Analysis Methods and Tools

Standing Technical Committee

Strategic Plan - February 2012

Committee Chair:

2012	Ben Polly	NREL

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1. INTRODUCTION

1.1 Standing Technical Committee Strategic Plan Overview

Standing Technical Committees (STCs) focus on resolving key technical action items required to meet Building America performance goals. STC chairs lead each committees' activities in addressing specific research challenges, gaps in understanding, and new research opportunities. Committees include experts from the Building America research teams, DOE, national laboratories, and outside organizations that possess specialized knowledge or heightened interest in the topics being addressed. Committee chairs can create sub-committees on an as-needed basis to address targeted research needs.

The Strategic Plan is a living document maintained by the committee chair, who coordinates input and review by the committee. Planned revisions follow the three annual Building America meetings (technical, stakeholder and planning). The document should be referenced by Building America teams when planning research and prioritizing opportunities. It will be used by DOE and other stakeholders when identifying market and research needs and setting priorities. In addition to clearly communicating and prioritizing current gaps (or market needs) and barriers, it serves as an archive of accomplishments and failures that inform all ongoing Building America efforts. The Strategic Plan is a living summary document and is NOT intended to be a compendium of all available knowledge.

The Strategic Plan should accomplish the following:

- Summarize and prioritize gaps and barriers including those identified during the Building America meetings;
- Identify key customers and stakeholders, identify their priorities and desired deliverable timelines;
- Summarize background knowledge related to each gap or barrier;
- Summarize system interactions and relationships specific to each gap or barrier;
- Identify ongoing and planned Building America, DOE, industry and/or academic research activities related to each gap or barrier and to which customers or stakeholders the research is targeted;
- Summarize how success is defined relative to the goals of research activities; and
- Define the research path, including approaches to collect data from market leaders, the timeline and milestones to resolve the gap, barrier or need.

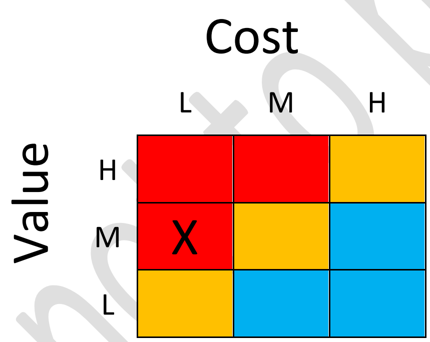
1.2 Prioritization of Gaps, Barriers and Needs

Priorities are set using the cost-value matrix (Table 1) and the professional judgment of the committee1. As a Committee, relative costs2 and values (low, medium, high) associated with all gaps, barriers and needs are established within the Committee's domain where:

- Cost is the estimated Building America funding required to research and develop solutions; and
- Value is defined by the key stakeholders and customers including the likelihood of widespread adoption and potential benefits (e.g., energy saving potential) in the marketplace. Other factors that may be taken into considering assigning value include:
  - Code cycles and needs to meet code goal targets;
  - Revisions to voluntary and mandatory standards (e.g., ENERGY STAR, minimum efficiency)

For example, in Table 1, the gap is assigned as a medium-value, low-cost, and is therefore given a high priority rating.

Table 1: Example Cost-Value Matrix



The summary sheets for each gap and barrier are ordered from highest to lowest priority. Table 17 in Appendix D ranks the gaps and barriers identified by the Analysis Methods and Tools STC.

1 The 3x3 cost-value matrix is a coarse approximation may not appropriately set priorities in all situations.
2 Cost in this context refers to the research and development costs that the Building America program would bear. Committees are encouraged to estimate costs to the best of their abilities.

1.3 Summary of Analysis Methods and Tools STC Strategic Plan

Overall Goal and Scope

The purpose of the Building America (BA) Analysis Methods and Tools Standing Technical Committee (STC) is to identify and track gaps and barriers related to energy analysis methods and tools that must be resolved to achieve the Building America Program goals[3]. It is expected that the Building America teams will propose research projects directed at resolving many of these gaps/barriers. The overall goal of the committee process and accompanying research is to resolve gaps/barriers that limit the widespread use of Building America analysis methods and tools to make accurate, consistent, transparent, documented, cost-effective, and time-effective predictions of:

- energy use and savings (including BA program metrics),
- costs,
- comfort,
- safety, and
- durability

in each U.S. climate region, at a whole-building (integration) level, for new construction and existing homes, for single and multi-family buildings, and for emerging and mature energy efficiency technologies. Although gaps/barriers are related to the 50% whole house energy savings goal for the residential integration program, part of the previous, current, and future work to resolve gaps/barriers may fall within the scope of other DOE programs (Emerging Technologies, Deployment, etc.). The two page assessments that are assembled in this document are meant to identify specific gaps/barriers, including previous, ongoing, and planned research in all programs that may lead to resolution. The two page assessments are not proposals; they are for planning purposes only and will be updated on a quarterly basis as more information becomes available.

