Past, Present and Future Directions in Residential Single-Family Energy Audits and Retrofits

Final Report

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Disclaimer

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Executive Summary

The objective of this project conducted for National Institute of Standards and Technology (NIST) was to evaluate various approaches to measuring energy use and energy savings associated with short- and long-term energy-related repairs, retrofits, remodeling and rehabilitation in existing single-family homes.

The Washington State University (WSU) Energy Program developed an advisory team of residential building science experts and other important stakeholders to assess promising new measurement technology and performance metrics using the analytical techniques discussed in the report. The report also provides an overview of past, present and future directions in single-family energy audits and retrofits from a national group of experts involved in the home performance contracting and heating, ventilating and air conditioning (HVAC) industries.

The use of "Round Robin" under this grant to assess auditing efforts may serve as a catalyst to improve energy auditing and retrofit practices within organizations such as Residential Energy Services Network (RESNET), Building Performance Institute (BPI) and U.S. Department of Energy (DOE) retrofits and/or research programs such as the DOE Building America Program. These efforts allowed for the inclusion of many different program approaches to energy auditing, and suggest considerable variability in audits and work scope recommendation.

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Acronyms and Abbreviations

ACCA	Air Conditioning Contractors of America
ACI	Affordable Comfort Inc.
AHFC	Alaska Housing Financing Corporation
ANSI	American National Standards Institute
ARRA	American Recovery and Reinvestment Act
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
BECOR	Building Envelope Council Ottawa Region
BEES	Alaska Building Energy Efficiency Standards
BOP	Building Option Package
BPA	Bonneville Power Administration
BPA	Building Performance Audit/Auditor
BPI	Building Performance Institute
Btu	British thermal units
BPCA/NYS	Building Performance Contractors Association of New York State
CAZ	Combustion Appliance Zone
CCHRC	Cold Climate Housing Research Center
CEC	Consortium for Energy Efficiency
CEQ	RESNET Contractor Education and Qualification provider
CETA	Comprehensive Employment and Training Act
CFM	cubic feet per minute
CGI	common gateway interface
CGSB	Canadian General Standards Board
CHA	Comprehensive home assessment
CHER	Comprehensive Home Energy Rater
CHIP	Canadian Home Insulation Program
CMHC	Canada Mortgage and Housing Corporation
CO	carbon monoxide
CPUC	California Public Utilities Commission
CSA	Canadian Standards Association
DHW	domestic hot water
DOE	U.S. Department of Energy
DSM	Demand-side management
EEBA	Energy & Environmental Building Alliance
EEPS	Energy Efficiency Portfolio Standard
EPA	United States Environmental Protection Agency
ERH	Energy Retrofits for Houses
ESP	external static pressure
EWX	Enhanced Weatherization Program
FDD	Fault Detection and Diagnostics
HEA	Home Energy Audit
HERs	RESNET Home Energy Raters

HES	Home Energy Survey
HESP	Home Energy Survey Professional
HPC	home performance contracting/contractors
HPCGO	Home Performance Contractors Guild of Oregon
HPwES	Home Performance with ENERGY STAR program
HRAI	Heating, Refrigeration, and Air Conditioning Institute of Canada
HRV	heat recovery ventilation/ventilators
H&S	health and safety
HUD	U.S. Department of Housing and Urban Development
HVAC	Heating, ventilating and air conditioning systems
IAQ	indoor air quality
IEA	International Energy Agency
IECC	International Energy Conservation Code
IEQ	indoor environmental quality
IR	Infrared thermal imaging, or thermography
ISER	Institute of Social and Economic Research, University of Alaska
LBNL	Lawrence Berkeley National Laboratory
MHEA	Manufactured Home Energy Audit
NAHB	National Association of Homebuilders
NEAT	National Energy Audit Tool
NECA	National Energy Contractors Association
NEEA	Northwest Energy Efficiency Alliance
NIST	National Institute of Standards Technology (an agency of the U.S. Department of Commerce)
NRC	National Research Council (Canada)
NRCan	Natural Resources Canada
NYSEG	New York State Electric and Gas
OBD-II	On-Board Diagnostics, version II
OEMs	outside equipment manufacturers
Pa	Pascal, a unit indicating pressure
pCi/l	picocuries per liter (unit used to measure radioactive particles released as radon gas decays)
ppm	parts per million
PSC	Public Service Commission
QA	quality assurance/quality assured
QI	quality installation
REE	Rural Energy Enterprises
RESNET	Residential Energy Services Network
RurAL CAP	Rural Alaska Community Action Program
RVA	rotating vane anemometer
SERI	Solar Energy Research Institute
SIR	savings to investment ratio
TEC	The Energy Conservancy
TMY	Typical Meteorological Year

TREAT	Targeted Retrofit Energy Analysis Tool
UFFI	urea formaldehyde foam insulation
VAV	variable air volume
WAP	U.S. Department of Energy Weatherization Assistance Program
WHO	World Health Organization
WSU Energy Program	Washington State University Energy Program

Introduction

This assessment of residential research measures seeks to improve the energy efficiency, durability and indoor air quality (IAQ) of existing residential single-family existing housing stock in the United States.

This report describes:

- Grant-implemented efforts to assess the measurement of building energy performance,
- Promising techniques to improve that measurement, and
- Implementation of energy audits and retrofits undertaken by the audit
- Home Performance Contracting (HPC), which follows a multi-disciplinary systems engineering approach that encompasses building envelope; heating, ventilating and air conditioning (HVAC) systems; and IAQ and ventilation.

The project focused on:

1. Creating an advisory group and meeting with advisory group members to guide project direction and assist with the final report.
2. Meeting with stakeholders involved in residential retrofits at federal government agencies industry:
    - U.S. Department of Energy (DOE),
    - U.S. Department of Housing and Urban Development (HUD),
    - U.S. Environmental Protection Agency (EPA) Building America teams,
    - Residential Energy Services Network (RESNET),
    - Energy & Environmental Building Alliance (EEBA),
    - Affordable Comfort Inc. (ACI)
    - Air Conditioning Contractors of America (ACCA),
    - American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE),
    - Northwest Energy Efficiency Alliance (NEEA),
    - Bonneville Power Administration (BPA), and
    - California Energy Commission/Lawrence Berkeley National Laboratory (CEC/LBNL).

    The meeting goals were to avoid duplication of efforts and solicit guidance in project planning. These meetings identified these key research focus areas:
    - Round robin testing and presentation of testing results and
    - Survey of building science community at the BSC Westford Symposium.
3. Developing, implementing and analyzing the results of two round robin pilots at:
    - ACI PNW regional conference in Portland, Oregon,
    - The ACI 2011 National Conference in San Francisco, California, and
    - RESNET 2012 national conference in Austin, Texas.

These round robins involved multiple energy auditors who conducted energy audits and developed work plans on identical homes at national and regional building science conferences. Results were compared and differences analyzed to identify the type and possible cause of problems and potential strategies to promote consistency. Round robin and other related grant activity findings have been submitted for publication in a 2012 Home Energy article developed under this grant activity.

This report is in part a scoping study that provides input from key advisory group members involved with building retrofit, remodeling and new construction. These experts were asked to document past, present and future directions in residential energy auditing and post-retrofit performance related to market-based energy efficiency home retrofits and government- and utility-sponsored low-income weatherization in New York, Alaska, Oregon and Canada. The report also includes contributions related to Home Performance Contracting efforts supported by organizations such as BPI, ACCA and RESNET. An overview of DOE's on-going evaluation of IAQ and a discussion of fault detection for residential HVAC are also provided to assist in assessing audit-related efforts.

Stakeholder discussions focus on four major subjects related to energy auditing:

- Energy simulation modeling software tools
- Utility billing analysis tools
- Building science field testing/training tools
- Home and equipment energy feedback tools

WSU Energy Program staff utilized resources from this grant to engage stakeholders and document feedback associated with the following activities:

- RESNET Technical Committee activities with Home Energy Raters (HERs) Guidelines and Standards
- ACCA Quality Installation Standards and ACCA manuals S 2011-12 updates
- American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) TC 6.3, TC 9.5, RP1449, Std. 193, Std. 62.2, Std. 119, and Std. 136
- California Energy Commission Research Roadmap on IAQ in residential buildings
- Participation in Affordable Comfort 2011 and 2012 National Conference programs Participation in the EEBA 2011 National Conference programs
- Participation in the 2011 Westford Summer Study

Home Performance Testing Measurement Tools

As the home performance contracting industry grows, so does the use of building diagnostic field test tools by home performance contractors (HPC). The tools discussed below are the primary tools employed by the energy auditor and/or the contractor conducting energy efficiency improvements as part of the work scope implementation. Links to manufacturer information, specifications, and operations and maintenance manuals for common equipment are provided at the end of this section.

Diagnostic field test tools are typically employed to:

- Provide education and training to HPC so they are better prepared to identify the appropriate energy retrofit measures and other related health and safety issues.
- Provide quality assurance that work was implemented as intended in the work scope.
- Identify energy efficiency, durability and health and safety improvement opportunities to the homeowner, lender or utility, including but not limited to:
  - Air leakage pathways in the building envelope
  - Anomalies in thermal envelope insulation, including:
    - Voids
    - Compression
    - Missing insulation
  - Leakage of centrally ducted thermal distribution systems, including:
    - Leaks at supply and return registers,
    - Leaks in the system not located near registers of equipment,
    - Leaks close to the HVAC system equipment and plenums, or
    - Leaks associated with “panned joists” and other areas where the building framing serves as the return duct. This may also include wall cavities, chases, cavities under stairways, HVAC equipment support platforms and other building framing used as ductwork.
  - Potential moisture problems that may cause mold and durability issues, including:
    - Roof leaks,
    - Wind-driven rain in walls,
    - Condensation in above- and below-grade walls, ceilings, crawlspace and at slabs, and
    - Pressure imbalances induced by HVAC system duct leakage and system design.
  - Inadequate air flow rates of HVAC systems, including:
    - Bathroom and kitchen exhaust fans,
    - Air flow at supply or return AC/HP coil,

        - Individual supply and/or return registers,
        - Total supply or exhaust flow rates of Heat Recovery Ventilation (HRV) systems, and
        - Individual supply and exhaust flow rates of HRV systems.
- Utilize test results as inputs to the models used to estimate energy savings of measures proposed in the work scope.
- Utilize test results as inputs to the energy savings models used to provide Home Energy Ratings.
- Assist the HPC to prioritize specific areas in the work scope developed for the client.
- Identify health and safety (H&S) issues that include, but are not limited to:
    - Back drafting and combustion safety issues associated with naturally vented water heaters and other combustion devices due to:
        - Inadequate exhaust flue design or installation,
        - Excess negative pressure induced by the operation of exhaust fans or HVAC system,
        - Gas piping leaks, or
        - CO measurements of combustion equipment such as domestic hot water, furnace or oven to identify proper operation.
    - Radon
    - Lead paint
    - Indoor environmental quality (IEQ) pollutants associated with household products used by the occupants or components of the building and furnishings.
- Provide occupant education and engagement to assist in "selling the job," such as "show and tell" to identify specific energy and H&S issues.

Measurement Tool Applications

Building Envelope Leakage

The Blower Door

The typical approach to assess building envelope leakage is to conduct a blower door test. A blower door is a calibrated fan installed in an exterior door used to measure the amount of air leaking into or out of the home in pressurized or depressurized conditions (typically depressurized). This data is used to determine an approximate annualized natural air change rate and assess the benefits of envelope air sealing to reduce air infiltration. In some cases, the results are used to determine if – and how much – mechanical ventilation is warranted to ensure compliance with ASHRAE Standard 62.2 or other mechanical ventilation guidelines.

The blower door is often used as a simple diagnostic tool, and is sometimes used in conjunction with smoke sticks and/or thermal imaging cameras to help identify the location of air leaks to be sealed. A blower door is also used after air sealing as a QA measure to confirm the air sealing was effective in specific areas of concern.

Blower door reference standards and protocols include:

- ASTM E779*, Standard Test Method for Determining Air Leakage Rate by Fan Pressurization*,
- ASTM E1827 *Standard Test Methods for Determining Airtightness of Buildings Using an Orifice Blower Door,* and
- RESNET Chapter 8, *RESNET Standards for Performance Testing and Work Scope: Enclosure and Air Distribution Leakage Testing.*

RESNET and BPI standards provide more specific guidance on how to conduct the test as part of the audit/rating**.** Blower door testing is conducted at one or more reference pressures (typically 50 Pascals, or Pa), based on the standard used. The ASTM standard is the most extensive but least practical of these standards without the use of a computer to take multiple readings at each reference pressure.

Tests generally fall into three categories: multipoint regression testing (E779), two-point tests (1827) and one point tests (E1827 and RESNET):

- Multipoint regression testing involves testing the leakage of the building envelope across a wide range of pressures (higher pressures than buildings experience most hours of the year) to allow extrapolation down to typical pressures.
- Two-point testing has the same goal but focuses on one high pressure and one low pressure in order to measure the response of leakage versus pressure.
- One-point testing focuses on a single, high pressure to characterize the leakage and assumes the response versus pressure to have a default value.

Proponents of single-point testing argue that it is simple, quick and repeatable and that this outweighs potential loss of accuracy at predicting low-pressure leakage. Furthermore, leakage of an individual building under normal operation is notoriously difficult to measure, negating some of the accuracy benefits of the multipoint test. Proponents of multipoint testing argue that accuracy is critical even if repeatability is compromised. This remains a vigorous debate that is also mirrored in ongoing discussions of duct leakage testing techniques.

Two major U.S. manufacturers offer blower doors designed for single-family home retrofits: The Energy Conservatory (TEC) and Retrotec. The test standards reference the need for calibration based on blower door manufacturer recommendations. Manufacturers suggests periodic field checking of the blower door pressure taps and hoses to identify blockage and verify alignment.

The original blower doors relied on mechanical analog pressure gauges with limited readability, repeatability and accuracy. The introduction of digital pressure gauges allowed for more accurate and repeatable results. The digital gauge can conduct multiple quick-and-easy measurements to reduce uncertainty when used in conjunction with manufacturer-supplied software. This improves the accuracy and repeatability of the tests, especially when gusty winds are present during testing or when small leakage rates are measured. This gauge is also used with the other tools discussed below to measure duct leakage and HVAC flow rates and to assess combustion safety and zonal pressure imbalances.

Periodic calibration of pressure gauges is recommended.

- Figure 1 and Figure 2 present the results of recalibration of a sample of more than 2,000 digital pressure gauges for one manufacturer. Figure 1 shows the percent of errors on channel A with negative pressures applied before recalibration. Figure 2 shows the percent of errors on channel B with positive pressures applied before recalibration. The applied test pressures varied from 15 to 1,220 PA. Calibration typically improves pressure gauge accuracy by about .2 percent after one year for this manufacturer.

- Figure 3 presents channel A negative pressure sensor drift as a function of time between calibrations. This figure presents a time series looking at the impact of the calibration intervals for all gauges recalibrated by the manufacturer over a seven-year period, indicating errors as high as 1.5 to 2.5 percent and shows errors increasing over time. Note that this is largely because most of the instruments shown in this data set have not been recalibrated at the recommended interval (one year). Results for other manufacturers may be significantly different.

Discussions with manufacturers suggest that, while it is important to conduct periodic pressure gauge factory calibration, field calibration checks and instrument inspection is even more critical. The issue of blower door testing accuracy is especially important when the equipment is used for QA programs or for software models used to estimate energy savings from air leakage control measures. When blower door technicians are responsible for determining a surface area or volume for use in normalizing the measured blower door flows, the largest error in the normalized parameters is often the area or volume.

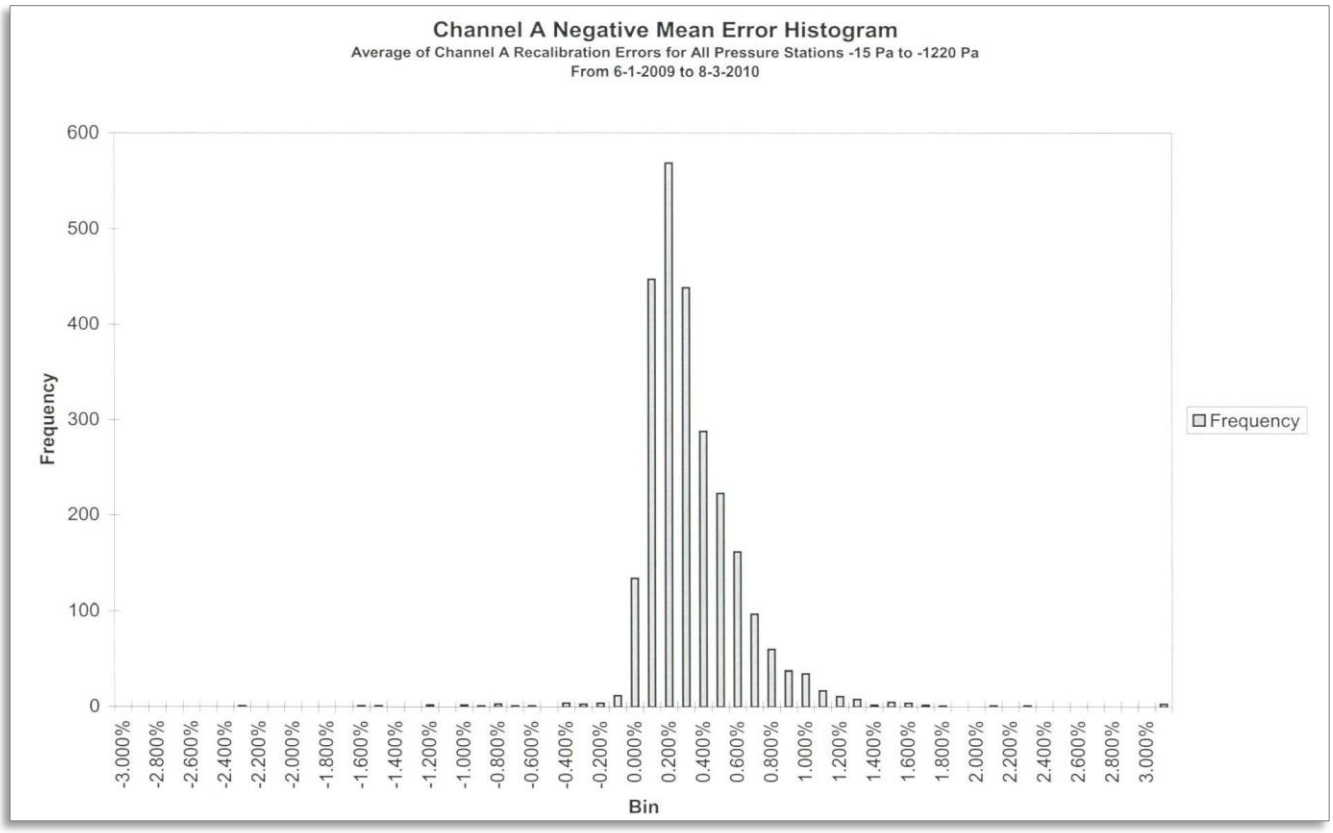

Figure 1. Channel A Negative Pressure Recalibration Errors

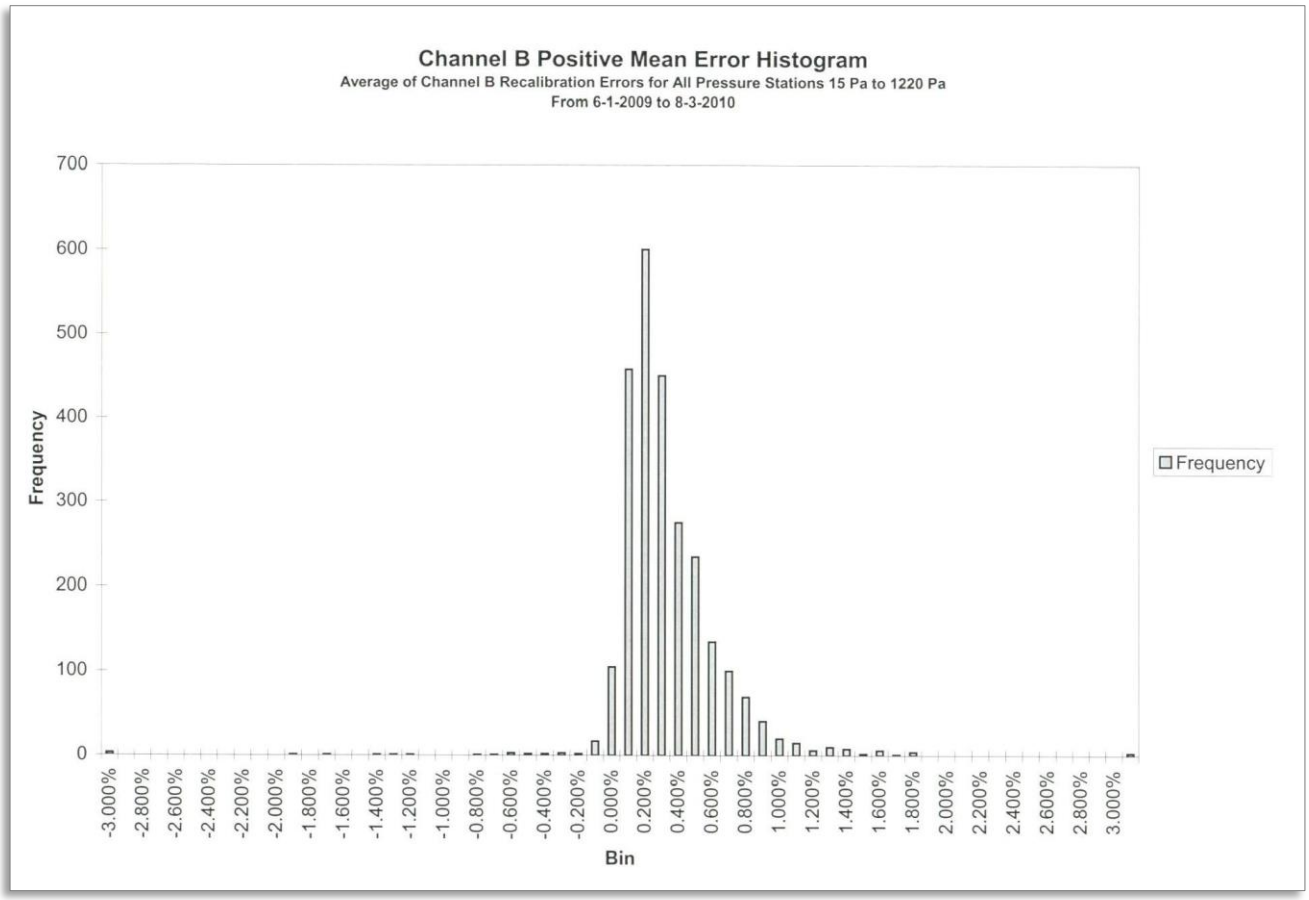

Figure 2. Channel B Positive Pressure Recalibration Errors

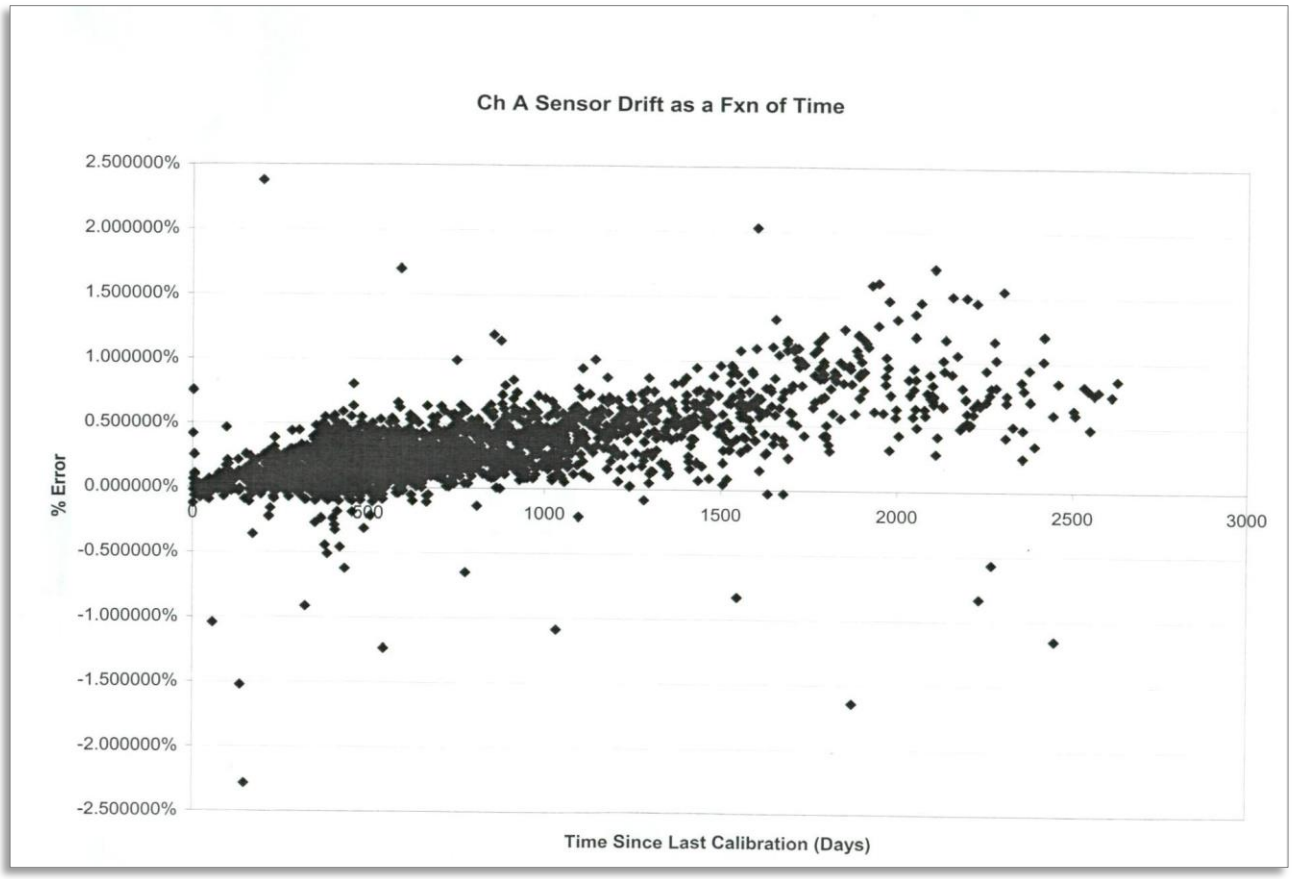

Figure 3. Channel A Negative Pressure Sensor Drift as a Function of Time Between Calibrations

HVAC Duct Leakage

The typical approaches for measuring HVAC thermal distribution duct leakage rates are duct leakage testers and pressure pans. Another test method, Delta Q, has not seen widespread use.

Residential Duct Leakage Tester

Duct leakage testers measure the leakage of ducts at a typical induced static reference pressure of 25 Pa. The test involves sealing off all HVAC registers and pressurizing and/or depressurizing the ductwork and HVAC equipment. Testing is typically conducted before duct sealing to determine if the home is a good candidate for this measure and after duct sealing for QA.

The pre- and post-test data can also be used to estimate energy savings with computer simulation modeling. To estimate energy savings, it is necessary to estimate only the leakage to outside. This is done by operating a blower door to pressurize the house to the same pressure as the duct. Total leakage – measured without the blower door – provides an assessment of the overall duct tightness, which may be important to the HVAC system distribution efficacy and indoor air quality.

Not much work has been done to study repeatability of fan pressurization duct leakage tests, possibly because there is not much concern about their repeatability.

When interpreting data from the duct leakage tests, we typically utilize ASHRAE Standard 152 equations to determine HVAC distribution system efficiency and HPC software models to estimate the energy savings from sealing HVAC ductwork as part of the retrofit. One limitation of this modeling is that Standard 152 is a steady-state model (designed around the idea of a system that is running continuously in heating or cooling mode). Typical annual duty cycles for HVAC equipment are somewhere in the range of 15-25 percent, which may impact the predictive power of modeling methods such as found in ASHRAE Standard 152. Standard 152 does include an equipment efficiency degradation factor that includes some effects of cycling, but other off-cycle effects, such as thermosiphoning or infiltration through duct leaks during fan-off periods, are not treated. Also, ASHRAE 152 requires separately measuring the leakage and operating pressures on the supply and return sides of the duct system. This is usually not done for field testing due to the time involved. Assumptions are made to simplify procedures in most non-research field situations.

Blower Door Subtraction

Before duct blasters were available, many HPCs relied on what is called the "blower door subtraction method" to measure duct leakage. This approach is not as accurate, repeatable or quantifiable for modeling as the duct blaster test, but it does not require the additional Duct Blaster® equipment. Using this approach, a blower door test is conducted with all HVAC registers sealed and then unsealed; the difference is the duct leakage estimate. For simple subtraction to work, the leaks to the inside must be small. Otherwise, corrected blower door subtraction should be used. For example, if all of the ducts are outside, then the leakage to inside is zero and this is a case where simple subtraction works.[1] Ecotope found that corrected blower door subtraction, using high-precision blower door measurements, worked fine.

Pressure Pans

Pressure pans are typically used in conjunction with a blower door to help estimate the magnitude and location of duct leakage to outside. Pressure pans have been used in large manufactured housing duct sealing programs as part of an efficient test and repair protocol, where there is already agreement about the cost effectiveness of duct sealing measures in this type of housing stock. This method provides feedback on the relative location of duct leakage areas to focus the retrofit work scope.

This approach does not provide air leakage rates and so does not feed into energy savings models. It also does not require the additional Duct Blaster equipment or that each register be

[1] See work by Francisco, et al., for ASHRAE in the duct leak management references for this chapter.

sealed, so there is substantially less test set-up time required and this method can be employed when register sealing is impractical. This approach is most practical when the focus is on identifying leakage locations, not on quantifying energy savings estimates.

Delta Q

This approach uses the blower door to measure duct leakage by running the blower door with and without the HVAC operating and with the house pressurized and depressurized (for a total of four blower door tests). A series of mathematical equations is then used to determine the duct leakage. The benefit of Delta Q is that it does not require a duct blaster and each register does not need to be sealed. Unlike the duct blaster or blower door subtraction methods that measure leakage under static reference pressures, Delta Q estimates duct leakage at HVAC operating pressures.

The primary drawback to the Delta-Q test is that it is more sensitive to wind, which can introduce noise that is of the same size or larger than the signal, especially in leaky houses or houses with tight ducts.

Studies have shown that the results of Delta Q tests are affected by wind-induced pressure fluctuations. It is also challenging, if not impractical, to apply this method without automated software and data acquisition equipment. These drawbacks may be limiting its use. In response, one manufacturer has provided automated software for performing this test. The author of that software does not feel that the method belongs in ASTM E1554 and further states that he feels the claimed benefits in "accuracy in measuring operating leakage" are found to be illusory when considering a real-world scenario and are, therefore, no compensation for the poor precision of the method. Other researchers disagree, noting that their research suggests sufficient accuracy as an audit tool.[2]

HVAC Flow Measurements

Plastic Bags

The bag inflation method requires the use of a bag of a known volume, a method to hold the bag open (typically a lightweight frame of wood, plastic or metal wire), a shutter to start the air flow and a stopwatch. The estimate of air flow is determined by the volume and the time it takes to fill the bag. This method can be used to measure supply or exhaust air flow, but is typically used for supply HVAC registers. While this is often a good, simple, low-cost method, it may change the static pressure in the duct upstream of a supply register more than with a standard or powered capture hood. Some researchers feel that insertion losses are small and should not significantly impact the audit measurement. This indicates that "insertion loss" could be more with this method.

[2] See work by Walker, et al., in the Delta Q references for this chapter.

Toilet Paper

One simple, low-cost screening method to determine if exhaust ventilation fans are operating is to place a piece of toilet paper on the grill and see if the fan can hold it in place. This approach is described in ASHRAE 62.2 guideline 24. This is less a measurement method and more of a simple check of the presence of some flow, with uncertain accuracy.

Fan Curve Data and External Static Pressure (ESP)

This approach utilizes the HVAC blower fan engineering data along with field measures or assumed duct design parameters to determine the overall system flow rate. The approach is employed more frequently by the HVAC industry than by HPCs. There are questions regarding the location to measure ESP[3] and the variability of using design data, which is often lower than anticipated in the field as a result of poor design, installation, or high filter or coil pressure drops resulting from poor maintenance. If the parameters that impact this measurement approach are just due to high loss elements, then the fan curve works well. However, in the real world, "system effects" often cause the fan curve to be affected by the velocity distribution going into the blower. Fan curves for air handlers are developed using long sections of straight ducts on both ends of the air handler and air goes straight into the end of the air handler. When there is a right-angle entrance into the air handler or a right-angle bend just before the entrance, the fan curve may be different than the one measured in the laboratory and published by the manufacturer.

Velocity Traverse

This approach measures air velocity in the duct or at a termination grill/register using a variety of handheld devices, including hot wire anemometers, Pitot tubes and rotating vane anemometers (RVA). Measurement techniques are described in the ASHRAE Handbook and a variety of other HVAC training manuals. The use of these measurement devices and the overall approach to measuring velocity may have significant uncertainty related to the uniformity of flow over the cross-sectional area. Taking numerous measurements in a grid pattern improves accuracy. Taking the measurements within a section of straight ductwork (difficult to find and/or access in residential HVAC systems) is required when conducting in-line duct measurements. Manufacturer engineering data is used when measuring at registers and other terminal devices.

It is difficult to make correct calculations if the velocity sensor is not oriented properly with respect to the local direction of the flow – which is something you cannot see – when taking velocity in-duct measurements. RVAs are extraordinarily unreliable for termination measurements, and were not generally deigned for field measurements of typical small

[3] The idea that factory-installed pressure taps may help improve this measurement is discussed in HVAC section of this report

residential systems. Some practitioners have had reasonable success using handheld RVA at return grills; however, more research may be needed on this with the smaller residential systems.

Flow Capture Hoods

This equipment is designed to fit over a supply or exhaust register termination fitting to directly measure the air flow rate through the hood while compensating for any addition pressure drop caused by the hood that may affect the measurement. Some equipment compensates while other devices do not.

A number of flow capture hoods are typically used for higher HVAC flow rates in commercial HVAC systems. These products have become part of the HPC tool kit, and discussions are occurring within the HPC and HVAC communities regarding accuracy at lower flow rates and through smaller registers that are common in residential systems, room-to-room balancing and measuring ventilation systems as required in ASHRAE 62.2.

Powered capture hoods can accurately measure flows from a wider range of register sizes and designs and at lower flow rates because they can have built-in flow conditioners before the flow measurement section that assures that the velocity distribution in the flow measurement section is the same – or close to it – as when the device was calibrated. They can also force a small flow through a small flow measuring section to get higher velocities that can be more accurately measured. A fan is used to compensate for any additional pressure drop associated with the flow conditioners and high velocity measurement sections.

There is some uncertainty with each measurement of individual flow rate, which is additive as more registers are measured. Considerable uncertainty may exist when adding the individual register flow rates to determine overall system airflow. In addition, there is uncertainty associated with duct leakage between the HVAC blower and the register. This uncertainty goes up with higher duct leakage. These two factors can lead to uncertainties that may impact the ability to measure overall airflow at the coil to determine if the CFM/ton design guidelines are achieved with AC and heat pump coils.

Because typical HVAC equipment is available in half-ton sizing increments, there is some limit to the level of accuracy needed. For example, higher accuracy may be required for the installation of a ducted energy or heat recovery whole-house ventilation system, as in a "deep energy retrofit,"[4] where the overall design flow rate may be 50 CFM split between three to five rooms.

[4] Deep energy retrofit is a term developed by the Thousand Home Challenge: http://thousandhomechallenge.com/.

Infrared Thermal Imaging

Infrared (IR) thermal imaging, or thermography, detects surface temperature. Temperature changes are recorded by making repeat measurements (or images) over time. These changes allow the HPC to discover problems associated with insulation and/or air sealing as part of the quality control process associated with energy audits and retrofits. Manufacturer-provided software is available to assist the operator in developing reports and conducting further analysis based on thermal camera images. The images of specific heat loss/gain problem areas provide useful information to the homeowner as part of the audit and/or when work has been completed, and may help sell the job.

Significant price reductions in the cost of IR equipment have resulted in more HPCs adding thermal imaging cameras to their field testing toolbox.

The referenced international standards have been used as a normative guideline in establishing these IR testing protocols and standards:

- ANSI/ASNT CP-105-2011 American National Standard Institute ASNT Standard Topical - Outlines for Qualification of Nondestructive Testing Personnel (referred to here as the Standard)
- ASNT Recommended Practice Number SNT-TC-1A Personnel - Certification and Qualification (2011)
- ASTM C 1060-90 (2003): Standard Practice for Thermographic Inspection of Insulation Installations in Envelope Cavities of Frame Buildings
- ASTM E 1186-03: Standard Practices for Air Leakage Site Detection in Building Envelopes and Air Barrier Systems
- ISO 6781: Thermal Insulation – Qualitative Detection of Thermal Irregularities in Building Envelopes – Infrared Method
- Canadian General Standards Board, Document 149-GP-2MP, Manual for Thermographic Analysis of Building Enclosures.
- British Standard: Thermal performance of buildings, qualitative detection of thermal irregularities in building envelopes, infrared method.
- ISO6781:1983 modified
- Canadian National Master Specifications (NMS), Section 02 27 13

RESNET has interim guidelines for thermographic inspections of buildings that utilize the above standards. The Standard provides guidance on the use of IR thermography for the thermal examination of low-rise (three stories or less) wood- or steel-framed residential and light commercial buildings. The Standard's purpose is to provide:

- A recommended path by which those wishing to obtain certification in IR thermography can do so,

- Examination and analysis guidance in using IR thermography for air intrusion and insulation inspections, and
- A substitute for Grade II and Grade III insulation examinations on a new building, where the insulation installation was not viewed before the drywall was applied. The Standard is a RESNET requirement for inspecting a building enclosure using an IR imaging system to locate defective insulation installations, framing issues, air leakage or thermal bypasses.

This Standard also includes information for:

- Using an IR imaging system to determine differences associated with surface temperature variations.
- Determining whether the areas being viewed meet the specifications in this Standard.
- Documenting the type and extent of any observed thermal anomalies.
- Locating areas needing more examination, such as thermal bridging, thermal bypasses and air infiltration.
- Providing a thermal indication of insulation performance and continuity.
- Identifying areas of air leakage when an IR imaging system is used in combination with blower door operation.

HPC Building Science Field Testing Tools

The following links are to manufacturer product information typically employed by the HPC and HVAC industries. This list does not to include all commercially available equipment nor is it an endorsement of any specific manufacturer or product.

Envelope and Duct Leakage

- The Energy Conservatory: http://www.energyconservatory.com/products/products1.htm
- Retrotec: http://www.retrotec.com/
- Infiltec: http://www.infiltec.com/

HVAC Air-Flow

- Alnor: http://www.alnor-usa.com/
- Shortridge Instruments, Inc.: http://www.shortridge.com/
- The Energy Conservatory: http://www.energyconservatory.com/products/products1.htm
- TSI: http://www.tsi.com/Products/
- TESTO: http://testohvac.blogspot.com/p/airflow.html

Infrared Thermography

- Fluke: http://www.fluke.com/fluke/usen/products/categoryti
- FLIR Thermography: http://www.flir.com/thermography/americas/us/

References

Modified BD Subtraction

Palmiter, L. and P.W. Francisco. "Measuring Duct Leakage with a Blower Door: Field Results." *Proceedings of the 2002 ACEEE Summer Study on Energy Efficiency in Buildings*, Washington, D.C., 2002.

Delta-Q

Dickerhoff, Darryl, Iain Walker. Evaluation of the Repeatability of the Delta Q Duct Leakage Testing Technique Including Investigation of Robust Analysis Techniques and Estimates of Weather Induced Uncertainty. LBNL-1209E, August 2008.
http://www.osti.gov/scitech/servlets/purl/943511

Dickerhoff, D.J., I.S. Walker, and M.H Sherman. "Validating and Improving the Delta Q Duct Leakage Test." *ASHRAE Transactions* Vol. 110, Pt. 2, 2004, pp.741-751, ASHRAE, Atlanta, GA. LBNL 53959.

Francisco, P.W., S. Pigg, and C. Olson. "A Field Comparison of the Delta-Q Test for Duct Leakage to Other Test Methods." *Proceedings of the 30th AIVC/4th BUILDAIR Conference*, Berlin, Germany, 2009.

Francisco, P.W. *Understanding and Reducing Uncertainties in the Delta-Q Test during Field Testing*. Prepared for the Ohio Department of Development and U.S. DOE, 2009.

Francisco, P.W. *Field Evaluation of an Updated Delta-Q Test.* Prepared for the Ohio Department of Development and U.S. DOE, 2006.

Walker, I.S., M.H. Sherman, and D.J. Dickerhoff. "Reducing uncertainty for the Delta Q duct leakage test." *Proc. ASHRAE/DOE/BTECC Thermal Performance of the Exterior Envelopes of Buildings IX*, ASHRAE, 2004. LBNL 53549.

Walker, I.S. and M.H. Sherman. "An Easier Way to Measure Duct Leaks," *Home Energy Magazine*, Vol. 19, No. 5, September/October 2002.

Walker, I.S., D.J. Dickerhoff, and M.H. Sherman. "The Delta Q Method of Testing the Air Leakage of Ducts." *Proc. ACEEE Summer Study 2002*, American Council for an Energy Efficient Economy, Washington, D.C. LBNL 49749.

Walker, I.S., M.H. Sherman, J. Wempen, D. Wang, J.A. McWilliams, D.J. Dickerhoff. "Development of a New Duct Leakage Test: Delta Q." LBNL 47308, 2002.
http://uc-ciee.org/downloads/NewDuctLeakageTest.Sherman.pdf

Walker, I.S., M.H. Sherman, J. Wempen, D. Wang, J.A. McWilliams, and D.J. Dickerhoff. "Development of a New Duct Leakage Test: Delta Q." LBNL-47305, 2001.

Duct Leakage Measurement

Delmotte, C., J. Laverge. "Interlaboratory Tests for the Determination of Repeatability and Reproducibility of Building Airtightness Measurements." AIVC 2012.

Francisco, P.W., L. Palmiter, E. Kruse, and B. Davis. "Evaluation of Two New Duct Leakage Measurement Methods in 51 Homes." *ASHRAE Transactions*, 2004.

Francisco, P.W., L. Palmiter, E. Kruse, and B. Davis. *Field Evaluation of Improved Methods for Measuring the Air Leakage of Duct Systems Under Normal Operating Conditions in 51 Homes.* Prepared for U.S. DOE, 2003.

Francisco, P.W., L. Palmiter, and B. Davis. "Insights into Improved Ways to Measure Residential Duct Leakage." *ASHRAE Transactions,* 2003.

Francisco, P.W., L. Palmiter, and B. Davis. "Field Performance of Two New Residential Duct Leakage Measurement Techniques." *Proceedings of the 2002 ACEEE Summer Study on Energy Efficiency in Buildings*, Washington, D.C., 2002.

Francisco, P., L. Palmiter, and B. Davis. *Improved Ways to Measure Residential Duct Leakage Final Report.* ASHRAE, 2002.

Jump, D., I.S. Walker, and M.P Modera. "Measured Air Distribution System Performance Improvements in 25 Sacramento Houses," *ASHRAE Trans.* Vol. 104, 1996b. ASHRAE, Atlanta, GA.

Jump, D.A., I.S. Walker, and M.P. Modera. "Field Measurements of Efficiency and Duct Retrofit Effectiveness in Residential Forced Air Distribution Systems," *Proc. ACEEE 1996 Summer Study*, Vol. 1 pp. 147-156. American Council for an Energy Efficient Economy, Washington, D.C. LBNL 38537.

Kruse, E., P. Francisco, L. Palmiter, and B. Davis. "Measured Duct Leakage at Operating Conditions in 48 Homes." *Proceedings of the 2004 ACEEE Summer Study on Energy Efficiency in Buildings*, 2004.

Pigg, S. and P. Francisco. *A Field Study of Exterior Duct Leakage in New Wisconsin Homes*. Prepared for Focus on Energy, 2008.

Siegel, J.A., J.A. McWilliams, and I.S. Walker. "Comparison Between Predicted Duct Effectiveness from Proposed ASHRAE Standard 152P and Measured Field Data for Residential Forced Air Cooling Systems." ASHRAE Trans., Vol. 109, Pt.1, 2003, pp. 503-512, ASHRAE. LBNL 50008.

Siegel, J. and I.S. Walker. “Integrating Ducts into the Conditioned Space: Successes and Challenges.” Proc. Architectural Engineering Institute Conference, Austin TX, September 2003.

Walker, I.S., M. Sherman, J. Siegel, D. Wang, C. Buchanan, and M. Modera. “Leakage Diagnostics, Sealant Longevity, Sizing and Technology Transfer in Residential Thermal Distribution Systems, Part II.” CIEE Residential Thermal Distribution Systems Phase VI Final Report, December 1998, LBNL 42691.

