**NIST GCR 14-976**

# Residential Home Performance Contracting Round Robin Guidelines

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*Washington State University Energy Program*

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National Institute of Standards and Technology
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Prepared for
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# Residential Home Performance Contracting Round Robin Guidelines

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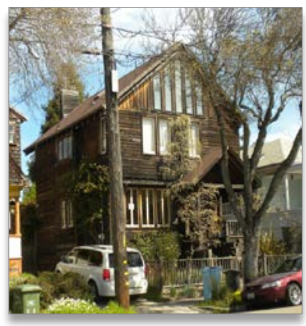
"Development of Single-Family Residential Energy Audit and Round Robin Guidelines"



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WASHINGTON STATE UNIVERSITY
EXTENSION ENERGY PROGRAM

*The homes where the first four round robin pilots were conducted by the WSU Energy Program are pictured on the cover (clockwise from upper left: Seattle, Denver, Portland and San Francisco). Feedback and lessons learned from the pilots were instrumental in the development of these draft guidelines.*

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## Contents

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## Acronyms

| | |
|---|---|
| ACCA | Air Conditioning Contractors of America |
| ACI | Affordable Comfort Inc. |
| ANSI | American National Standards Institute |
| ARRA | American Recovery and Reinvestment Act |
| ASHRAE | American Society of Heating, Refrigerating and Air Conditioning Engineers |
| BPI | Building Performance Institute |
| DOE | U.S. Department of Energy |
| EPA | United States Environmental Protection Agency |
| HERs | RESNET Home Energy Raters |
| HES | Home Energy Survey |
| HESP | Home Energy Survey Professional |
| HPC | home performance contracting/contractors |
| HPwES | Home Performance with ENERGY STAR program |
| HRAI | Heating, Refrigeration, and Air Conditioning Institute of Canada |
| HUD | U.S. Department of Housing and Urban Development |
| HVAC | Heating, ventilating and air conditioning systems |
| IAQ | indoor air quality |
| IECC | International Energy Conservation Code |
| IR | Infrared thermography |
| LBNL | Lawrence Berkeley National Laboratory |
| NIST | National Institute of Standards Technology (an agency of the U.S. Department of Commerce) |
| QA | quality assurance/quality assured |
| QI | quality installation |
| RESNET | Residential Energy Services Network |
| SIR | savings to investment ratio |
| WAP | U.S. Department of Energy Weatherization Assistance Program |
| WSU | Washington State University |

## Introduction

These guidelines describe the important considerations for planning, conducting, analyzing, and disseminating the results of a Home Performance Contactor (HPC) round robin study of a specific aspect of the HPC industry services. The round robin study focuses on gathering information needed to provide a better understanding of the variability in any number of performance characteristics of interest to a particular sector of the HPC industry. For example, a round robin can be used to estimate variability in the estimated energy performance of a given home, the necessary sizing of particular equipment, the potential savings from retrofit options, or a ranked list of cost-effective retrofit measures. Ultimately, it is anticipated that such activities will help developers of best practices, guidelines, and standards to improve those products to provide a more reliable prediction for the homeowner and to elicit confidence in those who will pay for enhanced building performance or measures to attain that performance.

Round robin studies are often used in well-controlled laboratory situations to characterize the reproducibility of measurements on the same item under different test conditions. Factors such as the test procedure, environmental setting, and operator can change, and the round robin ideally captures the variation brought about by factors of interest. That variation can be captured in the precision of the quantitative measures and predictions that result from the measurement process, where measurement precision is defined by the International Vocabulary of Metrology as the "closeness of agreement between indications or measured quantity values obtained by replicate measurements on the same or similar objects under specified conditions" (Appendix D).

While residential buildings would not be characterized as well-controlled laboratory situations, the concepts for formal round robins can be extended to help the HPC industry evaluate how well the different pieces (e.g., standards, guidelines, training programs, personnel) are performing to provide reliable information about home performance. In laboratory settings, "repeatability" is also a concern, where repeatability is assessed when the same exact process is used within a short period of time to measure some characteristic of an item. For the discussion to follow, we will focus more on the issue of reproducibility because we are interested in helping the HPC industry assess the ability of its standards and guidelines to provide consistent results when factors such as operators and weather change.

These guidelines are intended to be used by stakeholder organizations involved with the HPC industry on new and existing single-family housing. Contractors, program sponsors, implementers, training providers, and standards organizations all have an interest in the overall quality of their services and products.

The use of the term "round robin" in this guideline relates to "the implementation of procedures, manuals, or standards by multiple HPC participants when given identical assumptions and information using the same home to field test and/or home construction plans." Information resulting from round robin assessments will increase stakeholder organizations' technical understanding of variability, with the goal of:

- Improving consistency in implementing program efforts, and
- Improving technical understanding and support of HPC industry programs, practices, protocols, procedures, and policies.

The **consistency** of energy efficiency and related building science assessments is important to homeowners, homebuyers, builders, and emerging HPC industry stakeholders, and is pivotal to the success of a project, program, and/or the organization's credibility. Round robins provide the opportunity to consider variability of results from participants working for the same contractor firm and different contractor firms in the same house or different houses using different sets of test conditions.

These guidelines are designed to provide basic information to help plan, implement, evaluate, and disseminate round robin assessments to stakeholder organizations, including RESNET, BPI, ACCA, ACI, DOE, EPA, and HUD. Action taken based on information and lessons learned from HPC round robin activities can be used to assess and improve program delivery and information quality and usefulness. Organizations that utilize round robin guidelines are demonstrating a commitment to further improve the credibility of the information provided to clients and other stakeholders, who rely on these HPC organizations for credible and consistent information. Appendix A provides potential HPC focus areas (e.g., standards, guidelines, procedures) for round robin guideline implementation.

# Background

The Washington State University (WSU) Energy Program, with support from the National Institute of Standards and Technology (NIST), initiated a series of energy audits by trained professionals on the same existing houses at sites in Portland, Oregon, and San Francisco (Berkeley), California, in 2011. In 2013, a second round of pilot round robin testing was conducted on existing homes in Seattle, Washington, and Denver, Colorado. The audit sites were chosen in conjunction with the Western Regional Affordable Comfort Inc. (ACI) conference in Seattle on February 4-5, 2013 and the National ACI Conference in Denver on May 1-3, 2013. This second round of round robin testing was intended to expand the sample size, number of auditors, and housing types in differing climates.

The results of these pilot round robin tests are intended to provide insight into the quality and consistency of energy audit assessments being conducted in the marketplace. Feedback from these four pilot efforts informed the development of these draft guidelines for use in conducting similar round robin testing. The development of these draft guidelines is a result of:

- "Needs assessment" feedback and support from stakeholders and/or organizations involved with the HPC industry.
- "Lessons learned" from implementation and review of the results from the four pilot round robins.

HPC organizations that have indicated interest in implementing round robin guidelines are listed in Appendix A.

## Portland and San Francisco

The Portland and San Francisco results have been previously reported[1] and are provided in Appendix B.

### Portland

The goals, objectives, and scope of this pilot focused on energy auditors who had experience in combustion safety testing and who were familiar with the climate and housing stock, and who employed a variety of auditing approaches currently used in the Pacific Northwest (PNW) retrofit market in Washington and Oregon. Key findings in Portland included:

- 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 with different savings estimates.
- Auditors were challenged when defining the partially remodeled basement as conditioned space.

[1] WSU Energy Program (2012). *Past, Present and Future Directions in Residential Single-Family Energy Audits and Retrofits*. Prepared for the National Institute of Standards and Technology under award number 60NANB10D278.

## San Francisco

The goals, objectives, and scope of this pilot focused on energy auditors from all over the U.S. with experience in combustion safety. In addition, the participants were asked to develop work plans for energy audits retrofits, based on homeowner-specified budgets of $8,000 to $15,000. Key findings included:

- 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 infrared (IR) cameras.
- Projected energy savings were extremely variable, ranging from a 7.6% cost reduction to a 138% reduction!

## Seattle and Denver

Additional details about the pilots in Seattle and Denver are provided in Appendix C.

### Seattle

The goals, objectives, and scope of this pilot focused on energy auditors with experience in combustion safety testing, representing the majority of American Recovery and Reinvestment Act (ARRA)-funded energy audits in Washington and Oregon. All participants used a similar auditing protocol that relies on the Energy Performance Score (EPS) derived from an evaluation procedure called SIMPLE.

### Denver

The goals, objectives, and scope of this pilot focused on energy auditors with experience in combustion safety testing, representing the majority of those involved with the EXCEL Energy conservation program for existing homes.

### Key Findings

In both Seattle and Denver, an attempt was made to narrow the scope by selecting auditors with similar training who had experience following the same standardized protocol to generate a standardized report. Without some standardization of protocols, data collection, and reporting format, it becomes very difficult to make meaningful comparisons among audits. Even where the goal is to evaluate completely different auditing approaches, complete documentation of the analysis process is necessary to evaluate the basis of divergence.

In both Seattle and Denver, the basic characterization of the home, including diagnostic tests by the auditors, showed reasonable agreement. Basic safety issues were also addressed. A significant gas leak in the Denver home was detected by the auditors. Seattle auditors correctly tested for spillage and CO, but only two of the five auditors in Seattle reported the venting deficiencies (vent pipe slope and proximity to combustible surfaces).

Divergence increased on recommendations for specific energy performance measures. Both the Seattle and Denver programs represented by these auditors prioritize measure recommendations based on the savings to investment ratio (SIR). To determine a SIR, the savings over the measure life and the measure cost are needed. Significant variability in both of these values was seen in the reported documentation (Seattle did not include measure costs). Estimated savings by measure often varied by a factor of two, but measure cost estimates varied by a factor of 10 or more. In a real-world application, measure costs should be determined by competitive bid to determine the best value.

The round robins in Seattle and Denver focused on the characterization of the homes by the auditors, the recommendations for performance improvements, and the projected savings from the improvements. Homeowners look to the audit process for guidance on making sound investments to improve the performance of their homes. As with all round robin pilots, health or safety issues were identified at both sites. Improvement measures were proposed with estimated overall energy use reduction ranging from 30% to 60%.

## Round Robin Considerations and Planning

This section provides a general overview and discussion of the steps required to implement a broad range of HPC round robin applications. The steps can apply to new or existing homes, and can be implemented in the field and/or using blueprints and other field assumptions. Key items that need to be considered during each step of the process are identified below. Some overlap and refinement occur during progression from Step 1 through Step 5.