Strategic Goals

In addition to the overall goal described above, current committee efforts help guide Building America research toward accomplishing the following Strategic Goals:

1. Improve the accuracy of AMATs to reduce risks associated with buying, selling, and financing energy efficiency in residential buildings.
2. Enhance the capabilities of AMATs to predict the energy, cost, comfort, safety, and durability impacts of energy efficiency technologies, so industry, government, and researchers can evaluate the benefits and tradeoffs between individual technologies and packages of technologies to develop aggressive energy savings solutions for the market.
3. Establish field data collection procedures and house simulation protocols that optimize cost and accuracy tradeoffs to increase the credibility and profitability of analysis efforts in the field.

[3] http://www1.eere.energy.gov/buildings/building_america/program_goals.html

Relation to Other BA STCs
Six other BA STCs are in place:

- Automated Home Energy Management
- Building Envelope
- Hot Water
- Implementation
- Space Conditioning
- Testing Methods and Protocols

The first five STCs in the list above relate primarily to specific building technologies. The Analysis Methods and Tools STC, as well as the Testing Methods and Protocols STC, are more general. Each technology area may require analysis methods/tools and testing methods/protocols to resolve gaps/barriers identified in their areas. For this reason, it is expected that the Analysis Methods and Tools STC and the Testing Methods and Protocols STC will identify gaps/barriers that overlap significantly with gaps/barriers identified by the technology-specific committees. Committee Chairs and NREL Points-of-Contact for each committee will work to coordinate efforts between the STCs.

Initial List of Gaps and Barriers
In FY11, the committee created an initial list of gaps/barriers related to analysis methods and tools. Appendix D shows the full list ranked in order of priority (based on committee survey results), as well as gaps/barriers added after the survey. Each gap/barrier is grouped into one of the following categories (the number of gaps/barriers in each category is indicated in parentheses):

- Validation and Testing (6)
- Existing Methods and Tools (52)
- New Methods and Tools (3)
- Field Data and Audits (5)
- House Simulation Protocols (11)
- Other (1)

The majority of gaps/barriers fell into the "Existing Methods and Tools" category. Furthermore, many of the topics in this area were specific to NREL's Building Energy Optimization (BEopt) software development effort and would generally involve short-term implementation efforts by NREL to reach resolution. For such topics the committee decided it was not necessary to develop detailed two-page descriptions, but rather these topics should be tracked at a high level in the Strategic Plan (i.e., the list in Appendix D should clearly indicate which topics are BEopt specific).

Initial Set of Two-Page Gap/Barrier Descriptions
In FY11, the committee drafted and reviewed 14 two-page gap/barrier descriptions. The Chair recruited authors for the 12[4] highest priority topics (based on the survey), and two other committee members voluntarily created two-page descriptions for topics that were not in the top 12. <u>Just because a gap/barrier was not included in this initial set of two-pagers does not mean it will not be addressed.</u>

[4] This was the number of topics the Chair felt could be drafted and reviewed given the available resources.

Titles for the two page descriptions evolved from the survey topics (Appendix D). The following is a list of titles for each two-pager included in this initial Strategic Plan along with the topic ID(s) from Appendix D that each two-pager addresses:

1. Sensitivity Analysis (#6)
2. In Situ Furnace Performance (#22)
3. Validation Methodology—Accuracy Tests Based on Existing Empirical Data Sets (#2)
4. In Situ Air-Conditioner Performance (#21)
5. In Situ Water Heater Performance (#23)
6. High Efficiency Air-Conditioners and Heat Pumps (#50, #29, #30, #35, #33)
7. Wall Cavities (#24)
8. Multifamily Window-to-Wall Ratio (#67)
9. Ground Source Heat Pumps (#31)
10. Heat Pump Water Heaters (#32)
11. Data Transfer Standard (#62)
12. Storm Windows (#27)
13. Enhancing Documentation, Training, and Education for Building America Analysis Tools (#77)
14. Supplemental Dehumidification Modeling (#36, #57)

Descriptions of the various sections in each two-pager can be found in the next section.

1.4 Descriptions of Sections

Problem Statement
Describe the gap or barrier itself. What could the industry achieve if this wasn't a problem? What are the risks associated with ignoring this gap or barrier? What are the climatic considerations (e.g., is it isolated to a specific region)? Is the problem primarily cost effectiveness? (One problem can apply to gap/barriers across different categories.)

