The Energy Audit of an Existing Home

by

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Introduction

For knowledgeable professionals with training and experience in thermodynamics, fluid mechanics and system processes, Home Energy Auditing does not present the usual challenges one sees in a more sophisticated facility. But engineering skills may be used to go beyond the routine audit. Special problems that can occur during a home audit, which cannot be solved by an insulating or siding contractor who is also an energy auditor, might be better solved by someone who is knowledgeable in the fundamentals of energy systems and today's auditing standards. With the explosion of interest in the "Cash For Caulkers" and other incentive programs, experienced construction professionals are potential evening instructors for adult workers who require training in building energy systems. Large scale building energy audits and those associated with large commercial building performance contracting do require an architect or engineer's license in connection with the Energy Star program. And energy saving principles are identical for the larger and smaller scale single family dwellings.

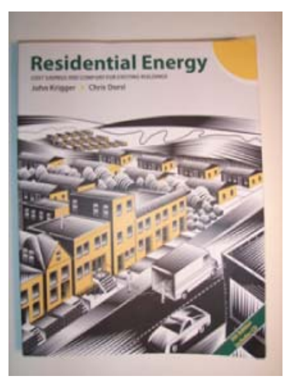
Beyond being a refresher course for many, completion of this SUNCAM course and test questions will add to practical knowledge useful in other areas. The investigative methods presented herein can be applied to other projects, and to new building design that involves the HERS (Home Energy Rating System) primarily for Energy Star Rating. Those seeking LEED AP status will find the information presented here helpful. Anyone involved with efficient retrofits such as geothermal heating and cooling will interact with the energy audit that is conducted first to size heat pump tonnage. Federal Stimulus funded geothermal rebates are requiring the energy audit and certain efficiencies as a first step.

Before proceeding with a "side business" of consulting on home energy audits on weekends, be forewarned that a thorough analysis requires the use of specialized and expensive equipment such as the Blower Door, the pressure reading Digital Manometer, and Carbon Monoxide detectors. Initial instrument equipment investment cost can exceed $10,000.

Commonly used home energy audit inspection instruments.

One purchasing source is *http://www.energyconservatory.com*

NOTE THAT WEB SITES ARE GIVEN THROUGHOUT THIS COURSE FOR REFERENCE ONLY. NO TEST QUESTIONS COME FROM THESE WEB SITES.



Knowledge of basic energy principles is essential. A text book and CD used in Building Performance Institute (BPI) training that comes highly recommended is:

RESIDENTIAL ENERGY *-COST SAVINGS AND COMFORT FOR EXISTING BUILDINGS*

- by John Krigger and Chris Dorsi.

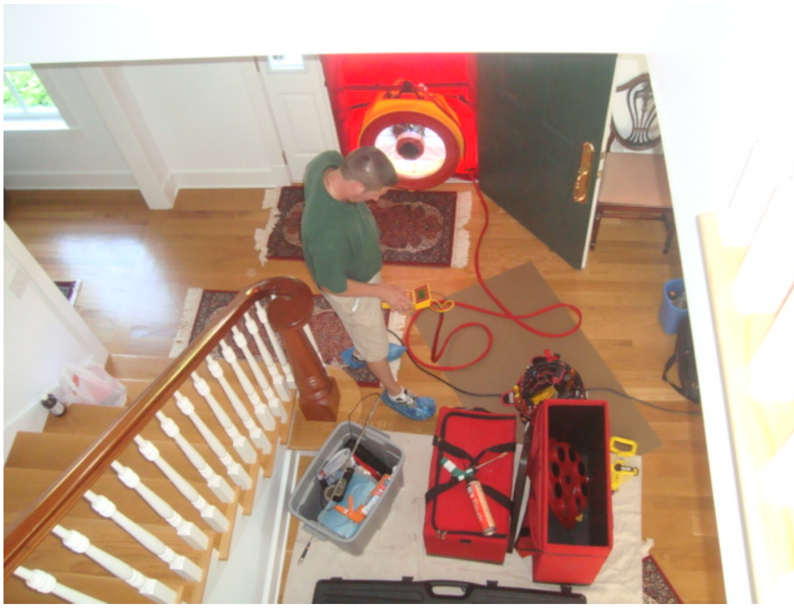
The Book Introduction items of interest are listed in bullet form as they appear:

* The 5% of the world's population in the USA uses 25% of its energy.
* Air conditioning can be found in 70% of existing and 80% of new homes.
* Single family & mobile homes comprise 80% of U.S. residences.
* 20 year and older old single family homes use 61,000 BTU/ft^2 per year.
- Newer homes use 45,000 BTU/ft^2 per year.
  - extremely efficient homes use 5,000 BTU/ft^2 per year.
    -inefficient homes use 100,000 BTU/ft^2 per year = 40 kWh/ft^2/yr.

* 105 million BTU's of electrical energy are used at the average home each year.
* Inefficient home heating & improper insulation cause 50%-100% more to be used.
* Weatherization can save a quarter of this wasted cost.
* The energy auditor finds the reasons why energy is being wasted.
* Air leakage, especially around insulation, is the primary culprit.
* Window replacement payback usually lags air sealing & more insulation.

The 10 Chapters then discuss Principles of Energy and the Building Shell, Air Leakage and Insulation, etc. with useful Appendices.

Engineers, architects, etc. are discouraged from promoting their PE and AIA qualification alone if they have not been certified by BPI (the Building Performance Institute, Inc.) described below. At a recent meeting of local Energy Task Forces, a home owner complained that the Utility Company's Energy Auditor would not perform a Blower Door test on her home. Her alternative to hire a non certified auditor was discouraged. The BPI Professional correctly identified asbestos in her basement, and properly refused to depressurize her house to minus 50 pascals. Such a dangerous violation of BPI practice would have sent dangerous fibers airborne throughout her living space.



Blower Door Fan in proper use.

The superior advice was to retain a qualified asbestos abatement contractor first, and a certified energy auditor after that, if depressurized or pressurized testing was essential. Perhaps air leaks would be investigated using infrared thermography only, or simply smoke or possibly candle fire.

Although Blower Door and Combustion Appliance Zone Tests require specialized training to be addressed later in this course, there are additional energy savings techniques that can be implemented prior to BPI certification. Professionals are more likely to excel at the energy audit and design stage, than the follow up implementation of the actual weatherization construction work such as caulking and insulating.

Audit and design work includes many aspects that require college mathematics skills:

* Calculation of Heating and Cooling Loads by Hand or ACCA (Air Conditioning Contractors of America) Manual J software, for equipment replacement.

For example, a simple 40' x 25' house loses heat through its 8' high walls with average R13 insulation at the following rate:

$$\text{Loss/hr.} = \frac{\text{Area x } \Delta\text{Temp}}{\text{Thermal Resistance}} = \frac{1040\text{sq. ft. x } (68^\circ \text{ F- } 10^\circ\text{F})}{13} = 4640 \frac{\text{Btu}}{\text{Hour}}$$

And air leakage rate calculations can be hand computed as well. One BTU raises one pound of water 1 °F, and similarly, 0.018 BTU's raise one cubic foot of air 1 °F. If the above area was losing 800 cu ft per hour (as measured and converted by the blower door test) then:

$$\text{Loss/hr.} = \text{Flow in Ft}^3\text{ / hr. x }\Delta\text{Temp x 0.018} = 800 \times 58 \times 0.018 = 835 \frac{\text{Btu}}{\text{Hour}}$$

ACCA Addendum B specifically allows hand calculations for single family detached dwellings served by a single zone, constant volume system.