### Step 1: Define Project Goals, Objectives, and Scope

It is important to discuss and secure consensus about round robin goals and objectives:

- Define general project goals, specific objectives, and an unambiguous scope through discussions with all HPC stakeholders.
- Determine and develop agreement as needed about how round robin results will be used and/or disseminated to meet the stated goals and objectives.
- Determine and develop various benchmarks by which specific results will be compared, and where benchmarks are not practical or useful to the project goals and objectives.
- Discuss what approach(s) will be used, such as employing an in-field or virtual (web-assisted) round robin approach.
- Get general "buy-in" support for the round robin implementation from all stakeholders that may be involved.
- Determine if a task group is needed to provide guidance throughout the round robin planning, implementation, and results dissemination.
- Identify legal contract requirements for all involved (e.g., homeowners, round robin participants, utilities, etc.).
- Obtain stakeholder agreements about how the data will be reported. Clarify if the participants and/or other stakeholders have veto power to prevent release of the data publicly, even if the results are presented anonymously.

When defining goals and objectives, it is useful to identify critical research questions. Examples of research questions include:

- What is the variability of energy ratings (e.g., HERS) by certified raters using the same set of new home floor plans and field data input assumptions?
- What is the variability associated with HVAC sizing in terms of design heat loss (e.g., ACCA manual J), equipment sizing (e.g., Manual S), and duct design (e.g., manual D)?
- What is the variability of field-acquired input associated with the general energy ratings by different participants in the same home?
- What is the variability in HPC audit modeling input assumptions employed by difference auditors using the same energy simulation software (e.g. REMRATE, EGUSA, TREAT, NEAT, BEOPT etc.)?
- What is the variability in auditor energy efficiency, comfort, and/or health and safety recommendations resulting from the implementation of HPC auditing on new or existing homes?

### Identify Group and/or Project Coordinator

Identify and recruit task group members and a task group coordinator to lead the round robin efforts. One individual should be appointed to act as overall coordinator. This person will supervise the round robin implementation and receive the test result reports from the participant's.

The task group should be provided with overall responsibility and adequate funding, and should help guide the team coordinator to ensure the study design and decision-making processes will yield useful data assessment and analysis.

The task group should specify all important considerations needed to achieve project goals, objectives, and scope. These should be refined as needed during the implementation of all steps:

- **The number of subjects and type of test results needed**: The task group must provide guidance on the target subjects and the types of testing based on the project goals, objectives and scope.
- **Any special calibration procedures**: The task group must provide guidance on all calibration and recalibration issues before round robin implementation. While doing so will help ensure relative independence of the test results, changes in calibration may increase the variability between test results.
- **Repeatability conditions**: The task group should discuss any special circumstances that must be addressed in implementing the repeatability conditions.
- **Communications protocol: The task group should discuss the process by which** participants notify the task group coordinator promptly whenever a round robin implementation problem is encountered so the procedures can be modified to address the problem, and any issues documented for the final report.

## Step 2: Identify Participants and Select Site/Plan Sample

Implementation of this draft guideline is designed to provide useful quantitative data findings and qualitative anecdotal results and lessons learned. The task group should:

- Determine a general target sample of homes/plans/procedures for round robin implementation based on the goals and objectives that have been defined.
- If existing homes are the focus of the round robin is the home utility bill history needed and available, to be used in the development of the test protocol.
- Ensure that the sample is adequate to answer or to inform stated research questions.
- Discuss the level of statistical analysis (if any) required by stakeholder organizations when answering the research questions.

### Select HPC Participant Sample

Determine the skill sets of individuals and/or organizations targeted to participate in the study and select participants. Skill sets may be tied to specific organizations' certification programs and policies (e.g., RESNET, BPI, ACCA, and ASHRAE).

## Select House/Plan Sample

Define criteria for selecting the sample homes, including housing type, home age, home condition, programmatic participants' requirements, home location and climate, fuel types, HVAC, and DHW type(s).

## Step 3: Devise Test Protocols

Confirm what approach(s) will be used, such as employing an in-field or virtual (web-assisted) round robin approach.

- **An in-field approach** requires access to a home and a homeowner agreement. This approach may limit implementation flexibility and sample size, but does provide real-world field data.
- **The virtual approach** may utilize an expert software system that allows round robins to be implemented without field visits allowing for larger sample participation and statistical representation. This could involve providing plans, pictures, and measured data from an actual house. This approach is limited to field provided (not acquired) assumptions, and may be a complementary step to a field approach, where more areas of variability may exist.

## Evaluate Logistics via a Pilot Round Robin

Determine a realistic timeline, budget, and potential HPC stakeholder partners. Before investing time in the full-scale round robin, it is usually wise to conduct a pilot round robin with smaller sample sizes to help determine if the round robin test protocol methods are clear and to help familiarize those who do not have sufficient experience with the procedure.

The pilot round robin may also be a "dry run" for larger-scale efforts by the HPC organization that is interested in the impacts of different assumptions (e.g., house type, location, and climate). A dry run can also be employed by the task group to help flesh out logical issues (e.g., conditions that require field testing, such as wind speeds, temperature, and compatibility of house type with research objectives) before the round robin and/or pilot. The dry run should be implemented by task group member(s) identified to facilitate the round robin process. Task group members shall determine and consistently provide all information to all round robin participants prior to and/or during round robin implementation.

All steps of the procedures described in the round robin protocol should be followed precisely to ensure that these directions are understood and to disclose any weaknesses in the protocol.

The pilot results also indicate how well participants may perform. Participants who exhibit poor performance should be encouraged and helped to take corrective action.

## Define Data Needs

Determine what data will be collected to help inform goals and objectives. This includes defining what forms or other means will be used to report the data collected by each participant. A data analysis plan should also be developed to determine how the data will to help answer research questions.

### Develop Database

Develop a database structure to support data analysis and reporting results to stakeholders. Determine who will collect and filter the data and address database access considerations.

### Develop Outreach Plan

Determine how the data analysis results will be disseminated and utilized for educational, quality assurance, program design, policy, or other purposes. For example, results from pilot round robins were summarized and presented in *Home Energy* magazine to stimulate discussion on the usefulness of this approach to the HPC industry and other stakeholders.

## Step 4: Implement Round Robin Testing

Implement the round robin in accordance with the research plan.

- Implement a dry run or actual pilot.
- Adjust any procedure based on findings from pilot efforts by staff identified by the task group that is responsible for overseeing and facilitating the round robin.
- In the test protocol, include the name, address, and telephone number of the project coordinator. Urge the participants to call the coordinator when any questions arise prior to, during, or after round robin implementation.
- Clearly state that all test results and test data sheets must be provided to the task group.
- Describe any special equipment calibration procedures in the test protocol.
- Ensure that all information needed to prepare the final research report is identified.
- Document all issues and procedural changes resulting from any unanticipated logistical problems.
- Collect and filter the data, and identify and resolve data issues and questions encountered during data review. As part of the data quality assurance check, members of the task group should plan to scan the reports for gross errors and check with the HPC when such errors are found. The process should always identify and document outliers, and provide justifications for using or removing the data from the analysis.

## Step 5: Analyze Data and Report Findings

Conduct data analysis in accordance with the task group guidance and plan. Answer the research questions in accordance with the analysis plan. In the draft report:

- Include all appropriate information acquired from implementing Steps 1-4, including all subtask details.
- Document data results as descriptive statistics by participant (coded to protect confidentiality).
- Include recommendations that, if implemented by HPC stakeholder, may improve the reproducibility of specific participants and/or the program.

Unusual data should be retained, and results based on these data should be published within the defined stakeholder group agreements. If unusual data is reported during the investigation, it is important to consider the following:

- If the HPC clearly and seriously deviated from the test protocol intent, the test results for that HPC must be identified in the report findings.
- Be on the alert for vagueness in the HPC procedures that permits a wide range of interpretation, which can lead to a loss of precision. Check for a lack of measurement tolerances, diversity of apparatus, and insufficient direction for operator technique. These problems need to be considered in the final report.

Provide the draft report to targeted stakeholders and the task group, and solicit comments for inclusion in the final report.

## 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. 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.

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WSU Energy Program (2012). *Past, Present and Future Directions in Residential Single-Family Energy Audits and Retrofits*. Prepared for the National Institute of Standards and Technology under award number 60NANB10D278. http://www.energy.wsu.edu/Documents/NIST%20Final%20Report_WSU%20Energy%20Program_July%202012_7-19-13.pdf

# Appendix A: Potential Applications of Round Robin Guidelines

The following Home Performance Contracting organizations have indicated interest in implementing round robin guidelines on the following standards and procedures utilized by organizations related to single-family new and existing site-built homes.

## Residential Energy Service Network (RESNET)

New HERS projected from plan:

- HERS confirmed on site*
- Development of Statement of Work (SOW) pre-retrofit on site

## Air-Conditioning Contractors of America (ACCA)

- Manual J – conduct room to room and overall home design heat loss from plan
- Manual J – conduct room to room and overall design heat loss on site
- Manual S – size HVAC system based on Manual J heat loss and climate
- Manual D – size HVAC ductwork based Manual S HVAC equipment sizing from plan
- Manual D – assess on-site ductwork and size new ductwork based on Manual S
- ACCA QI* – Implement ACCA QI as part of Quality Installation standard when installing HVAC equipment in new or existing homes.
- ACCA QM* – Implement ACCA QM as part of quality maintenance standard during site visit to existing homes.

## Building Performance Institute (BPI)

- Building Analyst Development of Statement of Work (SOW)
- Envelope professional assessment of new or existing home envelope
- Heating professional assessment of new or existing heating system
- Air conditioning/heat pump professional assessment of new or existing AC/HP
- Building envelope
- Whole-house air leakage controller installer
- Energy auditor (certified to use modelling software)
- Quality control inspector (post only)

* May require multiple site visits to the same site

## Appendix B: Portland and San Francisco Round Robin Pilot Energy Audits

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 B-1, 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 B-2 and Figure B-3, respectively. Inspection protocols used by the participating inspectors are listed in Table B-1.


