise as suboptimal codes are adopted. For example, the city of Chicago has adopted the 2006 IECC for climate zone 6 which is less energy efficient than the 2009 IECC, and the city of Evanston has adopted LEED Silver for its commercial code.

Needs

- Means of enforcement. DCEO acts only as an informational resource; it is not an enforcement division of the state. Other building codes, such as the Accessibility and Plumbing code have enforcement bodies that ensure the code is properly administered throughout the state.
- Providing home builders, developers, and new homebuyers with better metric that explain energy savings, cost of new construction practices as they related to the energy code, and shows return on investments. These metrics will help to overcome hurdles and improve compliance rates and education to homeowners. The Department of Energy could develop metrics as new codes are adopted that can be distributed throughout the country for each state.
- Outreach in downstate areas

Recommendations

- Development of a 3rd party enforcement system to help assist local officials.
- Continual development of informational materials related to energy use and cost/benefits.

Resources

Department of Commerce and Economic Opportunity, Bureau of Energy and Recycling
www.illinoisenergy.org

Bruce Selway
Energy Efficiency Program Specialist
IL Dept. of Commerce & Economic Opportunity
620 E. Adams Street
Springfield, IL 62701
217.785.2023 Phone
217.785.2618 Fax
Bruce.Selway@Illinois.gov

3.2 Indiana

Current Status

Indiana has recently adopted ASHRAE 90.1-2007 as its commercial code. It is in the process of adopting the 2009 International Residential Code with amendments that will make it equivalent to the 2009 International Energy Conservation Code (IECC). The Indiana Department of Homeland Security recently awarded a $500,000 grant to help with implementation of both the residential and commercial code. Work under this code would include: developing a strategic plan to achieve 90% compliance with the code as well as training on both the residential and commercial code.

Code Barriers

- Although the state of Indiana has had an energy code dating back to 1978, it has rarely been enforced.
- The recent adoption of a new commercial energy code has caused some concern among the building community. Very few practitioners in the state pay attention to the code at all. As a result, there is worry of a backlash among architects, engineers and builders about the enforcement of the code.
- There is widespread lack of understanding of even simple tools such as RESCheck and COMCheck.
- The code adoption process is burdensome and slow. Any new adoption of the code has to go through stakeholder committee that moves at a very slow pace and which is dominated by members of the homebuilder association.
- Indiana state law requires the development of a cost analysis for each new rule without incorporating the benefits of the new rule. As a result, even very non-costly rules such as a new building energy co can be made to look extremely expensive providing a clear path for opponents.
- Energy code requirements are bound up with other building code requirements. For example, even though the ASHRAE code does not require an upgrade upon change of use of a building, the Indiana building code does. As a result, there is some resistance to adding what many feel is an added exper to the redevelopment efforts in older cities.

Needs

- Information on design tools such as COMCheck and RESCheck as well as more sophisticated tools such as EQuest.
- Information on the availability and cost of specific technologies such as energy efficient windows, air and duct sealing and lighting.
- General informational efforts on the energy code explaining need, benefits, costs and how to comply.
- Support for building inspectors who cannot handle the additional load of checking for an energy code.

Recommendations

- Outreach to in state design professionals to cover issues dealing with COMCheck (knowledge of the specific state regulations is very important).
- Development of easy accessible database that includes in-state and national information on availability of key technologies.
- Development of a third party plan review/inspection system.
- Development and dissemination of informational metrics and how-tos.

Resources

Indiana Department of Homeland Security; Fire Prevention and Building Safety Commission
http://www.in.gov/dhs/2375.htm

Mara Snyder
Branch Director and Chief Counsel
Indiana Department of Homeland Security
302 W. Washington St., Room W-246
Indianapolis, IN 46204
317-233-5341

3.3 Iowa

Current Status

The Iowa Department of Public Safety adopted the 2009 IECC for both residential and commercial buildings at the beginning of the year. Current statutes require the adoption of the latest edition of the IECC for both residential and non-residential buildings. Moreover, the statute created the Commission on Energy Efficiency Standards and Practices which is charged with:

- Evaluate energy efficiency standards applicable to existing or newly constructed residential, commercial, and industrial buildings and vertical infrastructure at the state and local level and make suggestions for their improvement and enforcement. The evaluation of energy efficiency standards shall include but not be limited to a review of the following:
(1) the reduction in energy usage likely to result from the adoption and enforcement of the standards.
(2) The effect of compliance with the standards on indoor air quality.
(3) The relationship of the standards to weatherization programs for existing housing stock and to the availability of affordable housing, including rental units.

- Develop recommendations for new energy efficiency standards, specifications, or guidelines applicable to newly constructed residential, commercial, and industrial buildings and vertical infrastructure.
- Develop recommendations for the establishment of incentives for energy efficiency construction projects which exceed currently applicable state and local building codes.
- Develop recommendations for adoption of a statewide energy efficiency building labeling or rating system for residential, commercial, and industrial buildings and complexes.

Currently, the Commission is focusing on developing recommendations for a third party enforcement system.

Iowa can be viewed as a "hybrid" home rule state. Iowa requires statewide enforcement of the energy code while the rest of the codes are subject to home rule. This creates a difficult enforcement situation. The IDPS has recently hired two engineers who are responsible for helping to implement the new energy code.

Code Barriers

- The lack of a statewide building code poses the most difficult problem.
- Many jurisdictions across the state, particularly those located in rural areas, may not have any code enforcement at all. Those jurisdictions are unlikely to set up a department just to enforce the energy code.

Needs

- Method for enforcing the energy code outside of major urban areas.
- Central information area to respond to questions and concerns from practitioners, building officials, developers and homebuilders.
- Information on building energy rating systems.

Recommendations

- A group of stakeholders have submitted recommendations designed to improve enforcement. The recommendations envision developing a statewide third party enforcement system administered by the Department of Safety to diminish chances of gaming the system i.e. allowing developers and homebuilders to choose "friendly" inspectors.
- Work with the DPS to educate on the new DOE protocol for building energy measurement.

Resources

Iowa Department of Public Safety; State Fire Marshall Division; Building Code Bureau
http://www.dps.state.ia.us/fm/building/provisions/index.shtml

Brian Bishop
Construction/ Design Engineer
Iowa Department of Public Safety
State Fire Marshal's Office
Building Code Bureau
215 E. 7th Street
Des Moines, IA 50319-0047
Phone: 515-725-6158

3.4 Kansas

Current Status

A statewide energy code in Kansas is only mandated for commercial and industrial buildings. While there is no residential building energy code, home energy performance information must be disclosed and provided to potential homebuyers by means of a Kansas Energy Efficiency Disclosure form. Kansas has set an "applicable state standard" at the 2006 IECC. However, local jurisdictions can either amend or not adopt the standard altogether. There is a general belief that in the absence of a local commercial code, builders builds to the state standard. In May, 2009 the Kansas Energy Office, a division of the Kansas Corporation Commission (KCC) established the Energy Efficiency Building Codes Working Group to guarantee the state complies with federal requirements set forth by the American Recovery and Reinvestment Act and will convene on December 2nd to discuss further action.

Code Barriers

Multiple barriers exist in the state. The first barrier is the perception that adopting the 2009 (let alone the 2012) would increase costs. An example was noted in the city of Overland Park which rescinded its adoption due to this concern. The second barrier is the lack of capacity, particularly in smaller towns, to enforce the code.

Needs

- The state needs a way to achieve the Recovery Act goals without establishing a statewide code.
- The Commission is considering establishing a certification program but does not know if it is feasible.
- Detailed cost estimates of adopting the 2009 IECC.
- Ways of enhancing the capacity of building departments.
- Ways on doing outreach to different stakeholders.

Recommendations

- Establish regional sub groups to help monitor and aid activity in different regions of the state.
- Provide cost estimates that show the modest cost of building to the 2009 IECC (along with cost benefit analyses).
- Provide policy recommendations on establishing third party enforcement mechanisms.
- Develop coordinated outreach plan using workgroup members and other interested parties.

Resources

Kansas Energy Office
http://www.kcc.state.ks.us/energy/index.htm

Liz Brosius
Energy & Outreach Manager
State Energy Office, Kansas Corporation Commission
l.brosius@kcc.ks.gov

3.5 Michigan

Current Status

The Michigan Department of Energy, Labor and Economic Growth (DELEG) has just finalized the adoption of the 2009 IECC/ASHRAE 90.1-2007. The new energy code will become effective in March, 2011. This new code comes at the end of a long, bitter battle between advocates and homebuilders that included a multi-year lawsuit. Current statute requires DELEG to review and update codes through a codes commission. In practice, this occurs sporadically. A key problem is that any code upgrade must meet a 7 year payback test.

While this effort to finalize the 2009 IECC/90.1-2007 was underway, the code agency partnered with the Construction Management Department of Michigan State University (MSU), is building a new energy code training curriculum and will conduct training sessions across the state. This effort was very successful the last time it was attempted (after the adoption of the 2003 IECC) and it reached several hundred homebuilders, code officials, architects and other practitioners. MSU provides a very strong partnership in the codes effort. It has established a department devoted to construction management which provides an additional outlet to help adopt and implement codes. Through MSU, the possibility exists to explore non-traditional approaches to enforcement and compliance measurement. For example, training includes both classroom style and field training efforts. However, MSU could use climate specific resources such as streamlined checklists and best practices for building officials; these resources should include videos, detailed photos, exercises and online resources.

Currently, the MI (What department) has posted an RFP based on the Indiana example for about $500,000. Unlike Indiana, this RFP is not funded out of Recovery Act funds. The state has also received funding from the DOE to pursue innovative methods in training for the energy code.

Code Barriers

- The first major barrier is the statutory requirement that any upgrade to the code must pay itself back within 7 years. This places a very difficult hurdle to overcome. It lengthened the adoption process and it required a significant amount of extra work from the department.
- Extremely hostile homebuilder association.
- Cumbersome adoption process that is not helped by the 7 year rule.
- Lack of understanding among code officials about their roles in the 90% compliance mandate.

Needs

- Possible amendment of the 7 year rule.
- Bringing the HBA into the adoption and implementation process.
- Establishing non-traditional ways of training.
- Feedback upon practices and experiences identified in pilot states.
- Communications to code officials to further clarify their role in the 90% compliance mandate.
- Deeper insight into local jurisdictional practices.

Recommendations

- Coordinate efforts with MSU on developing innovative training methods.
- Utilities, particularly DTE, have shown interest in getting involved in the codes process as part of the EEPS.

- Continue outreach to homebuilders to bring them in on the training process.
- Direct outreach to code officials.
- Development of communication channels to disseminate information on the pilot study work.

Resources

Department of Energy Labor and Economic Growth; Bureau of Construction Codes
http://www.michigan.gov/dleg/0,1607,7-154-10575---,00.html

3.6 Minnesota

Current Status

Minnesota currently has a statewide code based on the 2006 IECC/ASHRAE 90.1-2004. The model codes have been extensively amended and made more energy efficient. For example, the Minnesota residential energy code contains important requirements related to ventilation. The DLI has not made any effort to adopt the 2009 IECC as it believes its amendments make their state code equivalent. The DLI might, however, work to adopt the 2012 IECC/ASHRAE 90.1-2010 once the codes are published.

Typically, the DLI has funded code training centers throughout the state. Recently, this effort has been scrapped due to funding concerns.

The Minnesota legislature recently passed legislation that requires the Department of Commerce to design an energy efficiency portfolio standard that requires 1.5% of the state's energy needs be met by energy efficiency. A taskforce was developed that is finalizing recommendation on what activities utilities can take to help meet the goal. One of the recommendations will focus on having utilities fund compliance activities.

Code Barriers

- The Department of Labor and Industry (DLI) faces a challenge in terms of statewide enforcement.
- Building departments in the main population centers tend to be reasonably well-staffed; however, in large portions of the state (primarily the western portion of the state) there is spotty enforcement.

Needs

- The DLI needs to develop mechanisms for enforcing the code in areas that have little or no enforcement.
- The DLI would like to reestablish the training centers.
- Development of a larger stable of qualified technicians for blower door and duct blaster tests.

Recommendations

- Enlist utilities across the state to help fund compliance activities by leveraging the 1.5% EEPS requirement.
- Develop training plan/strategy to guide the utility work.
- Work with established trainers such as BPI and RESNET to accelerate the accreditation of properly qualified technicians.

Resources

Minnesota Department of Labor and Industry
http://www.dli.mn.gov/CCLD/Codes.asp

Don Sivigny
Senior Code Development Representative
Minnesota Department of Labor and Industry
433 Lafayette Rd.
St. Paul, MN 55155
651-254-5874

3.7 Missouri

Current Status

Missouri is a home-rule state where the adoption of codes occurs at the local level. State-owned, single-family, and multi-family residential buildings must comply with the latest edition of the MEC or ANSI/ASHRAE Standard 90.2-1993. Commercial structures are not mandated by any statewide code; however, state owned buildings must comply with the 2006 IECC. St. Louis County, which also oversees the city of St. Louis, has adopted the 2009 IECC as their energy code. Missouri's diverse landscape is made up of large rural regions and few urban areas, resulting in a lack of consistency with respect to energy code adoption and enforcement. However, with larger jurisdictions adopting the code, more counties and cities might follow as a few are looking into adoption.

Code Barriers

- Split between urban and rural populations. Although the largest cities have adopted codes, most of the rural areas (which make up the majority of the state) continue to resist this action.
- Moreover, the state lacks a strong force dedicated towards moving forward with codes. There are a lot of interested and supportive parties such as utilities, building officials and activists. However, there is a lack of organized effort on behalf of codes. Work is needed to knit supportive parties into a cohesive force.
- Lack of understanding on the part of builders, consumers, realtors, appraisers and other key stakeholders.
- The opposition from homebuilders, in particular, makes any progress difficult.

Needs

- Consumer awareness to drive energy efficiency and advance energy codes
- Consistency throughout state
- Support from professional organizations such as Realtors, and Appraisers
- Organized support from key stakeholders such as utilities, activists, green builders and code officials.

Recommendations

- Training builders and energy auditors on building science principles
- Education of home building and new buyers on benefits of energy efficiency and energy codes
- Adoption of Energy Code by more populated counties and cities. This could cause a ripple effect thro many smaller counties throughout the state.

- Outreach to utilities, green builders and other key players.
- Comprehensive strategies for advocacy that ties all the groups together and helps them act and speak with one message.

Resources

Missouri Department of Natural Resource; Division of Energy
http://www.dnr.mo.gov/energy/

Tom Appelbaum
Missouri Association of Accredited Energy Professionals
www.maaep.org
Tom@MAAEP.org

3.8 Nebraska

Current Status

Nebraska's current Energy Code, the 2003 IECC was adopted by statute on July 1st, 2005, replacing the outdated 1983 Model Energy Code. The Code applies to all new buildings, or renovations of or additions to any existing buildings. Renovations that cost more than 50 percent of the replacement cost of the building must comply with the code. Nebraska held a preliminary hearing in front of the Urban Affairs Committee on November 19 2010 to discuss the statewide impact of updating to the 2009 IECC. The bill to adopt the 2009 IECC will be introduced into the Nebraska legislature in early January of 2011. The Nebraska Energy Office has received grants to adopt the 2009 IECC, educate individuals on the code, and have completed studies outlining the energy and cost impacts pertaining to the 2009 energy code. Nebraska has also received funds to adopt on the commercial side a code that is 30% beyond ASHRAE 90.1-2004 and 2006 IECC levels. A study has been published that outlines the basis of this 30% beyond code and can be found in the link below. Representatives from the city of Omaha have stated that the city plans to adopt the 2012 IECC. The state has also received funding from the DOE to perform a gap analysis on the state's enforcement infrastructure.

Code Barriers

- While the state has enacted a statewide code; unfortunately, the enabling legislation did not provide an enforcement mechanism.
- Currently, code enforcement happens through a complaint system. The state will look into any complaint by a homeowner. However, this is a haphazard system that provides no way of knowing (the complaints obviously occur after the home has been completed) or checking whether the builder has met the code.
- The level of understanding with respect to the energy code remains very low among the key stakeholders which exacerbate the problems related to compliance.

Needs

- Enforcement infrastructure consisting of enabling statutes and rules, well-trained local building officials and well trained building practitioners.
- Legislation that requires code enforcement
- Energy Raters/Auditors and other trained building science experts

Recommendations

- Training and education to build up a properly trained workforce
- Establish rules/regulations for incorporating energy raters/auditors into the enforcement infrastructure
- Perform a Compliance study

Resources

Nebraska Energy Office
www.neo.ne.gov

Lynn Chamberlin
Architect II
Nebraska Energy Office
PO Box 95085
Lincoln, NE
lynn.chamberlin@nebraska.gov

Nebraska specific Advanced Commercial Building Energy Code Study
http://www.neo.ne.gov/home_const/iecc/documents/NebraskaEnergyStudyFinalReport.pdf

3.9 North Dakota

Current Status

There is currently no mandatory state wide energy code in the state of North Dakota. In September, eligible voting jurisdictions approved to update the current voluntary Energy Code, ASHRAE/IESNA 90.1-1989 to the 2009 IECC beginning January 1st, 2011. The basis of this action was spurred by North Dakota's commitment to abide by all American Recovery and Reinvestment Act requirements. Energy provisions were lightened as the requirement for basement insulation were removed and will be slowly grandfathered into the code. While the state does not enforce or track compliance with the energy code; a city, county, or township that elects to adopt and enforce building codes must adopt and enforce the statewide adopted Building Code. Several cities and counties have already held training sessions on how to enforce the Code. The city of Fargo, which has the largest inspections department within the state, will be conducting seminars for designers to bring them up to speed on the IECC requirements. The Department of Commerce only assists in the adoption of the latest code for the state; it does not enforce or provide resources for compliance measures. However, the Department of Commerce will assist jurisdictions with the adoption of that code.

Code Barriers

- North Dakota suffers from haphazard code enforcement as there is no established statewide infrastructure.
- Code enforcement mainly falls on certain jurisdictions that have decided to adopt and enforce the coc
- Building officials continue to suffer from lack training on the new code.
- The general political culture also works against the adoption and implementation of a statewide code there is little support beyond architects and some building officials.

Needs

- Training centers/courses through a statewide education program
- Establishment of an enforcement infrastructure outside of building officials.
- New training methodologies that will incorporate more than just on-site training.
- General education of stakeholders on the importance of energy codes.

Recommendations

- Establish third party inspections for regular and manufactured housing.
- Perform gap analysis similar to work done by the Building Codes Assistance Project
- Outreach to key stakeholders across the state (focused on largest municipalities)

Resources

North Dakota Department of Commerce Division of Community Services; Government & Technical Assistance: State Building Code
www.ndbuildingcodes.com

James C. Simpson, AIA
Chairman of the North Dakota State Building Code Advisory Committee
YHR Partners
Principal/Project Manager
jsimpson@yhr.com

3.10 Ohio

Current Status

Currently, Ohio requires the use of the 2006 IECC for residential dwellings and 90.10-2004 for commercial buildings. Work to update the code has been stalled due to ferocious opposition from homebuilders who object to: the requirement to use 2x6 walls and full-depth insulation in the basement. The objections have been based primarily on cost considerations but also include issues around the ability of members to actually correctly implement the requirements (many object having to change master plans to accommodate 2x6 construction and others are worried about moisture problems in basements). Advocates, including the Sierra Club, the Ohio Chemical Technology Council, the Ohio Consumers Council and MEEA have been working on an innovative way to surmount this challenge based on trading off lower wall insulation for enhanced building infiltration. Work on the commercial code has been stalled until a resolution to the residential code issues is found.

Code Barriers

- Opposition mounted by the Ohio Homebuilders Association. This group has the ability to stop or indefinitely delay any update to the 2009 IECC and also, by extension, can hold up the development of the commercial code.
- The new code will probably include requirements for mandatory blower door tests. A major concern rests on how such testers will be trained and certified.

Needs

- Development of acceptable methodologies that address homebuilder concerns.

- Strategies to help increase the supply of people qualified to perform building infiltration and duct testing. The possible compromise solution will require the use of duct blaster and blower door tests. This will increase the demand for these services.

Recommendations

- Establish a link between utility code programs and testing. For example, if utilities can find a way to help cover the cost of blower door testing, the utilities should receive credit towards their Energy Efficiency Portfolio Standards goals.
- Partner with homebuilders and advocates to develop alternative strategies of meeting the energy requirements of the 2009 IECC.
- Partner with stakeholders to figure out new ways to adequately ventilate air tight homes.

Resources

Ohio Bureau of Building Standards
http://www.com.ohio.gov/dico/bbs.aspx

Steve Regoli/Debbie Ohler
Ohio Board of Building Standards
Staff Architect/Staff Engineer
6606 Tussing Rd,
Reynoldsburg OH 43068
dohler@com.state.oh.us
spregoli@com.state.oh.us

3.11 South Dakota

Current Status

South Dakota does not have a statewide code. Current statutory language merely requires that local jurisdictions that adopt a code use the 2009 International Building Code. Even this requirement does not help very much with respect to the energy code. While the 2009 IBC does contain a reference to the IECC, many jurisdictions that adopt the 2009 IBC remove the 2009 IECC. On the other hand, given the very severe weather typically experienced in the state, the general consensus is that most builders use tight 2x6 construction.

The governor recently appointed a committee to look into the possibility of adopting the 2009 IECC statewide as per Recovery Act requirements. Moreover, there has been a significant amount of discussion in the committee on how to meet the 90% compliance requirement. Discussion has centered on the possibility of meeting the requirement without adopting a statewide code. The logic behind this reasoning rests on the fact that many of the largest jurisdictions have already adopted the code and that most of the construction in the state takes place in these jurisdictions.

Code Barriers

- Many of the key decision makers in the state have a strong libertarian streak and oppose any kind of regulation. Although state leaders feel a certain amount of responsibility in taking Recovery Act money, the general consensus is to find ways of meeting the requirements without adopting a statewide code.

- A significant portion of the opposition arises due to a lack of familiarity with the energy code.

Needs

- Statewide education program on energy codes. The majority of practitioners appear to be unaware of the code and its requirement and that poses a major obstacle to either adopting a statewide code or getting the type of general compliance needed.

Recommendations

- Continue gap analysis to determine the specific needs in the different municipalities.
- Enlist utilities in the adoption and compliance effort. Determine whether there is an EEPS in the state and if it can be leveraged to provide code help.
- Perform a baseline compliance study to learn where the state stands with respect to the 90% requirement.

Resources

South Dakota Bureau of Administration
http://www.state.sd.us/boa/ose/OSE_Statewide_Energy.htm

Michele Farris
Statewide Energy Manager
Energy Management Office
523 E. Capitol Ave.
Pierre, SD 57501
Michele.Farris@state.sd.us

3.12 Wisconsin

Current Status

Wisconsin has a history of adopting the most recent Energy Code that is available and employing many innovative strategies to ensure enforcement. Current law requires the Department of Commerce to consider upgrades to the building code (including the energy code) on a regular basis. Wisconsin had a minor setback this past year when the 2009 IECC was not adopted as the statewide code. Presently, the state's mandatory building code is the 2006 IECC. Wisconsin held a hearing in October to discuss the approval and impact of adopting the 2009 IECC as the Commercial code in the state. Once approved, this code will become effective in March of 2011. The Department of Commerce, which oversees building code regulations, has regional offices setup throughout the state through which it coordinates enforcement work. The Department of Commerce also must give jurisdictions clearance before they can start enforcing the code; otherwise, enforcement is done through the DOC. This ensures that all building departments performing plan reviews and inspections are, in fact, capable of doing the work. Another innovative process is through the use of a database that tracks and records all Commercial buildings constructed in the state. This type of database is unique in the Midwest.

Code Barriers

- A lack of commitment from the Governor. With the Governor not seeking a third term, energy codes were not a key priority before stepping down from office.

- Key supporters of the energy code missed an opportunity that would have ensured adoption of the code.
- Cumbersome adoption process which must go through a code committee, a public hearing process and a legislative review prior to adoption.

Needs

- Better enforcement on residential energy codes
- Stronger commitment from key governmental leaders.

Recommendations

- Residential enforcement training and education
- Development of third party enforcement structure to supplement regular enforcement of residential energy code.
- Greater utility involvement

Resources

State of Wisconsin Department of Commerce
http://commerce.wi.gov

Brian Ferris
Section Chief
Division of Safety and Buildings Bureau of Integrated Services
(608) 785-9335

Brian.ferris@wi.gov

John Spalding
Section Chief
Division of Safety and Buildings Bureau of Integrated Services
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John.spalding@wi.gov

Appendix 1: Enabling Statutes/Relevant Regulations

State	Enabling Legislation	Relevant Regulation
Illinois	Public Act 096-0778	
Indiana	IC 22-13-2-2	Title 675 Article 19; Section 3-1 through 3-76
Iowa	Title 111; Subtitle 6; 103A.8A	Administrative Code: Public Safety; Section 661; Chapters 303.1-303.5
Kansas	Chapter 12, Article 12; Section 27 Chapter 12, Article 33; Sections 01 through 05.	KSA 66-1227
Michigan	Section 125.504	Construction Code 10 R408.31059-31086 (Res) Construction Code 10A R408.31087-31099 (Com)
Minnesota	Chapter 326B; Section 118	Chapter 1322 and Chapter 1323
Missouri	None	None
Nebraska	Chapter 81 (Sections 1608-1626) Chapter 72 (Sections 804-806) (state buildings)	State Energy Office Title 107, Chapters 1-6
North Dakota		
Ohio	Title 37; Chapter 3781 Section 10A	Chapter 4101:1-13 and Chapter 4101:1-35-01
South Dakota	Title 11, Chapter 10	
Wisconsin	Chapter 101.027	Comm. 63; Comm 22

8/1/07
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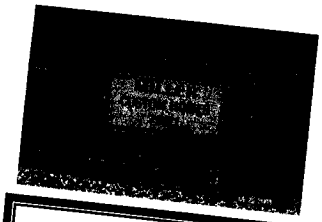

Charles Miller

21 years in the Building Business

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(Board of Directors)

Member of HBAV
(Board of Directors)

Member of TBA
(Executive Committee, Board of Directors)

Member of BBB

Member of EO

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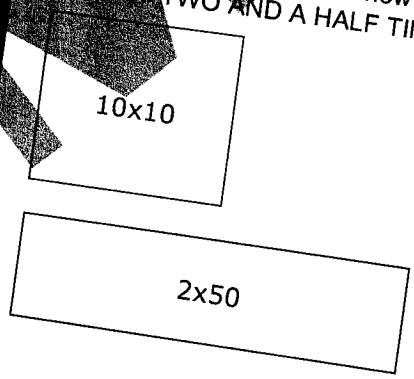
CHESAPEAKE CITY COUNCIL MEETING

On June 19, 2007 I spoke to the Chesapeake City Council about green building and it's role for Chesapeake in the future. I explained that green building is going to be a large factor in bringing back affordable housing to our area. Green Building provides the ability to run a house using less energy, which allows the homeowner to afford more house or afford a house that does not stretch their budget too far. MCH plans to start the 2nd EarthCraft House in Tidewater in the next few weeks.

HOW MUCH IS YOUR HOUSE PER SQUARE FOOT?

I can't tell you how many times I get asked, "How much do you charge per square foot?" This is a very difficult question to answer because there are so many variables that go into a house that affect the square foot price. Not only the finishes in the house but the design of the house. Lets take an example of the two diagrams below. The building that is 10x10 has the same square footage but will cost less to build. There is 40 linear feet of footing and block. The square footage of the slab is the same as the 2'x50' building. When we construct the walls if we figure 1 stud per foot I need 40 studs for the 10x10 box and 104 studs for the 2x50 box. I will need 10 sheets of plywood for the 10x10 box and 26 sheets for the 2x50 box. When we transfer this to dollars on the next page we can see how much more just the early stages of construction will cost. TWO AND A HALF TIMES MORE EXPENSIVE!!



HOW MUCH PER SQUARE FOOT? Cont.