Other areas where professionals excel:

* Recommendations on mitigation of basement moisture or drainage problems.

* Interpreting air flow volumes existing, versus model air flow desired by calculating the BAS (Base Airflow Standard) prior to a Blower Door test.

* The SIR (Savings to Investment Ratio) for new windows, insulation or equipment.

* Use of the Kill-A-Watt meter to interpret electrical wattage differentials and cost of various appliances.

BPI

The Building Performance Institute, Inc. www.BPI.org was organized in 1993 to enhance and verify the skills of workers engaged in the fledgling Weatherization Industry. It began certifying Energy Auditors shortly thereafter. With headquarters in upstate Malta, New York, it operates under a Board of Directors and Technical Experts, served by a staff of two dozen. Consumers are urged to use only certified BPI professionals, as listed on their web site. For existing homes, the Building Analyst 1 (BA1) certification applies. Upon completion of this SUNCAM course, the additional training needed to pass the BPI written exam portion will be minimal. And by associating yourself with an accredited BPI auditor to obtain practical field experience, the field exam can be passed as well. Alternatively, interested candidates should take an approved week long course from trainers such as Performance Systems Development, Inc. www.psdconsulting.com (who trained the author in Bangor, Maine) for both classroom and field training. The practicing building professional will do well in the on-line 100 question closed book multiple choice test, passed with a grade $\geq$ 70%. The follow up field exam by a trained BPI proctor requires familiarity with BPI procedures and proper use of instruments. The minimum passing grade is 85% for certain critical safety questions.

Beyond the Building Analyst is certification in specialties such as Building Envelope Professional, Heating, AC and Manufactured Housing. BPI also lists accredited contractors. Engineers are encouraged to support the evolving work on BPI Building Performance Standards that emphasize Energy Conservation Measures and Comfort. Standards that have been proposed are at: http://www.bpi.org/documents/BPI-EA-7_Standard.pdf

Utility and State Energy Programs rely on trained BPI professionals to enter private homes, and conduct proper energy audits. A typical arrangement in one state is for the homeowner to pay a $75 fee for their home energy audit. The Utility then contracts out that job at a cost to them of approximately $600-700. The approved contracting company sends two auditors to the home for half a day. At least one in responsible charge is BPI certified. Customers who invested the $75 report that it is worthwhile, and the utilities and government agencies have continued to provide funding. A DallasNews.com story noted that Texas spent $1.8 million in administrative costs that had only seven homes weatherized so far. But traction was gained in many states and the high rate of return on investment has been noted.

Engineers or Contractors not on the approved list have difficulty competing in existing home energy audits backed by big subsidies. But they may work at competitive pricing doing business building audits. And construction experience along with BPI certification is an advantage when utility companies and agencies choose their energy auditing contractors. In areas without subsidy, prices are at market rates as shown below:

With permission from
Caleb's web site:
http://esaverenabler.com

Another sample website is Chuck's company performing audits and weatherization at www.energysaversofflorida.com

Best Practices for Field Protocol

A typical home energy audit starts with an interview of the homeowner(s) perhaps at their kitchen table. Their electric and fossil fuel (gas or heating oil) bills are reviewed and discussed. The homeowner is encouraged to follow the energy auditors and ask questions.

All energy audits are different and strive to achieve various goals. Not everything prompted here is mandatory, but for guidance, the course will expand on this Protocol:

1. Check the outside of the home for water and moisture issues.
2. Check inside and outside for propane or natural gas leaks.
3. Test the CAZ areas (Combustion Appliance Zone) for Carbon Monoxide.
4. Inspect insulation, moisture, thermal and pressure boundaries.
5. Ascertain safe conditions, and conduct the Blower Door Test.
6. Evaluate lighting, water use and appliances. Change out some bulbs.
7. Check domestic hot water temperature.
8. Use the Duct Blaster to check for leaks in the unconditioned spaces.
9. Demonstrate on refrigerator, etc. the Kill A Watt meter.
10. Discuss recommendations with homeowner.
11. Return all controls and settings to "As was" condition.

A multicolor form is usually filled out with a Comments Section to draw attention to important and especially safety issues. Both the home owner and Energy Auditor sign and keep a copy.

Conducting the Energy Audit

according to the 11 steps listed above

1. Check the outside of the home for water and moisture issues.

Energy Auditors arrive on premises prepared and equipped with all necessary OSHA safety equipment, such as the items listed in the 17 page BPI Technical Standards: http://bpi.org/documents/Building_Analyst_Standards.pdf that is the main reference document. Items include: Fitted respirators with canister filters, Dust Masks, Gloves, Protective Clothing, Safety Glasses and Hard Hats, as required.

Besides including the Technical Standards on clip board, the MSDS (Material Safety Data Sheets) are kept in crew vehicles for all materials used and installed on the job.

Inspection of the house exterior and grounds is perhaps the simplest task for a civil engineer. For solar gain, south facing orientation is noted. The watershed leading to the house can be evaluated, and proper positive slope to shed runoff away is ascertained. A laser instrument is not usually required if homeowners know where puddles form. Clogged gutters, footing or sump pump drains, trees too close to the house, and evidence of moisture or mold on the siding and roofing should be documented. Efflorescence or peeled paint indicates such. Take notes from the outside for potential adjacent basement or attic moisture problems on the inside. Digital photos may be taken if desired. Record the outside temperature, needed for a calculation later in the audit. Make recommendations based on outdoor work solutions.

2. Check inside and outside for propane or natural gas leaks.

Gas leaks tend to be at connection fittings and valves. Such leaks add to methane in the atmosphere that is highly undesirable because methane is considered far worse than carbon dioxide. If the natural gas line from the street is exposed, examine the portion beyond the meter that the gas company does not prioritize. Use the Leakator or an instrument as shown below that works like a Geiger counter to emit a loud noise or other signal if gas is detected.

Proper gas leak detection.

The correctly recommended technique is to run it along the straight copper pipe runs, and completely around all connection points. Since propane is heavier than air and natural gas, prioritize below the piping and connections for propane. Some outdoor propane tanks have expansion valves that allow the slow escape of some propane. Notify the homeowner to contact the gas supplier if there is detectable gas being wasted into the outdoor atmosphere. Propane should settle, and not pollute the atmosphere, but large concentrations could pose a risk of explosive flare up. Once inside, continue to check all gas lines for leaks. Use soap bubbles to specifically locate a leak if indicated by instrument.

Bubble detection for Gas Leak

Recommend the replacement of any flexible gas line that is kinked, corroded, worn, soldered or made before 1973.

3. Test the CAZ areas (Combustion Appliance Zone) for Carbon Monoxide

This important test addresses heating safety. The energy audit testing is not to be confused with, nor overlap the annual efficiency testing and cleaning conducted by a licensed furnace service contractor. The BPI goal is to prevent dangerous CO (Carbon Monoxide) and other noxious gases from entering the house during the course of an energy saving audit. Conditions exist especially where a gas fired orphan natural draft hot water heater with a small exhaust flue does not have enough draft to draw all the combusted gases up that flue and out of the house. Other negative pressures exerted by fans and miscellaneous equipment could be overwhelming the ability of the flue to release all the exhaust produced during the combustion. Depending on the configuration, any fuel burning unit could fail this way.

Note that in some jurisdictions, only licensed heating contractors test combustion appliances, so sometimes an energy audit will not include a CAZ safety test.