**Figure B-1. Portland Home**

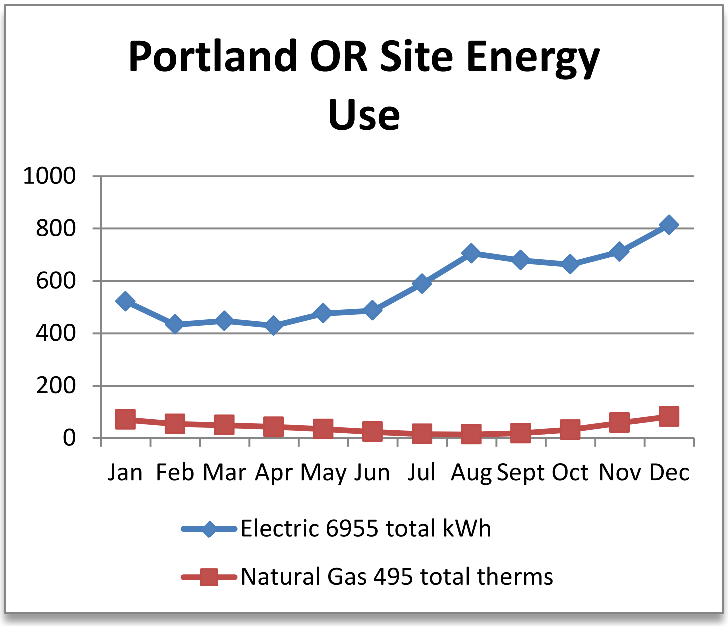



Figure B-2. 2010 Energy Use from Utility Bills for Portland Home

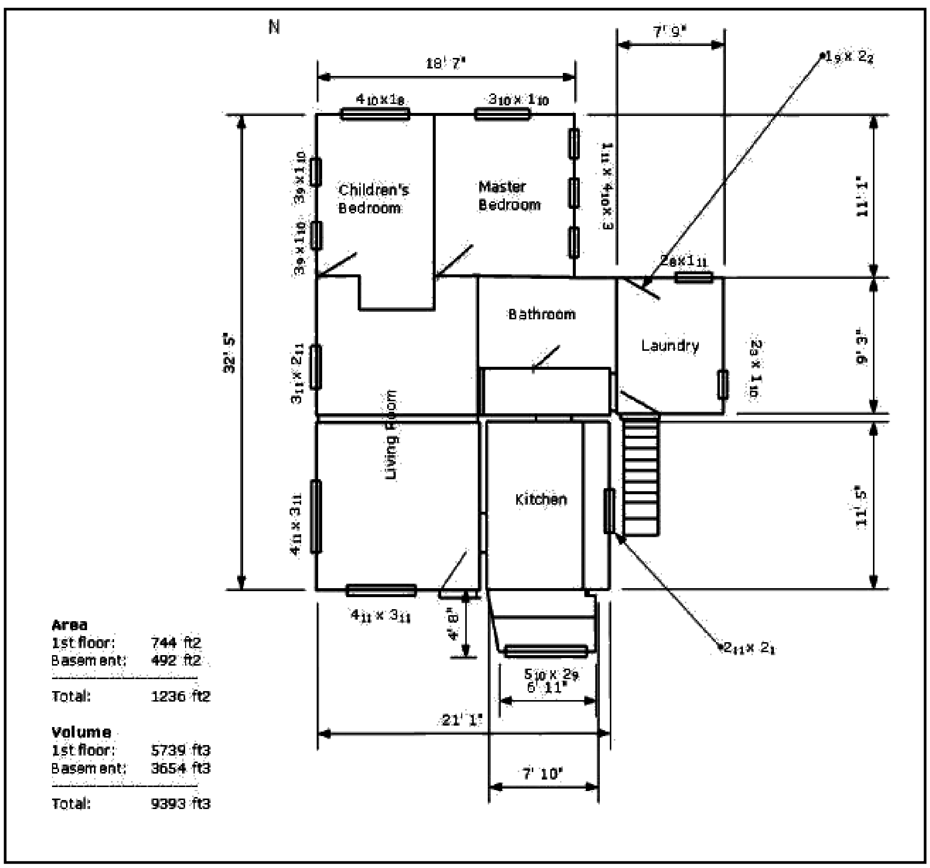



Figure B-3. Floor Plan of Portland Home

**Table B-1. 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 B-2), 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 $ACH_{50}$ was close to 25, as seen in Figure B-4.

**Table B-2. 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 | - | |

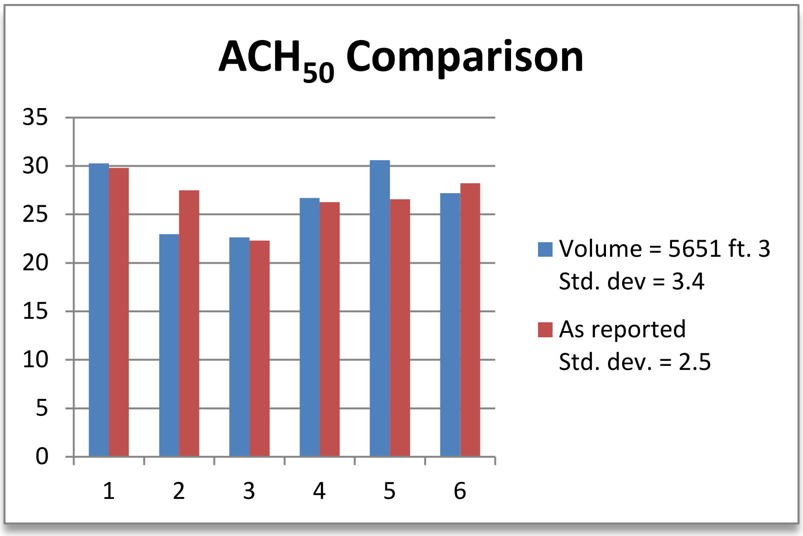



**Figure B-4. House Tightness**

## 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 B- 5.

## Infrared Inspections

Auditors who performed IR imaging were able to provide more details on where air leakage was occurring (see Figure B-6), 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 B-5. Audit Observations at Portland Home

No insulation in attic above laundry – five auditors

Dry rot at sill plate – three auditors

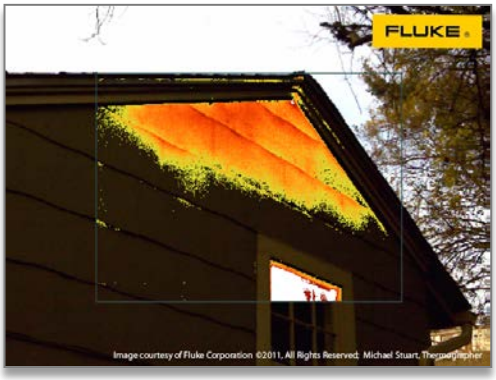
Gas leak at meter – two auditors

Water heater draft hood not secured – one auditor

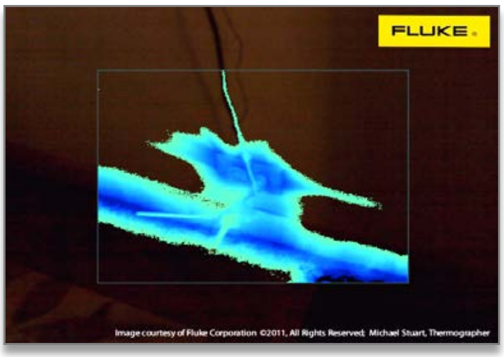
Furnace - CO level at 53 ppm – one auditor

One auditor noted “no need to test.”

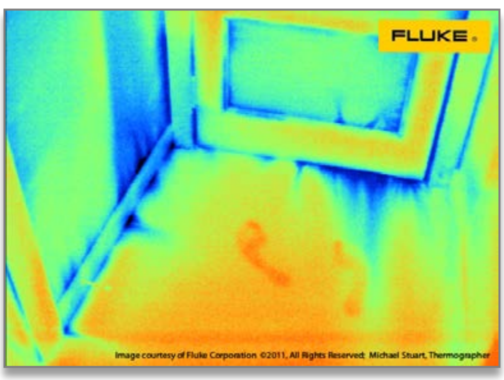
### Figure B-6. Infrared Inspection of Portland Home



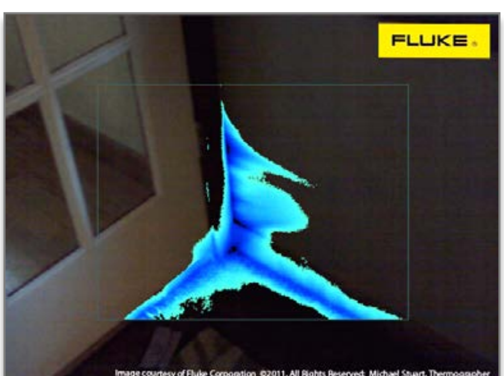

Evidence of warm air infiltration into attic



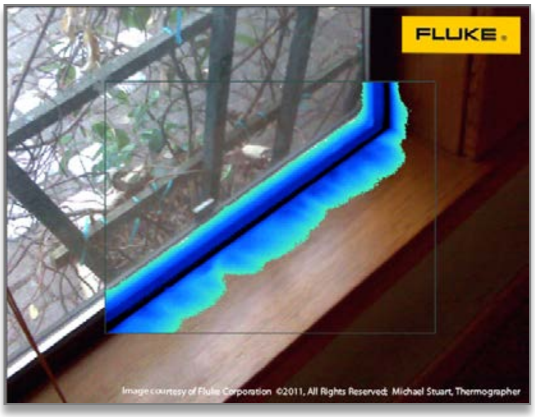

Air infiltration around electrical outlet and floor




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 B-3.

**Table B-3. 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 B-4, Table B-5, and Table B-6.

### Table B-4. 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<br>- | 19.1 $ACH_{50}$ –<br>8.0 $ACH_{50}$ | 7.2<br>- | Utility incentive level<br>Add. Opportunities |
| 4 | 400-2,000 | 7.0 $ACH_{50}$ | 6.1 | EPS (Simple) |
| 5 | - | No perf. Level specified | - | |
| 6 | 400-2,000<br>500 | 7 $ACH_{50}$<br>10 $ACH_{50}$ | 5.5<br>5.9 | EPS (Simple)<br>Rem/Rate |

**Table B-5. 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 B-6. 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, although they addressed different levels of improvement and provided different savings estimates.