10'x10' Building	Units	Quantity	Unit Cost	Total Cost
Footing	LF	40	$11.76	$470.59
Foundation	LF	40	$24.00	$960.00
Slab	SF	100	$3.00	$300.00
Studs	Each	40	$2.25	$90.00
Wall Sheathing	Each	10	$6.00	$60.00
Brick	Each	1920	$1.50	$2,880.00
			Total	[illegible]0.59
			Square Footage	[illegible]00.00
			Cost /SF	[illegible]61

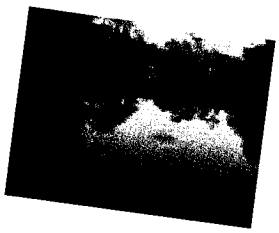
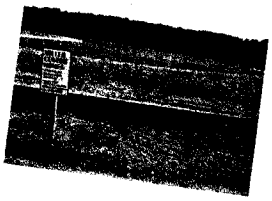
2'x50' Building	Units	Quantity	Unit Cost	Total Cost
Footing	LF	104	$11.76	$1,223.53
Foundation	LF	104	$24.00	$2,496.00
Slab	SF	100	$3.00	$300.00
Studs	Each	104	$2.25	$234.00
Wall Sheathing	Each	26	$6.00	$156.00
Brick	Each	4992	$1.50	$7,488.00
			Total	$11,897.53
			Square Footage	100.00
			Cost /SF	$118.98
Difference			Total	$7,136.94
			Square Footage	0.00
			Cost/SF	$71.37

MCH

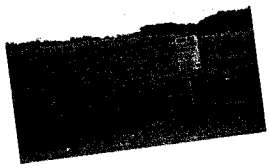
UPDATE ON HOME-A-RAMA 2007

Believe it or not, Home-a-rama is just around the corner. The last time MCH built in Home-a-rama was in 2002 in Warrington Hall, Chesapeake. Well we are in Chesapeake again. This time we are building the "Earthcraft House." The Earthcraft House is a green house built under the Earthcraft House program that was originated in Atlanta, Georgia and has been adopted by the Home Builder's Association of Virginia. The house features green building products and techniques like 2 green roofs, tank-less hot water heaters, and poly-foam insulation. Many of these features have been used on homes we have built over the last ten years. Home-a-rama will open in early October, we hope to see you there. If you would like an early tour of the house, we are open on Saturday and Sunday generally from 1-5.

PROPERTIES FOR SALE

Address	Price	Description
Virginia Beach		
 1028 Michaelwood Drive	$899,000	1 acre deep water lot with old 4 bedroom house In Little Neck Area. Build Your Home Here!! The value is in the land. Where else is there a 1 acre deep water lot in Virginia Beach? The house can be used as a rental until you're ready to build.
2609 Willowlawn Way ***GREEN HOUSE	$899,000	[illegible] 5 Bedroom, 4-1/2 [illegible] Green Home" In [illegible] Plantation Appraised at $950,000!! House includes R-21 Poly Foam insulation, Tank less Hot Water Heater, on Recirculation Pump, Built in Cabinets in Living Room, Steam Shower, Game Room, Media Room, 28000SF Lot, DW, Microwave, Cook top, Oven, Refrigerator. TAX CREDITS!!
Indian River Plantation-Lots	$256,000-$400,000	26000SF+ Lots For Build Packages. Several lots on the Golf Course. Pick your lot and build your custom home on it. We will build from your plans or ours. Build packages starting in the 700's. These are some of the last golf course lots in Virginia Beach.
2124 Heron Ridge Lane Picture Coming Soon	$800,000+	THE LAST LOT FOR SALE IN HERON RIDGE ESTATES TO BUILD ON. We will build from your plans or ours. Build package starting in the 800's.
 Lot 37 Pungo Ferry Landing	$250,000	1.75 acre Corner lot in Pungo Ferry Landing Enjoy Peacefulness in the Country on a large but manageable lot. We will build from your plans or ours.

MCH



Lot 19 Pungo Ferry Landing

$250,000

3.75 acre lot in Pungo Ferry Landing Enjoy Peacefulness in the country on a little bit larger lot. We will build from your plans or ours.

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Picture Coming Soon

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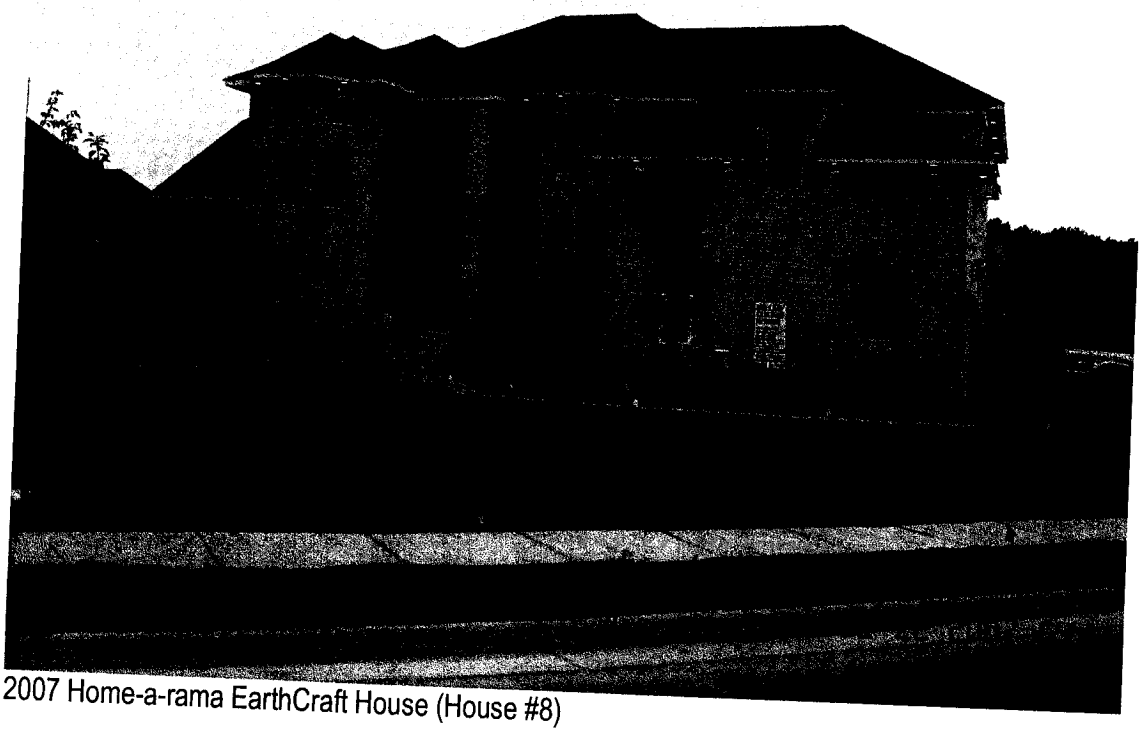
EarthCraft and Green Building

Miller Custom Homes was the first builder in Hampton Roads to be "Certified" as an EarthCraft Builder. Earthcraft is the Green building program that the Home Builders Association of Virginia adopted as their green building program.

"LIVING IN THE GREEN"

Chuck Miller is co-hosting a radio called "LIVING IN THE GREEN" on 790 WNIS radio on the 4th Saturday of every month form 8AM to 9AM. Please tune in and call in with any questions you may have about green building or heating and cooling.



2007 Home-a-rama EarthCraft House (House #8)

This Issue's Green Feature

What is Green Building?

- As the environmental impact of buildings becomes more apparent, a new field called green building is gaining momentum. Green or sustainable building is the practice of creating healthier and more resource-efficient models of construction, renovation, operation, maintenance, and demolition. Research and experience increasingly demonstrate that when buildings are designed and operated with their lifecycle impacts in mind, they can provide great environmental, economic, and social benefits.

THE DUCT BLASTER TEST

Leaky ducts can be a significant source of energy loss in both new and existing homes. Leaky supply ducts can send expensive conditioned air into unconditioned spaces such as attics and crawlspaces, and can be responsible for inadequate air distribution resulting in rooms that are too cold or too warm for occupant comfort. A measure of the airtightness of the duct system can help identify leaks; simple duct sealing methods can save energy and increase comfort.
A Duct Blaster test is usually performed prior to the wallboard being hung. This will allow any leaks in the duct system to be repaired before they are covered. A duct blaster test is where all of the intentional holes (registers and returns) in the duct system are sealed shut. A fan is then attached to the system and it tries to suck the air out of the duct system. The airflow that comes from the leaks in the duct system is then measured. Chuk Bowles of Earthcraft has stated that typically across the country when ductwork is tested there is between 18-25% air leakage in the duct system. The Earthcraft House Program requires that there is a maximum of 6% of the floor area served. If there is <5% leakage of the floor area served, the builder can earn additional points. ***** The 2007 Earthcraft House for Oklahoma had 3.2% leakage on one zone and 1.2% leakage on the second zone.**

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FINAL REPORT NCEMBT-080215

DUCT LEAKAGE MEASUREMENTS IN RESIDENTIAL BUILDINGS

FEBRUARY 2008

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NATIONAL CENTER FOR ENERGY MANAGEMENT AND BUILDING TECHNOLOGIES TASK 05-11: DUCT LEAKAGE MEASUREMENTS IN RESIDENTIAL BUILDINGS

February 2008

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EXECUTIVE SUMMARY

Duct leakage in forced-air distribution systems has a significant impact on the energy consumed in residential buildings. It is a common practice to place the ducts outside the conditioned space in a large portion of US homes. This can result in significant loss of energy by leakage to the outside on the supply side and the infiltration of unconditioned air into the system on the return side. Field studies have shown that existing residential air distribution systems can leak as much as 40% of the total supply air. As ducts are often outside the conditioned space, this leakage corresponds to a proportionate amount of energy loss from the duct system.

Several methods for estimating duct leakage have been used in the past with varying degrees of accuracy. One of the widely used techniques is the Duct Pressurization Test. In this test, the total supply or return leakage is estimated by measuring the flow from a calibrated fan into the duct system at a specific test pressure (usually 25 Pa) using the blower door measurement technique. More recently, DeltaQ and Nulling tests have been proposed to determine both total supply and return duct leakage rates.

The DeltaQ test is an extension of the Duct Pressurization Test using the same blower door measurement technique. It measures air leakage flows for the ducts and the building envelope over a large range of pressures with the air handler on and off. The supply and return are leakages are determined from the fitting curves of the difference between the air handler off and on blower door flows at each pressure recording station. The DeltaQ test forms the basis for ASTM Standard E1554-03 "Determining External Air Leakage of Air Distribution Systems by Fan Pressurization". Similarly, the Nulling test uses a calibrated fan to counteract the pressure change across the envelope due to duct leakage.

All of these techniques focus on determining the total supply and return leakages irrespective of where the leaks are located along the air distribution system. However, the location and nature of the leak may be particularly important for selecting an appropriate method to mitigate leaks more cost effectively than the existing methods. Therefore, a method that simultaneously measures the "local" and "total" leakages is needed as a means of targeting resources on leaky homes and on portions of ducts that have the most problems.

The goal of this project was to develop a new measurement method for locating and estimating the local and total leakage rates. To achieve this goal, the following steps were performed: (i) an experimental facility, the Air Duct Leakage Laboratory (ADLL), was set up at UNLV; (ii) a validation procedure for the new measurement method was developed; (iii) a test protocol for the developed technique was established; and (iv) the new measurement method was analytically and experimentally validated in the ADLL.

The new measurement method, named *Zone DeltaP,* was derived from the duct pressurization technique in which the duct system is pressurized by using a calibrated fan while all registers are sealed off. Zone bags are used to create artificial restrictions inside the duct and consequently different levels of leak pressures and flows. When the zone bag is inflated inside the duct, two different levels of pressures and leak flows (upstream and downstream of the zone bag) are artificially created. A very simple calculation is then performed to estimate the leakage in these two locations. The tests can be repeated to measure the leakages in different locations.

The *Zone DeltaP* test offers several advantages over existing measurement methods. It determines the quantity of each leak within the air distribution system, i.e., it pinpoints where in the air distribution the leak is located and its rate of leakage. Thus, duct repair efforts can be focused on the most leaky locations. Other advantages of the *Zone DeltaP Test* are: (i) it estimates the duct leakage to outside or inside without the need to perform the house-Duct Pressurization Tests simultaneously as described in

Appendix A of ASHRAE Standard 152-2004, (ii) it reduces the uncertainty associated with converting the leakage at an artificial pressure (e.g. 25 Pa) to leakage at the operation pressures, and (iii) it solves certain practical problems associated with duct pressurization technique, e.g., the difficulty to separate the supply from the return leakages or the problem of an inaccessible air handler cabinet.

The report presents results from an extensive laboratory and simulation evaluation. It also provides insight of the performance of several current measurement methods such as Duct Pressurization Test, DeltaQ, and Nulling test for comparison with the newly developed *Zone DeltaP Test*.

1. PROJECT OBJECTIVE

The main objective of this project was to develop and validate a measurement method for locating and estimating the leakages in typical residential air distribution systems. The specific goals of this project were:

- Develop a new measurement methods to locate and quantify leakages in residential air distribution systems
- Validate the new measurement methods numerically and experimentally
- Compare the new measurement methods to establish protocols, such as Delta Q, Duct Pressurization Test and Nulling Test.

2. BACKGROUND

Duct leakage in forced-air distribution systems has a significant impact on the energy consumed in residential buildings (Jump et al. 1996, Siegel et al. 1998, Davis et al. 1998, Walker et al. 1998, Siegel et al. 2003 and Francisco et al. 2002a, 2002b, 2003). It is a common practice to place the ducts outside the conditioned space in a large portion of US homes. This can result in significant loss of energy by leakage to the outside on the supply side and the infiltration of unconditioned air into the system on the return side. Field studies have shown that existing residential systems typically lose 40% of the total supply air in the form of duct leakage (Jump et al. 1996; Cummings et al. 1990; Downey and Proctor 1994; Modera and Wilcox 1995). As ducts are often outside the conditioned space, this leakage corresponds to a proportionate amount of energy loss from the duct system (Sherman et al 2000). There are also comfort, humidity and indoor air quality problems associated with return leaks drawing air from outside or unconditioned spaces within the structure (Francisco et al 2002 and Francisco et al 2003). In addition, a system with more supply than return leakage causes increased infiltration of air that must be conditioned (Sherman et al 2000).

Several methods for estimating duct leakage have been used in the past with varying degrees of accuracy. One of the widely used techniques is the Duct Pressurization Test that is part of ANSI/ASHRAE Standard 152-2004 (ASHRAE 2004). In this test, the leakage is estimated by measuring the flow from a calibrated fan into the duct system at one test pressure (e.g. 25 Pa). Generally, the measurement method here is the same as for a blower door test (Sherman 1995, ASTM 2003b). The approach is to mask of all registers and pressurize the duct system either from the air handler or a return grille using a calibrated fan. The amount of air flowing through the calibrated fan serves as an indicator of the total leakage rate in the duct. To estimate the leakage in the supply and return sides separately, a physical barrier has to be installed to block the air flow between the supply and return. The blower door can be used simultaneously with the Duct Pressurization Test to pressurize the house to measure the leakage to outside.

More recently, Delta Q and Nulling tests have been used to measure total duct leakage. The Delta-Q test was developed by Lawrence Berkeley Laboratory (Walker et al 2001; Walker et al 2004; Dickerhoff et all 2004) based on an idea by Dr. Chuck Gaston of the Pennsylvania State University. The Delta-Q test method utilizes four multi-point blower door tests (ASTM 2003). Two of these are tests that pressurize the house, and the other two depressurize the house. The test requires measuring the difference in flows at the same envelope pressure difference, with the air handler fan on and the air handler fan off. The difference between these blower door flows is called the "DeltaQ" (see Appendix G).

The Nulling test (Francisco and Palmiter 2001; Francisco and Palmiter 2000; Francisco et al 2004; Francisco et al 2003) uses a calibrated fan to counteract the pressure change across the envelope due to duct leakage. The Nulling test consists of two parts. The first part is the unbalanced duct leakage test, which is done with the air handler and duct system in their normal operating mode. The second part, referred to as the supply-only part, is performed to allow for the separate estimation of supply and return leakage by using a second calibrated fan attached to the front of air handler in place of the air handler cabinet cover.

All the previous techniques focused on determining the total supply and return leakages irrespective of where the leaks are located along the air ducts. The location and the nature of the leak may be particularly important for selecting an appropriate method to mitigate duct leakage cost effectively. Therefore, a technique that measures simultaneously the "local" and "total" leakages is needed as a means of targeting resources on leaky homes and focusing efforts on portions of ducts that have the worst problems.

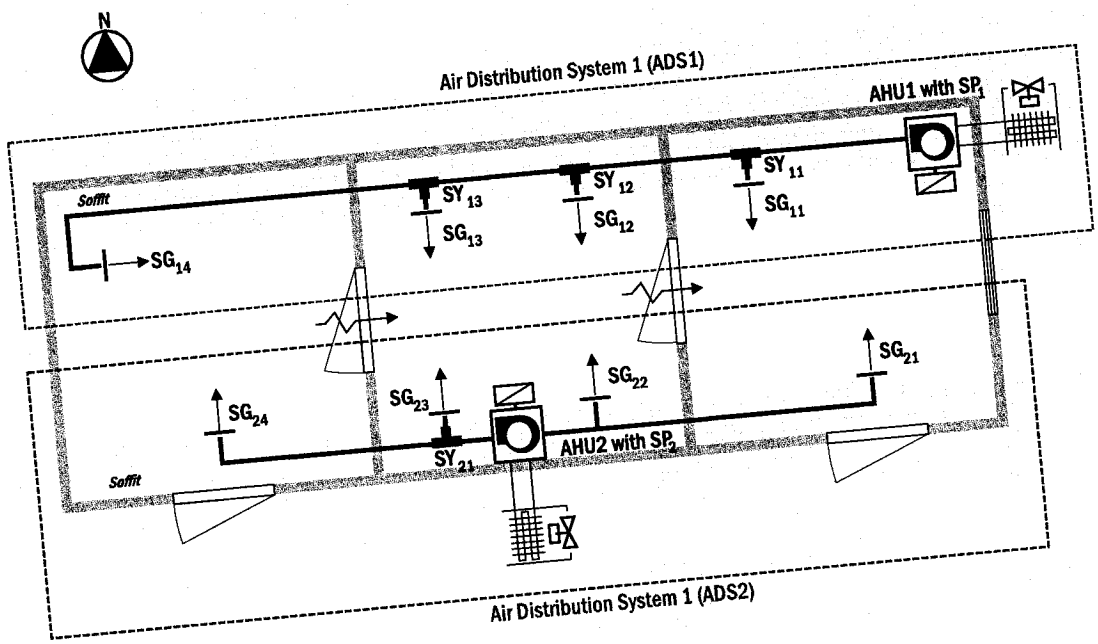
3. METHODOLOGY

3.1 AIR DUCT LEAKAGE LABORATORY

As a first step towards meeting these goals and objectives, a research and testing laboratory, the Air Duct Leakage Laboratory (ADLL), was set up (Figure 1). This was done by customizing an existing building on the UNLV campus to suit the needs of the project. With the help of a local building contractor, some features like partitions, trusses and soffits which are regularly seen in tract type homes in Las Vegas were added. he installation of units and ducts was done by a local HVAC contractor. The rationale was to use typical components and standard field installation practices that are being used by HVAC contractors in Las Vegas area so that the design integrity of standard field practices could be analyzed.

The basic set up was to create zones inside the laboratory space. Two independent HVAC units were installed with different configurations of air distribution systems (ADS1 and ADS2) (see Figure 1). . The HVAC units are outdoor-mounted, air-cooled, split-type heat pumps. Both air handlers are 1.5 ton single phase Carrier units each with nominal air flow of 800 cfm. The first air handler (ADS1) is in the northwest corner of the building with the flex duct running along the west wall. The duct branches off in an asymmetrical fashion to four different registers from three regular sheet metal Y connections. For ease of identification numbers are designated to the registers and the Y connections as shown in Figure 1. The second air handler (ADS2) is placed in the middle of the room and the duct configuration is symmetrical. The flex duct for this configuration runs on either sides of the supply plenum along the East wall. Air is supplied through four registers with just one sheet metal Y connection. The flex duct runs through a series of flat trusses in the framed soffits to simulate realistic duct runs in a typical attic. The soffits are vented to the outside to simulate attic ventilation. One of the lateral surfaces of the soffit has been faced with drywall and the other with transparent plexiglass for visual observations. The ducts in ADS2 are housed completely in the dropped down soffits, whereas in ADS1 they are partially open to the inside. The former demonstrates leakage to outside and the latter, leakage to inside. The supply plenum is placed right on the air handler. The return system is open to the inside. It has just one return grille that is ducted to the return plenum placed under the air handler.

To improve the range of experimentation, a wide range of leakage levels can be introduced for both configurations by creating holes (4.76 mm, 3/16" dia. each hole) at several locations of ductwork. Additional leaks can be introduced in both supply and return ducts to vary leakage from 1% to 25% of total system air flow. The detailed description of ADLL can be found in Appendix A. Owing to the small length of the return duct, the local leakages in the return side were not determined but were treated as a single section and the aggregate return side leakage was determined.



Legend
AHU ___ Air Handler
SG ___ Supply Grille
SP ___ Supply Plenum
SY ___ Supply Duct Y-Connection

Figure 1. Layout of the Air Duct Leakage Laboratory

3.2 ZONE DELTAP METHOD TO LOCATE AND QUANTIFY DUCT LEAKS

A new method for locating and quantifying the total leakage and local leaks in residential air distribution systems, *Zone DeltaP*, has been developed. It is based on the duct pressurization technique in which the duct system is pressurized by using a calibrated fan while all registers are sealed off. The basic approach is to create a pressure differential in the air distribution system, i.e., one zone of high air pressure and the other of low pressure. By comparing the pressure differences in the air distribution system before and after the pressure differential has been induced, the local leakage rates can be quantified and located.

The pressure differential in the air duct is created by a zone bag. The zone bag creates an artificial restriction inside the duct and consequently two different levels of leak pressures and flows. Figure 2 shows the zone bag assembly used in the *Zone DeltaP* test. The zone bag assembly consists of the zone bag and a pressure pan including a provision to insert a pressure hose and a rubber sealing strip around it. The zone bag is made up of a thick inner rubber bladder covered with a layer of puncture resistant vinyl cloth. The open end of the rubber bladder is connected to a PVC hose through which the bag can be pressurized. The hose has a ball valve on its end for quick shut-off. A detailed description of the zone bag can be found in Appendix B. To create a restriction inside the duct, the fully deflated zone bag is introduced into the duct and inflated using a small portable air compressor.

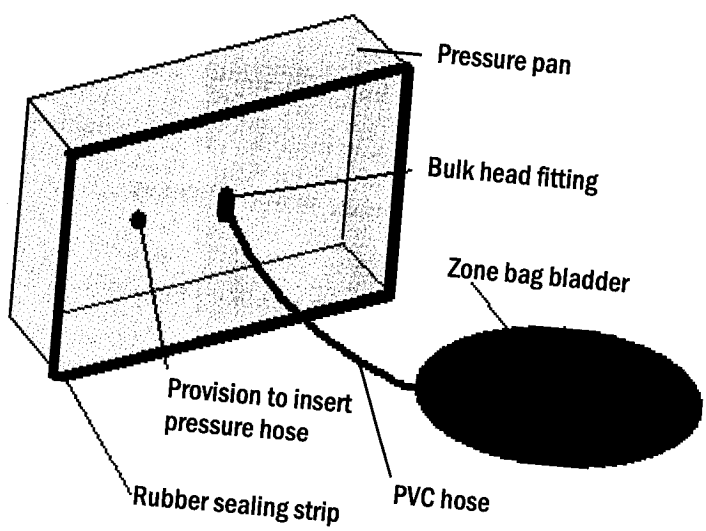


Figure 2. Zone Bag Assembly

3.3 Derivation of the Zone DeltaP Relationships

The *Zone DeltaP* method uses a calibrated fan to pressurize the duct system to a specific pressure with the registers sealed off, similar to the Duct Pressurization Test. The fan is placed either at the air handler cabinet or at any appropriate supply or return register. The zone bag is placed inside the duct from an accessible register to create an artificial restriction. For the test, the register is removed and the opening is covered by the pressure pan. By inflating the zone bag, two levels of pressures inside the duct will be created: (i) a high pressure section (H) and (ii) a low pressure section (L), as shown in Figure 3.

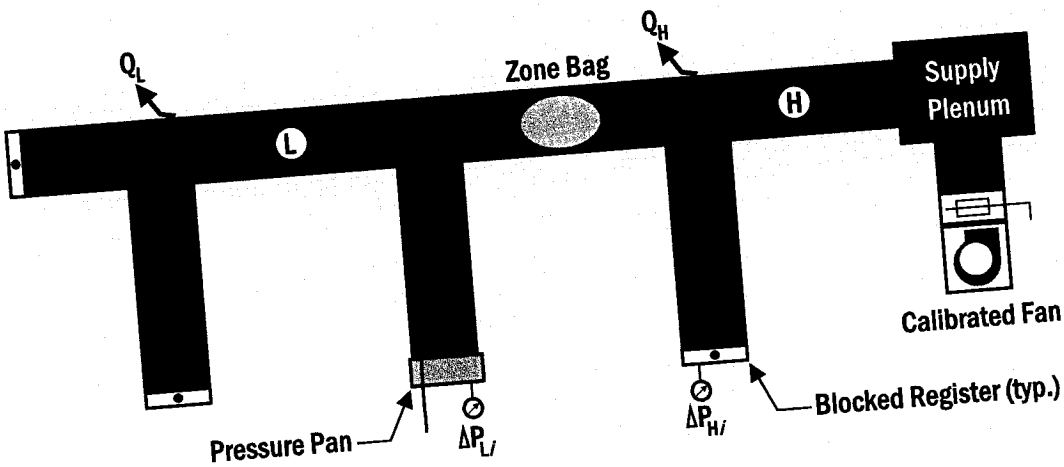


Figure 3. Schematic of the Zone DeltaP Method

The flow through the calibrated fan before and after using zone bag is related to the leak flows in these sections (H and L) as follows:

$$Q_{f0} = Q_H + Q_L \tag{1}$$

$$Q_{fz} = Q_H + Q_L \cdot \left(\frac{\Delta Ps_{Lz}}{\Delta Ps_{L0}} \right)^n \tag{2}$$

where

Q_{f0} = *Air flow rate through the calibrated fan before inserting the zone bag*

Q_{f2} = *Air flow rate through the calibrated fan after inserting and inflating the zone bag*

Q_H = *Leakage in section H (upstream of the zone bag) corresponding to a pressure differential between the duct section H and the house (ΔPs_H) of 25Pa*

Q_L = *Leakages in section L (downstream of the zone bag) corresponding to pressure differential ΔPs_{Lz}*

ΔPs_{L0} = *Pressure difference between the section L of duct and house before inserting the zone bag*

ΔPs_{Lz} = *Pressure difference between the section L of duct and house after inflating the zone bag*

n = *Pressure exponent*

Using Equations 1 and 2, the leakage rates in sections L and H (Q_L and Q_H) can be calculated as follows:

$$Q_L = \left(Q_{f0} - Q_{fz}\right) \cdot CF$$

$$Q_H = Q_{f0} - Q_L \tag{3}$$

where

$$CF = \text{Correction factor} \tag{4}$$

The correction factor is given by the following equation:

$$CF = \frac{1}{1 - \left(\frac{\Delta Ps_{Lz}}{\Delta Ps_{L0}}\right)^n} \tag{5}$$

The pressure exponent is assumed to be 0.6. This value has been found to be a reasonable approximation in a variety of studies based on fan pressurization tests (Francisco et al 2002b). However, to improve the test results, the pressure exponent can be determined from the test data and will be discussed later. The correction factor can also be tabulated as a function of the ratio of pressure differences in the section L before inserting and after inflating the zone bag (Table 1).