Pressure Pan Testing

Siegel, J. and B. Manclark. “Pressure Pans: New Uses and Old Fundamentals,” *Home Energy*, January/February 1998. Viewed online 7/25/2012:
http://www.homeenergy.org/show/article/nav/auditing/page/8/id/1363

Utility Billing Analysis

To improve the energy efficiency, durability and indoor air quality of existing residential single-family housing stock in the United States, we need to "close the loop"; that is, use the measured results of energy efficiency retrofits to inform how performance can be improved. A key aspect of retrofit performance is indicated in utility bills, which are the richest source of actual residential energy data. We need to get better at employing this data to help identify best practices that improve performance. In this section, we make some observations[5] about the need for more utility billing data analysis, outline issues that need to be addressed and identify key outcomes.

The Need for Utility Billing Data Analysis

Why do we need to get better at taking advantage of utility billing data? We offer two observations about our current reality that illustrate this need:

1. The energy models used to determine what retrofit work should be done and estimate the resulting energy savings have significant limitations and need further testing and refinement based on empirical data.
2. Many evaluations of residential retrofit programs do not make effective use of utility billing data or have problematic evaluation methods that limit their value.[6]

Building Energy Models

Energy modeling, often done as part of the energy audit process for individual homes, can play a key role in determining what measures are installed in a residential energy efficiency retrofit. The energy models are typically used to estimate the energy savings from each measure, identify which measures are most cost effective and create guidelines or requirements for the measures.

While energy models can be useful tools, they have limitations in estimating the energy savings from energy efficiency measures that limit the accuracy of estimates about the cost-effectiveness of retrofit options. Studies based on actual energy use data have shown that

[5] Many of the observations made in this section are based on the work of Michael Blasnik, which has been presented at various conferences over the years, most recently at ACI 2012.

[6] After completing this chapter, the authors learned of the Uniform Methods Project being led by the U.S. Department of Energy. The goal is to "strengthen the credibility of energy efficiency programs by improving Evaluation, Measurement and Verification (EM&V), increasing the consistency and transparency of how energy savings are determined." One of the protocols being drafted is on Whole Building Retrofits (primarily residential buildings). This draft protocol gives a very complete treatment of utility billing analysis, noting it is the recommended approach for whole building retrofits. See: "Whole-Building Retrofit Protocol, Uniform Methods Project," Ken Agnew and Mimi Goldberg, DNV KEMA for U.S. DOE, June 2012.

energy models frequently over-predict energy savings from common retrofits. A report by Oak Ridge National Laboratory[7] noted:

> "Empirical data comparing estimated energy savings to the actual savings achieved by weatherization efforts came from several different reports (Brown and Mihlmester, 1995; Nadel and Keating, 1991; Gettings et al., 1998). The documents reviewed suggest that an adjustment factor of 0.60 is appropriate to use for residential direct assistance programs, because actual savings typically amount to about 60 percent of the predicted reduction in energy usage."

The National Energy AudiT (NEAT),[8] developed by ORNL in 1993, is widely used in the National Weatherization Assistance Program (WAP). NEAT employs standard algorithms for estimating energy savings from retrofits and has been the subject of several studies[9,10,11] that compared model-predicted savings to billing analysis results. These studies found that measured savings typically range from 50 percent to 70 percent of the model prediction. One of the studies (New York, 1998) also modeled the homes using DOE-2 and found very similar results, indicating that the problem occurred when the researchers used the algorithms employed by NEAT and when they used a state-of-the-art hourly simulation model.

ORNL also developed the Manufactured Home Energy Audit (MHEA) for energy modeling of mobile homes in WAP. A study[12] of MHEA's savings projections found that savings measured from billing data analysis averaged just 34 percent of the modeled savings. Pre-retrofit energy use was over-estimated by 33 percent while post-retrofit energy use was accurately predicted.

Many other studies of retrofit programs have found billing analysis savings that are much lower than projections. A billing analysis of the New York Home Performance with ENERGY STAR program[13] found gas savings that averaged just 38 percent of projected savings. The analysis attributed this low savings realization rate to unrealistically high savings projections; projected savings exceeded 60 percent of pre-program gas use in more than one-third of homes analyzed, and sometimes exceeded pre-program use by 100 percent.

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[7] Martin Schweitzer and Joel F. Eisenberg. "Meeting The Challenge: The Prospect of Achieving 30 Percent Energy Savings Through the Weatherization Assistance Program." Oak Ridge National Laboratory, ORNL/CON-479, May 2002.
[8] See http://weatherization.ornl.gov/assistant.shtml.
[9] Gettings, Michael B., L.G. Berry, M.A. Beyer, and J.B. Maxwell. "Validation of the National Energy Audit (NEAT) with Data from a Gas Utility Low-Income Residential Weatherization Program in New York State." ORNL/CON-457, January 1998.
[10] Sharp, T. R. "The North Carolina Field Test: Field Performance of the Preliminary Version of an Advanced Weatherization Audit for the Department of Energy's Weatherization Assistance Program." ORNL/CON-362, 1994.
[11] Dalhoff, G. "An Evaluation of the Performance of the NEAT Audit for the Iowa Low-Income Weatherization Program." International Energy Program Evaluation Conference, Chicago, IL, 1997.
[12] Ternes, M.P. "Validation of the Manufactured Home Energy Audit (MHEA)." ORNL/CON-501, November 2007.
[13] Herndon, J. and D. Gowans. "M&V Evaluation: Home Performance with ENERGY STAR® Final Report." Nexant, NYSERDA, June 2007.

Other studies[14,15] have found that energy models that seem to perform fairly well at estimating the energy use of newer and more efficient homes significantly over-estimate the energy use of inefficient (i.e., poorly insulated and leaky) homes. The Oregon study found that REM/*Rate* – the most popular RESNET-approved HERS rating software – over-estimated natural gas use by 76 percent on average in 86 homes built before 1960, yet over-estimated use by only 17 percent in the 41 homes built after 1989. That study found less dramatic, but similar, results using the Home Energy Saver model (an on-line front-end to DOE-2, built by LBNL), which over-estimated gas use by 41 percent in older homes and by 13 percent in newer homes.

The Wisconsin study used REM/*Rate* to analyze existing homes and found that heating energy use was severely over-estimated in inefficient homes, as shown in Figure 4.

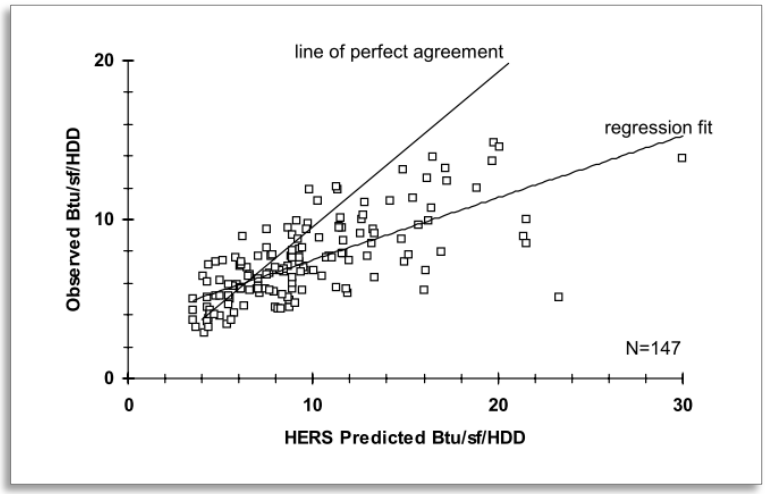


Figure 4. Over-Estimation of Heating Energy Use Using REM/*Rate*

The Wisconsin researchers observed:

> "The results indicate a systematic error in the estimates of heating energy use: the greater the predicted heating energy intensity, the greater the error. For most homes, the error is a moderate over-prediction in heating use (on the order of 20 percent), but the software substantially overestimates heating use for a minority of homes that are predicted to have high heating energy intensity. These are mostly homes that have some combination of large un-insulated wall or ceiling areas, high measured air leakage, or heating systems with low estimated seasonal efficiency.

[14] Pigg, S. and M Nevius. "Energy and Housing in Wisconsin – A Study of Single-Family Owner-Occupied Homes." Energy Center of Wisconsin, ECW 199-1, 2000.
[15] "Energy Performance Score 2008 Pilot," Earth Advantage Institute and Conservation Services Group, Energy Trust of Oregon, 2009.

> "It has been suggested that the difference might arise from a tendency for people who live in older inefficient homes to keep their thermostat set lower to save on their heating bills (these homes are indeed more likely to be occupied by low-income households). The questionnaire data show just the opposite, however: people in older homes keep their thermostat set somewhat higher, probably to overcome comfort problems associated with drafts and cold wall surfaces."

The over-estimation of savings is often blamed on occupant behavior (the "take-back" effect), but available data does not support this hypothesis. In addition to the Wisconsin findings on thermostat settings, the current national WAP evaluation found that monitored indoor temperatures were essentially unchanged after weatherization, indicating no take-back effect for heating. It appears that the problem with savings predictions may lie more with the model assumptions or algorithms than with occupant behavior.

There are a number of reasonable hypotheses for why models over-predict retrofit energy savings:

- **Assumptions/defaults biased toward low existing efficiency**: Many model default values and assumptions – particularly for the effective R-values of un-insulated building components and the seasonal efficiency of older HVAC equipment – appear to underestimate the true efficiency of the component and represent something closer to a worst-case scenario than a typical value.
- **Auditor bias**: Auditors want to be able to specify retrofits and often have to make judgment calls about existing conditions, such as the effective R-value of an attic with varying levels of insulation or the estimated seasonal efficiency of an older furnace. These judgment calls often seem to be made in a way that increases estimated retrofit savings and qualifies more measures as cost-effective.
- **Algorithm errors**: Some commonly employed algorithms for complex phenomena such as air leakage and duct system efficiency appear to over-estimate energy losses. For example, careful research[16] found that the LBNL/Sherman-Grimsrud infiltration model over-states the impact of wind, leading to over-estimated infiltration rates. In addition, field technician judgment about wind exposure and defaults in most software appear to over-estimate wind exposure of many homes, which exacerbates the over-estimation. In the 20 years since the research was published, the model has not been revised and warnings about field-estimated exposure values have not been made.

[16] Palmiter, L. and T. Bond. "Modeled and Measured Infiltration: A Detailed Case Study of Four Electrically Heated Homes." Electric Power Research Institute, RP 2034-40, Report CU-7327, 1991.

- **Interactive effects**: Buildings can have complex interactive effects between heat transfer mechanisms and system efficiencies that tend to lead to less overall energy use than otherwise modeled. For example, air leakage through poorly insulated buffer zones can lead to the regain of conductive and distribution system losses in complex ways.
- **No reality check**: Model results are not usually compared to utility bills or other benchmarks to determine if the results are reasonable. Recent efforts to address this issue include the new standard BPI-2400-S-2011 "Standardized Qualification of Whole House Energy Savings Estimates," which limits projected savings claims and defines methods to calibrate models to utility bills.

It is tempting to address these problems with modeling by using more sophisticated models with more data inputs or more exacting measurements. However, the Oregon study cited previously indicated that simpler models based on fewer inputs may perform as well or better than more complex models. As the number of data inputs grows, so do the possibilities for things to go wrong. Other researchers' Parker/Mills ACEEE 2012 work suggests this is an issue of contention within the building science community.

Regardless of the sophistication of the algorithms, model accuracy is always limited by our ability to measure the required inputs accurately as well as fundamental limitations in our ability to model complex phenomena. Some challenges and limitations for model accuracy include:

- Solar gain through windows depends on shading, which involves knowing about occupant use of interior shades and curtains, the colors and fit of those shades, exterior shading from foliage that varies by season and over time, the cleanliness of the windows and screens, and other factors.
- Heat transfer through basement walls depends on soil properties and ground water levels, which are not well known for any given site.
- Duct system efficiency involves estimating leakage rates under operating conditions, identifying leakage locations, and quantifying regain effects as duct losses in buffer zones, such as basements and crawlspaces, alter the temperatures of those zones, which affects conduction and infiltration gains and losses.
- Air infiltration rates depend on knowing not just the leakage area of the home (which can be tested with a blower door), but also the distribution of leaks and the actual wind speeds at the house over the course of the year.
- In poorly insulated and leaky homes, conductive and distribution system losses into basements and crawlspaces can be regained by infiltrating air. Exfiltrating air leaving through attics can warm the attic space, reducing conductive losses.

These complex effects impose some fundamental limitations to modeling accuracy. In addition, attempts to collect more – and more accurate – inputs for use in more complex models can add significantly to the cost of delivering retrofits: more time is required to perform the energy audit and additional training and skill levels are required for staff and auditors. In addition, time spent on tedious data collection and entry into software applications can detract from the auditor's ability to interact with the homeowner, sell the job, and potentially identify a better understanding of the "big picture" at a given home.

These observations suggest the need for simple tools that provide reasonably unbiased estimates of energy use and retrofit savings and that have been optimized to match empirical results. Utility billing analysis can be used to assess the performance of large numbers of houses so we can learn from actual field experience and use the results to inform the simple tools and models. The results of the analysis can also help identify the important things we need to get right.

Evaluations

Residential retrofit programs run by utility companies and government agencies sometimes have independent evaluations performed to assess how well the program is meeting its goals, including energy savings. Many of these evaluations do not use large-scale analysis of actual energy use data, instead relying on "deemed" or calculated savings based on modeling software or pre-calculated values for estimated typical conditions. Often, evaluations that analyze actual billing data employ methods that provide only limited insights into the performance of retrofits.

The lack of sound empirical results about the program and the effectiveness of retrofit measures limits the value of these evaluations for improving program performance (i.e., closing the loop). We believe there are several reasons for this trend:

- **Limited focus**: Evaluations are designed to satisfy the program's authorizing stakeholders, such as the utility company or state public service commission. Thus, they tend to focus more on assessing overall cost-effectiveness than providing insights into the performance of the specific retrofit measures or approach.
- **Less reliance on actual energy usage data**: The trend in evaluation seems to be toward deemed savings estimates or some other engineering calculation to estimate energy savings from program tracking information. This is a simple and practical approach to estimate savings, but gives no indication of actual energy savings.
- **Complex "black box" methods**: The state of the art in billing data analysis appears to be *pooled econometric modeling*. These pooled regression models are easier and quicker to implement than house-level billing analyses, but they rarely provide sufficient detail for understanding the results and identifying opportunities for program improvement. The

models often involve complex specifications that lead to many potential avenues for analytical mistakes. The results are often impenetrable to readers, sometimes even to authors.

The methodological problems[17] in energy program evaluation have led to evaluation results that sometimes make no sense and defy explanation. Major problems with analyses are often identified when studies are carefully scrutinized by third parties, especially those with access to the raw data. One outcome of this scrutiny is that results can change dramatically. When the Energy Trust of Oregon became frustrated by program evaluation results that varied wildly from year to year, they began to assess the evaluation methods. This included evaluating the same program data using multiple evaluators and then exploring the differences. As a result, the Energy Trust moved most impact evaluation work internally, where they employ fairly clear and consistent house-level weather normalization models followed by measure level regression modeling. Evaluation results are used to adjust assumptions about retrofit savings going forward, helping to complete the feedback loop of design→ implementation→ evaluation→ redesign.

Clear and consistent approaches are needed that involve *house level* weather normalization of utility billing data followed by statistical analysis of savings from each implemented measure. The overall approach employs a quasi-experimental design using a difference-in-differences analysis.

- First, gross savings are calculated as the difference between pre- and post-program weather normalized energy usage for participants. The same analysis is conducted for a comparison group selected to match the participants as closely as possible. The role of the comparison group is to reflect non-program changes in energy usage that may be due to general demographic or technical trends in the population (e.g., greater use of DVRs, laptops and tablet computers) as well as weather effects that are not captured properly by the weather normalization. The net[18] program savings are then calculated as the gross savings for the participants minus the gross savings for the comparison group.
- The house-level savings results are then further analyzed to look for patterns in the savings across homes related to program measures, housing characteristics and other factors. The savings from individual measure can be estimated using regression modeling based on measure level indicator (dummy) variables or measure quantities (e.g., square feet of insulation), or by using projected savings for each measure (referred to as SAE – Statistically Adjusted Engineering analysis).

[17] For a discussion of some of these statistical issues, see Blasnik, M. "The Need for Statistical Analysis and Reporting Requirements: Some Suggestions for Regression Models," *Proceedings of Energy Program Evaluation Conference*, Chicago, 1995.

[18] Further adjustments to net savings are sometimes made to adjust results for free-riders and spillover effects.

The advantages of the *house level* utility billing analysis compared to *pooled econometric* models are:

- Results can be "seen," distributions of savings from high to low can be examined, and outliers can be identified.
- Results can be directly and more easily broken out by factors such as treatment, housing characteristics and demographics.
- Relationships can be explored with graphs and statistics.
- The analysis can identify and explicitly deal with outliers, unoccupied homes, and homes with misclassified heating or water heating fuels.

The primary analytical advantage of the pooled econometric modeling approach is that by pooling the monthly bills across homes, month-specific temporal effects may be estimated, which may better control for seasonal usage fluctuations unrelated to degree day variables.[19] However, the pooled models do not control for weather as well as house-level models because they employ a fixed degree day balance point temperature for all homes and also estimate a pooled average temperature dependence, which is meant to represent an average across all homes to avoid having to model each home's unique weather dependence pattern.

Issues that Need to be Addressed

There are some challenges related to conducting a *house level* utility billing analysis. To improve utility billing analysis efforts, the following issues need to be considered and addressed:

- **Data quantity and quality**: Getting good utility data is often difficult and expensive. Privacy issues must be addressed. For evaluations that are not sponsored by the utility, homeowners will typically need to sign a release form before the utility will provide the data to the evaluator. Collecting and verifying account information and release forms for each home can be tedious and time intensive. Getting electronic data in a usable form can sometimes be a challenge. Data quality issues include missed meter readings (estimated readings) and occupant turn-over (or not enough historical pre-retrofit data). In addition, program tracking information usually needs to match the utility data, which requires some identifying information. Smart meters and other technology (like the Nest thermostat) have the potential to make household energy usage data more accessible.
- **Privacy concerns**: Policies and procedures that allow large batches of data to be collected while addressing privacy concerns could make it much easier to collect and analyze utility billing data.

[19] Agnew and Goldberg, 2012, recommended pooled models when utility billing data are limited (bi-monthly or missing readings) or there is no valid control group and they describe the conditions for obtaining reliable results.

- **Participant group and control group and bias**: It is rarely possible to have an experimental design where the participants (treatment group) are randomly selected and the control group reflects what would have happened without the treatment. Because participants usually choose to have their houses retrofitted, they are not "typical": they might be more affluent; more likely to be homeowners; have older, less efficient houses; or be better educated. Finding a control group that matches the participants is a significant challenge and becomes even more difficult if utility release forms are needed to access their data. This challenge is often addressed by using "future participants" as the control group. Ideally, there would be large pools of utility data (or panels of households) available to use as control groups.
- **Small samples and/or small savings and outliers**: Because of the challenges noted above, utility billing analyses are often hampered by small samples. This is a problem because outliers can have a significant impact on the results, particularly if the sample is small. Deciding when an outlier should be removed can be difficult and can also bias the results. Small energy savings can be difficult to identify when the variation in the data is comparable to the size of the savings (signal to noise ratio).
- **Need to incorporate building science into the analysis**: Evaluators can have a limited understanding of the science of building energy use and or retrofit performance. Econometric modeling problems and outliers may lead to statistical conclusions that make no physical sense. A lack of subject matter expertise allows analytical errors and problems to go undetected and can lead to program managers making decisions based on erroneous information. The famed quality control guru Edward Deming said, "Statistical significance by itself is not a rational basis for action."[20] For evaluation results to be reliable and useful for improving programs, people with strong technical understanding are needed to participate throughout the evaluation process to help interpret results and guide potential avenues of exploration.

For sound and reliable utility billing analysis to become more common and robust, the collection of utility bill data and the creation of control groups needs to be made easier and automated to the extent possible. We need to take advantage of advances in hardware and software to more efficiently obtain data in large batches. Policies need to be created that address privacy concerns in a way that does not make it too difficult to collect the data. We also need to be sure that statisticians and building science experts are working together to produce robust results.

[20] Deming, W. Edwards. "Statistical Adjustment of Data." New York: Dover Publications, 1943.

Key Outcomes

More effectively using measured data to "close the loop" would result in the following outcomes:

- **Improved service delivery**: We will have better decision-making tools to determine what work needs to be done to deliver the best value and quality. Program results can inform guidelines for appropriate measures and testing, effective techniques and methods, and efficient delivery processes.
- **Sound policy**: We will have results that demonstrate the public benefit from policies that support widespread application of retrofits in existing residential housing. This includes policies that support public funding for retrofit programs such as the DOE Low Income Weatherization Program, discussed earlier in this report, which is an example of how an evaluation using utility billing analysis will influence policy.
- **Financing**: We will have the data to show the value of a residential retrofit and what level of investment is justified. This will help generate the financing necessary to support residential retrofits on a wide scale. In a recent study commissioned by Deutsche Bank[21], 231 affordable housing multi-family retrofit projects in New York were analyzed to provide lenders with the data they need to assess the risk associated with lending against energy savings projections. Pre- and post-project energy use was assessed, the reliability of predicted savings was analyzed, and an approach for incorporating energy savings projections (modified based on empirical data) into underwriting was developed. This underwriting tool is intended to help unlock the billions of dollars necessary to realize the energy savings potential in low-income residential buildings.

We will not begin to make significant progress to improve the energy efficiency, durability and indoor air quality of the existing residential housing stock until we measure the actual value of these retrofits and use that information to continuously improve that value.

[21] Steven Winter Associates and HR&A Advisors. "Recognizing the Benefits of Energy Efficiency in Multifamily Underwriting, Deutsche Bank." 2012. https://www.db.com/usa/img/DBLC_Recognizing_the_Benefits_of_Energy_Efficiency_01_12.pdf

Energy Simulation Software

Since the early 1970s, energy modeling was used primarily by national laboratories and utility programs to estimate energy savings in new and existing single-family residences. Software programs were developed by DOE government laboratories such as Las Alamos and Solar Energy Research Institute (SERI) on larger mainframe high-speed computers. The programs typically utilized weather data and information based on ASHRAE steady-state heat loss calculations, thermal mass, thermostat setpoints, internal gains and solar gains to predict monthly and annual energy use for space heating and cooling.

These programs were also used to develop estimates of energy savings from standard design, typically focused on passive solar, solar sunspace and direct gain in the design of new homes. The programs often assume the home to be a single-zone model and annualize space conditioning energy use based on hourly, daily or time-step intervals as part of the annual simulation. In some cases, thousands of simulations were conducted to develop simplified tables based on large parametric analysis of weather, home type and efficiency levels as curve fits, which could then be used by designers who did not have access to these simulation tools.

Energy simulation software programs were developed in the 1990s. Two programs that were used frequently by low-income agencies in support of federal and state low-income residential weatherization programs were the National Energy Audit Tool (NEAT) and Targeted Retrofit Energy Analysis Tool (TREAT). Approved software such as TREAT and/or NEAT are required by DOE in low-income weatherization programs when software is used to verify that the savings-to-investment ratio (SIR) is greater than one for any energy efficiency measure installed. In some cases, energy analysis software was used by program designers to prescriptively determine cost-effective energy efficiency retrofit measures, in lieu of requiring case-by-case simulations using approved software.

Today, with the ready availability of modern computers, energy simulation software is more available to those working with low-income weatherization programs and to a broader group of users such as HPCs, energy auditors, home energy raters and even homeowners. The two most popular software programs believed to be used by HPCs and associated with RESNET are REM/*Rate* and Energy Gauge USA. HPCs working with RESNET HERS use these programs for energy rating of new and existing home retrofits.[22]

[22] "Home Energy Rating System Building Energy Simulation Test (HERS BESTEST)," Vol. 1 and 2, NREL/TP-472-7332. National Renewable Energy Laboratory, Golden, Colorado. Available at: http://www.nrel.gov/publications.

The energy software used to rate homes must be approved using the BESTEST and RESNET process. A list of nationally accredited rating software and discussion of BESTEST may be found at RESNET Accredited Rating Software Tools: http://www.resnet.us/professional/programs/providers/directory.aspx.

A directory sponsored by the DOE Energy Efficiency and Renewable Energy (EERE) program provides software tools to help researchers, designers, architects, engineers, builders, code officials and others involved in the building lifecycle to evaluate and rank potential energy-efficiency technologies and renewable energy strategies in new or existing buildings. Many of the 50 tools in the first version (August 1996) were sponsored by DOE at some point in their lifecycle. This directory currently provides information on 406 building software tools for evaluating energy efficiency, renewable energy and sustainability in buildings. The energy tools listed in this directory[23] include databases, spreadsheets, component and systems analyses, and whole-building energy performance simulation programs. A short description is provided for each tool, along with other information including expertise required, users, audience, input, output, computer platforms, programming language, strengths, weaknesses, technical contact and availability.

Numerous studies have shown that the ability of these residential energy simulation software programs to predict energy savings is affected by the potential uncertainties of input assumptions associated with accurately characterizing the home thermal envelope, HVAC system, appliances, DHW and other electric loads. Most important are the assumptions about occupant behavior, which can drive the two key variables of internal gain and thermostat setting. These uncertainties limit the ability to estimate pre/post energy use and savings. Savings can also be impacted when assumptions change from pre- to post-retrofit scenarios.

There seems to be an evolving discussion within the HPC industry and DOE regarding the use of utility data to adjust the pre-retrofit model and to determine if savings estimates from software analysis are realized (provided in the Utility Billing Analysis section of this report). DOE-approved weatherization software programs can adjust (sure-up) the pre-retrofit estimates using utility data, as is required in DOE low-income weatherization programs when software is used to estimates SIR.

Other emerging software tools such as SIMPLE utilize basic information about the home and occupant lifestyle to estimate energy use and savings based on correlations with large empirical utility data sets. These tools have been shown to predict energy use as well as – if not better than – many software simulation programs.

[23] DOE EERE Building Energy Software Tools Directory: http://apps1.eere.energy.gov/buildings/tools_directory

Many HPCs utilize predicted energy savings in selling and financing HPC services to customers; the customers then utilize the savings to make their loan payments on the energy efficiency improvements that were financed. The cost to conduct energy simulation analyses varies from less than $100 to over $400 per home. Given these costs and questions regarding the reliability of the energy savings predictions, significant discussions are occurring regarding the usefulness and programmatic cost effectiveness of requiring energy simulation analysis in homes receiving energy efficiency retrofit improvements. Discussions are also underway regarding the need to assess predicted energy savings with real-world utility savings realized at the meter, and to adjust the energy simulation models based on those empirical data findings.

Table 1 provides links to software producers' websites.

Table 1. Links to Software Products

REM/*Rate*	http://www.archenergy.com/products/remrate
EnergyGauge USA	http://energygauge.com/usares/default.htm
TREAT	http://www.psdconsulting.com/software/treat
NEAT	http://weatherization.ornl.gov/assistant_features.shtml
Home Energy Score	http://www1.eere.energy.gov/buildings/homeenergyscore/
Energy Performance Score	http://energy-performance-score.com/
SEEM	http://www.ecotope.com/ssframe.html
AKWarm	http://www.ahfc.us/reference/akwarm.cfm
BEOPT	http://beopt.nrel.gov/

REM/*Rate*

REM/*Rate*™ software is used by organizations that operate HERS. HERS rates the energy efficiency of homes to identify cost-effective improvements and provide energy-efficient mortgages. Climate data is available for cities and towns throughout North America.

REM/*Design*™ software calculates heating, cooling, DHW, lighting and appliance loads, consumption, and costs based on a description of the home's design and construction features as well as local climate and energy cost data. Additionally, REM/*Design* is DOE-approved for weatherization assistance programs in all states.

REM/*Rate* is a user-friendly, yet highly sophisticated residential energy analysis, code compliance and rating software program developed specifically for HERS providers. REM/*Rate* software calculates heating, cooling, hot water, lighting and appliance energy loads, consumption and costs for new and existing single- and multi-family homes. Climate data is available for cities and towns throughout North America. REM/*Rate* complies with National Home Energy Rating Standards as promulgated by RESNET. REM/*Rate* has many unique

features including a simplified input procedure, extensive component libraries, automated energy efficient improvement analysis, duct conduction and leakage analysis, latent and sensible cooling analysis, lighting and appliance audit, and active and passive solar analysis. The software has a user-defined reference home feature that enables the HERS provider to create other reference homes (reflecting local construction practices and local codes) that can be compared to the rated home. It also has an export database feature that creates a database of inputs and outputs for statistical analysis, archiving ratings and custom report generation.

EnergyGauge USA

This user-friendly but highly sophisticated home energy simulation software tool was designed to easily and accurately evaluate home energy efficiency. The software uses the powerful and widely respected DOE 2.1-E hourly building energy simulation software to simulate and evaluate energy use alongside the financial impacts of energy-efficiency improvements in existing and new high-performance homes.

EnergyGauge USA complies with all requirements of the International Energy Conservation Code (IECC) for energy code compliance calculations and reporting and with all national accreditation procedures and technical guidelines for HERS, including the HERS BESTEST procedures.

EnergyGauge USA was developed specifically to allow the easy and accurate calculation of energy use and demand in residential buildings. In the past, most residential energy analysis tools have used simplified methods to calculate residential building energy performance. EnergyGauge USA takes advantage of personal computer technology and DOE-2.1E software to complete an hourly annual simulation in under 30 seconds.

The software has been used to simulate homes that have been monitored in detail in the field with excellent results. The EnergyGauge USA BESTEST Report[24] is on permanent file with RESNET, the nation's accreditor of HERS Providers and Rater Training Providers. As a HERS tool, EnergyGauge USA offers, compliance with the National Renewable Energy Laboratory's HERS BESTEST4 procedures. HERS is in full compliance with the Mortgage Industry National Home Energy Rating System Standards as adopted by the National Association of State Energy Officials Standard DOE-2 reports, including hourly reports.

[24] Validation of EnergyGauge USA against monitored field data can be accessed on-line at: http://www.fsec.ucf.edu/en/publications/html/FSEC-CR-1670-00/index.htm.

Documentation of EnergyGauge USA compliance within the HERS BESTEST can be accessed on-line at: http://www.fsec.ucf.edu/en/publications/html/FSEC-RR-55-00/index.htm.

Weatherization Assistant

The Weatherization Assistant is a family of easy-to-use but advanced energy audit computer programs that identify the cost-effective energy-efficiency retrofit measures for a home after taking into account local weather conditions, retrofit measure costs, fuel costs and construction details of the home. The Weatherization Assistant is designed to help states and local weatherization agencies implement the DOE Weatherization Assistance Program, although it is also used by utilities and other home energy professionals.

NEAT and MHEA

The Weatherization Assistant serves as the umbrella program for two programs: the National Energy Audit Tool (NEAT) for site-built single-family homes and the Manufactured Home Energy Audit (MHEA) for mobile homes. A third program addressing small multi-family buildings is planned for the future.

NEAT, developed by the Oak Ridge National Laboratory, was formally introduced in the summer of 1993 and was already being used by local weatherization agencies in 20 states by 1994. During 1995, NEAT was used by approximately 500 local weatherization agencies in 30 states to make retrofit decisions for more than 80,000 low-income dwellings.

The unique construction characteristics of mobile homes require evaluating and installing measures specifically designed for such homes so weatherization efforts save energy and money.

NEAT and MHEA evaluate each home individually, after taking into account local weather conditions, retrofit measure costs, fuel costs and specific construction details of the home. After describing envelope components, heating and cooling systems, and base load equipment (e.g., refrigerators, water heaters, lighting), NEAT and MHEA produce a prioritized list of cost-effective weatherization measures customized for the dwelling being evaluated. The output includes estimates of the projected energy savings, savings-to-investment ratios (SIRs), installation costs, a list of the major materials necessary to perform the recommended weatherization retrofits, and design heating and cooling loads needed to size any replacement equipment.

NEAT and MHEA use engineering calculations and weather data from one of 216 weather cities in the U.S. to compute the annual heat loss and heat gain of the home, and the annual space-heating and space-cooling energy consumption required to keep the home at a specific thermostatic set point. Both programs calculate heat loss and heat gain on a monthly basis using a variable-base degree-day method and ten-year average weather data for the selected city.

Home Energy Saver

The Home Energy Saver, the first Internet-based tool to help homeowners reduce energy use in their homes, quickly computes a home's energy use. By simply changing one or more features of the home, users can estimate potential energy savings of energy-efficiency improvements.

Home Energy Saver is designed for the layperson, but is also useful to energy analysts, utilities, residential builders and equipment/service vendors. This web-based approach has several advantages over the traditional process of designing and deploying energy tools, such as a dynamic web-based information network and low-cost, immediate software distribution.

The website serves as a do-it-yourself home energy audit, helping homeowners identify the best energy upgrades, providing information to help implement these upgrades, and connecting users to an expanding array of websites that provide information on energy-efficient products, home builders, residential utility programs, newsletters, energy software and other useful topics.

The site is being developed as part of the EPA ENERGY STAR Program for reducing CO_2 emissions from homes. Separate modules are provided for heating/cooling, DHW, lighting, appliances and miscellaneous uses. Energy consumption is estimated using state-of-the-art models and data developed at Lawrence Berkeley National Laboratory, most notably the DOE-2 building simulation model for the heating/cooling module. A coordinated system of software and hardware makes this program easy to use, and an interactive database is accessible through common gateway interface (CGI) scripts.

Energy Performance Score

Energy Performance Score (EPS) is an exciting new tool that provides a standardized estimate of a home's energy use and associated carbon emissions. The EPS allows you to compare the energy use of one home to another without the influence of varying occupant behavior. Homeowners can also use the tool to compare the typical energy use in the house in its current state versus what it could be like after energy upgrades.

EPS is being used by utility programs, local and state governments, community-based organizations and independent energy assessors across the nation. As a homeowner or energy assessor, you can access specific information about a program in your community and create your own EPS account. Energy efficiency programs funded by DOE in coordination with state governments and local utilities are utilizing the EPS technology platform. In addition, homeowners, contractors, and auditors in Alabama, Massachusetts, Virginia, Washington and Oregon can access the EPS technology platform through existing energy efficiency programs.

The software is based on Michael Blasnik's SIMPLE model, which utilizes large sets of utility data and basic information about the home in lieu of a simulation model.

SEEM

The SEEM program, designed to model small-scale residential building energy use, consists of an hourly thermal simulation and an hourly moisture (humidity) simulation that interacts with duct specifications, equipment and weather parameters to calculate the annual heating and cooling energy requirements of the building. It is based on algorithms consistent with current ASHRAE, AHRI and International Organization for Standards (ISO) calculation standards.

SEEM simulations do not require extensive training or technical sophistication in building thermal modeling, and have become standard design tools in many localities in the Pacific Northwest. SEEM is used extensively in the Northwest to estimate conservation measure savings for regional energy utility policy planners. It is the simulation engine used to provide heating and cooling energy savings estimates for the residential sector in the National Research Council's (NRC) Power Plan, for the Performance Tested Comfort System (PTCS) incentive program, the Northwest ENERGY STAR for Homes program and other utility program offerings.

SEEM was developed by Ecotope and has been greatly enhanced by Larry Palmiter as its primary author. This program was developed by and for the NRC and NEEA. SEEM is also used to support state building energy code revisions including the Washington and Oregon state energy codes.

To create a simulation, SEEM takes a number of input parameters including those for occupancy, equipment, ducts, envelope, foundation and infiltration. The input structure makes the program flexible and allows it to model a diverse set of building construction types, such as split-level, heated basements, slab-on-grade and cantilevered floors. SEEM generates a number of outputs including building UA, heating load, heating equipment input requirements, cooling load and cooling equipment input requirements.

SEEM offers a number of advantages over other simulation programs. The step-by-step hourly calculations accurately model air temperature and mean radiant temperature using a state-of-the-art algorithm. Heat pumps and air conditioners are modeled on real performance data from manufactures' catalogs. SEEM also provides the capability to use multiple control strategies and thermostat setups for the equipment. SEEM also closely tracks duct losses to user-specified zones (inside, outside, crawl, attic) and accurately models their impacts. Additionally, SEEM contains a comprehensive below-grade heat loss algorithm to model building/ground contact through slabs, crawl spaces and basements. Weather data for the simulation comes from the widely used typical meteorological year (TMY) datasets.

AKWARM

AHFC released AkWarm in 1996 as a software tool for builders, designers, energy raters, lenders and homeowners. The software can be used for energy design or retrofit, or to determine an energy rating.

AkWarm accesses a wide range of Alaska-specific databases for weather, fuel, utility and material costs in more than 200 locations. On-screen calculators and input wizards make data entry simple and accurate. AkWarm will allow the user to create house data files, analyze energy use, calculate design heat load, easily make changes to the description of any energy component, compare energy performance and energy costs, and compute the savings of individual energy-conservation measures.

AkWarm is certified to show compliance with the State of Alaska's BEES and the Municipality of Anchorage's heat loss calculations, eliminating the need for additional energy analysis. AkWarm is accepted by AHFC, FHA, VA, Fannie Mae and Freddie Mac for their energy-efficiency financing programs

BEOPT

The BEopt™ (Building Energy Optimization) software was developed by NREL in support of the DOE Building America program goal to develop market-ready energy solutions for new and existing homes.

This program evaluates residential building designs and identifies cost-optimal efficiency packages at various levels of whole-house energy savings along the path to zero net energy. BEopt provides detailed simulation-based analysis based on specific house characteristics such as size, architecture, occupancy, vintage, location and utility rates. Discrete envelope and equipment options, reflecting realistic construction materials and practices, are evaluated. BEopt can be used to analyze new construction and existing home retrofits through evaluating single building designs, parametric sweeps and cost-based optimizations.

BEopt uses existing, established simulation engines (currently DOE2.2 or EnergyPlus). Simulation assumptions are based on the Building America House Simulation Protocols. The sequential search optimization technique used by BEopt finds minimum-cost building designs at different target energy-savings levels and identifies multiple designs, allowing for equivalent solutions based on builder or contractor preference.

References

Bourassa, N.J., L.I. Rainer, E. Mills, and J. Glickman. "The Home Energy Scoring Tool: A Simplified Asset Rating for Single Family Homes," to be presented at the ACEEE Summer Study on Energy Efficiency in Buildings, August 2012. Viewed online 7/25/2012: http://evanmills.lbl.gov/pubs/pdf/HEScore-ACEEE-2012.pdf

Chojnowski, D., K. Straub, E. Mills, and T. White. "Online Communities for Creating Change: Home Energy Pros, to be presented at the ACEEE Summer Study on Energy Efficiency in Buildings," August 2012. Viewed online 7/25/2012: http://evanmills.lbl.gov/pubs/pdf/Home-Energy-Pros-ACEEE-2012.pdf

Mills, E. and P. Mathew. "Web Services that Foster Innovation in Buildings Energy Analysis Tools," to be presented at the ACEEE Summer Study on Energy Efficiency in Buildings, August 2012. Viewed online 7/25/2012: http://evanmills.lbl.gov/pubs/pdf/APIs-ACEEE-2012.pdf

Parker, D., E. Mills, L. Rainer, N.J. Bourassa, and G. Homan. "Accuracy of the Home Energy Saver Energy Calculation Methodology," to be presented at the ACEEE Summer Study on Energy Efficiency in Buildings, August 2012. Viewed online 7/25/2012: http://evanmills.lbl.gov/pubs/pdf/HES-accuracy-ACEEE-2012.pdf

Home and Equipment Energy Feedback Tools

Overview

Like the fuel gauge indicator on a Prius or a heart rate/pulse monitor attached to your finger, both of these devices are providing you with valuable information that will tell you what to do in the near future. As with both technologies, there are displays or indicators that help guide or even change your behavior. With energy feedback monitors, there too lies a potential opportunity to adjust how we as energy consumers behave when we see our utility costs rise with feedback. The increased market penetration of energy feedback tools is being driving primarily by behavior change programs and smart grid/meter capabilities while leveraging the technology industry's (high-tech) fast pace as the platform to push opportunities out to consumers. Moreover, this evolution has created prospects in the behavior arena that is being capitalized beyond that provided by utilities, and includes commercial businesses, organizations and individual innovators, which may ultimately provide long-term and sustained energy savings.

The intention of several commercial, large and small scale firms to promote the idea of changing home owner/renter's behaviors as it relates to their energy use has expanded in the past few years. There are complex systems requiring licensed electricians to the simpler, do-it-yourself system, all of which have some information feedback component for the consumer. Additionally, several organizations and the telecom industry have come into the fold with programs and/or services that can be implemented quickly, and with recent initiatives such as Green Button and Smart Grid, there will be continued growth in this arena on the feedback effort.

Understanding the information that is provided through feedback devices is one variable of the large equation: sustained energy conservation = feedback devices + education/awareness + behavior change + electricity rates + reliability + demographics + incentives. While data collection tools are the key to unlocking potential, it is the functionality or analysis and the appearance of the user interface that will ultimately steer the consumer in the direction that is needed to either change behaviors (long term) or install energy efficiency measures (short term). There are many web-based user interfaces that aggregate energy data and provide useful information to the consumer, however, the trend appears to be moving in the direction of mobile phone/device based applications for the energy audit process (input) and energy efficiency retrofit recommendations (output), as well as the program deployment approach for comprehensive evaluations (input, output, implementation and evaluation).

The oldest of such tools that provides home occupants the ability to enter data and analyze this information is the web-based Home Energy Saver, developed by the U.S. Department of

Energy's Lawrence Berkeley National Laboratory. This tool has been updated and expanded to include a more comprehensive analysis and has features for the trade professionals to access the tool as an energy audit provider. This web-based tool has both a simple and comprehensive information collection format. The more details that are provided by the homeowner or energy auditor, the more useful the tool becomes and therefore the results on energy use estimates, recommendations, and the energy savings from those suggestions will become more valuable. This tool uses the modeling engine, DOE2, to analyze the information collected to produce results and recommendations. While there is no current integration of smart meter data, Green Button data or utility access (the user must input this), it paved the way for Microsoft's and Google's effort with their energy use evaluation projects.

With Hohm, Microsoft utilized (and licensed) the same framework as the Home Energy Saver, to better assess opportunities for efficiency improvements and attempted to dig further to make this tool more relevant. WSU supported Microsoft by providing guidance on the use of the tool; the need to have better integration with utility providers, their incentive programs & local contractors; and fresh content to reflect the current state of opportunities for the dwelling. After a few successful attempts to partner with utility providers, engage with manufacturers of tools that collect energy use data (BlueLine), create a collaboration with Ford and their electric vehicle and involve the contractors' organizations, the benefits and interests to the company seemed to wane and hence, the project was scrapped. Similarly, the Goolgle project, Google Power Meter, a competitor in this area suffered the same fate.

Google Power Meter was also off to a promising start, having incorporated a data collection tool earlier in their process to develop a useful interface for consumers to help save energy and/or monitor energy production from renewable energy systems. The use of The Energy Detective (TED) as the primary tool to aggregate and/or separate a home's energy data and provide relevant information to the occupant of the home proved to be of value. This endeavor for Google provided the energy consumer a live stream of their energy use. Additionally, the user interface provided cost data, historical and comparison options as well as the capability to access and share data from anywhere with web access. Additionally, they, too, successfully partnered with a handful of utilities to integrate this platform for their customers. Their interface and open integration capabilities also spawned a new industry in which several companies have capitalized on. Unfortunately, this tool is no longer available.

Some organizations moved onward more successfully utilizing similar concepts mentioned above. Opower is one entity that implemented a program approach for utilities by integrating energy use data from the energy provider, which is pushed through their analytics engine with the resultant outputs of suggestions for improving energy efficiency, community comparisons to encourage behavior changes, and an energy alert functionality through mobile

communications and email. This program has been consistent in their approach and energy savings. Their focus is geared around creating social norms by comparing neighbors to enlighten consumers and change the energy consumption patterns through the use of their feedback tools. The approach they have taken has shown consistent energy savings of 1.5-3.5%.

Energy Savvy, another program implementer, takes a slightly different approach. Rather than focus on behavior changes, their efforts are specific to getting the energy consumer to implement changes or measures into their living spaces. Their tool uses a specific algorithm to determine which measures or recommendations to implement in the home. The basis of the algorithm utilizes Michael Blasnik's Simple tool, which provides a very easy user interface and a small amount of consumer time to input data. The purpose and objective of the tool is to get early acceptance of energy efficiency technologies and implement the suggested measures. The success rate of the Energy Savvy model is quite high with 80% of users completing the on-line audit process (input).

The Green Button initiative enables participants whose utility has incorporated standards and protocols to allow energy use data to be shared with third party application developers. These developers utilize this data to provide the owner/renter of the home to be more engaged with their energy use. The data is visualized via an array of user interfaces that include web portals and mobile applications. The purpose of this initiative is to inform the consumer of his/her energy use, provide suggestions or actionable tips to conserve energy and improve comfort, create a competitive environment by comparing your use to others in the community, verify retrofit measure savings and provide external information about the home to others (e.g. real estate transactions, energy efficiency contractors). The basis of the initiative is to create a common platform or data language that can be interpreted easily for utility program efforts or research organizations.