## Berkeley

The home studied in Berkeley, California, is shown in Figure B-7. Table B-7 lists the inspection protocols used by the participating inspectors. Figure B-8 shows the energy use of this home.

Figure B-7. 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 B-7. Inspection Protocols Used – Berkeley Home

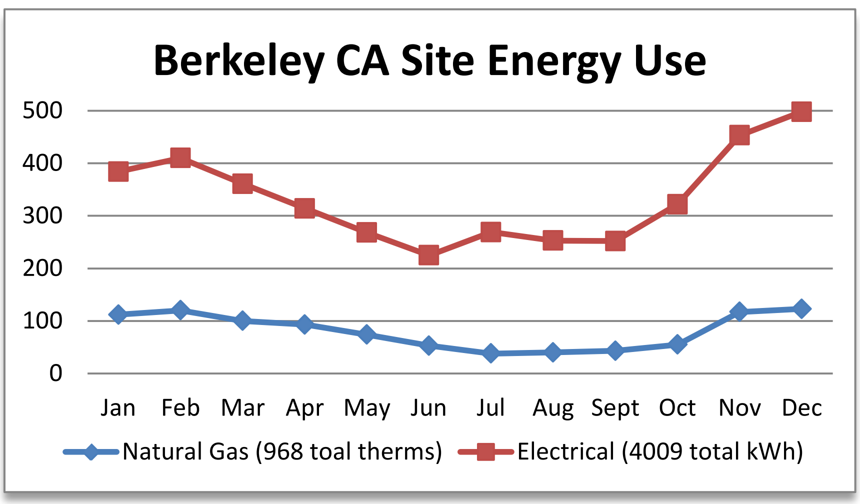



Figure B-8. Energy Use at Berkeley Home

## Performance Testing Results

An expert panel defined the characteristics of the Berkeley home, as summarized in Table B-8.

**Table B-8. 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% 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. Images of combustion safety testing are provided in Figure B-9.

### Figure B-9. Combustion Safety Testing in the Berkeley Home

Domestic hot water tank in closet

Hot water and furnace vent

Corroded furnace vent

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 B-10.

**Figure B-10. 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

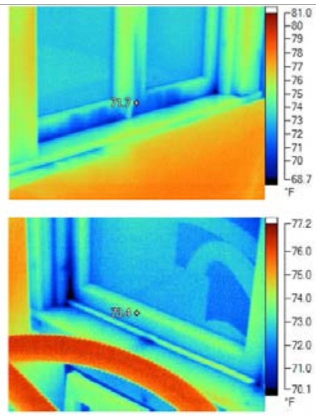
South-facing glazing that causes overheating

Constricted flex duct in crawlspace

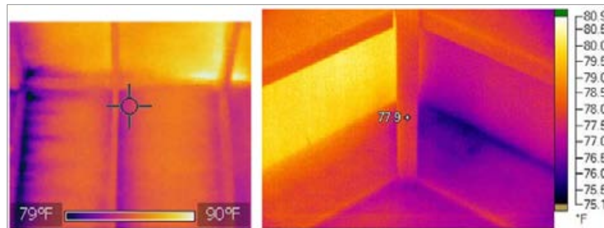
## Infrared Inspection

The images provided in Figure B-11 are from the IR inspection of the Berkeley home.

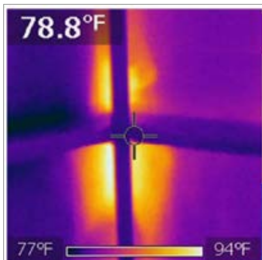
### Figure B-11. Infrared Inspection of Berkeley Home



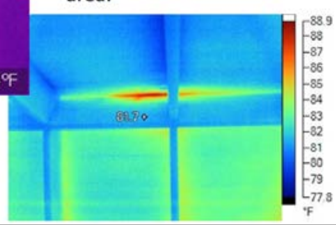
Depressurized, showing air leakage sites on window sash, a common issue throughout.

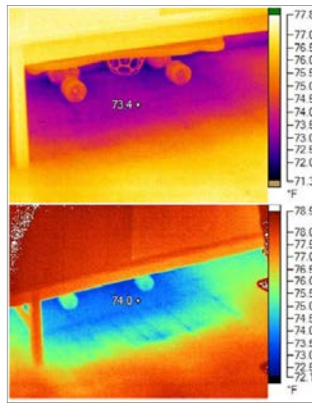



Depressurized, showing air leakage sites on boarded ceiling, a common issue throughout.

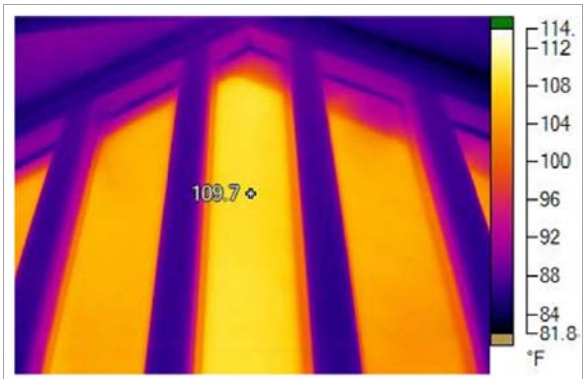



Depressurized, showing air leakage site along ridge. Previous condensation staining was noted in the area.

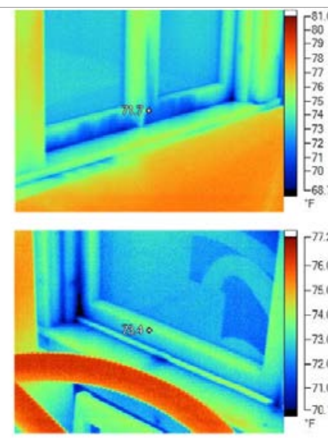




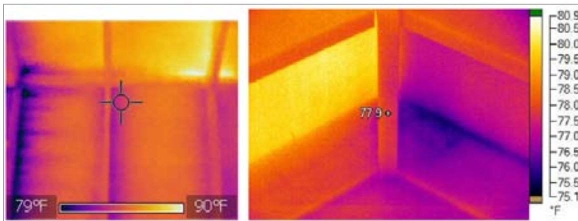
Normal pressures (top) and depressurized (bottom), showing uninsulated area on first floor and associated air leakage from crawlspace.



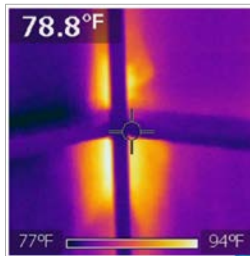

"Solar heaters" disguised as windows on south gable wall at high solar noon.



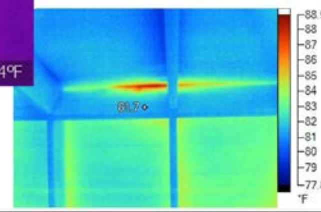
Depressurized, showing air leakage sites on window sash, a common issue throughout.

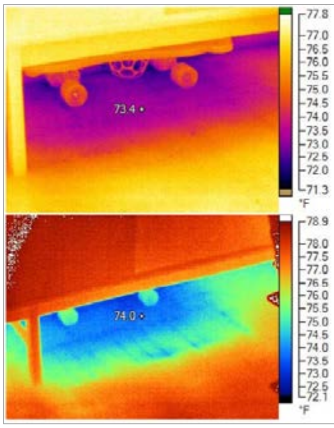



Depressurized, showing air leakage sites on boarded ceiling, a common issue throughout.

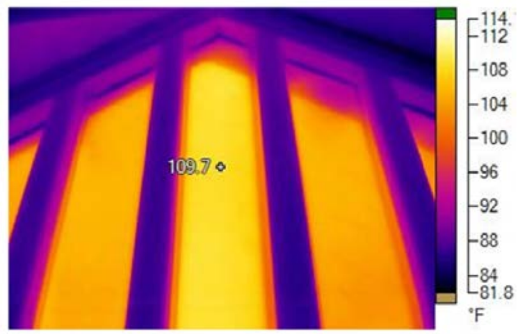



Depressurized, showing air leakage site along ridge. Previous condensation staining was noted in the area.






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




"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, $8,000 and $16,000. Table B-9 and Table B-10 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 was 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%, averaging 41.5%. With a $16,000 budget, estimated savings ranged from 17% to 137%, averaging 47% after 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.

All of the auditors recommended installing a higher efficiency heating system. Given the condition of the existing system, this was a good call. Costs 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% cost reduction to a 138% reduction!

### Table B-9. 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 B-10. 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

## Appendix C: Round Robin Pilot of Energy Audits – Seattle and Denver

The WSU Energy Program, with support from the National Institute of Standards and Technology (NIST), initiated a series of energy audits by trained professionals on the same house at sites in Portland, Oregon and Berkeley, California in 2011. The results of these "round robin" tests were intended to provide insight about the quality of energy audit assessments being conducted in the marketplace and have been previously reported.

In 2013, a second round of round robin testing was conducted on homes in Seattle, Washington and Denver, Colorado. The audit sites were chosen in conjunction with the Western Regional ACI Conference in Seattle on February 4-5 and the National ACI Conference in Denver on May 1-3. The continuation of the round robin testing was intended to expand the sample size, number of auditors, and housing types in differing climates, and to begin the development of guidelines for use in conducting similar round robin tests as a quality assurance tool.

Contractors, program sponsors and implementers, training providers and standards organizations all have an interest in the overall quality of their services and products. The objectivity, accuracy, and repeatability of the energy audit of a home are pivotal to a homeowner's decision process and the eventual evaluation of a project's success or failure.

### Auditors

Auditors were recruited for this round of testing from a narrower base than in the first round.

- The five auditors at the Seattle site all worked in Washington in programs supported by the Community Energy Efficiency Program (CEEP). They used the Energy Performance Score (EPS) developed regionally by Earth Advantage based on Michael Blasnick's analytical spreadsheet "Simple" as their assessment tool. As regional practitioners with local field experience, they were familiar with the climate, housing stock, and market costs of the area. In the first round of testing, all of these factors had proven problematic in comparing results from auditors with much more diverse backgrounds.
- The six Denver audits were all completed by practitioners from Colorado with field experience in the energy retrofit program run by the utility Xcel Energy

### Process

Each auditor was given access to the home for testing and inspection for up to 2.5 hours. General background information from the homeowner and any concerns about comfort or indoor air quality (IAQ) was provided to each auditor. Utility billing histories were provided if available. Each auditor provided their own test equipment and was encouraged to follow standard audit procedures. The auditors were asked to make recommendations for improving home performance. Written reports were requested to be submitted within a week of the audits. The auditors were compensated for their time.