Table 1. Correction factors (CF) for the Zone DeltaP method

$\frac{\Delta Ps_{Lz}}{\Delta Ps_{L0}}$	CF	$\frac{\Delta Ps_{Lz}}{\Delta Ps_{L0}}$	CF	$\frac{\Delta Ps_{Lz}}{\Delta Ps_{L0}}$	CF
0.00	1.000	0.35	2.139	0.70	5.190
0.05	1.198	0.40	2.364	0.75	6.307
0.10	1.335	0.45	2.627	0.80	7.980
0.15	1.471	0.50	2.939	0.85	10.763
0.20	1.614	0.55	3.317	0.90	16.324
0.25	1.770	0.60	3.788	0.95	32.995
0.30	1.944	0.65	4.390	1.00	∞

The duct system is pressurized to maintain the specific pressure differential (i.e. 25 Pa) between the duct and the house at section H (e.g. measured at the supply plenum). The zone bag is inflated to create a restriction between the two sections H and L. The more the zone bag is inflated, the higher the restriction it creates and the higher the pressure differential between the L and the H sections of the duct system. If the zone bag is inflated too much, i.e., it blocks the duct completely, the pressure in section L will be zero. As the zone bag is inflated the pressure in section H is increased and the flow though the calibrated fan must be reduced to maintain the target pressure in section H at the original pressure (25 Pa). The reduction of the flow will be equal to the leak flow in section L if the zone bag completely blocks the duct. However, it is not necessary to completely block the duct. In that case, the leakage in location L will be higher than the actual reduction in fan flow rate and can be accounted for using the correction factor CF from Equation 5 or Table 1.

The pressure difference ΔP_{SH} does not appear in the equations as its value is 25 Pa.

3.4 Zone DeltaP Test Procedure

The *Zone DeltaP* method requires two set of tests:

- **Reference Test ($Test_0$).** This test establishes the total supply or return leakage. It is similar to the standard Duct Pressurization Test.
- **Zone Bag $Tests_{zn}$.** This consists of a series of tests {$Test_{z1}$, $Test_{z2}$…, and $Test_{zn}$} to determine the local leakage rates. The number of tests is one greater than the number of locations n considered (i.e., it is equal to n+1).

The following test procedure shall be used for the *Reference Test* ($Test_0$):

1. Block the supply side from the return side at either the supply or return plenum. Air filters are often located in an ideal location for this blockage and can be replaced with blocking materials.
2. Seal off all supply and return registers
3. Install the calibrated fan (flow meter) at the air handler cabinet to pressurize either the supply or return side
4. Install pressure probes at the supply and return plenums to record the pressure difference between supply/or return duct and the house (ΔP_{SH} or ΔP_{RH} respectively). Alternate locations such as the nearest registers may be used for the pressure measurement instead. In addition, it is required to measure the pressure difference (ΔPs_{L0}) in one selected location - ideally as far from the supply plenum as possible - that will be used to determine the local leakage rates in the *Zone Bag Tests*.
5. Adjust the calibrated fan to provide 25 Pa measured at the supply plenum (ΔP_{SH}) when the supply side is being pressurized or measured at the return plenum (ΔP_{RH}) when the return side is being pressurized.
6. Record the flow through the flow meter Q_{f0} as an indication of total supply or return leakage.

The following procedure shall be used for the *Zone Bag $Tests_{zn}$*:

7. Select one accessible register, preferably in the middle of the supply duct. Remove the register and insert the zone bag through the opening to be located in the main supply duct (see Figure 3).
8. Cover the opening with the zone bag assembly as seen in Figure 2. This cover is to be equipped with a pressure probe to measure the pressure inside the duct.

9. Inflate the zone bag while monitoring the pressure (ΔPs_{Lz}) at the zone bag assembly. Stop inflating the zone bag when the pressure difference ΔPs_{Lz} becomes less than 5 Pa.
10. Readjust the flow meter to maintain the target supply plenum difference (ΔP_{SH}) of 25 Pa
11. Record the airflow through the calibrated fan Q_{fz} and the pressure difference in section L (ΔPs_{Lz}).
12. Calculate the flow difference $\Delta Q_f = Q_{fz} - Q_{f0}$ and the correction factor CF from equation 5 (or Table 1).
13. Determine the leakage in section L (Qs_L) as the product of the flow difference ΔQ_f and correction factor CF (Equation 3). Determine also the leakage in section H (Q_{SH}) by subtracting the leakage in section L from the total supply leakage Q_{f0} (Equation 4).

Steps 8 to 13 are repeated to cover the required locations or duct sections as shown in Figures 4 and 5 {$Test_1$, $Test_2$, …,$Test_n$). Note that the order of the tests of the *Zone DeltaP* method shown in Figures 4 and 5 is just an example and for only the local leakage on the supply side. The tests need not be carried out in the section yielding low leakage rates to reduce the time of the testing, i.e., if the leakage in location H is much higher than location L (see $Test_1$ of Figure 4), then $Test_3$ and $Test_4$ will be performed without the need to perform $Test_5$, $Test_6$, and $Test_7$.

It should be noted that the product of the difference between the flows through the calibrated fan ($Test_0$ and $Test_n$) and the CF results in the leakages in section L. This is why the $Test_0$ is referred to as the reference test.

The local leakages measured at the test pressures are not equal to the actual leakage rates at the operating pressure unless the operating pressure happens to be 25Pa. The leakage at operating conditions can be determined by the following:

$$\textit{Leakage at operating pressure} = \textit{Leakage at test pressure} \cdot \left(\frac{\textit{Operating presssure}}{\textit{Test pressure}} \right)^n \qquad (6)$$

where

n = *Pressure exponent*

As mentioned earlier, the pressure exponent n in Equation 5 and Equation 6 may be assumed to 0.6. However, to improve the test results, the pressure exponent could be determined from the test data and will be discussed later.

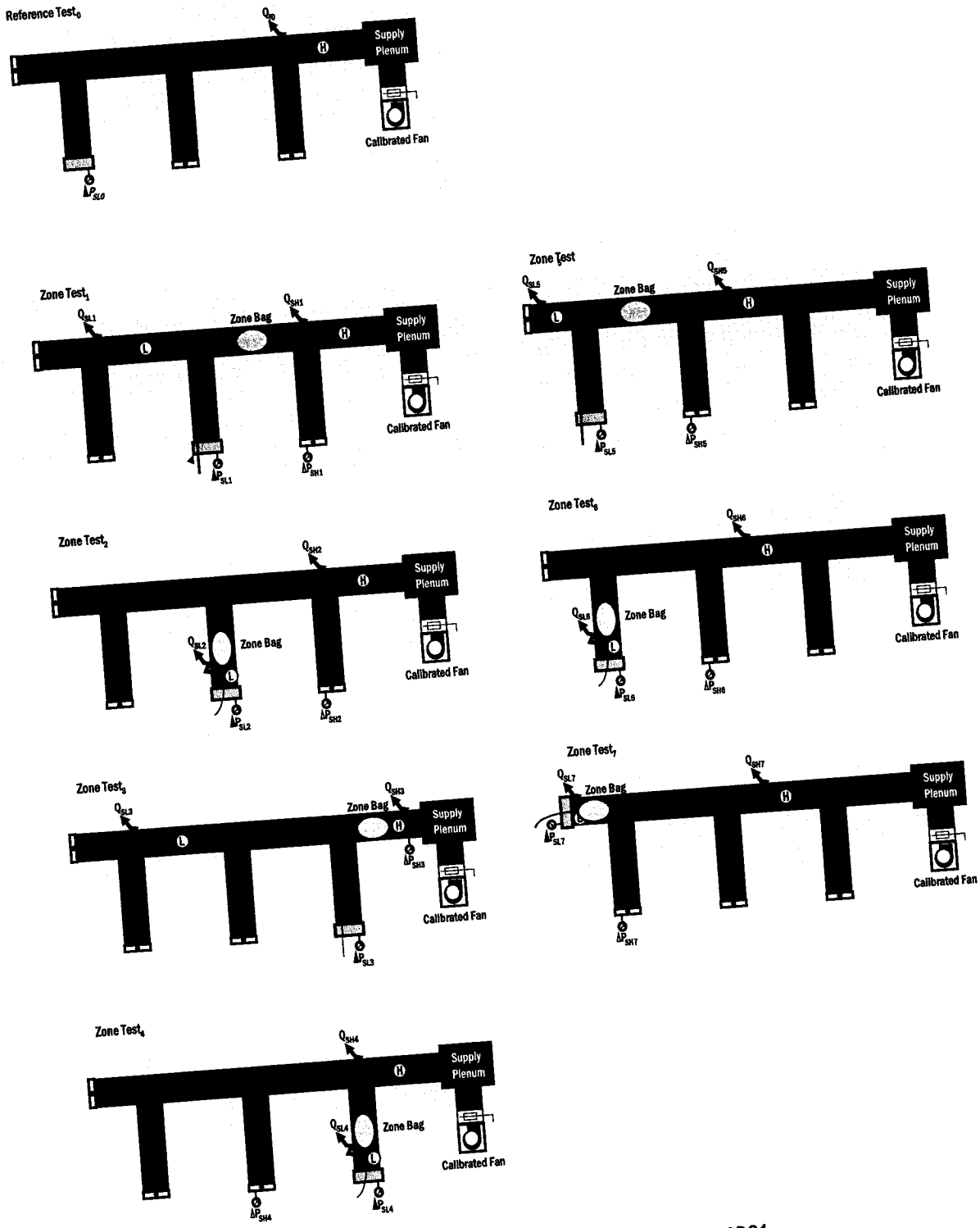


Figure 4. Potential *Zone DeltaP* Test Sequence for ADS1

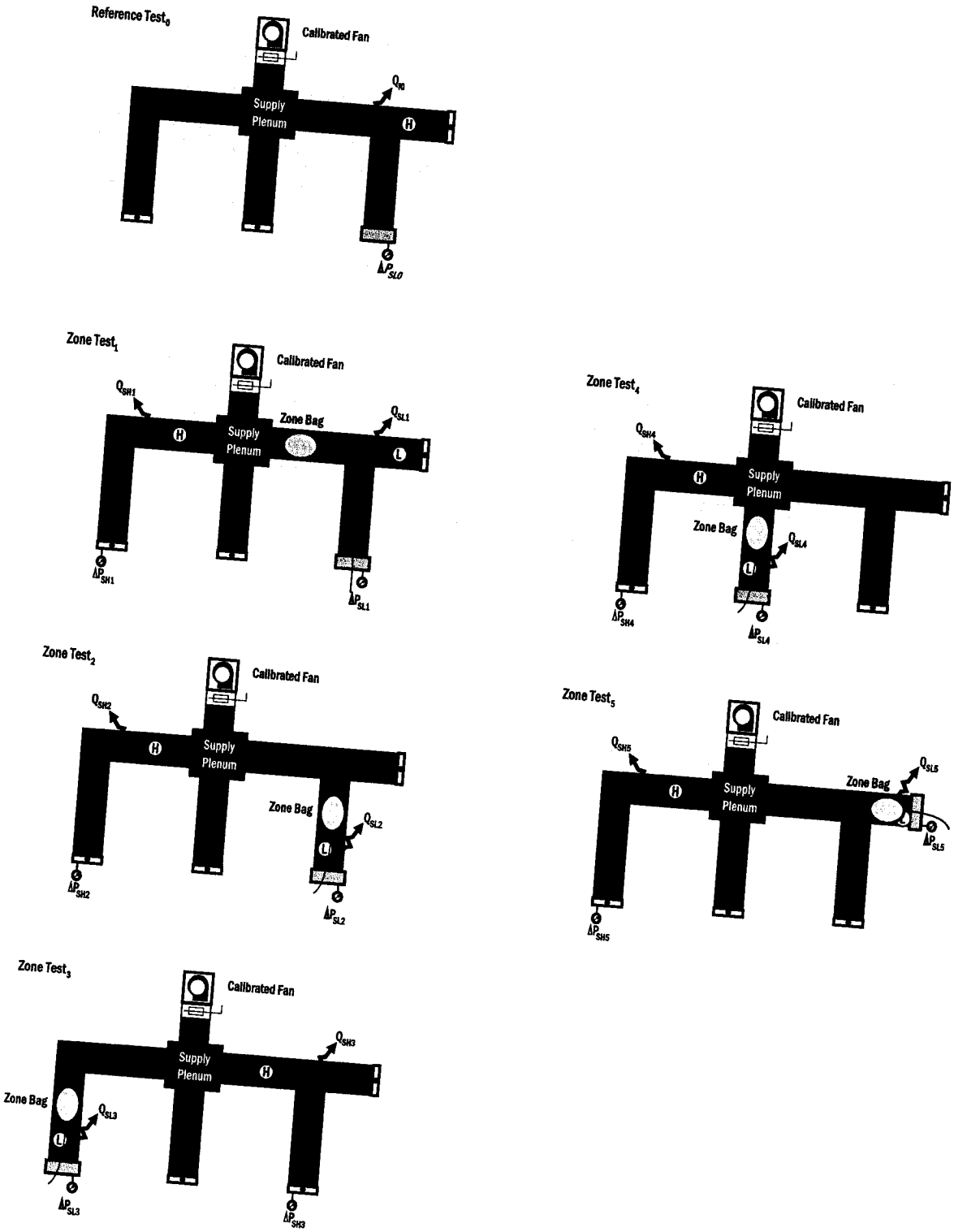


Figure 5. Potential *Zone DeltaP* Test Sequence for ADS2

3.5 MODIFICATIONS AND IMPROVEMENTS

Most houses have some duct leakage, but if the duct system is installed properly, the total supply or return duct leakage determined by the screening or reference test ($Test_0$) is likely to be a small percentage, i.e., less than 5% of the overall system. It may not be cost-effective to repair duct leakage in these homes with low total leakage. An analysis of the cost effectiveness will be done in the second year of this research project. Furthermore, the total supply or return leakage to the outside may be even lower than that determined by $Test_0$. Therefore, the $Test_0$ may be used for screening of low leakage levels. When the leakage is relatively low, proceeding to the next stage of the test (*Zone Bag Tests*) may not be very useful. It is expected that the air duct with the low leakage will not usually require a major retrofit and thus information on the locations of leakage may not be required. Even for energy loss calculations, using half the operating plenum pressure to convert the leak flow at 25 Pa to the leakage at the operating pressure, as in a typical Duct Pressurization Test, will not lead to significantly high uncertainty when the leakage is relatively low. Because the leakage estimated in $Test_0$ is the total supply or return leakage, not the leakage to outside, it may overestimate the leakage required for energy loss estimates but will be relatively small. However, when accuracy is important or when there are high leakages obtained in the *Reference Test* ($Test_0$), the *Zone Bag Tests* should be carried out.

The procedure for $Test_0$ is similar to the standard Duct Pressurization Test for total leakage estimation. However, certain modifications were done to reduce the testing time and to improve the accuracy:

- Magnetic sheets were used to seal the registers instead of tape. This may significantly reduce the time required for sealing registers by tape. This magnetic sheet also protects the register and dry wall from damage incurred by the adhesive tape.
- To make sure that the barrier between the supply and return sides was airtight if used, pressures were measured in the return side during the testing of the supply duct (or measured in the supply side during the testing of the return duct). Any leak would show up as a pressure change on the return side (or supply side). If the barrier was airtight there would be no pressure change.
- The $Test_0$ may be performed to different test pressures (e.g., 25, 40, 55, and 70 Pa). The exponent pressure (n) of the total leak holes can be determined by fitting data to obtain the power-law relationship between the total flow and pressure. This determined exponent pressure n can then be used in Equations 5 and 6. Although this requires additional test readings, this may improve the accuracy of the results significantly.
- In some cases it may be difficult to fix the calibrated fan at the air handler cabinet or to separate the supply and return sides using a physical barrier. In such a scenario, the entire duct system can be pressurized by installing the fan at one accessible return register. The details of this technique are described in more detail in section 4.4.

3.6 METHOD FOR DETERMINING SUPPY AND RETURN LEAKAGE RATES WHEN PHYSICAL SEPARATION IS NOT POSSIBLE

In some cases, it may be difficult to separate the supply and return sides using a physical barrier. A new technique is described here to overcome this problem by conducting two Duct Pressurization Tests: (a) pressurizing the duct system from an accessible return grill to 25 Pa to be measured either at the supply plenum or at an accessible location (see Test a in Figure 6) and (b) pressurizing the duct system from the closest register (SR_1) to the same pressure 25 Pa at the same location (see Test b in Figure 6). The measured flows through the calibrated fans for both tests (Q_{fa} and Q_{fb}) can be expressed as a function of return and supply leakages as following:

$$Q_{fa} = Q_s + Q_r \left(\frac{25 + \Delta P_a}{25} \right)^n$$

$$Q_{fb} = Q_s + Q_r \cdot \left(\frac{25 - \Delta P_b}{25} \right)^n \tag{7}$$

where (8)

Q_{fa} = *Air flow rate through the calibrated fan installed at a return grill, i.e., Test(a) in Figure 6*

Q_{fb} = *Air flow rate through the calibrated fan installed at supply register, i.e., Test(b) in Figure 6*

Q_s = *Total supply leakage at 25 Pa*

Q_r = *otal return leakage at 25 Pa*

ΔP = *Pressure drop between the supply and return plenums that is equal to the difference between the measured return and supply plenums {ΔP_a for Test(a), ΔP_b for Test(b)}*

The difference between the flow rates through the calibrated fan (Q_{fa} - Q_{fb}) for both tests i.e. one when pressurizing the duct from return grill (Test a) and the second from the closest register (Test b), as shown in Figure 6, results from the change in the static pressure measured in the return duct (ΔP_a-+ΔP_b). The static pressure drop, ΔP is due to the pressure drop in heating and cooling coils between the supply and return plenums. Typically, the (ΔP_a-+ΔP_b) could be higher than 20 Pa. Using Equations 7 and 8, the leakages in supply and return sides can be then determined:

$$Q_r = \frac{Q_{fa} - Q_{fb}}{\left(1 + \frac{\Delta P_a}{25}\right)^n - \left(1 - \frac{\Delta P_b}{25}\right)^n} \tag{9}$$

$$Q_s = Q_{fa} - Q_r \cdot \left(\frac{25 + \Delta P_a}{25} \right)^n \tag{10}$$

It should be noted that by introducing the zone bag in the register closest to the supply plenum ($Test_4$ in Figure 4) one can estimate the total supply leakage excluding the leakage in the supply plenum and the

total return leakage including the leakage in the supply plenum. Using the supply leakage determined by Equation 10, the leakage in the supply plenum can be determined.

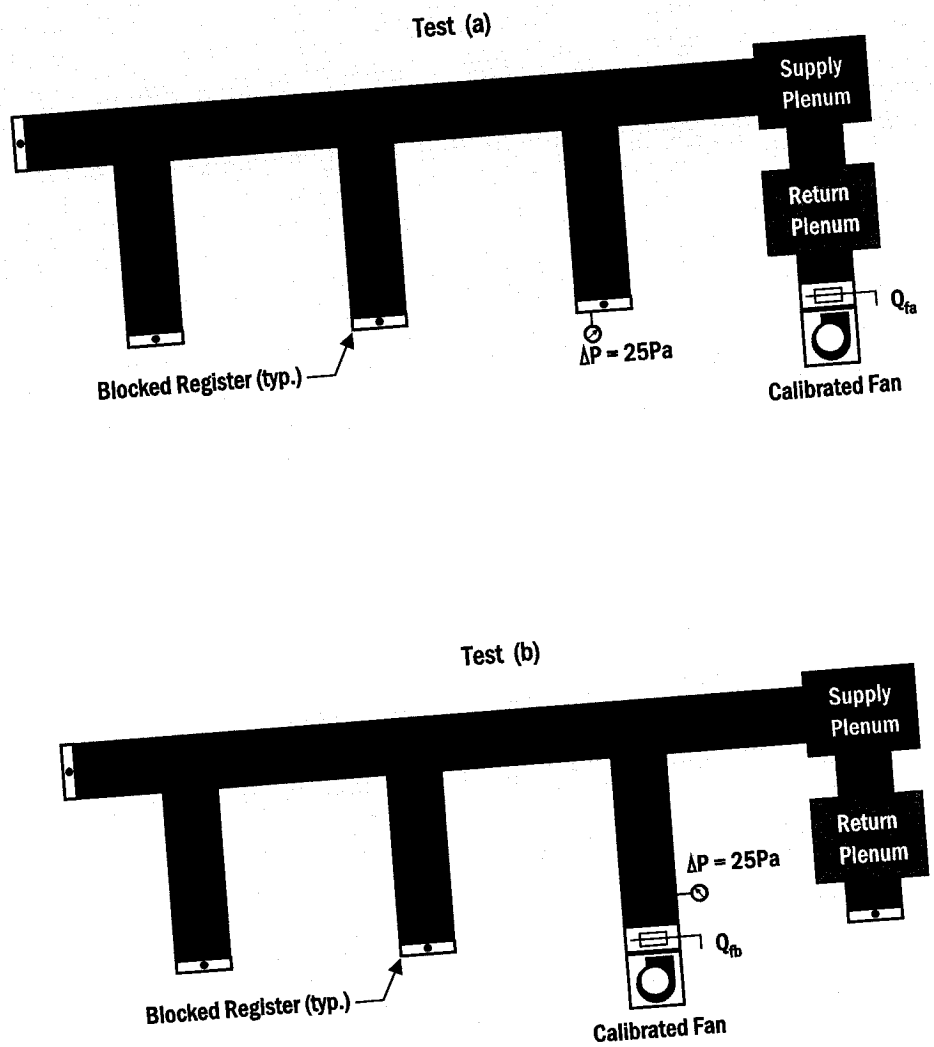


Figure 6. Method for Determining Supply and Return Leakage Rates When Physical Separation Is Not Possible

4. RESULTS

The *Zone DeltaP* method was validated using analytical and experimental approaches.

4.1 ANALYTICAL VALIDATION

To study a very wide range of leakage levels, the analytical validation of the *Zone DeltaP* method was done using a simulation model developed and described in Appendix F. The objective of this model is not to simulate the accuracy of the *Zone DeltaP* method but rather to perform a quick comparison with other duct leakage measurement techniques for a large number of tests and to reveal the effects of any potential or inherent test errors. The duct model was based on the characteristics of the air distribution systems installed at the ADLL. Thus, it was expected that the modeling results will be close to the actual test performance.

Local leakage levels were introduced by simulation (*assigned leakage rates*) and then the simulated leakage rates by the *Zone DeltaP* method were compared with these known assigned local leakage rates. In addition, the total leakage rates as determined by the *Zone DeltaP* and other existing techniques (such as Duct Pressurization Test and DeltaQ) were compared with those assigned leakages. Ten thousand different combinations of leakage values were simulated, varying from 0 to 3 % of total system airflow rate in the registers, from 0 to 4% in the connections and from 0 to 6% in the supply plenum. A high leakage rate was introduced in the supply plenum to replicate the real systems. Data obtained by simulation is referred to as "simulated data" in this report to distinguish it from the data obtained from real measurements.

The developed duct distribution model is very simple and does not consider some effects such as wind effect on house pressure; thus, artificial random errors were applied to the values of the simulated flows and pressures. This approach replicated the effects of potential inherent errors from tests, such as errors in measurements, operator induced errors, and other unknown or neglected effects. For ten thousand simulated tests, a random normal distribution error with a specific standard deviation σ was applied. Figure 7 shows the case with a standard deviation (σ) of $\pm$ 1%. The ten thousand simulated tests were repeated several times with a random normal distribution error having different standard deviations (0%, 1%, 2%, 3%, and 4%). The error is applied on the simulated "measured" values of flow and pressure. In this case, a data set expected to be close to the real situation was obtained for validation purposes.

The *Zone DeltaP* method developed in this study was evaluated by comparing the local leakages rates determined (simulated) by the duct distribution model with assigned leakage rates. The actual local leakage flow at operating conditions was determined using the operating pressure at that location. For the *Zone DeltaP* method the operating pressures were considered only for locations where pressure measurements can be done practically such as the registers and plenums. The operating pressures of inaccessible locations such as connections were estimated, based on averaging the pressures in nearby locations.

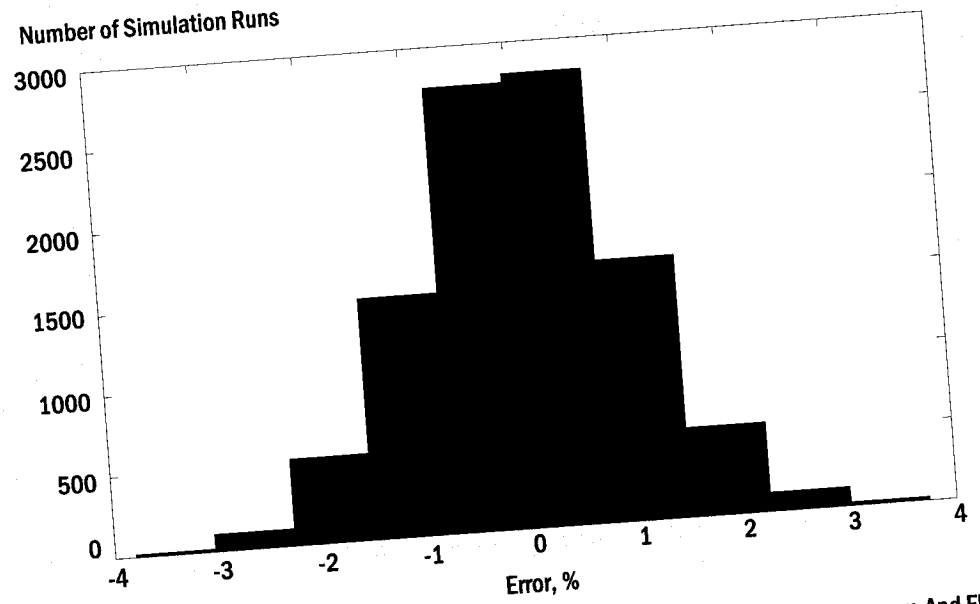


Figure 7. Histograms For Normal Distribution Errors With A Standard Deviation Of 1 Applied To Pressure And Flow Values

Figure 8 shows a comparison *assigned leakage rates* and simulated results using the *Zone DeltaP* method with different errors (1%, 2%, 3%, and 4%) applied to the flow and pressure values. These were considered as they were close to the real systems. The *Zone DeltaP* provides accurate estimates of local leakage compared to the assigned leakages. It is clear that an applied higher error leads to a higher error in estimating of the local leakages. Most importantly, the *Zone DeltaP* tends to be relatively consistent when changes in the error are applied, which may be indicative of the potential inherent test error in the field. As an example, the simulated leakage in the supply plenum changes from 16.5 to 16.8 CFM and the estimated leakage in SR1 changes from 14.5 to 15.1 CFM with a change of the errors applied on the measurement data from 0% to 4%. Thus the accuracy of the leak flow estimation by the *Zone DeltaP* does not significantly deteriorate with higher associated test errors.

To encompass a wide range of leakages, 10,000 combinations of local leakage ratess were assigned and then simulated using the *Zone DeltaP* method. The simulation runs (10,000 combinations) were repeated applying normal distribution errors with a different standard deviation (0%, 1%, 2%, 3%, and 4%). The simulated local leakage rates are shown in Figure 9 for two different cases: normal distribution errors with standard deviations of 1% (left) and of 4% (right). The straight line indicates agreement between the assigned values and those obtained by the *Zone DeltaP* method. The mean difference (MD) and mean absolute differences (MAD) are listed in Table 2. The results are expressed as a fraction of air-handler flow. The results indicate that the accuracy of the *Zone DeltaP* does not change significantly with the test errors, i.e., the MAD in supply grilles varies from 0.01 to 0.16% with a change in the standard deviation of the error applied from 0 to 2%. The greatest error occurs in the connections due to the estimation of the operating pressures. It appears that there is a tendency to overestimate the local leakage rates in the connections and underestimate in the supply grilles. It seems that the accuracy of the *Zone DeltaP* method does not deteriorate even with high inherent errors. In the field these errors could stem from measurements or operators.