Gas hot water heater with natural draft vent to be CAZ tested

The first step is to define and locate all the combustion appliances in the home. The Zone simply refers to the approximate immediate vicinity near the appliance unit. An electrical baseboard radiator is not a combustion appliance. Combustion appliances are those which burn fuel inside the home for heating, cooking or decoration. They include the furnace, domestic hot water heater, space heaters such as kerosene, etc. the oven or stove, both for cooking or heating with wood or pellet burning. Fireplaces that burn wood or gas (even for just decorative purposes) are all combustion appliances. A gas clothes drier is a combustion appliance, but an electric clothes drier is not. Air conditioners, electric heat pumps and electric stoves are not combustion appliances. Some gas fireplaces are un-vented, but that is generally discouraged, and a CO monitor with alarm should be placed nearby.

The energy auditor must play devil's advocate, and determine which appliances could emit harmful gases, and then test that under no circumstance configuration of pressure changes will this occur. The homeowner might not always run all the exhaust fans plus the clothes drier, and open a door or windows on the leeward side of the house on a windy day. But if this were to happen, and a suction or negative pressure was produced that was greater than the positive venting pressure of an internally burning appliance, the negative pressure could draw Carbon Monoxide into the home at dangerous levels. Exhaust should be going up the flue vent under all circumstances.

The homeowner does not have access to the sophisticated instrumentation needed to detect back draft. So the BPI Energy Auditor is charged with the task of checking for this condition. This is the worst case depressurization test of the CAZ. Depressurization is at small levels, and would not affect asbestos or mold.

Two primary instruments used are the digital manometer and the portable Combustion Analyzer that measures CO. http://bacharach-inc.com/index.htm Take constant note of CO levels. If ambient level exceeds 35 parts per million, stop the test, and leave the area.

Portable Carbon Monoxide Detector and a separate DG-700 Digital Manometer

The DG 700 digital manometer is the same instrument shown later, and used for the Blower Door Test. With this instrument, one can read pressure differentials WRT (with respect to) a separate area such as another room, the outdoors, or the area near a combustion appliance.

Select naturally and induced draft appliances to test one at a time starting with the smallest, and always testing a smaller BTU water heater before the larger furnace. A warm chimney could cause updraft that is unavailable when the furnace was not used.

Before commencing, inspect all vent systems to be sure they are operating properly. Check that there is no flammable material or VOC (Volatile Organic Compound) stored near the furnace, and that all equipment works properly, and filters are not clogged. Review the heating and cooling components. A simple diagram of duct register supply and return is helpful to understand worse case depressurization results. Steam and hot water heating line loops should also be sketched.

The six steps to take from page 12 of the Standards , again at: http://bpi.org/documents/Building_Analyst_Standards.pdf are summarized:

1. Close all outside doors, windows and the fireplace damper to replicate a winter condition. (Temporary wind impact is accounted for WRT the outside ambient pressure.) Turn off all combustion appliances, or set to pilot. Many auditors leave their car keys near the equipment they turn off, so that they do not drive away later without turning appliances back on. Using the manometer, measure and record the base pressure of the CAZ WRT the outdoors, by placing the flexible hose tubing through a small opening at a door or window. This pressure difference could be 1, 2 or perhaps 3 pascals. (Conversion is 249 pascals = 1" of water column.)

2. Depressurize the house to its worst case condition by turning on all exhaust fans, the dryer, and opening or closing interior doors that make the CAZ pressure more negative (devil's advocate). The digital manometer measures these ambient pressures in pascals. Turn on the air handler if CAZ pressure goes down. Re-measure and adjust for the previously recorded base pressure. Record this worst case depressurization, and compare it to the BPI limits. If exceeded, construction improvements must be made.

3. Activate the appliance, and check for spillage at the open draft diverter. This means exhaust is coming into the house. One can see vapor on a mirror, or use smoke that shows it blowing away from and not up the duct vent. A little spillage at first is common. If spillage ends

in one minute, then test the draft pressure with the digital manometer hose and probe at a drill hole located 18" after the diverter or first elbow, but not in a power induced vented flue or sealed combustion unit. For a fuel oil burner, test at the damper flap.


Damper flap. Test both pressure and CO level.

Check this pressure against the acceptable Draft Test Ranges.
The BPI minimum Draft Pressure Standard between 10°F and 90°F

$$= \frac{\text{Temperature}}{40} - 2.75.$$

At 60°F outside, minimum pressure = -1.25 pascal.
So -1 pascal or any positive reading will be acceptable draft to exhaust CO up the flue.

Once steady state is achieved or in ten minutes, insert the CO detector probe in the same stack drill hole or flap. Record the worst case CO levels of this undiluted flue gas in parts per million. Compare CO with BPI action levels.

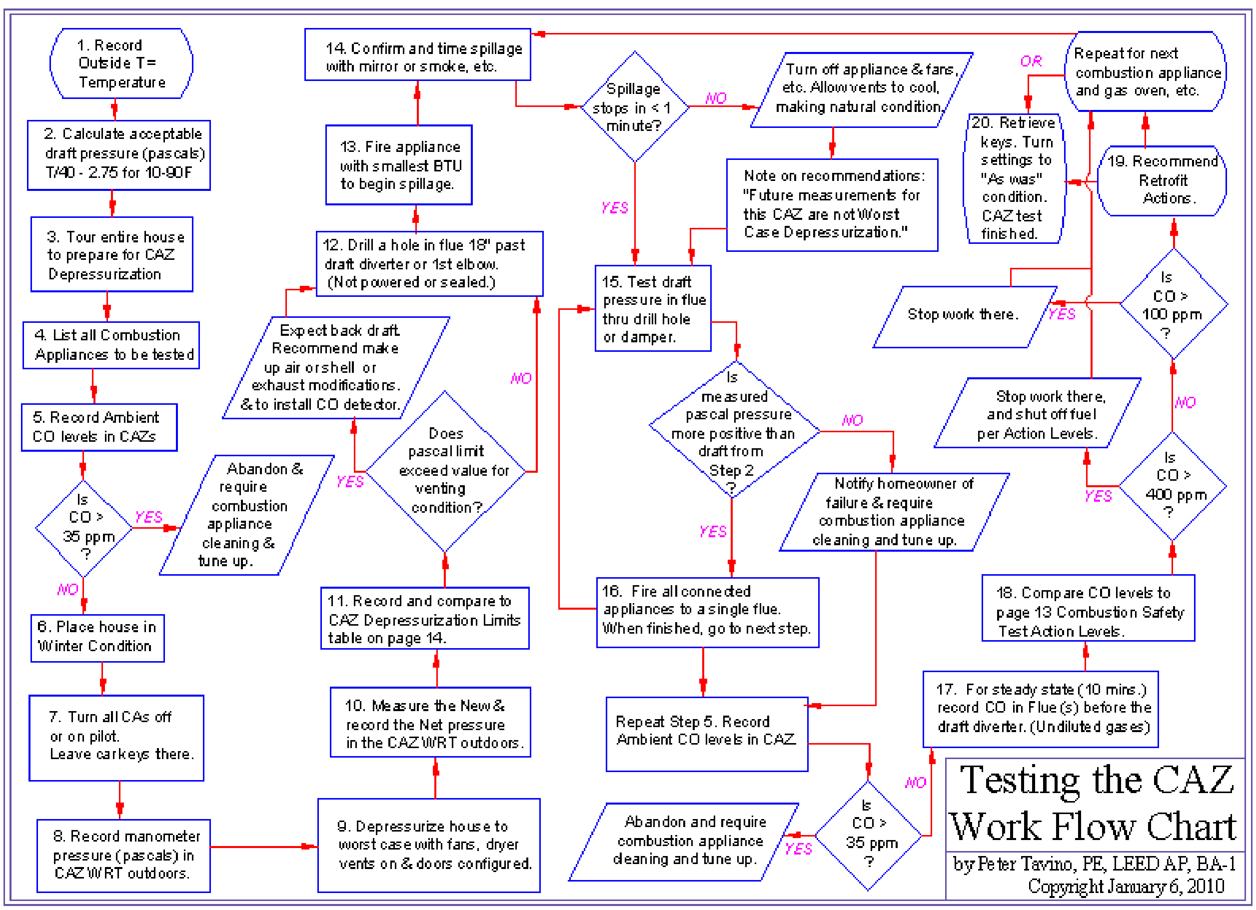
4. If spillage does not end in one minute, turn off everything and allow for natural conditions, and retest that way. Record Δ P.