## Seattle Site

The Seattle site, shown in Figure C-1, is a 1.5 story house built in 1909 on a partial basement with attached crawlspace. The home has three full-time occupants. The basement level is set up as a separate living space with a complete second kitchen. General characteristics are summarized in Table C-1. The layout is shown in Figure C-2.

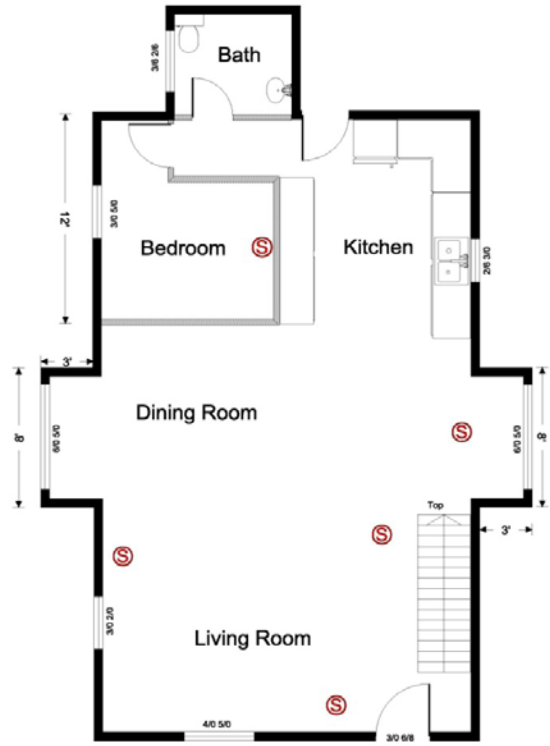
**Figure C-1. Seattle Site, Front and Back Views**

**Table C-1. Seattle Site Characteristics**

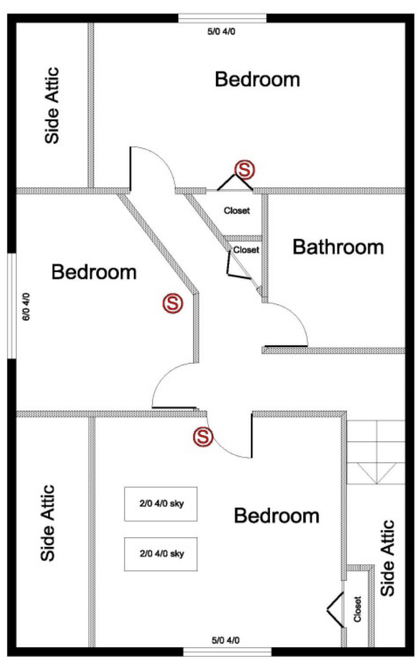
| Component | Site Characteristic |
|---|---|
| Ceiling | No attic access/R-11 |
| Walls | Wood frame/ up to R-11 |
| Floors | Below grade slab un-insulated, floor over crawl R-19 |
| Windows | Original single glaze wood frame U=1.0 some replaced, modern skylight U=0.5 |
| Doors | Wood panel |
| Conditioned floor area | 2,170 $ft^2$ |
| Space conditioning | 92.5% gas/central forced air/no AC/electric space heater for comfort |
| Ducts | Leakage to exterior 150 cfm 50/96 cfm25, un-insulated in crawlspace |
| Air infiltration | 5297 cfm50. ACH50 = 17.4 |
| Bedrooms | 3 |
| Baths | 3 |
| occupants | 3 |
| Ventilation | Spot fans: bath up 0 cfm; main bath 27 cfm: bath down 26 cfm; Range hood 0 cfm |
| Domestic hot water | Gas/atmospherically vented/ in conditioned space |
| lighting | Incandescent |
| Appliances | Two sets main/apartment (old refrigerator in apartment) |

## Figure C-2. Layout of Seattle Home


Seattle home – basement

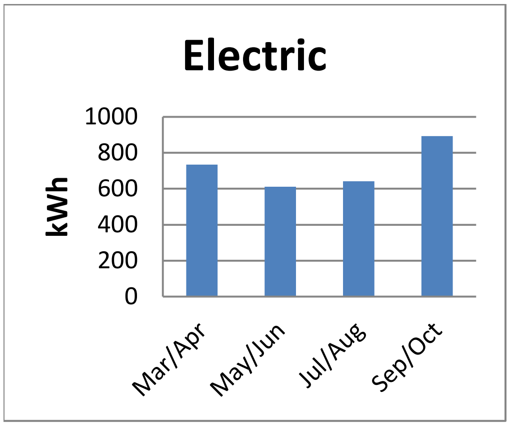



Seattle home – first floor




Seattle home – second floor

At the time of the Seattle audits, only five months of gas bills and eight months of electric bills were available to the auditors (see Figure C-3). Based on this information, the extrapolated estimate for annual electric use is 4,324 kWh. Actual electrical usage obtained later from additional billing data showed 4,541 kWh in 2011 and 4,909 kWh in 2012. The actual gas usage obtained later was 905 therms in 2011 and 843 therms in 2012.



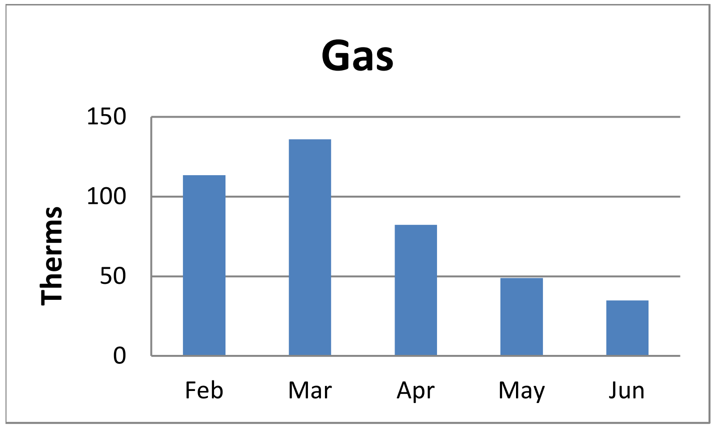




Figure C-3. Seattle Site Energy Consumption from Utility Bills

The pictures in in Figure C-4 show noteworthy items from the visual inspection of the site.

Figure C-4. Pictures from Visual Inspection of the Seattle Site

Orphaned atmospherically vented water heater with potentially dangerous venting. Single-walled venting runs from the tank to a masonry chimney. The venting does not maintain proper slope and runs within ½ inch of combustible material. The system was able to establish proper draft at the 55°F outdoor test conditions. The water heater produced 24 ppm of CO at steady state.

Combustion vent within 1/2 inch of combustibles


Dryer vent disconnect from outside in crawl


Disconnected dryer vent in crawlspace


Insulation in crawlspace attached to the conditioned basement. The crawl was vented but had a poorly defined pressure boundary between the crawl and the basement, which made a large contribution to the overall house air leakage. Some wall and floor insulation was displaced and ducts were un-insulated and poorly sealed.

Inspecting for gas leaks


Modern sky lights on second floor


Original single glazed wood frame windows

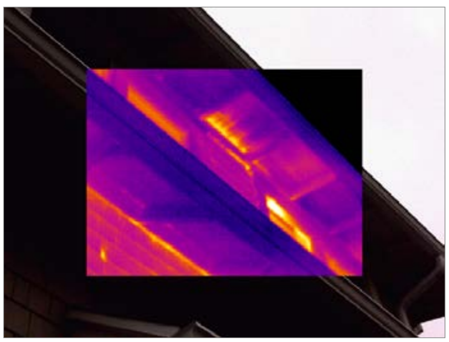

92.5% sealed combustion furnace

Electric space heater used in the basement apartment for comfort. There is only one small supply register in the roughly 575 sf conditioned space in the basement.

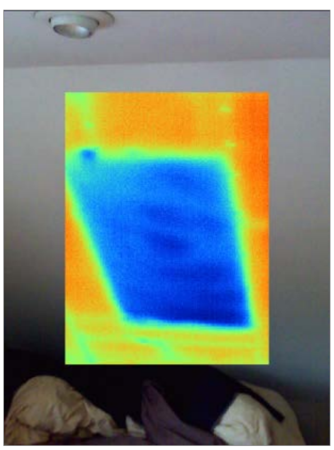
Figure C-5 shows images taken with an infrared camera. They confirm the extensive heat loss expected from air leakage that was indicated by the blower door test and show areas of high thermal conductivity and ineffective insulation.