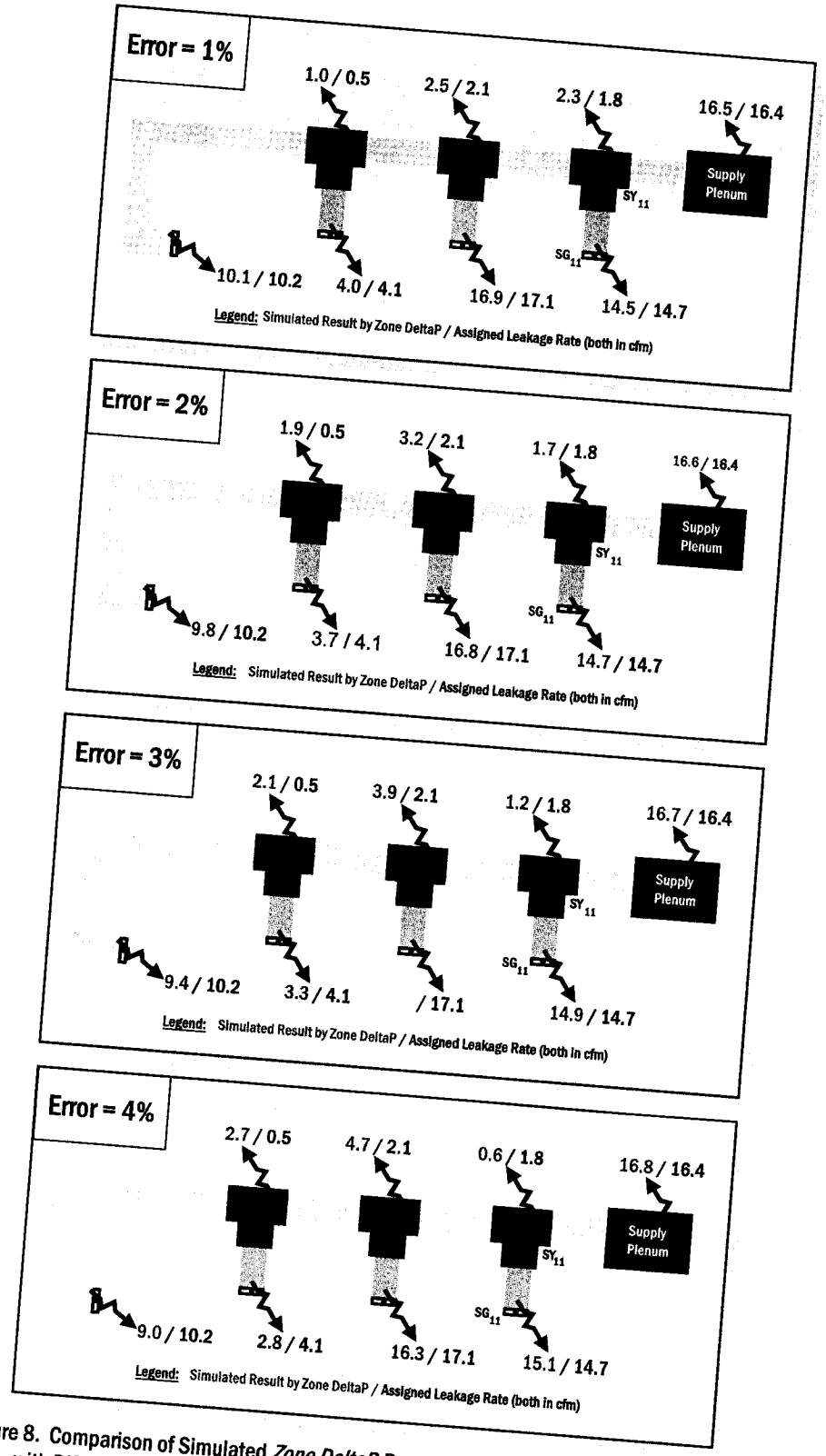


Figure 8. Comparison of Simulated *Zone DeltaP* Results vs. Assigned Leakage Rates for ADS1 with Different Errors (1%, 2%, 3% and 4%) Applied to the Flow and Pressure Values

Care should be taken while analyzing the MAD in different locations. The MAD in the plenum is related to the mean leakage value of 3%, whereas the MAD in the supply grilles is related to the mean value of 1.5%. If it is required to compare different locations, it may be better to divide the MAD by the mean value and use other appropriate statistical criteria.

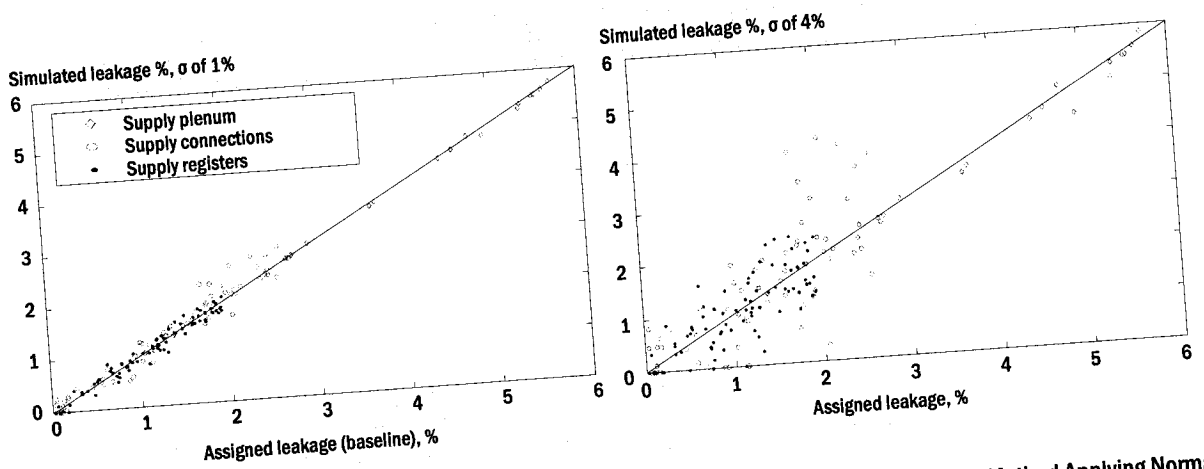


Figure 9. Comparison of the Assigned Leakage Rates and Simulated Results Using the *Zone DeltaP* Method Applying Normal Distribution Errors with Standard Deviations (Σ) of 1% (Left) and 4% (Right)

Table 2. Mean Difference (MD) and Mean Absolute Difference (MAD) as Determined by Comparing the Assigned Leakages vs. Simulated Results Obtained Using the *Zone DeltaP* Method

Cases	Standard Deviation Σ Of The Applied Error	Plenum Max=6% Mean=3%		Connections Max=4% Mean=2%		Registers Max=3% Mean=1.5%	
		MAD	MD	MAD	MD	MAD	MD
1	σ of 0%	0.00	0.00	0.02	0.02	0.01	-0.01
2	σ of 1%	0.02	0.01	0.15	0.05	0.08	-0.02
3	σ of 2%	0.04	0.02	0.30	0.07	0.16	-0.02
4	σ of 3%	0.07	0.03	0.45	0.10	0.24	-0.03
5	σ of 4%	0.09	0.04	0.59	0.14	0.31	-0.03

The total assigned leakage (sum of local assigned leakages) was compared with those simulated by the *Zone DeltaP* and other methods, such as the DeltaQ and Duct Pressurization Test. Table 3 shows the MD and MAD determined by comparing the total assigned leakages and simulated results by different techniques and different standard deviations. Figure 10 shows the comparison of total assigned leakage rates and simulation results using the three duct leakage methods when the normal distribution error was applied with a standard deviation σ of 1%. The results indicate that the *Zone DeltaP* method produces

better estimation of the total leakage compared to the Duct Pressurization Test. The *Zone DeltaP* is better (MAD =0.49 at σ of 4%) even with a high inherent error compared to the Duct Pressurization and DeltaQ techniques *without* an error (MAD = 0.62 for Duct Pressurization Test and MAD = 1.41 for DeltaQ at σ of 0%). The reason for this is that the duct pressurization uses half of the plenum pressure to convert the leakage at 25 Pa to the leakage at operating conditions. On the other hand, the *Zone DeltaP* estimates the local leakage rates using the operating pressures at each location and hence uses that pressure to convert the leakage at the test pressure to the operating pressure.

Table 3. Mean Difference (MD) and Mean Absolute Difference (MAD) as Determined by Comparing the Total Assigned Leakages vs. Simulated Results Obtained Using Different Duct Leakage Methods

Cases	Standard Deviation Σ Of the Applied Error	*Zone DeltaP*		Duct Pressurization Test		DeltaQ	
		MAD	MD	MAD	MD	MAD	MD
1	σ of 0%	0.03	0.03	0.62	0.08	1.41	-1.41
2	σ of 1%	0.10	0.05	0.63	0.04	1.46	-1.49
3	σ of 2%	0.22	0.10	0.64	0.01	1.49	-1.44
4	σ of 3%	0.35	-0.03	0.64	0.17	1.57	-1.53
5	σ of 4%	0.49	0.28	0.69	-0.06	1.61	-1.59

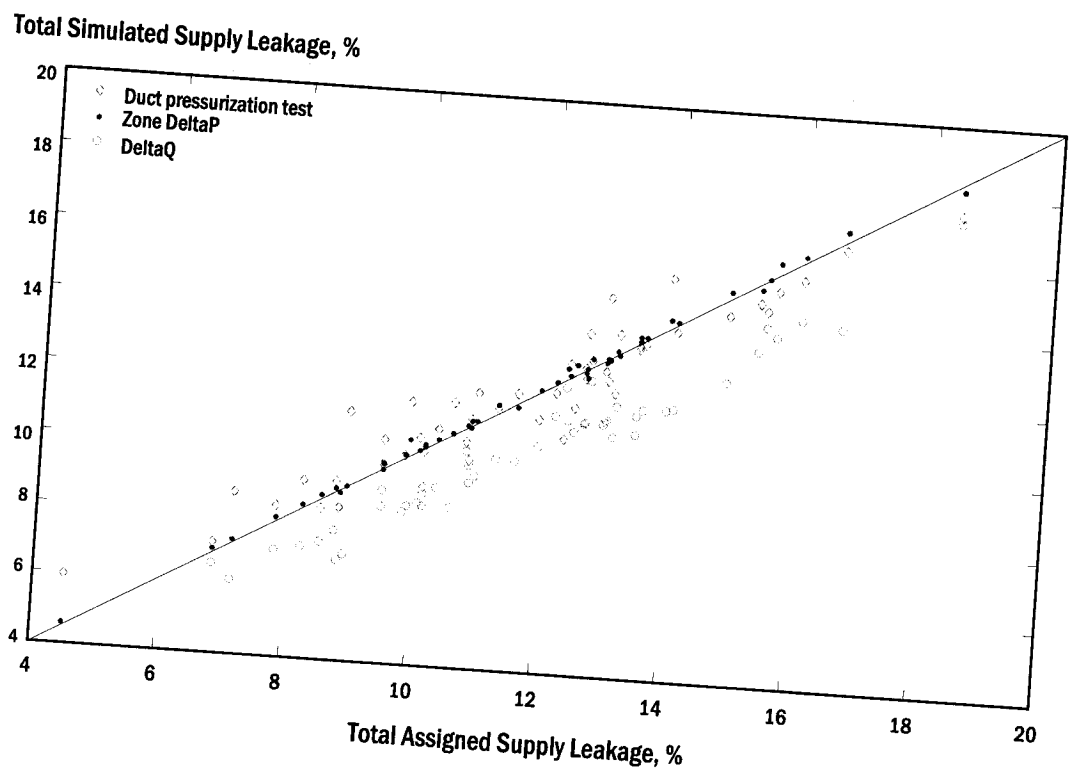


Figure 10. Comparison of the Total Assigned Leakage Rate and Simulated Results Using the *Zone DeltaP*, Duct Pressurization and DeltaQ Method Applying Normal Distribution Errors with Standard Deviations (Σ) of 1%

4.2 EXPERIMENTAL VALIDATION

Experimental studies were conducted on two air distribution systems ADS1 and ADS2 installed at the ADLL (see also Figure 1). The accuracy of the *Zone DeltaP* method was compared to those of baseline tests as described in Appendix C, the Duct Pressurization, DeltaQ, and Nulling tests (see Appendix G for description of these methods). Baseline testing was performed to find the actual local leakage rates in both ADS1 and ADS2 as explained in Appendix C.

The flow and pressures for the baseline, *Zone DeltaP*, and Duct Pressurization tests were measured using a *DG 700 Pressure and Flow Gauge* with a sample time of 1 second. The data was acquired and processed by *TECLOG software* as described in Appendix B. The flow and pressure readings for the DeltaQ and Nulling tests were acquired and processed by an Automated Performance Testing unit, also described in Appendix B. The local leakage rates were converted to the operating pressures measured at each location considered.

Table 4 compares the local leakage rates measured by the baseline test with the results for *Zone DeltaP* for the supply side of the two air distribution systems (ADS1 and ADS2). Owing to the small length of the return duct, the return side was treated as a single section and the aggregate return side leakage (not local) was determined (see Table 17 in Appendix B for return side leakages). Five set of test were run for both the baseline and the *Zone DeltaP* method. The standard deviations for the leakage rates were determined and are listed in Table 4.

Table 4. Comparison of Baseline Local Leakages and *Zone DeltaP* Measured Values for ADS1 and ADS2

System	Leakage (cfm) Standard Deviation (cfm)	Air Distribution Component							
		SP	SG_{i1}	SG_{i2}	SG_{i3}	SG_{i4}	SY_{i1}	SY_{i2}	SY_{i3}
ADS1	Baseline	16.5 (1.08)	14.7 (1.36)	17.1 (1.23)	4.1 (0.23)	10.2 (0.95)	1.9 (0.08)	2.1 (0.09)	0.9 (0.06)
	Zone DeltaP	16.0 (0.95)	14.3 (1.10)	16.3 (1.01)	4.3 (0.34)	11.5 (1.23)	1.2 (0.11)	2.0 (0.08)	0.5 (0.05)
ADS2	Baseline	13.1 (0.98)	14.1 (0.817)	8.5 (0.73)	7.4 (0.511)	7.2 (0.79)	1.3 (0.03)	-	-
	Zone DeltaP	14.1 (0.81)	14.0 (0.72)	8.3 (1.11)	6.5 (0.63)	7.1 (0.85)	1.8 (0.03)	-	-

Note: See Figure 1 for location of each air distribution component
i = 1, 2 refering to ADS1 and ADS2 respectively

Figure 11 compares the results of the baseline tests with those of the *Zone DeltaP* method. The agreement between the two sets of values is very good. The absolute error remains less than 1 CFM for all locations. The results for both air distribution systems showed that the *Zone DeltaP* provided an accurate estimation of the local leakage rates with a good repeatability.

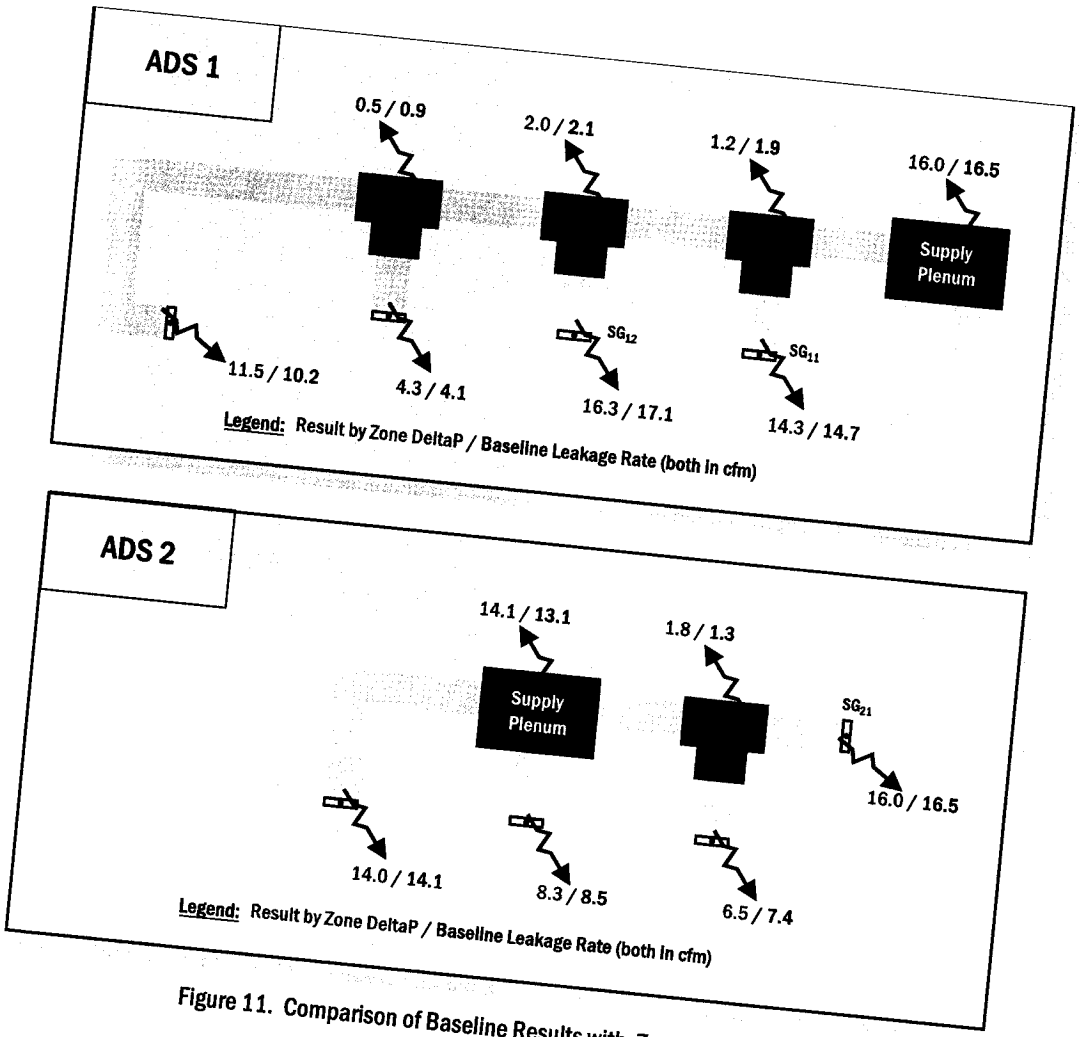


Figure 11. Comparison of Baseline Results with *Zone DeltaP* Ones

The higher leak rates from supply grilles SG_{12} for system ADS1 and SG_{21} for system ADS2 were due to a wide space left between the lateral face of the boot and the dry wall. Sealing these accessible leaks for ADS1 would reduce the total leakage from 8.4% to 4.5%. A high leakage rate was also found in the supply plenum. Using a visual inspection device, as described in section B.9 of Appendix B, a still image of the leak in the supply plenum was captured and is shown in Figure 12. The leakage was due to an incomplete crimp joint.

Identifying the location and nature of the leakage may be particularly important for selecting an appropriate method to try to mitigate some of these leaks cost effectively. Repairing leaks at the supply plenum would have reduce the total leakage about 2%. Repairing leaks both at the supply plenum and the supply grilles SG_{11} and SG_{12} would have reduce the total leakage from 8.4% to 2.5%. Because these locations are accessible, the sealing could have performed in a timely and cost-effective manner.

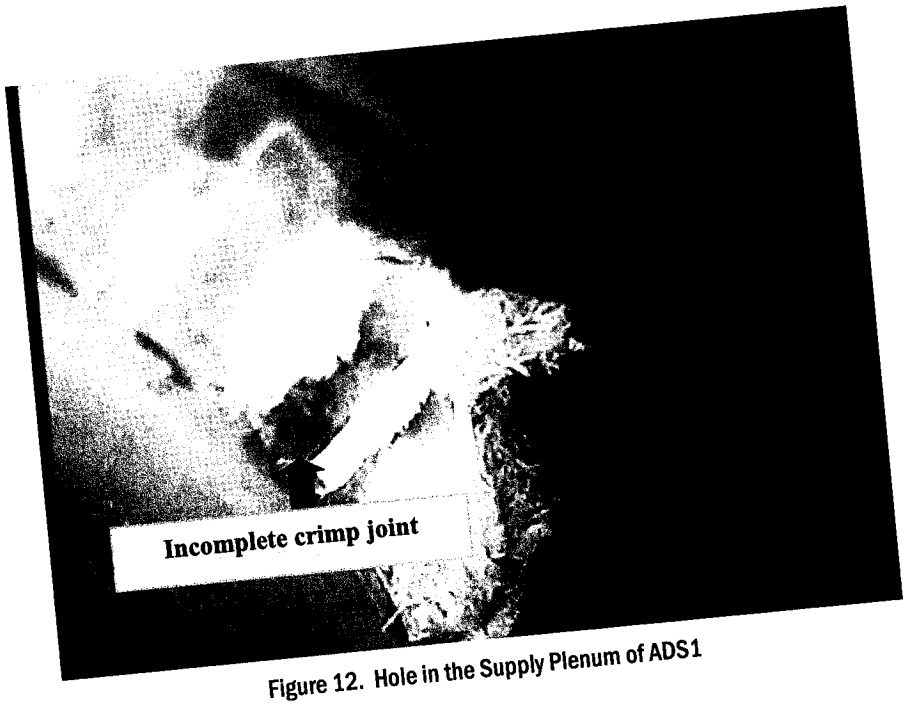


Figure 12. Hole in the Supply Plenum of ADS1

The local leakage rates on the supply side (or the return side) determined by the baseline tests were added to find the baseline total supply leakage (or total return leakage) rate. This total leakage rate was compared with that derived from the *Zone DeltaP* (sum of all local leakages) and the other methods: DeltaQ, Nulling and Duct Pressurization Tests.

The DeltaQ and Nulling tests were applied only to ADS2 because the soffit that housed the ducts was sealed tightly so that all leakage from the ducts was to the outside. This was not the case for ADS1 (some part of the leakage was to the inside), therefore the results from Delta Q and Nulling test were not comparable with the results from the *Zone DeltaP* method and Duct Pressurization Tests on ADS1. In addition, because the return duct was located inside the conditioned space, the actual leakage on the return side was considered leakage to the inside. Thus an artificial leakage to the outside was created using PVC tubes (one located in the return plenum and another in the boot of the return grill). Due to these effects, only the leakage on the supply side (leakage to outside) can be compared and these data are presented in Table 5.

Table 5. Total Supply Leakage Rate As Determined By The Various Methods

Air Distribution System	Baseline Test	*Zone DeltaP*	Duct Pressurization Test	DeltaQ	Nulling Test
ADS1	67.6 CFM (8.4 %)	66.1 CFM (8.2 %)	105 CFM (13 %)	-	-
ADS2	52 CFM (7.2 %)	51 CFM (7 %)	67 CFM (9.3 %)	44 CFM (6.1 %)	46 CFM (6.3 %)

The total supply leakage determined by the Duct Pressurization Test was calculated using half the plenum pressure (see Appendix G in this report or Appendix B in ANSI/ASHRAE standard 152). For the Delta Q technique, the supply and return pressures were fitted from the measured data (see Appendix G in this report or ASTM standard E 1554 – 03).

The *Zone DeltaP* method provides better estimate of the total leakage rate compared to the Duct Pressurization Test as the local operating pressures are incorporated in the calculation instead of half of the plenum pressure, as indicated in Table 5. Compared to the Delta Q and Nulling Tests the *Zone DeltaP* estimated the total supply leakage more accurately. The Duct Pressurization Test overestimated the leakage because half the plenum pressure does not really represent the pressure across the leaks (high leakage was found in the registers and low leakage in connections). For these particular systems, it appeared that using one third of plenum pressure yielded better results. Because the majority of the duct leaks in ADS1 are at low pressure locations, such as registers, the Duct Pressurization Test will indicate a very high supply leakage. These results show that the *Zone DeltaP* methods provides more accurate information about the leak locations and a better estimate of the actual total supply or return leakage.

To corroborate our results, tests were performed by introducing controlled leakage rates from artificial holes made in the boot of each register. Several combinations of open and closed holes were studied. The leakages from these artificial holes were measured as described in Appendix D. Each air distribution system (ADS1 and ADS2) was tested at different operation conditions, which were created by closing one of the registers completely when the air handler fan was on. This represented a new air distribution system with only three operating registers resulting in the operating pressures that were higher than the original configuration. A sample of data of the leakages from holes with different system configurations (operating pressures) is listed in Table 16 of Appendix D.

Figure 13 shows a comparison of the local leakage measured by the *Zone DeltaP* and known leakage from holes in ADS1 and ADS2. The leakage in the registers of ADS2 was only from the artificial holes because the leaks in the original system were sealed very well, whereas the leakage in the registers of ADS1 is from the leaks in the original system (see Figure 11) as well as the holes. As no holes were added to the plenum, the leakage in the plenum does not change for either system.

The local leakage rates determined by the *Zone DeltaP* method are very close to the actual leakage from those holes. Several cases with different combinations of closed and opened holes were studied. Some experimental runs have had the holes of the same register always open. However, the leakage estimated in this register by the *Zone DeltaP* methed for each case did not yield the same value. Thus, only the average values are presented in Figure 13 for the *Zone DeltaP* method results. For instance, the leak in grille SG_{24} as determined by the baseline test was 3.8 cfm and the leakage obtained by the *Zone DeltaP* method was 3.6 cfm. Hence, the value of 3.6 is the mean derived from different tests, having a standard deviation of 0.3 cfm. The mean measured leakage in the supply plenum was 15.7 cfm with a standard deviation of 0.53 cfm. It indicated that the repeatability of the test was quite good. In addition, the *Zone DeltaP* provided an accurate estimate of the local leakages with a low variability (mean absolute value was 0.5 cfm) and with unnoticeable bias (mean value was 0.1 cfm).

The total leakage measured by the *Zone DeltaP* (sum of the local leakages) was also compared with the known leakage from the holes and with those measured using the DeltaQ and Nulling Tests. Figure 14 shows a comparison of the total supply leakage measured by the investigated methods and the known leakage rates from holes for ADS2. The total supply leakage varies with the total number of the holes opened. Actually, in ADS2, the leakage in the registers changes with holes but the leakage in the plenum and connection SY_{21} (see Figure 1) is always maintained as determined by the baseline tests (13+1.6 cfm). As mentioned above, the DeltaQ and Nulling Tests were only applied to ADS2.