Key Customers and Stakeholders
List the key customers and stakeholders and the roles they play delivering or implementing solutions. Describe the value to customers and stakeholders if the gap/barrier was resolved.

Background Knowledge
Describe the relevant background knowledge and reference key papers.

System Considerations
Reference how this gap, barrier or need relates to other known gaps, barriers or needs.

Planned or Ongoing Research
Summarize the "who" (Building America and other organizations) and "what" of existing or planned research activities that may resolve the gap, barrier or need. Can and should BA research supplement private industry's efforts by addressing the gap or barrier? Why is there no planned or ongoing research (if applicable)?

"Closing the Gap"
What is the goal and how do we know if it has been achieved? Define desired outcome in terms of relevant metrics that can be applied/measured.

Timeline
Estimate whether resolving the gap/barrier is a short-term, mid-term, or long-term effort.

2.1: Sensitivity Analysis

BA Enclosures		BA Hot Water	
Walls		Test Standards	
Roof/Ceiling		Distribution	
Foundations		Condensing/Tankless	
Moisture		Heat Pump Water Heater	
Windows		Combined Space and DHW Heating	
Other: __________________		Other:__________________	
BA Space Conditioning		**BA Miscellaneous Loads**	
Heating		Home Energy Management	
Cooling		Lighting	
Dehumidification		Large MELs (pools, etc.)	
Distribution		Small MELs (TVs, VCRs, etc.)	
Ventilation		Other: __________________	
Other: __________________			
Testing Methods/Protocols		**BA Implementation**	
House Simulation Protocol	x	Quality Control / Quality Assurance	
Lab Test Methods		Training	
Field Test Methods		Documentation / Resources	
Analysis Methods/Tools		Needs Evaluation / Identification	
Analysis Tools	x	Other: __________________	
Strategic Analysis	x		
Other: __________________			

House Type	
New	x
Existing	x
Single Family	x
Multi-Family	x
DOE Emerging Technologies	
Walls and Windows	
Efficient Appliances	
Advanced Heating and Cooling Fluids	
Solar Heating and Cooling	
Geothermal Heat Pumps	
Solid State Lighting	
Bulk Purchase	
Onsite Renewables (Building-Integrated Photovoltaic, onsite cogen)	
DOE Deployment	
Labeling/Rating	
Codes	
Standards	
Large Scale Retrofit (Better Buildings)	

Problem Statement:
Building energy simulation (BES) programs contain many physical models to predict the thermal behavior of a building system. Each model requires various input parameters, which are either defaulted/calculated automatically in the program or are required as input information from the user. Sensitivity analysis is needed to estimate the inputs that have the most influence on software predictions and recommendations. With this information, energy analysis could be improved by 1) collecting only information in an energy assessment that is necessary to achieve a specified level of accuracy and 2) focusing on validating and enhancing models that have the most influence on software predictions. If this barrier is not addressed, industry will be forced to design software and input collection methods with insufficient information. This could lead to more expensive and less-accurate energy analysis than is necessary. Because simulation inputs include weather information, analysis should be conducted across all major climate regions.

Key Customers and Stakeholders:
DOE Speed and Scale Programs: Would benefit from a better-understanding of which inputs have the most influence on simulation predictions and therefore are the most important to accurately collect in the field.

Software Developers: Would develop and supply software that is used in the sensitivity analysis. If the barrier is resolved, they would benefit from better software performance.

Homeowners: Would provide feedback regarding improved software and input collection procedures from the buyer's perspective. If this barrier is resolved, they would benefit from more accurate software and faster audit/analysis procedures.

Home Energy Contractors: Would test the improved software and input collection procedures in the field. If the barrier is resolved, they would benefit from better software performance and streamlined audit/analysis procedures (faster, more accurate energy assessments).

Utilities: Would help set targets for software performance and energy assessment time/cost. If this barrier is resolved, they would benefit from more affordable and reliable home energy assessments (energy assessment incentive $'s have more impact).

Educators: Information from sensitivity analyses would help instructors teach building energy simulations programs.

Background Knowledge:
Whole building energy models can require 10's to 1000's of user inputs. The inputs generally fall into three categories: 1) Site, 2) Building, and 3) Occupants. Inputs are collected using a variety of methods, which include measurement, observation, estimation, survey, and calculations based on other inputs. Sensitivity studies examine the "influence" of different model inputs on software predictions and recommendations. A typical approach is to systematically vary input values in a program and study the changes in output. For example, in one method, all input values are held constant except the input of interest, which is varied. The ratio of the change in output over the change in input can be used as a metric to gauge the "influence" of the input. Other sensitivity analysis methods employ more advanced techniques (e.g., capture non-linear effects, employ statistical models, consider input interactions).