Most of the above mentioned programs are taking data from the customer or utility, analyzing this information and providing suggestions or feedback on opportunities to save energy. How they provide this information to the consumer and the ease of implementing a suggestion or recommendation is of a considerable weight that will determine the basis of long-term energy savings.

Monitoring Devices: Equipment and Tools

There is a host of monitoring devices on the market. These are to be distinguished from home energy management systems that actually control energy use. Home energy monitors such as The Energy Detective (TED) provide feedback on energy use to home occupants. According to a recently completed survey of studies by the American Council for an Energy Efficient Economy (ACEEE), the range of energy savings from feedback is ranged from 0-19.5%, with average

savings across the pilots of 3.8%. The largest savings came from the replacement of pre-existing prepayment meters in Northern Irish homes with new prepayment meters having a real-time display. The smallest savings were observed in two pilots, which found no aggregate effect of real-time feedback on overall electricity consumption. One of the most promising results is that a small percentage of households in several of the pilots had large savings of up to 25%. (Source: *Results from Recent Real-Time Feedback Studies*, B. Foster, S. Mazur-Stommen, ACEEE, Report B122, 2012.)

In addition to the TED system, some of these devices report energy use to smart phones, allowing some enthusiasts to track their energy use wherever they are. The utilization of these tools by consumers may be an indicator of the motived and engaged energy consumers, and indicates a trend that can probably be encouraged – especially if energy use tracking could be linked to social media/marketing, thus making energy monitoring and low energy use "cool." This consumer behavior or "compare thy neighbor" trend models the recycling effort in the 1980s and '90s, pressuring those who do not have their cart out on their driveway to do so. The norming of the recycling behavior provides the path energy conservation is currently on.

Other monitoring tools that have more comprehensive functionality include the recent intelligent thermostat NEST. This thermostat not only allows for the programming of heating or cooling set points for the home, but monitors motion and energy use patterns to "learn" about the occupant's behaviors as it relates to comfort, and less so on energy savings. However, it also serves as a feedback device, because it records temperature and energy use and reports it to the internet where it can be accessed by the home occupant—and by Nest for mass impact analysis if the homeowner does not elect to prevent anonymous sharing of energy use data. By making the thermostat smarter, the intervention of the human input is removed.

Smart Meters (Utilities-Smart Grid): may enable the utility or third parties to provide consumption data with specific suggestion to improve the home or change behavior. As with many of the energy monitoring tools available, the implementation of smart meters may be another opportunity to provide real-time feedback, warning or alert notifications and suggested approaches for energy conservation to the consumer. A smart meter or automated metering infrastructure (AMI) provides information to both the consumer and utility; however, there continue to be concerns regarding the privacy of the information or the control of the provided electricity.

Many of the more comprehensive home energy management systems tend to be expensive and complex requiring professional installation and programming. These systems are less likely to be cost effective however, bundled packages or services from telecommunication companies who are taking advantage of this gap, are providing energy monitoring services and home security packages with the energy monitoring feature. With inexpensive monitoring devices or

services and utilities piloting smart meters, energy management for a homeowner may become more acceptable and less sophisticated, allowing for those who seek an efficient and effective way to engage in their use of energy.

There are many other tools or devices available that have similar capabilities by searching the web (e.g. TED, Envi, BlueLine, ZigBee-based products, etc.) Some of these are do-it-yourself installs from plug-based devices to more comprehensive installations that may require a licensed electrician.

Behavior Change Using Feedback Tools

The Energy Audit and Retrofit Survey highlighted in this report shows that the building science community (practitioners and researchers) feel there is an opportunity for consumers to save energy by using feedback tools. While the energy consumption information may be readily available, the mechanism of "feedback", regardless of how it is communicated, will still face the persistent barrier of a consumer's acceptance to behavior change.

While there are significant efforts being implemented throughout the country, many studies indicate varying ranges of energy savings using feedback tools. Most have no direct correlation with feedback tools, but rather a combined effort (retrofits/measure implementation and education/awareness) with the devices and a high cost of implementing such programs.

The long-term changes that are necessary to changing one's behaviors regarding their energy use can be summed up by the following actions:

- Relevance and correlation between consumer and what is being consumed (electricity/gas cannot be seen)
- Cost-effective tools to provide real-time information about specific actions
- Significant increase in costs for electricity or gas for higher energy consumers

There are vast amounts of research on the behavior aspects within energy conservation, adoption of energy efficiency or renewable energy technologies and the like. Many of the studies indicate several factors the can guide the appropriate approach to take based on regional or climate differences, cost of electricity and income, as well as cultural or societal values that may reflect successful adoption of behavior changes related to energy use. Through the use of feedback tools, there are many opportunities to make the next leap in the right direction and show long-term or persistent changes that will be part of our daily lives. (reference to attached bibliography on feedback devices)

Future Direction

With current trends on the smart grid front and the deployment of innovative devices, applications, services and initiatives, the penetration of building feedback tools will further be integrated into our lives with our smartphones and perhaps allow for the increased adoption of what were once considered behavior change concepts for early adopters to creating norms which may be inherent to our behaviors.

As feedback tools become more prominent in the energy field, there will be further opportunities to cost-effectively evaluate technologies or measures implemented in homes for weatherization programs, retrofit-programs or behavior-based initiatives. The energy use data will continue to be of value, however the inconsistency of analytics or standards that are in place to evaluate implementation will continue to be debated with regards to accuracy. As the devices or monitoring tools evolve to allow for disaggregation of specific data points (e.g. water heaters, lighting, plug-loads) or have the capability of monitoring multiple circuits, the accuracy of analytical tools or modeling engines may be moot.

The identification of the proper monitoring tool (s), accuracy of data collection methodologies and a consistent and standardized process to evaluate the data will be the only necessary actions to justify which measures or technologies need to be implemented and thus so, recomputing the changes made will provide clear results to any and all who follow this standardization.

It is difficult to see there being a common ground on the analysis process in the near future and it is suggested that future research and collaboration take place to determine the appropriate path for analysis of energy data. As monitoring devices (smart meters) or services, and data collection (Green Button, NEST) become a commonplace for the energy consumer or researcher, the analysis debate can be put on a shelf. While practices in the field are inherent to human errors, the continuation of quality assurance within organizations that provide training, the education process should continue to find ways of improving. This suggestion on the research front would be secondary, but would inherently need to integrate the consistent use of the same analytical tools to represent accurate and consistent feedback to the energy consumer.

With consistency amongst those who analyze data, factual results may lead to a truer understanding for both consumer and provider and allow for feedback mechanisms to be more successful. Early adopter behaviors may become societal norms and energy conservation will be as simple as breathing.

Bibliography

2012

Foster, B. and S. Mazur-Stommen. "Results from Recent Real-Time Feedback Studies." ACEEE, Report B122, 2012.

Parker, D. "Engaging Homeowners with Residential Feedback Devices." Florida Solar Energy Center, Presentation at ACI, 2012.

2011

Collins, Myles T. *Managing Residential Energy Demand Through Provision of Better Feedback*. Doctoral Dissertation, # RGSD-277, RAND Corporation, 2011. http://www.rand.org/content/dam/rand/pubs/rgs_dissertations/2011/RAND_RGSD277.pdf

2010

Domestic Energy Displays: An Empirical Investigation, ACEEE Summer Study, 2010. http://eec.ucdavis.edu/ACEEE/2010/data/papers/2139.pdf

Ehrhardt-Martinez, K., K.A. Donnelly, and J.A. Laitner. "Advanced Metering Initiatives and Residential Feedback Programs: A Meta Review for Household Electricity Saving Opportunities." ACEEE, Report E105, 2010.

2009

"Investigating the Impact of a Minimalist In-Home Energy Consumption Display." CHI EA '09 Proceedings of the 27th International Conference, 2009. http://dl.acm.org/ft_gateway.cfm?id=1520676&ftid=643492&dwn=1&CFID=42316822&CFTOKEN=35883019

"Evidence from Two Large Field Experiments that Peer Comparison Feedback Can Reduce Residential Energy Usage." NBER Working Paper Series 15386, National Bureau of Economic Research, 2009. http://www.nber.org/tmp/24469-w15386.pdf

Donnelly, K. "Empowering Consumers to Save with Feedback Devices: Technologies to Motivate, Enable, and Engage Consumers to Reduce Energy Usage." DOE Briefing: Social Science Insights for Energy Efficiency, October 5, 2009. http://www.aceee.org/files/pdf/presentation/KDonnelly-2009-Oct-5-DOE-Briefing.pdf

Energy Trust of Oregon. "The Net impact of Home Energy Feedback Devices." Energy Program Evaluation Conference, Portland, OR, 2009. http://energytrust.org/library/reports/Home_Energy_Monitors.pdf

"Residential Energy Use Behavior Change Pilot: Research Study." Franklin Energy for the Minnesota Department of Commerce, April 2009. http://opower.com/uploads/library/file/3/residential_energy_use_behavior_change_pilot.pdf

"Residential Electricity Use Feedback: A Research Synthesis and Economic Framework." #1016844, EPRI, February 2009. http://opower.com/uploads/library/file/4/residential_electricity_use_feedback.pdf

"Automated Home Energy Management Expert Meeting." Building America, EERE Building Technologies Program, October 2009. http://www1.eere.energy.gov/buildings/building_america/ahem_expert_mtg.html

2008

"Smart Metering and Consumer Feedback: What Works and What Doesn't." ACEEE Summer Study, 2008. http://eec.ucdavis.edu/ACEEE/2008/data/papers/2_252.pdf

"Pilot Evaluation of Energy Savings from Residential Energy Demand Feedback Devices." #FSEC-CR-1742-08, Florida Solar Energy Center, January 2008. http://www.fsec.ucf.edu/en/publications/pdf/FSEC-CR-1742-08.pdf

Schembri, J. "The Influence of Home Energy Management Systems on the Behaviours of Residential Electricity Consumers: An Ontario, Canada Case Study." Thesis presented to the University of Waterloo in fulfillment of the thesis requirements for the degree of Master of Environmental Studies in Environment and Resource Studies, 2008. http://www.environment.uwaterloo.ca/research/greenpower/projects/documents/SchembriThesis2008.pdf

"Residential Energy Display Devices: Utility Pilot Update." #1016088, Electric Power Research Institute (EPRI), 2008. Description only, cost $2,375 for full report. http://my.epri.com/portal/server.pt?space=CommunityPage&cached=true&parentname=ObjMgr&parentid=2&control=SetCommunity&CommunityID=404&RaiseDocID=000000000001016088&RaiseDocType=Abstract_id

2007

Robinson, J. "The Effect of Electricity-Use Feedback on Residential Consumption: A Case Study of Customers with Smart Meters in Milton, Ontario." Thesis presented to the University of Waterloo in fulfillment of the thesis requirement for the degree of Master of Environmental Studies in Environment and Resource Studies, 2007. http://www.environment.uwaterloo.ca/research/greenpower/projects/documents/Robinson-finalthesis.pdf

2006

"Effectiveness of Displaying Energy Consumption Data in Residential Buildings: To Know is to Change." *ACEEE Summer Study*, 2006.
http://www.aceee.org/sites/default/files/publications/proceedings/SS06_Panel7_Paper22.pdf

"The Effects of Household Characteristics and Energy Use Consciousness on the Effectiveness of Real-Time Energy Use Feedback: A Pilot Study." *ACEEE Summer Study*, 2006.
http://www.aceee.org/sites/default/files/publications/proceedings/SS06_Panel7_Paper01.pdf

"The Effectiveness of Feedback on Energy Consumption: A Review for DEFRA of the Literature on Metering, Billing and Direct Displays." Environmental Change Institute, University of Oxford, April 2006.
http://www.eci.ox.ac.uk/research/energy/downloads/smart-metering-report.pdf

"How Much Energy Are We Using? Potential for Energy Demand Feedback Devices." *ACEEE Summer Study*, 2006.
http://www.aceee.org/sites/default/files/publications/proceedings/SS06_Panel1_Paper19.pdf

Woodridge Energy Study & Monitoring Pilot, Whirlpool Corporation, 2006.
http://uc-ciee.org/downloads/Woodridge_Final_Report.pdf

Home Performance/HVAC Contractor Experiences

Building Performance Institute

The Building Performance Institute, Inc. (BPI) operates as a non-profit, building performance credentialing, quality assurance and national standards-setting company in North America. It develops technical standards for home performance and weatherization retrofit work. BPI supports the development of the building performance industry through individual and organizational credentialing and quality assurance programs.

BPI was founded in New York in 1993 as part of an effort to establish minimum standards for professionals working in the weatherization industry. Defining skillsets and mitigating risk through credentialing and QA were early goals. Over the next 10 years, BPI became a *de facto* standard for retrofit weatherization across North America. BPI standards became widely used by low-income weatherization programs and the emerging home performance industry, supporting programs such as Home Performance with ENERGY STAR. The process culminated in 2004, when requirements for QA of all certified contractors were added, which provided increased accountability for the industry and homeowners.

A period of rapid expansion occurred from 2009 -2011 as federal stimulus dollars spurred a ten-fold increase in low-income weatherization activity and the home performance industry speculated about the possibility of "Home Star" legislation.

BPI develops standards using an open, transparent, consensus-based process built on building science. From these standards, BPI has developed professional credentials for individuals and accreditation for contracting companies – including quality assurance programs. Current BPI credentials for individual technicians include building analyst, heating, AC/heat pump, shell/envelope and multi-family designations. Since 2010, BPI has been recognized as an ANSI standards development organization and is currently updating and reviewing all of their existing standards.

BPI has developed rigorous written and field exams based on their nationally recognized standards. Through a network of affiliate test centers, exams are currently delivered in all 50 states and five foreign countries in compliance with ANSI testing protocols. With support from DOE, BPI is currently piloting the roll out of new certifications for field workers in support of the

newly developed Standard Work Specifications for the National Guidelines for Home Energy Efficiency Retrofit Workforce.

Current Standards

- **BPI-104: Envelope Professional** – Technical standard outlining the scope of envelope diagnostics.
- **BPI-2400-S Standardized Qualification of Whole House Energy Savings Estimates** – This standard specifies a process for calculating standardized estimated savings: a difference (delta simulation) between the modeled energy usage before an energy upgrade (or set of upgrades) and the modeled energy use after an upgrade (or set of upgrades), using approved building energy use simulation software.
- **Building Analyst Professional** – The technical standards applied by a BPI Building Analyst Professional in conducting a residential energy audit, including development of a recommended scope of work.
- **(Amended) BA Clarification of CAZ Depressurization Limits** – Defines more clearly the definition of an orphaned naturally drafted DHW heater for the purpose of establishing a combustion zone depressurization limit.
- **Heating Professional** – Technical standard applied by a BPI Heating Professional during the evaluation and/or installation of heating equipment.
- **Manufactured Housing Professional** – Technical standards applied by a BPI Manufactured Housing Professional during the inspection or installation of energy performance measures in manufactured housing.
- **Multifamily Building Analyst Professional** – Procedural outline of the required steps in conducting a BPI multi-family building energy audit.
- **Multifamily Energy Efficient Building Operator** – Technical standards applied by a BPI Multifamily Building Operator to assure safe energy efficient operation.
- **Multifamily Hydronic Heating Professional** – Technical standards applied by a BPI Multifamily Hydronic Heating Professional for the design and installation of energy efficient hydronic heating systems in multi-family housing.

Standard Under Review

- **BPI-1100-T-2010 (formerly BPI-101): Home Energy Auditing Standard** – Defines the scope of a BPI home energy audit.

Looking to the Future

BPI board members and supporters have articulated a number of challenges that focus primarily on expanding the home performance industry:

- Continue to expand the awareness of the value of BPI accreditation to contractors and consumers. This is necessary to ensure the stability of BPI as an organization and to promote the growth of the home performance industry in an open marketplace by contributing to the accountability of contractors.

- Following the implementation of BPI Standard 2400, which establishes a standard for making creditable estimates of energy savings from home performance measures, establish consistent methodologies to verify and count *actual* energy savings. Verifying actual performance is the final step in providing accountability to consumers and program implementers.
- Determine a process to monetize actual savings in the marketplace. In the final analysis, the motivation and ability to make comprehensive improvements to the energy performance of existing homes depend on the creditable demonstration of value to the consumer.
- Establish a database of energy retrofit data and a jobs registry that is creditable and recognized by the players in the capital markets. Based on variability of climates, housing types and energy resource costs, the analysis of creditable data on actual performance can streamline the audit process and mitigate risk for capital.

Residential Energy Services Network

The Residential Energy Services Network (RESNET; www.resnet.org) is an industry-formed, not-for-profit corporation established in 1995 to develop a national market for home energy rating systems and energy efficient mortgages. RESNET's standards are officially recognized by the federal government for verification of building energy performance for federal tax incentives, the EPA ENERGY STAR program and the DOE Building America Program. RESNET standards are also recognized by the U.S. mortgage industry for capitalizing a building's energy performance in the mortgage loan and certifying “White Tags” for private financial investors. RESNET is a member of the United Nations Sustainable Buildings and Climate Initiative.

ACCA and RESNET Team Up

RESNET and ACCA each identified specific portions of the building performance market that were within their areas of expertise. Each organization focused on their core competencies and worked on whole-house retrofits for energy savings. However, neither association had adequate breadth to execute a whole-house energy solution.

RESNET and ACCA realized the value of providing homeowners with a team of skilled technicians that uses an integrated approach and leverages the training and strengths of team members. Recognizing the complimentary nature of their organizations, ACCA and RESNET are now collaborating to launch a comprehensive, whole-house building performance platform. Together, the organizations have in their collective arsenals the standard practices and training regimes that position industry practitioners to perform a whole-house performance evaluation, design and upgrade.

ACCA and RESNET have defined how a home performance team is to operate and is credentialed, and the specific responsibilities of each team member. The goal is to ensure that home performance improvements are predictable and achievable.

RESNET's Energy Smart Home Performance teams bring all of the ingredients needed to provide homeowners with a comprehensive and verifiable turnkey energy-saving retrofit. Additionally, the completed jobs will include an independent third-party verification designed to protect the homeowner's interests and the integrity of the home performance effort. Homeowners can now benefit from a multi-disciplinary team approach to whole-house diagnostics and upgrades.

Vital for implementing a whole-home performance team concept is establishing an industry-developed method for conducting an audit, identifying opportunities, executing the work authorized by the homeowner and verifying that the upgrades were undertaken properly. The ACCA 12 QH – 201x (*Existing Home Evaluation and Performance Improvement*) standard supports a multi-industry team approach for energy auditing experts, weatherization professionals, HVAC participants and other trade contractors.

RESNET Auditors Ensure Quality

RESNET's Energy Smart Home Performance teams will audit, prioritize opportunities and complete home improvements using the ACCA 12 QH Standard. The team will be comprised of a project manager and the trade professionals necessary to complete the project. HVAC-related work will be complete by a quality-assured HVAC contractor recognized by ACCA. Insulation-related work will be performed by an insulation installer certified by the Insulation Contractor Association of America. The teams will be monitored by a RESNET Contractor Education and Qualification (CEQ) provider.

The first step in the team-based approach is to provide homeowners with a complete energy audit and a performance improvement plan. Recommendations on insulation, HVAC repair/replacement, air sealing and window upgrades are prioritized based on a benefit vs. cost analysis. After the homeowner authorizes the specific remediations to be undertaken, the specially trained project leader oversees the work performed by the different trades.

Upon completion of the improvements to energy use, durability and IAQ, the work is audited by an independent, third-party rater. The rater examines the contract specifications and verifies that the work is completed as specified. (Auditing and rating standards used by RESNET energy auditors are noted in the RESNET Resources section.)

ACCA's Quality Assured Contractors Make the Difference

Traditional home performance improvement programs fail to properly address the performance of the HVAC system. HVAC systems are responsible for 40 percent or more of a

home's energy usage. In addition to potentially wasting energy, ignoring HVAC systems can lead to health and safety issues from combustion appliances, contaminants and moisture.

To respond to this need, ACCA has developed a recognition program for HVAC contractors that observe industry-recognized standards. To participate in the QA contractor program for existing homes, HVAC contractors must follow industry-recognized standards as confirmed by third-party verifications. QA contractors do not need to be ACCA members to participate.

ACCA and EPA Support ENERGY STAR Programs

Quality Installation Standards Set the Path

EPA's ENERGY STAR HVAC Quality Installation (QI) program provides guidance to local sponsors (such as electric or gas utilities) on how to install replacement HVAC systems in residential applications for optimized energy savings and occupant comfort. This program uses the ANSI/ACCA 5 QI Standard to ensure proper equipment sizing, duct sealing, balanced airflows and refrigerant charges. A growing number of utilities are embracing this ENERGY STAR program, which was implemented in 2009.

Quality Assured Contractor Recognition Program

In support of EPA's revamped EPA ENERGY STAR for Qualified New Homes Program, ACCA has established the QA contractor recognition program. Key aspects of the program are that HVAC contractors are to observe the requirements in the ANSI/ACCA 5 QI Standard and maintain written policies/procedures (as identified in the QA Essential Elements) to ensure that quality is consistently achieved in the field. Per the ENERGY STAR requirements, RESNET HERS raters undertake in-field verifications and report to the homebuilder on the outcome of those inspections.

The QA Program recognition effort helps:

- Raise the professionalism of the U.S. HVAC industry,
- Homebuilders identify quality contractors, and
- Program administrators find quality HVAC contractors for their incentive programs.

Sensitivity Studies on HVAC Quality Installation and Quality Maintenance

It is widely recognized that residential and commercial heating and cooling equipment suffer significant performance loss (i.e., capacity and efficiency) depending on how the components are sized, matched, installed and maintained. The International Energy Agency (IEA) is evaluating how installation and/or maintenance deficiencies cause comfort-conditioning systems to perform inefficiently and waste energy. The agency sought to determine the significance of operational deviations, if the combined deviations have an additive effect on

equipment performance, and if some deviations (among country-specific equipment types and locations) have larger impacts than others.

International Research Effort

The IEA Annex 36 (*Quality Installation/Quality Maintenance Sensitivity Studies*), established in 2010, is a new international research effort based on the ANSI/ACCA 4 QM and ANSI/ACCA 5 QI Standards. Annex 36 participating countries are France, Sweden, United Kingdom and the United States; ACCA, NIST (an agency of the U.S. Department of Commerce) and Oak Ridge National Laboratory (a DOE laboratory) are serving as cooperating agents for the initiative. The purpose of Annex 36 is to evaluate how deficiencies in the installation and/or maintenance of heating and cooling systems can cause inefficient performance and energy waste. The annex is scheduled to run through November 2013. Annex 36 activities are described in Table 2.

Table 2. Annex 36 Activities

Task	Activity	Dates	Effort
1	Critical literature survey	Nov 2010 – Apr 2011	Literature review and critical analysis of results from prior research to identify QI & QM metrics and to secure quantitative and qualitative impacts of various deviations from the specified levels recommended in relevant QI & QM standards.
2	Identify sensitivity parameters	May 2011 – Oct 2011	Identify participant-specific QI & QM elements to be included in the participant's sensitivity investigation
3	Modeling, lab-controlled measurements, and/or in-situ investigations	Nov 2011 – Jul 2012	Undertaken to verify the results provided by earlier researchers, fill in holes regarding quantifying the impacts of QI & QM vs. non-QI & QM applications, and better understand the singular and additive impacts on equipment effectiveness
4	Simulations on seasonal impacts	Aug 2012 – Apr 2013	Determine the role that seasonal temperature differences have on the varied QI & QM elements and the resultant impact on heat pump performance.
5	Country reporting and information dissemination	May 2013 – Nov 2013	Each country participant is to report the results of these tasks and the U.S. operating agents will consolidate this information into a final report for subsequent dissemination.

NIST Undertaking QI Analysis

NIST, a U.S. Commerce Department laboratory, undertook a sensitivity analysis of the ACCA QI Standard elements in 2011. The NIST contribution is in two main areas:

- *Laboratory investigations:* Cooling and heating tests with imposed faults that include duct leakage (to unconditioned space), supply airflow misbalance (room to room), HVAC equipment over- and under-sizing, indoor coil airflow (over and under design), refrigerant charge (over and under requirements), electrical voltage (over- and under-rated) and expansion device mismatch.

- *Modeling*: Seasonal analysis modeling include effects of different single-family house types (slab vs. basement foundations, etc.) and climates (hot-humid, hot-dry, mixed, and heating dominated) in the assessment of various faults on heat pump performance.

Examples of Third-Party QI & QM Interest and Involvement in the U.S.

The ANSI/ACCA 4 QM and ANSI/ACCA 5 QI Standards are embraced by the industry, as described in Table 3.

Table 3. Examples of QI/QM Adoption by Others

Organization	Activity
EPA	• ENERGY STAR HVAC Quality Installation Program uses the ANSI/ACCA 5 QI Standard as the basis for HVAC equipment installations. • ENERGY STAR Qualified New Homes Program uses the ANSI/ACCA 5 QI Standard as the basis for HVAC equipment installations.
DOE	ANSI/ACCA 5 QI is recommended by the DOE Builders Challenge program
USGBC LEED for Homes rating system	ANSI/ACCA 5 Q is a prerequisite for certification (draft version pending public comment)
California Public Utilities Commission (CPUC)	Requires its investor-owned utilities to undertake activities that promote QI and QM in the field. ANSI/ACCA 4 QM and ANSI/ACCA 5 QI are specifically recognized.
Consortium for Energy Efficiency (CEC)	Has adopted the ANSI/ACCA 5 QI Standard as a recommended requirement for its utility members with energy programs
National Association of Homebuilders (NAHB)	ENERGY STAR HVAC Quality Installation Program homes are automatically accepted at the bronze level in the 2012 Green Building Standard
Outside Equipment Manufacturers (OEMs)	Require that their dealer base install HVAC systems per the ANSI/ACCA 5 QI Standard
Utilities	Numerous utilities have incorporated elements of the QI & QM Standards into their incentive programs

Net-Zero Energy Homes

As homes become more efficient and on-site electricity generation equipment (e.g., solar panels, fuel cells, micro-turbines and windmills) become more reliable and cost-effective, there will be a need for practitioners who know how to help homeowners progress towards net-zero energy buildings. With the development of its quality standards, ACCA is positioning contractors to undertake net-zero energy building implementations in addition to their current offerings related to health, safety, IAQ, energy and water conservation improvements. This complements the efforts currently being undertaken by the EPA, DOE and others to encourage efficiency and operation improvements in heating, ventilation and air conditioning systems; water heating systems; lighting and the building envelope.

Significant reductions in home heating and cooling loads will become evident as home envelopes become tighter, insulation levels improve, internal loads are reduced and ducts are

relocated to the conditioned space. Air conditioners can be dramatically downsized; one ton of refrigeration effect will be adequate for approximately 2,000 square feet of conditioned living area. Compare this with air conditioning requirements in today's housing stock:

- One ton of refrigeration effect is needed for every 400 to 600 square feet in homes built before the 1980s.
- One ton of refrigeration effect is needed for every 900 to 1,200 square feet in homes built to a relatively recent version of the energy code.

The following will be needed:

Equipment:

- Air conditioning equipment and control strategies for conventional systems that are 18,000 Btu/h and less.
- Heating equipment and control strategies for conventional systems that are 35,000 Btu/h and less.
- Redesigned low-flow grilles and registers that provide proper throw and air mixing.
- Cost-effective alternative equipment, components and controls.
- Tools and instrumentation that are even more accurate for measuring reduced capacities, airflow, refrigerant charges, etc.

  Initially, OEMs might offer packaged equipment that contains a small coil with a big blower in a bypass cabinet. A small heat exchanger's CFM is compatible with a small load, and bypass air plus conditioned air is compatible with the mixing effectiveness needs for the conditioned space.

Guidance:

- Updated building parameters so load calculations can address newer building approaches and applications.
- Revised equipment selection procedures based on the new equipment to be offered to the field.
- New HVAC designs and information on how to get at least half of today's home airflow throughout a net-zero energy house when the equipment is at one-fifth the capacity.
- Alternative strategies for ventilation and moisture/humidity control.

RESNET's original focus was on the existing housing market. The focus shifted to new homes with the incorporation of RESNET standards in the EPA ENERGY STAR program, state code compliance and federal tax incentives. But with the recent downturn in the new construction industry and increased focus on the need to retrofit existing housing stock, RESNET has once again identified existing homes as a high priority

As a national standards-setting organization in North America, RESNET develops and maintains the Home Energy Rating System (HERS) standards for new and existing home inspections and evaluation, and establishes criteria for software analysis tools. As of 2012, RESNET is an ANSI Standard Development Organization, responsible for creating standards using a consensus-based development and amendment process that includes formal public review and comment.

RESNET accredits organizations (providers) to train and oversee RESNET-developed certifications; while RESNET does not certify individuals, it does administer online certification exams and oversees the quality assurance efforts for each provider.

RESNET's membership is composed of rater/auditors, contractors, providers and associate members. RESNET is governed by a 17-member board of directors elected by the membership. The RESNET Board of Directors has established the following standing committees, each of which provides the Board with policy, implementation and technical guidance:

- Accreditation – Responsible for the oversight of RESNET's accreditation application review process and accreditation procedures.
- Quality Assurance – Responsible for issuing interpretations on RESNET's quality assurance standards and provider quality assurance program.
- Ethics and Appeals – Responsible for review and determination of quality assurance appeals and ethics violations.
- Training and Education – Responsible for issuing interpretations on RESNET's training standards, maintenance of RESNET's certification exams, approval of all RESNET education programs and maintenance of RESNET rater certification categories.
- Technical – Responsible for interpretation of technical standards, procedures and guidelines; technical evaluation of issues and programs; and continuing maintenance of technical standards.
- Standards – Responsible for assuring that RESNET's standards development and maintenance meet ANSI requirements.

Homes assessed, or "rated," under the RESNET standards undergo a plan review and visual inspection by a home energy rater. The homes also receive a rating, or assessment, of their energy performance. This rating is generated from a software program; a full list of qualifying programs is available at http://www.resnet.us/professional/programs/energy_rating_software. The rating is indexed so that a rating of 100 is representative of a home with layout, siting and orientation identical to a home built to the 2004 International Energy Conservation Code. A rating higher than 100 represent a home with higher energy use; a rating lower than 100 represent a home with lower energy use.

As of 2010, the RESNET standards provide a framework for an energy audit process for existing homes. The audit standard allows for three approaches:

- **A Home Energy Survey (HES)** – A general assessment of the condition of the home with respect to energy performance, conducted either by a DOE- or RESNET-approved computerized online survey or by a (provider-certified) Home Energy Survey Professional (HESP).
- **A Building Performance Audit (BPA)** – A comprehensive assessment of the performance characteristics of the home, including leakage testing for building envelopes and ducts, and combustion safety testing (similar to BPI requirements). A work order for the home is also included. These audits are administered by (provider-certified) Building Performance Auditors.
- **A Comprehensive HERS Rating (CHER)** – Includes all of the elements of a BPA, above, as well as a complete rating using RESNET-approved software.

RESNET maintains standards for RESNET EnergySmart contractors and teams. EnergySmart contractors receive training in building science, combustion safety and work scopes from a Contractor Education and Qualification (CEQ) provider, who also administers a certification exam. EnergySmart teams are composed of a program manager, certified EnergySmart and ACCA QI contractors and raters or Building Performance Auditors. (For more information on the RESNET/ACCA partnership, see "**ACCA and RESNET Team Up**," below.)

In addition to the standards for inspections and evaluation, RESNET provides credentials for the following provider organization types:

- **Accredited Rating Providers** – Provide oversight and quality assurance for home energy raters.
- **Accredited Home Energy Audit (HEA) Providers** – Provide oversight and quality assurance for Home Energy Survey Professionals and Building Performance Auditors.
- **Accredited Rating Sampling Providers** – Provide oversight for raters applying RESNET sampling protocols for ratings.
- **Accredited Rater Training Providers** – Administer training to RESNET-defined minimum competencies and provide testing for home energy raters.
- **Approved Contractor Education and Qualification (CEQ) Providers** – Administer training to EnergySmart contractors.

RESNET's future efforts in the existing housing market will focus on expanding the use of EnergySmart contractors and teams to provide comprehensive upgrades to existing homes, and advocating for federal action on tax credits and financing the improvements of building energy performance. RESNET will also continue to foster strategic partnerships with organizations such

as ACCA, the National Remodeling Industry Association and the Insulation Contractor's Association of America.

ACCA Resources for Residential Applications

ACCA Quality Standards

ANSI/ACCA 4 QM (Maintenance of Residential HVAC Systems)

ANSI/ACCA 4 QM prescribes basic maintenance inspection tasks and offers recommended corrective actions to maintain residential HVAC systems. It provides guidance for the inspection of typical residential HVAC systems to improve heat transfer, energy efficiency, durability, indoor air quality and comfort and provides recommended maintenance procedures. Equipment checklists detail the minimum visual inspections, performance tests and measurements to be performed.

ANSI/ACCA 5 QI (HVAC Quality Installation Specification)

ANSI/ACCA 5 QI focuses on the actual installation and how the system is selected, installed and commissioned. For this standard, core areas that characterize a quality installation include specific aspects related to design, air and water distribution, equipment installation and system documentation and owner education. For each aspect, the standard proscribes the tolerance, acceptable procedures, and acceptable documentation.

ANSI/ACCA 6 QR (Restoring the Cleanliness of HVAC Systems)

Recognizing that maximum benefit is achieved when the system is addressed in its entirety, the *ANSI/ACCA 6 QR* standard details a methodology to restore the cleanliness of a complete HVAC system (e.g., heat exchangers, airside surfaces, ducts). The standard proscribes cleaning methods and procedures that focus on improving the overall indoor air quality and safeguarding building occupants through comprehensive restoration practices. The standard also provides direction to assess the economic viability of replacing HVAC components or systems versus restoring them.

ANSI/ACCA 9 QIvp (HVAC Quality Installation Verification Protocols)

ANSI/ACCA 9 QIvp provides the verification protocols to ensure that the ANSI/ACCA 5 QI elements are properly performed. The QIvp standard positions program administrator to protect the value and integrity of their QI programs through qualified and objective examination of specific HVAC system installations. The QIvp Standard details the elements to be verified, tolerances, sampling routines and documentation requirements.

ACCA 12 QH (Existing Home Evaluation and Performance Improvement)

ACCA 12 QH provides guidance to the varied organizations involved in home retrofit and energy renovation. It establishes the minimum criteria by which deficiencies in existing homes are identified by audit, improvement opportunities are assessed, scopes of work are finalized, work

is performed in accordance with industry-recognized procedures and improvement objectives are met.

ACCA Design Manuals

ANSI/ACCA 1 Manual D (Residential Duct Systems)

Manual D® provides the procedures for designing residential air duct systems. It includes information about constant volume and variable volume systems, system performance characteristics, duct materials, blower performance, airside components and airway sizing procedures. The manual also includes information about duct system efficiency and synergistic interactions between the duct system, the building envelope, the HVAC equipment, the supply and return vents, and the household appliances. Indoor air quality, noise control, testing and balancing are also discussed. Manual D is specified in the national building codes and enforced by many local code jurisdictions.

ANSI/ACCA 2 Manual J (Residential Load Calculations)

The eighth edition of Manual J (*Manual J8™)* estimates heating and cooling loads for all types of residential, low-rise structures. Once the heating and cooling loads are known, the proper HVAC equipment can be selected and the duct system can be designed to deliver the correct amount of air to all of the rooms in the home. In practice, *Manual J8* produces "the smallest defensible load" for equipment sizing in order to optimize system performance, minimize operating costs and maximize customer satisfaction. Manual J is specified in the national building codes and enforced by many local code jurisdictions.

ANSI/ACCA 3 Manual S (Residential Equipment Selection)

Manual S illustrates how to select and size heating and cooling equipment to meet Manual J loads based on local climate and ambient conditions at the building site. Manual S addresses sizing strategies for all types of cooling and heating equipment, as well as how to use comprehensive manufacturer's performance data on sensible, latent, or heating capacity for various operating conditions. Manual S is specified in the national building codes and enforced by many local code jurisdictions.

ANSI/ACCA 10 Manual SPS (HVAC Design for Swimming Pools and Spas)

Manual SPS provides the information needed for buildings that contain indoor pools and spas, addressing the unique moisture, temperature and equipment requirements for these uses.

ANSI/ACCA 11 Manual Zr (Residential HVAC System Zoning)

Manual Zr provides guidance for designing zoned comfort systems for low-rise, residential buildings. Detailed are zonal load calculations; zoning strategies and protocols (diversity issues, multi-level construction, diverse floor plans, winter/summer room and zone CFM variations, etc.); zoned systems types/attributes (multiple furnaces or refrigeration cycle units, central

heating-cooling with variable air volume (VAV) dampers, split coil refrigeration cycle with multiple indoor coils); controls and control strategies (damper sizing; multi- or variable-speed; airflow management, bypass air); and zonal duct design elements.

ACCA Manual T (Air Distribution Basics for Residential and Small Commercial Buildings)

Manual T provides information on sizing, selecting, and locating supply air diffusers, grilles and registers and the return grilles. Manual T content minimizes the drafts and stagnant air problems caused by improper application of these terminal units.

RESNET Resources for Residential Applications

2006 Mortgage Industry National Home Energy Rating System Standards

The *Home Energy Rating System Standards* – developed by a joint NASEO/RESNET Accreditation Task Force – provide the methodology to ensure that accurate and consistent home energy ratings are performed. This document contains the procedures for accrediting home energy rating providers and technical standards by which home energy ratings shall be conducted so results will be acceptable to public and private sector industries that may require an objective, cost-effective, sustainable home energy rating process.

700 RESNET National Standard for Home Energy Audits

Home Energy Audits provides uniform, comprehensive home energy surveys, audits and ratings for existing residential buildings. A certified auditor, an accredited provider and/or a program administrator would apply this standard to improve the energy performance of existing homes. The standard encourages investments by building owners and ensures that energy improvement recommendations are portrayed with reasonable and consistent projections of energy savings.

RESNET ENERGY STAR Homes Program Accreditation Procedures for Builder Option Package Providers

The *Accreditation Procedures* provide the methodology for accrediting Building Option Package (BOP) providers and was developed by the EPA. The procedures are used by homebuilders to demonstrate compliance to the ENERGY STAR Homes Program. The BOPs have been demonstrated to meet the Home Energy Rating score 86 point threshold under “worse case” scenarios. The procedures involve the same building performance inspection elements as a home energy rating. The accreditation criteria are based on the Mortgage Industry National Home Energy Rating System Accreditation Standard.

Rating and Home Energy Survey Ethics and Standards of Practice

The *Energy Survey Ethics* details principles and rules of conduct for home energy raters and providers in order to deliver quality and professional service. RESNET follows specific

procedures contained in its Accreditation Standards to enforce this 'code of ethics' that addresses professional conduct, representations of services and fees, and conflicts of interest.

Procedures for Verification of International Energy Conservation Code Performance Path Calculation Tools RESNET Publication No. 07-003

The *IECC Performance Calculation Tools*, created with support from DOE through NREL, calculates a home's energy performance to determine compliance with the performance requirements of the International Energy Conservation Code (IECC, §404). The IECC performance path is comparative (proposed home as compared with the standard reference design home) and requires software modeling tools that comply with this RESNET publication for accuracy and comparability purposes.

RESNET EnergySmart Contractors Guidelines

The *EnergySmart Contractor Guidelines* define a framework for designating contractors as RESNET EnergySmart Contractor participants and defines recognition measures for EnergySmart Home Performance Teams. It details the approval of CEQ providers, the oversight organizations through which a contractor may receive designation as a RESNET EnergySmart contractor. It also details the process by which an alliance of RESNET EnergySmart contractors working in partnership with a certified Comprehensive Home Energy Rater (CHERS Rater) or Building Performance Auditor may become RESNET-recognized as an EnergySmart Home Performance Team.

Air Conditioning Contractors of America

by Glenn Hourahan

The Air Conditioning Contractors of America (ACCA; www.acca.org) is a non-profit trade association serving more than 60,000 professionals and 4,000 businesses in the HVACR community. ACCA seeks to promote professional contractors that install energy efficient equipment to provide healthy, comfortable indoor environments. The association's roots stretch back to the early 1900s, and ACCA is well known for developing industry-recognized guidelines, manuals and standards. As an American National Standards Institute (ANSI) Standards development organization, a number of ACCA's manuals and standards have undergone the ANSI review process.

Positioning for Whole-House Performance

For years, industry professionals have envisioned innovative approaches to provide whole-home energy savings by applying the latest technologies and the best home performance practices. Unfortunately, the multi-trade skill sets required to complete a comparative cost-benefit analysis have been elusive. Worse, the complexity of coordinating the multi-trade

design and installation tasks necessary for cohesive whole-house retrofits make actual, achieved energy savings elusive in practice.

The traditional piecemeal method to home performance provided mixed results and left many homeowners without any real energy savings. Homeowners were forced to pick and choose from a multitude of tradesmen, each touting their individual products and services. Achieving sound results from this non-integrated approach was mostly wishful thinking.

HVAC Fault Detection and Diagnostics for Residential HVAC Systems

By Roy Crawford

Fault detection and diagnostics (FDD) for residential HVAC systems is typically performed manually by a service technician with a limited amount of measurement equipment. FDD provides equipment performance data and diagnostic rules based on the technician's training and experience. Attempts to improve this process with better measurement equipment and automated diagnostic algorithms have not gained widespread use for various reasons.

A summary of past and current FDD equipment and algorithms is given below, along with suggestions for future directions. This discussion is limited to forced-air HVAC systems.

Typical Requirements

Most needs for FDD are in the following areas:

- Refrigerant charge: Either the system was not charged properly during installation or after a repair, or refrigerant has leaked.
- Supply airflow rate: The system is not supplying the proper airflow rate due to an improper set up during installation or repair, or the ductwork is too restrictive for the required system capacity. Improperly serviced air filters can also restrict airflow rate.
- Component malfunctions: Failure of various fan motors, compressors, relays, expansion valves, etc.
- Outdoor coil fouling: Dirt, grass or other debris collect on the outdoor coil and impede airflow and heat transfer.
- Incomplete combustion: Lack of combustion supply air, restricted flue gas flow or improper fuel flow.

Manual FDD

Most residential HVAC FDD has been and still is performed by service technicians using some of the following equipment:

- Multi-meter: measures electrical voltage, current, and resistance
- Refrigerant gauges: measures low- and high-side refrigerant pressure
- Temperature sensors: measure refrigerant line surface, air or flue gas temperatures
- Humidity sensors: measure air humidity (typically relative humidity or wet-bulb temperature)

- Manometer: measures duct pressures
- Anemometer: measures air velocities, typically in ducts
- Combustion analyzer: measures concentrations of various flue gas components

With these instruments, a trained and experienced technician can usually determine if an operating system is performing as expected, or why a failed system will not operate. This is especially true for single-capacity equipment with simple electro-mechanical controls because most of the aforementioned sensing equipment is analog in nature and most equipment manufacturers use similar components and control methodologies.

As HVAC equipment becomes more sophisticated in terms of capacity control and other efficiency improvements, electronic controls are typically required. The electronic components are not easily diagnosed with generic sensing equipment and their design varies widely across different manufacturers. The market failure of variable-speed compressor systems in the U.S. during the 1990s is often attributed to the failure of service technicians to properly diagnose electronic problems.

Automated FDD

Although equipment with electronic components and controls is difficult to diagnose with simple sensing equipment, it does provide the opportunity to embed the necessary sensing capability and diagnostic algorithms within the equipment itself. However, this usually requires higher hardware costs for any additional sensors and user interfaces as well as additional software costs for the necessary algorithms. Some systems have been introduced in the past that use flashing LEDs or simple error codes as a low-cost user interface for displaying system faults. Because no industry-wide protocols were developed for this type of interface, and instructions for interpreting these signals were typically lost after installation, these interfaces never gained widespread acceptance. Some manufacturers have developed systems with more sophisticated user interfaces that are more self-explanatory to the service technician, but these have had limited acceptance due to their high costs.

One attempt at providing built-in automated FDD is the Copeland “Comfort Alert” diagnostics system. This is an electronic module that monitors various thermostat signals and compressor inputs for systems using Copeland scroll compressors. Faults are displayed with a bank of flashing LEDs. This feature has been incorporated in the higher efficiency air conditioners and heat pumps from Lennox.

Because the additional sensors and user interface required for effective FDD systems appear to still be cost prohibitive when permanently installed with most equipment, attempts have been made to develop and market hand-held FDD equipment that can be applied in the field by technicians during equipment servicing. Although these systems cannot provide any proactive

FDD, they can be useful as periodic maintenance and repair tools. Several manufactures now sell electronic refrigerant pressure/temperature sensors that can give direct measurement of refrigerant superheat or subcooling. Although this is a useful input for FDD, these instruments do not provide any direct diagnostics.