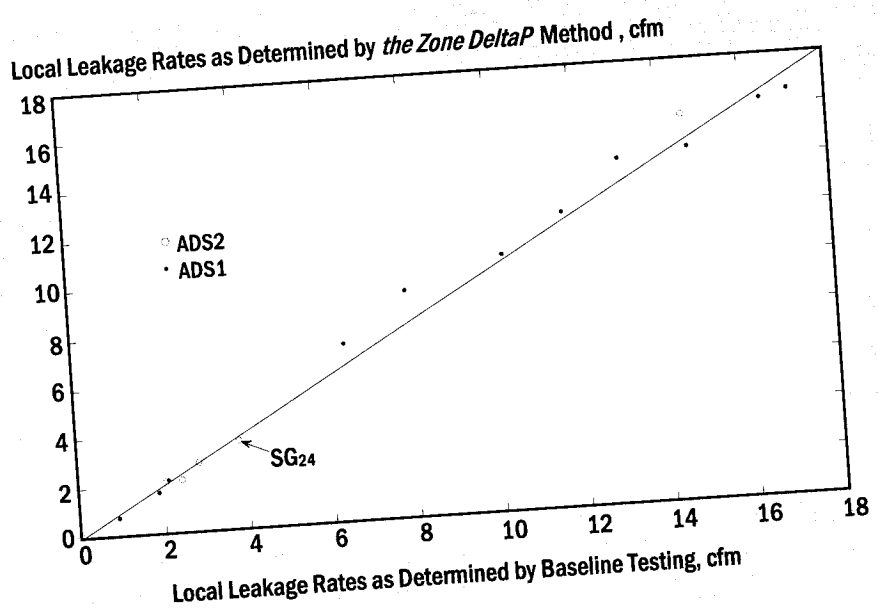


Figure 13 Comparison of Known Local Leakages From Holes with Those Measured by the *Zone DeltaP* Method

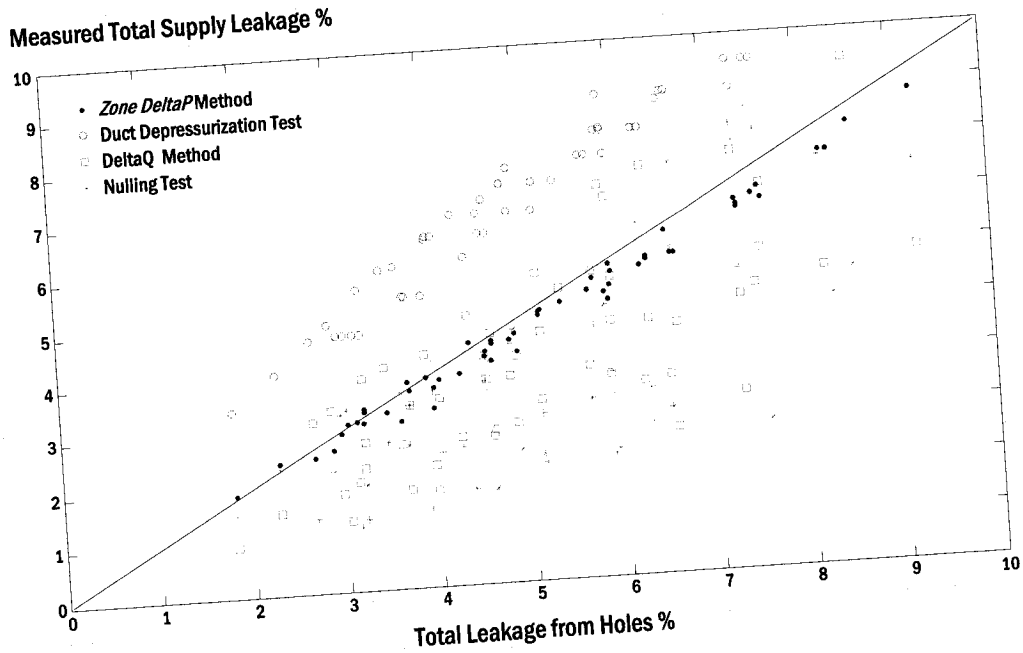


Figure 14 Comparison of Known Total Supply Leakages from Holes with Those Measured by the Investigated Methods

Table 6 lists the mean absolute difference MAD and the mean different MD for both ADS1 and ADS2. The *Zone DeltaP* method provided the most accurate estimation of total leakage. The Duct Pressurization Test which uses half the plenum pressure overestimated the total leakage for both systems. This overestimate is caused because the leaks were located on the low pressure side in these systems, such as at the registers, and half the plenum pressure is too large to represent the actual pressure at those points. The Delta Q and Nulling tests underestimated the leakages for ADS2.

Table 6. Comparison of Mean Absolute Difference (MAD) and the Mean Different (MD) for Both ADS1 and ADS2 for the Four Investigated Duct Leakage Measurement Methods

Air Distribution System	*Zone DeltaP*		Duct Pressurization Test		DeltaQ		Nulling test	
	MAD	MD	MAD	MD	MAD	MD	MAD	MD
ADS1	0.41	-0.29	2.51	2.51	-	-	-	-
ADS2	0.30	-0.27	2.11	2.11	1.32	-0.91	1.51	-1.31

5. CONCLUSION

This project developed a new method, *Zone DeltaP*, for locating and measuring leakages in residential duct systems. The *Zone DeltaP* method was validated using analytical and experimental approaches. The experiments were conducted in the ADLL at UNLV which features two residential air distribution systems set-ups.

The Zone DeltaP method was compared to other currently applied measurements techniques: the Duct Pressurization, DeltaQ and Nulling Tests. The results show that the *Zone DeltaP* estimates the total and local leakages more accurately than these methods. The *Zone DeltaP* method can be used to locate leaky duct locations in a house. In summary:

- The *Zone DeltaP* can accurately estimate the leakages at different locations of a residential air duct system. The results were in very good agreement with the baseline testing. When artificial holes were added, the *Zone DeltaP* provided an accurate estimation of the local leakages with a low variability (mean absolute value = 0.5 cfm) and with unnoticeable bias (mean value = 0.1 cfm) in systems having mean local leakages of 8 cfm.
- The *Zone DeltaP* is not affected by the associated test error. The simulation results showed that the accuracy of the local leakage estimated by the *Zone DeltaP* does not change significantly with the test errors, e.g., the mean absolute difference varies from 0.01 to 0.16% of total supply flow with a change of the standard deviation from 0 to 2% when the normal disribution errors is applied using 10,000 simulation runs. The performance of the *Zone DeltaP* does not deteriorate even with high inherent errors caused by the measurement process or the operator.
- The *Zone DeltaP* provides useful information about leak locations in the duct. For example, results indicate that a large portion of leakage was from the supply plenum at the connection between the duct and the plenum. Leaks in these locations present a serious concern because, even though a relatively small hole exists, the leakage rate will be significantly high due to high operating pressure at that location.
- The *Zone DeltaP* can find the most leaky locations (e.g. disconnected, poor sealing) and thereby, repairing these locations may be very simple and straight forward without spending considerable time and effort.
- Visual inspection along with the *Zone DeltaP* can be used to provide a visual picture of the leaky parts of the duct. The location and the nature of the leak may be particularly important for selecting the right type of sealant. In addition, this could be a very good means to make the case to the home owner to support recommended interventations based on the findings.
- The *Zone DeltaP* can reduce the uncertainty associated with converting the leakage at artificial pressure to the leakage at the operation pressures by identifying the exact leakage locations. Compared to the duct pressurization technique, the *Zone DeltaP* can provides a better estimate of the total leakage rate.
- The exeperimental results also indicate that the *Zone DeltaP* method may provide a better estimate of total leakage than the DeltaQ and Nulling Tests. As the sample size for the experiments was small, field testing will be required to make a more comprehensive comparison.
- The *Zone DeltaP* can estimate the total leakage to the outside or inside without the need to perform simultaneously the house pressurization test as required when applying the Duct Pressurization Test. The *Zone DeltaP* may be an alternative way to determine both the leakage to outside and to inside by providing leak flow in each duct segment whether located in

unconditioned or conditioned space. Because the leakage in each duct section is directly determined without the need for other equipment besides the duct blaster, the accuracy of leakage-to-outside/inside estimation is high. This saves time required for setting up the blower door, taking extra pressure measurements, and balancing the pressure difference.

- The initial or screening test of the *Zone DeltaP* method can provide a quick estimate of the total leakage and allows to make a determination if further testing is necessary or desirable.

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APPENDIX A. AIR DUCT LEAKAGE LABORATORY

The main objective of this project was to develop and validate a measurement method for estimating the local and total leakages in typical residential air distribution systems. Thus, the laboratory set-up had to be representative of the duct systems found in typical tract homes in the Las Vegas area. The available area of 30' x 10' was originally bounded by walls and equipped with basic electricity. A view of the building is shown in Figure 15. With the help of a local building contractor dry wall partitions were installed dividing the area into three rooms of approximately the same area (see Figure 1). Two soffits were built along the east and the west wall of the building. The soffits are vented to the outside to simulate attic ventilation. One of the lateral surfaces of the soffits has been sided with drywall and the other with transparent plexiglass (Figure 16). The soffits space also envelopes wooden trusses placed between equally spaced studs (Figure 17).

Based on the proposed layout, the design cooling and heating loads were calculated using U.S. Department of Energy EnergyPlus[1] energy simulation software. Two heat pump units were selected as the cooling equipment for the laboratory building. The specifications are listed in Table 7.

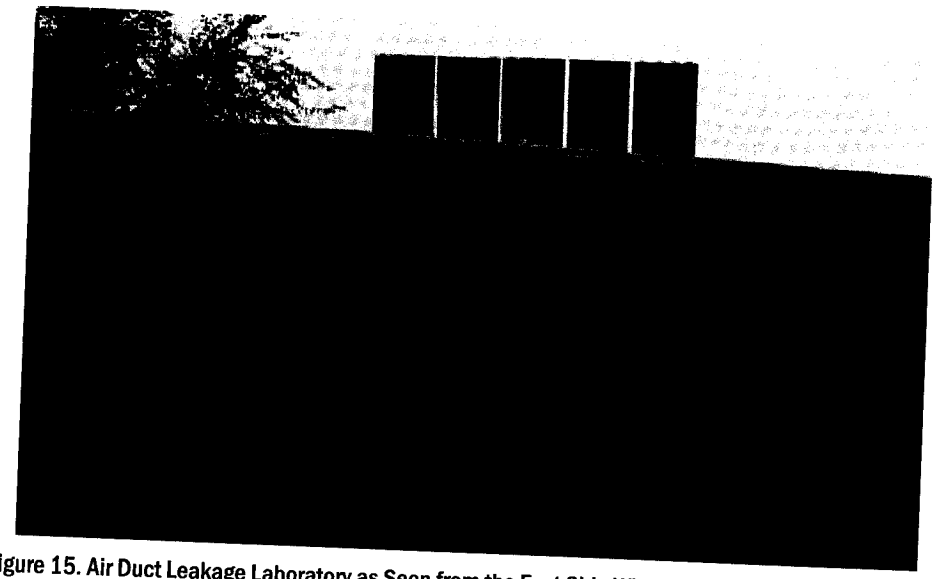

Figure 15. Air Duct Leakage Laboratory as Seen from the East Side With the Heat Pump Servings ADS2

[1] http://www.eere.energy.gov/buildings/energyplus/

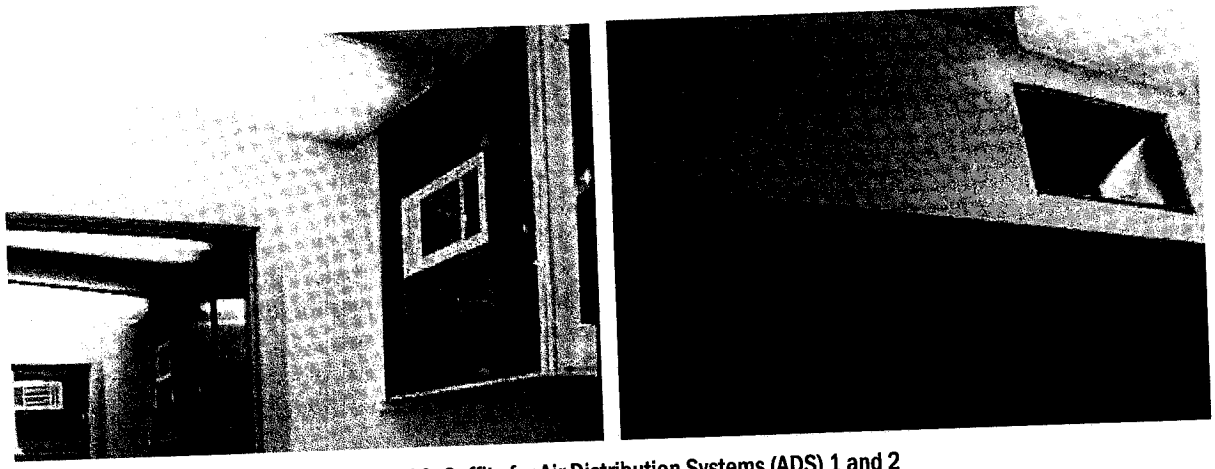

Figure 16. Soffits for Air Distribution Systems (ADS) 1 and 2

Figure 17. Truss Structure in Soffits

Table 7. Specifications of the Air Conditioning Systems

Air handler specifications	Capacity	1.5 ton
	Nominal air flow	800 CFM
	Energy ratings	13 SEER / 11.5 EER/7.9-8.5 HSPF
Heat pump specifications	Air discharge	Vertical
	Air quantity	2614 cfm
	Motor speed	800 RPM

The duct system by itself is a relatively simple distribution system and the installation is similar to ducts in regular tract type homes in Las Vegas. Two independent HVAC units were installed with different duct configurations, indicated by Air Distribution System (ADS1) and ADS2 (see Figure 1). The first air handler (ADS1) is in the northwest corner of the building with the flex duct running along the west wall. The duct branches off in an asymmetrical fashion to four different registers from three regular sheet metal Y connections. For ease of identification numbers were designated to the registers and the Y connections.

The second air handler (ADS2) is placed in the middle room. The duct configuration is symmetrical in this case. The flex duct runs on either sides of the supply plenum along the east wall. Air is supplied through four registers with just one sheet metal Y connection. The flex duct runs through a series of flat trusses in the framed soffits. The ducts in ADS2 are housed in the dropped soffits completely, whereas in ADS1 they are partially open to the inside. The former demonstrates leakage to outside and the latter, leakage to inside. The supply plenum is placed right on the air handler. The return system is open to the inside. It has just one return grille that is ducted to the return plenum placed under the air handler.

Another aspect that was addressed while setting up the lab was versatility. A number of standard techniques and the newly developed *Zone DeltaP* method needed to be tested in the facility. Therefore, the ADLL is equipped with versatile features. For example, the total leakage for the ducts can be varied between 1% to 25% of total system air flow. This was achieved by adding artificial leaks in different locations. The leakage from these holes was measured by conducting the fan pressurization test before and after creating the holes. Ducts in ADS 2 were originally housed completely in the soffits. Whereas for the ADS1, the soffits envelopes only a part of the ducts. This could be later modified so that the entire duct system could be enclosed in an envelope that is connected to the attic. Similarly, the return ducts were originally designed to be open to inside and with little effort could be held in an envelope that is connected to the outside. This in a way provided additional variation to vary the leakage that goes to the inside and outside.

APPENDIX B. INSTRUMENTATION

The following instrumentation was procured to perform investigation of the duct leakage tests.

B.1 ZONE BAGS

Zone bags can be introduced into the duct to isolate the air flow sequentially from the air outlet supplies upstream to the fan. This allows sequential determination of where leaks exist and to what percentages they do exist as part of the overall duct leakage. Zone bags are generally used in duct cleaning to block sections of ducting to make big jobs more manageable. Commercially available zone bags are made up of a thick inner bladder covered with a layer of puncture resistant vinyl cloth and the open end of the rubber bladder is connected to a PVC hose through which the bag can be pressurized as shown in Figure 18. The hose has a ball valve on its end. The zone bags are introduced into a section of the duct and then inflated using compressed air. In a completely inflated state the zone bag fills into the ridges of the helical groves of the flex duct to give a larger area of contact to provide air tightness.

Figure 18. Zone Bag with a Nominal Size of Eight Inches

B.2 DUCT BLASTER

The duct blaster is a calibrated air flow measurement system designed to test the air tightness of forced air duct systems (Figure 19). The air flow through the duct blaster fan required to pressurize the duct system to the test pressure is the measured total duct leakage rate. Specifications of the Minneapolis Duct Blaster manufactured by Energy Conservatory that was used for some of the experiments are listed in Table 8.

The duct blaster fan consists of a molded fan housing with a variable speed motor. The Duct Blaster fan can move up to 1,500 cubic feet of air per minute (cfm) at zero back pressure (i.e. free air), and approximately 1,350 cfm against 50 Pascals (0.2 inches w.c.) of back pressure. With the flexible extension duct attached, the fan can move 1,250 cfm (free air) and 1,000 cfm against 50 Pascals of back pressure. Fan flow is determined by measuring the slight vacuum created by the air flowing over the flow sensor attached to the end of the motor. The duct blaster fan can accurately measure flows between

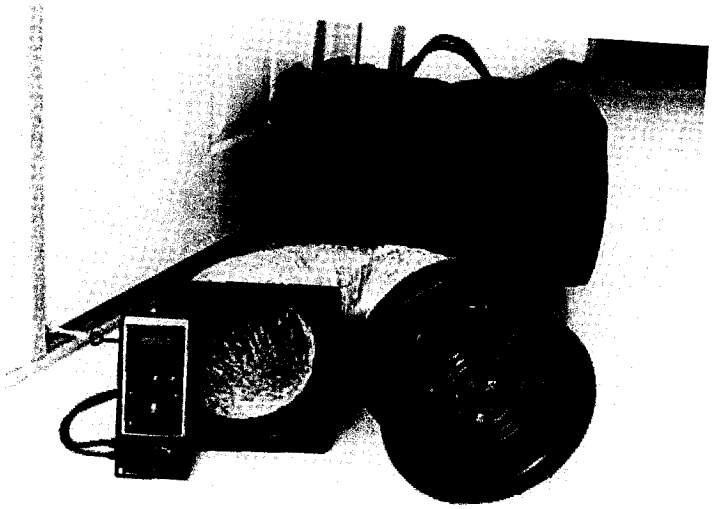

Figure 19. Minneapolis Duct Blaster[2]

10 and 1,500 CFM using a series of three calibrated Flow Rings which are attached to the fan inlet. Though the duct blaster fan motor is not reversible, the fan can be installed to either pressurize or depressurize the duct system.

Table 8. Duct Blaster Specifications

Maximum Flow	1,250 cfm @ 0 Pa, 1,000 cfm @ 50 Pa
Minimum Flow	20 cfm (Ring 3)
Dimensions	Fan: 10" diameter, 8" long
Flow accuracy	+/- 3% (DG-700 or DG-3 digital gauge)
Calibration	Meets both ASTM Standards E779-87, ASHRAE 152 and CGSB- 149.10-M86
Fan Controller	Variable Speed Solid State DC (maximum controller output is 60 Volts DC nominal). Maximum 4 amp current draw (110V AC input)

B.3 TECLOG

TECLOG is the datalogging software by Energy Conservatory. It can monitor and store data from differential pressure channels installed in the digital pressure gauges. TECLOG Version 1.1 can simultaneously record data from two data acquisition devices. This program provides easy control of data acquisition parameters such as pressure and analog channel settings, sampling rates and auto-zero intervals. Figures 21 and 22 show screenshot of TECLOG.

[2] Image source: http://www.conservationstrategies.com/shop/images/6605.jpg

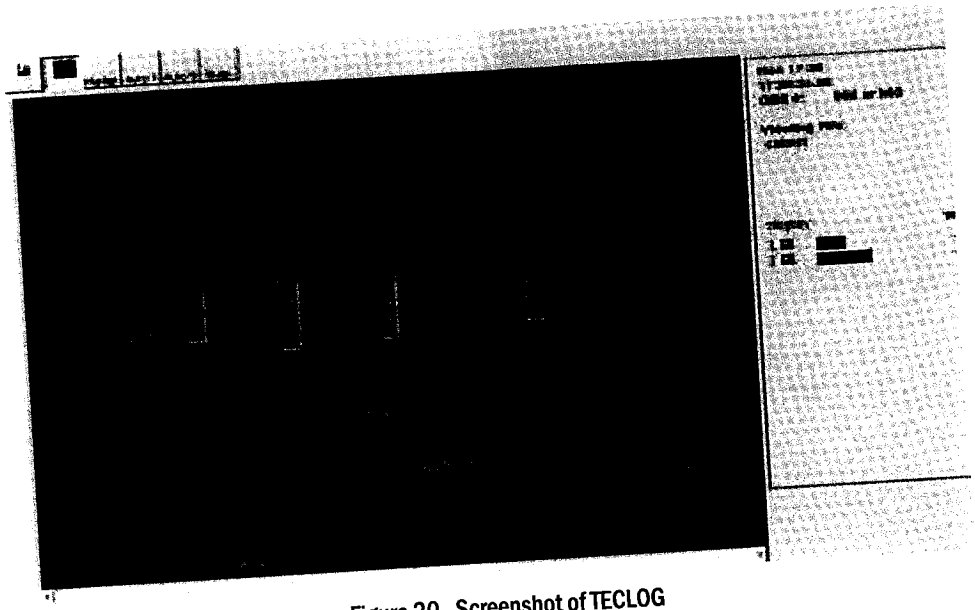

Figure 20. Screenshot of TECLOG

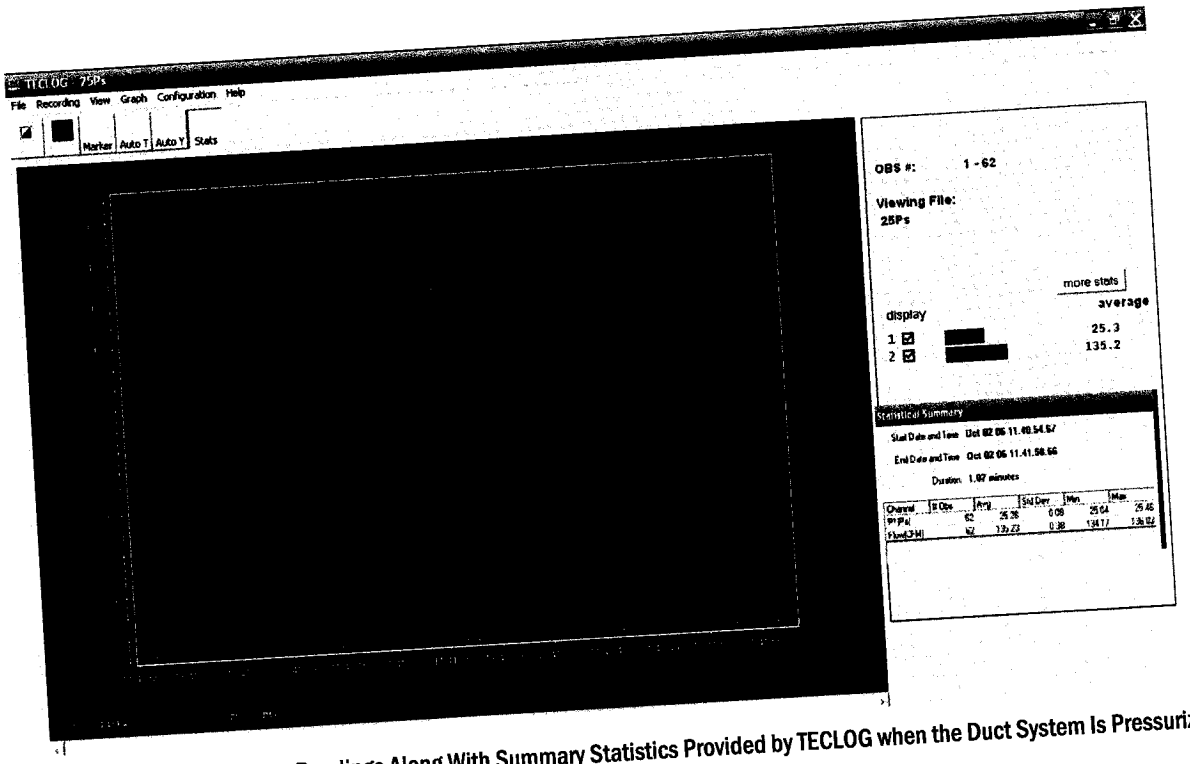

Figure 21. Flow and Pressure Readings Along With Summary Statistics Provided by TECLOG when the Duct System Is Pressurized

B.4 Blower Door

The blower door is a calibrated fan used to measure building air tightness. It is fixed into an exterior doorway. The fan blows air into or out of the building to create a pressure difference between inside and outside. The pressure difference forces air through all holes and penetrations in the exterior envelope. By measuring the air flow through the fan and its effect on the air pressure in the building, the blower door system measures the airtightness of the building envelope. The kit consists of the fan, the fan speed controller and the adjustable alumunium door frame. The blower door fan can accurately measure airflow over a wide range of flow rates using a series of calibrated flow rings which are attached to the inlet of the fan. Figure 22 shows the blower door in an typical building diagnostics setup. Specifications of the blower door manufactured by Energy Conservatory that were used for testing envelope leakage are listed in Table 9.

Table 9. Blower Door Specifications

Maximum Flow	6,300 cfm at free air, 5,350 cfm at 50 Pa.
Minimum Flow	11 cfm with Ring E
Dimensions	20 in. inlet diameter, 10.25 in length.
Flow accuracy	+/- 3% using DG-700 or APT system Rings D & E +/- 4% or 1 CFM.
Calibration	Meets ASTM Standard E779-03, CGSB-149.10-M86, EN 13829 and ATTMA Technical Standard 1.

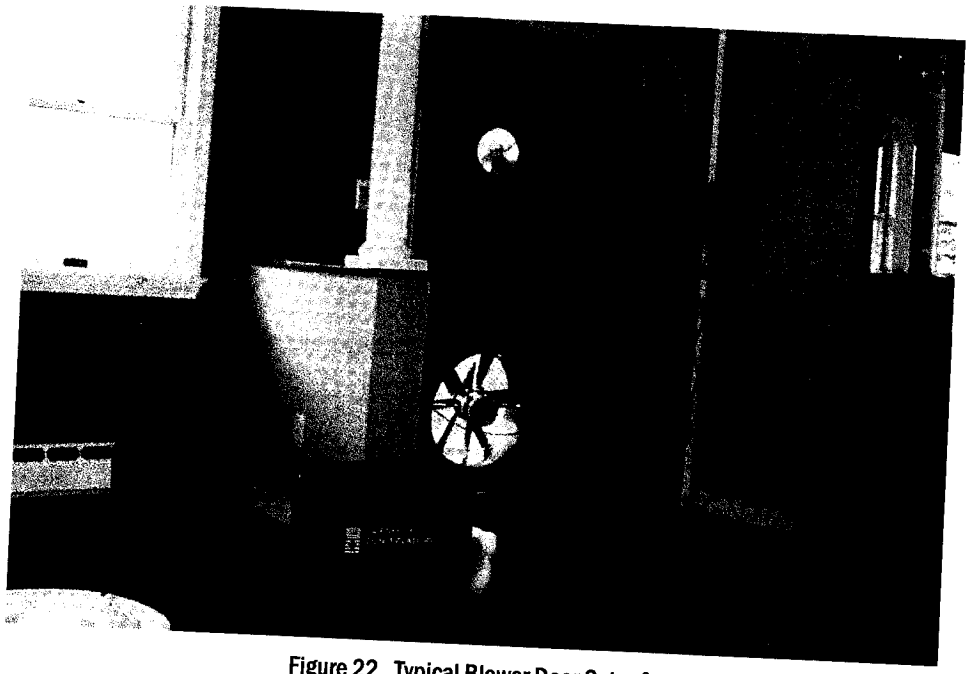

Figure 22. Typical Blower Door Setup[3]

[3] Image source: http://infrareddiagnostic.com/db4/00313/infrareddiagnostic.com/_uimages/IMG_8092.JPG

B.5 DG 700 PRESSURE AND FLOW GUAGE

The DG-700 Pressure and Flow Gauge manufactured by Energy Conservatory is a multi-functional differential pressure gauge with two independent measurement channels. In addition to providing high resolution pressure measurements, the DG-700 is programmed to provide air flow measurements during building performance test procedures based on the information about the type of calibrated fan and the flow ring. Figure 23 shows the DG 700 Pressure Gauge and Table 10 lists the specifications.

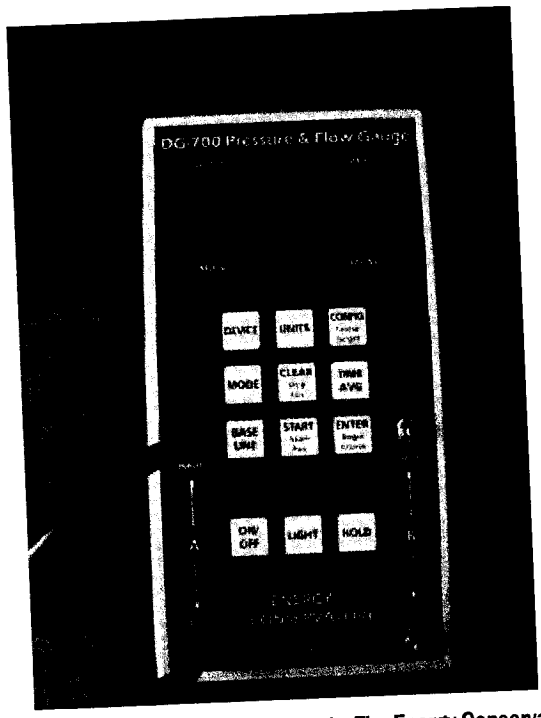

Figure 23. DG 700 Pressure Gauge by The Energy Conservatory

Table 10. DG-700 Pressure and Flow Gauge Specifications

Pressure range	-1,250 Pascals to +1,250 Pascals
Pressure channels	2 differential pressure channels.
Units	Pascals or Inches w.c.
Accuracy	+/- 1% of reading, or 2 times the resolution, whichever is greater
Baseline	Baseline feature to measure and record a baseline pressure reading, and then display the baseline adjusted pressure reading.
Resolution	Auto ranging with 0.1 Pascal resolution.
Auto-zeroing	For position and operating temperature sensitivity during operation
Time averaging	1 sec, 5 sec, 10 sec and long-term average

B.6 AUTOMATED PERFORMANCE TESTING SYSTEM

Automated blower door tests can be performed using the Automated Performance Testing (APT) System (Figure 24) by The Energy Conservatory. Testing procedures and control options are selected using the TECTITE software also manufactured by The Energy Conservatory. The APT system automatically adjusts the speed of the Blower Door fan while simultaneously monitoring the building pressure and fan flow using two on-board differential pressure channels. Test results are recorded, displayed on the screen, and can be saved to a file. Additional channels can be used to monitor and record more pressures. The APT system consists of a data acquisition box with 2 to 8 on-board pressure channels and phone jacks for 8 voltage input channels, a 6' serial cable and a fan speed controller with a communication jack, and a fan control cable. Specifications of the Automated Performance Testing (APT) system are listed in Table 11.