System Considerations:
Sensitivity analysis inherently involves the entire building system. It is a way to understand the relative importance of different input parameters in a BES program. The results of this analysis could therefore apply to many other gaps/barriers. For example, sensitivity analysis should help focus and inform model validation efforts.

A specific gap/barrier that has been identified by the Analysis Methods and Tools STC is the need for streamlined audit procedures. Sensitivity analysis will help prioritize which inputs should be collected in an audit given specific time, cost, and accuracy requirements. Additionally, sensitivity analysis results could improve remote diagnostic analysis approaches where information regarding a home's energy performance characteristics is extracted from utility billing data and limited information about the home (e.g., assessor data).

Planned or Ongoing Research:
Sensitivity analysis was performed using EnergyPlus in the beginning stages of the development of BESTEST-EX, which is a comparative software test suite for existing homes. The analysis is limited to a single house type in a single climate.

In FY11, NREL developed sensitivity and uncertainty analysis capabilities for the BEopt software program. The capabilities allow researchers to perform differential sensitivity analysis for many site, building, and occupant inputs. EnergyPlus is currently used as the simulation engine in these analyses, but DOE-2.2 may eventually be used, which would allow for the comparison of analysis results across two commonly-used simulation engines. NREL also performed some preliminary sensitivity studies (not broad, focused on individual inputs and algorithms) when investigating potential sources of software inaccuracy.

Researchers at FSEC have conducted some internal sensitivity studies (including sensitivity to financial assumptions) using the EGUSA software, the results of which may be useful for designing larger studies.

"Closing the Gap":

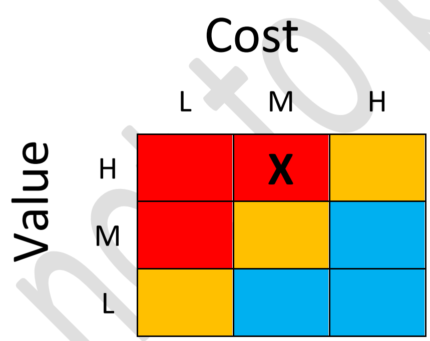
The goal is to determine the inputs that have the most influence on software predictions and recommendations. It will be necessary to define prototypical homes in various climate regions at various efficiency levels to investigate a range of site, occupant, and building input conditions. It is important to understand that analysis is always specific to the software that is used, which means that analyses should be conducted across a variety of software tools to understand and explore differences in results. Furthermore, the methodology for performing the analysis should be described in a way that allows other parties to conduct similar analysis using their tools. Optimization programs are also available to help conduct and automate these analyses for different software tools[5].

We will know that the gap/barrier has been addressed when results of sensitivity analyses for multiple tools are publically available to the key stakeholders.

Timeline:

Resolving this gap/barrier should be viewed as an ongoing effort since software tools will change with time and analyses will need to be updated accordingly. A single sensitivity analysis is typically a short-term activity, especially once the analysis approach is automated.

Table 2: Cost-Value Matrix for "Sensitivity Analysis"



[5] For example, http://gundog.lbl.gov/GO/

2.2: In Situ Furnace Performance

BA Enclosures		BA Hot Water	
Walls		Test Standards	
Roof/Ceiling		Distribution	
Foundations		Condensing/Tankless	
Moisture		Heat Pump Water Heater	
Windows		Combined Space and DHW Heating	
Other: __________________		Other:__________________	
BA Space Conditioning		**BA Miscellaneous Loads**	
Heating	x	Home Energy Management	
Cooling		Lighting	
Dehumidification		Large MELs (pools, etc.)	
Distribution		Small MELs (TVs, VCRs, etc.)	
Ventilation		Other: __________________	
Other: __________________			
Testing Methods/Protocols		**BA Implementation**	
House Simulation Protocol	x	Quality Control / Quality Assurance	
Lab Test Methods		Training	
Field Test Methods	x	Documentation / Resources	
Analysis Methods/Tools		Needs Evaluation / Identification	
Analysis Tools	x	Other: __________________	
Strategic Analysis			
Other: __________________			

House Type	
New	x
Existing	x
Single Family	x
Multi-Family	x
DOE Emerging Technologies	
Walls and Windows	
Efficient Appliances	
Advanced Heating and Cooling Fluids	
Solar Heating and Cooling	
Geothermal Heat Pumps	
Solid State Lighting	
Bulk Purchase	
Onsite Renewables (Building-Integrated Photovoltaic, onsite cogen)	
DOE Deployment	
Labeling/Rating	
Codes	
Standards	
Large Scale Retrofit (Better Buildings)	

Problem Statement:
The in situ performance of furnaces is not well characterized and, as a result, it is difficult to confidently assess the benefits of retrofitting a house with newer furnaces. Without proper characterization, contractors and energy analysts may be overstating or understating the value of furnace retrofits, which could ultimately result in unnecessarily high costs to the homeowner or unrealized energy saving potential.