Another company, Field Diagnostics Services, Inc., has taken this concept further with an HVAC Service Assistant tool that measures several refrigerant and air temperatures on an air conditioning system and then analyzes this data to detect possible faults and provide diagnostic information. This device has been on the market for over 10 years but has been primarily applied to the commercial rooftop air conditioning market.

One OEM (Trane) has developed a diagnostic system called Charge Assist, which uses factory-installed refrigerant pressure and temperature sensors to determine when the proper amount of refrigerant has been added to the system. This feature can only be used by a technician while servicing the equipment and does not provide any automated diagnostic information during normal equipment operation.

FDD Issues

Contrary to popular belief, the widespread use of FDD in residential HVAC systems is probably not limited by a lack of technical knowledge in this area. The primary issues are applied cost and reliability. Equipment installers and homeowner do not seem to wish to pay much for this capability. In addition, equipment manufacturers have to be careful that the additional complexity of FDD sensors and electronics do not result in lower system reliability. Thus, these systems require significant development costs in terms of algorithm development and testing.

Currently, most residential HVAC OEMs have decided to develop their own propriety control and FDD systems for competitive reasons. Since this is a highly fragmented industry, this results in higher applied costs. Furthermore, technicians typically service equipment from any manufacturer, so having many different types of control and FDD systems causes further complications in the field.

Third-party vendors have tried to provide aftermarket controls and/or FDD systems that might work on equipment from multiple OEMs. Not only is it unlikely that these systems will perform satisfactorily on all equipment, there may also be reliability and safety issues if these systems alter the OEMs control systems.

FDD Opportunities

Standard Refrigerant-Charging Methods

There currently is no consistent refrigerant-charging method across the industry. Each manufacturer has its own variations, but most are based on measuring the amount of

refrigerant sub-cooling at the condenser outlet. If the OEMs could agree on a standard method via a possible AHRI, ACCA or ASHRAE standard, this could make it easier for technicians to service the wide range of equipment in the field, and could also be used to develop consistent third-party tools. Although a simple, standard charging method would probably be limited to lower-efficiency, single-capacity systems, these types of systems still deliver the highest sales volumes for most OEMs.

Standard Static Pressure Ports

The difficulty in measuring the static pressure rise across an air handler is in selecting the appropriate locating for the pressure taps. If OEMs built these taps into their air handlers, it would simplify this measurement. The OEMs could also develop a graph and/or equation for converting this static pressure measurement to airflow for their equipment and make that information available to the service technicians. This type of static pressure measurement would also be useful for diagnosing undersized or restricted ductwork.

Variable-Speed Air Handlers

Air handlers with electronic variable-speed blowers (e.g., ECM or ICM motors) have significant potential for embedded airflow and static pressure diagnostics. The nature of the flow control algorithms typically used in this equipment can provide information on the predicted blower power and static pressure rise along with the desired airflow rate without additional sensors. If this information were made available to the service technician, it could be used to give additional FDD information.

OBD for HVAC

By law, all automobiles built since 1996 must incorporate a communication protocol called OBD-II (On-Board Diagnostics, version II), which can be used for diagnosing engine problems. This requirement was primarily for meeting EPA emission requirements, but it used for many other FDD functions also. The FDD functions are built into the automobile and OBD-II provides a standard hardware connection, communication protocol, and set of fault codes that can be used by anyone for developing a user interface for viewing and interpreting these fault codes. This protocol was developed to protect the independent auto mechanic and has resulted in the development of code readers that cost less than $50. Perhaps a similar protocol could be developed for HVAC equipment so that equipment installers and service technicians could use a single tool for servicing this equipment. If the OEM's jointly developed this protocol, it could be voluntarily applied to their equipment with the goal of getting incentives from various utilities or government agencies who believe in the value of improved FDD.

References

ACCA Manuals and Standards

Manual B®	ACCA Manual B – 2009 (*Balancing and Testing of HVAC Systems*)
Manual D®	ANSI/ACCA 1 Manual D – 2009 (*Residential Duct Systems*)
Manual J®	ANSI/ACCA 2 Manual J – 201x (Residential Load Calculation, 8th ed.) as of October 2011, pending ANSI reaffirmation
Manual RS®	ACCA Manual RS – 1997 (*Comfort, Air Quality, and Efficiency by Design*)
Manual S®	ANSI/ACCA 3 Manual S – 201x (*Residential Equipment Selection*); currently being updated
Manual SPS®	ANSI/ACCA 10 Manual SPS – 2010 (*HVAC Design for Swimming Pools and Spas*)
Manual T®	ACCA Manual T – 1992 (*Air Distribution Basics for Residential and Small Commercial Buildings*)
Manual Zr®	ACCA 11 Manual Zr – 201x (*Residential HVAC System Zoning*); as of October 2011, pending ANSI approval as an American National Standard
ACCA 4 QM	ANSI/ACCA 4 QM – 2007 (*Maintenance of Residential HVAC Systems*)
ACCA 5 QI	ANSI/ACCA 5 QI – 2010 (*HVAC Quality Installation Specification, 2010*)
ACCA 6 QR	ANSI/ACCA 6 QR – 2007 (*Standard for Restoring the Cleanliness of HVAC Systems*)
ACCA 9 QIvp	ANSI/ACCA 9 QIvp – 2011 (*HVAC Quality Installation Verification Protocols*)
ACCA 12 QH	ACCA 12 QH – 201x (*Existing Home Evaluation and Performance Improvement)* as of October 2011, pending ANSI approval as an American National Standard

Other Documents

- "Bob's House: Understanding the Residential HVAC Design Process," 2007
- "Technician's Guide for a Quality Installation," 2010
- "Residential Duct Diagnostics and Repair," 2003
- "HVAC Practices for Residential and Commercial Buildings: A Guide for Thermal, Moisture and Contaminant Control to Enhance System Performance and Customer Satisfaction," 2003

RESNET Standards and Guidelines

- 2006 Mortgage Industry National Home Energy Rating System Standards
- 700 RESNET National Standard for Home Energy Audits
- RESNET ENERGY STAR Homes Program Accreditation Procedures for Builder Option Package Providers
- Rating and Home Energy Survey Ethics and Standards of Practice
- Procedures for Verification of International Energy Conservation Code Performance Path Calculation Tools RESNET Publication No. 07-003
- RESNET EnergySmart Contractors Guidelines

Round Robin Pilot Energy Audits

NIST Round Robin Report

With growing market interest in the benefits of residential retrofits to improve the energy performance of homes, consumers are looking for professional guidance to establish priorities and evaluate cost and benefits of a growing number of measures promising improved energy efficiency. Better energy performance gained with window replacement; added insulation and improved efficiency of HVAC equipment has long been at least a contributing factor in homeowners' decisions during maintenance and remodeling projects. With growing concerns about the cost of energy; energy independence on a national level and ultimately the sustainability of energy resources, everyone from individuals to utilities to policy makers has been looking for improved efficacy in the process of upgrading the performance of our housing stock.

Over the last 15 years, a growing infrastructure of trained energy professionals focused on residential energy performance has emerged, encouraged by government policy, utility program requirements and market forces. The most prevalent model on a national level consists of trained individuals certified by private non-profit organizations setup to develop and maintain consensus standards within the housing industry (such as BPI and RESNET). These organizations have joined other trades based organization such as ACCA and NATE who focus on HVAC in offering quality assurance, guidance on best practices and overall professionalism in the residential construction and retrofit markets.

In order to gauge the effectiveness of energy assessments being conducted in the market, it was decided to have trained professionals conduct independent energy audits on the same house and compare the results. In 2011 audit sites in Portland, Oregon, and Berkeley, California, were chosen in conjunction with the West Regional ACI conference in Portland February 1-2 and the National ACI conference in San Francisco March 28 thru April 1. By conducting the audits in conjunction with the ACI conferences access to a large pool of potentially experienced auditors from different backgrounds and working in a variety of markets was assured. The Portland site was seen in part as a trial run for the event in Berkeley which anticipated wider national participation.

In both cases the homes were evaluated by an expert panel to establish a baseline for the conditions as found. Participants were only instructed to test and evaluate the homes as they deemed necessary to characterize the homes and prepare recommendations to improve the energy performance. At the Berkeley site, participants were further asked to prioritize their recommendations based on budgetary limits of $8,000 and $16,000 and create two separate proposals for upgrading the energy performance. In both cases, participants were given utility

energy bills for a full year and feedback from the occupants about comfort issues, perceived IAQ and occupant behavior.

The following equipment was available to all participants:

- Blower door (Minneapolis model 3 or Retrotec model 2000)
- Duct tester (Minneapolis model B or Retrotec model DU200)
- Digital manometers (Minneapolis DG700 or Retrotec DM2)
- IR cameras (Fluke Ti32 [320x240, 50mK]; FLIR i7 [120x100, 100mK])
- Gas leak detector (Bacharach junior)
- Combustion Gas Analyzer (Bacharach)

The participating auditors were also allowed to use any other equipment that they could provide themselves.

The emphasis at the Portland site was on diagnostic results used as the basis for the auditors' recommendations. Comparisons provided here include both the diagnostic results and the auditors' recommendations. For the Berkeley site the emphasis was placed on developing a scope of work in a format normally presented to the homeowner at two different price points.

Portland

The home studied in Portland, Oregon, is shown in Figure 5, alongside a thermographic image indicating heat loss from the windows and doors. Energy use and the floor plan of the Portland home are provided in Figure 6 and Figure 7, respectively. Inspection protocols used by the participating inspectors are listed in Table 4.

Figure 5. Portland Home

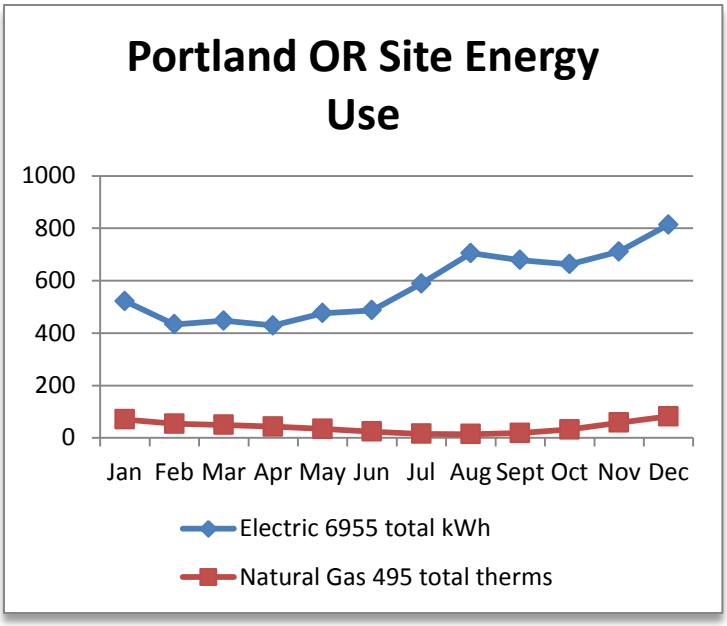


Figure 6. 2010 Energy Use from Utility Bills for Portland Home

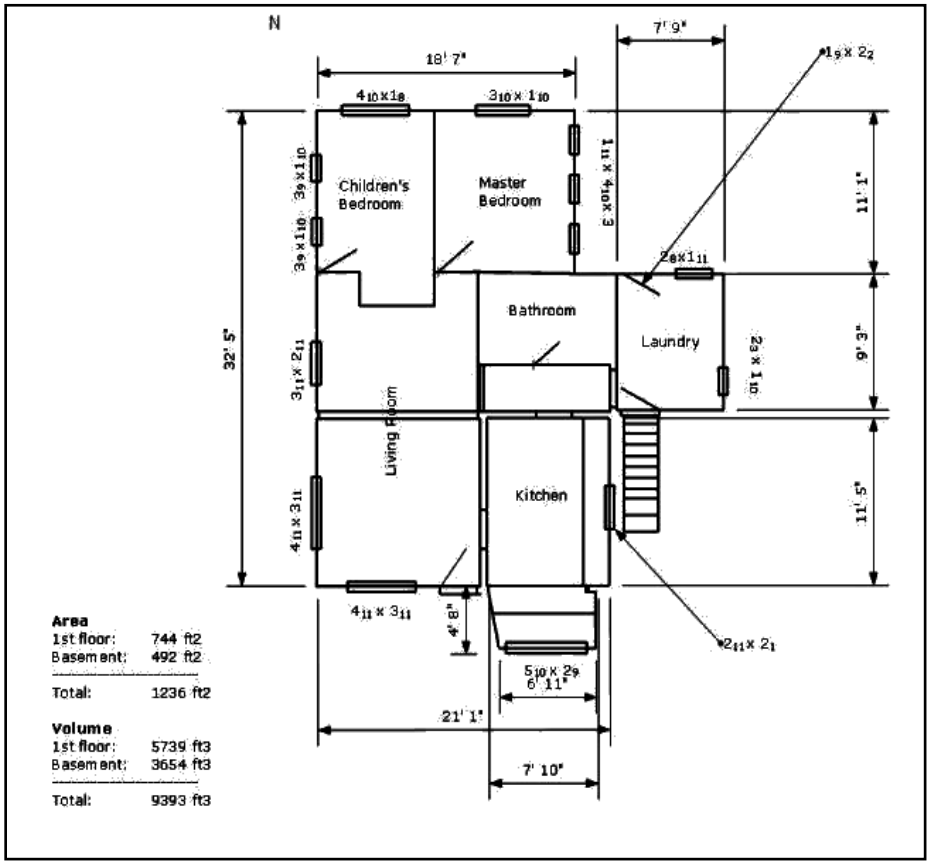


Figure 7. Floor Plan of Portland Home

Table 4. Inspection Protocols Used by Participating Auditors

Auditor	Inspection Protocol
1	HERS, BPI, Simple
2	Home Perf. w/ Energy Star Home Assessment
3	Home Perf. w/ Energy Star Energy Audit
4	Energy Performance Score
5	BPI Energy Audit
6	Energy Performance Score, HERS
Base 1	TechTite (automated BD test)
Base 2	Infiltrometer (automated BD test)

Performance Testing Results

- Results differed depending on if the auditors included the basement as part of conditioned space.
- Most auditors tested the envelope under both scenarios.
- Two auditors did not perform duct leakage tests (see Table 5), but evaluated duct sealing and condition by visual inspection. One also performed pressure pan tests.
- Each of the auditors determined that the home had high levels of leakage based on blower door testing. The average reported ACH50 was close to 25, as seen in Figure 8.

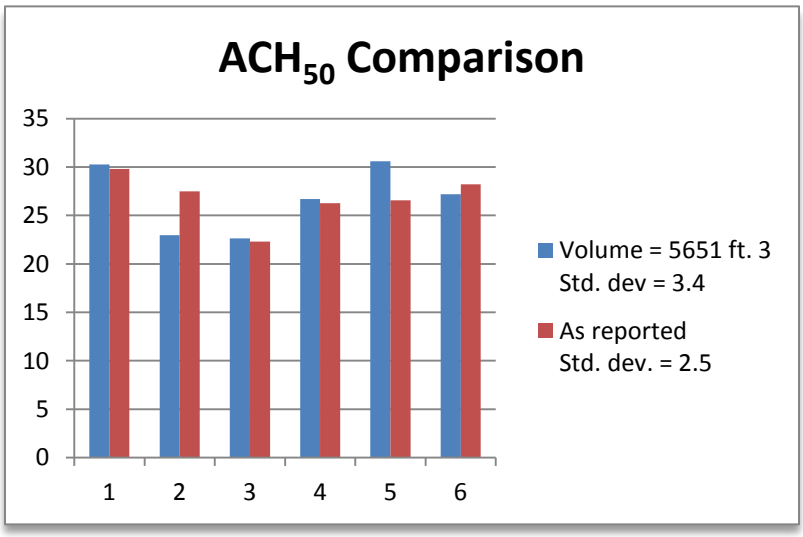


Figure 8. House Tightness

Table 5. Duct Leakage

Auditor	Bsmt. door	LTE (CFM_{50})	Total (CFM_{50})	Notes
1	Open	20	-	
2	Open	36	421	
3	Closed	400	-	
4	No Test	-	-	
5	No Test	-	-	Pressure Pan
6	Closed	299	-	Improved air barrier to crawl
6a	Open	85	-	

Combustion Safety Testing

All auditors conducted combustion safety testing, including Combustion Appliance Zone (CAZ) depressurization, draft and CO on the water heater. All found results below BPI action levels and CAZ depressurization was found between .6 and 1.2 Pa. In all cases, draft was achieved in worst case in less than 60 seconds and CO levels were found between 7 and 13 ppm.

Audit Observations

All auditors identified:

- Significant air leakage, through BD testing, visual inspection and, for five out of six, infrared (IR).
- Lack of insulation at the floor above the crawlspace
- Inadequate attic hatch seal
- Inadequate duct sealing, especially in crawlspace

Photographs of conditions found are provided in Figure 9.

Infrared Inspections

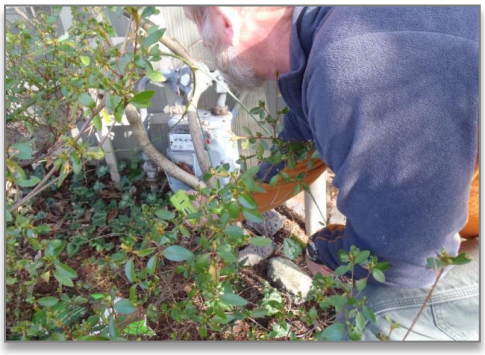
Auditors who performed IR imaging were able to provide more details on where air leakage was occurring (see Figure 10), but reports were inconsistent in providing:

- Methodical description of specific issues documented in infrared (both conduction-related and air leakage-related).
- Documentation that proper infrared procedure was executed, separate from air-tightness testing.
- Documentation of environmental conditions.
- Better Indication of what was, and what was not, inspected with IR.

Figure 9. Audit Observations at Portland Home

No insulation in attic above laundry – five auditors

Dry rot at sill plate – three auditors



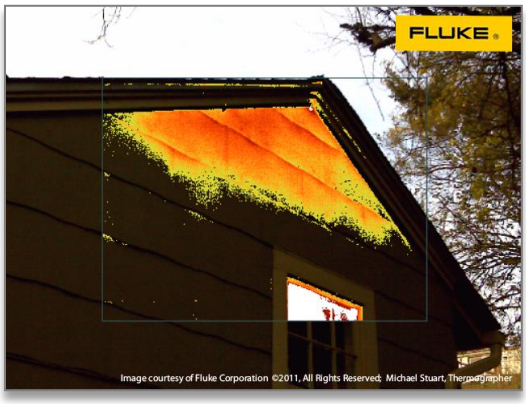
Gas leak at meter – two auditors

Water heater draft hood not secured – one auditor

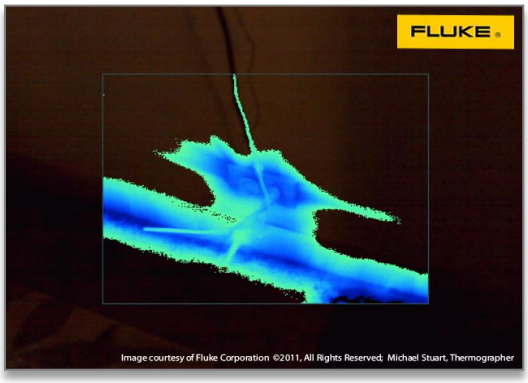
Furnace - CO level at 53 ppm – one auditor

One auditor noted “no need to test.”

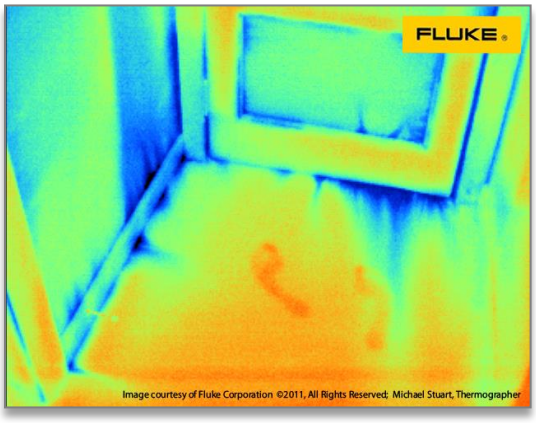
Figure 10. Infrared Inspection of Portland Home



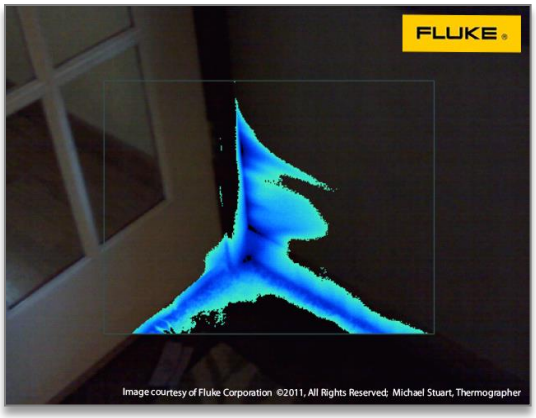
Evidence of warm air infiltration into attic



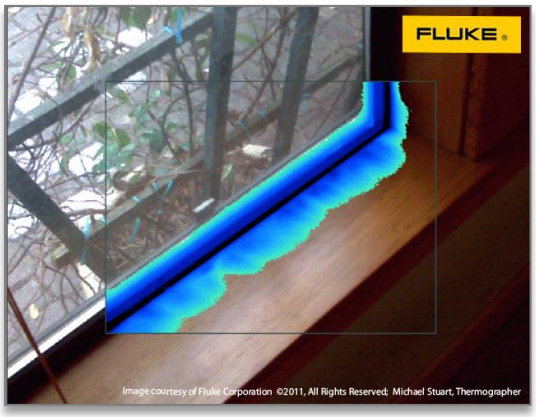
Air infiltration around electrical outlet and floor



Air infiltration on interior wall, floor and door



Air infiltration on interior walls and at floor



Air infiltration around window

Cool air infiltration around kitchen window trim and interstitial air flow in adjacent wall

Portland Audit Recommendations

Audit recommendations for the Portland home are provided in Table 6.

Table 6. Portland Audit Recommendations

	1 HERS	2 HPES	3 HPES	4 EA	5 BPI	6 EA/HERS
General air leakage control	X	X	X	X	X	X
Insulate crawlspace floor	X	X	X	X	X	X
Seal and insulate ductwork	X	X	X	X	X	X
Air seal basement walls, rim and sill	X	X	X	X	X	X
Install and seal crawl hatches	X	X	X	X	X	X
Ensure adequate drainage	X	X	X	X	X	X

	1 HERS	2 HPES	3 HPES	4 EA	5 BPI	6 EA/HERS
Insulate laundry attic	X	X	X		X	X
Install 100% CFLs	X	X	X		X	X
Upgrade DHW	X	"Newer and in good condition"		"operating properly"		X
Add in return area/ air return paths		X	X			
Insulate basement walls	X (R-21+5)	X (R-13-15)			X (R-13)	
Replace windows and doors		X				Laundry, if finished
Install attic radiant barrier & solar fan						X

Estimated Savings

Estimated savings from weatherization activities are provided in Table 7, Table 8 and Table 9.

Table 7. Estimated Savings from Air Sealing

Auditor	Cost ($)	Improvement Measure	Savings (MMBTU)	Notes
1	-	7.0 ACH_{50}	7.8	Simple
2	1500	6.78 ACH_{50}	12.6	
3	900 -	19.1 ACH_{50} – 8.0 ACH_{50}	7.2 -	Utility incentive level Add. Opportunities
4	400-2,000	7.0 ACH_{50}	6.1	EPS (Simple)
5	-	No perf. Level specified	-	
6	400-2,000 500	7 ACH_{50} 10 ACH_{50}	5.5 5.9	EPS (Simple) Rem/Rate

Table 8. Estimated Savings from Duct Sealing and Insulation

Auditor	Cost ($)	Improvement Measure	Savings (MMBTU)	Notes
1	-	Seal & insulate ducts in crawl	1.1	Simple
2	-	-	-	
3	1,050	200 CFM_{50}, R-11	3.7	Utility incentive level
4	400-1200	Seal ducts in crawl, insulate to R-8	6.8	
5	-	Seal all connections	-	
6	400-1200	Seal ducts in crawl, insulate to R-8	7.5	

Table 9. Estimated Savings from Crawlspace Insulation

Auditor	Cost ($)	Improvement Measure	Savings (MMBTU)	Notes
1	-	R-30	-	
2	347.50	R-21	2.1	
3	500	R-21 – R-30	5.0	
4	650-950	Flash + Batt, R-38	8.5	
5	-	R-25	-	
6	350-650	R-30	6.1	

Portland Conclusions

- The circumstances of the audit (mid-retrofit, home operated differently pre and post-retrofit) created challenges.
- Most major energy efficiency findings were consistent
- Health and safety findings varied considerably
- Major energy efficiency recommendations were consistent among raters, though to different levels and savings estimates

Berkeley

The home studied in Berkeley, California, is shown in Figure 11. Inspection protocols used by the participating inspectors are listed in Table 10. Energy use of the Berkeley home is provided in Figure 12.

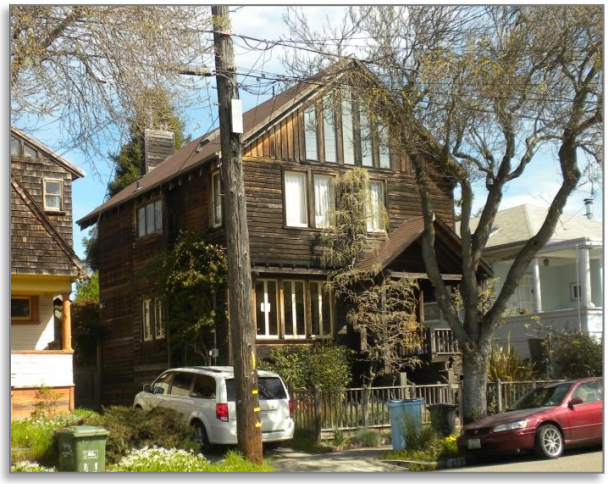


Figure 11. Berkeley Home

Auditor	Inspection Protocol
1	Green Point
2	BPI
3	BPI
4	BPI/HERS
5	BPI
6	Recurve
7	BPI
8	BPI/HERS

Table 10. Inspection Protocols Used – Berkeley Home

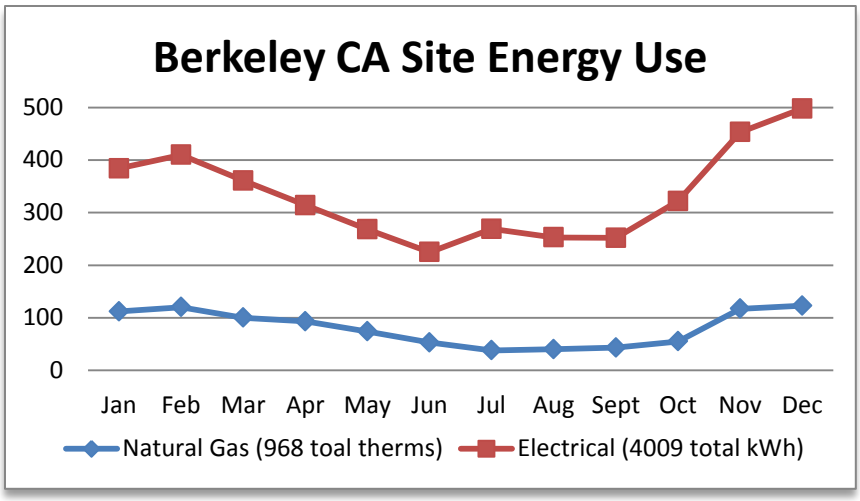


Figure 12. Energy Use at Berkeley Home

Performance Testing Results

An expert panel defined the characteristics of the Berkeley home, as summarized in

Table 11.

Table 11. Characteristics of Berkeley Home

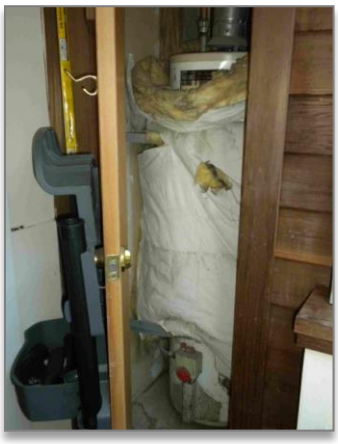
Year built	1914 major gut retrofit and addition 1990s
Conditioned floor area	Approx. 1,500 ft^2
Occupants	2 adults/ 1 child
House type	Site-built two-story + loft on vented crawlspace
Heating	Central forced air; 80% gas furnace in crawlspace; wood stove rarely used
Cooling	None
Domestic hot water	Atmospherically drafted gas
Walls	2 x 4 frame with R-11
Floors	Poorly installed R-19 + missing batts
Ceiling	Vaulted R-19 estimated
Windows	Wood, single glazed, leaky with water damage some fixed double pane
Appliances	Not ENERGY STAR-rated
Lighting	25% CFLs
Ducts	Some R-4, 320 CFM_{25} total/ 140 CFM_{25} to exterior
House tightness	2,400 CFM_{50}/10 ACH_{50}
Comfort issues	Seasonal overheating from south glazing

Combustion Safety Testing

The atmospherically drafted DHW heater is in a closet in conditioned space, has a failing insulation wrap and vents into a separate flue. It is nearing the end of its service life. It passed BPI standards for spillage, draft and CO.

The atmospherically drafted 80 percent gas furnace is in the crawlspace, vents into a separate flue with a very long horizontal run, the flue was disconnected at the furnace, the gas flex line was kinked and both the flu and the furnace show extensive corrosion. The furnace is at the end of its service life and should be replaced for safety reasons. It failed BPI standards for spillage, draft and CO. Figure 13 is a series of images of combustion safety testing.

Figure 13. Combustion Safety Testing in the Berkeley Home



Domestic hot water tank in closet

Hot water and furnace vent

Corroded furnace vent

Figure 13. Combustion Safety Testing in the Berkeley Home

Corrosion inside gas furnace

Horizontal furnace vent run in crawlspace

Kinked gas line to furnace

Disconnected furnace flue in crawlspace

The gas oven tested within BPI specification so no service is needed.

Audit Observations

Observations made in the Berkeley home are shown in Figure 14.

Figure 14. Audit Observations of Berkeley Home

Desiccated mouse found in return air plenum duct

Poorly installed dryer vent was completely blocked with lint

Poorly installed floor insulation

South-facing glazing that causes overheating

Constricted flex duct in crawlspace

Infrared Inspection

The images provided as Figure 15 are from the IR inspection of the Berkeley home.

Figure 15. Infrared Inspection of Berkeley Home

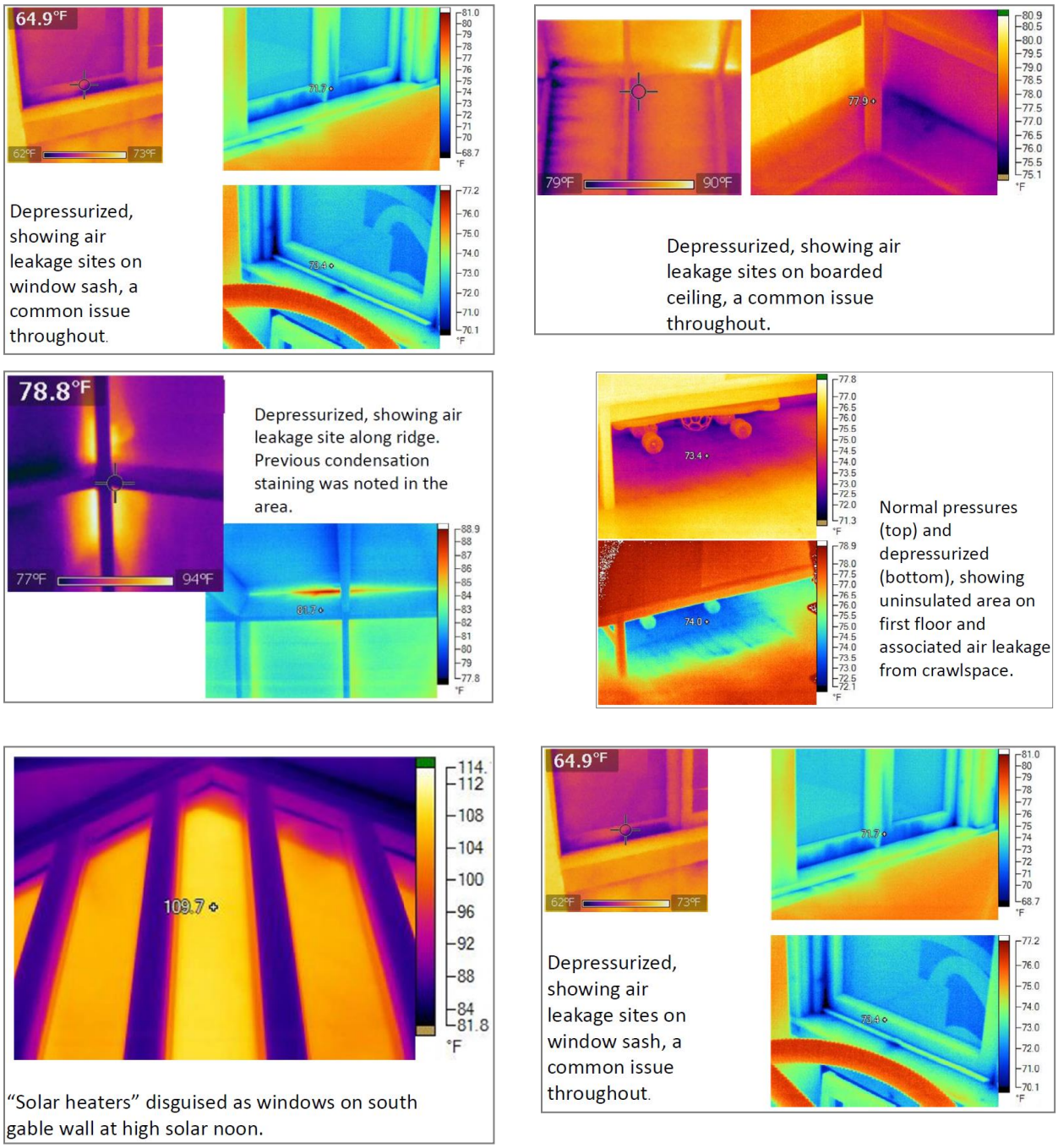
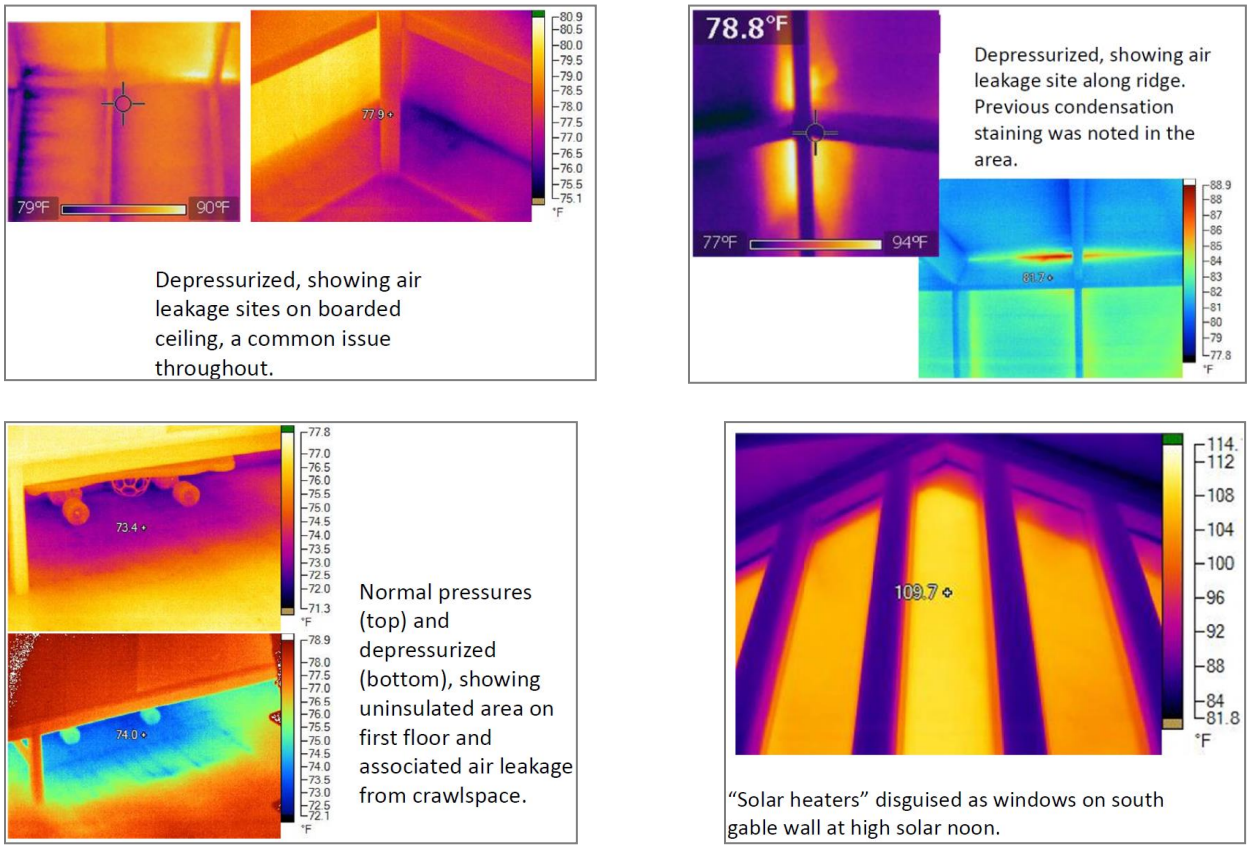


Figure 15. Infrared Inspection of Berkeley Home



Audit Recommendations

For the Berkeley site, auditors were asked to provide scopes of work at two different price points, $8,000 and $16,000. Table 12 and

Table 13 present comparisons of the measures recommended by each auditor and the projected costs and savings estimated by the auditors. Auditors were asked to use their own estimated costs, which varied considerably from contractor to contractor and regionally. Auditor 1 only provided recommendations with a $16,000 budget. Auditor 4 only provided recommendations with an $8,000 budget.

As reflected in these tables, there were a wide range of recommendations at the Berkeley site. Estimated annual savings ranged from $139 per year to $2,500 per year, even though the participants were given a year's worth of utility bills that only totaled $1,817. With an $8,000 budget, estimated savings ranged from 7.5 to 82.5 percent, averaging 41.5 percent. With a $16,000 budget estimated savings ranged from 17 to 137 percent, averaging 47 percent removing the outlier. Some of this variation is probably a result of participants from other parts of the country failing to adjust their analysis tools to the relatively mild climate in Berkeley.

Table 12. Berkeley Measures with $8,000 Budget

Measure	Audit							
	1*	2	3	4	5	6	7	8
Air sealing				X	X	X	X	X
Ductless minisplit HP				X				
High efficiency 95% gas furnace		X	X		X	X	X	X
High efficiency DHW 30 gal				X				X
Tankless DHW condensing							X	
Insulate existing DHW tank and pipes					X	X		
Ceiling add R-19			X					
Floor R-25			X				X	
Dense pack floor					X			
Duct Insulation R-11			X		X		X	
Operable skylights w/shades								X
Low flow aerators/shower heads								X
Duct sealing					X		X	X
CFLs				X		X	X	X
Clothes line								X
Fix dryer vent					X	X		
TOTAL COST	na	$8,903	$7,816	$8K	$6,092	$8,241	$8,275	$7,675
TOTAL ESTIMATED ANNUAL SAVINGS	na	$1,044	$581	$501		$139		$1,500

*Auditor 1 only provided recommendations with a $16,000 budget

Table 13. Berkeley Measures with $16,000 Budget

Measure	Audit							
	1	2	3	4*	5	6	7	8
Air sealing	X	X			X	X	X	X
Combo system						X		
High efficiency 95% gas furnace	X	X	X		X		X	X
Heat pump 14.5 SEER 8.5 HSPF	X	X						
High efficiency DHW 30 gal								X
Tankless condensing DHW	X	X					X	
Insulate existing DHW					X	X		
Operable skylights w/shades							X	X
Low flow aerators/shower head								X
Duct sealing					X	X	X	X
Duct cleaning		X				X		
Duct Insulation R-11		X	X		X		X	
Floor Insulation R-22 spray foam								X
Floor insulation R-19 batts	X	X						
Floor insulation R-25 batts			X				X	
Dense pack Floor					X			
Add R-19 ceiling			X					
Whole house fan						X		X
Windows south double low E	X							X
Add storm windows					X			
All windows double low E			X				X	
CFLs	X					X	X	X
Fix dryer vent					X	X		
TOTAL COST	$16K	$15,908	$15,588	na	$14,592	$16,085	$15,225	$15,675
TOTAL ESTIMATED ANNUAL SAVINGS	$491	$1,044	$791	na		$316	$984	$2,500

* Auditor 4 only provided recommendations with an $8,000 budget

All of the auditors recommended installing a higher efficiency heating system. Given the condition of the existing system, this was a good call. Cost varied substantially and recommendations ranged from dual fuel systems with furnace + heat pump, to combo systems, to condensing furnaces, to a ductless mini-split.

Berkeley Conclusions

- Health and safety issues were identified as the primary concern at this site by all auditors (venting failure on gas furnace in crawlspace).
- Air sealing the envelope and upgrading the heating system were the most common recommendations.
- No apparent attempt was made to reconcile estimated savings with actual utility bills.
- The auditors made minimal or ineffective use of IR cameras.
- Projected energy savings were extremely variable, ranging from a 7.6 percent cost reduction to a 138 percent reduction!

Summary and Conclusions

The overall results of the round robins – admittedly based on a small sample – suggest that the home performance industry still has work to do to better meet consumers' expectations in the marketplace. Consumers want to know what a retrofit job will cost and what the resulting savings and benefits will be, and the audits conducted during the round robins showed that the greatest uncertainty occurred when trying to answer these questions. The development of specific climate and house type databases that track both costs and savings could help reduce the uncertainty.

The authors hope the round robin auditing efforts serve as a catalyst to improve energy auditing and retrofit practices. Recommendations have been made to DOE and others to support implementation of future round robins with interested energy efficiency retrofit program market players such as RESNET, ACCA and BPI. These ongoing round robin efforts should allow for the inclusion and evaluation of many different program approaches to energy auditing and work plan development.

If implemented around the country, the round robins can address variability in retrofit approaches based on differences in regional housing stock and/or climate. Feedback from round robins provides ongoing quality assurance that helps ensure that homeowners get relatively consistent, reliable, repeatable and useful recommendations from the home performance contracting industry.

Westford Symposium Survey Results

The WSU Energy Program and our building science experts prepared a survey to capture a broad range of perspectives within the community of building science researchers and practitioners. The results will indicate where future efforts are needed, as defined by the following objectives:

- To better understand the directions in single-family residential energy audits and retrofits.
- To improve the measurement of residential energy performance to better inform energy decisions and to better assess the effectiveness of retrofit efforts.

The survey consisted of 13 questions about field diagnostic measurements, field energy audits, the post-retrofit process, industry standards and market opportunities. This survey was provided online via the Survey Monkey tool during the Building Science Corporation's Westford Symposium on August 1-3, 2011. The survey continued to be available for the Symposium's attendees through August 26.

A total of 135 people started the survey wand 118 completed the entire survey (87 percent). While answers were not required for all of the questions, the majority of the participants were either extremely familiar with or had significant experience in the field.

The survey questions incorporated the following styles:

1. A ranking-based structure to identify the range of responses and delineate potential opportunities for improvement (specific to the energy audit process for diagnostic measurements).
2. A simple response (Yes/No) question format.
3. An open-ended style that allowed participants to either freely respond to a single question or follow-up with explanation from the aforementioned types of survey questions.[25]

This summary highlights the results of the questions posed during the survey period. The full survey is provided in Appendix C, along with the full results used for analysis. We have segmented the survey results and forthcoming analysis into the following areas:

- Residential Home Energy Audit

[25] Tabulating the responses from the open-ended questions involves looking for similar responses, creating a set of categories that reflects the most common responses, and then tabulating the responses into those categories. This is a subjective exercise because some judgment is required to decide if a response fits in a certain category. Therefore, the results should not be viewed as exact, but they do provide a sense of what people were saying.

- Post-retrofit (Energy Efficiency Measure Implementation)
- Standards for Energy Efficiency in Residential Housing
- Market Opportunities

Residential Home Energy Audit

Aligning the results of the survey from the perspective of the building science expert, we have grouped the survey responses (1) that were focused on the energy audit process or the individual who conducts the audit and (2) the needs of the homeowner (from the same building professional perspective).