**Figure C-5. Infrared Pictures of Seattle Site**

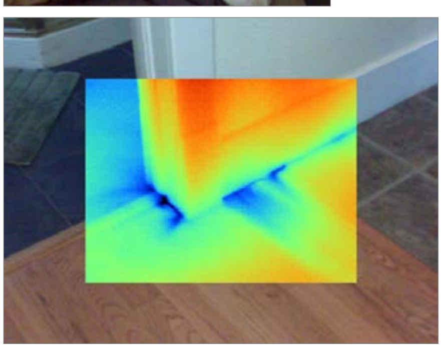
Heat loss at foundation



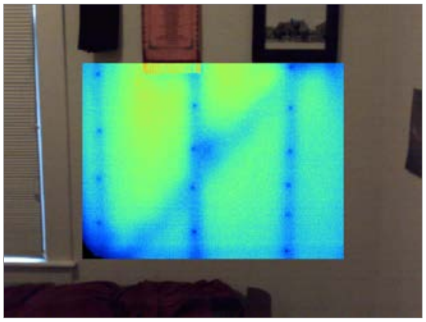
Heat loss at eaves and bad joist



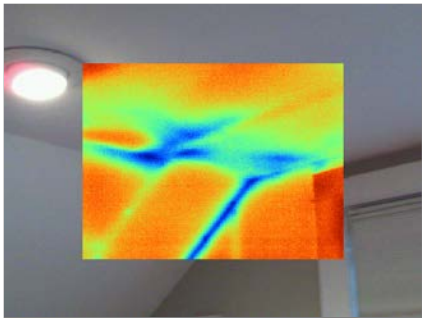
Insulation void in ceiling



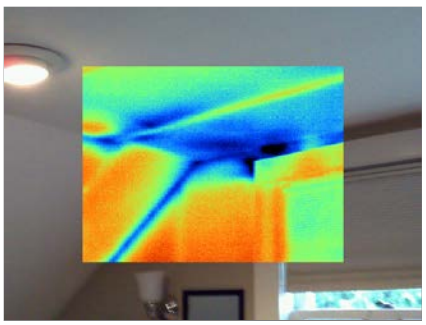
Air leakage at wall plate



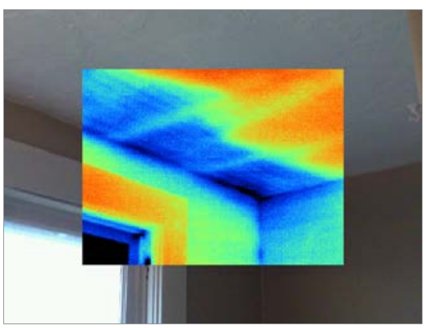
Uneven insulation in blocked wall



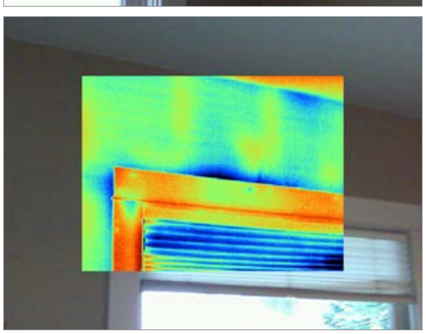
Cold spots in ceiling



Ceiling after depressurization with blower door



Blower door-induced leakage at band joist



Air leakage at window

### *Seattle Audit Results*

All of the auditors at the Seattle site used the Energy Performance Score (EPS) as the core assessment tool in their audits. Based on the analytic spreadsheet called "Simple," developed by Michael Blasnick, the EPS uses a minimal number of inputs to create an asset assessment that can then be used to evaluate potential savings from proposed measures. The EPS also makes predictions of carbon impacts using regionally generated factors for site energy versus source energy generation. The EPS score represents the total site energy use in units of kWh. Table C-2 shows the audit results for the five audits at the Seattle site and includes projected EPS scores with proposed upgrades.

**Table C-2. Seattle Audit Results**

| Auditor | EPS kWh/yr | kWh/yr | Therms/yr | Carbon (tons) | EPS w/upgrades kWh/yr | Projected Savings (%) |
|---|---|---|---|---|---|---|
| 1 | 35,000 | 7,900 | 900 | 9.6 | 15,000 | 57 |
| 2 | 38,000 | 5,900 | 1,100 | 7.7 | 22,000 | 42 |
| 3 | 35,000 | 8,600 | 900 | 7.7 | 24,000 | 31 |
| 4 | 39,000 | 7,300 | 1,100 | 10.2 | 22,000 | 44 |
| 5 | 35,000 | 7,300 | 900 | 7.4 | 23,000 | 34 |
| Actual use | 30,340[1] | 4,725[1] | 874[1] | | | |

[1] Average of 2011 and 2012 billing data

All EPS were above the actual energy use. Three scores were high by 15%. The other two were within 28.5%. Closer examination shows that all the estimates for heating and hot water (gas usage) were within about 25% of the actual usage, and three scores were within 3%. Estimates of electrical usage (lighting and appliances) all significantly overestimated actual usage by from 25% to 82%. All of the estimated savings from the various proposed upgrades produced very similar estimated savings, as seen in the column "EPS w/upgrades," except for Auditor 1, who questionably proposed replacing the 92.5% AFUE gas furnace with a high-efficiency heat pump. This significantly lowered the site energy use and the EPS score but at a higher operating cost for fuel (electricity vs. gas).

Table C-3 shows the auditors' estimated breakout of the heating, hot water, and light/appliance loads for the house as-found, and the projected breakout after their recommended upgrades.

**Table C-3. Audit Estimates for Annual Heating, Hot Water, and Lighting/Appliance Loads**

| Auditor | As-Found Heating kWh | Retrofitted Heating kWh | As-Found Hot Water kWh | Retrofitted Hot Water kWh | As-Found Lighting & Appliances kWh | Retrofitted Lighting & Appliances kWh |
|---|---|---|---|---|---|---|
| 1 | 20,800 | 3,900 | 6,000 | 3,200 | 7,900 | 7,700 |
| 2 | 25,800 | 13,100 | 6,000 | 3,600 | 5,900 | 5,700 |
| 3 | 20,700 | 10,900 | 6,000 | 6,000 | 8,600 | 6,500 |
| 4 | 27,000 | 13,100 | 5,200 | 3,200 | 7,300 | 5,200 |
| 5 | 21,800 | 12,300 | 5,800 | 5,800 | 7,300 | 5,400 |

While total projected savings were closely equivalent (except for those from Auditor 1), closer examination shows that the auditors arrived at these conclusions by different paths. Three of the five auditors proposed upgrades to the hot water system with significant savings. Only Auditor 1 proposed changing the heating appliance. All the others reached similar levels of projected heating performance with a variety of envelope measures including air sealing, duct sealing, and insulation. The largest divergence was in lighting and appliances, where projected savings varied from 200 kWh/year to 2,100 kWh/year.

Table C-4 shows how the auditors graded the elements of the site as found. These qualitative inputs are used by "Simple" in generating the EPS.

**Table C-4. Auditors' Grades of the Elements at the Seattle Site**

| Element | Auditor 1 | Auditor 2 | Auditor 3 | Auditor 4 | Auditor 5 |
|---|---|---|---|---|---|
| Air leakage | Very Poor | Poor | Very Poor | Very Poor | Very Poor |
| Ceiling/attic | Average | Average | Poor | Poor | Average |
| Walls | Average | Average | Poor | Very Poor | Average |
| Floors/Foundation | Average | Poor | Poor | average | Average |
| Windows | Poor | Poor | Poor | Poor | Poor |
| Heating | Good | Good | Good | Good | Good |
| Ducts | Excellent | Poor | Average | Poor | Average |
| Water heating | Average | Average | Average | Average | Average |
| Lights/appliances | Poor | Poor | Average | Average | Average |

In most cases there was good agreement among the auditors. Only two grades differed by more than one step:

- Auditor 1 graded the ducts "Excellent" where everyone else considered them "Poor" or "Average."
- Auditor 4 graded the walls as "Very Poor" based on the assessment that most were un-insulated. Auditors 1, 2 and 5 saw the walls as insulated, except the knee wall between the basement and crawl, and rated them average. IR indicated that the walls were insulated but with numerous discrepancies.
- Auditor 5 reported a blower door number that was off by 35% (suggesting a ring configuration error), but still graded air leakage as "Very Poor." Everyone else was in agreement within 5%.

While all the auditors conducted combustion safety testing and reported acceptable results for spillage, draft, and CO for the furnace and water heater, only Auditors 4 and 5 identified the venting problems of improper clearance to combustible materials and negative slope on the horizontal run from the water heater to the chimney. Table C-5 summarizes the various measures proposed by the auditors. No one suggested the low-cost possibility of displacing the electric-resistance space heater used for comfort in the basement apartment by cutting in an additional supply register in the trunk duct exposed in the ceiling.

### Table C-5. Proposed Energy Performance Upgrade Measures for Seattle Site

| Element | Auditor 1 | Auditor 2 | Auditor 3 | Auditor 4 | Auditor 5 |
|---|---|---|---|---|---|
| Air leakage | Seal to .35 ACHn | Seal to .35 ACHn | Seal to .35 ACHn | Reduce 2000 CFM50 | Seal to .35 ACHn |
| Ceiling/attic | None | Insulate to R-49 | Insulate to R49 | Insulate to R-49 | Insulate to R-49 |
| Walls | Dense pack where R-0 | Insulate knee wall to crawl | Dense pack where R-0 | Dense pack all walls | Dense pack where R-0 |
| Floors/foundation | Insulate crawl floor | Insulate crawl floor | Insulate basement crawlspace walls to R-15 | Replace missing insulation in crawl floor | None |
| Windows | Replace $\leq$ U=.30 | Install storm windows | Install storm windows | None | Install storm windows |
| Heating | Install HP and make dual fuel | None | None | None | None |
| Ducts | Seal and insulate in crawlspace | Seal and insulate in crawlspace | Seal | Seal and insulate in unconditioned space | Seal and insulate in crawlspace |
| Water heating | Install condensing tankless | Install condensing unit | None | Install condensing tankless | None |
| Lights/appliances | Replace washer, dishwasher, and refrigerator<br>Use CFLs | CFLs | CFLs | CFLs<br>Refrigerator | CFLs |
| Additional long-term measures | 5 kW PV solar hot water | | | | |

## Denver Site

The Denver site, shown in Figure C-6, is a single-family, single-story detached home built in 1946, with an attached garage that was later converted to a bonus room. The home's floor plan is provided in Figure C-7 and its general characteristics are summarized in Table C-6.