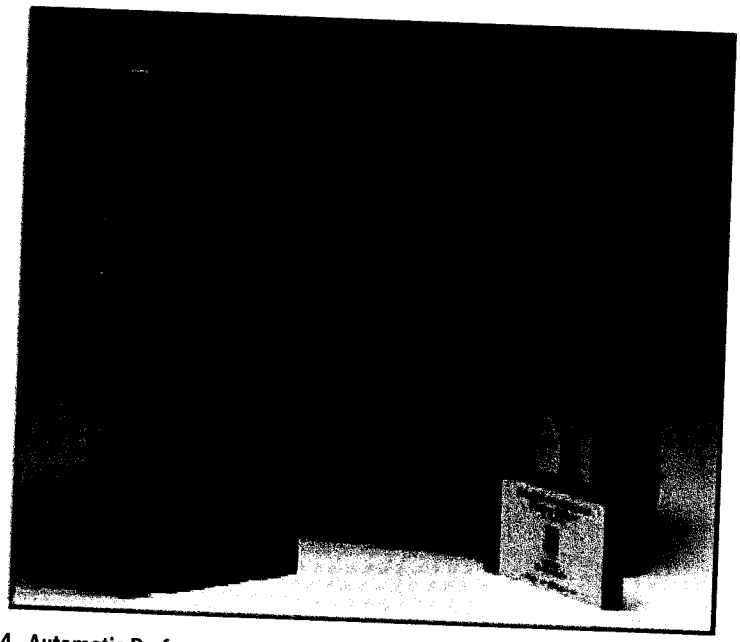

Figure 24. Automatic Performance Testing System Manufactured by The Energy Conservatory

Table 11. Automated Performance Testing (APT) System Specifications

Pressure channels	8 differential pressure channels with auto-zeroing
Pressure resolution	Switch able between 0.1 Pa and 0.5 Pa, with corresponding ranges of approximately +/-400 Pa and +/- 1,000 Pa, respectively
Voltage channels	8 differential analog DC voltage input channels
Voltage resolution	Switch able between 0.1 mV and 1 mV, with corresponding ranges of approximately +/-400 mV and +/-4 V, respectively
Communication	RS-232 connector (9-pin) to interface with PC at 9,600 baud
Pressure accuracy	+/- 1% of reading, or 2 x resolution, whichever is greater from 0- 800 Pa (at 10 °C to 30 °C). +/- 2% of reading from 800-1,000 Pa

B.7 Register Sealing Film

Register sealing film is an adhesive backed plastic that can be used provide a quick temporary seal on registers (Figure 25) when measuring duct leakage with a duct blaster or blower door. The film can be easily removed from the register and does not harm the register's finish. It is available in 8" and 24" width rolls. It is perforated to provide easy dispensing.

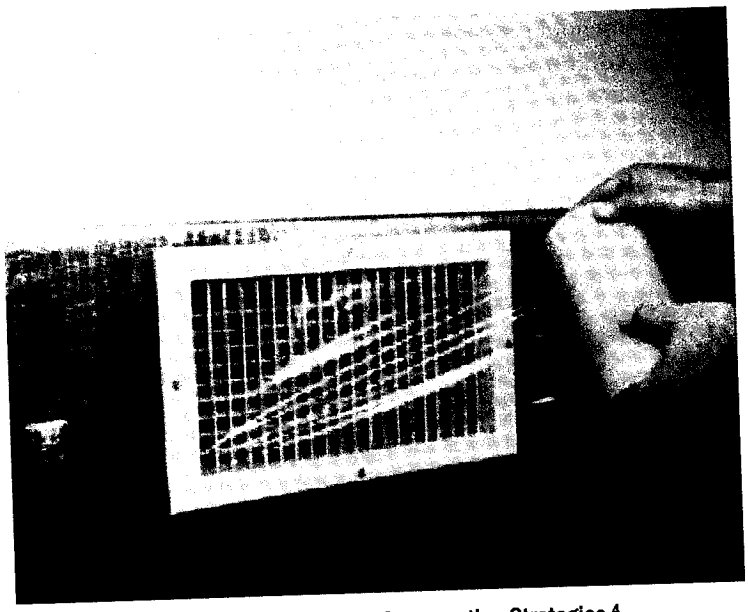

Figure 25. Duct Mask by Conservation Strategies [4]

B.9 Visual Inspection System

The visual inspection system is an inspection tool for air conditioning systems (Figure 26). This tool was used to confirm the leak location information obtained by local leak detection techniques. It consists of a high resolution color camera head consisting of six LEDs with diffusers and 25-foot reinforced vinyl insertion cable. The camera can be connected to a laptop or a television screen using appropriate cables to view the inside of the duct in real time. Specifications of the visual inspection system are listed in Table 12.

Table 12. Visual Inspection System Specifications

Resolution	400 line, high resolution NTSC Color
Illumination	6 built-in white LEDs
Lens	Wide angle 4.3 mm lens Coated optical glass protective lens

[4] http://www.conservationstrategies.com/home/cs1/page_73_16/register_sealing_film.html

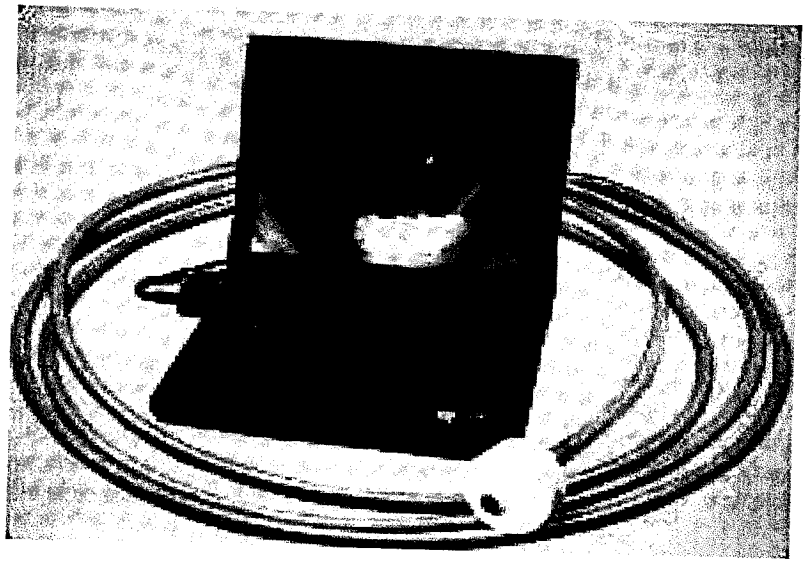

Figure 26. Visual Inspection System

B.10 PRESSURE PAN

The pressure pan is a quick diagnostic tool for leak detection. It is a shallow pan with a pressure tap in the middle and gasketed edges. For testing, the blower door is used to depressurize/or depressurize the house to a test pressure. The pressure pan is placed over each of the registers and the pressure difference across each register is measured, as shown in Figure 27. A large pressure difference indicates that the leak is nearer to the register. Pressure pans are available in two sizes: 12"x14"x4" and 22"x22"x2".

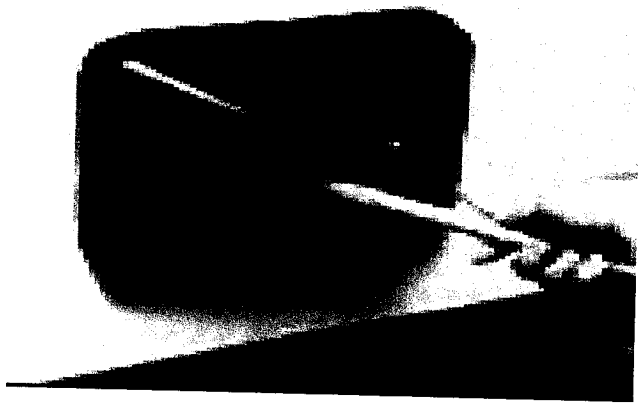

Figure 27. Pressure Pan by Conservation Strategies [5]

[5] http://www.conservationstrategies.com/home/cs1/smartlist_16/diagnostic_equipment

APPENDIX C: BASELINE TESTING

To evaluate the accuracy of the investigated duct leakage measurement methods independent baseline testing was performed. This baseline was developed to evaluate the performance of the investigated techniques applied on the system as found. The baseline technique uses the designed zone air bag to block tightly the duct section or location considered for leakage estimation. The baseline requires a calibrated fan to pressurize the insulated duct section to multiple pressures to map the relationship between the local leak flow and pressure. Initially, parametric studies were carried out to determine the required pressure inside the zone bag to block the airflow in a duct section.

C.1 PARAMETRIC STUDIES ON ZONE BAGS

The primary focus of these studies was to investigate the effectiveness of the zone bag to block the air flow in flexible ducts. Parametric studies were performed to determine the right amount of pressure that will be required inside the zone bag to ensure a proper seal between the zone bag and the duct. The tests were conducted on a straight duct as well as a tee section with diameters such as 8", 10", 12", and 14". The duct caps used for testing are shown in Figure 31. One section of the duct was connected to the calibrated fan and the remaining sections were blocked using sheet metal duct caps as shown in Figure 28.

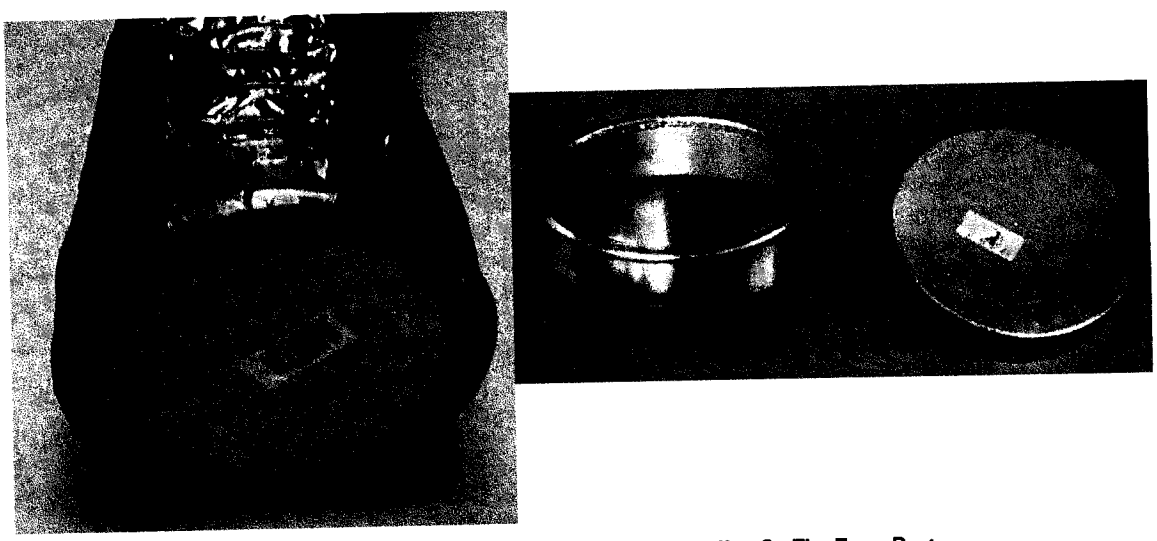

Figure 28. Duct Caps Used For Parametric Studies On The Zone Bag

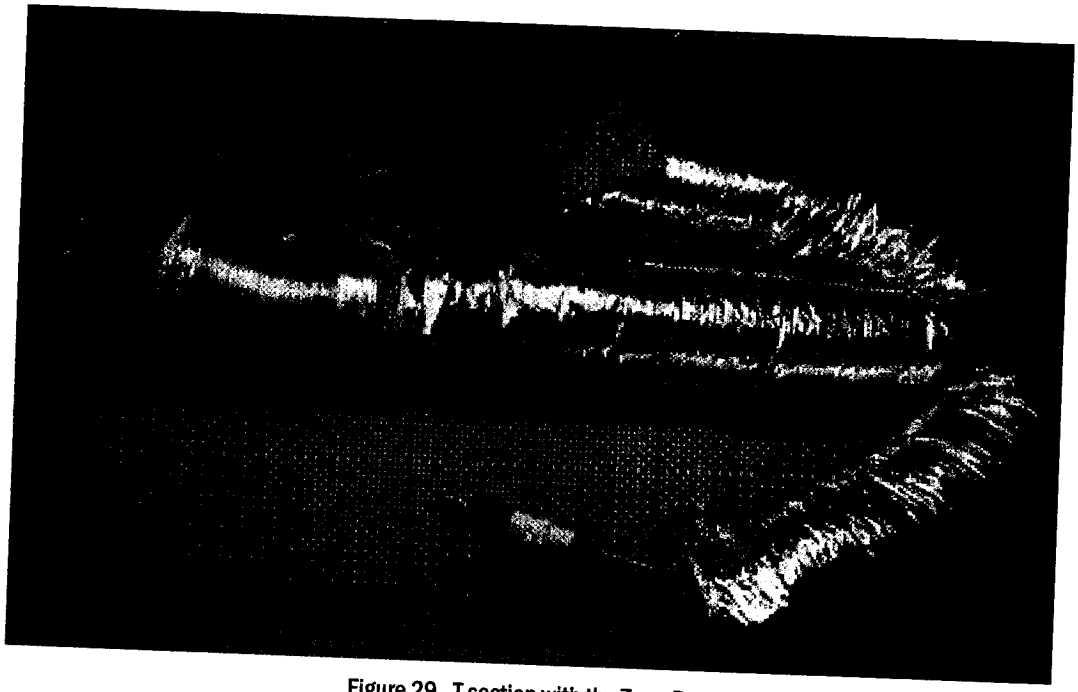

Figure 29. T section with the Zone Bag

A multipoint Duct Pressurization Test was conducted on this set up while recording the duct pressure and the calibrated fan flow. This served as an estimate of the leaks in the system and a baseline to test the effectiveness of zone bags. The duct caps were then replaced with zone bags as shown in Figure 29. The test was repeated by varying the pressure in the zone bags and the duct section.

Figures 30 and 31 show the effectiveness of the zone bags in straight duct and Tee sections, respectively, and for different pressures inside the 8'' duct and zone bag. Because the caps were fastened very well to the ducts, the leakages were considered to be from the ducts and the connection with the calibrated fan. The leaks from the duct system were not sealed to avoid a zero flow situation that would deteriorate the accuracy of the flow measurements. The performance of the zone bags is very close to that of the duct caps when the pressure inside the zone bag is higher than 0.28 PSI. As one increases the pressure in the zone bags, a tighter seal might be obtained. Nevertheless, there is clear possibility of bursting the zone bag. If the zone bags are pressurized to the right extent, their performance can match that of a more rigid barrier, in this case a sheet metal duct caps. Based on such observations, the operational range of pressures for the zone bags was identified (Table 13).

Table 13. Operational Range of Pressures for the Zone Bag

Duct diameter (Inches)	8"	10"	12"	14"
Pressure range (psi)	0.28-0.35	0.25 -0.30	0.23-0.28	0.19-0.22

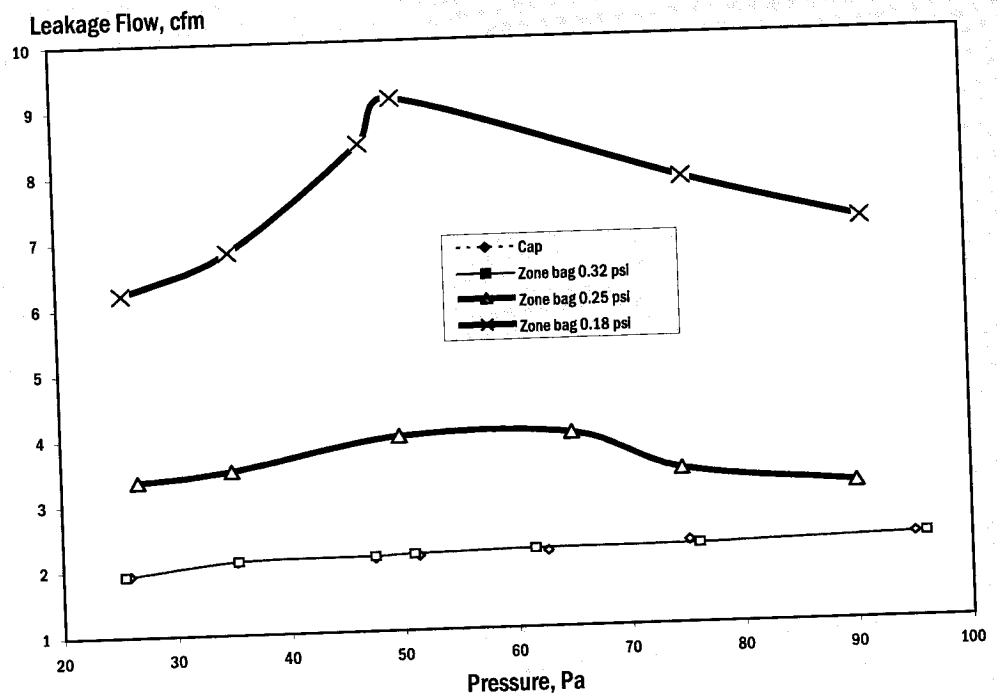

Figure 30. Effectiveness of the Zone Bags in 8" Straight Duct For Different Pressures Inside the Duct and Zone Bags

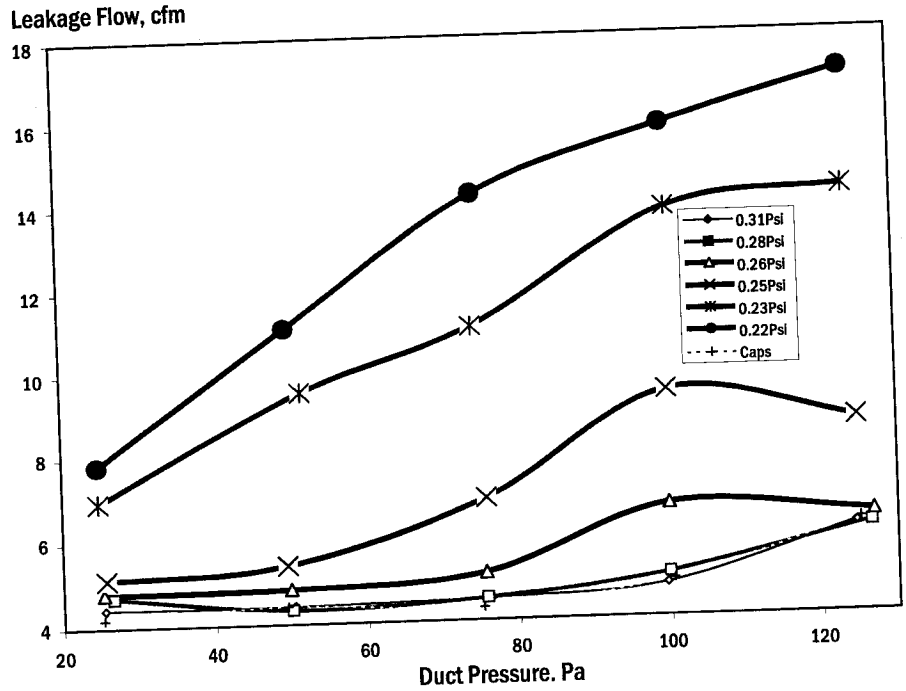

Figure 31. Effectiveness of the Zone Bags in 8" Tee Duct Section for Different Pressures Inside the Duct and Zone Bags

Another important aspect is the sudden decrease in leakage at high duct pressures (see curves of zone bag at 0.18 and 0.25 psi in Figure 30 and at 0.25 psi in Figure 31). Initial segments of these curves show that the zone bag is not conforming very well to the inner surface of the duct. However, at higher pressures the leakage seems to decrease. This could be due to reorientation of the zone bag owing to higher flow of air in the duct. This phenomenon seems to be random. To avoid any ambiguity, it is suggested not to work at such low pressures with the zone bags.

To confirm the leak locations detected by the zone bag method, qualitative tests were performed using visible vapor from a theatrical fog generating machine. A smoke test was done on the tee section when one duct section was connected to the calibrated fan and the remaining sections were blocked using sheet metal duct caps, as mentioned earlier. The fog machine was placed in front of the calibrated fan at a distance of two feet. The smoke released from the fog machine was drawn into the calibrated fan and passed through the duct. No smoke was observed on the other ends of duct. The duct caps were then replaced with zone bags and the test was repeated while varying the pressure in the zone bags. No smoke was observed on the ends when the static pressure inside the zone bag was higher than 0.30psi, which demonstrates that the zone bags block the air flow in ducts efficiently.

C.2 Test Procedure

The basic procedure was to isolate sections of duct using zone bags. The leakage from the isolated section was determined by pressurizing it to multiple pressures (similar to the multipoint pressurization test). The relation between the leak flow and pressure was then mapped. To isolate the investigated portion of duct, the fully deflated zone bag was introduced into a section of the duct and inflated using compressed air. In a completely inflated state the zone bag fills up the ridges of the helical grooves of the flex duct to give a large contact area with the duct surface. 457.2 mm (18") diameter zone bags were used in this study as the maximum duct size was 406 mm (16"). The pressure required inside the zone bags to block the flow of air was determined by parametric studies as discussed above (see Table 13). The test procedure is based on the standard Duct Pressurization Test, which uses a calibrated fan to pressurize the duct to the required pressure.

As shown in Figure 1, the locations considered for leakage estimations are connections SY_{11}, SY_{12}, and SY_{13}, the grilles SG_{11}, SG_{12}, SG_{13} and SG_{14} and the supply plenum SP_1 for ADS1 and connection SY21 and the grilles SG_{21}, SG_{22}, SG_{23} and SG_{24} and the supply plenum SP_2 for ADS2. Owing to the small length of the return duct, the return side is treated as a single section and the aggregate return side leakage (not local) was determined.

Figure 32 and Figure 33 show the steps required for determining the local leakages for ADS1 and ADS2. A portion of the duct is blocked using a zone bag. In the ADS1, the leakage in the section SG_{11} (Step 1) is determined using the calibrated fan. The position of the zone bag is then changed to include another section of the duct SY_{11} (Step 2 in Figure 32). The cumulative leakage for these two sections at a specific pressure is estimated. The additional leakage thus found is attributed to the latter section. The same procedure is repeated for the entire length of the duct (Steps 3 through 8 in Figure 32).

In ADS2, an alternative approach was used (refer to Figure 33). The total leakage is first determined by conducting the standard Duct Pressurization Test. The duct mask or duct tape was then removed from one of the grilles (for instance the first grille SG_{21}, Step 2) and a zone bag was placed in the duct leading to this terminal boot. The pressurization test was then repeated. The decrease of flow through the calibrated fan is equal to the leakage in that particular grille. The process was repeated sequentially for other registers and sheet metal connections (Steps 3 through 6 in Figure 33). The leakage from the supply

plenum SP_2 is equal to the difference between the flow through the calibrated fan in Step 1 and the sum of the local leak flows determined in Steps 2 through 6.

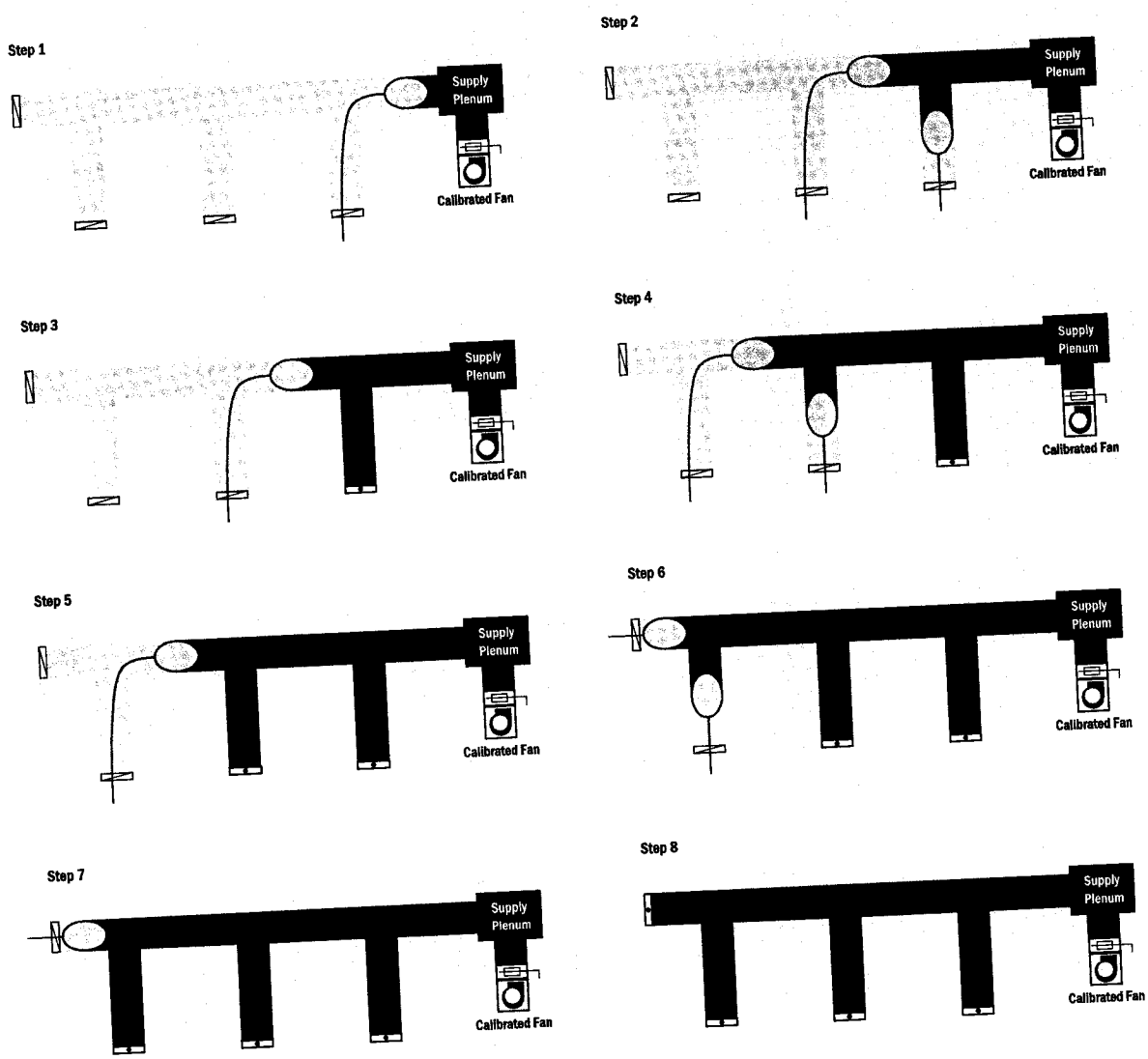

Figure 32. Steps Used for Determining the Local Leakages of ADS1

The operating static pressures were measured at the grilles using the pressure pan and at the connections and plenums using a static pressure probe. This was done with the air handler on and all grilles open. These operating pressures were then used to determine the local leakages at actual operating conditions. Each step described above was done at multiple pressures to achieve greater accuracy. The parameters of the power law relation were derived from the test data. The local leakage was then determined by using these parameters with the measured operating pressure.