Energy Audit Process/Energy Auditor

There are several certification programs throughout the country, and as popular or stringent as they may be, areas of potential improvement can be addressed. The energy auditor must be able to perform numerous measurements using an array of tools including infrared thermography cameras, computer software for modeling/analysis, duct testing and blower door tools, among others. The consensus from the survey participants shows that the primary or essential diagnostic measurements that should be inclusive to all energy audits include:

1. Visual inspection of assembly areas – walls, windows, ceilings (89 percent)
2. Envelope leakage rates (87 percent)
3. Combustion safety (86 percent)
4. Homeowner interview (83 percent)
5. Utility bill analysis (83 percent)

Although these results point to the primary focus areas of an energy audit, the additional ranking of the same diagnostic measurements (in Figure 16) shows that this community of experts has a range of confidence (higher percentage = higher confidence) in their accuracy for:

1. Utility bill analysis (70 percent)
2. Envelope leakage rates (56 percent)
3. Visual inspection of assembly areas (54 percent)
4. Appliance survey (52 percent)
5. Combustion safety (48 percent)

Mapping these two sets of data provides a visual perspective of the opportunities for:

- Further research into the deviations of the data (e.g., need for more granular data, specific focus group research areas) to identify why confidence/accuracy is lower or
- Applying the necessary actions at the training or continuing education level for existing certified auditors.

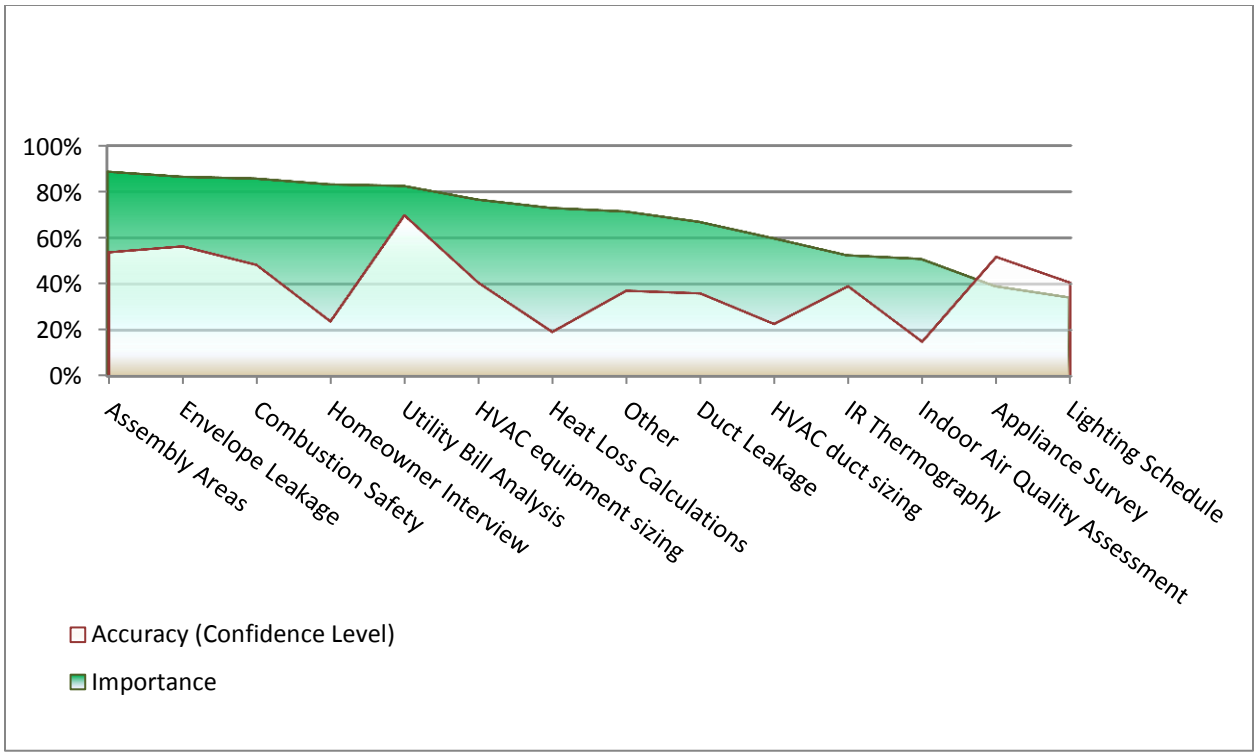


Figure 16. Ranking of Diagnostic Measurements

As the graph shows, there are gaps between the importance of and confidence level for each of the diagnostic measurements that were provided in the questionnaire. These gaps represent opportunities for improvement to researchers and training organizations; however, the drivers that impact confidence levels, especially within the primary measurements identified in the first data set, should be investigated.

Our survey results also indicate that there is no significant consensus regarding the need to develop new audit measurements or measurement techniques; rather, it was stated that "…making what we are doing, better." Of those who indicated yes (53 percent), the primary suggestions indicate that the energy audit industry should improve on what exists.

Another focused measurement question specific to energy analysis or energy savings calculations as part of the energy audit process was aligned to three groupings based on the responses: (a) energy modeling, (b) experience/simple methods and (c) diagnostic tools.

As this was an open-ended question, an array of responses was provided by participants who identified over 20 different modeling tools, provided multiple answers, noted concerns regarding the inaccuracy of models or indicated that tools or models were required. The data indicates no clear trend, but shows the following:

a. Energy model – 50 percent of the responses indicated the use of modeling tools, with REM/Rate being mentioned by the most (over 10 percent of the total).
b. Experience/simple methods – 30 percent of the responses indicated using their experience, utility bills or simple spreadsheets for the analysis.
c. Diagnostic tools – 20 percent of the responses indicated using blower doors, duct blasters or other measuring device as their primary tool for the analysis.

Costs

Additional areas that were ranked include costs of each measurement and identifying which diagnostic measurement is part of a basic, detailed or comprehensive audit.

Table 14 illustrates how the diagnostic measurements are grouped into each level of audit and the associated cost attribute from the responses.

Table 14. Diagnostic Measurement Groupings

Diagnostic Measurement	Response	Level of Audit	Response	Cost
Homeowner Interview	70 percent	Basic	59 percent	Low
Appliance Survey	64 percent	Basic	81 percent	Low
Utility Bill Analysis	63 percent	Basic	68 percent	Low
Assembly Area	50 percent	Basic/Detailed	49 percent	Average
Lighting Schedule	50 percent	Basic/Detailed	64 percent	Low
Combustion Safety	47 percent	Detailed	56 percent	Average
Other*	42 percent	Detailed	48 percent	Low
Envelope Leakage Rates	28 percent	Comprehensive	62 percent	Average
Heat Loss Calculations	26 percent	Comprehensive	60 percent	Average
IR Thermography	26 percent	Comprehensive	48 percent	Average
HVAC Equipment Sizing	25 percent	Comprehensive	58 percent	Average
Duct Leakage Rates	19 percent	Comprehensive	49 percent	Average
IAQ Assessment	13 percent	Comprehensive	49 percent	Average
HVAC Duct Sizing	12 percent	Comprehensive	52 percent	Average

**Based on the responses provided, the defined "Other" includes: ventilation flows, assurance of controls for temperature and ventilation, proper circulation water temperatures to match outside temperatures and optimize boiler performance, comfort, classification of house construction era, use of data loggers to verify electric use and temperature/humidity, measured HVAC system performance, site orientation, room pressurization, heat gain/cooling load and outdoor air quality.*

The results show consensus among the building science experts regarding each diagnostic measurement and their affiliated grouping for basic, detailed and comprehensive audits. However, the lower response percentages attributed to the range of costs segmentation of

each measurement may indicate the perspective of the participant, their level of experience, cost differences specific to regions or other variance that require further exploration.

To capture deeper insights, an additional question provided an opportunity to specify the actual costs of an energy audit, but the question was not explicit enough regarding the level or type of audit; some responses indicated the cost of a basic audit was $250 to $300 and a comprehensive audit might cost $800 to $1,200. The results indicate an average of $300 to $500, potentially indicating that the most common audit is more detailed in measurements taken. Additionally, some responses noted that the cost of an audit was subsidized, where it was indicated the audit was free or less than $300.

Of those who responded to how the energy audit cost was paid, almost half (49 percent) indicated that it was subsidized by utility programs, state agencies or retrofit programs through contractors; the other half indicated the homeowner paid directly for the services.

Needs of the Homeowner

Moving toward implementing solutions or recommendations from the energy audit process, we sought the perspective of our participants regarding cost barriers (of the audit) to determine if an actual retrofit would result. Only a slight majority (55 percent) said yes.

This data may reflect an opportunity to better identify the barriers to retrofit implementation, but may also be used to identify the market barriers to further deploy the more cost-effective measures into homes with more consistent and validated energy savings. Furthermore, almost half of the responses indicated the subsidy for the audit, which leads to the assumption that the barrier may be the cost of the retrofit, not the cost of the audit.

Inherent to the audit process, however, is the question of the value of information to the homeowner. As with several questions in the survey, there were multiple responses and these have been grouped into two categories: cost and non-financial benefits. These benefits stressed the information needs of homeowners, but may also indicate the barriers to retrofit implementation.

Half of the responses were financial and included energy cost savings, cost of recommendations, return on investment and payback. The responses also indicated that homeowners want information on prioritizing the recommendations provided through the audit. Many of the responses emphasized the same financial requirements, but stressed the need for prioritization for the homeowners.

Of the non-financial aspects, many of the experts identified health and safety and performance as other important needs of a homeowner, along with comfort, behavior (education), defects (correcting problems) and durability, as shown in Figure 17.

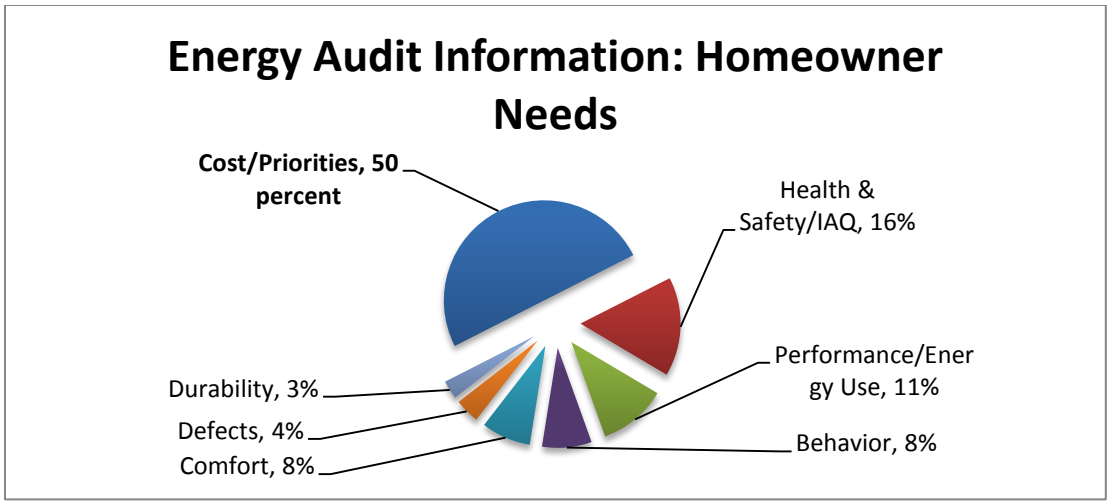


Figure 17. Audit Information: Homeowner Needs

Post-Retrofit (Energy Efficiency Improvements)

The next set of questions and results target the post-retrofit process; that is, after certain measures or technologies have been installed that may have been recommended as a result of the energy audit process. The questions target the behavior and information needs of homeowners and look broadly at identifying successes of large-scale retrofit programs.

A large majority of respondents (88 percent) felt that energy feedback devices can play a role in saving energy after a retrofit. About a third explained their answer by saying that feedback is an effective way to change energy use behavior and a number mentioned the "Prius effect" as an example. Another group said that energy feedback devices make homeowners more aware and help them understand their energy use, which can result in changes in habit. Some illustrated this by saying "you can't manage what you don't measure." A smaller group of respondents said the homeowner behavior is an important part of the solution for reducing energy use (not just retrofit measures). This needs to be addressed as part of the project, and feedback devices provide a way to do this. A few people mentioned that it is important to make these devices seem like games or take advantage of the "geek effect" of electronic devices.

However, about a quarter of the respondents said that energy feedback devices play a limited role in saving energy after a retrofit. To be effective, homeowners need to be educated and motivated. Only a small proportion of homeowners (about 20 percent) may apply the information from the feedback device. The impact also might be short-lived as people lose interest.

Some respondents thought feedback devices could be valuable for verifying performance, commissioning retrofits, diagnosing problems and helping installers learn how to do a better job. A few provided comments about specific devices or methods to get feedback.

A follow-up question about the information provided to the homeowner **after** a retrofit showed significant consensus from the participants. Almost 98 percent of the responses indicated that information should be provided to the homeowner. Of those who responded positively, an opportunity was provided to identify preferences that included utility bill analysis, performance test/score, post QA inspection and other, which allowed for an additional layer of responses.

Similarly, cost is prevalent for post-retrofit information to the homeowner; however, there is a higher need for validation of the retrofit measures or activities implemented. This data is grouped differently from the energy audit and cannot be interpreted in the same way.

Utility bill analysis is cost- and performance-related, validating both dollar and energy savings. However, the focus is on simply using utility bill data. Separating the performance test or score from the utility bill aspect allows us to identify the need for a scoring metric, model or mechanism such as ENERGY STAR (or DOE's Home Performance), and includes before and after comparisons of energy savings, comparisons of similar homes and retrofits, continuous feedback and a report documenting the performance data.

Post QA inspection was almost equally called out and included warranty information, assessment of the work performed, health and safety improvements/correlation, and credibility of the information. The "Other" category included items such as further recommendations (prioritized, long-term), education (operation and maintenance, post interview), and tax credit or rebate information for additional retrofit suggestions, as illustrated in Figure 18.

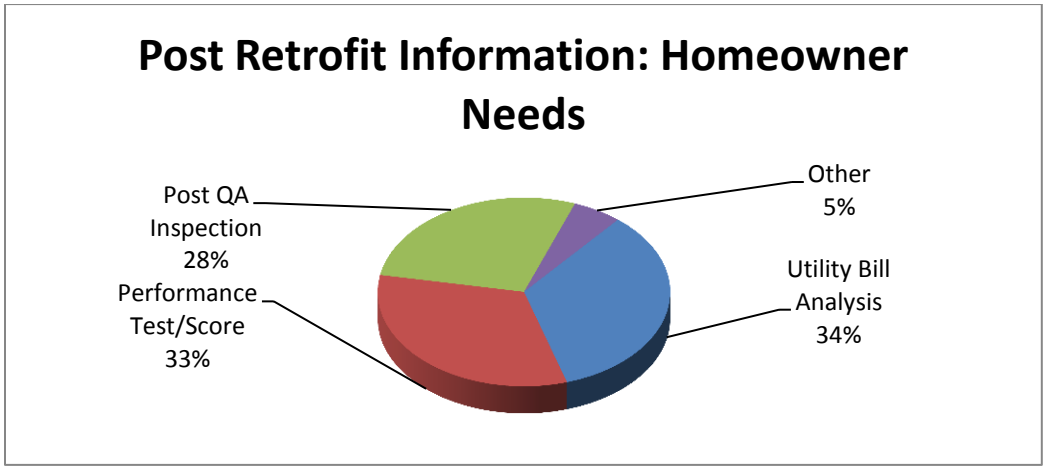


Figure 18. Post-Retrofit Information: Homeowner Needs

While this survey did not focus on the decision point, several data points indicate that improving the energy audit and post-retrofit process may lead to greater acceptance of recommended improvements and future strategies for energy efficiency.

The broader context of the next question combines many responses to earlier questions to validate the success and the energy savings of retrofits. Participants were asked to provide insights on validating energy performance of large-scale retrofit programs.

All but two respondents indicated that measured performance rather than predicted performance (modeled, deemed) should be used to determine program energy performance. The majority of respondents said that utility bills should be used. Some of these implied doing large-scale pre/post billing analysis while others seemed to suggest monitoring energy bills on a house-to-house basis. A few suggested the need for more detailed data loggers or sub-metering on a sample or large group of homes and a couple emphasized the need to measure heating and cooling demand directly.

Some suggested the need for field testing (blower door tests, measure verification, etc.) on a sample (or all) homes and making sure that the work completed was accurately reported. Related to this, some said a homeowner survey should be conducted on the benefits of the retrofits and occupant habits and equipment use. Other ideas include universal standards for collecting utility and performance information, requiring utilities to provide utility bill data and setting up a database for individual home monitoring information.

Standards

We asked several questions about standards. We did not specifically define what we meant by standards, except to say we were referring to standards about audits and implementation of measures. Most of the questions were open-ended and we received a wide mix of responses, suggesting there was not strong consensus about standards among those participating in our survey.

While a majority of the respondents said there are ***competing standards*** (69 percent), when asked if this was a problem, the responses were mixed. A small portion of those that said there are competing standards felt this was not a problem (16 percent) and more than a quarter said they did not know or gave a response that was not mentioned by anyone else.

Of those who did feel there was a problem with competing standards, the biggest concern was creating confusion for the market, particularly for homeowners (24 percent). Other related problems mentioned by more than 10 percent of the respondents were: conflicting requirements between different standards; that homeowners, contractors, or programs choose the standard that sets the lowest bar, is easiest to meet, or is most financially beneficial (thus producing sub-optimum results); and different groups competing with each other through their standards. A few respondents mentioned the higher costs for dealing with multiple standards, requirements or certifications and a handful said it was important to create a single national standard.

We asked ***what standards have been effective*** in increasing the energy efficiency of existing housing. The wide mix of responses suggests there was not strong agreement on what standards have been effective or on their importance. The largest group of responders (26 percent) said they were not aware of any standards that were effective in increasing the energy efficiency of existing housing, did not think there were any, or thought they were of limited value. There were also many "other" responses (25 percent) that were only mentioned by one or two people. The most frequent group of related standards mentioned was building codes (16 percent), ENERGY STAR (15 percent), and appliance/HVAC/lighting standards (11 percent). BPI was most frequently mentioned as an effective audit and weatherization standard (15 percent) along with several ASHRAE standards (11 percent). RESNET, ACCA and Passive House each received a few responses.

We then asked ***what standards are needed*** to significantly increase the energy efficiency of existing housing. Again we received a wide mix of responses. About a third of the respondents suggested something that fell into the "other" category (responses identified by one or two others or that really were not a standard). About a third of the respondents indicated there was not a need for more standards or were not sure what standards could improve existing housing energy efficiency. These responses suggest that about half the respondents do not believe there is a need for new standards or cannot identify what those standards should be.

The area that received the most support for new standards (or requirements) was energy use reporting and labeling requirements (19 percent). This included mandatory utility reporting of energy use to homeowners and reporting/labeling at the time of sale. Related to this were requirements for audits at the time of sale, minimum efficiency upgrade requirements at the time of sale, or minimum energy performance requirements (8 percent).

About 12 percent of the respondents mentioned building energy codes. Some suggested that codes were more important than standards, needed to be more stringent, and/or better enforced. A few said building codes needed to include energy efficiency requirements when a home is renovated.

There was a small group of responses about increasing existing appliance/HVAC standards (8 percent) and increasing insulation requirements (4 percent). About 10 percent of the respondents felt there was a need for air tightness standards. There were a few responses about tightening auditing requirements (2 percent) and some others about simplifying the audit process/requirements (6 percent). There were a small number of suggestions about performance verification and commissioning requirements (3 percent) and training/certification/licensing requirements (3 percent).

While there was not strong consensus in the responses to the questions on standards and their importance, they do suggest areas where standards have been effective, where new standards may be useful and what the problems are. These areas need further research to identify specific opportunities.

Market Opportunities

Respondents gave a wide range of responses when asked ***how to best bring U.S. existing housing to higher efficiency.*** There were no clear favorites. Many people provided more than one option. The responses tended to fall into four main categories:

- Marketing and education campaigns that raise awareness (11 percent)
- Financial incentives such as utility and government incentives/rebates and tax credits (16 percent)
- Standards and regulations such as energy codes that require improvement at the time of sale or energy reporting at the time of sale (20 percent)
- Mechanism that send a financial signal, such as taxes on energy use, feebate/rebate/pay for performance mechanisms and higher energy prices (16 percent)

Other ideas that were mentioned included financing (on-bill, PACE, no interest, 4 percent), training (5 percent), stable, long-running national program (5 percent), focused set of measures (insulation, air sealing) or sequence of measures (5 percent), and emphasize quality (2 percent). A small group of respondents (6 percent) said just let the market work instead of relying on subsidies, regulations, or other mechanisms.

We also asked about the **best market opportunities for increasing the adoption of energy efficiency in existing homes.** Many of the responses were similar to the ones above. Respondents who realized we were asking about good market opportunities (types of homes, locations, etc.) mentioned things like stable housing markets and communities (people do not retrofit their house if the mortgage is under water or they do not have a good job); integrating energy efficiency into addressing homeowner concerns about repair/remodeling, comfort and indoor air quality; leveraging opportunities for energy efficiency when a contractor is in the home for other work; focusing on opportunities for basic efficiency measures like insulation and air sealing; and climates with significant heating and/or cooling loads.

Retrofit Program Experiences

Alaska – 30 Years of Energy Retrofit Experience

By Dan Berube, November 2011

Alaska, the Great land, really plays true when you consider energy retrofitting. It encompasses one-fifth of the landmass of the lower 48 states, with 640 square miles of land for every mile of paved road. Despite its size, it ranks 47th in total road miles compared to other states. About 75 percent of the state is accessible only by boat or airplane, so it stands to reason that Alaska has the most airplanes per capita. In addition, Alaska ranks number one in the U.S. for heating degree-days and uses the most energy per capita of any state.

One of the most successful programs in Alaska for energy improvements and retrofit has been the Weatherization Assistance Program. Since its inception in the late 1970s, this program has served almost 40,000 homes.

Topographical Features

Alaska is the westernmost extension of the North American continent. Its east-west span covers 2,000 miles; its north-south span covers 1,100 miles. The state's coastline – 33,000 miles long – is 50 percent longer than that of the conterminous United States. The Aleutian Islands and hundreds of other islands, mostly undeveloped, are located along the northern coast of the Gulf of Alaska, the Alaska Peninsula and the Bering Sea Coast. Alaska contains 375 million acres of land and thousands of lakes.

Climate Zones

As indicated in Figure 19, the Northern Pacific greatly influences the climate of the south central and south eastern regions of the state. Annual precipitation in these regions is very high compared to the rest of the state, and the lack of extreme temperatures speaks to the maritime influence.

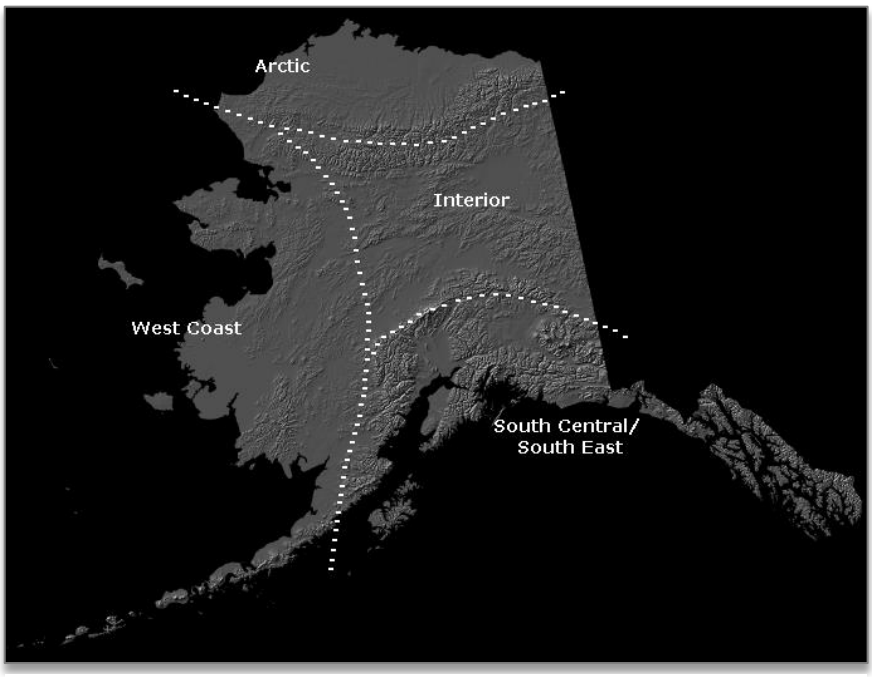


Figure 19. Climate Zones in Alaska

The Bering Sea, with its annual influx of sea ice and

high winds from strong storms, also influences the climate of the west coast area of the state, as does the extreme nature of air masses in the interior. Together, these influences make the west coast region a truly transitional zone.

The Arctic Ocean and its persistent sea ice impacts the climate of the Arctic region. Average annual temperatures in Barrow are 8 to 12°F and precipitation is very light, averaging only 4.5 inches per year.

The climate of the interior region is the most extreme in terms of temperature range. Its continental location, isolated by the Alaska Range to the south and the Brooks Range to the north, allows summer temperatures to climb above 80°F and winter temperatures to dip below -40°F. The mountain ranges also limit the amount of precipitation that falls in the interior by limiting the advection of moisture.

Degree Days

Average heating degree days vary from about 7,000 in the southeast panhandle to 10,000 degree days in Anchorage (south central region), 14,000 in Fairbanks (interior region) and up to 20,000 in Barrow (Arctic region). The state on average has 11,358 degree-days.

Precipitation

In the maritime zone, a coastal mountain range coupled with plentiful moisture produces annual precipitation of up to 200 inches in the southeastern panhandle and up to 150 inches along the northern coast of the Gulf of Alaska. Amounts decrease to near 60 inches on the southern side of the Alaska Range in the Alaska Peninsula and Aleutian Island sections. Precipitation amounts also decrease to the north, with an average of 12 inches in the continental zone and less than 6 inches in the Arctic region.

Snowfall makes up a large portion of the total annual precipitation throughout the state; for example, Yakutat averages 216 inches of snow annually and has a total annual precipitation (rain plus water equivalent of snow) of about 130 inches. Along the Arctic slope, Barrow receives an average of 29 inches of snow annually and a total annual precipitation of slightly more than 4 inches.

Early Days of Weatherization – 1970s and 1980s

Alaska began weatherizing homes with federal money in 1978, which was used to weatherize 465 homes. The average spent per home was $1,075.

The Comprehensive Employment and Training Act (CETA) Amendments of 1978 yielded a federal grant that the Municipality of Anchorage received to weatherize homes. The average amount spent per house was approximately $300.

In 1980, Alaska began the Residential Conservation Services Program, the first subsidized energy audit program in the state. It provided a comprehensive, hand-calculated 13-page report on a building's energy use and possible upgrades. The homeowner could receive a $300 rebate for receipts on improvements or a $1,500 loan to do energy improvements.

The Weatherization Assistance Program continued through the 1980s. In the early 1980s, the program had a budget of around $1,500 per house, which was divided approximately equally between labor and materials. There were five sub-grantees in the state broken down by region. This has been one of the most successful programs for encouraging energy improvements and retrofits in Alaska. Since its inception in the late 1970s, it has served almost 40,000 homes.

Around 1985, an interesting concept was presented in a training given by Frank Kinsell from Philadelphia, where heating improvements were promoted as the first priority for the row houses. Although Alaska did not have row houses, we did have extreme fuel use and inefficient heating systems, so Kinsell's concept we was received here.

Fuel oil is used for heating by a third of the population in Alaska, mostly in the roadless and remote areas. Fuel oil is expensive because it has to be barged or flown in. It is not uncommon to see prices up to $7 or $8 per gallon. Until the late 1980s, most homes used a pot burner type of stove as the main source of heat. These stoves were extremely inefficient, temperatures were difficult to control and backdrafting was common.

In 1987, Rural Alaska Community Action Program (RurAL CAP) established Rural Energy Enterprises (REE) as a for-profit entity within the agency's energy department. It secured the market franchise in Alaska for the efficient Japanese space heater Toyostove, which ran on fuel oil and was direct vent. Because the Toyostove was significantly more efficient that pot burner stoves (84 percent efficient for Toyostove vs. less than 60 percent efficient for an existing pot burner), this was a huge advance for rural homeowners.

One of the most remarkable pieces of technology to arrive in the late 1980s was the blower door, delivered and demonstrated by Gary Nelson of Minneapolis Blower Door whose sister lives in Anchorage. I was there on that cold winter day, in a small low-income dwelling over in the Mountain View neighborhood. One of the first production model blower doors on the market, it revolutionized energy rehab and weatherization.

Home Rating Program

Alaska has the highest penetration of ENERGY STAR-labeled homes in the nation. Alaska's success can be attributed to the strength of its residential energy efficiency programs that started before the ENERGY STAR Homes Program was launched.

The nation's first statewide home energy rating program, Energy Rated Homes of Alaska, began in 1985. The state's energy code is stringent (see the Alaska Building Energy Efficiency Standards, or BEES) – 83 points on the HERS scale. Most builders use the rating method to demonstrate compliance with the energy code. Alaska's penetration was enhanced by a mortgage loan interest rate reduction program offered by the Alaska Housing Finance Corp. The home energy ratings are linked to energy code compliance, and a great majority of builders in the state take advantage of this compliance option.

The 1990s

Thanks to instruments like the blower door and digital pressure gauges, the weatherization industry embraced a more comprehensive understanding of building science in the late 1980s and early 1990s. We started seeing the cause and effect of applied technology, especially in the extreme climate zones of the Arctic. Up to this point, we had focused mostly on insulating and tightening the building shell, without too much concern for health and safety issues such as moisture, combustion safety and indoor air quality.

Alaska's weatherization program managers had the insight to educate those in the weatherization industry by implementing trainings and standards that focused on building science. We experimented with innovative techniques and concepts such as dense-packed cellulose and exterior insulation retrofits. We discovered the importance of the drainage plain in the maritime regions and began addressing combustion safety by encouraging sealed combustion appliances and proper drafting.

Institute of Social and Economic Research Study

In 1993, the Institute of Social and Economic Research (ISER) at the University of Alaska evaluated the measured energy savings from the Alaska Low-Income Weatherization Assistance Program. It was one of the first formal attempts to quantify savings from weatherization programs in Alaska on a large scale. It used PRISM, an evaluation tool developed by Princeton University, and three sets of data for each home analyzed:

1. Monthly utility reading for several months, preferably 12 months before and after.
2. Average daily temperatures from a nearby weather station for the same period.
3. A set of normalized average daily temperatures computed from data covering at least a 10-year period.

The evaluators chose single-family homes and mobile homes that where heated by natural gas because utility readings where readily available. These homes where in the Anchorage area where natural gas was available. A total of 102 homes where evaluated; of these, 58 where single-family homes and 44 where mobile homes. Of the 102 homes evaluated, 26 had reliable data and showed an average savings of 11 percent. While this result was not great, it was not

bad, either, considering the sophistication of applied science at the time and the limited budget.

Alaska Building Energy Efficiency Standards

BEES were established by the State of Alaska to promote the construction of energy-efficient buildings. It sets standards for thermal resistance, air leakage, moisture protection and ventilation as they relate to efficient use of energy in buildings.

All new residential homes and community-owned buildings that began construction on or after January 1, 1992, must comply with the Alaska BEES that were in effect at the time the home was constructed in order to qualify for Alaska Housing Financing Corporation (AHFC) or other state financial assistance used in its construction or purchase.

The current standard is the 2009 International Energy Conservation Code (IECC) with Alaska Specific Amendments and ASHRAE 62.2 2010. The weatherization assistance program recognizes BEES and attempts to meet it even with existing construction.

Enhanced Weatherization Program

Another innovation was the Enhanced Weatherization Program (EWX) that began 1991. It provided a deeper retrofit approach for dwellings in the roadless areas of the state. Using State of Alaska funds, a budget that was three times greater than the usual amount per house was approved to complete a more comprehensive work scope and help compensate for the extra cost of logistics and freight. This approach has been very successful because it helps offset upfront costs – very important because the cost of energy resources in remote areas is several times higher than in road-connected areas.

So far, over 100 communities have been served and 2,000 homes have been weatherized. EWX has been a good proving ground for addressing rural-style housing that is often small, overcrowded and in need of maintenance because of funding shortfalls.

Alaska Housing Finance Corporation

AHFC is a self-supporting public corporation with offices in 16 communities across in Alaska. It was founded in 1971 but became more active in the mid-1990s when it took over responsibility for housing from the state Division of Community and Regional Affairs. It provides statewide financing for multi-family complexes, congregate facilities and single-family homes, with special loan options for low- to moderate-income borrowers, veterans, teachers, health care professionals and those living in rural areas of the state.

AHFC also provides energy and weatherization programs and low-income rental assistance in 17 communities, and special programs for the homeless and those seeking to become self-

sufficient. AHFC has contributed more than $1.9 billion to Alaska's state budget revenues through cash transfers, capital projects and debt-service payments.

AKWarm®

In 1996, the AHFC began using software developed by Analysis North – AkWarm – to help energy raters and mortgage loan officers determine the energy efficiency of a home, including the heating and air handling systems, building envelope and foundation. The weatherization assistance program began using AkWarm as a way to prioritize and confirm the cost effectiveness of energy improvement measures. DOE has approved it for this task in single- and multi-family homes. AkWarm is now also used to establish a home's energy rating in preparation for rebates from the AHFC Home Energy Rebate Program.

Weatherization Programs in Alaska Today

Cold Climate Housing Research Center

In September 2006, the Cold Climate Housing Research Center (CCHRC) Research and Testing Facility opened on land leased from the University of Alaska – Fairbanks, which allows staff to work closely with students, faculty and researchers at the university. Alaska offers an excellent testing ground for cold-climate technologies and products. The geography provides the full range of climatic conditions a researcher would encounter across the northern United States — from the windy, cool, wet weather in southeast Alaska to the very cold, snowy conditions across Alaska's northern tier. In addition, Alaska's cold season lasts for six months or longer, allowing ample time for researchers to conduct experiments and evaluate housing performance.

Re-Invigorating the Weatherization Assistance and Energy Rebate Programs

In 2008, the State of Alaska, under the governorship of Sarah Palin, appropriated $300 million to AHFC for weatherization assistance and energy rebate programs. The weatherization program raised the qualifying income to 100 percent median income. The significant new funding eclipsed prior weatherization program budgets, which had averaged $6 million to $8 million per year.

The original weatherization programs and several housing authorities received funds to implement the weatherization assistance program. The per-house budget was raised to $11,000 average per dwelling on the road system and $30,000 average per dwelling in the remote roadless communities.

In addition to funding the weatherization assistance program, $100 million of this appropriation was used to revamp the energy rating program to include rebates for energy improvements. Using AKWarm, the state-approved energy modeling program, the homeowner receives an

audit by a certified energy rater along with a list of possible improvements. The audit includes a blower door test and a worst-case depressurization test.

The qualified homeowner must improve the energy efficiency of the home by at least one step using the energy rating system. A final rating of 1 Star Plus or more must be achieved to be qualified for a rebate. The amount of the rebate is determined by the number of steps between the as-is and post-improvement energy ratings. Participants can choose whatever improvements will help them achieve enough points to increase their energy rating. The maximum rebate of $10,000 is issued if the dwelling increases its efficiency by five steps.

Homeowners may complete the improvements by themselves or by hiring a contractor, as long as the final energy rating as suggested in the program guidelines is achieved.

The program has been a huge success; over 5,300 homes were signed up in the first few months of the program. Since its inception in 2008, almost 28,000 homes have been rated and almost 16,000 have completed improvements and received rebates.

A recent analysis of energy savings based on AkWarm ratings and actual natural gas fuel usage show that the energy rebate program and the weatherization assistance program are saving, on average, 30 percent per house. Most of the savings for the rebate program are attributed to upgrades to the heating system. In the weatherization program, savings are mostly attributed to improvements to the building envelope.

The federal American Recovery and Reinvestment Act (ARRA) infused additional money into the State of Alaska. It was mostly applied to multi-family buildings, with a large portion going to public housing.

Alaska Retrofit Information System

Recently, a database system was developed by Resource Data Inc. and managed by CCHRC to collect, manage, access and report on information relating to the AHFC rebate and weatherization programs and other official uses of AkWarm. It cleanly, securely and reliably integrates AkWarm, weatherization and energy rebate program data, data processing and reporting.

Weatherization Standards

A new set of weatherization standards for Alaska was written and implemented in 2009. Based on a set of regional standards and incorporating the latest in building science testing and best practices, it sets a benchmark for energy rehabilitation work in Alaska. A work in progress, it is continually updated to reflect the latest in applied building technology.

Training

The weatherization and energy rebate programs continue to promote and offer trainings in energy rehabilitation and building science. BPI certification for building analysts is now required for all energy raters.

The Tlingit and Haida tribes received $1.1 million in ARRA funds to develop a training center in Juneau. Part of the money was used to buy a manufactured home to use as a classroom and hands-on lab. So far, over 100 attendees have completed courses in Wx. Tech 1, Wx Tech 2 and Assessor.

Other training entities include Alaska Builders Science Network, Alaska Craftsman Homes, and Steve Wisdom and Associates. All have been active in providing training for the weatherization and energy rating programs.

The Future of Residential Energy Retrofitting in Alaska

The state has set a goal of a 15 percent increase in energy efficiency by 2020. To achieve this, Alaskans will mine the wisdom gained from 30 years of applying energy technologies to improve residential buildings in Alaska. State government continues to provide funding and residents continue to accept, participate in and benefit from these energy programs. Because energy resources in Alaska will continue to be expensive, efficiency is still the most cost-effective way to reduce demand.

Research and development continue to be carried out by entities such as CCHRC. Adoption of better standards and best practice is evolving, and an energy use standard of British thermal units (Btu) per square foot is being considered. The possibility of a more concise and directed training program for energy technology using the existing state university system is also being considered. An association for the state energy raters is being developed.

Resources

- Alaska Housing Finance Corporation: http://www.ahfc.us
- Cold Climate Housing Research Center: http://www.cchrc.org/
- Alaska Builders Science Network: http://www.absn.com

Canadian Weatherization Programs

By Don Fugler, Canada Mortgage and Housing Corporation

Canada is cold in winter. Canadian homes need to be relatively airtight and well-insulated to avoid occupant discomfort and high heating costs. New Canadian houses are designed to minimize heat losses, but older houses are often poorly insulated and prone to air leakage. Energy retrofits can help homeowners minimize energy use by adding insulation, diligent air sealing, upgrading windows and replacing older mechanical systems with new, high-efficiency equipment.

Despite the obvious benefits to homes and their occupants of energy retrofits, these programs in Canada have a mixed history. Compared to the weatherization industry in the U.S. which has evolved over the past 30 years, Canadian weatherization efforts have been episodic. When they are actively promoted, they have been quite effective, resulting in retrofits to a large proportion of the national housing stock.

Canadian home retrofit programs from the 1970s to the present are evaluated here, along with an examination of how the programs have been catalysts for developing the weatherization industry in Canada and prompting new technical research. This section concludes with an appraisal of where retrofit programs now stand for the industry, for the governments that sponsor them, and for homeowners who are the potential consumers.

Retrofit Programs

Saving energy in houses is worthwhile, and doing it safely and cost-effectively is preferable. Focusing on low-income homeowners can provide benefits to those who need it most. Canadian experience with retrofit programs parallels the U.S. experience in many ways; the programs are usually politically inspired, they are often launched without adequate preparation and they usually fall short of their saving targets. Many lack rigorous evaluation, making it difficult to evaluate the programs' effectiveness, costs and benefits.

The more significant Canadian energy retrofit programs are described below, starting with the oldest programs and working up to current programs. The three major federal initiatives – the Canadian Home Insulation Program (CHIP), EnerGuide for Houses and ecoENERGY – are included, along with other federal, provincial and utility initiatives. These smaller programs are included if they specifically:

- Changed the way that retrofits were conducted, through research and/or demonstration,
- Were especially well documented, or
- Were of a particularly long duration.

Most of these programs are directed at low-rise, residential dwellings, although there have been many programs for multi-unit buildings. All quoted numbers are approximate unless there is a specific program report reference.

The Canadian Home Insulation Program

Reason for initiation	Oil embargo in 1973-74. Subsequent shortage in 1979 proved the point.
Duration	1977-1987
Number of houses treated	450,000 homes across Canada
Extent of house treatment	Largely attic and wall insulation, with some whole-house upgrades.
Program successes	High number of houses retrofitted. This program introduced retrofit concept to Canadian homeowners and landlords. Aggregate energy savings of 17 percent in participating houses.
Problems/repercussions	Urea formaldehyde foam insulation (UFFI) problems resulted in the product being banned in Canada and a $500 million lawsuit against the federal government that was eventually dismissed. Indoor air quality and moisture problems resulted from many of the installations due to lack of knowledge about house moisture balance and ventilation needs.
Available references	Scanada 1996

Manitoba Home Retrofit Projects

Reason for initiation	Energy saving program launched by Manitoba Hydro
Duration	Energy Demo (pilot) project 1983, town energy audit match (TEAM) 1984, Home Check-up Program (circa 1984-1990)
Number of houses treated	Energy Demo had 154 audits and 83 retrofits, the TEAM project had 640 audits, the Home Check-Up program averaged about 4,000 houses per year
Extent of house treatment	Extensive audit, airsealing and insulation program. Averaged up to 40 percent of the total energy consumption in the demo retrofits.
Program successes	One of the first comprehensive programs using blower doors, proper airsealing, monitored results. Proceeded from pilot to town project where auditors were trained for the program, to province-wide implementation.
Problems/repercussions	Pilots were undertaken prior to electronic reports so data is not readily available.
Available references	Final Report on the Energy Demo - Home Energy Saving Demonstration Program. UNIES Ltd., March 1985. Energy Savings Analysis Energy Demo Program. UNIES Ltd., May 1988. Final Report on the Town Energy Audit Match (T.E.A.M.) Project, March 1985.

PowerSmart (BC Hydro) Home Improvements Program

Reason for initiation	Utility energy-saving program
Duration	1990 to mid-90s
Approximate cost	Program provided loans (up to $7,000) only to homeowners so program costs were largely administrative and training
Number of houses treated	27,000 electrically heated houses with whole-house retrofits in British Columbia
Extent of house treatment	Audited by trained personnel at start; airtightness tested; depressurization tested; airsealing, insulation, mechanical systems, ventilation added.
Program successes	Whole-house approach, airtightness testing became common in BC, lots of contractor training, good contractor uptake at the end of the program.
Problems/repercussions	Three disgruntled homeowners and lawsuits diminished Hydro enthusiasm; insufficient documentation of results.
Available references	Scanada 1996

Espanola Community-Based Energy Conservation Program

Reason for initiation	Demand-side management (DSM) pilot for Ontario Hydro using a single, isolated town to test house and commercial building audit and retrofit strategies.
Duration	Approximately 1989-1996, including planning, execution, monitoring and analysis.
Approximate cost	For electrically heated houses, average retrofit costs were $3,000 from the homeowner and $5,000 from Hydro. Houses with other heating sources had lighting retrofits only with an average total cost of about $200. Commercial building retrofits were about double the cost of houses ($17,500). Program support was about $7.5 million.
Number of houses treated	1,767 homes and commercial buildings (of a potential total of 2,035) in Espanola, Ontario, with the major retrofits being for electrically heated buildings.
Extent of house treatment	Extensive: trained auditors, blower door testing, IAQ testing, followed by air sealing treatments, insulation, mechanical system replacements, windows and door replacements, heat recovery ventilators (HRV) installations, nominal lighting replacements.
Program successes	Average annual saving in electrically heated houses was 7,673 kWh. Commercial buildings showed average savings of 37,052 kWh annually. House assessment and moisture assessment procedures were developed during the course of the project.
Problems/repercussions	Unexpectedly large number of homes with moisture problems. Project reports hard to locate. Hydro did not use the pilot to make a provincial program.
Available references	Scanada 1996

Eval-Iso

Reason for initiation	Research project and pilot program for planned province-wide retrofit program
Duration	1992-1994
Number of houses treated	Approximately 1,100 dwellings audited and retrofitted, including single family, duplexes, triplexes, and multi-unit buildings.
Extent of house treatment	Attic and wall insulation, basement insulation, window and door replacement, air sealing.
Program successes	Comprehensive project that developed cost estimates for work and savings on a wide variety of Quebec houses. Used most current contemporary practices from Canadian and U.S. sources.
Problems/repercussions	The need for ventilation (and its consequent costs) became apparent, which would reduce anticipated savings. Although the project was to be a model for ensuing Hydro Quebec programs, the subsequent initiatives were smaller and more limited than anticipated.
Available references	Scanada 1996

EnerGuide for Houses (EGH)

Reason for initiation	Federal government initiative to reduce greenhouse gas creation and need for imported energy.
Duration	1998-2006
Number of houses treated	266,000 houses evaluated across Canada with many provinces offering supplemental funding. Roughly 83,000 houses had sufficient work done to warrant the post-retrofit evaluation and compensation. (Parekh et al., 2007)
Extent of house treatment	Varied from house to house. Government rebates depended on the increase in the house rating (EGH number) between the pre- and post-retrofit tests.
Program successes	High number of houses treated. Development of cadre of trained auditors for house testing. Huge, central database of airtightness test and house characteristic data now available for Canadian housing stock. Provinces and utilities would piggyback their incentive programs upon the EGH results, leading to better uptake by homeowners. This program, popular with the public, is near the end of its run.
Problems/repercussions	High program overhead compared to number of houses treated. Many of the retrofits were basic furnace replacements or basement insulation with very little emphasis on whole-house savings. Lack of documented energy savings from houses (initial usage and savings were predicted using HOT2000 software).

ecoENERGY

Reason for initiation	Federal energy-saving program launched after strong public response to government cancellation of previous EnerGuide program
Duration	2007-2011, with a small break and then an extension from 2011-2012
Approximate cost	Average grant to homeowner in the range of $1,000-$1,500
Number of houses treated	750,000 houses on pre-retrofit audit and over 500,000 houses with post-retrofit results
Extent of house treatment	Varies from furnace replacement to whole-house retrofit. Payment to homeowners now linked to specific actions and improvements, and not the EGH rating pre- and post-retrofit
Program successes	Huge number of houses. Excellent airtightness test and house characterization data. Predicted annual heating savings of 21 percent
Problems/repercussions	Simulated energy usage for calculating savings

The Effect of Retrofit Programs on Industry

Sustained programs tend to encourage the growth and maturity of the retrofit industry and affiliated trades.