5. Turn off, ventilate the space and evacuate if ambient CO > 35ppm in the CAZ breathing space. (unlikely)

6. Consult Actions Table, and formulate recommendations.

Repeat for all appliances, including the hot water and furnace together. Remove anything in a gas oven before testing. Measure steady state CO in the oven vent about 9" above the burners. Specifically follow the BPI oven test procedure. Note the importance BPI attaches to this Combustion Safety Testing by requiring a passing grade of 85% in this part of the Field Examination.

Continued Carbon Monoxide safety analysis involves checking the UL-2034 CO alarm detector installation. Visually inspect the furnace flame, and attached garages must not have air leaks to the home. The six step BPI procedure from above can be followed more precisely with the Flow Chart below (not on exam) which provides guidance on how to conduct a BPI CAZ test:



4. Inspect insulation, moisture, thermal and pressure boundaries.

Insulation:

Before running the essential Blower Door Test, the audit team inspects the entire house with the utmost care not to dent walls or furniture, and often with protective fabric booties over work shoes. There is not a rush to move quickly through a house. Insulation is generally hidden behind wall sheetrock or plaster. But unfinished basements and attics allow for visual inspection. The basement perimeter above the foundation is a source of great air leaks and heat loss. At this location referred to as the rim joist, header joist or band joist, is an opportunity to make valuable improvements.

The attic is the other "low hanging fruit harvest" area. There are occasions where an elderly or infirmed owner or renter will not have entered a narrow attic hatchway for a long time. The related inspection is likely to reveal intrusions by animal pests, etc. that can be halted with some future air sealing or by calling for an exterminator.
The author has seen a situation where a disgruntled handy man purposely removed many attic floor bays of fiberglass insulation batts some seasons ago. The woman occupant below, who could not enter the hatchway herself, was tricked into wasting heat without her knowledge until the situation was corrected - and she was so informed.

Accessible attic insulation above the ceilings of the conditioned rooms can be tape measured for thickness. The standard R-30 is met when fiberglass is placed within 2 by 10 joist bays, and protrudes up slightly. The BPI standard on page 7 rates it at 3.0 per inch, and the auditor must evaluate its effectiveness as Good, Fair, or Poor with resulting factors. Many types of insulation are rated there.

The Dept. of Energy website at http://www.ornl.gov/~roofs/Zip/ZipHome.html includes a Zip Code Insulation Calculator to account for extra R value required in the north. Voids and gaps in insulation especially at electrical and mechanical fixtures or framing irregularities are recorded for their net square footage. Use the page 9 table with NFRC (National Fenestration Rating Council) to assign R values to windows and doors. Record the SHGC (Solar Heat Gain Coefficient). Check glass etching for a label about its low-e (emittance) coating. Besides air leakage during the Blower Door test, the auditor should be sure windows and doors open and close properly, by sampling and homeowner interview. Sometimes weather stripping opportunities are apparent.

The experienced auditor knows that attic stairways cause huge air leakage. The 2" Extruded Polystyrene rigid board makeshift hatch shown below is R10, by the per inch thickness. But beyond the R factor is the important black gasket air seal as shown below left.

Attic Hatchway. *Attictent.com*

Before making a recommendation to increase attic insulation, be sure there is a proper air barrier below, or recommend air sealing there as part of the scope. For example, use a smoke puff generator in the attic during the Blower Door Test. The finished work after blowing in loosely filled cellulose over inadequate insulation will look like this.


Well insulated Attics.   Note proper sealing and ventilation baffles at eaves, above right.

Attics that have inadequate insulation behind sheetrock are difficult to improve. Where warranted, cellulose can be blown in through drill holes from the inside or outside by removing certain sidings. Newer construction methodology featuring unconditioned attic rafter insulation techniques will probably not be encountered in older existing home energy audits.

Moisture

One of the major reasons for IAQ problems is moisture condensation that causes respiratory problems for millions of Americans. Whether in heating or cooling season, uncontrolled residential condensation causes enormous difficulty. Krigger and Dorsi tell us that billions of dollars are lost when condensation warps wood, corrodes metal, weakens mortar and dissolves glue.

Biological molding agents deteriorate the building as they cause breathing challenges to the home occupants. Wet insulation loses effectiveness as its thermal resistance properties are compromised. There are instances where water can freeze beneath the roof shingles in unheated space yielding potential expansion and contraction problems on structural members, especially at edges where ice dams can back up water inside.

Water travels by many methods, and in homes especially through roofs and plumbing leaks or up from basements by capillary action or under head pressure.

Uncontrolled movement of air that contains excessive vapor can deposit it throughout the structure as a liquid when it reaches its dew point. And vapor moves through solid objects as a function of pressure and permeability. Recall this phenomenon through Darcy's Law:

Flow (Q) = Hydraulic Conductivity (K) x Cross Sectional Area (A) x Hydraulic Gradient (i= Δ Head /Length)

$$Q = K\,A\,i$$

Cutting off the portions of the Leakage Areas that are significant enough to conduct water and vapor can rectify problems. An example is silicone caulking the basement slab where it has contracted away from the concrete or block walls as shown below.


Silicone caulking always < 3/8" dia. bead at opening.

It is particularly important that weatherization work not exacerbate moisture problems by trapping historically free flowing movements. Energy saving retrofits must mitigate condensation and water seepage.

During the heating season, moist indoor air escapes out, leaving the relative humidity lower (as the energy auditor can measure with a Hygrometer.)

Dual Display Thermometer / Hygrometer

Summer relative humidity should be < 60% for comfort.
Winter relative humidity should be < 40% for restricting condensation.
But individual comfort can be satisfied by controlled ventilated humidity.