Figure C-6. Denver Site Front and Back

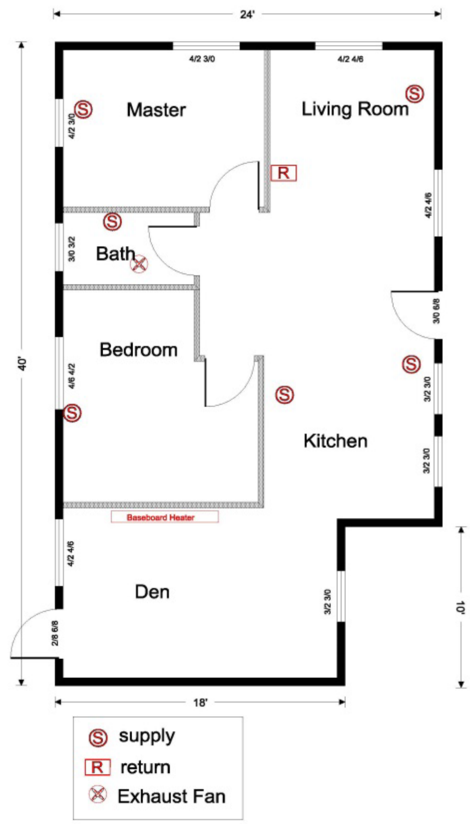
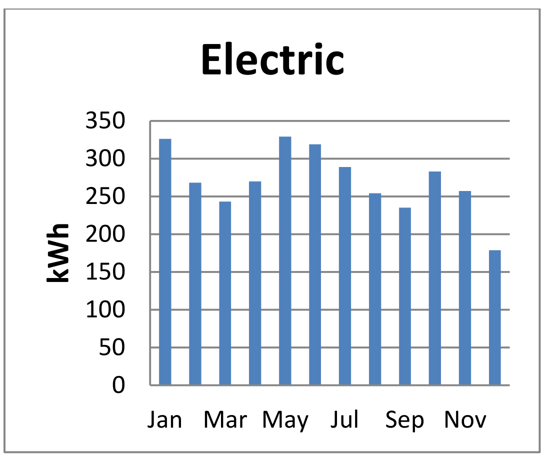



Figure C-7. Floor Plan of Denver Site

Energy consumption at the Denver home is shown in Figure C-8. The owner paid a total of $775.64 for gas and electric in 2012. Total annual gas consumption in 2012 was 390 therms. Total electrical consumption was 3252 kWh. This is a small house with an informed, motivated owner who is trying to minimize energy consumption. The heating season set point was reported to be 66°F, with a night setback to 62°F. While a number of areas for improvement can be identified, paybacks are small, as is consistent with the overall low levels of energy consumption.

### Table C-6. Denver Site Characteristics

| Component | Site Characteristic |
|---|---|
| Ceiling | R-20 blown cellulose |
| Walls | 8"CMU with plaster and brick veneer, no insulation |
| Floors | 720 ft$^2$ un-insulated wood frame over vented crawl, 180 ft$^2$ un-insulated slab on grade (garage conversion) |
| Windows | Upgraded U=.40 double-glazed vinyl frame low E |
| Glazing area | 121.25 ft$^2$, 13.5% glass/floor area |
| Doors | Insulated w/storm |
| Conditioned floor area | 900 ft$^2$, 8-foot ceilings |
| Space conditioning | 80% gas/central forced air/AH in vented crawl/electric baseboard in converted garage/AC in summer from master bedroom window unit |
| Ducts | Leakage to exterior 205 cfm50/131 cfm25, un-insulated metal in crawlspace |
| Air infiltration | 1,530 CFM50; ACH50=12.8 |
| Bedrooms | 2 |
| Baths | 1 |
| Occupants | 2 |
| Ventilation | Spot fan: Bath 0 cfm as found, 36 cfm after repair, range hood re-circulates |
| Domestic hot water | Gas/atmospherically vented/ in vented crawl |
| Lighting | 60% CFL |
| Appliances | ENERGY STAR |



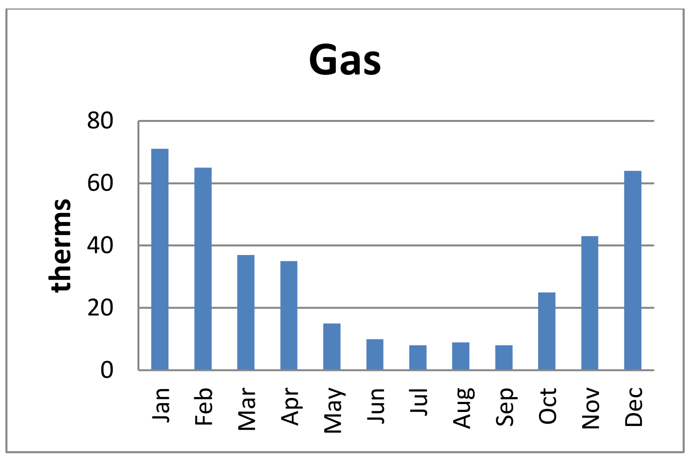




Figure C-8. Denver Site Energy Consumption from Utility Bills

Figure C-9 show noteworthy items from the visual inspection of the Denver site.

Figure C-10 shows images taken with an infrared camera. They confirm the extensive heat loss expected from air leakage that was indicated by the blower door test and show areas of high thermal conductivity and ineffective insulation.

**Figure C-9. Pictures from Visual Inspection of the Denver Site**

The floor above the vented crawlspace is un-insulated and there is no ground vapor barrier.


All the ductwork and the furnace of the central forced-air system are located in the crawlspace, and are un-insulated and poorly sealed.

Gas furnace in crawlspace


The air filter that was removed from the furnace was heavily loaded and appears to be seldom cleaned.

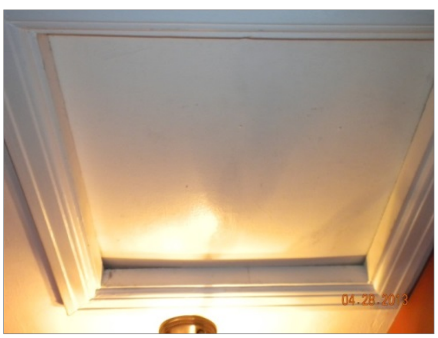
Poorly installed water heater in crawlspace.

The water heater is in a dug-out pit. This installation does not meet code in several ways. The tank is poorly supported and is also vulnerable to flooding because there is no way for water to drain from the pit.

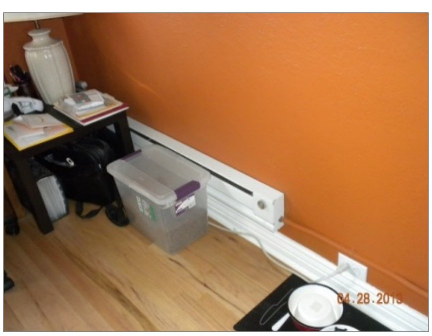
Gas leak testing identified two gas leaks. The flex gas pipe connector was kinked and had a significant leak as confirmed with a soap bubble test.

Corrosion on leaking hot water pipe.

No heat traps are installed with the tank and none of the piping is insulated.



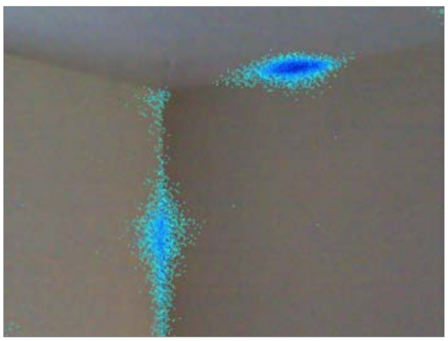
The attic access hatch is poorly insulated and was identified as a significant air leakage point (see Figure C-10).



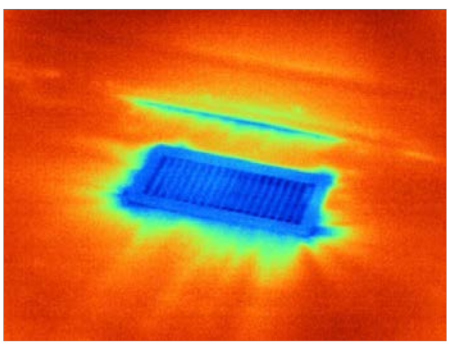
Electric baseboard heat in bonus room

### Figure C-10. Infrared Pictures of Seattle Site

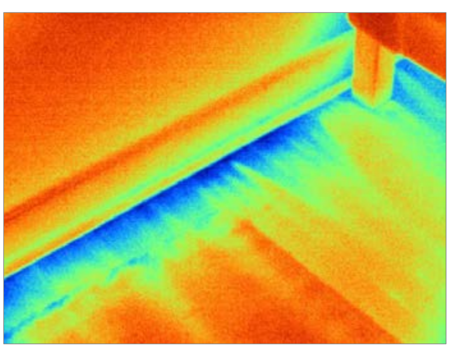
Front of house showing uninsulated masonry wall



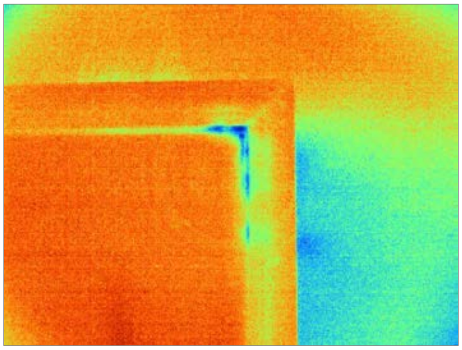
Insulation defects causing thermal bridging



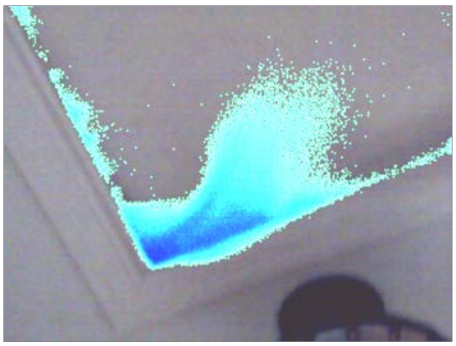
Duct leakage-induced air infiltration at supply register



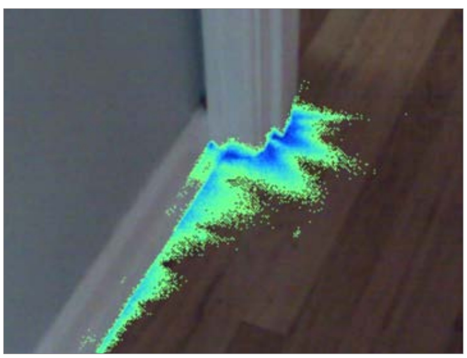
Blower door-induced air infiltration at sill plate



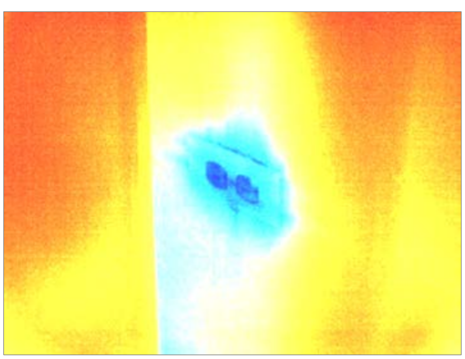
Blower door-induced infiltration at front door



Blower door-induced infiltration at attic hatch



Blower door-induced air leakage from crawl space on interior wall



Blower door-induced air leakage at electrical outlet

## Denver Audit Results

Auditors at the Denver site presented their results and analysis in dollars rather than energy units. The Denver site is serviced by Xcel Energy for both gas and electric. Xcel Energy's residential rates are shown in Table C-7.