Training

The large national programs provided an incentive across the country and spurred development of residential retrofit training programs. This has also been true of the more sizeable provincial or utility programs. Some of the smaller, focused provincial programs (such as those concentrating on social housing multi-units) have also encouraged the evolution of contractor skills and expertise by dint of their longevity.

Training in the 1980s-wave of retrofits was coordinated by trade associations such as the National Energy Contractors Association (NECA) or the Heating, Refrigeration, and Air Conditioning Institute of Canada (HRAI), often with the support of federal funds. The development of the R-2000 standard for new houses and the training courses for that program also prompted the formation of a group of trainers well versed in building science who handled new house and retrofit training.

Innovation

Insulation companies are ubiquitous in Canada and they can increase output when demand is ramped up by programs. With rare exceptions, they tend to deal specifically with the installation of insulation and have only recently begun to explore the related specialties of air tightening and moisture control. The major changes in insulation practice over the last thirty years (e.g., dense-pack cellulose, spray foam and loose fill combinations) have usually migrated northward from the innovative work being done by U.S. weatherization crews.

The Canadian retrofit experience showed leadership (or at least parity) with their U.S. counterparts in three areas: research, consulting firm expertise and equipment development. The CHIP program initiated much of Canada's building science research as moisture problems and IAQ concerns arose following the installation of insulation in older homes.

Generally, Canadian building science research has evolved from the National Research Council (NRC), where a series of scientists and engineers from 1950 to 1990 (including Handegord, Wilson, Latta, Hutchings and Shaw) laid the groundwork for understanding how buildings function. The list of Building Digests on the NRC website (NRC 2011) shows the extent and accuracy of this seminal research. The NRC Prairie Regional office in the 1970s and 1980s was equally fruitful in its work, developing super-insulated houses and early blower doors.

The specific research on energy retrofits and IAQ was led by agencies such as NRC, Natural Resources Canada (NRCan) and Canada Mortgage and Housing Corporation (CMHC). NRCan published widely on its new house and retrofit research. Among its many accomplishments was developing the popular house energy simulation program – HOT2000 (NRCan 2011).

CMHC, the federal housing agency, was instrumental in energy and IAQ research, providing basic information for the Canadian and U.S. weatherization industry on issues such as combustion spillage, ventilation issues and garage-to-house air movement (CMHC 2011). CMHC also released guidelines on retrofitting houses of particular types and ages (CMHC 2004).

The consulting and engineering firms that undertook this research became experts in those fields, and helped promote and expand the lessons learned in research. Often among the speakers at engineering and trade conferences, they applied their acquired expertise to provincial, municipal and private enterprise projects, especially when federal programs were in abeyance.

Knowledge Sharing

The research and testing fields prompted the development and manufacturing of Canadian test tools (such as blower doors) and weatherization products.

Canadian retrofit knowledge was also translated into the development of codes, standards and guidelines. The first blower door test equipment standard was from the Canadian General Standards Board in 1986 (CGSB 1986). The first field test to predict combustion spillage was also from CGSB (CGSB 1995). The first North American standard on residential mechanical ventilation was from the Canadian Standards Association (CSA 1991). Health Canada published the first set of residential guidelines for indoor air quality in 1987 (HC 1987), which have been used in research and monitoring ever since their issue.

Canadian conferences on the advances in energy retrofits are not held as regularly as their U.S. counterparts of ASHRAE (ASHRAE 2011) and Affordable Comfort (AC 2011). There are presentations on energy retrofit and building science topics at an annual builders' conference in Toronto (CC 2011), but the focus is predominantly new houses. A series of biennial conferences by the Building Envelope Council of Canada (BECOR 2011) cover retrofit and energy matters. A targeted conference for Canadian home energy retrofits, inspired by the Affordable Comfort series, was held in Toronto in 2009 to deal with the issue comprehensively (ERH 2009), but was not repeated.

Conclusions

Canada's house energy retrofit history is characterized by several massive federal programs that changed the landscape. These programs – CHIP, EnerGuide and ecoENERGY – resulted in hundreds of thousands of house energy retrofits, a large proportion of the existing housing stock. The programs inspired the growth of a retrofit industry and training of trade professionals, and also prompted the energy characterization of Canadian homes by region and by age, which created a valuable database.

The actual energy savings for each homeowner, or for the country as a whole, can only be estimated because recording energy consumption was not part of these programs. The sporadic nature of the programs has made it difficult for contractors and professionals to commit themselves to the training and professional development that might accompany a healthy industry that shows steady growth.

Besides the large federal programs, many smaller, local programs were initiated by provincial or municipal governments or local utilities. While most of these lack public documentation of their successes and shortcomings, they have improved the housing stock, both low- and high-rise, in their vicinities and encouraged growth in their local retrofit industries.

The means of doing energy retrofits, and the hazards involved, have been the subject of research, technical knowledge transfer and training since the early 1980s. A developed cadre of engineering and trade professionals understands how to undertake the work effectively. However, there is a good chance that the tradesperson who shows up on site to do the work is not aware of these issues.

There is no question that a supported industry can develop the skills and expertise to properly retrofit houses. It is not known whether the energy retrofit business can thrive without program support. It is also unclear whether Canadian homeowners value quality retrofits, as demonstrated through supporting the government expenditure on programs or by paying directly for effective retrofits by trained contractors.

Resources

Affordable Comfort, 2011. Retrieved from http://www.affordablecomfort.org/, July 2011.

ASHRAE, 2011. Retrieved from http://www.ashrae.org/, July 2011.

BECOR, 2011. Retrieved from http://www.becor.org/main.php?page_numb=9, July 2011.

Construct Canada, 2011. Retrieved from http://www.constructcanada.com/pre_show_2011/index.php, July 2011.

Canadian General Standards Board. *The Spillage Test*. 1995.

Canadian General Standards Board. *Determination of the Airtightness of Building Envelopes by the Fan Depressurization Method*. 1986.

Canadian Mortgage Housing Corporation. *Renovating for Energy Savings Series*. 2004. Retrieved from http://www.cmhc-schl.gc.ca/en/co/renoho/reensa/reensa_003.cfm?K1=type&Submit=Search, July 2011.

Canadian Mortgage Housing Corporation. Website list of research highlights. Retrieved from http://www.cmhc-schl.gc.ca/en/inpr/rehi/ July 2011.

Canadian Standards Association. *CAN/CSA F326: Residential Mechanical Ventilation Systems*. 1991.

Energy Retrofits for Houses. Materials retrieved in 2009; website no longer available as of July 2011.

Health Canada. *Indoor Air Quality Guidelines*. 1987. Retrieved from http://www.hc-sc.gc.ca/ewh-semt/air/in/res-in/index-eng.php, July 2011.

National Research Council. Electronic list of Building Digest series. Retrieved from http://www.nrc-cnrc.gc.ca/eng/ibp/irc/cbd/digest-index.html , July 2011.

National Research Council. *HOT2000*. Retrieved from http://canmetenergy-canmetenergie.nrcan-rncan.gc.ca/eng/software_tools/hot2000.html, July 2011.

Parekh, Roux, and Gallant. "Thermal and Air Leakage Characteristics of Canadian Housing," *11th Canadian Conference on Building Science and Technology*, Banff, Alberta, 2007.

Scanada. "Review of Retrofit Studies and Programs," prepared for Michael Swinton, National Research Council of Canada, Ottawa, Ontario, 1996.

The New York Experience

By Dick Kornbluth, dick@dickkornbluth.com

The Market Before Home Performance with ENERGY STAR

Central New York has a climate of 6,800 heating degree days. The Middle East oil crisis in the mid-1970s stimulated significant growth in the local Syracuse retrofit insulation industry. The business listings in the 1981 phone book for the metropolitan Syracuse area – population 250,000 – listed 75 retrofit insulation companies.

In 1977 New York passed the Home Insulation and Energy Conservation Act (HIECA) which mandated that private utilities offer residential energy efficiency services including audits and financing for energy efficiency improvements (Hamburg). As indicated in Figure 20, three upstate New York utilities participated in this program:

- Niagara Mohawk Power Company, which served central New York to Albany,
- New York State Electric and Gas Company (NYSEG), which served the lower tier (Binghamton) and
- National Fuel Gas, which served the Buffalo area.

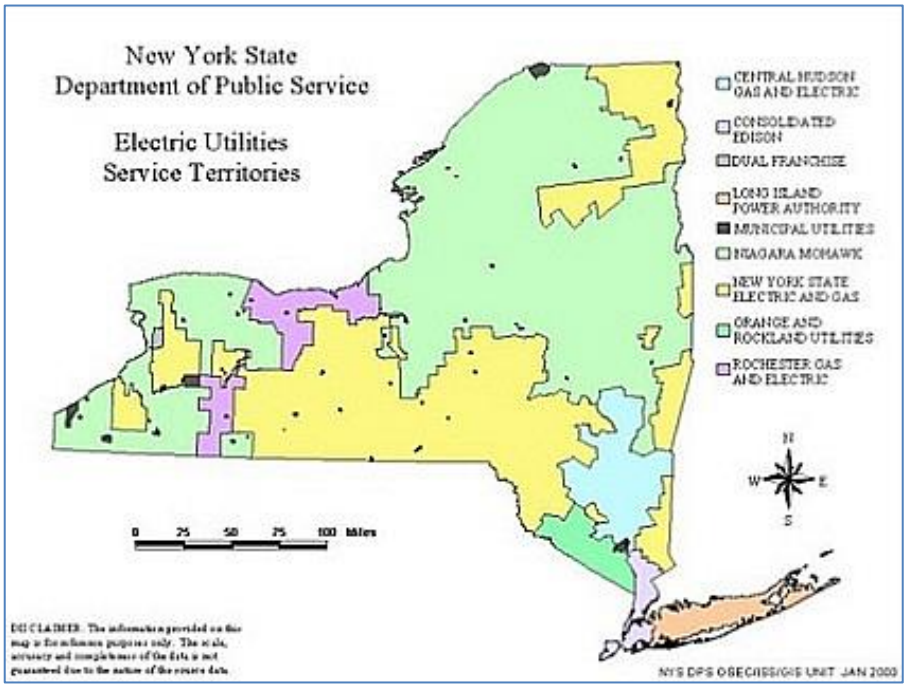


Figure 20. Electric Utilities Service Territories in New York State

Niagara Mohawk and NYSEG provided both electricity and gas. National Fuel Gas was a gas-only provider.

Initially, audits were available through two paths: a do-it-yourself audit and a utility-provided audit. The do-it-yourself audit was an eight-page workbook into which the homeowner entered basic information about the house (square feet of walls and attic, number of windows, existing insulation value of walls and attic). There were calculation factors that calculated projected savings. When the homeowner entered their heating fuel type and costs, projected simple pay-back was calculated. In 1983, the do-it-yourself audit was discontinued.

The utility-provided audit was a walk-through clipboard audit done by a utility employee who collected data that was similar to the data requested in the do-it-yourself workbook. Eligible measurements include attic, wall and floor insulation, storm windows and storm doors, clock thermostats, furnaces and boilers, including fuel conversion and weather stripping. Air sealing as a retrofit measure was unknown at the time.

Energy efficiency improvement measures that showed a simple seven-year or better payback were eligible for financing. In 1981, loan interest rates were in the range of nine to ten percent. (For comparison, in 1980-1982, consumer loan interest rates were 18 to 22 percent.) Maximum loan amounts were $2,500 for single family, $3,500 for two-family, $4,000 for three-family and $4,500 for four-family homes. (Hamburg). Sometime in the mid-1980s, the interest rates for HIECA loans were reduced to zero.

There were no specific training or experience requirements for contractors to participate in the program. This program was discontinued in the late 1980s.

By 1990, the number of retrofit insulation companies in the Syracuse phone book had dropped to fewer than 10, and only three of the companies listed in the 1981 phone book were still in existence. With the exception of one company, all of the companies used the basic “blow and go” insulation technique, which did not include air sealing, blower door testing or combustion safety testing, including draft, spillage, and carbon monoxide testing.

In 1991, Niagara Mohawk, under orders from the Public Service Commission (PSC), created a performance-based low-income weatherization program called the Power Partnership program. The program was eventually replaced by the Empower program in the early 2000s, which used private contractors to deliver the services and included a four-day training program. The Power Partnership program included:

- Pre- and post-retrofit blower door testing,
- Blower-door guided air sealing using a computer-generated calculation of the minimum ventilation guideline,
- Combustion safety testing including draft, spillage and efficiency,
- Pressure balancing to determine duct leaks and
- Duct sealing.

A similar program was instituted by the New York State Electric and Gas (NYSEG) utility that serviced the upstate New York area in the Binghamton area and Rochester Gas and Electric that served the Rochester, New York market.

Unfortunately, the knowledge and experience gained in the program were not transferred to the private sector. With a few exceptions, participating contractors returned to their traditional insulate-only model when doing private sector work.

In 1998-1999, Niagara-Mohawk attempted to create a private sector Home Performance Contractor industry. They recruited and trained contractors using staff from the Kansas Building Science Institute and other subject matter experts. Billing inserts and television commercials were created to market whole house services. An audit was offered that included blower door testing, combustion health and safety testing including worst-case depressurization, spillage, and draft and carbon monoxide testing. The set fee for this audit was $99.

Unfortunately, the effort failed to generate significant business for contractors and it was eventually abandoned. The one positive outcome of the program, however, was the creation of the Building Performance Contractors Association of New York State (BPCA/NYS), which has thrived and grown to over 300 members (www.home-performance.org).

Home Performance with ENERGY STAR®

The breakthrough in New York occurred with the start of the Home Performance with ENERGY STAR program (HPwES) in 2001. The program, administered by the New York State Research and Development Authority (NYSERDA), is funded from the Systems Benefit Charge (SBC) that was established in 1996 by the New York PSC when private utilities in the state were deregulated. SBC funds are collected from customers by the state's six investor-owned electric utilities through a small surcharge on customers' bills. Its purpose is to support energy efficiency, education and outreach, research and development, and low-income energy assistance. SBC funds are administered by NYSERDA.

In 2010, New York passed the Green Jobs/Green New York bill, which provided additional funding for NYSERDA's Home Performance with ENERGY STAR® program from funds collected through New York's Regional Greenhouse Gas initiative.

Home Performance Contracting Models

Here we look at basic models for home performance contracting and the New York program. These models are compared in Table 15.

Table 15. Home Performance Contracting Models

Model Types		Consultant	General Contractor	Trade Contractor	Full Service Contractor
Advantages	Low barrier to entry	Yes	Yes	No	No
	Low capital investment	Yes	Yes	No	No
	Low operating costs	Yes	Yes	No	No
	Homeowners may be willing to pay for independent third-party consultant who will ensure quality	Yes	N/A	N/A	N/A
	Reduced liability; liability shared or transferred to sub-contractors or referred contractors	Yes	Yes	Only for non-in-house work	No
	Not bound to installers; can change installers if QC problems occur	Yes	Yes	Partially - only for work not done in-house	N/A
	Network of sub-contractors/ referred contractors can be a good lead source	Yes	Yes	Yes	No
	Provides point of entry to home performance contracting that allows for phased approach	No	Yes	Yes	N/A
	Services delivered in-house provide greater control over quality	N/A	N/A	Yes	Yes
	Higher profitability for in-house work	N/A	N/A	Yes	Yes
	Easier to schedule in-house jobs	N/A	No	Yes	Yes
	Easier to manage service with in-house jobs	N/A	No	Yes	Yes
Disadvantages	Limited revenue per customer; need lots of customers to make business model work	Yes	No	No	No
	Lower profit/job since profit must be shared with sub-contractors	N/A	Yes	Yes	No
	Can take time to develop network of skilled qualified sub-contractors/ referred contractors	Yes	Yes	Yes	No
	Production scheduling is more complicated since contractor must work around sub/referred-contractor's schedules	Yes	Yes	Yes	No

Model Types		Consultant	General Contractor	Trade Contractor	Full Service Contractor
	QC and QA more difficult to control with sub-contracted/referred work	Yes	Yes	Yes	No
	Managing service and call-backs can be a problem	Yes	Yes	Yes	No

Consultant Contractor Model

The consultant contractor works for the homeowner directly or for the trade contractor. When the consultant works for the homeowner, he/she performs a comprehensive home assessment (CHA) energy audit and develops a detailed workscope. The consultant provides a list of approved trade contractors that the homeowner can choose to do the work.

The consultant oversees the work to ensure that it is done correctly and to the specifications that he/she has written. The consultant performs a final QA check on the work and a test-out to ensure that there are no issues of combustion health and safety or building over-tightness. The test-out includes the same set of combustion health and safety tests and the blower door test that was performed during the CHA.

Consultant contractors may also work directly with trade and remodeling contractors. Consultants typically work with insulation, HVAC, general remodelers and home improvement companies. For example, after a customer hires an insulation or HVAC contractor, the contractor could hire a consultant to perform the CHA and develop the workscope. The value of this arrangement is that the consultant, as an independent third-party expert, can ensure that the job will not create problems for the house or the homeowner, and the QA provided by the consultant can be a powerful selling tool for the contractor. The consultant's fee would be built into the cost of the project.

General Contractor Model

The general contractor performs the CHA, develops the workscope, sells the job, processes NYSERDA financing applications and performs the test-out. All installations are sub-contracted.

Trade Contractor Model

The trade contractor performs the CHA, develops the workscope and offers some, but not all, of the services required to perform comprehensive whole house work. For example, the trade contractor may offer insulation and air sealing services but not HVAC. The trade contractor has several options for delivering whole house services, including referral to the trade not delivered in-house or sub-contracting the services not delivered in-house. The trade contractor also performs the test-out at the end of the project.

Full-Service Contractor Model

The full-service home performance contractor offers insulation, air sealing and HVAC services in-house. All work is done by employees.

Other Contracting Considerations

In addition, there is a model where a third-party performs the CHA for a fee and simply provides a report with recommendations to the homeowner. The homeowner can then look for a contractor to do the work. Although there are a few companies doing audits only, this model has not shown significant growth in the program.

NYSERDA Model

The NYSERDA model is based on the home performance contractor models: the contractor does the CHA, which includes combustion health and safety tests, a blower door test, software building modeling and workscope development with recommendations. The contractor performs the work and does the test-out, which includes combustion health and safety testing and blower door testing.

The home performance contracting model that was most common in New York was the trade contractor model. The dominant trade participating in the program was shell contracting for insulation and window replacement.

In the residential sector, the general contracting model most closely fits the general remodeling industry. However, NYSERDA struggled for several years to find a way to incorporate remodeling contractors into the HPwES program but was unable to develop a workable model.

It is interesting to note that, for many years, the HPwES program was unable to attract significant participation from the HVAC industry. Possible reasons for this include:

- The whole house model, with its emphasis on treating the shell first to reduce the heating/cooling load, is not compatible with an HVAC contracting model that is based on simple heating system replacements (box-swapping).
- The financing offered through the HPwES program, which made it attractive for shell contractors who were unused to offering financing, was less attractive to HVAC contractors who had access to manufacturer-supplied financing.

For many years after the HPwES program began, few, if any, full-service home performance contractors (HPCs) were available. Shell contractors either referred the HVAC work or sub-contracted it out. Reasons for this include licensing requirements for HVAC contracting in some

areas[26] and concern that if an HVAC specialist was hired, there might not be enough work to keep him/her busy. For contractors, requirements to participate in the HPwES program include:

- Accreditation by the Building Performance Institute (BPI)
- BPI Certified staff sufficient to deliver the contracted services, including
  - Building analyst
  - Envelope specialist (for insulation)
  - Heating specialist (for HVAC heating)
  - Cooling specialist (for HVAC air conditioning)

Contractor Incentives

To encourage the growth of the Home Performance Contracting industry in New York, NYSERDA offers the following contractor incentives:

- **Comprehensive Home Assessment Reimbursement**
  In order for homeowners to qualify for financing and incentives under the HPwES program, they must receive a CHA. The CHA could take anywhere from two to four hours in the house and an additional one to three hours modeling the house with the program's required energy modeling software, TREAT. Contractors were free to charge whatever they felt was required for the CHA until the passage of the Green Jobs/Green New York legislation, which mandated free audits. To help the contractors, NYSERDA agreed to pay $250-$400 to the contractors for performing the CHAs.

- **Advanced Modeling Incentive**
  Five percent of the value of the eligible measures installed, up to $500/project.

- **General Contractor/Referral Incentive**
  This incentive is given to the general contractor when there is a single contract for a project and portions of the work are sub-contracted. It is also available to a participating contractor who refers work to another participating contractor, who signs a separate contract with the customer as long as both contracts are part of the same project. It is worth two percent of the value of the eligible measure installed, up to $400 per project.

- **Equipment Incentive**
  This is a one-time offer for new contractors or contractors who are expanding into a new region in the state, worth 20 percent of the cost of new equipment, up to $4,000.

[26] In New York State, there is no state licensing for trade contractors; licensing is by community or county. There is no licensing anywhere in the state for insulation contracting but there is for HVAC, electrical contracting and plumbing.

- **Co-operative Advertising**
  Available to participating contractors who meet certain spending and production levels. Incentive is 50 percent of the cost of advertising.

- **Company BPI Accreditation**
  Worth 50 percent of the cost for new and renewal BPI accreditation.

- **Incentives for Contractors Participating and Completing Jobs in SBC Territory** (territory serviced by the investor-owned electric utilities)
  - Electric Reduction Incentive
    - ENERGY STAR refrigerator: $75
    - ENERGY STAR dishwasher: $60
    - ENERGY STAR room A/C: $25
    - ENERGY STAR lighting (hardwired CFL or electronically ballasted fluorescent fixtures): $25
    - ENERGY STAR dehumidifier: $25
  - First Completion Incentive
    One-time $500 incentive
  - First-Year Production Incentive
    One-time $1,500 incentive awarded when contractor completes 24 program projects (or $180,000 in work) within 12 months of participation.
- **Training/Certification Incentives**
  - Tuition Reimbursement
    - 50 percent one-time reimbursement per BPI designation (available to anyone)
    - Additional 25 percent for staff of participating HPwES contractors
  - BPI Certification Reimbursement
    - 75 percent of written and field exam fees for new certifications (available to anyone)
    - Additional 25 percent for staff of participating HPwES contractors that achieve new certifications
    - 75 percent of field exams for renewal certifications

These incentives are summarized in Table 16.

Table 16. Contractor Incentives

Contractor Incentives									
Year	Equipment Reimbursement	Training Reimbursement	Certification Reimbursement	Accreditation Reimbursement	5% Advanced Modeling Incentive	Electric Reduction Incentive	General Contractor Incentive	Referral Incentive	Co-Op Advertising Incentive
2001	$122,153	$52,050	$83,381	$52,550	$130,460	$15,170	$41,170	$1,169	$136
2002		$139,965		$39,769	$239,968	$64,777	$26,992	$6,756	$39,524
2003		$118,409	$27,150	$88,088	$637,881	$14,945	$67,833	$11,095	$51,615
2004		$237,195	$75,788	$99,131	$800,221	$30,750	$92,632	$20,551	$104,561
2005	$87,389	$270,921	$92,813	$124,275	$965,100	$30,700	$95,769	$8,973	$224,173
2006	$38,462	$603,348	$105,327	$138,921	$1,325,460	$50,459	$88,090	$10,434	$206,329
2007	$25,592	$525,816	$237,115	$285,344	$1,377,009	$10,146	$101,721	$8,861	$639,180
2008	$19,372	$1,369,457	$132,175	$313,317	$1,732,501	$32,570	$97,563	$19,452	$824,013
2009	$42,286	$1,757,319	$104,925	$359,625	$2,049,335	$24,340	$113,438	$20,717	$1,049,154
2010	$120,437	$1,028,002	$114,006	$262,762	$1,999,671	$17,060	$109,407	$23,606	$701,038
2011	$55,351	$212,111	$20,806	$160,701	$1,447,321	$10,477	$65,274	$12,996	$588,801
Total	$511,042	$6,314,592	$993,485	$1,924,483	$12,704,926	$301,394	$899,888	$144,609	$4,428,523

The growth in contractor participation in the HPwES program is shown in Table 17 (source: NYSERDA):

Table 17. Growth in Contractor Participation in the HPwES Program

2011 Data is through 9/30/2011

Year	Number of Total Participating Contractors	Shell Only	Heating Only	Both Heating & Shell	Heating and Coolling	Building Analyst
2001	52	18	13	21	0	52
2002	84	24	26	34	0	54
2003	103	33	26	44	0	103
2004	99	23	31	45	0	99
2005	109	27	20	62	18	109
2006	127	37	16	74	26	127
2007	144	37	18	89	34	144
2008	154	40	23	91	45	154
2009	208	70	22	116	57	208
2010	289	116	33	138	68	289
2011	297	105	23	132	60	297

The data here indicate that this program has attracted more growth on the shell (insulation) side of the industry than on the HVAC side of the industry. During the 10 years of the program, there was relatively little growth in HVAC contractor participation while shell contractor participation increased three- to four-fold. A glance through any business telephone listing verifies that the number of HVAC contractors in a given area is significantly greater than the number of shell contractors.

Also note the more than six-fold increase in the number of contractors doing both HVAC and shell work. The original goal of NYSERDA's HPwES program was market transformation. The data from Table 17 indicates that, to some extent, market transformation has occurred as single trade shell contractors have transformed their business to whole-house services by adding the HVAC component.

Homeowner Incentives/Financing

Traditionally, insulation projects were relatively low cost ($1,000-$4,000) and were rarely financed. Most residential single-trade insulation contractors had little to no experience with financing. The average cost for a comprehensive, multi-trade home performance project was $8,500-$9,000. This was beyond most homeowners' ability to pay for without financing or assistance. The ease with which financing could be arranged through the HPwES program became the lubricant that enabled contractors to sell comprehensive services.

- **Unsecured Loan**
  - Borrower eligibility: Applicant who owns a one- to four-unit residential building
  - Credit Requirements :
    - FICO score greater or equal to 640
    - Debt to income ratio less than 50 percent
  - Loan amount: Up to $13,000, or $25,000 if the financed portion of the project has a payback of 15 years or less.
  - Loan term: 5, 10 or 15 years
    Term may not exceed weighted useful life of financed measures
  - Interest rate: 3.99 percent (3.49 percent if paid through ACH payment)
  - Fees: $150 lender processing fee (may be included in amount financed)
- **On-Bill Recovery Loan**
  - Borrower eligibility: same
  - Credit requirements: same
  - Loan amount: same
  - Loan term: same but, in addition, monthly loan installment amount may not exceed 1/12 of estimated annual energy savings
  - Interest rate: 2.99 percent
  - Fees: Same
  - Other:
    - Applicant must have account with participating utilities
    - Loan payment is on utility bill
    - Loan stays with meter if house is sold
    - Requires a mortgage to be signed and filed by NYSERDA to provide notice to any subsequent purchaser of the property The mortgage is not subject to any fees or

NYS recording tax and is subordinate to any current or future mortgage on the property
    - When house is sold, the unpaid balance of loan can be transferred to the new owners
- **Energy $mart Loan Fund**
    - Loan amount: up to $20,000
    - Loan term: 10-year maximum
    - Interest rate: Bank interest rate decreased by up to 4.0 percent
    - Offered by not-for-profit affordable housing organizations
    - Can be combined with High Efficiency Measure Incentive (see below)
- **Assisted Home Performance (50 percent subsidy)**
    - Based on income eligibility equal to or less than 80 percent of the state or local median family income, whichever is greater.
    - Subsidy of 50 percent of cost of approved project up to $5,000 for single-family home and up to $10,000 for a two- to four-family home.
    - Can be combined with unsecured financing
- **High Efficiency Measure Incentive (HEMI)**
    - 10 percent of cost of eligible measures up to $3,000
    - Can be combined with an unsecured loan

The tables and figures on the following pages provide additional details about this program.

Table 18. NYSERDA HPwES® Projects

	Total Projects			Core Energy		Central Heat		Windows		ealth & Safety and Accessorie	
Year	Project Cour	Contracted Valu	Avg Contract Pr	Project Cour	Contracted Valu	Project Cour	Contracted Valu	Project Cour	Contracted \	Project Cour	Contracted Valu
2001	350	$2,842,039	$8,120	311	$1,592,987	0	$0	153	$1,009,288	74	$239,765
2002	1,091	$7,199,852	$6,599	1,020	$4,775,628	3	$20,764	337	$2,044,840	187	$358,620
2003	2,459	$17,884,376	$7,273	2,015	$7,361,084	1,022	$4,232,523	927	$5,761,125	564	$529,643
2004	2,561	$18,393,073	$7,182	2,336	$8,371,707	931	$4,133,168	1,056	$5,501,679	655	$386,519
2005	3,161	$22,693,523	$7,179	2,576	$10,005,101	1,028	$4,754,171	1,303	$7,350,544	971	$583,706
2006	4,235	$31,859,512	$7,523	3,453	$14,884,902	1,479	$7,180,779	1,585	$9,082,660	1,456	$711,171
2007	4,301	$34,543,340	$8,031	3,206	$14,890,820	1,561	$7,287,142	1,875	$11,421,289	1,779	$944,089
2008	5,213	$43,004,128	$8,249	3,855	$18,997,486	2,155	$9,927,047	2,072	$12,834,145	2,426	$1,245,451
2009	6,343	$49,757,392	$7,844	4,627	$22,154,449	2,771	$14,042,379	2,069	$12,247,892	2,676	$1,312,672
2010	6,468	$50,283,272	$7,774	4,699	$21,425,218	2,991	$14,191,773	2,235	$13,419,259	2,531	$1,247,022
2011	5,454	$41,747,306	$7,654	4,522	$20,763,293	2,960	$13,475,313	1,408	$6,521,001	2,072	$987,699
Total	41,636	$320,207,813	$7,691	32,620	$145,222,675	16,901	$79,245,058	15,020	$87,193,722	15,391	$8,546,357

Table 19. NYSERDA HPwES® Financing

	ENERGY STAR FINANCING			*Energy $mart Loan Fund*			*GJGNGY Financing*	
Year	# Loans	Loan Amount	NYSERDA Buydown	# Loans	Loan Amount	NYSERDA Buydown	# Loans	Loan Amount
2001	303	$2,843,904.45	$487,003.13	252	$2,037,438.00	$195,067.00		
2002	832	$5,846,524.76	$884,723.48	596	$4,646,610.00	$446,157.00		
2003	945	$6,528,671.09	$862,975.72	653	$4,659,835.00	$535,063.00		
2004	589	$4,273,837.67	$599,884.19	143	$1,257,957.00	$172,629.00		
2005	504	$3,774,518.13	$669,534.82	141	$1,466,880.00	$192,857.00		
2006	654	$4,822,834.94	$895,395.01	254	$2,653,796.00	$364,213.00		
2007	541	$4,229,137.47	$766,569.23	333	$3,749,349.00	$522,212.00		
2008	620	$4,845,120.39	$814,257.50	474	$4,926,393.00	$782,976.00		
2009	506	$4,086,210.52	$701,724.15	307	$2,520,046.00	$417,517.00		
2010	372	$3,232,610.59	$651,193.52	245	$2,529,023.93	$346,984.10	9	$80,390.58
2011	52	$504,810.20	$96,262.02	99	$773,678.45	$95,011.40	579	$4,773,814.95
Totals	**5,918**	**$44,988,180.21**	**$7,429,522.77**	**3,497**	**$30,447,327.93**	**$3,975,675.10**	**588**	**$4,854,205.53**

Table 20. Homeowner Incentives

Year	10% HEMI $	50% Subsidy $	10% HEMI # of Projects	50% Subsidy # of Projects
2001	$0	$1,104	349	1
2002	$58,145	$425,178	979	112
2003	$459,999	$4,315,019	1,322	1,137
2004	$621,090	$4,420,098	1,334	1,227
2005	$1,049,190	$4,481,725	1,952	1,209
2006	$1,509,289	$6,159,140	2,727	1,508
2007	$1,897,536	$5,213,407	2,963	1,338
2008	$2,572,090	$6,003,207	3,761	1,452
2009	$3,329,169	$6,809,052	4,650	1,693
2010	$3,637,272	$5,404,011	4,856	1,612
2011	$2,618,722	$5,847,597	3,370	1,948
Total	$17,752,501	$49,079,537	28,263	13,237

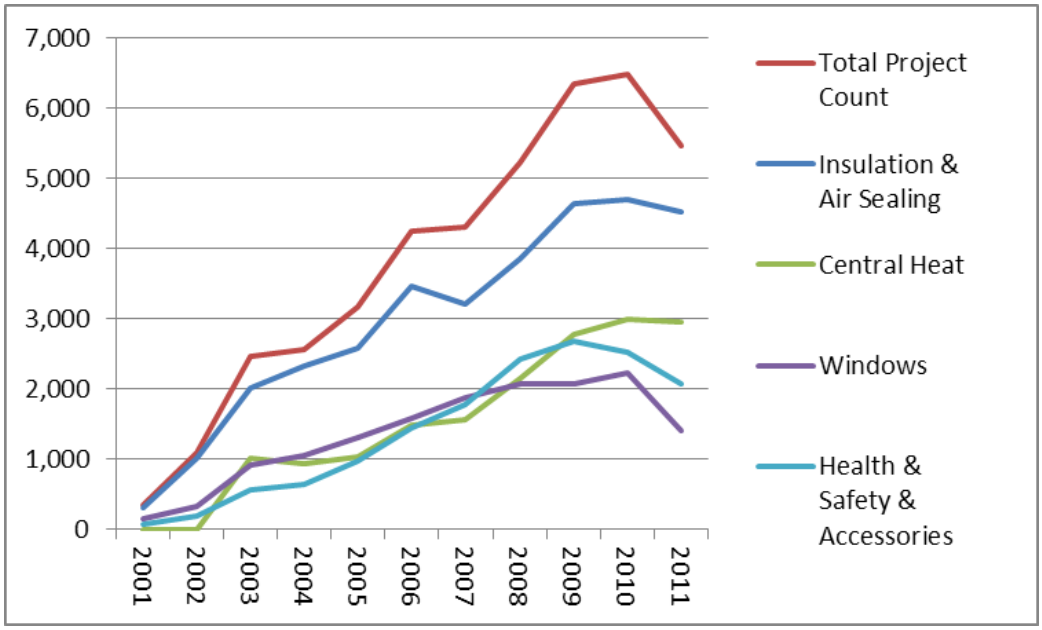


Figure 21. NYSERDA HPwES® Project Count

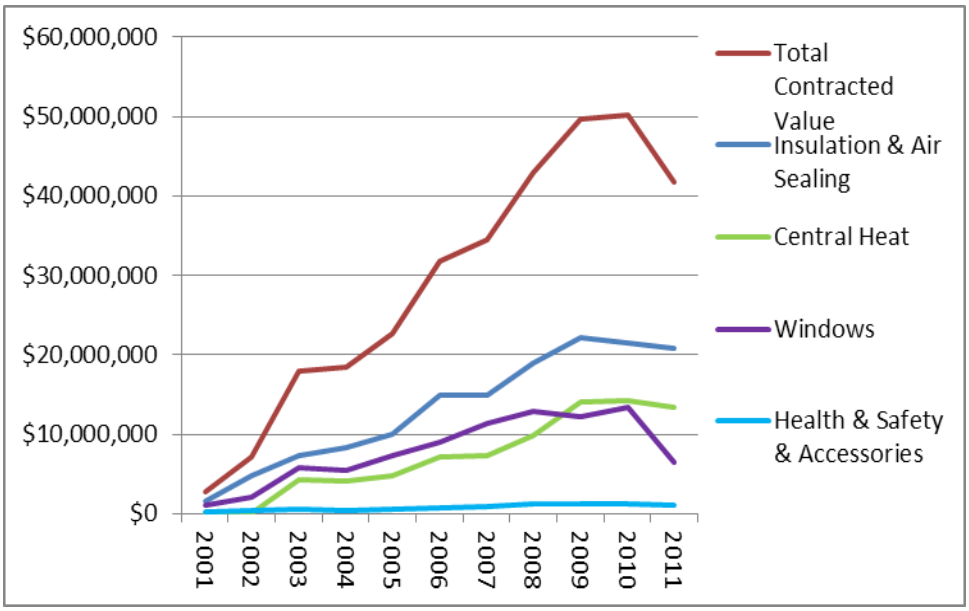


Figure 22. NYSERDA HPwES® Project Value

A review of industry growth in New York shows that, from 2007 through 2010, the total number of projects put through the program yearly increased from 4,301 to 6,468 – an increase of 50 percent with an increase of 45.5 percent in contracted value. The decline in total projects and project value from 2010 to 2011 can be attributed to several factors. The economy may have played a role, but the single largest factor was a change in the rules regarding the cost-effectiveness criteria for projects put through the program.

In 2011, the PSC moved the Home Performance with ENERGY STAR program into the Energy Efficiency Portfolio Standard (EEPS). This program was created as part of New York's plan to reduce energy use 15 percent by 2015. Under EEPS rules, all projects were required to pass a TRC cost-effectiveness test on a measure-by-measure basis rather than on a project or program basis.

Under the new rules, window replacements would no longer qualify for program incentives. The number of replacement windows sold in the program dropped dramatically and window projects dropped 37 percent, with a corresponding decline in window project value of $6,898,259. This represented 81 percent of the total decline in project value between 2010 and 2011. The decline in insulation and HVAC jobs can also be partly explained by the decline in window projects because window contractors who expanded into whole-house services pulled out of the program due to the new rules.

According to the 2010 census, there are 5,273,776 one- to four-family housing units in New York. NYSERDA's Home Performance with ENERGY STAR program completed 41,636 projects

from its inception until mid-September 2011. This represents a market penetration of .79 percent. While this can be interpreted as a failure to significantly transform the market, it is important to note that the industry is still at a very early stage of development.

At this time, there is no category in the phone book for home performance contracting. The success of the New York program has spurred similar programs around the country and the HVAC industry is starting to embrace whole-house services.

Resources

Sherman, K. "Low Interest Loans and Free Audit Available." December 3, 1981.
http://fultonhistory.com/Newspaper%2011/Hamberg%20NY%20Front%20Page/Hamberg%20NY%20Front%20Page%201978-1979/Hamberg%20NY%20Front%20Page%201978-1979%20-%200089.pdf#xml=http://fultonhistory.com/dtSearch/dtisapi6.dll?cmd=getpdfhits&u=ffffffffc28f82e6&DocId=17918587&Index=Z%3a%2fFulton%20Historical&HitCount=7&hits=de+ec+101+121+174+1fd+247+&SearchForm=C%3a%5cinetpub%5cwwwroot%5cFulton%5fNew%5fform%2ehtml&.pdf

U.S. Census Bureau. New York Housing Units. 2010.
http://factfinder2.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_10_1YR_DP04&prodType=table

Energy Trust of Oregon

The Northwest has a long history of delivering services to improve the energy efficiency of residential buildings. These services have been supported by the Bonneville Power Administration and public and private electric utilities. More recently, natural gas utilities have also supported residential energy efficiency programs.

In March 2002, the Energy Trust of Oregon (Energy Trust) began operation, charged by the Oregon Public Utility Commission with investing in cost-effective energy efficiency. Energy Trust provides cash incentives, information and services to help customers of Portland General Electric (PGE), Pacific Power, NW Natural (NWN) and Cascade Natural Gas manage energy costs, increase comfort at home, improve productivity in the workplace and protect the environment. It is funded by customers of all four utilities who pay a dedicated percentage of their utility bills to support a variety of energy efficiency and renewable energy services and programs. Thus, Energy Trust is responsible for delivering residential energy efficiency programs to customers of the investor-owned utilities in Oregon.

Energy Trust delivers significant economic and environmental benefits. Since 2002:

- Utility customers participating in Energy Trust programs have saved nearly $800 million on their energy bills.
- Energy Trust investments have helped create almost 2,500 full- and part-time jobs, and stimulated $81 million in wages and $12 million in new business income (as verified by independent economic analysis).
- The Energy Trust network of nearly 2,100 trade ally contractors and allied professionals have been important contributors to local economies across the state.
- Energy Trust has helped Oregonians avoid emitting more than six million tons of carbon dioxide emissions—the equivalent of removing one million cars from our roads for one year.

Residential Retrofit Programs

Energy Trust is a leading national participant in the support of market-based, single-family, energy efficiency retrofits. For existing single-family homes, Energy Trust has two program tracks: cash incentives or rebates, and Home Performance with Energy Star (HPwES).[27]

The cash incentives or rebate track provides cash incentives to customers for installing certain measures that meet energy efficiency qualifications set by Energy Trust. This program was

[27] Energy Trust also offers a home energy review that provides a quick on-line assessment of a home's energy use. They recently collaborated with utilities to provide OPOWER's Personal Energy Report on a pilot basis to 60,000 single-family households in both NWN and PGE's territories in the Portland Metro Area.

started in 2003 and is a traditional à la carte energy efficiency program that follows in the path of predecessor utility programs in Oregon.

Home Performance Track

HPwES got off the ground in 2006. There was recognition that outside of the Low-Income Weatherization Program, no one was offering an audit-based (using diagnostic measurements), comprehensive approach for residential energy efficiency upgrades in the Oregon market. HPwES was intended to address this by developing a self-sustaining market for performance contracting in Oregon. It is a residential whole-house energy efficiency program option for the existing homes market, delivered exclusively by contractor firms employing Building Performance Institute (BPI) certified field staff. Home Performance is founded on the "house as a system" approach to building functionality, which integrates progressive concepts of building science, and places a strong emphasis on health and safety as well as incorporating best building science practices**.**

The Home Performance program trains contractors to assess and improve the energy performance of homes through work that incorporates diagnostic testing and follows BPI Standards. Program contractors present homeowners with a comprehensive scope of work that, when implemented, provides increased energy efficiency, durability and comfort, and creates a safe and healthy dwelling.

In addition, Energy Trust is allied with Clean Energy Works Oregon (CEWO) to deliver HPwES services and provides incentives for energy efficiency measures installed through CEWO. Energy Trust helped conceive and manage the City of Portland pilot, Clean Energy Works Portland (CEWP) that laid the groundwork for Clean Energy Works Oregon. Funding to support this effort came from Federal Stimulus Dollars (American Recovery and Reinvestment Act). The Oregon Legislature passed the Energy Efficiency and Sustainable Technology (EEAST) Act in 2009 which provides direction for this funding. Energy Trust contracts with CEWO to fulfill Energy Trust's EEAST obligations to demonstrate on-bill financing. The services provided through CEWO fall under the Home Performance program track, but this is a full service offering that includes free audits[28], complete financing, and instant rebates that are based on the percentage of energy savings. These features are not available in the standard HPwES offering.

HPwES is still a small part of Energy Trust's existing single-family retrofit program participants (Figure 23). The majority of participants use the ala carte cash incentives program (single family homes site). Growth in HPwES services has been through CEWO and CEWP. Energy Trust staff report there is a robust set of comprehensive jobs being done through Clean Energy Works and

[28] Customers are screened before being offered a free audit. Energy Trust staff report almost a 70% conversion rate from the audit to implement measures.

the home performance contractors. They have seen over a thousand jobs so far in 2012 and expect to reach 2,000,[29] so demand continues to grow. There are about 95 home performance trade allies and about 650 total trade allies in the existing homes program, so about 15% of the contractors are home performance

The HPwES jobs emphasize insulation and air sealing. There has been a shift in the number of air sealing jobs done by home performance contractors. In 2009, 89 percent of air sealing was done in the standard rebate portion of the Energy Trust single-family program. In 2010 this dropped to 40 percent. By 2011, home performance contractors accounted for 75 percent of the air sealing work. Because of the higher standards in HPwES, this also provides a little more confidence that the people doing the air sealing are addressing the key needs in the home.