In recommending vapor barrier improvements, it is best to follow the advice of Joe Lstiburek Ph.D., P.Eng., ASHRAE Fellow at http://www.buildingscience.com/websiteinfo/atw-authors/atw-authors-joe ASHRAE.org (American Society of Heating Refrigerating and Air-Conditioning Engineers)

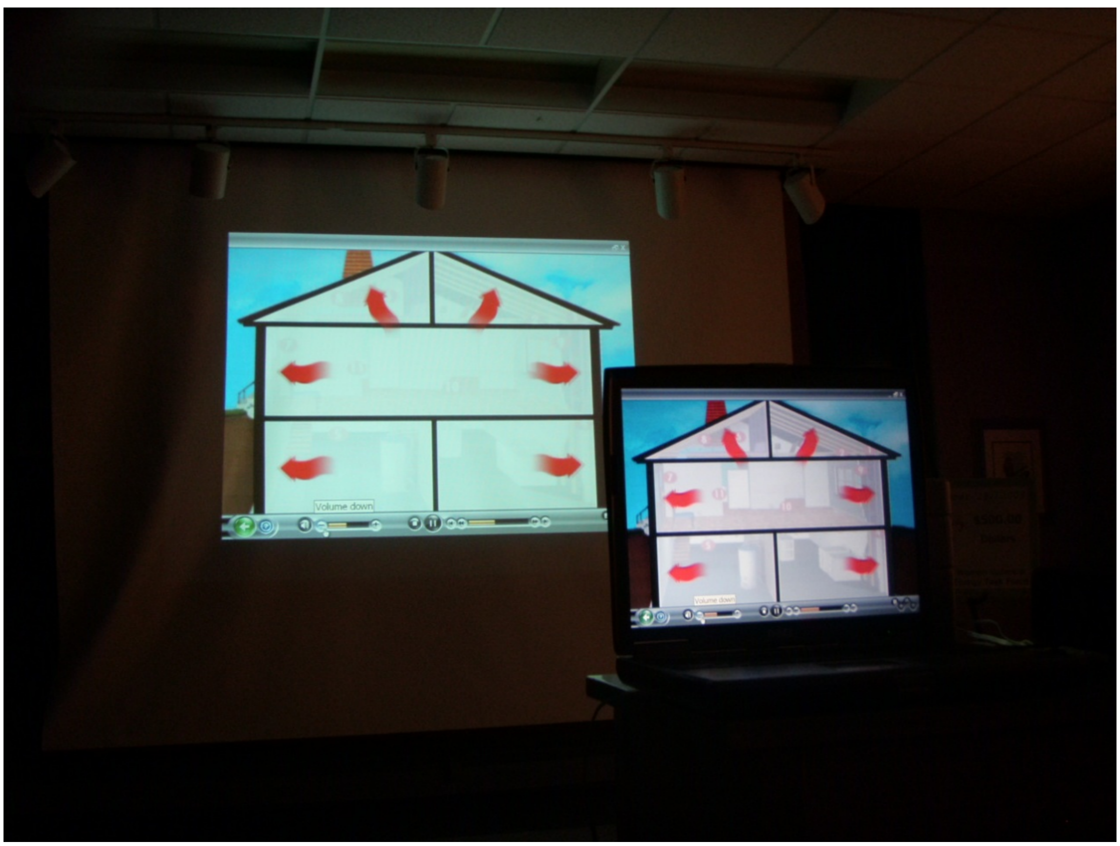
His web site gives separate tips for both those in the Northern US and those in the South. Some of Joe Lstiburek's summary tips from Krigger and Dorsi:

*Vapor barriers should not trap moisture.
*Use a vapor retarder instead of a barrier where feasible.
* Do not place on both sides of a wall or ceiling.
* For air conditioned buildings, do not place even vapor retarders on the inside.
*Ventilate properly to control humidity.

Thermal and Pressure Boundaries

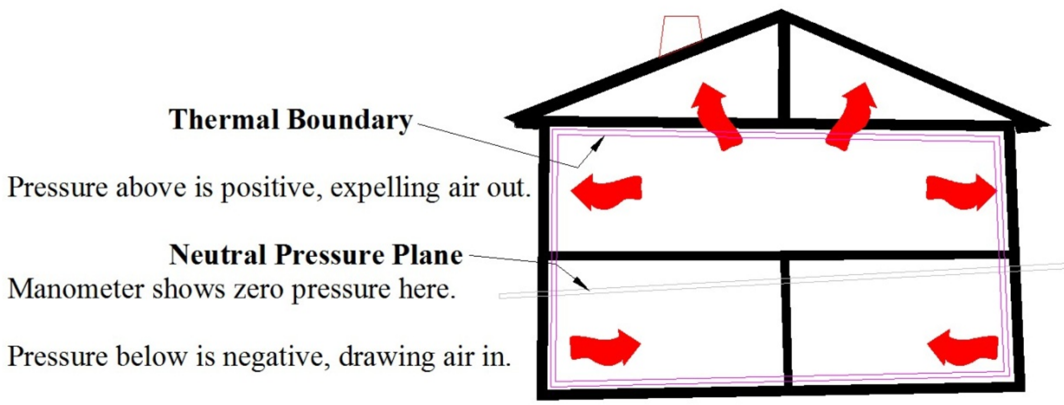
One aspect tested during the BPI field Examination is the proper identification of "air barrier/thermal boundary alignment issues." A basic principle holds that if air is leaking out of a house, (especially if it is rising because it is more buoyant than cooler air) then an equal amount must be entering the house for no change in indoor pressure.

There is a neutral pressure plane where air is generally entering inside below the plane, and exiting to the outside above the plane. This simplistic utility company image (projected from the energy saving dvd on the laptop computer to a larger screen) for the audience is not exactly accurate, because it does not depict the incoming cooler air.



Public education video scene of heat leaving a building.

A more detailed diagram would show the neutral pressure plane as shown below:



Neutral Pressure Plane in a House *(AutoCAD sketch by Peter Tavino PE)*

This stack effect results in emphasis on air sealing the attic for the greatest loss of air and heat. Exact workings of this complex phenomenon are unknown. Warm air with lower density tends to rise while cooler denser air falls, but heat moves in all directions. Heat can be lost through a floor below at lower rates, and rising heat is not automatically expelled by an uninsulated attic in the South. If so, no air conditioning would be required. While areas such as Vermont have a word of mouth reputation for not adding heat upstairs because it rises, proper air circulation by controlled means is the best solution. Uncontrolled pressure differentials yield uncontrolled temperature differentials.

By using Pressure Diagnostic Methods for finding the pressure difference between the living space and the un conditioned attic, optimal air leakage reduction can be determined through various charts such as at Krigger and Dorsi Appendix 14- Air Leakage at Various House Pressures.

5. Ascertain safe conditions, and conduct the Blower Door Test.

The Blower Door Test is controlled depressurizing by fan. It is always conducted as part of a BPI home energy audit, under correct safety procedures. It is important for two reasons:

1. It allows comparison of measured air leakage performance rates to Standards that establish whether the house is properly ventilated for IAQ (Indoor Air Quality.)

2. It allows the temporary amplification of air leakage locations so that they can be identified, and possibly sealed.

Blower door on display at an Energy Fair.

The No Flow Plate covers the Fan.
Rings A, B, or C would replace the Plate.

The DG-700 manometer Pressure and Flow Gauge is attached in the upper right.
One tube goes outside, and one to the Fan.

A viewport is in the red shroud, held in position by an unseen metal frame.

It is best not to conduct the blower door test right away, but to familiarize yourself with the house before hand. Testing the CAZ, before depressurizing the house with the Blower Door, allows a better sampling of stabilized and conventional pressures and temperatures. The house does however, revert back to its normal condition soon after the Blower Door Test is complete.

Background development of the Blower Door Test:

The Building Air flow sections of the BPI standards on page 4 refer to LBL "N" factors. LBL is the Lawrence Berkeley Laboratory at the University of California, Berkeley. Max Sherman's 1998/2006 paper(s) here http://epb.lbl.gov/publications/pub_index.html describe the evolution of Blower Door Technology.