**Table C-7. Xcel Energy Residential Rates**

| Fuel | Monthly Service Charge | Tier 1 per kWh | Tier 2* >500 kWh/month | 2 & 3 Quarters Per Therm | 1 & 4 Quarters Per Therm |
|---|---|---|---|---|---|
| Gas** | $11.15 | na | na | $0.40 | $0.54 |
| Electric | $6.75 | $0.09847 | $0.14307 | na | na |

*Tier 2 only applies from June thru September

**Gas rates are approximate but vary seasonally

Electrical consumption is so low at the site that Tier 2 rates never apply, reducing potential pay back on measures. Gas rates are generally quite low as well.

At the Denver site, auditors were given up to three hours to complete their onsite audit and were asked to submit their written reports within a week. The quickest on-site audit time was 1.5 hours by Auditor 6. All of the others took between two and three hours (the maximum time period allowed). The first five audits were completed on April 28 and 29; the last audit was not conducted until about two weeks later because of scheduling issues. By the time of the last audit, the gas leak had already been fixed.

Table C-8 shows a comparison of the physical parameters of the house as reported by each auditor.

**Table C-8. Reported Physical Parameters of the Denver Site**

| Item | Auditor 1 | Auditor 2 | Auditor 3 | Auditor 4 | Auditor 5 | Auditor 6 |
|---|---|---|---|---|---|---|
| Conditioned area | 1,000 $ft^2$ | 976 $ft^2$ | 986 $ft^2$ | 1,100 $ft^2$ | - | - |
| Volume | 8,000 $ft^3$ | 7,808 $ft^3$ | 7,592 $ft^3$ | 8,800 $ft^3$ | - | - |
| Attic insulation | 4-6 in. | 7-9 in. | 4-6 in | 8 in | R-32 | R-30 |
| Wall insulation | None | None | None | None | None | None |
| Floor insulation | None | None | None | None | None | None |
| Windows | Dbl low-E | Dbl low-E | Dbl low-E | U=0.4 | Dbl low-E | - |
| Air leakage | 1,523 CFM50 | 1,523 CFM50 | 1508 CFM50 | 1,500 CFM50 | 1,769 CFM50 | 1,512 CFM50 |
| Heating | Gas 60 kBtu | Gas 75 kBtu | Gas 100 kBtu | Gas | Gas | Gas |
| AFUE Heat | | | | 82% | 80% | 72% |
| Set Points H/C | 65/78 | 65/78 | 65/78 | - | - | - |
| Cooling | - | - | - | Window AC | - | - |
| Duct Leak ext. | 15% | 6% | 30% | 110 cfm25 | Some leaks | 62 cfm25 |
| Duct insulation | None | None | None | - | None | - |
| Water heating | Gas | Gas | Gas | Gas | Gas | Gas |
| Gas leak | Yes | No | Yes | fixed | Yes | Yes |
| DHW location | Indoors | Garage | Indoors | - | Crawl | Crawl |
| Lighting | >50%CFL | >25% CFL | - | - | No # | Average |
| Appliances | <5 yrs Frig | 6-10yr Frig | - | ok | - | Estar Frig |

Table C-9 and Table C-10 provide details about retrofit recommendations made by each auditor.

### Table C-9. Auditor Estimates of Costs and Savings for Retrofit Recommendations

| Item | Auditor 1 | Auditor 2 | Auditor 3 | Auditor 4 | Auditor 5 | Auditor 6 |
|---|---|---|---|---|---|---|
| Estimated retrofit cost | $8,100 | $9,200 | $14,060 | $14,130 | $824 | No costs |
| Estimated savings | $260/yr | $380/yr | $450/yr | $192 | $162 | No estimate |
| Energy reduction | 42% | 51% | 60% | 34% | 29% | No estimate |

### Table C-10. Proposed Energy Performance Upgrade Measures for Denver Site

| Element | Auditor 1 | Auditor 2 | Auditor 3 | Auditor 4 | Auditor 5 | Auditor 6 |
|---|---|---|---|---|---|---|
| Air leakage | Goal 1,220cfm50 | Goal 1,142cfm50 | Goal 1,131cfm50 | Seal | 15% reduction | Seal |
| Ceiling/ attic | R-49 | R-49 | R-49 | R-42 | R-49 addition only | R-50 |
| Walls | | R-13 | R-13 | | | |
| Floors/ foundation | R-19 floor/ R-11 foundation | R-19 floor/ R-11 foundation | R-19 foundation | Floor 3" closed cell foam | R-11 foundation | R-11 foundation |
| Windows | good | good | good | good | good | good |
| Heating | 95% down size 60kBtuh | 92% | | 96% down size 60kBtuh | Not cost effective | |
| Ducts | Close crawl[1] | Close crawl[1] | Seal/close crawl[1] | New ducts sealed R-8 | Seal/insulate R-6 | Close crawl[1] |
| Water heating | Tankless EF= 84 | Replace EF=82 | Lower temp Replace EF=82 | Replace insulate pipes | Insulate tank | |
| Lights/ appliances | LED | CFL | CFL | | CFL | |
| Additional long-term measures | | | | HRV radon mitigation | Flow restrictors | |
| Total cost[2] | $8,100 | $9,200 | $14,060 | $14,103 | $824 | No costs |
| Savings/yr | $260 | $380 | $450 | $192 | $162 | No estimate |

[1] Because this is a high risk radon area recommended testing for radon when closing crawl

[2] Measures prioritized based on a calculated savings to investment ratio

Results of combustion appliance zone testing are provided in Table C-11.

### Table C-11. Combustion Appliance Zone Testing

| Item | Auditor 1 Measures | Auditor 2 Measures | Auditor 3 Measures | Auditor 4 Measures | Auditor 5 Measures | Auditor 6 Measures |
|---|---|---|---|---|---|---|
| Worst case | -2.2 PA | 0 PA | No report | -.3 PA | 0 | OK |
| WH spillage | Pass | Pass | | Pass | Pass | OK |
| Furnace spillage | No test | No test | | No test | Pass | OK |
| WH draft | -3.8 PA | -3.9 PA | | -3.8 PA | -4.3 PA | OK |
| Furnace draft | -7.0 PA | -6.9 PA | | -5.0 PA | -6.0 PA | OK |
| WH CO | 18 ppm | 12 ppm | | 18 ppm | 0 ? | OK |
| Furnace CO | 33 ppm | 32 ppm | | 19 ppm | 20 ppm | OK |

## Evaluation of the Round Robin Process

The process of conducting effective round robins has proven challenging. The houses were selected for this study based on convenience and did not always provide opportunities to evaluate all the aspects of an audit that had been anticipated. Houses should be prescreened and tested to determine their suitability for evaluating the processes under review.

In both Seattle and Denver, an attempt was made to narrow the scope by selecting auditors with similar training who had experience following the same standardized protocol to generate a standardized report. Without some standardization of protocols, data collection, and reporting format, it becomes very difficult to make meaningful comparisons among audits. Even where the goal is to evaluate completely different auditing approaches, complete documentation of the analysis process is necessary to evaluate the basis of divergence.

In both Seattle and Denver, the basic characterization of the home, including diagnostic tests by the auditors, showed reasonable agreement. Basic safety issues were also addressed. The significant gas leak in Denver was detected by the auditors. Seattle auditors correctly tested for spillage and CO, but only two of the five auditors in Seattle reported the venting deficiencies (vent pipe slope and proximity to combustible surfaces).

Divergence increased when the auditors provided recommendations for specific energy performance measures. Both the Seattle and Denver programs represented by these auditors prioritize measure recommendations based on the savings-to-investment ratio (SIR). To determine a SIR, the savings over the measure life and the measure cost are needed. Significant variability in both these values was seen in the reported documentation (Seattle did not include measure costs). Estimated savings by measure often varied by a factor of two, but measure cost estimates varied by a factor of 10 or more. In a real-world application, measure costs should be determined by competitive bid to determine the best value.

The round robins in Seattle and Denver focused on the characterization of the homes by the auditors, the recommendations for performance improvements, and the projected savings from the improvements. Homeowners look to the audit process for guidance on making sound investments to improve the performance of their homes. At both sites, health or safety issues were identified and improvement measures were proposed with estimated overall energy use reduction ranging from 30% to 60%.

As a tool, round robins can provide programmatic quality assurance, feedback for trainers and practitioners and guidance in establishing acceptable and/or attainable levels of precision, repeatability, and reproducibility.

# Appendix D: ASTM E691-11 – Standard Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

## Repeatability

The International Vocabulary of Metrology (VIM)[2] defines measurement repeatability as the "measurement precision under a set of repeatability conditions of measurement." This definition requires further explanation. First, precision is defined as the "closeness of agreement between indications or measured quantity values obtained by replicate measurements on the same or similar objects under specified conditions." These conditions, the repeatability conditions of measurement, are defined as those "that include the same **measurement procedure**, same operators, same **measuring system**, same operating conditions and same location, and replicate measurements on the same or similar objects over a short period of time."

For the HPC industry, the concept of repeatability may have merit when considering tools used to assess performance characteristics, such as air tightness or combustion efficiency. For example, it may be of interest to gauge the repeatability of a blower door test by having the same crew use the same exact equipment, protocol, and analysis tools on the same house within an hour. The measurement repeatability would typically be characterized by some measure of variation such as standard deviation.

## Reproducibility

VIM defines measurement reproducibility as the **measurement precision** under **a** condition of **measurement**, out of a set of conditions that includes different locations, operators, **measuring systems**, and replicate measurements on the same or similar objects. It notes that a specification should be provided to identify the specific conditions that change during the testing.

Reproducibility has important implications for the HPC industry. A good example of the need to assess repeatability is to have multiple energy auditors perform an assessment of the same house using the same protocol. Alternatively, one may be interested in reproducibility across different auditing protocols, either with the same auditor or with multiple people using the procedures of their own choosing. Reproducibility can also have a place with individual measures, as discussed with repeatability. For example, one may wish to assess how airtightness results depend upon the equipment used or the procedure implemented in determining the values.

[2] JCGM 2012, International vocabulary of metrology – Basic and general concepts and associated terms (VIM), JCGM 200:2012.