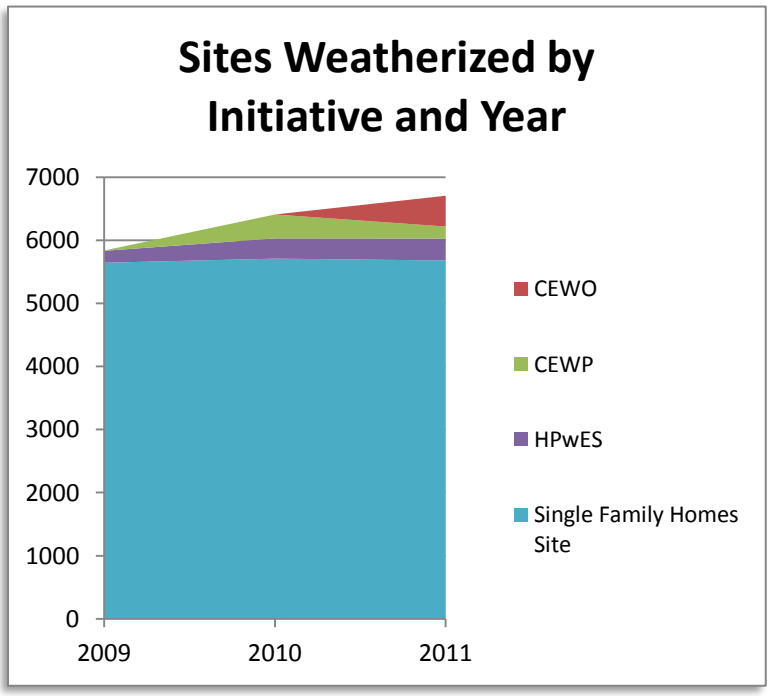


Figure 23. Participation in Energy Trust's Single-Family Weatherization Programs

The majority of contractors doing HPwES projects are weatherization contractors, but more heating contractors are coming on-board and promoting weatherization features as opposed to just heating system changes. There have also been some shifts in the low income weatherization providers that historically where the only providers of comprehensive

[29] Note that these figures tend to underestimate the number of comprehensive jobs being done because some contractors take projects through the standard rebate track to avoid some of the software tool and reporting requirements of the HPwES track.

weatherization. They have put more emphasis on becoming BPI certified, are becoming vendors of BPI training, and are considering creating for-profit arms to do weatherization.

Energy Trust went through a redesign in 2008/2009 to focus their program more on what the customer wants and helping the customer take action. They have restructured themselves to focus on the customers and the actors that they can leverage to reach customers. For customer engagement with HPwES, they are working on getting the customer the right stuff in the right form coming out of the audit to help the customer take action. The energy performance score is a way to consistently educate the customer on the performance of their home. The custom home energy recommendations report is also intended to educate the customer and give them more information than a checklist and list of contractors. This is all about the customer getting comfortable enough to take action out of the audit process.

Energy Trust is also improving its data system to include customer relationship fields to better understand the customer side of the experience and what drives and motivates a customer to take action. This will also allow them to see relationships between customers and contractors over time and whether contractors reengage customers that have opportunities.

The delivery process starts with the customer contacting the Energy Trust or a contractor may identify a potential customer and submit a form. Energy Trust helps to connect a contractor with the customer and from this point the contractor drives the process. Only certified contractors can do HPwES projects. This is one of the benefits to customers of choosing this path. The contractor conducts an HPwES comprehensive assessment (there is a $150 incentive for the assessment), installs instant savings measures (like CFLs) and submits the information on that customer's home.

All HPwES projects are eligible for the same incentives as the standard rebate track. A bonus incentive of $150 is paid for completing attic, wall, and floor insulation (as needed[30]) and air sealing measures. The contractor provides the customer with the custom home energy recommendations report and works with the customer to select and install measures. Energy Trust is developing a lender ally group to ensure good financing options are available to help customers pay for their projects (loan products are currently available). A test out is included once the job is complete. There are also reporting requirements.

Energy Trust is looking at moving away from modeling software being a requirement of HPwES. They are trying to improve their system to capture the data from the home. They would like a methodology where contractors use the system to send the data to Energy Trust as well as to get feedback that provides value to the customer and contractor. They do not want to mandate

[30] At least two insulation measures must be installed to receive the bonus.

a specific audit tool, but just that data of specific quality and meeting certain specifications is delivered.

As noted earlier, a primary goal of HPwES is to develop a self-sustaining market for performance contracting in Oregon. Energy Trust sees the Building Performance Institute and the creation of national standards around home performance helping the home performance industry in Oregon take its first steps. Energy Trust has invested a lot of resources in developing the home performance market, but at this point is shifting to reliance on other market actors like the Home Performance Contractors Guild of Oregon (HPCGO)[31] and CWEO to continue to develop the home performance industry. The role of Energy Trust is to support this market-based infrastructure and be a third party that provides quality assurance and credibility for home performance.

The HPCGO is a guild of over 50 companies, contractors, and individuals dedicated to providing home performance products and services that meet the highest standards. They are a non-profit with paid staff that supports their members through peer-to-peer mentoring and facilitating training opportunities. They also provide a voice for their members in policy matters related to home performance. Energy Trust has a sponsorship agreement with HPCGO.

Energy Trust views the HPCGO as a champion and advocate for HPwES. They look to the market to drive the value of home performance and the energy and non-energy benefits. Energy Trust will support this and continue to steer customers who are interested in the benefits of home performance to contractors qualified to offer these services. HPwES will be one of the choices customers have, but other prescriptive offerings will also be available from Energy Trust.

Home Performance Evaluation Findings

Energy Trust recently conducted a process evaluation of its Home Performance with ENERGY STAR® track.[32] This process evaluation focused on documenting the current operational practices and identified areas of improvement. It considered operations from June 1, 2009 to June 10, 2011. The findings from this process evaluation provide guidance for the Energy Trust staff and program management on ways to re-position this offering in the Oregon Home Performance market.

The following program findings are taken directly from the evaluation report:

- **Program Tracking:** The program databases are tracking all the key metrics as required by both the Energy Trust and the national Home Performance with Energy Star program.

[31] See the Guilds website at http://www.oregonhpcg.org/ for more information.
[32] Johnson, K. "Process Evaluation of the Home Performance Program Track." Energy Trust of Oregon, 2012. http://energytrust.org/library/reports/HP-Process-w-staff-response.pdf

- **Program Marketing:** The participating contractors like the ways in which they receive information from the Energy Trust and Account Representatives about the program. The most effective ways to reach participating customers is via the Energy Trust website, from the contractors directly, and through bill inserts. Moreover, the findings suggest that the decision to install energy efficient measures is viewed as a priority by program participants. Marketing the Home Performance program remains a challenge as it is a difficult concept to explain to customers.

- **Program Changes:** The Home Performance program has shifted away from trade ally development-focused to trade ally maintenance.

- **Role of Home Performance Contractors:** Home Performance contractor participation is dominated by a few large contractors who specialize in air sealing and subcontract out most other services. Home Performance contractors play an important role in encouraging customer participation.

- **Home Performance Contractors Guild:** The guild is viewed as giving the contractors a voice in the Home Performance community; however it is dominated by contractors in the Metro-Portland area.

- **Participation in Other ETO Programs:** Home Performance contractors are actively participating in additional energy efficiency programs, including some sponsored by the Energy Trust as well as some utility specific programs.

- **Role of Account Representatives:** The participating contractors view the Account Representatives as essential to their success in the program and rely on them for support, especially with the new software tool.

- **Home Performance Assessment Software:** The Home Performance software assessment tool was viewed as unusable by the majority of participating trade allies.

- **Measures Installed:** The majority of installed measures are for air and duct sealing. Some type of insulation was also installed. There were few heating or water heating equipment measures.

- **Non-Energy Benefits:** The initial driver for customer participation is energy savings. However, as customers become more educated about the Home Performance program track, their interest in non-energy benefits increases. The three top non-energy benefits are comfort, ability to pay the bill, and reducing the environmental impact.

- **Program Satisfaction:** Overall, customers are happy with the Home Performance program offering. The features customers seem to like best are receiving the incentive, receiving an assessment, and seeing actual energy savings.

- **Non-Participants:** There is currently no follow-up mechanism in place to encourage non participants to move forward with even modest energy efficiency improvements after completing the initial Home Performance assessment.

Some of the recommendations include:

- Encourage customers to make energy efficiency a priority, even encouraging saving for major efficiency improvement
- Ensure that contractors receive adequate support
- Streamline the customer application
- Pay incentives directly to contractors
- Use webinars or podcasts to reach contractors outside the Metro-Portland area
- Consider restructuring the contractor rating system
- Provide a better differentiation of HPwES from other Energy Trust residential programs
- Improve the home assessment software

The Energy Trust is considering these recommendations. For example, there is a stakeholder group to provide feedback on improving the home assessment software and they are considering modifying the requirement for energy modeling. Energy Trust has also made improvements to the application process.

The experience in Oregon suggests that a market for home performance contracting can be developed. HPwES is still a small part of the residential retrofit market in Oregon, but it is growing and there seems to be customers interested in these services. Market actors are emerging to support the Home Performance Industry. Energy Trust's role is to support and leverage this infrastructure so that home performance services are available in Oregon.

DOE Low-Income Weatherization Program Evaluation

DOE recently completed a national evaluation of its Weatherization Assistance Program (WAP). This study included energy evaluations and indoor air quality (IAQ) impacts. The full results are not yet available. However, the study design and preliminary pre-weatherization results for 288 homes have been published.[33] A discussion regarding the IAQ component of the effort is provided.

Indoor Air Quality

By Paul Francisco

In the DOE National WAP study, the IAQ portion included measurements on over 500 homes. Contaminants of interest were carbon monoxide (CO), radon, formaldehyde and moisture. Not all contaminants were measured in all homes. Approximately three of every eight homes were control homes in which weatherization services were provided outside of the study window so no retrofit was performed in the "retrofit period" as defined by the study. Control homes – located in the same general area as sample homes and measured concurrently with treatment homes – provide insights to account for changes that are due to environmental issues and not weatherization. This is especially critical for radon, which is known to be significantly impacted by changes in weather.

CO was measured in combustion appliances and in ambient (room) air. For appliances, CO was measured in the exhaust gases along with oxygen level to assess levels on an air-free basis. This was done in vented and unvented appliances (such as ranges and ovens). For atmospherically vented appliances, spillage and draft tests were also done under worst-case house depressurization conditions. Measurements of ambient room air were made using dataloggers that recorded data every 1 to 5 minutes.

CO in flue gases was not a common problem in the 288 homes for which preliminary pre-weatherization results have been published. Of 107 fuel-fired furnaces tested, 87 percent had flue CO levels under 50 parts per million (ppm), and 4 percent had readings above 500 ppm. Since these results were from flue gases, no implication is made for room air levels. For 122 tested fuel-fired water heaters, only two had CO levels above 50 ppm in the flue gases. For 112

[33] Tonn, B., S. Pigg, D. Cautley, P. Francisco, K. Tohinaka, D. Carroll, M. Blasnik. "Indoor Air Quality in Low-Income Homes." Presented at the Indoor Air 2011 Conference, Austin, TX, 2011.

Francisco, P.W., D. Cautley, K. Tohinaka, S. Pigg, B. Tonn, and D. Carroll. "Indoor Air Quality in Weatherization Homes: Study Design and Pilot Results." Presented at the Indoor Air 2011 Conference, Austin, TX, 2011.

World Health Organization. *WHO Handbook on Indoor Radon.* 2009.

ovens/ranges, 13 percent of ovens and 7 percent of ranges (at least one burner) had air-free CO levels above 800 ppm, which is the industry standard for new appliances.

Radon was one of the primary contaminants of concern, and the study oversampled high-radon-risk areas based on the EPA radon map. In sample homes, diffusion barrier canisters were placed in foundation spaces and main living levels for about a week before and after the retrofit period. Blanks or duplicates were placed at a rate of about 1 per 8 canisters.

Results for radon must be interpreted carefully because tests were done under closed-house conditions and for only about a week. While this is longer than many tests performed by homeowners and home inspectors, it still is not sufficient to determine whether an individual home will exceed the EPA-recommended level of 4 picocuries per liter (pCi/l) as an annual average. Indeed, the WHO recommends measuring for a minimum of three months to estimate annual average exposure. The primary focus of the radon measurements in this study was to evaluate the *change* due to weatherization services being performed; measurements in the control homes were used to account for environmental impacts.

Because these results have not yet been published, we cannot discuss them at this time. But the preliminary pre-weatherization results did show that even under closed-house winter-time conditions, no mobile/manufactured homes and no homes in the lowest radon risk areas had levels that exceeded the EPA recommended level.

Formaldehyde was evaluated in approximately 25 percent of homes. These measurements were also about one week in duration, using N571 assay badges placed adjacent to the radon canisters. There are no formal thresholds for formaldehyde in the United States. No homes in the preliminary pre-weatherization sample exceeded the 100 ppb that has been established by the WHO, and only one exceeded 50 ppb. Mobile homes were found to have higher levels of formaldehyde than site-built homes.

Temperature and relative humidity were also measured in homes using dataloggers, typically located at the thermostat. Additionally, visual observations were made of moisture problems such as standing water in foundation spaces, mold, musty odors and water staining.

In order to analyze the data, additional house characteristics were recorded, such as foundation space type, wall material, house size and height, house leakage rate, and leakage in duct systems.

In addition to this study, other initiatives have assessed IAQ in homes undergoing retrofit. From a field measurement perspective, several studies were undertaken by the State of Wisconsin to evaluate the use of the ASHRAE 62.2 ventilation standard in their weatherization program. These studies concluded that using ASHRAE 62.2 instead of the obsolete ASHRAE 62-1989

reduced humidity and carbon dioxide levels, especially during swing seasons when background infiltration rates are lowest.

There have also been initiatives from a programmatic perspective. The U.S. EPA published *Healthy Indoor Environmental Protocols for Home Energy Upgrades*, and the U.S. DOE drafted *Workforce Guidelines for Home Energy Upgrades*, currently in review, which includes considerations for IAQ.

Appendix A. DRAFT Article Submitted to *Home Energy* Magazine

(Published July 2013)

Past, Present and Future Directions in Single-Family Energy Auditing and Retrofits

By **Michael Lubliner,** Member ASHRAE**, David Hales,** Member ASHRAE**, Rick Kunkle,** Member ASHRAE and **David Shepard Gaw**

About the authors: **Michael Lubliner, David Hales, Rick Kunkle, PE and David Shepard Gaw** are energy researchers at the Washington State University Energy Program

Introduction

First-hand feedback from those who currently work in the home performance industry must be used to inform technical and policy discussions about the effectiveness of energy auditing, retrofit practices and measurement of energy use and savings in retrofits of existing single-family homes.

To capture the insights and expertise of those in the field, the National Institute of Standards and Technology (NIST) Building Research Grants and Cooperative Agreements Program funded an "Assessment of Residential Research Measures" scoping study to help improve the energy efficiency, durability and indoor air quality (IAQ) of existing U.S. residential single-family homes. The scoping study was developed and implemented by researchers at the Washington State University (WSU) Energy Program with significant contributions and assistance from building scientists, practitioners and home performance contracting industry stakeholders.

This research assessed:

- Building energy performance measurements (energy audits) to identify ways to improve the audit process, and
- Home improvement recommendations resulting from the audit.

Single-family energy auditing and retrofits that focus on home performance contracting follow a multi-disciplinary systems engineering approach that encompasses a home's envelope, HVAC, IAQ and ventilation. This work is often performed by home performance and low-income weatherization contractors. These contractors represent an emerging green jobs industry, poised to improve the energy efficiency, durability and indoor environmental quality (IEQ) in millions of the existing U.S. single-family residences.

WSU worked with staff from the U.S. Department of Energy (DOE) Building America teams and national laboratories, U.S. Department of Housing and Urban Development (HUD), U.S. Environmental Protection Agency (EPA), Residential Energy Services Network (RESNET), Affordable Comfort, Inc. (ACI), Air Conditioning Contractors of America (ACCA) and American Society of Heating Refrigeration and Air Conditioning Engineers (ASHRAE) stakeholders to identify two initial project tasks that would address our research question: round robin testing/auditing of a single home by multiple home performance contractors and a survey of building science stakeholders. This article provides initial findings from these tasks and a brief overview of other work included in the research.

Round Robin Pilots

Two energy audit "round robin" pilot efforts were implemented at the ACI 2011 Home Performance conferences in Portland, Oregon and San Francisco, California. These round robins involved multiple energy auditors who conducted energy audits and developed work plans on the same home in Portland and Berkeley. The research team compared the results and analyzed the differences to identify the type and possible causation of these differences. The Researchers then discussed potential means to promote consistency and presented the results at the RESNET 2012 conference (see Appendix B).

Background

Over the last 15 years, a growing infrastructure of trained energy professionals who focus on residential energy performance has emerged. Growth in this industry was encouraged by government policy, utility program requirements and market forces. Nationally, the most prevalent model consists of trained individuals certified by private non-profit organizations that develop and maintain consensus standards within the housing industry (such as BPI and RESNET). These organizations have joined other trades-based organization, such as ACCA and North American Technician Excellence (NATE), which focus on HVAC, in offering quality assurance, guidance on best practices and overall professionalism in the residential construction and retrofit markets.

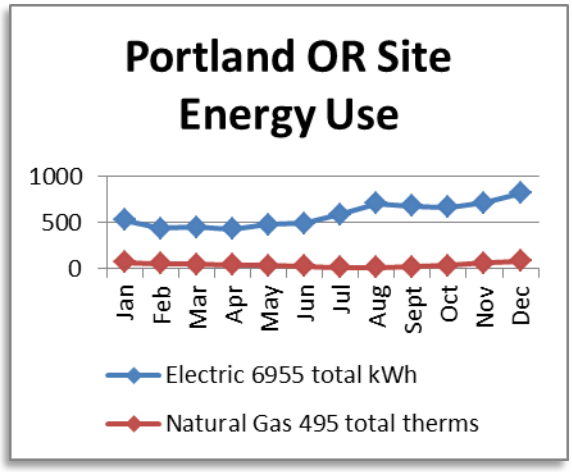
To gauge the effectiveness of energy assessments being conducted in the market, we asked trained professionals to conduct independent energy audits on the same house and compare the results. Conducting the audits in conjunction with the ACI conferences assured access to a large pool of experienced auditors from different backgrounds who worked in a variety of markets. The Portland site was seen in part as a trial run for the event in Berkeley, where we anticipated wider national participation.

Both homes were evaluated by an expert panel to establish a baseline for the conditions as found. Participants were only instructed to test and evaluate the homes as they deemed necessary to characterize the homes and prepare recommendations to improve its energy

performance. In both cases, participants were given utility energy bills for a full year and feedback from the occupants about comfort issues, perceived IAQ and occupant behavior. At the Berkeley site, participants were also asked to prioritize their recommendations based on budgetary limits of $8,000 and $16,000 and create two separate proposals for upgrading energy performance.

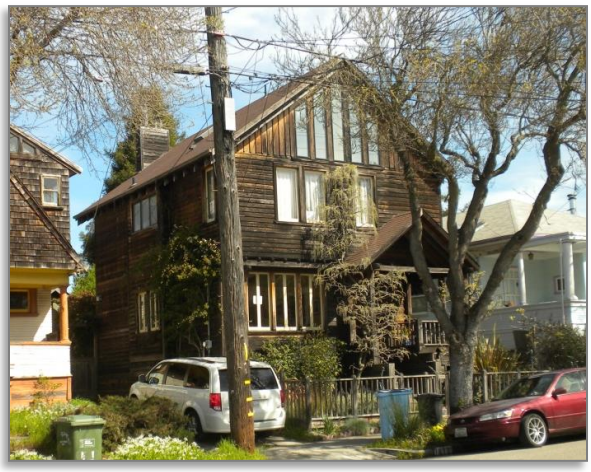
Homes Visited

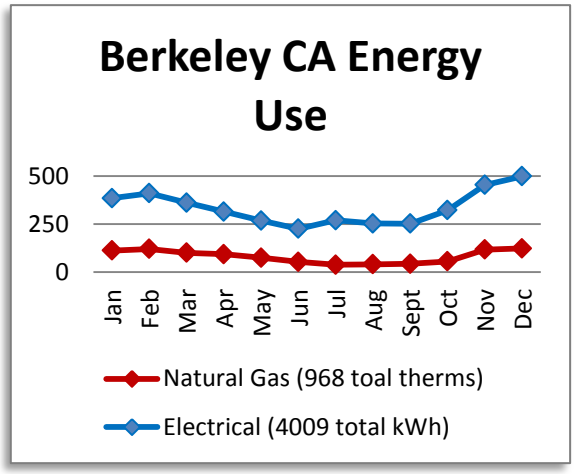
Portland



Portland Home: Information Provided to Auditors	
Year built	1920, some upgrades/remodeling to make basement conditioned space
Conditioned floor area	Approx. 1,240 ft^2, 744 ft^2 finished/492 ft^2 unfinished
Occupants	2 adults, 1 child
House type	Site-built one story + daylight basement and partial crawlspace
Heating	Central forced air, 90%+AFUE natural gas furnace in basement
Cooling	None
Domestic hot water	Atmospherically drafted gas
Walls	2 x 4 frame with R-11
Floors	No insulation in floor over vented crawlspace
Ceiling	Flat R-38, none over laundry area
Windows	Most double glazed U=0.5 or better
Appliances	Non-ENERGY STAR®
Lighting	25% CFLs
Ducts	Un-insulated, 420 CFM_{25} total/ 190 CFM_{25} to exterior
House tightness	2,850 CFM_{50}/>25ACH_{50}
Comfort issues	Drafts, cold bedroom floor

Berkeley





Berkeley Home: Information Provided to Auditors	
Year built	1914, major gut retrofit and second-floor addition in 1990
Conditioned floor area	Approx. 1,500 ft^2
Occupants	2 adults, 1 child
House type	Site-built two-story + loft on vented crawlspace
Heating	Central forced air, 80% gas furnace in crawlspace, wood stove rarely used
Cooling	None
Domestic hot water	Atmospherically drafted gas
Walls	2 x 4 frame with R-11
Floors	Poorly installed R-19 + missing batts
Ceiling	Vaulted R-19 estimated
Windows	Wood, single glazed, leaky with water damage, some fixed double pane
Appliances	Non-ENERGY STAR®
Lighting	25% CFLs
Ducts	Some R-4, 320 CFM_{25} total/ 140 CFM_{25} to exterior
House tightness	2400 CFM_{50}/10 ACH_{50}
Comfort Issues	Seasonal overheating from south glazing

Findings

Portland

The tables below show the recommendations developed by each of the six auditors who participated in Portland. Estimated measure costs and savings are broken out by auditor for the most commonly recommended measures. Savings estimates were based on modeling by the auditors in a variety of programs.

	Auditor					
Measure	**1**	**2**	**3**	**4**	**5**	**6**
Air leakage	X	X	X	X	X	X
Insulate crawlspace	X	X	X	X	X	X
Seal/insulate ducts	X	X	X	X	X	X
Air seal basement	X	X	X	X	X	X
Drainage	X	X	X	X	X	X
Laundry attic insulation	X	X	X		X	X
Install 100% CFL	X	X	X		X	X
Upgrade DHW	X					X
Add furnace return		X	X			
Insulate basement walls	X	X			X	
Upgrade windows/doors		X				X
Attic radiant barrier						X

General Air Sealing			
Auditor	**Cost ($100)**	**Improvement Measure**	**Savings MMBTU**
1		Sealed to 7 ACH50	7.8
2	15	Sealed to 7 ACH50	12.6
3	9	Sealed to 19 ACH50	7.2
4	4-20	Sealed to 7 ACH50	6.1
5		Not Specified	
6	4-20	Sealed to 7 ACH50	5.5

Ducts			
Auditor	**Cost ($100)**	**Improvement Measure**	**Savings MMBTU**
1		Seal/R-8	1.1
2		Seal/insulate	
3	10.5	Seal/R-11	3.7
4	4-12	Seal/R-8	6.8
5		Seal/insulate	
6	4-12	Seal/R-8	7.5

Crawlspace Insulation			
Auditor	**Cost ($100)**	**Improvement Measure**	**Savings MMBTU**
1		R-30	
2	3.5	R-21	2.1
3	5	R-30	5.0
4	6.5-9.5	Flash/Batt R-38	8.5
5		R-25	
6	3.5-6.5	R-30	6.1

As the data above indicate:

- Auditors disagreed about upgrading windows and doors, upgrading the domestic hot water (DHW), adding insulation to basement walls and the use of an attic radiant barrier.
- Major energy-saving measures where most auditors agreed included: air-sealing, duct insulation and sealing, using compact fluorescent lights (CFLs), and adding insulation to the un-insulated laundry attic.
- Auditors all agreed on the need for better water management and drainage on the site.
- Estimated measure costs and savings showed extreme variability. Costs for crawlspace insulation varied by a factor of over 2.5; cost for duct measures varied by a factor of 3 and air-sealing cost varied by a factor of 5. Estimated savings for these measures varied by factors of 2 to almost 7.

Berkeley

The auditors in Berkeley were not asked to break out estimated costs and savings by measure but rather prioritize their recommendations to meet two different budgets capped at $8,000 and $16,000, respectively. Auditor 1 only provided recommendations for a $16,000 budget. Auditor 4 only provided recommendations for an $8,000 budget. Any inconsistencies reflect the information as submitted by the auditors.

Measures – $8,000 Budget	Auditor							
	1*	2	3	4	5	6	7	8
Air sealing				X	X	X	X	X
Ductless mini-split HP				X				
High efficiency 95% gas furnace		X	X		X	X	X	X
High efficiency DHW 30 gal				X				X
Tankless DHW conditioner							X	
Insulate DHW tank & pipes					X	X		
Ceiling add R-19			X					
Floor R-25			X				X	
Dense pack floor					X			
Duct insulation R-11			X		X		X	
Operable skylights								X
Low-flow fixtures								X
Duct sealing					X		X	X
CFLs				X		X	X	X
Clothes line								X
Fix dryer vent					X	X		
Total estimated annual savings ($)		***1,044***	***581***	***501***		***139***		***1,500***

* Auditor 1 only provided recommendations for a $16,000 budget.

Measures – $16,000 Budget	Auditor							
	1	2	3	4*	5	6	7	8
Air sealing	X	X			X	X	X	X
Combo System						X		
High efficiency 95% gas furnace	X	X	X		X		X	X
HP 14.5 / 8.5 HSPF	X	X						
High efficiency DHW 30 gal								X
Tankless DHW conditioner	X	X					X	
Insulate existing DHW					X	X		
Operable skylights w/s							X	X
Low-flow fixtures								X
Duct sealing					X	X	X	X
Duct cleaning		X				X		
Duct insulation R-11		X	X		X		X	
Floor insulation R-22 foam								X
Floor insulation R-19 batts	X	X						
Floor insulation R-25 batts			X				X	

Measures – $16,000 Budget	Auditor							
	1	2	3	4*	5	6	7	8
Dense pack floor					X			
Add R-19 ceiling			X					
Whole house fan						X		X
Windows south double low E	X							X
Add storm windows					X			
All windows double low E			X				X	
CFLs	X					X	X	X
Fix dryer vent					X	X		
Total estimated annual savings ($)	***491***	***1,044***	***791***			***316***	***984***	***2,500***

* Auditor 4 only provided recommendations for n $8,000 budget.

As the data above indicate, important areas of agreement among auditors include:

- That health and safety issues were the primary concern at this site (venting failure on gas furnace in crawlspace).
- Air sealing the envelope
- Upgrading the heating system
- Improving floor insulation
- Improvement to the hot water system

Areas with inconsistencies among the auditors included:

- Extreme variability in projected energy savings ranging from a 7.6 percent cost reduction to a 138 percent reduction with no apparent attempt to reconcile estimated savings with actual utility bills
- Type of heating system upgrade (recommendations included: condensing furnace, mini-split heat pump and hydronic combo system

The homeowner in the Berkeley case chose to upgrade both the furnace and water heater to condensing appliances and close the crawlspace including perimeter insulation and improved vapor barrier ground cover at a cost of about $10K. The homeowner also continues to look at alternatives to reduce the solar gain of the south facing glazing.

The reported results are for a very small sample of houses and auditors and should not be construed as representative of home performance contracting as a whole.

Survey of Building Science Stakeholders

To obtain input from home performance experts, a survey was conducted at the Building Science Corporation's Westford Symposium August 1-3, 2011.[34] The survey had 13 questions about energy audit diagnostic measurements and analysis tools, post-retrofit information, feedback, measurement, and broad questions about how to improve home energy performance. The survey was provided on-line during and after the symposium. Responses were provided by 135 symposium participants, and 118 of these completed the survey.[35]

Responses to the energy audit diagnostic and measurement survey questions include:

- Respondents rated the importance of 12 energy audit diagnostic measurements. All but two of the measurements were rated as important or very important. Lighting and appliance surveys were rated least important, while assembly area measurements, envelope leakage rates, the homeowner interview, utility bills, and combustion safety test were rated most important.
- Respondents most frequently identified assembly area measurements, lighting and appliance surveys, the homeowner interview, utility bills, and combustion safety tests as the diagnostic measurements they include in a basic audit.
- When asked whether new audit measurements or techniques need to be developed, the responses were split, with slightly more than half (53 percent) saying yes. The largest group of respondents said we need to improve what we are doing through streamlining, simplifying, standardizing and providing training. Three areas were identified as needing new measurements or techniques: air quality and health and safety (ventilation, IEQ, combustion safety), wall heat loss (wall assemblies), and air leakage (air infiltration, duct leakage). The responses suggest the emphasis should be on improvements rather than new measurements.
- When asked what information from the audit is most important to homeowners, respondents most frequently identified energy cost savings and prioritizing what the homeowner should do (recommendations). Financial aspects were mentioned in over half of the responses. Many responses also included one or more non-financial items – comfort, health and safety, durability, defects (correcting problems), behavior (education), performance (building performance, ratings, etc.) or IEQ.
- Respondents were asked about the primary analysis tool/energy savings calculation they use. The responses fell into three main categories:
    - Energy model (over 20 different models were mentioned, and only one was identified by more than 10 percent of the respondents);

[34] See the following link about the Symposium, commonly referred to as "Summer Camp" - http://www.greenbuildingadvisor.com/blogs/dept/green-building-blog/official-summer-camp-program

[35] Respondents could respond to some survey questions without completing the entire survey.

    - Diagnostic tools (blower door and other diagnostic measurements); and
    - Simple methods and experience (spreadsheets, hand calculations, rules of thumb).
- When asked about the cost of an audit, a wide range of values were given. Costs were most frequently in the $300 to $600 range. The majority of respondents indicated that audit costs were subsidized by utilities (most frequent), government or contractors. A little more than half of the respondents (55 percent) said that audit costs were a barrier to energy efficiency retrofits.

Results

Round Robins

The overall results of the round robins – admittedly based on a small sample – suggest that the home performance industry still has work to do to better meet consumer's expectations in the marketplace. Consumers want to know what a retrofit job will cost and what will be the resulting savings and benefits. Comparing the audits conducted during the round robins showed the greatest uncertainty when trying to answer these questions. The development of specific climate and house type data bases that track both costs and savings could help reduce the uncertainty. Standards, some still in development, at BPI and RESNET address issues of quality assurance, energy savings estimates and contractor certification and should continue to build consumer confidence.

The authors hope the round robin auditing efforts serve as a catalyst to improve energy auditing and retrofit practices. Recommendations have been made to DOE and others to support implementation of future round robins with interested home performance contractor market implementers such as RESNET, ACCA, BPI and other energy efficiency retrofit program market players. These ongoing round robin efforts should allow for the inclusion and evaluation of many different program approaches to energy auditing and work plan development. If implemented around the country, the round robins can address variability in retrofit approaches based on differences in regional housing stock and/or climate. Feedback from round robins provides ongoing quality assurance that helps ensure that homeowners get relatively consistent, reliable, repeatable and useful recommendations from the home performance contracting industry. The results could also be used as feedback to further inform the development of training programs and close the loop between instruction and practice.

Building Science Stakeholder Survey

One overarching conclusion that can be drawn from the survey results is that the diverse views and opinions in the home performance industry are unified by the perception that there are opportunities for improvement. While there may not have been a consensus in the responses

to many questions, the responses do lay out the universe of perspectives that can be used to inform future work to improve home performance.

Additional Features of This Research

Advisory Team Member Contributions

The project scoping study included feedback from key advisory member experts involved with building retrofit, remodeling and new construction. These experts were asked to document past, present and future directions in residential energy auditing and post-retrofit performance related to market-based energy efficiency home retrofits and government/utility sponsored low-income weatherization, including an overview of:

- Experiences from New York, Alaska, Oregon and Canada, where there has been significant long-term support by states and utilities of the home performance industry and weatherization program.
- BPI's past, current and future directions in home performance contracting.
- ACCA and RESNET efforts to provide skilled technicians to use an integrated approach that leverages the training and strengths of their members.
- Fault Detection and Diagnostics (FDD) for residential HVAC equipment and the case for FDD standardization, as the automobile industry implemented in 1996 with on-board diagnostics (OBD-II).
- DOE current research in energy efficiency and IAQ in the low-income weatherization program.
- Building feedback devices and other related efforts to improve energy efficiency via occupant behavior and actions.
- Bibliography of relevant energy retrofit research on measured energy savings from billing analysis evaluations.

Consumer Education

The NIST grant provided resources to develop a DVD entitled "Air Leakage in Homes," which provides builders, building officials and homeowners with an overview of opportunities to improve home energy efficiency by addressing air leakage in the home. This video is available from http://www.energy.wsu.edu/BuildingEfficiency/EnergyCode.aspx#PRESENTATIONS.

Recommendations and Conclusions

Information from the round robin pilot, stakeholder needs assessment survey and advisory group input helped to inform technical and policy discussions regarding energy auditing, retrofit practices and measurement of energy use and savings in single-family existing home retrofits.

Other key recommendations resulting from the research effort include continued investigation and support of:

- Research that focuses on the variance and other real world uncertainties associated with the energy audit information collected and used to develop work scopes.
- A whole-house systems engineering approach that focuses on energy savings, comfort, improved IAQ, durability and health and safety.
- Market research of non-energy savings benefits such as comfort and health and safety improvements. Encouraging people to invest in home performance improvements requires an understanding of customer needs and wants. This may involve an energy audit that includes a Home Energy Rating and/or utility bills as part of the audit.
- Efforts to efficiently acquire and utilize utility billing history at the programmatic and/or individual home level to help ensure that energy savings estimates are reasonable and realistic. A policy need was identified and efforts are underway to help make it easier to acquire utility data in a consistent electronic format.
- A variety of market-based approaches to home performance audits and work-plan development that add value and improve market penetration while ensuring that home performance improvements are predictable and actionable.

Acknowledgments

The authors would like to thank William Healy at NIST for his support and guidance in managing this grant, and the numerous industry, government and not-for-profit organizations and individuals that contributed to this effort.

Bibliography and Related Links

1. Affordable Comfort Inc. (ACI): http://www.affordablecomfort.org/
2. Air Conditioning Contractors of America (ACCA): http://www.acca.org/
3. Building Performance Center (BPI): http://bpi.org/
4. DOE Weatherization (DOE WX): http://www1.eere.energy.gov/wip/wap.html
5. DOE Building America (DOE BA): http://www1.eere.energy.gov/buildings/building_america/
6. EPA Home Performance with ENERGY STAR (HPeS): http://www.energystar.gov/index.cfm?fuseaction=hpwes_profiles.showSplash
7. Energy Performance Score (EPS): http://energy-performance-score.com/programs
8. Lawrence Berkley National Laboratory Home Energy Savers: http://hes.lbl.gov/consumer/
9. Oak Ridge National Laboratory: http://www.ornl.gov/sci/eere/research_weatherization.shtml'
10. Residential Energy Service Network (RESNET): http://www.resnet.us/
11. Washington State University Extension Energy Program: http://www.energy.wsu.edu
12. Westford Symposium: http://www.greenbuildingadvisor.com/blogs/dept/green-building-blog/official-summer-camp-program

Appendix B. RESNET Round Robin PowerPoint Presentation

Energy Audit Round Robin Results
"A study in uncertainty"

Michael Lubliner, Andy Gordon and David Hales,
Washington State University Energy Program
Duncan Prahl, IBACOS
RESNET 2012 Conference - Austin, TX

Acknowledgments

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- The Energy Conservatory
- Fluke
- Snell Group
- Retrotec
- Affordable Comfort
- Energy Trust of Oregon
- Earth Advantage
- GreenHomes America = Mike Rogers
- Lawrence Berkeley Lab - Iain Walker
- Layla Thomas
- Many others!

Session Goals

- Present "round robin" energy audits work scopes on energy retrofits of a single home and discuss audit findings and work scope consistency
- Touch on BSC Westford Symposium survey results:
- Open Panel & Audience Discussions;
  - Round Robin & Westford Survey feedback
  - Idea of future round robins w/RESNET etc.

Background

- Consumers are looking for professional guidance to establish priorities and evaluate cost and benefits of a growing number of measures promising improved energy efficiency.
- Encouraged by government policy, utility program requirements and market forces, a growing infrastructure of trained energy professionals focused on residential energy performance has emerged

Background

- The most prevalent model on a national level consists of trained individuals certified by private non-profit organizations setup to develop and maintain consensus standards within the housing industry (examples: BPI, RESNET).

- These organizations have joined other trades based organization such as ACCA and NATE who focus on HVAC in offering quality assurance, guidance on best practices and overall professionalism in the residential construction and retrofit markets

Background

- In order to gauge the effectiveness of energy assessments being conducted in the market, an ad hoc group decided to have trained professionals conduct independent energy audits on the same house and compare the results.

- In 2011 audit sites in Portland Oregon and Berkley California were chosen in conjunction with the West Regional ACI conference (Pilot) in Portland February 1-2 and the National ACI conference in San Francisco March 28 thru April 1.

Round Robin

- In OR and CA, the homes were evaluated by an expert panel to establish a baseline for the conditions as found.
- Participants were only instructed to test and evaluate the homes as they deemed necessary to characterize the homes and prepare recommendations to improve the energy performance.

Round Robin

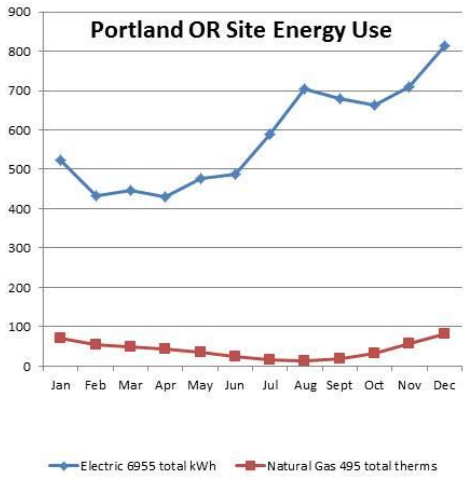
- At the Berkley site, participants were further asked to prioritize their recommendations based on budgetary limits of $8,000 and $16,000 and create 2 separate proposals to the hosmeowner for upgrading the energy performance.
- In both cases participants were given utility energy bills for a full year and feedback from the occupants about comfort issues, perceived IAQ and occupant behavior.

Equipment Available for Audits

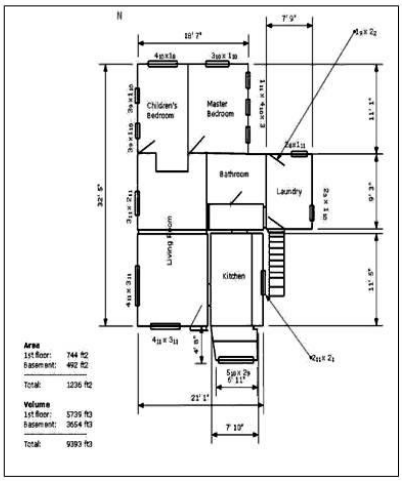
- Blower door (Minneapolis model 3 or Retrotec model 2000)
- Duct tester (Minneapolis model B or Retrotec model DU200)
- Digital manometers (Minneapolis DG700 or Retrotec DM2)
- IR cameras (Fluke Ti32 [320x240, 50mK]; FLIR i7 [120x100, 100mK])
- Gas leak detector (Bacharach jr.)
- Combustion Gas Analyzer (Bacharach)

Portland Site

- The emphasis at the Portland site was on diagnostic results used as the basis for the auditors' recommendations.



Portland Site

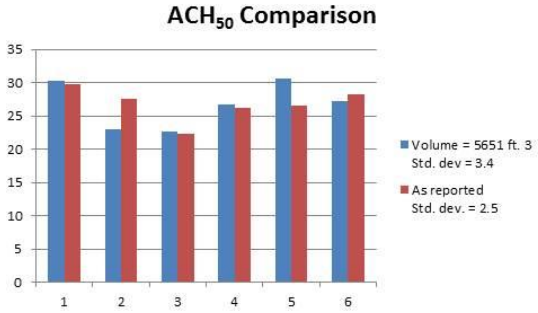


Six Participants with Three Approaches

Auditor	Inspection Protocol
1	HERS, BPI, Simple
2	Home Perf. w/ Energy Star Home Assessment
3	Home Perf. w/ Energy Star Energy Audit
4	Energy Performance Score
5	BPI Energy Audit
6	Energy Performance Score, HERS
Base 1	TechTite (automated BD test)
Base 2	Infiltrometer (automated BD test)

Portland Results

- Results differed if basement included as conditioned space
- Most tested envelope under both conditions
- Two did not perform duct leakage tests, but evaluated duct sealing and condition by visual inspection.
- One also performed pressure pan tests.



Auditor	Bsmt. door	LTE (CFM_{50})	Total (CFM_{50})	Notes
1	Open	20	-	
2	Open	36	421	
3	Closed	400	-	
4	No Test	-	-	
5	No Test	-	-	Pressure Pan
6	Closed	299	-	Improved air barrier to crawl
6a	Open	85	-	

Combustion Safety Testing

- All auditors conducted combustion safety testing, including CAZ depressurization, draft and CO on the water heater. All found results below BPI action levels
- CAZ depressurization was found between .6 – 1.2 Pa,
- In all cases, draft was achieved in worst case in less than 60 seconds
- CO levels were found between 7 and 13 ppm

Audit Findings

- Significant air leakage, through BD testing, visual inspection, and for five, IR.
- Lack of insulation at the floor above the crawlspace
- Inadequate attic hatch seal
- Inadequate duct sealing, especially in crawlspace
- No attic insulation above laundry noted by three
- Dry rot at sill noted by three

CAZ testing

DHW draft hood not secured – 1 auditor

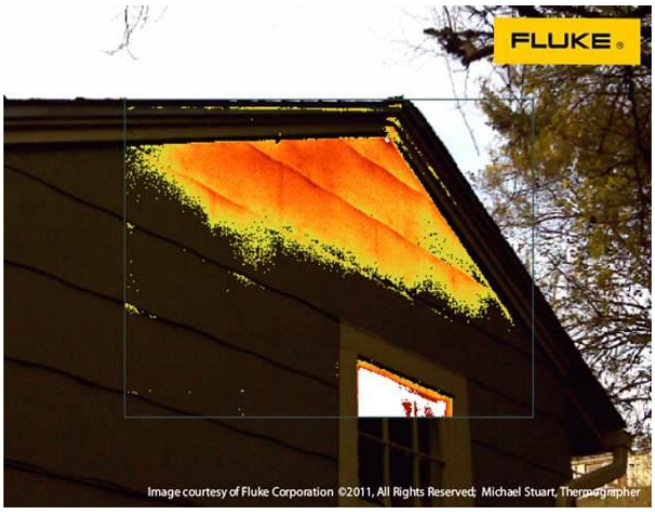
Gas leak at meter – 2 auditors

Furnace - CO @53 ppm - 1 auditor
1 auditor - "no need to test."