In the late 1970's scientists began using window and door fans to learn that buildings were leaking more than previously recognized. By the late 1980's ASHRAE had standards showing that the controlled Orifice Flow through the fan could be used to determine the ELA (Effective Leakage Area) with a flow exponent. This was the beginning of the studied balance between desirable IAQ and the desirable but opposing Conservation of Energy. An air tight house was not good for diluting indoor air pollutants, but was good for saving heating and cooling costs. The properly recommended balanced ventilation levels were sought.

Equations in that paper were developed to show that Infiltration (or Exfiltration) is a function of weather, and thus complex. By averaging the "equivalent constant infiltration rate" it was discovered that the Average was greater than the Average for energy savings reasons, but less than the average for IAQ. Adjustment factors were thus applied. It was agreed that -50 pascals pressure would be the standard pressure used.

(Side note to the Engineering Community: Some Communication publications are unclear about depressurization (as a suction effect) versus pressurization. The term CFM_{50} means Cubic Feet per Minute at -50 pascals, not at +50 pascals. When conducting a home inspection, the fan is of

course blowing air out the door, not into the living space. Do not confuse CFM_{50} with CFM_{-50}. This is unfortunate nomenclature, because the distinction between positive and negative pressures is so important.)

These were the early attempts to establish what is now the very useful and important BAS (Building Airflow Standard.) This is the ideal level between healthful air flow within the home, and minimal loss of conditioned air to the outside. At -50 pascals, the NL (Normalized Leakage) was found to be the ACH (Air Changes per Hour) divided by 20 for a typical single-story residence.

$$NL = \frac{ACH_{50}}{20}$$

Ventilation fluctuates because of Air Leakage, and is not as reliable as controlled ventilation. And both are a function of the W (Weather) as factored. The ACH was established at 1.44 times the weather factor W times Normalized Leakage:

$$ACH = 1.44 \times W \times NL$$

when $0.67 < 1.44W < 1.0$ in the United States. W also depends on height, leakage distribution and wind.

The established formula: $ACH = \frac{ACH_{50}}{20}$ = Ventilation due to air leakage, but not air changes for energy conservation purposes.

Energy lost from leaks was found to be the threshold that a building is too tight if:

$$NL < \frac{0.24}{W}$$

(And from the prior CAZ discussion, insufficient air leakage could cause back draft.)

Similarly, a building is too loose if:

$$NL < \frac{2000}{IDD}$$ (Infiltration Degree Days)

Recommendations to balance the two through mechanical ventilation resulted in this important table that "summarizes the need for mechanical ventilation for different building leakages." From this, we have today's Standard.

TABLE 1. CHARACTERIZATION BY BUILDING LEAKAGE.

LEAKAGE CLASS	Minimum NL	Maximum NL	Typical ACH_{50}	Ventilation Requirement	Recommended Ventilation Type
A	0	0.10	1	Full	Balanced Only
B	0.1	0.14	2	Yes	Balanced
C	0.14	0.20	3	Yes	Either
D	0.20	0.28	5	Some	Either
E	0.28	0.40	7	Likely	Unbalanced
F	0.40	0.57	10	Possible	Unbalanced Only
G	0.57	0.80	14	Unlikely	Unbalanced Only
H	0.80	1.13	20	None	None
I	1.13	1.60	27	**	**
J	1.60			**	**

*** Buildings in this range may be too loose and should be tightened.*

The table values also recognized that intermittent kitchen and bathrooms fans were not reliable contributors to IAQ, and Balanced Mechanical Ventilation, such as Air to Air heat exchangers should be used when needed. A sample Ventilating system is shown below:

Honeywell mechanical ventilator with heat exchange. Note supply and return air ducts to the outside.
(Also referred to by workers as the "Fan in a Can")

Another vendor that supplies Heat Recovery Ventilators for under $500 is Airiva.
http://www.youtube.com/watch?v=ci960m4SSC0

http://www.youtube.com/watch?v=Skcoqs1rUdY

Thanks to those Pioneers with Max Sherman, today's Energy Auditor can easily compute the need for ventilation in tight buildings or air sealing in loose buildings based on Table 1 findings adjusted to today's BPI formula. Sherman's group also made adjustments for weather factor by using more than 200 weather sites and mapping four zones in the U.S. This map from 1998 has been refined to the BPI map of the US on page 5, using Lawrence Berkeley Lab "N" Factors to adjust for Weather Zone and Number of stories in a building above ground.

Evolved from Table 1, and the N factor Zone Map is the BPI Minimum Building Air Flow Standard provided by ASHRAE 62-89. An excellent example application in the Standards shows that a USA Zone 2, 1500 sq. ft. (with 700 sf basement) two story home that requires (0.35 x Volume/60 = 102 cfm) x 15.4 "N-factor" = 1570 CFM_{50} or 0.71 CFM_{50} per square foot. (The alternative occupant rate of 15 CFM per person is less.)

In subject conclusion, the BAS (Building Airflow Standard) can be hand computed for every building before a Blower Door Fan is even installed. The energy auditors can set up the blower door frame, shroud, fan, and digital manometer. They add or remove flow rings A, B or C to depressurize the house to -50 pascals, and record the actually measured Air Flow in CFM_{50}. They compare that actual reading to what it should be, equal to the calculated BAS.

For the above example, if the BAS > the Blower Door Tested CFM_{50} and >70% of the BAS, there is not enough ventilation, and the house is too tight. Continuous Mechanical Ventilation must be recommended to the Homeowner. If the Blower Door tested CFM_{50} is less than 70% of the BAS, continuous Mechanical Ventilation must be installed. Similarly, if the Blower Door tested CFM_{50} is > the calculated BAS, the house is loose, and should be air sealed with caulk, foam, etc. and then retested by Blower Door to ascertain the new and lower Air Leakage, closer to the BAS rate.

Some weatherization contractors price jobs at a rate such as $0.60 per CFM_{50} reduced. For the example house above: with1570 CFM_{50} BAS, suppose the initial Blower Door reading from the digital manometer was 2845 CFM_{50}. The contractor crew caulks and air seals for several hours, and at retest, the new Blower Door reading is improved to 1760, close to but not under the 1570 BAS. They are paid $651.00. Some weatherization pictures:

Foam air sealant around duct opening

Socket and Receptacle Sealing

Window film blocks UV rays and insulates.
Be sure Plexiglas window inserts allow fire escape egress.

Twin draft guard.com for under $10.

The contractor who also performs the energy audit can gain knowledge of where best to seal. The Blower Door Test also serves a second parallel service besides measuring the air flow in a home against the recommended Standard. It allows amplification of air leaks that become more easily observed. Under normal circumstances, one might not feel the minor air wind around a loose ceiling light or window. But with the house at - 50 pascals because of the operating Blower Door Fan, placing your hand near that fixture or window might allow you to feel the air leaking out.

And there are more sophisticated ways to identify air leak locations. Max Sherman reported that by 1991, ASTM (American Society of Testing materials) had published Standard E116 to include "Smoke movement, sound propagation and (infrared) thermography." These are the tools and instruments energy auditors use for target air sealing. These tools allow identification of air leaks, which can be readily sealed, and which otherwise would be invisible to the eye or sense of touch.

Infrared Thermography Camera. (Cost is > $5,000.)

Professional designers will observe that the role between designer and contractor is blurred, compared to the normal design - bid process. Some companies offer discount audit / inspection services so that they can give free weatherization estimates, usually with no competing bidders. And some energy auditors have been known to recommend colleagues who sell window replacements, etc. The auditor must be careful to fulfill the ethics behavior that is partially observed during the certifying field examination.