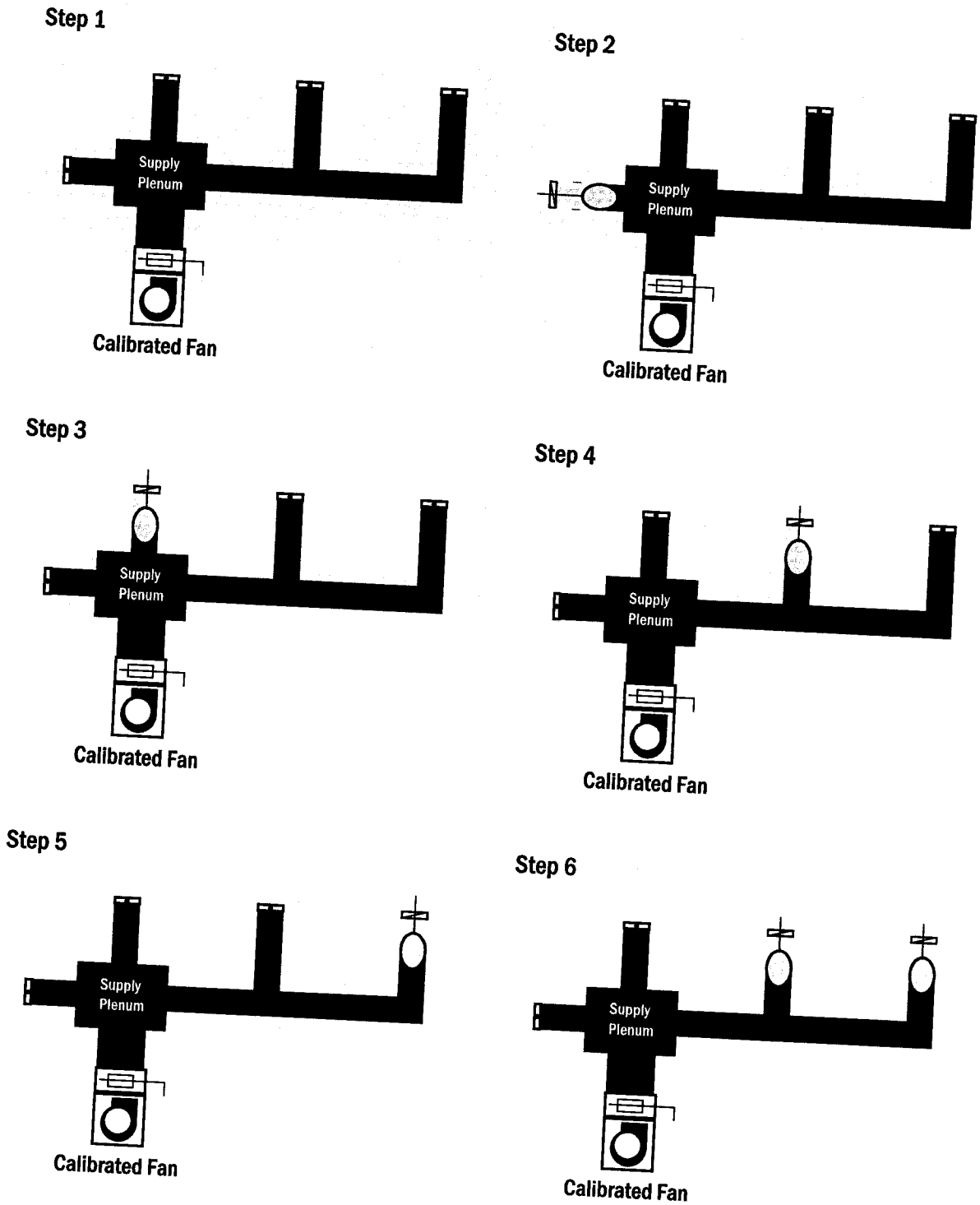

Figure 33. Steps Used for Determining the Local Leakages of ADS2

C.3 BASELINE LOCAL LEAKAGES

Figures 34 and 35 depict the local leakage as a function of the leak pressure for ADS1 and ADS2, respectively. Because the leakages in sheet metal connections (SY_1, SY_2, and SY_3) were small (about 1.42 L/s, 3 cfm), they are not shown on the graph. These relations were developed by pressurizing the duct sections shown in the steps in Figures 34 and 35 at multiple pressures. To determine the local leakage under operation condition, the static pressures were measured in each investigated duct section as shown in Table 17 and the local leak flows were determined accordingly. For example, the operating pressure in the supply plenum for ADS1 is 29 Pa. The multipoint pressurization curve for this section of the duct is shown in Figure 34. From this curve the leakage corresponding to 29 Pa is 16.4 cfm. This is done for each section of the duct as shown in Table 14 for ADS1 and Table 15 for ADS2.

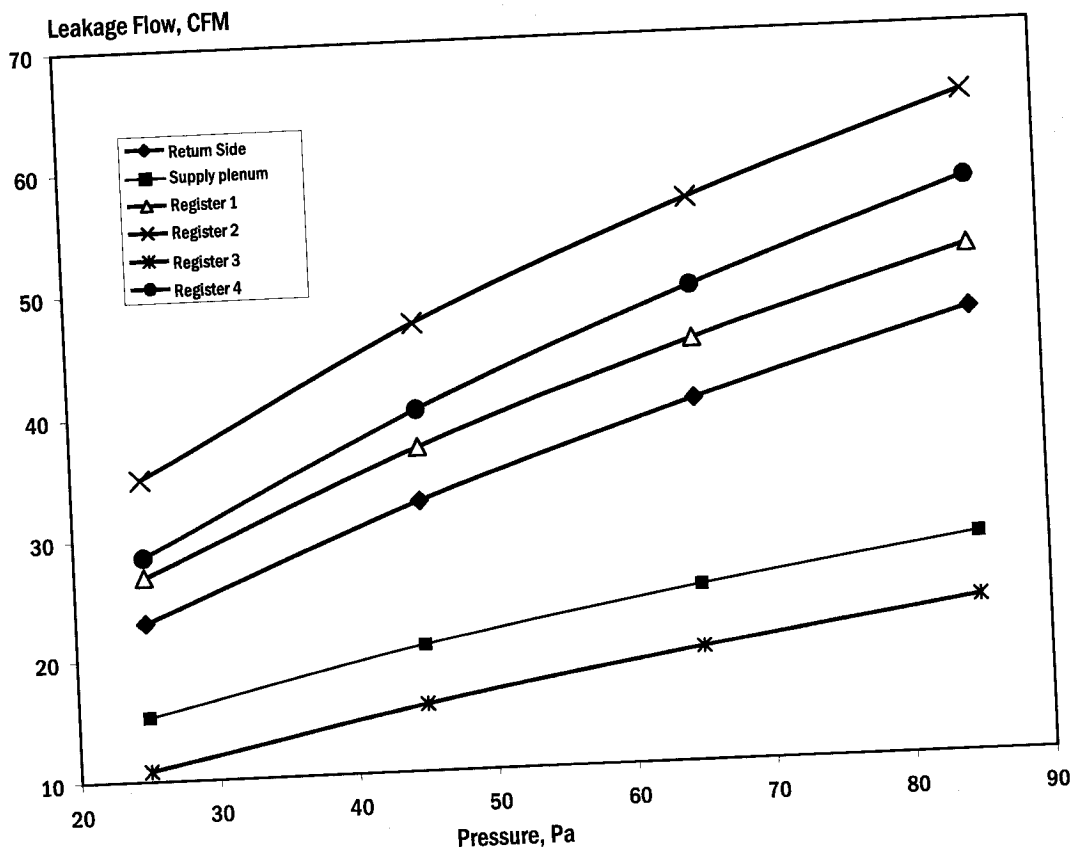

Figure 34. Local Leakage as a Function of the Leak Pressure for ADS1

The baseline testing for determining the local leakage described above was repeated five times and the standard deviation of the leakage estimated at each location was calculated. To assure the accuracy of the baseline testing, the known leakages were added as described in Appendix D and then compared with those determined by baseline testing. The agreement was good and the mean absolute differences are always less than 1 cfm for a mean leak flow of about 10 cfm. This difference is within the range of the standard deviation.

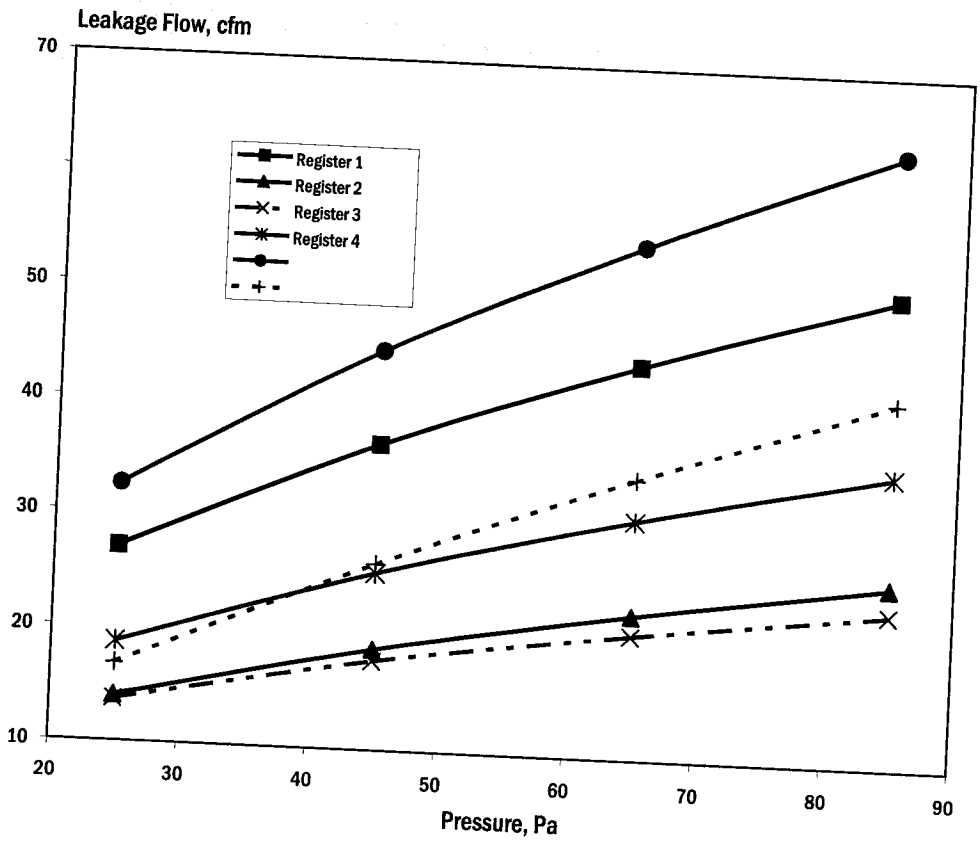

Figure 35. Local Leakage as a Function of the Leak Pressure for ADS2

Table 14. Leak Pressures and Flows for ADS1

	SP_1	SG_{11}	SG_{12}	SG_{13}	SG_{14}	SY_{11}	SY_{12}	SY_{13}	RP
Operating pressure (Pa)	29	8	6	5	4	22	18	10	-34
Leak exponent	0.5	0.53	0.5	0.6	0.56	0.5	0.52	0.53	0.57
Leakage @ 25Pa (CFM)	15.2	26.8	34.9	10.8	28.5	2	2.5	1.5	23.1
Leakage @ OP (CFM)	16.4	14.7	17.1	4.1	10.2	1.8	2.1	0.9	27.5
Standard deviation (CFM)	1.08	1.36	1.23	0.23	0.95	0.08	0.09	0.06	2.00

Total supply leakage =67.5
Total supply leakage to outside = 67.5 cfm
Total return leakage=27.5 cfm
Total return leakage to outside = 27.5 cfm
Total flow rate =800 cfm

RP = Return Plenum

Table 15. Leak Pressures and Flows for ADS2

	SP_2	SG_{21}	SG_{22}	SG_{13}	SG_{24}	SY_{21}	RP
Operating pressure (Pa)	17.80	7.00	9.00	6.00	4.00	10.0	-56.0
Leak Exponent	0.74	0.51	0.49	0.43	0.52	0.50	0.55
Leakage at 25Pa (cfm)	16.79	26.95	13.99	13.66	18.69	2.00	32.40
Leakage at OP (cfm)	13.0	14.0	8.4	7.3	7.2	1.2	50.4
Standard deviation (cfm)	0.98	0.817	0.73	0.511	0.79	0.028	2.87

RP = return Plenum

Total supply leakage= 51 cfm
Total supply leakage to outside=51
Total return leakage =50 cfm
Total return leakage to outside <<50 cfm
Total leakage =101cfm
Total flow rate CFM=700

Additional experiments were conducted using a 400W theatrical fog machine fog machine to visualize the leaks occurring due to improper sealing between the zone bag and the duct. No smoke emanated from the register confirming that the zone bag blocks the air flow in ducts completely.

APPENDIX D. FLOW CHARACTERSTIC OF HOLES

To get as much information as possible from both investigated ADS1 and ADS2 systems and to corroborate our results, different level of leakages were created by (i) adding controlled leaks at various locations along the duct and (ii) varying the operating pressure across the leak. The latter was accomplished by closing one of the grilles completely with the air handler fan on. This represented a new air distribution system with only three operating grilles as the operating pressures were higher than the original configuration.

The characteristics of the artificial leaks created in the terminal boots were determined by conducting a Duct Pressurization Test before and after creating the holes. All grilles were sealed and the calibrated fan was installed at air handler cabinet with a physical barrier between the supply and return sides. The duct system was pressurized at different pressures (25, 40, 55, 70, and 85 Pa) with all holes closed. Twenty of the artificial leaks located in the first grilles were opened and the duct system was pressurized again to the aforementioned test pressures. The increasing in flow rate indicated the leakage from these holes at the specified test pressures. Figure 36 shows the flow characteristics of the 20 holes introduced on the boot of the grilles. The test was repeated for 40 holes located at the same grille. Because all the holes were the same size, the leakages from any number of the holes can be interpolated.

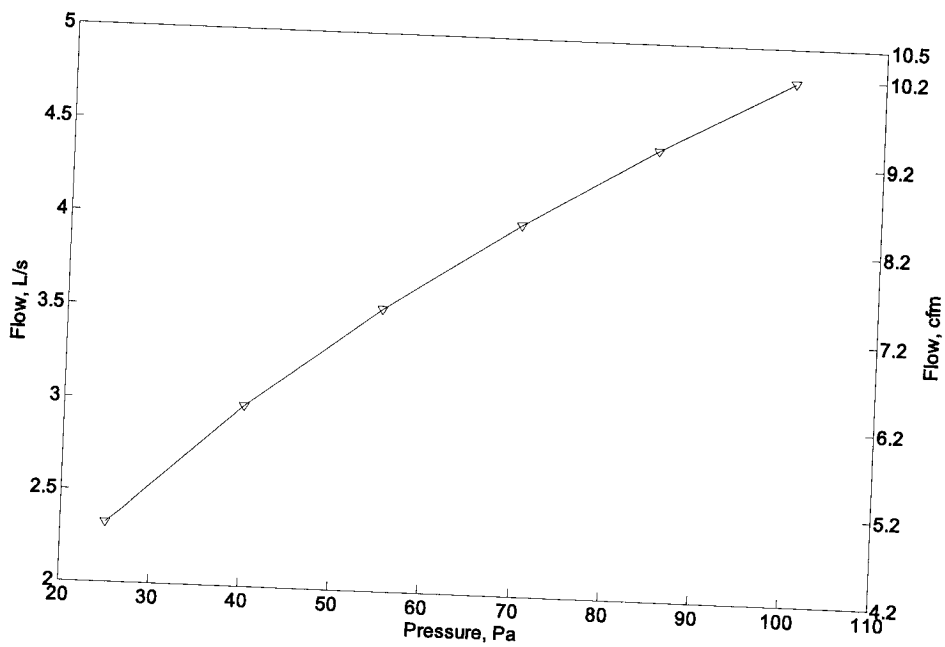

Figure 36. Flow Characteristics of the 20 Holes Introduced on the Boot of the Grilles

Table 16. Total Leakages for ADS1 and ADS2 with Different Combinations of Opened or Closed Holes Located on Boots of Different Grilles

System	Description	Total Leakage at 25 Pa	Total Leakage at operation pressure				
			Sys_0	Sys_1	Sys_2	Sys_{12}	Sys_{23}
ADS1	SG_{11}, SG_{12} and SG_{13} closed; SG_{14} open	145.6	67.5	95.3	93.4	155.0	139.4
	SG_{11}, SG_{12} closed; SG_{13},SG_{14} open	155.5	71.1	99.7	97.9	163.2	146.8
	SG_{11}, SG_{13} closed; SG_{12},SG_{14} open	165.4	74.8	104.	102.5	171.9	159.5
	SG_{11} closed; SG_{12}, SG_{13}, SG_{14} open	165.4	75.9	105.6	107.2	176.9	160.1
	All open	175.3	79.7	110.3	111.8	185.6	172.8
ADS2	SG_{21}, SG_{22} and SG_{23} closed; SG_{24} open	124.4	51.9	71.4	75.2	111.4	98.8
	SG_{21}, SG_{22} closed; SG_{23},SG_{24} open	134.3	55.7	75.7	79.9	118.7	106.6
	SG_{21}, SG_{23} closed; SG_{22},SG_{24} open	144.2	61.1	81.7	86.3	126.7	116.5
	SG_{21} closed; SG_{22}, SG_{23}, SG_{24} open	144.2	61.7	82.3	91.1	132.2	119.7
	All open	154.1	67.1	88.4	97.5	140.2	129.6

Approximately 40 holes could be opened or closed in each grille boot to control the leakage level in the duct to test various leakage configurations. In one of the configurations the holes in the first and third grilles SG_{11} and SG_{13} were left open and the holes in remaining grilles (SG_{12} and SG_{14}) were completely closed. Several such combinations could be created.

For ADS2, the leaks in all registers as found from the original installation were sealed and leakage tests were conducted only for the artificial leaks from the grilles. For ADS1, the actual leakage must be added to the artificial leakage from the holes as the original leaks were not sealed before testing. Artificial leaks were not introduced in supply Y connections. Thus, the leakages in these locations remained the same as the actual leakage from original installation.

Table 16 shows the total leakage for ADS1 and ADS2 for different combinations and levels of artificial leakage. The leakage rates at 25 Pa and operating conditions are listed here.

To test for a wide range of leakage levels, the operating pressures across the leaks were varied, leading to an altogether new duct configuration. When one register was closed with the air handler fan on, a new configuration of the air distribution system was created with different operating pressures along the duct and consequently different pressures across the leaks and a completely different leakage pattern. In this case, the air distribution system was assumed to have only three operating registers. For example, if the grille SG_{11} was closed when the air handler fan was on, a new artificial system was created and was designated here as SYS_2. In the original state with all the grilles open the air distribution system is referred to as SYS_0. Closing two grilles (SG_{11} and SG_{12}) resulted in a new configuration referred as SYS_{12}. The operating pressures for each of the artificially created configurations (e.g. SYS_1, SYS_{12}) were recorded for subsequent calculation of leakage at operating conditions.

APPENDIX E. CHARACTERISTICS OF AIR DISTRIBUTION SYSTEM

The main objective of these tests was to identify the flow characteristics of the air handler fans. The airflow through the air handler fan was measured by the method described in Annex A of ANSI/ASHRAE Standard 152-2004 (ANSI/ASHRAE 2004). The test was repeated by changing the flow resistance in ducts by partially closing one or more grilles to develop the fan performance curve (flow vs. pressure drop between return and plenum sides). When artificial leaks were introduced (physically or by simulations), the pressure drop between the return and plenum sides was measured (or simulated) at operating conditions and the new air handler flow was determined using the fan performance curve. Fan performance curves for both ADS1 and ADS2 are shown in Figure 37. The curve represents the relation between the fan flow and the pressure difference between the return and supply plenum. For each case, the supply and return plenum pressure difference was measured and the flow determined accordingly.

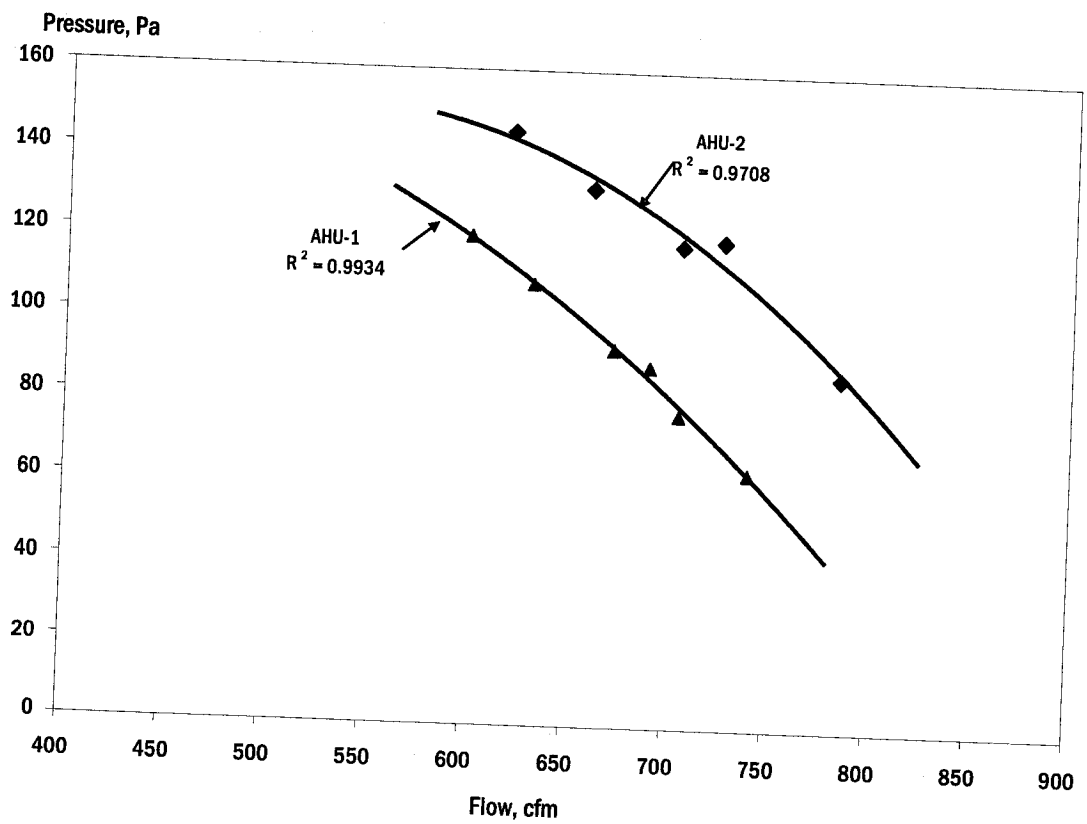

Figure 37. Fan performance Curves for ADS1 and ADS2

APPENDIX F. DUCT DISTRIBUTION MODEL

The goal of this model is to simulate the performance of the investigated methods. The model determines the airflow rates and pressure drops in each duct section. The model is based on the non-Darcy functional form:

$$Q = C(P)^n \tag{11}$$

where

C = flow coefficient

Q = volumetric airflow

n = pressure exponent

P = static pressure

The duct system model is based on the characteristics of the two duct configurations installed at the ADLL. The flow coefficients and pressure exponents of holes were used to calculate the leak airflows. The pressure exponents n for air flowing through duct sections was assumed to be 0.5. However, the flow coefficient C of each duct section was determined by using Equation 11 with measured flow rates and operating pressures measured at each individual duct section. These pressures were measured with all artificial leaks closed. The leakage exponent for the house envelope was determined using the data obtained by conducting a blower door test.

To evaluate the investigated methods by simulation, a model was developed for each technique. The flow rate through the calibrated fan required to pressurize the duct system at a specific pressure needs to be determined for the *Zone DeltaP* and Duct Pressurization Test. This requires calculating the leak flows in each individual duct section. It should be noted that the leaks are assumed to occur only at the following locations (see Figure 1): grilles SG_{11}, SG_{12}, SG_{13}, and SG_{14}, connections SY_{11} and SY_{12}, and supply plenum (SP). The leak flow rates were determined at the specific test pressures in the duct system. The pressure drops in the ducts and resulting leak pressures were determined accordingly. The new values of pressures were used to determine the leak airflows. These iterations were carried out until the solution converged for a required tolerance. For DeltaQ, the wind effect on house pressure was neglected. The DeltaQ model is dealt in more detail in Appendix G.

As mentioned in the simulation studies, to consider systematic errors, artificial random errors were applied to the values of the simulated measured flow and pressure. This took care of the potential errors, such as error in measurements, the assumptions used by the individual method, and other unknown and neglected effects. The objective of this model was not only to simulate the accuracy of the investigated methods but also to perform a quick comparison among them for a very large number of tests and to reveal any potential or inherent errors. Because the characteristics of the air distribution systems installed at ADLL were used, it was expected that the simulation results would be close to the actual test values.

APPENDIX G. OVERVIEW OF DUCT LEAKAGE MEASUREMENT METHODS

G.1 DUCT PRESSURIZATION TEST

The fan pressurization test is one of the oldest and widely used duct leakage estimation techniques. It is based on the idea that with all registers and grilles closed, any flow through the calibrated fan will be released through the leaks in the duct. To prepare for the test, all registers and grilles need to be sealed. The pressure through the duct is assumed to be relatively uniform. The leakage in cfm is then estimated as the flow through the calibrated fan when the duct system is pressurized to 25 Pa. To estimate the leakage to outside, a blower door is used to pressurize the house to the same level that the ducts are pressurized, such that the pressure between the ducts and the house is zero. To estimate supply and return leakage separately, an airtight barrier must be placed between the supply and return duct systems, and the test must be conducted for each portion of the ducts separately. Either of the tests can be conducted at multiple test pressures to enhance the accuracy.

The main disadvantage of the test is considered to be the setup process. In addition, the test suffers from the assumption that the pressure is uniform in the duct. It does not give any indication of the leakage at operating conditions. The use of half of the plenum pressure is an attempt to account for differences between systems. As duct leaks can occur at any point along the duct, the leakage estimation may not be accurate.

G.2 DELTAQ

The Delta-Q test is based on the standard envelope tightness measurement technique. To perform this test the house is set up as would be done for a blower door test. The baseline pressure is measured with the air handler off and the blower door sealed. Four possible combination of tests with the air handler on and off and the calibrated fan in the pressurization and depressurization modes are conducted at test pressures (pressure inside the building envelope with respect to outside) ranging from -50 Pa to 50 Pa with 5 Pa increments. At each test pressure, the difference in envelope flow between air handler off and air handler on is called a "delta-Q." Regression is conducted on all the delta Q values using the following equation:

$$\Delta Q(P) = Q_s \cdot \left[\left(1+\frac{\Delta P}{\Delta Ps}\right)^{n_s} - \left(\frac{\Delta P}{\Delta Ps}\right)^{n_s}\right] - Q_r \cdot \left[\left(1-\frac{\Delta P}{\Delta \mathrm{Pr}}\right)^{n_s} + \left(\frac{\Delta P}{\Delta \mathrm{Pr}}\right)^{n_s}\right] \qquad (12)$$

where

$\Delta Q\ (\Delta P)$ = delta-Q at pressure ΔP

ΔP_s and ΔP_r = supply and return duct pressures, respectively

Q_s *and* Q_r = estimated supply and return leakages, respectively

The exponent of 0.6 is an assumed exponent to characterize the power law nature of duct leakage, and it has been found to be a suitable average exponent in many studies. The supply and return duct pressures can be obtained from the respective plenum.

The equations are based on the assumption that the pressure difference between the ducts and the house remains constant throughout the test. The model assumes that there is a single supply or return leakage pressure and, thus, there is one leak on each side. This may lead to a characteristic inflection point in the delta Q curve. In reality leaks are be distributed at multiple pressures and hence the delta-Q curve would have multiple inflection points. However, as the leaks characteristics are not known before hand, only the equivalent or effective leakage can be determined. Regardless of how leak pressures are determined, there are some potential biases inherent when using them in the Delta-Q model, caused by some of the simplifying assumptions.