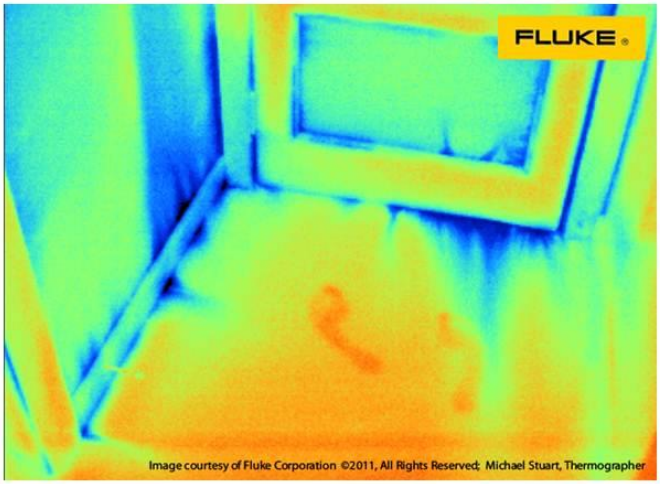
Infra-red inspections

- Infrared imaging users were able to provide more details on where air leakage was occurring, but reports were inconsistent in providing:
  - Methodical description of specific issues documented in infrared (both conduction-related and air leakage related.)
  - Documentation that proper infrared procedure was executed, separate from air-tightness testing.
  - Documentation of environmental conditions
  - Better Indication of what was, and what was not, inspected with infrared

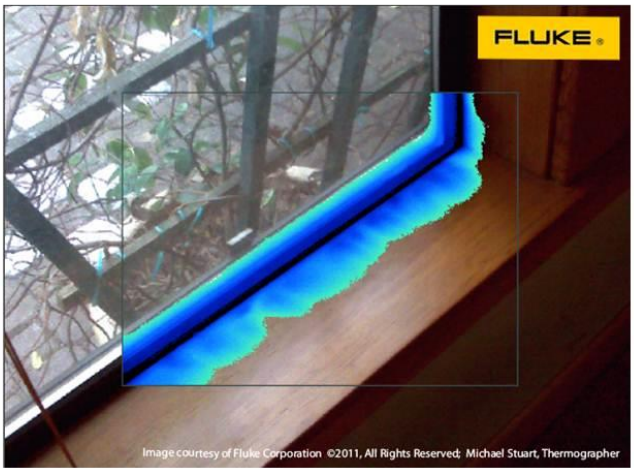
Evidence of warm air infiltration into attic



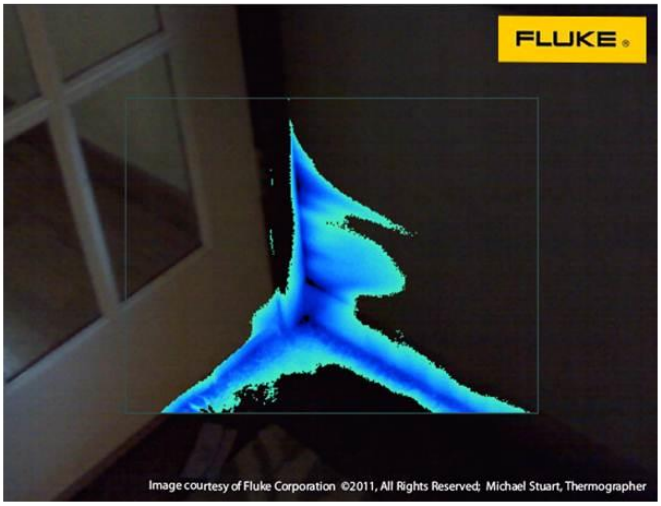
Air Infiltration on Interior Wall, Floor and Door



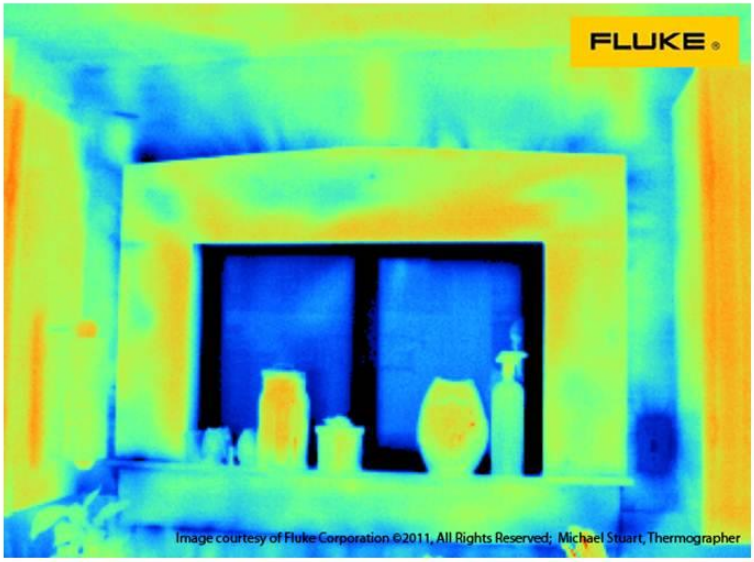
Air Infiltration around Window



Air Infiltration on Interior Walls and at Floor



Cool Air Infiltration around Kitchen Window Trim and Interstitial Air Flow in Adjacent Wall



Audit Recommendations

	1 HERS	2 HPES	3 HPES	4 EA	5 BPI	6 EA/HERS
General air leakage control	X	X	X	X	X	X
Insulate crawlspace floor	X	X	X	X	X	X
Seal and insulate ductwork	X	X	X	X	X	X
Air seal basement walls, rim and sill	X	X	X	X	X	X
Install and seal crawl hatches	X	X	X	X	X	X
Ensure adequate drainage	X	X	X	X	X	X

Audit Recommendations

	1 HERS	2 HPES	3 HPES	4 EA	5 BPI	6 EA/HERS
Insulate laundry attic	X	X	X		X	X
Install 100% CFLs	X	X	X		X	X
Upgrade DHW	X	"Newer and in good condition"		"operating properly"		X
Add in return area/ air return paths		X	X			
Insulate basement walls	X (R-21+5)	X (R-13-15)			X (R-13)	
Replace windows and doors		X				Laundry, if finished
Install attic radiant barrier & solar fan						X

Estimated Savings – Air sealing

Auditor	Cost ($)	Improvement Measure	Savings (MMBTU)	Notes
1	-	7.0 ACH_{50}	7.8	Simple
2	1500	6.78 ACH_{50}	12.6	
3	900 -	19.1 ACH_{50} – 8.0 ACH_{50}	7.2 -	Utility incentive level Add. Opportunities
4	400-2,000	7.0 ACH_{50}	6.1	EPS (Simple)
5	-	No perf. Level specified	-	
6	400-2,000 500	7 ACH_{50} 10 ACH_{50}	5.5 5.9	EPS (Simple) Rem/Rate

Estimated Savings – Duct sealing & Insulation

Auditor	Cost ($)	Improvement Measure	Savings (MMBTU)	Notes
1	-	Seal & insulate ducts in crawl	1.1	Simple
2	-	-	-	
3	1,050	200 CFM_{50}, R-11	3.7	Utility incentive level
4	400-1200	Seal ducts in crawl, insulate to R-8	6.8	
5	-	Seal all connections	-	
6	400-1200	Seal ducts in crawl, insulate to R-8	7.5	

Estimated Savings – Crawlspace Insulation

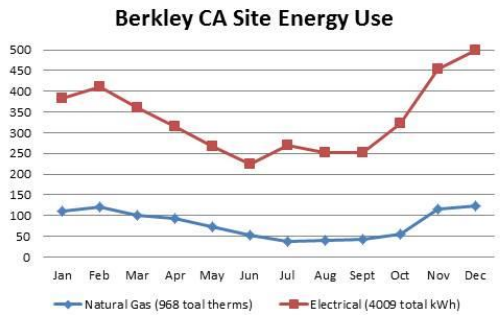
Auditor	Cost ($)	Improvement Measure	Savings (MMBTU)	Notes
1	-	R-30	-	
2	347.50	R-21	2.1	
3	500	R-21 – R-30	5.0	
4	650-950	Flash + Batt, R-38	8.5	
5	-	R-25	-	
6	350-650	R-30	6.1	

Portland Conclusions

- Audit circumstances (mid-retrofit, home operated differently pre and post-retrofit) created challenges.
- No two inspectors had the same findings, even when using the same protocols
- Most major energy efficiency findings were consistent
- Health and safety findings varied considerably
- Major energy efficiency recommendations were consistent among raters, though to different levels and savings estimates

Berkeley Site

- For the Berkley site the emphasis was placed on developing a scope of work in a format normally presented to the homeowner at two different price points.



Eight Participants with Approaches

Auditor	Inspection Protocol
1	Green Point
2	BPI
3	BPI
4	BPI/HERS
5	BPI
6	Recurve
7	BPI
8	BPI/HERS

Year built	1914 gut retrofit , 1990's addition
Conditioned floor Area	Approx. 1500 ft^2
Occupants	2 adults/ 1 child
House type	Site-built 2 story + loft on vented crawl
Heating No cooling	Central forced air; 80% Gas in crawlspace; wood stove rarely used
DHW	Atmospherically drafted gas
Walls	2 x 4 frame with R-11
Floors	Poorly installed R-19 + missing batts
Ceiling	Vaulted R-19 estimated
Windows	Single leaky single wood, w/water damage, some fixed double pane
Appliances/Lighting	Non-Energy Star, 25% CFLs
Ducts	Some R-4, 320 CFM_{25} total/ 140 CFM_{25} to exterior
House tightness	2400 CFM_{50}/10 ACH_{50}
Comfort Issues	Seasonal overheating from south glazing

Combustion Safety Testing

- The atmospherically drafted DHW heater is in a closet in conditioned space, has a failing insulation wrap and vents into a separate flue. It is nearing the end of its service life. It passed BPI standards for spillage, draft and CO.

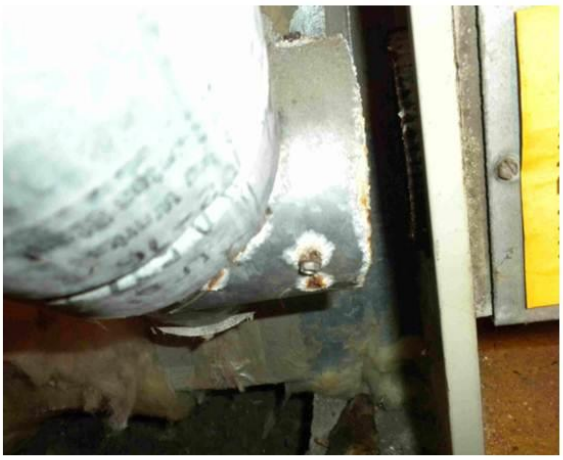
Combustion Safety Testing

- The atmospherically drafted 80% gas furnace is in the crawlspace, vents into a separate flue with a very long horizontal run, the flue was disconnected at the furnace, the gas flex line was kinked and both the flue and the furnace show extensive corrosion. The furnace is at the end of its service life and should be replaced for safety reasons. It failed BPI standards for spillage, draft and CO.

- The gas oven tested within BPI specification with no need for service.

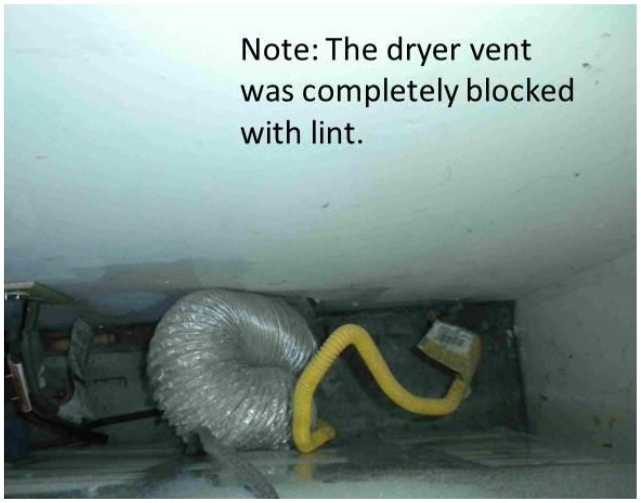
Horizontal Furnace Vent Run in Crawl

Disconnected Furnace Flue in Crawlspace



Audit Observations –
Desiccated Mouse Found in Return Air Plenum

Audit Observations –
Poorly Installed Dryer Vent Duct

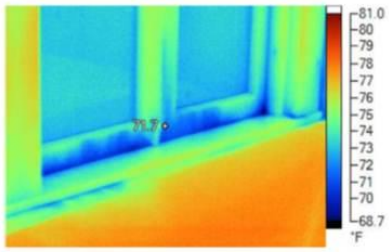


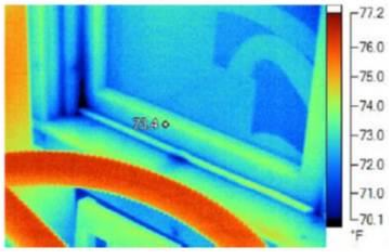
Audit Observations –
Poorly installed floor insulation

Audit Observations –
South facing glazing that causes overheating

Audit Observations –
Constricted flex duct in crawlspace

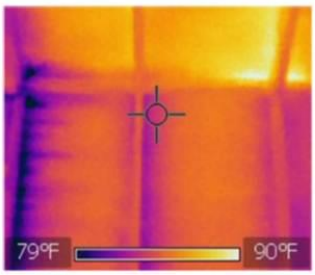
Infra-red Inspection

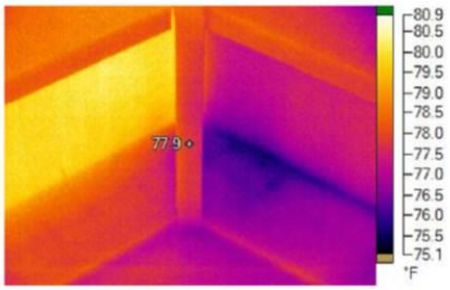




Depressurized, showing air leakage sites on window sash, a common issue throughout.

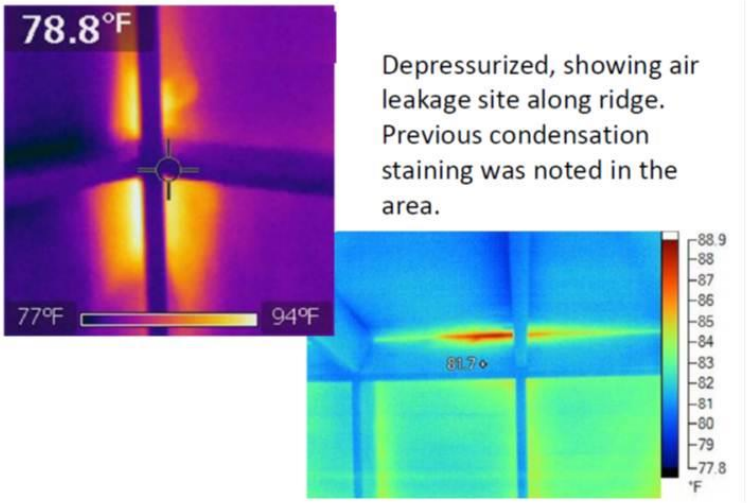
Infra-red Inspection





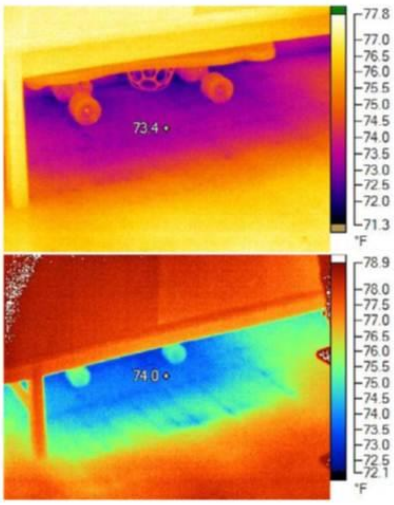
Depressurized, showing air leakage sites on boarded ceiling, a common issue throughout.

Infra-red Inspection



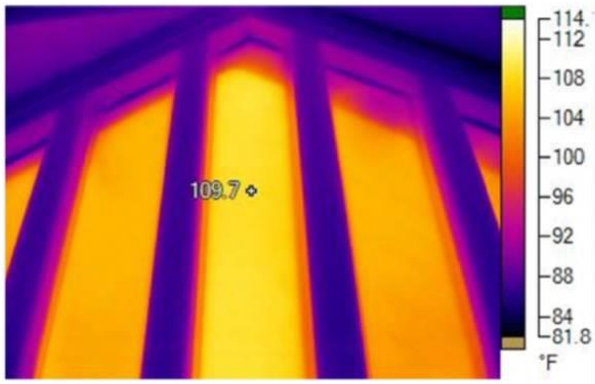
Depressurized, showing air leakage site along ridge. Previous condensation staining was noted in the area.

Infra-red Inspection



Normal pressures (top) and depressurized (bottom), showing uninsulated area on first floor and associated air leakage from crawlspace.

Infra-red Inspection



"Solar heaters" disguised as windows on south gable wall at high solar noon.

Audit Recommendations

- For the Berkeley site auditors were asked to provide scopes of work at two different price points, $8K and $16K.
- Auditors were asked to use their own estimated costs which varied considerably from contractor to contractor and regionally from different parts of the country.
- The following tables compare the measures recommended by each auditor and the projected costs and savings estimated by the auditors.

Measure	Audit $8000						
	2	3	4	5	6	7	8
Air sealing			X	X	X	X	X
Ductless Mini-split HP			X				
High Eff. 95% gas furnace	X	X		X	X	X	X
High Eff. DHW 30 gal			X				X
Tankless DHW condensing						X	
Insulate DHW tank & pipes				X	X		
Ceiling add R-19		X					
Floor R-25		X				X	
Dense Pack floor				X			
Duct Insulation R-11		X		X		X	
Operable skylight/shades							X
Low flow aerators/shower							X
Duct sealing				X		X	X
CFLs			X		X	X	X
Clothes Line							X
Fix dryer vent				X	X		
Total cost ($)	8903	7816	8000	6092	8241	8275	7675
Total estimated$ saved/yr.	1044	581	501		139		1500

*Auditor (1) only submitted a $16K budget

Measure	Audit $16,000							
	1	2	3	4	5	6	7	8
Air sealing	X	X			X	X	X	X
Combo System						X		
High Eff. 95% gas furnace	X	X	X		X		X	X
Heat Pump 14.5 SEER 8.5 HSPF	X	X						
High Eff DHW 30 gal								X
Tankless condensing DHW	X	X					X	
Insulate existing DHW					X	X		
Operable skylights w/shades							X	X
Low flow aerators/shower head								X
Duct sealing					X	X	X	X
Duct cleaning		X				X		
Duct Insulation R-11		X	X		X		X	
Floor Insulation R-22 spray foam								X
Floor Insulation R-19 batts	X	X						
Floor Insulation R-25 batts			X				X	
Dense Pack Floor					X			
Add R-19 ceiling			X					
Whole house fan						X		X
Windows south double low E	X							X
Add storm windows					X			
All windows double low E			X				X	
CFLs	X					X	X	X
Fix dryer vent					X	X		
Total cost	$16K	$15908	$15588		$14592	$16085	$15225	$15675
Total estimated annual savings	$491	$1044	$791			$316	$984	$2500

Work Scope Findings

- Estimated annual savings ranged from $139/yr to $2500/yr even though the participants were given a year's worth of utility bills that only totaled $1817.
- With an $8K budget, estimated savings ranged from 7.5% to 82.5% averaging 41.5%.
- With a $16K budget estimated savings ranged from 17% to 137% averaging 47% removing the outlier.
- Some variation due to participants from other parts of the country failing to adjust their analysis tools to the relatively mild climate in Berkley?

Work Scope Findings

- All of the auditors recommended installing a higher efficiency heating system. Given the condition of the existing system, this was a good call.
- Cost varied substantially & recommendations ranged from dual fuel systems with furnace + heat pump, to combo systems, to condensing furnaces, to a ductless mini-split.

Final Retrofit Included

- Closed Crawl with perimeter foam and vapor barrier liner
- Condensing furnace
- Condensing tank type water heater

Cost $10K

Home Owners Response

"We are thrilled with the results already. It's certainly a relief having the dangerous furnace issue fixed. And we've already noticed the floors are more comfortable, and the house quieter."

Berkley Conclusions

- Wide variation in quality and presentation of recommendations
- We are still in the “horse and buggy age”

Round Robin Summary & Conclusions

- How consistent should recommendations be?
- How consistent should the information provided be?

Energy Audit Round Robin Results
"A study in uncertainty"

Michael Lubliner, Andy Gordon and David Hales,
Washington State University Energy Program
Duncan Prahl, IBACOS
RESNET 2012 Conference - Austin, TX

Westford Summary Background

Survey Objectives

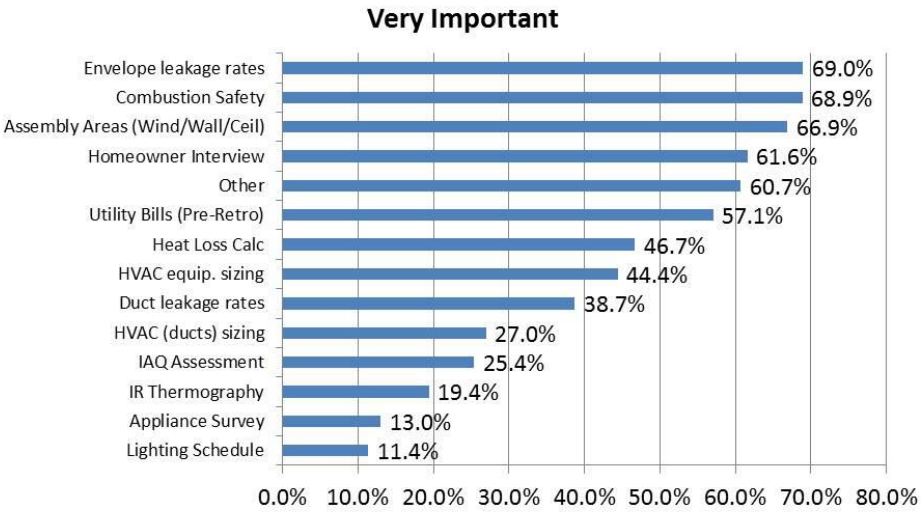
1. To better understand the directions in single-family residential energy audits and retrofits
2. To improve the measurement of residential energy performance to better inform energy decisions and to better assess effectiveness of retrofit efforts

Survey Background

- Survey between August 1st-26th
- Total of 16 questions on field diagnostic measurements, field energy audits, post-retrofit process and broader questions
- Survey responses from 135 people; 118 fully completed

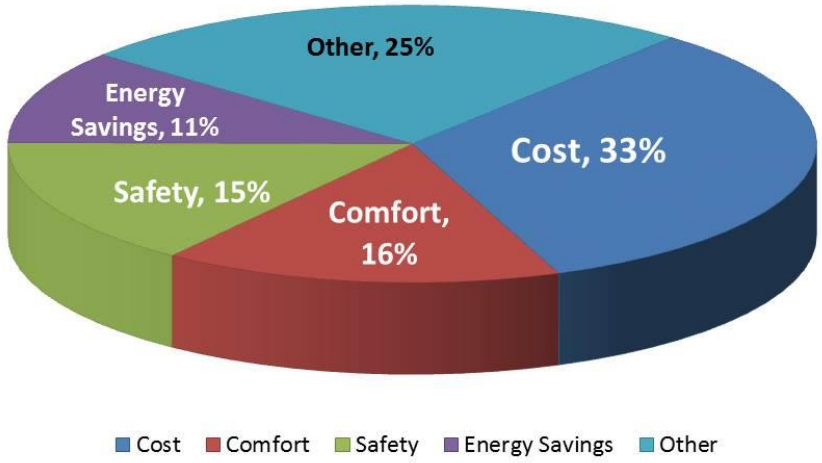
Westford Summary Key Findings

Field Diagnostic Measurements (Ranking by Importance)



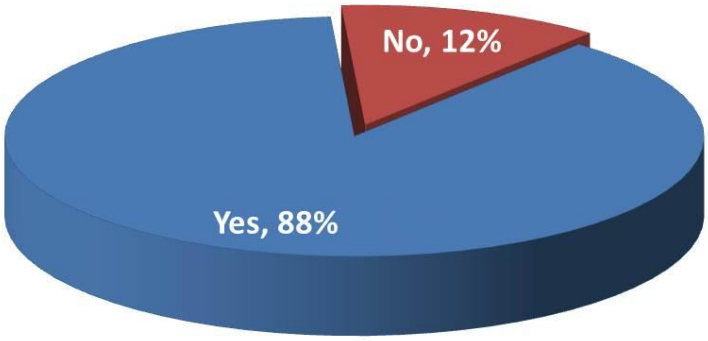
Westford Summary Key Findings

Most important information for a homeowner to get from an energy audit:



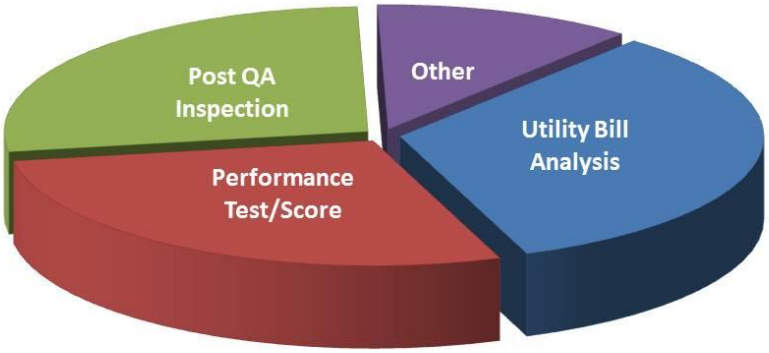
Westford Summary Key Findings

Should homeowners receive information regarding the performance of their home after a retrofit?



Westford Summary Key Findings

What type of information should the homeowner receive (after a retrofit)?



Questions for Group Discussion

- Round Robin & Westford Survey feedback
- Would future round robins w/RESNET, EEBA, ACI, ACCA, etc. be useful to provide on-going feedback and improve audit and work scopes?

Appendix C. Westford Survey Questions and Results

Purpose of Survey

- To better understand the directions in single-family residential energy audits and retrofits, and
- To improve the measurement of residential energy performance to better inform energy decisions and better assess the effectiveness of retrofit efforts.

Technical Questions (Audits)

1. The following field diagnostic measurements are commonly taken during an energy audit. Please rank each for the following:
   - How important is each measurement? (1 very important)
   - How confident are you in the accuracy for each measurement? (High, Medium, Low)
   - What is the retail cost of each measurement? (Low, Med, High)
   - What measurements are included in different levels of energy audits (1 is simplest audit, 2 is more detailed, 3 is the most detailed* audit)?

Measurements Type	Rank 1-5	% Accuracy	Retail (US$)	Detail Level
Assembly areas (other than floors)	_____	_____	_____	_____
Heat loss calculations	_____	_____	_____	_____
Envelope leakage rates	_____	_____	_____	_____
Duct leakage rates	_____	_____	_____	_____
IR thermography	_____	_____	_____	_____
HVAC equipment sizing	_____	_____	_____	_____
HVAC (ducts) sizing	_____	_____	_____	_____
Appliance survey	_____	_____	_____	_____
Lighting schedule	_____	_____	_____	_____
Utility bills (pre-retrofit)	_____	_____	_____	_____
Homeowner interview	_____	_____	_____	_____
Combustion safety (use text box)	_____	_____	_____	_____
IAQ assessment (use text box)	_____	_____	_____	_____
Other (use text box)	_____	_____	_____	_____

**Level 1 audit – items in a basic audit, Level 2 audit – more detail, Level 3 – high detailed audit*

2. Do new audit measurements or measurement techniques need to be developed? (Yes/No; if yes, list new measurements in text box)

3. What information from the audit is most important to the homeowner? (text box)
4. What is the primary analysis tool/energy savings calculation you use? (text box)
5. What does an audit typically cost? (text box)
   How is it paid for? (text box)
   Is the cost of an audit a barrier to getting an energy retrofit done? (Yes/No)

Post-Retrofit Questions

6. Should homeowners receive information regarding the performance of their homes after a retrofit? (Yes/No)
   If yes, what should they be provided? (multiple choice: utility bill analysis, performance test/score, post QA inspection, other (check all that apply?))
7. Do you think energy feedback devices can play a role in saving energy after a retrofit? (Yes/No; add comment box – explain)
8. How should we determine whether aggregate energy performance is being achieved by large-scale retrofit programs? (text box)

Broad Questions

9. What is your view of how to best bring U.S. existing housing to higher efficiency? (text box)

Describe:

_____
_____
_____
_____

10. What standards* have been effective in increasing the energy efficiency of existing housing? (text box)

_____
_____
_____
_____

11. What standards* are needed to significantly increase the energy efficiency of existing housing? (text box)

_____
_____
_____
_____

12. Are there competing standards* and if yes, is this a problem? (text box)

_____
_____
_____
_____

13. What are the best market opportunities for increasing the adoption of energy efficiency in existing homes? (text box)

_____
_____
_____
_____

* Standards are defined to include audit and/or measure implementation

Survey Results

Summarized below are responses to:

- Questions 1, 2 and 4 from the audit category
- Question 6 from the post-retrofit section and
- Question 12 from the broad question section.

Responses to Question 1

The first question was a comprehensive technical assessment of survey taker's knowledge of field diagnostic tools or practices (measurements) and allowed them to:

- Rank each on the order of importance as it pertains to performing an audit
  Scale of 1-5 (1=very important)
- Confidence of respondent/participant as to their accuracy in performing this measurement; on a scale of high, medium or low
- Cost for each measurement; on a scale of high, medium/average, low
- Which measurements should be included at the different levels of audits provided
  Scale of 1-3 (1=basic audit, 2=detailed, 3=comprehensive)

The measurement types included:

- Assembly areas (other than floors)
- Heat loss calculations
- Envelope leakage rates
- Duct leakage rates
- IR Thermography
- HVAC equipment sizing
- HVAC (ducts) sizing
- Appliance survey
- Lighting schedule
- Utility bills (pre retrofit)
- Homeowner Interview
- Combustion safety
- Indoor air quality assessment
- Other

For this question, we highlight the first two ranking or rating portions from the survey. The respondent's survey results show that the most important measurement types for energy audit were:

- Assembly areas (windows/walls/ceilings) – 66.9 percent
- Heat loss calculations – 46.7 percent
- Envelope leakage rates – 69.0 percent
- Duct leakage rates – 38.7 percent
- HVAC equipment sizing – 44.4 percent
- Utility bills (pre retrofit) – 57.1 percent
- Homeowner interview – 61.6 percent
- Combustion safety – 68.9 percent
- Other (describe below) – 60.7 percent (17)
  Respondents provided the following examples:
  - Ventilation flows.
  - Assurance of controls for temperature and ventilation.
  - Proper circulation water temperatures to match outside temperatures and optimize boiler performance.
  - Comfort.
  - Classification of house construction era.
  - Use of data loggers to verify electric use and temperature/humidity.
  - Measured HVAC system performance.
  - Site orientation.
  - Room pressurization.
  - Heat gain/cooling load.

Insights on performance and confidence can provide opportunities to improve trainings, calibration of instruments, and/or the accuracy in which they are implemented during an audit. The findings here show the measurement types that respondents were most confident in performing as it relates the accuracy of the results:

- Assembly areas (windows/walls/ceilings) – 53.7 percent
- Envelope leakage rates – 56.3 percent
- Appliance survey – 51.7 percent
- Utility bills (pre retrofit) – 69.7 percent
- Combustion safety (describe below) – 48.2 percent

With a moderate level of confidence in the remaining measurement types, there are opportunities for improving upon an auditor's ability to perform comfortably so their confidence can improve.

Responses to Question 2

Question 2 was specific to identifying new audit measurements or techniques from respondents with a yes or no response (see Figure C-1), followed with specific examples or ideas.

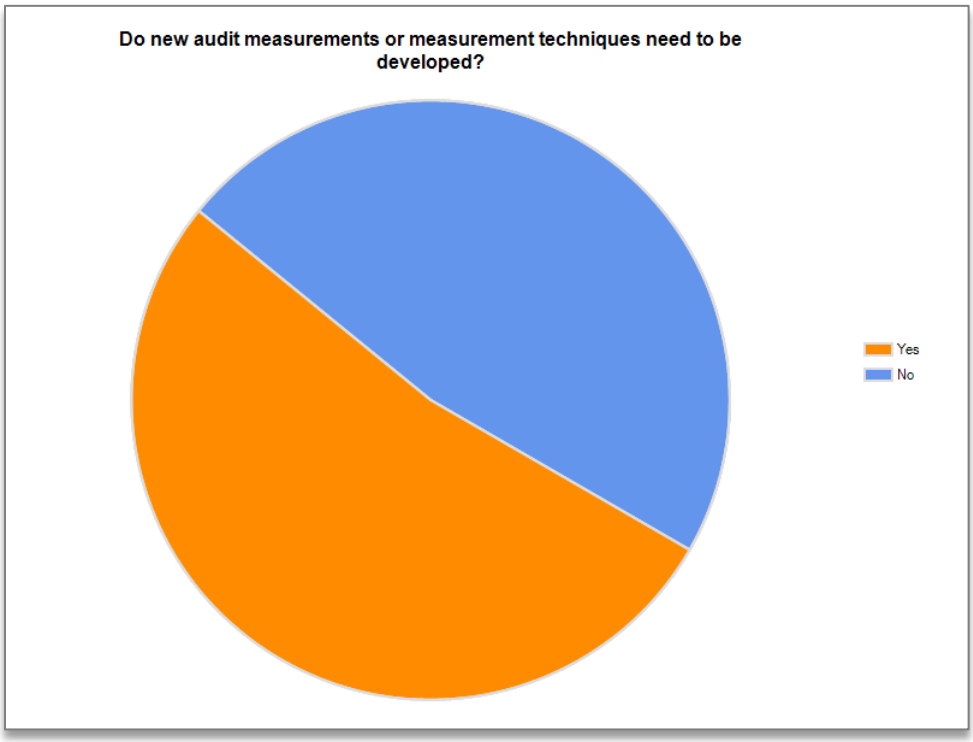


Figure C-1. Survey of Measurements and Techniques Needed

The following is a snapshot of ideas suggested by participants:

- Measurement of range hood ventilation
- A simpler screening test for combustion safety risks that could be part of basic audits, similar to ASTM E1998, part 9
- Field measurement of air leakage through specific areas of exterior
- Uniformity in industry training and qualifications of practitioners
- Techniques that can speed the collection of building take-off data
- Methods to speed the collection of house performance data
- Protocols to more quickly ascertain the moisture, indoor air quality, health and safety issues
- Low-cost, device-specific, real-time energy use tracking. High equipment cost ok if the device can be cheaply installed for a few months per audit.
- Heat loss analysis through framed building enclosures. Thermal short evaluation.

- Better way to use pressure pans to assess ducts
- Wall u-value tests similar to those used in Europe as opposed to a grading system based in mythological percentage reductions
- Faster ways of characterizing duct leakage for the audit/recommendation stage (mapping pressure pan test results to overall leakage) – leave detailed pre- and post-duct testing as part of work completion. Along with this we need to set limits on what savings can be projected by recommending work, if there is no pretest conducted.
- Low-cost ventilation quantity measurement
- I believe it is more critical to train certified auditors than develop new techniques. There are not enough truly qualified auditors, and there is a lot of inconsistency.
- I would like to see energy modeling use assembly u-values based on hot box testing rather than cavity R-values
- Standardization, specifically ASHRAE Std 100
- Yes - additional calculations for ASHRAE 62.2

Responses to Question 4

Question 4 was an open-ended question specific to the analysis tools or energy savings calculations that are used (by participant or seen in the field) during an energy audit. The following results are a snapshot of the respondents' answers:

- Simple by Blasnik - upgraded to include past energy use
- Not just one - many computerized audits
- REM/Rate
- The simpler the better
- Questionable plug load schedule for home energy program verified with utility bills.
- Calculation for energy savings
- Blower door test
- Energy gauge
- Treat
- Microsoft Excel calculation or rough Passive House Planning Package calculation. Simple, transparent, reliable
- REM/Design
- Write soft manual J, and predictions based on square foot heating and cooling costs derived from our work in our climate. We can offer guaranteed energy bills for conditioning
- Heat loss
- REM/*Rate*

- Energy Gauge
- Treat
- Energy Measure Home (CSG)
- EE4, eQuest, HOT2000, hand calculations
- Work w/ big buildings; use customized spreadsheet calculations. In residential, see canned programs used that many of the auditors do not really understand well and sometimes appear to "game" to get the "right" results.
- Energy models
- REM/*Rate* or energy gauge
- Blower door
- Systems checklist that I have developed on my own because existing tools don't work
- Rough screen utility bill analysis (kBtu/sf/year of conditioned space). DERs with simulation software (REM/*Rate*, PHPP, proprietary spreadsheet calculations).
- REM/*Rate*
- Real abridged Manual J – with emphasis on accuracy of input,s which means spending time in house and not cookie-cutting the audit
- REM/*Rate*
- Air leakage, envelope R values
- Predicted energy use
- REM/*Rate*
- Rem rate, techtite
- We use REM/*Rate*, but others such as Recurve seem to show some promise
- Duct blaster
- Blower door test
- Energy savings calculations don't matter to the homeowner
- History from previous jobs
- REM/*Rate* and blower door
- Crude rules of thumb
- Being from the South in a major cooling climate, manual J load calculation to identify areas of greatest potential improvement
- REM/*Rate*
- Florida requires a basic energy calculation for all residential and non-residential buildings for homeowner desired energy savings, making improvements for the best ROI (lower energy bills) is the goal
- Many utility based tools, Apogee or Aclara for two. Treat, Optimizer, REM/*Rate*
- Blower door
- Pre- and post-retrofit consumption

- RESNET?
- AkWarm, Tectite
- Excel, TREAT
- For audits under state programs it is whatever software you are required to use. Real home analyzer for NJ.
- Energy modeling software
- In-house software
- TREAT, CSG HomeCheck (or whatever it's called now)
- In NYS retrofit we have been burdened with TREAT for retrofit work under state programs that offer incentives for what feels like forever
- ENERGY STAR
- REM/Design, VisualDOE
- REM, Optimizer
- REM/*Rate*
- Blower door, duct blaster, good auditor
- Tape measure, pencil, paper, and my five senses. This works well where auditor has triple-digit IQ and some knowledge of how homes work.
- Real Home Analyzer
- AkWarm
- ResNet
- Most of the time I see visual techniques used that include a walk through and maybe thermal imaging. In my area SW Ohio I see little blower door testing or other performance evaluation of the existing prior to weatherization.
- REM/*Rate*
- RESNET
- Eyes

As the results show, there are a variety of options when assessing a home and assumptions can be made on the accuracy of and/or comparison of results when comparing one home to another using different methods or software(as an example).

Responses to Question 6

The next set of questions target the post-retrofit process; that is, after certain measures or technologies have been installed that may have been recommended by the result of an energy audit. Question 6 asked if homeowners should receive information regarding the performance of their homes after a retrofit, with a yes or no response (see Figure C-2), followed with a

multiple choice option. With 97.6 percent of respondents answering yes, the following represents their selections on what information should be provided.

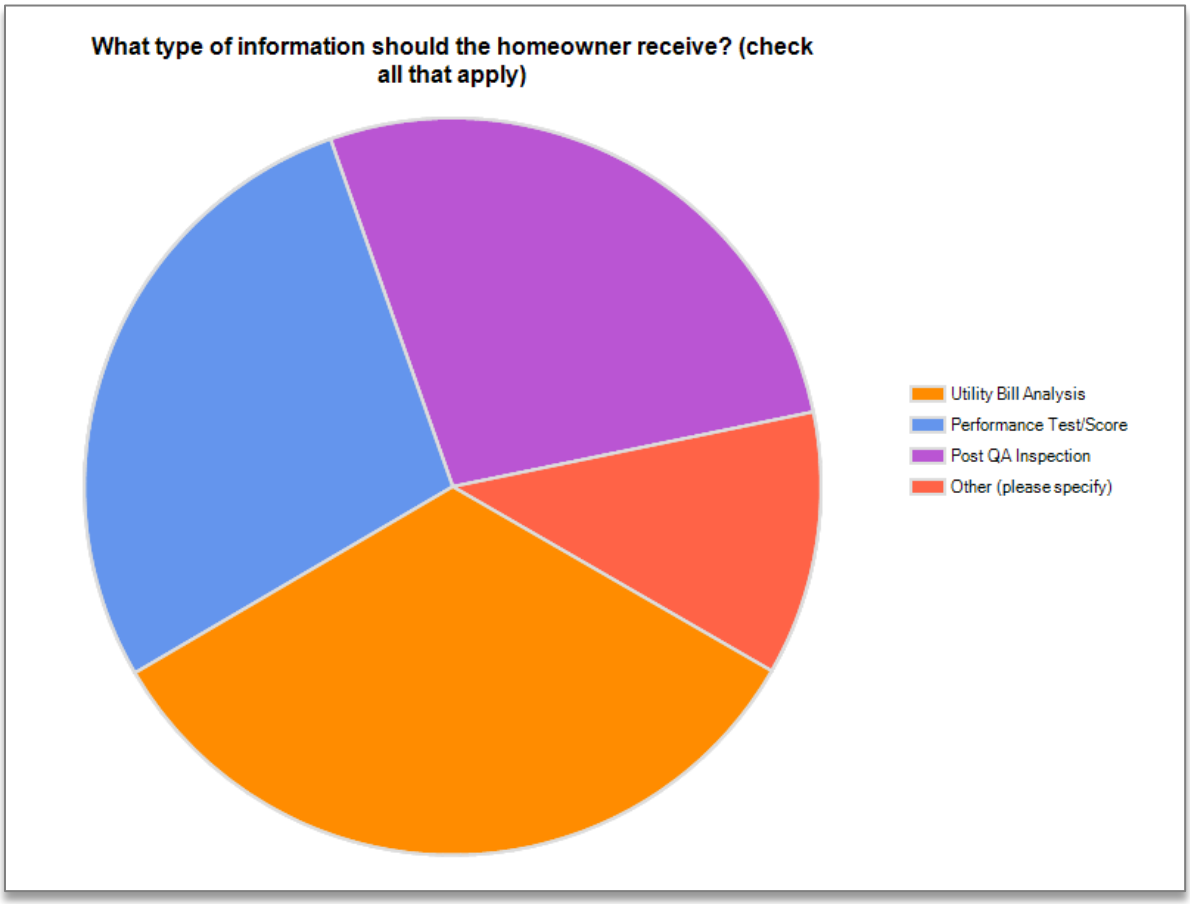


Figure C-2. Survey of Types of Information Homeowners Should Receive

The other category includes the following suggestions from respondents:

- Long term opportunities as part of home's required maintenance
- They already do - the utility bills - that is the most important one to them
- Interview post retrofitting
- Show numbers relative to others in the same climate per sf and per household
- Tools to track future usage to quantify results
- Info on long-term "capital improvement" strategies--when to plan for work that will allow additional energy upgrades at a minimal incremental cost (remodel, re-siding, re-roofing). And preferably trigger another audit/assessment at that time.
- Some interactive meter to encourage future savings through modified behavior
- Brief consulting /interpretation of data to client

- Online (low cost, automated) analysis of energy performance with recommendations for further savings, habit changing, etc.
- Again, a real truth statement about achievability of reductions in demand
- Guide to operating and maintaining their home, equipment
- Again, read the *Wired* article
- Connection of the changes to any health issues
- Findings/recommendations/priorities
- Not sure what you had in mind for "Performance Score" but any metric utilized should have a pre and post with estimated impact
- Full envelope analysis pre and post
- Scope of work with ROI

Responses to Question 12

Question 12 was considered a broad question and we asked respondents if there were competing standards (as it relates to existing housing and energy efficiency). Nearly 70 percent of the respondents answered yes and were offered an opportunity to answer whether this is a problem. The following results show the respondents testament to the issue:

- Various standards can confuse homeowners but since every house is different it is hard to create one standard that applies to all
- Not necessarily – There needs to be a clear recognition that "energy efficiency upgrades" do not represent anything that is homogeneous - huge array of investment, drivers, opportunity, and delivery systems.
- Not yet
- BPI, RESNET, ASTM, and DOE are all working on overlapping spaces that end up causing confusion in the market, even if the groups don't explicitly compete
- Not necessarily competing standards but competing industry groups of ASHRAE and IECC which makes it confusing
- Not many people can go through a maze of ICC green, ASHRAE, ASTM, USGBC, LEED, etc.
- I'm sure there is depending on location
- No
- Maybe – none of them are very good
- The utilities and political people seem to like whatever sets the bar lowest
- Some, but hopefully SWS should help with this
- Only that they are all flawed thus creating a circus of idiotic banter
- It may be confusing, mostly to people entering the field. Again, see #12.

- Consumer cannot generally differentiate between rating systems (builders usually can't either), often easier & cheaper rating is implemented rather than more robust rating/standard
- High-efficiency standards appear to be converging; support allowing particular jurisdictions to higher requirements
- I don't know, however, there are inconsistent methods for energy audits, many people calling themselves an "energy auditor." Need to have a stringent certification process for an energy auditor and elevate this to a profession.... not a hobby.
- Yes... they should be standardized around a national standard... ASHRAE Std 100
- Let me give an example. New fire sprinkler code requirements could undermine effectively aligned insulation at the roof/ceiling interface.
- DOE is trying to compete with RESNET standards, this is worthless duplication that will only serve to confuse the market and cost more money
- Programs? Not a problem. They do create confusion but also increase awareness. Effective change will come with code changes and mandatory reporting of energy use.
- IECC 2009 is in direct conflict with IRC 2009 and each of those with ASHRAE 62.2 with regard to minimum and maximum OA supplies to homes
- n/a
- No. There are silly standards like Passiv Haus that have no real impact on the big energy standard; ENERGY STAR.
- Not a problem when people are presented with the options and allowed to choose
- It can create confusion
- Don't know
- Competing software and testing standards creates some confusion
- Don't believe we have an authoritative uniform conformance standard at this time
- Many organizations, companies, energy retrofit businesses, etc. have different standards.
- Yes, different applications of combustion safety standards is a mess ranging from too little to be of use, or overly complex as a barrier to work being done
- Yes, especially for the homeowner who has no idea where to look or how they measure up

There are significant opportunities in which collaboration and coordination can create better results for the industry and their customers, where value on the energy audit process may provide more promising adoption of new technologies and their energy savings during the post-retrofit process.