The Minneapolis or Retrotec Blower door and DG700 digital pressure and flow gauge manometer (with cruise control, to keep flow steady through the fan, for a -50 pascals indoor pressure with respect to outdoors) can cost about $3,000. One source with these and other instruments is http://www.energyconservatory.com .

Test procedure is to first check the house and especially the basement for asbestos, lead, mold and/or other potentially hazardous material. If suspected, follow State and EPA guidelines. Remember the BPI motto: "First, do no harm…to life, limb or property." If none, then the house is ready to be depressurized.

1. Seal off windows, doors and fireplace damper to simulate winter conditions.
2. Turn off or leave turned off all combustion appliances (leaving car keys as a reminder)

3. Seal off or turn off vents, hoods, AC units and all exhaust fans.
4. There would be no fire in a wood stove or fire place, etc. and no loose ashes.
5. Allow free interior flow by opening all interior doors.
6. Decide if basement is semi conditioned, and whether to include it in the test.
7. Calculate and record the BAS (Building Airflow Standard).
8. Install the aluminum frame and nylon shroud to completely seal a 3'± wide door.
9. Install the fan at the bottom of the shroud to blow outside, with flow rings and No flow plate inside.

The assembly is now ready for the digital manometer. There are many aspects of the operation that will not be reiterated here. One source for setup guidance is from the Quick Guide BD-DEP700-CR. And full description of all manometer functions is at http://www.energyconservatory.com/sites/default/files/documents/dg700man.pdf

DG-700 red tubing attached to Channel A for measuring pressure at the end of the tubing .

In summary, the green tubing is connected to the lower left Channel A Reference tap, and the other end is extended outside a few feet away from any blockage. The Shroud usually has a small 1/4" diameter port hole through which to run the tubing.

On the right side, at Channel B, connect the red tubing to the upper input tap. The red tube other end connects to the Fan. The Upper left Channel A input tap and lower right Channel B Reference tap remain open. Upon turning on the DG-700, pressing the MODE button twice to show PR/FL@50 mode. Channel A will measure building pressure, while Channel B will display the leakage CFM_{50}.

With the fan inlet still covered with the circular plate, press BASELINE for a Channel A measurement. Press START. Channel B will begin showing timed seconds. When baseline measurement appears satisfactory, press ENTER to accept. Remove the No-flow plate and install the Flow Ring by experience that matches the fan flow. (Refer to the configuration and range table.) As rings are adjusted, be sure the Device and Rings used are configured.

Now the plugged in Blower Door fan can be activated using either Manual or Cruise Control, if the newer DG700 is so equipped. Manual knob control resulting in flow giving between -45 and -55 pascals is close enough. Adjust rings and configuration, if CFM flow desired is not reached (by making orifice larger or smaller). Read the CFM_{50} air leakage on Channel B.

Record and compare it to the BAS. Step 1 concerning Ventilation requirements is finished. Record the recommendations that will be reported to the home owner. From the above example, Channel B would display the numbers 2845, meaning 2,845 CFM leak through the building that should have a BAS of 1,570 CFM.

Step 2 now begins with the search for air leakage. The experienced Energy Auditor recognizes the difference in CFM_{50}, and where to begin searching for leak bypasses. With the fan maintaining -50 pascals, walk through the entire house with the previously described instruments that detect leakage, and record or remember where they are.

Air current testing with a smoke generator:

Smoke pen and smoke puffer:

http://www.positive-energy.com/energy-auditing-tools/

If part of the audit involves weatherization itself for minor CFM_{50} differences, the caulking can be done immediately after the fan is turned off. After the weatherization is completed, a post work, second CFM_{50} reading is taken and recorded.

A quick conversion of CFM_{50} to air leakage rates per hour for use in the heat loss calculation is to divide by the N Factor for USA Zone and building height. The Blower Door fan is then disabled and placed in its carry case, and returned to the vehicle. This portion of the audit is completed.

6. Evaluate lighting, water use and appliances. Change out some incandescent bulbs to CFLs (Compact Fluorescent Light bulbs)

Approximately 20% of household electric bills are for lighting. And CFLs can use 75% less energy and last 10 times longer. As part of the Kill A Watt demonstration described later, the auditor should plug in lamps for the home owner, and compare a 60 watt incandescent bulb to the 16 watts used by a CFL. Utility audits can include a change out of bulbs in locations selected by the home owner. These locations are documented, perhaps to allow research about consumer behavior, regarding where they feel comfortable with the different lighting conditions. Some bulbs do take longer to fully illuminate, and the white / yellow color differential is being constantly improved. It is measured according to the Kelvin Scale. Only dimmable CFLs should be used on dimmers. Exterior CFLs must be protected from moisture. Move CFLs away

from remote controls such as television or cordless phone if interference is observed. Check the efficiency of fixtures for electronic ballast by spinning a 3" dia. Flicker Checker on a table top beneath a fluorescent light fixture:
http://www.maced.org/E3/documents/E3%20Flicker%20Checker.pdf

Information on Mercury within the CFL's and proper disposal is at **http://www.epa.gov/osw/hazard/wastetypes/universal/lamps/faqs.htm**
Bulbs only contain 1/100th the amount of Mercury as in an old Thermometer. But special precautions should be taken if a glass CFL breaks. Carefully clean up the Mercury, and follow disposal instructions. Used bulbs should be recycled and never incinerated.

After initiation of discussion, the homeowner can generally decide for themselves. Government subsidies are being made at the retail level to lower CFL costs. The initial poor quality control problems causing a high percentage of bulbs to fail early on, has mostly been resolved.

7. Check domestic hot water temperature.

Water use can also be addressed by discussing types of low flow showerheads that are easier to install than low flow toilet retrofits. Wasted water costs in two ways.

* First in increased public water utility billing where it is metered. Or submersible or other pump electrical costs from privately drilled wells.
* And second to heat hot water for showers, washing and cooking.

DHW (Domestic Hot Water) heaters and tanks have temperature controls that can be set by the home owner. Setting at the highest levels can not only scald a victim, but waste heat especially during air conditioning, which must compensate. 120 degrees F seems a common setting to disinfect and not waste. Discussion on costs associated with lingering showers can also be productive, as can awareness that washing and drying a single pair of blue jeans can be equated into specific costs.

Pipe insulation especially in unheated areas should be checked, and properly sized (for the1/2" or 3/4" pipe diameter) insulation specified that the homeowner can purchase and install. Address the situation if exposed DHW pipes offset air conditioning. The actual water heater and storage tank should be confirmed as water leak free.

One related topic is that the EPA (Environmental Protection Agency) recently approved Energy Star rating for geothermal heating and cooling systems that heat hot water (and solar hot water as well.) The 30% tax credit is applied. In air conditioning season, using a DHW desuperheater to use heat being expelled into the ground is extremely cost effective. Not only does it heat domestic water for internal home use, but the heat exchanging water and biodegradable antifreeze solution circulating in a closed underground loop returns colder, and increases the EER (Energy Efficiency Rating) of the heat pump, saving large quantities of electricity. Use of a buffer tank allows 50 degree Fahrenheit incoming water to be preheated to 90F, so that electricity or fossil fuels need only heat from 90F to 120F. The btu savings is easy to calculate.