G.3 Nulling Test

When the supply leakage is greater than the return leakage, the house is depressurized and vice versa. Imbalance of pressure in the house is created due to leakage. Therefore, measuring this pressure imbalance would give a direct indication of the leakage in the house. To do this the house is set up as would be done for a blower door test. The baseline pressure is measured with the air handler off and the blower door sealed. The building is then pressurized using the blower to the baseline pressure with the air handler on and the corresponding flow through the calibrated fan is recorded. For accuracy, a multipoint test can be done at some test pressures above and below the baseline. A linear regression is applied to the flow vs. pressure data with the air handler on, and the average of the two measurements with the air handler off is applied to the resulting equation to get the unbalanced duct leakage estimate.

The next step is to estimate the supply leakage alone by isolating the supply from the return using a physical barrier at the filter slot. A calibrated fan is then attached at the air handler cabinet. The air handler fan is then turned on and the second calibrated fan is adjusted to match the supply plenum pressure measured under normal operation. The blower door is again adjusted to find the pressure imbalance. As the second calibrated fan takes air from the house, the change in flow though this fan is the supply leakage. On windy days, data may be recorded for longer periods of time at each station, and the calibrated fan can be adjusted to provide different sampling flows instead of specific pressures. The unbalanced leakage can be subtracted from the supply leakage to estimate the return leakage.

The main advantage of Nulling test is that it estimates leakage directly without any mathematical calculations. According to previous studies, the primary source of error for the Nulling test is the noise due to wind. The wind can significantly affect the accuracy of the test when the test is performed at low pressures. Apart from that the estimation of the supply leakage is considered to be time-consuming. The test might find some application in houses with non-ducted returns as the second portion of the test need not be conducted and the set up is similar to that of the blower door test.

NATIONAL CENTER FOR ENERGY MANAGEMENT AND BUILDING TECHNOLOGIES
601 NORTH FAIRFAX STREET, SUITE 240
ALEXANDRIA, VA 22314
www.ncembt.org

Save Energy at Home with Electric Efficiency

Save money, improve comfort and ensure a cleaner environment with energy saving offers for residential electric customers from National Grid.

- ENERGY STAR® Thermostats
- Central Air Conditioning
- Central Air Source Heat Pump
- ECM Furnace Fan
- Electric Heat Pump Water Heater
- Duct and Air Sealing

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Wouldn't it be great if you could save money, improve the efficiency of your home, and help ensure a cleaner environment?
You can with efficiency from National Grid.

Follow these steps to participate:

1) **Consult your qualified contractor.**
2) **Complete this application and determine anticipated rebate.**
3) **Return application with a copy of your dated invoice/receipt and a copy of Manual J sizing. Include pre/post blower door and duct blaster readings if needed.** (Remember, your invoice or receipt must include the complete model number of each unit installed.)

Mail to: National Grid Electric Efficiency
40 Washington Street, Suite 2000
Westborough, MA 01581

For questions please call **1-866-543-9303**, email ngridinfo@efi.org or visit **www.thinksmartthinkgreen.com.**

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2009 Residential Energy Efficiency Rebates

PRODUCT	REBATE	BPI Contractor Incentive**
REPLACEMENT THERMOSTATS		
ENERGY STAR® rated programmable thermostats maximum 2 per household	$25/ea	
CENTRAL AIR CONDITIONING		
SEER ≥ 15, EER ≥ 12.5	$400	$200*
SEER ≥ 16, EER ≥ 13.0	$600	$200*
CENTRAL AIR SOURCE HEAT PUMPS		
SEER ≥ 15, EER ≥ 12, HSPF ≥ 8.5	$400	$200*
SEER ≥ 16, EER ≥ 13.0, HSPF ≥ 9.0	$600	$200*
OTHER MEASURES		
Electronically Commutated Motor (ECM) furnace fan	$200	
Electric heat pump water heater, Energy Factor > 2.0	$400	
Duct and air sealing by BPI certified contractor†	up to $600	

SEER = Seasonal Energy Efficiency Ratio. EER = Energy Efficiency Ratio. HSPF = Heating Seasonal Performance Factor.

* To qualify for these rebates, a copy of Manual J must be attached to indicate that an Air Conditioning Contractors of America (ACCA) Manual J calculation has been completed to determine proper sizing.

† Duct and air sealing must be assisted by blower door and duct blaster testing, and be completed by a BPI certified/accredited contractor. The receipt must include pre and post blower door and duct blaster readings and materials installed.

** Contractors who are certified/accredited by the Building Performance Institute may receive incentives directly from National Grid for installations in qualified customers' homes if customer correctly completes the contractor information in the attached rebate application. BPI is a national resource for building science technology that sets standards for assessing and improving energy performance, health and safety of homes. For more information, visit www.bpi.org.

Upstate New York Residential Electric Energy Efficiency Rebate Application

Please review terms and conditions. Form must be completed entirely.

Customer: _____
(Name and address where equipment was installed)

Street: _____ National Grid Electric Account #: _____

City: _____ ☐ Existing Dwelling ☐ New Construction

E-mail: _____ State: _____ Zip: _____ Phone: _____

CONTRACTOR INFORMATION (Required for contractor to receive incentives from National Grid)

Company Name: _____

Installing Contractor's Name: _____

Street: _____ City: _____ State: _____ Zip: _____

Business Phone: _____ E-Mail Address: _____

Tax ID #: _____ National Grid Work Request #: _____ (if applicable) BPI Certified? ☐ [redacted]

ACCA Manual J calculation completed to determine proper sizing? ☐ Yes ☐ No BPI Accredited? ☐ Yes ☐ No
An ACCA Manual J calculation is required. Please include copy of Manual J summary.) Pre/post blower door + duct blaster readings required? ☐ Yes ☐ No
(Please attach if applicable for duct and air sealing.)

ENERGY EFFICIENT EQUIPMENT REBATE

Central Air/Heat Pump

INSTALL DATE	AHRI REFERENCE #	MANUFACTURER	CONDENSER MODEL #	COIL MODEL #	MANUAL J SIZING	AHRI-RATED SEER*	AHRI-RATED EER*	HSPF	ANTICIPATED TOTAL REBATE
4/15/09	1419446	XYZ Company	XYZ Co. 4A7A5030A1	XYZ Co. 4TEE3D31A1	☒ Yes ☐ No	15	12.5	N/A	$400
					☐ Yes ☐ No				
					☐ Yes ☐ No				

Other Efficiency Measures

TYPE(S) OF EQUIPMENT INSTALLED	INSTALLED COST	MANUFACTURER*	MODEL NUMBER*	REBATE AMOUNT	QUANTITY INSTALLED*	ANTICIPATED TOTAL REBATE
ENERGY STAR Thermostats	$135.56	Rite-Temp	8022C sku#467-430	$25.00/ea.	2	$50.00
ENERGY STAR Thermostats**						
Electric Heat Pump Water Heater†						
ECM Furnace Fan Retrofit? ☐ Yes ☐ No						
Duct and Air Sealing by BPI Contractor						
					TOTAL REBATE	

* Not required for duct and air sealing. See requirements on previous page.
** Thermostats cannot be self-installed. Thermostats must be installed by a contractor.
† Manufacturer's documentation must be submitted with application to show SEER, EER and HSPF.

Where did you hear about this program? ☐ Sales Rep/Account Executive ☐ Equipment Supplier ☐ Internet ☐ Heating Contractor ☐ Trade Show ☐ Radio/TV ☐ Energy Auditor ☐ Print Advertising ☐ Other

Work Completion and Rebate Validation.
I hereby affirm the following Prescriptive Energy Efficiency Equipment has been installed. I acknowledge that all work is subject to on-site work verification and inspection as may be required by state and local law and by National Grid. I am aware of and agree to the Terms & Conditions stated on the reverse side of this application and am attaching copies of itemized proofs of purchase and invoices for the installation performed.

Customer Signature: _____ **Date:** _____

Upstate New York

Equipment installed from 3/17/09 to 12/31/09 is eligible. Rebate form and required documentation must be postmarked by 1/31/10. One account number per form. Some restrictions may apply. Rebate offers are subject to change without notice.

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Home Performance with ENERGY STAR®

Take advantage of the incentives* available through Home Performance with ENERGY STAR offered by the New York State Energy Research and Development Authority (NYSERDA).

- Get an expert assessment of your home by a participating Home Performance Contractor
- Find exactly where you're losing energy and how to fix it
- Low-interest financing
- Income-eligible households qualify for a grant of up to $6,000

*Customers cannot receive National Grid rebates and incentives from NYSERDA for the same equipment.

Through a Comprehensive Home Assessment, a participating Home Performance Contractor can determine areas of your home where energy efficiency, comfort, and health and safety improvements should be made. Using special diagnostic equipment, a series of tests and visual inspections check the efficiency of appliances and heating and cooling equipment. In addition, your contractor can find where air is leaking out of your home. When the assessment is complete, you'll receive a report of recommended improvements, the cost of each improvement, and estimated payback.

NYSERDA's Home Performance with ENERGY STAR program [illegible] home improvement contractors who are accredited by the Building Performance Institute (BPI). BPI is a national resource for building science technology that sets standards for assessing and improving energy performance, health and safety of homes. BPI-accredited contractors are trained to take a "whole-house" approach — one that considers how the house works as a system.

To find a Home Performance Contractor near you, call 1-877-NY-SMART or visit www.getenergysmart.org for information.

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www.thinksmartthinkgree

National Grid Residential Energy Efficiency Programs
Terms & Conditions

1. **Incentives** - Subject to these Terms and Conditions, this program is offered by Niagara Mohawk Power Corporation (the "Company"). The Company, through its contractual vendor, Energy Federation Incorporated (the "Vendor"), will pay incentives to eligible customers and BPI contractors in the Company's Service Territory, for the purchase and installation of the equipment/products described in this literature and within this application.
2. **Customer Eligibility** - New equipment installed from 3/17/09 to 12/31/09 is eligible. It must have been new equipment installed at the installation address listed on this application and the required documentation listed must be postmarked no later than 1/31/10. Customer must be a residential electric customer of the Company in Upstate New York. Check www.thinksmartthinkgreen.com frequently for program updates or installation extensions.
3. **Post-Installation Work Verification** - The Company reserves the right to perform a verification of the specified installation. If the Company and/or Vendor determines that the equipment was not installed in a manner that is consistent with program guidelines, the Company and/or Vendor may require that the installation be modified before making any incentive payments. The cost of such modifications is the responsibility of the customer. I hereby authorize the Company to release my energy use information to Energy Efficiency Program Sponsors (EEPS) and System Benefit Charge (SBC) program administrators and/or its designee. I understand that such information will be kept confidential and used only for the purpose of determining program eligibility and energy savings.
4. **Installation Requirements** - Installations must be completed in conformance with state and local code requirements and by a qualified contractor to qualify. Customer self installs do not qualify for rebates. Central air conditioning systems and electric air source heat pumps must be listed and certified by the Air Conditioning, Heating and Refrigeration Institute (AHRI) and meet the program SEER, EER and HSPF (for electric air source heat pumps) to qualify. The air conditioning condenser and evaporator coil must be new and replaced together. The condenser and coil are separate components in a split air conditioning or heat pump system; but for rebate purposes, these are considered one unit. To verify central air conditioning and heat pump system eligibility, please refer to the AHRI directory (ahridirectory.org) or the Consortium for Energy Efficiency (ceehvacdirectory.org). Manufacturer's spec sheets may be accepted ONLY if equipment is not yet AHRI rated and only if AHRI rating is pending.
5. **Proof of Proper Installation** - As part of its incentive application, the Customer is required to submit dated copies of all paid invoices documenting the installation (including all materials, labor and equipment invoices) which reflect the actual cost of purchasing and installing the equipment. Installing contractor must complete and attach the ACCA Manual J Calculation for proof of proper sizing of air conditioning equipment and heat pumps.
6. **Indemnification** - Customer shall defend, indemnify and hold harmless the Company and its officers, directors, employees, agents, servants and assigns from and against any and all losses, claims, demands and/or liability for damage to property, injury or death of any person, or any other liability incurred by the Company, including all expenses, legal or otherwise, arising out of or related to the equipment or installation, except to the extent attributable to the negligence of Company. In no event shall Company's liability to Customer exceed the incentive amounts.
7. **Limited Scope Review** - The scope of review by the Company and the Vendor and their inspector of the installation of the equipment is limited solely to determine whether incentives are payable. It does not include any kind of safety or code review and should not be relied upon as one.
8. **Incentive Amounts** - The Company will provide incentives for approved high-efficiency measures, up to incentive amount indicated in the program literature and within this application. If more than ten (10) units of equipment are installed in a single dwelling, the Customer must obtain pre-approval from National Grid for incentive funds to be reserved. Customers cannot receive a rebate from National Grid and incentive from NYSERDA for the same equipment.

. **Payment** - The Company, through the Vendor, expect to make incentive payments to eligible customers within 45 days of a satisfactory work verification. The customers must refund any incentive made to the extent the contractor or equipment does not satisfy program requirements.

. **No Warranties** - The Company and the Vendor do not endorse, guarantee or warrant any particular contractor, manufacturer or product installation. The Company and the Vendor do not make any representation of any kind regarding the results to be achieved by the equipment or the adequacy or safety of such equipment.

Changes in the Program - Equipment Incentive Program/Tax Liability Conditions and details of the Program are subject to change without prior notice and incentive offers may increase or decrease over time. The Company reserves the right to modify or terminate the Incentive Program without notice. Participants of the program may be subject to tax liability for the value of goods and services eceived through the program pursuant to state or Federal income tax codes. The Company is not responsible for any tax liability hich may be imposed as a result of receipt of the rebate by the Customer.

ontractor Insurance - The Company is not responsible for any damage that may be caused by or arise out of an installation of any uipment. The customer is responsible for selecting Contractors who are qualified and carry adequate insurance coverage.

ational Grid is one of the largest investor-owned energy companies in the world. In the US, we serve arly 5 million electric and 3.4 million gas customers in Massachusetts, New Hampshire, New York and Rhode Island. ve energy and money with our award-winning efficiency programs. **Visit www.thinksmartthinkgreen.com.**

ditional energy efficiency services may be available from the New York State Energy Research and Development hority (NYSERDA). For more information, visit www.getenergysmart.org.

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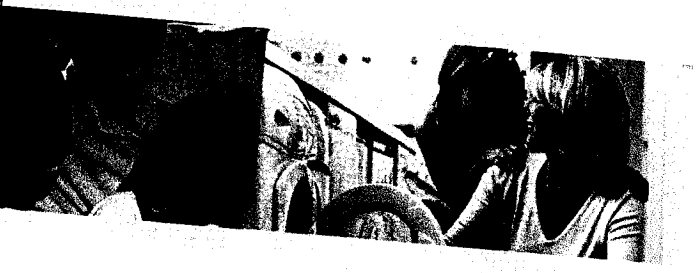
Upstate New York

Save Energy at Home with Natural Gas Efficiency

Save money, improve comfort and ensure a cleaner environment with energy saving offers for residential natural gas heating customers from National Grid.



- High-Efficiency Heating Equipment
- High-Efficiency Water Heaters
- Duct/Air Sealing
- ENERGY STAR® Thermostats
- Outdoor Boiler Reset Controls

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Use this form to apply for any of the equipment rebates listed below.

Save money, improve the efficiency of your home and help ensure a cleaner environment with energy efficiency programs from National Grid.

Follow these steps to receive a rebate for the equipment listed below:

1) Consult a qualified heating contractor or plumber.
2) Go to **www.powerofaction.com/efficiency** and enter your zip code to navigate to the Natural Gas Heating Program. Click on the link to view available funds and to view the online reservation form.
3) Fill out the online form with the required information in order to reserve your anticipated rebate incentive. You will receive confirmation of your reservation via email or letter. (In order to receive a rebate incentive it is REQUIRED that you obtain pre-authorization via the online form).
4) Complete this application and mail it in with a copy of your dated ITEMIZED invoice within 60 days of your installation date. (Please make sure your invoice includes the complete model number(s), cost of each unit installed, and labor costs.)

Mail to: **Upstate NY National Grid Residential Efficiency**
40 Washington Street
Suite 2000
Westborough, MA 01581

For questions please call **1-866-716-8099**, e-mail ngridinfo@efi.org or visit **www.powerofaction.com/efficiency**.

2010 Residential Energy Efficiency Rebates

PRODUCT	REBATE
REPLACEMENT THERMOSTATS**	
ENERGY STAR rated and/or 7-day Programmable Thermostats** Maximum 2 per household.	$18/ea.
OUTDOOR BOILER RESET CONTROLS	
Add on unit attached to forced hot water boiler	$70
HIGH-EFFICIENCY HEATING EQUIPMENT	
Furnaces (forced hot air) AFUE* ≥ 90% rating	$140
Furnaces (forced hot air) AFUE* ≥ 92% rating & ECM± motor	$280
Furnaces (forced hot air) AFUE* ≥ 94% rating & ECM± motor	$420
Boilers (steam with electronic ignition) ≥ AFUE* 82% rating	$350
Boilers (forced hot water) AFUE* ≥ 85% rating	$350
Boilers (forced hot water-condensing) AFUE* ≥ 90% rating	$560
HIGH-EFFICIENCY WATER HEATERS	
Indirect water heater attached to a natural gas ENERGY STAR forced hot water boiler	$210
DUCT AND AIR SEALING	
Duct and air sealing by BPI certified/accredited contractor†	up to $420

ASK ABOUT ENERGY STAR

** Programmable thermostats must be installed by a contractor at the time of a furnace or boiler replacement.

* AFUE = Annual Fuel Utilization Efficiency

± ECM = Electronic Commutated Motor

† Duct and air sealing must be assisted by blower door and duct blaster testing, and be completed a BPI certified/accredited contractor. The receipt must include pre and post blower door and duct blaster readings and materials installed.

Find more ways to save through additional efficiency programs.

Home Performance with ENERGY STAR®

Take advantage of the incentives* available through Home Performance with ENERGY STAR offered by the New York State Energy Research and Development Authority (NYSERDA).

- Get a Comprehensive Home Assessment of your home by a participating Home Performance Contractor
- Find exactly where you're losing energy and how to fix it
- Low-interest financing
- Income-eligible households qualify for a grant of up to $5,000

Through a Comprehensive Home Assessment, a participating Home Performance Contractor can determine areas of your home where energy efficiency, comfort, and health and safety improvements should be made. Using special diagnostic equipment, a series of tests and visual inspections check the efficiency of appliances and heating and cooling equipment. In addition, your contractor may indentify areas in the home where air leakage and infiltration is occurring. When the assessment is complete, you'll receive a report of recommended improvements, the cost of each improvement, and estimated payback.

NYSERDA's Home Performance with ENERGY STAR Program uses a network of independent home improvement contractors who are accredited by the Building Performance Institute (BPI). BPI is a national resource for building science technology that sets standards for assessing and improving energy performance, health and safety of homes. BPI-accredited contractors are trained to take a "whole-house" approach—one that considers how the house works as a system.

To find a Home Performance Contractor near you, call **1-877-NY-SMART** or visit **www.getenergysmart.org** for information.

*Customers cannot receive National Grid rebates and incentives from NYSERDA for the same equipment.

Residential Natural Gas Energy Efficiency Rebate Application

Please review terms and conditions. Form must be completed entirely.

Customer: _____ National Grid Gas Account Number: _____
(Name and address where equipment was installed)

Rebate Reservation Number: _____ Approximate Age of Home: _____ yrs

Street: _____ City: _____ State: _____ Zip: _____

Mailing Address: _____ Phone: _____

E-mail: _____ National Grid Representative: _____

Please check one: ❒ I'm an existing natural gas heating customer. ❒ I'm converting from oil or propane to a natural gas heating system.

CONTRACTOR INFORMATION

Remember, all equipment MUST be installed by a qualified contractor.

Heating Contractor Name: _____ State: _____ Zip: _____

Street: _____ City: _____

Business Phone: _____

EQUIPMENT INFORMATION

TYPE(S) OF CONTROLS INSTALLED	TYPE OF HEATING UNIT	INSTALLED COST	MANUFACTURER	MODEL NUMBER	INSTALL DATE	REBATE AMOUNT	QUANTITY INSTALLED	ANTICIPATED TOTAL REBATE
ENERGY STAR Thermostats	❒ Furnace ❒ Hot Water Boiler ❒ Steam Boiler	$135.56	Rite-Temp	8022C sku#467-430	1/1/2010	$18.00/ ea.	2	$36.00
	❒ Furnace ❒ Hot Water Boiler ❒ Steam Boiler							
	❒ Furnace ❒ Hot Water Boiler ❒ Steam Boiler							

TYPE(S) OF HEATING AND WATER HEATING EQUIPMENT INSTALLED	INSTALLED COST	MANUFACTURER	MODEL NUMBER	AFUE RATING (OR THERMAL EFFICIENCY)	TOTAL BTU INPUT	GALLONS	INSTALL DATE	REBATE AMOUNT	QUANTITY INSTALLED	ANTICIPATED TOTAL REBATE

TYPE(S) OF EQUIPMENT INSTALLED	ATTACH DOCUMENTATION	INSTALLED COST	ANTICIPAT TOTAL REB
ct and Air Sealing by BPI Contractor	Attach the receipt, which must include pre and post blower door and duct blaster readings and materials installed.		
		TOTAL INCENTIVE	

FOR CONTRACTOR'S USE — AIR SEALING/BLOWER DOOR TEST RESULTS

BPI CONTRACTOR NAME	FAN PRESSURE (Pa)	FLOW (CFM)	SQUARE FOOTAGE OF FLOOR AREA	CONTRACTORS SIGNATURE
PRE TEST				
POST TEST				

FOR CONTRACTOR'S USE — DUCT SEALING TEST RESULTS

BPI CONTRACTOR NAME	FAN PRESSURE (Pa)	FLOW (CFM)	KBTU/HR OUTPUT (Gas)	SEALED LEAK PERCENTAGE (MEASURED AS % OF SYSTEM AIR FLOW)	CONTRACT SIGNATU
PRE TEST					
POST TEST					

Where did you hear about this program? ❒ Sales Rep/Account Executive ❒ Heating Contractor ❒ Energy Auditor ❒ Equipment Su
❒ Trade Show ❒ Print Advertising ❒ Internet ❒ Radio/TV ❒ Other

Work Completion and Rebate Validation.
I hereby affirm the Prescriptive Energy Efficiency Equipment listed above has been installed. I acknowledge that all work is subject to on-site work v and inspection as may be required by state and local law and by National Grid. I am aware of and agree to the Terms and Conditions stated on th side of this application and have attached copies of **ITEMIZED** proofs of purchase and invoices for the installation approved. **I also agree and un that rebate offers are subject to change without notice and the program may be terminated due to funding constraints at anytime.**

I hereby authorize the Company to release my energy use information to Energy Efficiency Program Sponsors (EEPS) and System Bene (SBC) program administrators and/or its designee. I understand that such information will be kept confidential and used only for the pu determining program eligibility and energy savings.

Customer Signature: _____ **Date:** _____

Upstate New York

nationa

THE PO

...ipment installed from 9/1/10 to 12/31/10 is eligible contingent upon availability of funds. Rebate form and required ...t be post marked **within 60 days of the installation date**. One account number per form. Some ...**ffers are subject to change without notice and the program may be terminated**

National Grid Residential Energy Efficiency Programs
Terms & Conditions

1. Incentives - Subject to these Terms and Conditions, this program is offered by Niagara Mohawk Power Corporation (the "Company"). The Company, through its contractual vendor, Energy Federation Incorporated (the "Vendor"), will pay incentives to eligible customers in the Company's Service Territory, for the purchase and installation of the equipment/products described in this literature and within this application. Check **AHRIdirectory.org** to find qualifying equipment.
2. Customer Eligibility - New equipment installed from 9/1/10 to 12/31/10 is eligible contingent upon availability of funds. It must have been new equipment installed at the installation address listed on this application and the required documentation listed must be postmarked within 60 days of the installation date. It is required that you reserve your rebate incentive using the online rebate reservation system at **www.powerofaction.com/efficiency**. Your rebate reservation is valid for 60 days. Customer must be a gas heating customer of the Company in Albany, Columbia, Fulton, Herkimer, Jefferson, Madison, Montgomery, Oneida, Onondaga, Oswego, Rensselaer, Saratoga, Schenectady, Warren or Washington County in New York State. Check **www.powerofaction.com/efficiency** frequently for program updates or installation extensions.
3. Post-Installation Work Verification - The Company reserves the right to perform a verification of the specified installation. If the Company and/or Vendor determines that the equipment was not installed in a manner that is consistent with program guidelines, the Company and/or Vendor may require that the installation be modified before making any incentive payments. The cost of such modifications is the responsibility of the customer. I hereby authorize the Company to release my energy use information to Energy Efficiency Program Sponsors (EEPS) and System Benefit Charge (SBC) program administrators and/or its designee. I understand that such information will be kept confidential and used only for the purpose of determining program eligibility and energy savings.
4. Installation Requirements - All installations must be completed in conformance with state and local code requirements and by a contractor to qualify. Customer self-installations do not qualify for rebates. Duct and air sealing must be completed by a BPI certified/accredited contractor. Customers are not eligible to receive financial incentives/rebates for the same eligible measure from NYSERDA and National Grid.
5. Proof of Proper Installation - As part of its incentive application, the Customer is required to submit dated copies of all paid invoices documenting the installation (including all materials, labor and equipment invoices) which reflect the actual cost of purchasing and installing the equipment.
6. Indemnification - Customer shall defend, indemnify and hold harmless the Company and its officers, directors, employees, agents, servants and assigns from and against any and all losses, claims, demands and/or liability for damage to property, injury or death of any person, or any other liability incurred by the Company, including all expenses, legal or otherwise, arising out of or related to the equipment or installation, except to the extent attributable to the negligence of Company. In no event shall Company's liability to Customer exceed the incentive amounts.
7. Limited Scope Review - The scope of review by the Company and the Vendor and their inspector of the installation of the equipment is limited solely to determine whether incentives are payable. It does not include any kind of safety or code review and should not be relied upon as one.
8. Incentive Amounts - The Company will provide incentives for approved heating, water heating, thermostat or boiler reset control equipment, up to incentive amount indicated in the program literature and within this application.
9. Payment - The Company, through the Vendor, expect to make incentive payments to eligible customers within 45 days of a satisfactory work verification. The customers must refund any incentive made to the extent the contractor or equipment does not satisfy program requirements.
10. No Warranties - The Company and the Vendor do not endorse, guarantee or warrant any particular contractor, manufacturer or product installation. The Company and the Vendor do not make any representation of any kind regarding the results to be achieved by the equipment or the adequacy or safety of such equipment.
11. Changes in the Program - Equipment Incentive Program/Tax Liability Conditions and details of the Incentive Program are subject to change without prior notice and incentive offers may increase or decrease over time. The Company reserves the right to modify or terminate the Incentive Program without notice. Participants of the program may be subject to tax liability for the value of goods and services received through the program pursuant to state or Federal income tax codes. The Company is not responsible for any tax liability which may be imposed as a result of receipt of the rebate by the Customer.
12. Contractor Insurance - The Company is not responsible for any damage that may be caused by or arise out of an installation of any equipment. The customer is responsible for selecting Contractors who are qualified and carry adequate insurance coverage.
13. Air/Duct Sealing - Must be completed by a BPI certified contractor. In order to receive the rebate, the customer shall submit an itemized invoice that details the cost of work and materials. For duct sealing, pre-work scores and results for duct blaster test must be provided. A blower door test can be waived if mold or asbestos reach unhealthy standards. The customer may do one measure or a combination of the two, with a maximum rebate of $420.

National Grid is one of the largest investor-owned energy companies in the world. In the US, we serve nearly 5 million electric and 3.4 million gas customers in Massachusetts, New Hampshire, New York and Rhode Island. Save energy and money with our award-winning efficiency programs. Visit **www.powerofaction.com/efficiency.** Additional energy efficiency services may be available from the New York State Energy Research and Development Authority. For more information visit **www.GetEnergySmart.org**.

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Reduce your annual fuel consumption, decrease air pollution and save on your energy bill when you install a natural gas high-efficiency heater or water heater.

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