8. Use the Duct Blaster to check for leaks in the unconditioned spaces.

Ducts pressurized to +25 pascals

BPI does not require specific duct leakage numbers like the Blower Door test. But it does require the identification of significant duct leakage in unconditioned space. If the Duct Blaster is used, (www.ductblaster.com) the filters are removed, and the filter access port cover is replaced, before conducting the test. All supply and return registers are sealed with a plastic wrap and tape.

The duct blaster tests the ducts in pressure at half the blower door scale = +25 pascals. Sometimes a safe fogging agent, similar to that used in the entertainment industry, is introduced, to show where leakage occurs.

Duct air flow should be 300- 400 CFM per ton (12,000 BTU/Hr) because lower rates could allow the cooling coil to form ice and lose efficiency, or in heating to lose efficiency as well. If flow is inadequate, have a licensed HVAC contractor correct the air flow problem before administering any air sealing. If air is leaking out of ducts within the unconditioned space, it should never be sealed with duct tape, but only mastic tape, etc.

The homeowner sometimes needs to be reminded about changing air filters. Duct insulation follows the Law of Diminishing Returns. Once an R rating of 5, 6 or 7 is achieved, a lot more insulation will not significantly improve it, because of pressure differences. And although this interior duct insulation is suspected of causing IAQ by harboring dust mites, etc., it is often not the case. New York State Society of Professional Engineers offers an informative continuing education course that shows that the turbulent and never laminar flow within ducts is mostly self cleansing. Be aware also that the pressure test might loosen dust particles attached to the duct inside walls. If vacuumed right after the duct test, further dust in the house could be reduced. A laboratory in Pennsylvania that can test house dust samples, will show that the prominent component is plant cellulose from many possible sources.

9. Demonstrate on refrigerator, etc. (and give as a gift?) the Kill A Watt meter

Kill A Watt Electricity Use Monitor by P3 International:
www.p3international.com/products/special/P4400/P4400-CE.html

Electrical Appliances that are wasting electricity should be discussed with the homeowner. A simple SIR (Savings to Investment Ratio) is often available from refrigerator dealers. For any retrofit, SIR is the life cycle savings divided by the initial investment.

Eg. A $500 retrofit that saves $50 per year has a payback of ten years and an annual return of 10%. Suppose the retrofit lasts 20 years.

$$\frac{20 \times \$50}{\$500} = 2.0$$ = the SIR, at zero interest rate, pays for itself twice.

More sophisticated analyses with inflation "guestimates" are available by computer model.

Return on investment is the key to wise decision making. The industry uses the term *low hanging fruit*, and for obvious improvements, "*the fruit on the ground*".

The electrical cost of the existing refrigerator/freezer, or any plug in electrical fixture can be examined easily with the Kill A Watt. The auditor should know and understand how to operate it, and be able to answer all homeowner questions. Citizens can often check out a Kill A Watt from their local library, and may already be familiar with it. Some utilities give them away free with the energy audit to encourage their use. Simply plug into an outlet, and plug the appliance into the Kill A Watt. The simplest function is the center button labeled "Watt" activated by pressing it once. Homeowners are familiar with wattage use from light bulbs, and can compare usage of a tested appliance, to leaving certain lighting on.

One watt is being used by the "plug in alarm clock" that is being tested by the Kill A Watt.

Other qualities of the P4400 are the ability to determine costs each day, week, month or year. The Kilowatt Hour function takes time to determine, so the alternative is to multiply by 720 hours per month for a quicker calculation. (See video below.)

Determine the quality of power from the electric company, if brown outs occur frequently that could hurt appliances, by reading:

- voltage with Volt key,
- Line Frequency (Hz button) and,
- Power Factor (VA key by toggling).

Do not exceed the maximum voltage of 125 VAC (Volts Alternating Current) nor current of 15 Amps.

One issue that can be settled with the Kill A Watt concerns "Vampire Power Use". But it has been reported that only $15 per year is saved by plugging and unplugging appliances every day. Homeowners needlessly worried about minor and unimportant electric use, can be redirected to real cost savings remedies.

10. Discuss recommendations with homeowner.

Most homeowners or renters responsible for utility costs are interested in the SIR (Savings to Investment Ratio) achieved by paying for improvements. With experience in costs and reduced electrical or fossil fuel use, one may estimate the payback period for such investments. Ultimately, the homeowner must decide which items they wish to pursue. Some of the mandatory BPI Safety Standards not addressed by the homeowner might be enforced by the agency paying for the audit. Be prepared with literature to offer and discuss the advantages of programmable thermostat alternatives that automatically satisfies indoor comfort control preferences. Homeowners interested in monitoring their indoor temperatures can install a HOBO Indoor Temperature Data Logger http://www.microdaq.com/occ/h8/hobotemp.php

Energy Auditors have come to learn that much weatherization work, such as significant air sealing, occurs through government subsidized programs, and takes place in the loose older stock housing where SIR is greatest.

The Federal Tax Credit and state incentives are kept up to date at www.dsireusa.org

These apply to certain heating and cooling improvements, insulation, windows and doors, etc. Consult with your tax accountant for the latest rules, before giving advice to energy audit clients. Stimulus funding has generally been completed.
http://www.whitehouse.gov/assets/documents/Recovery_Through_Retrofit_Final_Report.pdf
Another program concerning the $5 billion Federal weatherization stimulus showed energy saving as a government priority.

For middle class payers, ECL (Energy Conservation Loan) programs exist, to provide low interest loans depending on income threshold.

Rebates for Energy Star Residential high-efficiency products are also available state by state. Be familiar with your state's rebates for Natural Gas Hot Water Equipment, Furnace or Boiler replacement, Dehumidifiers, Refrigerator and Washing Machine appliances, insulation, etc. Major retrofits like solar powered photo voltaic cells and geothermal systems are also incentivized. Understand the conditions required for all rebates. Application Forms are often given to the Homeowner with the exit interview paperwork.

This brochure can also contain positive promotional documents about your Energy Auditing Company. Liability insurance for your energy auditing company that you may or may not wish to disclose to the home owner is available through RESNET (Residential Energy Services Network Tel (800) 806-0263 or http://www.resnet.us/

In addition to discussing the specific recommendations, the homeowner can be referred to future reading references about ways to save energy costs. One web site with over 500 tips to save power and water is at http://dailyhomerenotips.com/energy-conservation

11. Return all controls and settings to "As was" by retrieving car keys from the CAZ.

At the conclusion of the exit interview, the completed forms are signed by both the Energy Auditor and homeowner representative, and each keeps a copy. Auditors working with renters can send the owner a copy. Keys are retrieved from the CAZ so that the Energy Auditor remembers to turn all units back on before leaving. It is unacceptable to drive away with the furnace or hot water turned off, to the surprise of the homeowner.

As in any business transaction, professional conduct will result in positive feedback from the home owner, and usually more energy audit work through their word of mouth recommendations to others.

Conclusion

Home energy auditing is all about reassuring occupants that their house is safe for IAQ, and empowering them to make decisions on how best to stop wasting energy. Although the emphasis is on air sealing leaks, the process does address a multitude of areas where Building Professionals have good understanding of the phenomenon occurring. You are encouraged to use this skill set to assist in any area of implementation you can. Whether teaching folks about heating and cooling their home, or helping to solve drainage problems, or preparing cost and benefit analyses, the identification of energy losses in a home, and the remediation that follows can only have a positive impact on our lives.

All those who complete this course are thanked for their interest, and encouraged to visit the many web site links provided to further their education knowledge base, and make a real difference in forging our sustainable future.