Most often, an Annual Fuel Utilization Efficiency (AFUE) is used to rate furnace performance. However, the AFUE alone is not enough to characterize the full performance of furnaces over a wide range of operating conditions. The actual performance depends on several factors, including:

- Steady-state burner efficiency
- Burner type (atmospheric, forced draft, pulse combustion, etc.)
- Part-load performance
- Pilot light consumption
- Auxiliary electric consumption (e.g. draft fans).

The following two important research questions pertain to the in situ performance of furnaces:

1. How can we best estimate the full range of performance parameters for furnaces given a limited amount of information (e.g., climate, vintage, fuel type, name-plate information)?
2. How does furnace performance change over time and how can degradation be accurately modeled in simulations?

Key Customers and Stakeholders:
DOE Speed and Scale Programs (e.g. Better Buildings) – Accurate predictions of furnace performance will influence DOE programmatic decisions and are necessary to find the most cost-effective way to meet national energy saving targets.

Others (Furnace manufacturers, Energy retrofit contractors, Homeowners) - Accurate predictions of furnace performance will lead to suggesting appropriate, energy-saving, cost-effective solutions.

Background Knowledge:
The current Building America House Simulation Protocols (HSP) describes a method (based on a single reference and engineering judgment) to de-rate the AFUE of furnaces based on age and level of maintenance. The HSP also relies on the AFUE as the only metric for performance and does not describe the full set of performance metrics for old furnaces, such as burner efficiency, draft-type, pilot light consumption, or draft fan efficiency.

De-rating furnace performance is a common procedure in energy assessments of buildings, but the supporting literature on this procedure could be improved. What components of the furnace are actually degrading to cause reduced performance? There are a couple factors that may contribute to degraded performance of furnaces:

- Incomplete fuel combustion – either inadequate combustion air supply or inadequate fuel supply.
- Fouling/scaling of the burner

A good resource for information on furnaces is the following Technical Support Document provided by DOE: http://www1.eere.energy.gov/buildings/appliance_standards/residential/fb_tsd_0907.html.

System Considerations:
Furnaces are typically packaged with the blower for the air distribution system. It is important to also be able to characterize the performance of the blower.

There are several considerations that revolve around replacing an old furnace, such as: downsizing the new equipment (e.g., the resulting impact on energy consumption and equipment cost), replacing the air conditioner and evaporator, and the effect replacement will have on meeting loads (improving capacity means the unit will be able to meet more of the load, and possibly use more energy).

Planned or Ongoing Research:
PARR (BA) – PARR has put together a test plan entitled "Maximizing the Installed Performance of High-Efficiency Gas Furnaces", which will explore the impact of poor installation practice on furnace AFUE.

WAP – DOE's Weatherization Assistance Program has performed steady-state efficiency tests on a large number of furnaces. These results should be reviewed further to better understand degradation of furnace performance.

PARR (BA) – 5%-30% energy savings potential of HVAC system improvements (measure guideline for furnace tune-up).

"Closing the Gap":
Energy Analysis tools need to provide an accurate estimate of the in situ performance of furnaces. From the modeling perspective, this means characterizing the as-used performance of furnaces ranging in age, fuel type, level of maintenance, etc.

A survey of installed equipment could be conducted to better understand the causes and effects of furnace performance degradation under different maintenance scenarios.

Additionally, field measurement methods should be established to best capture the performance of specific furnaces when necessary. This may include the need for improved tools for auditors to make simple yet meaningful measurements in the field related to furnace performance (e.g., steady-state efficiency).

The HSP could be updated to reflect a better understanding of in situ furnace performance. For a given vintage and maintenance level, the HSP could define typical:

- System efficiency (AFUE, burner efficiency)
- Part-load performance
- Capacity degradation
- Draft fan power
- Pilot light consumption.

As part of this process, sensitivity/uncertainty analysis should identify parameters (such as burner fouling and air-to-fuel ratio) that have large impacts on simulation results and are not typically accounted for in simulation models. These identified parameters will inform what information is important to collect on the pre-retrofit HVAC system and what information should be defaulted based on best practice procedures (stated in the HSP).

The accuracy of energy analyses after the HSP and analysis tools have been updated can be validated against field test data.

Timeline:
Mid-term.

Table 3: Cost-Value Matrix for "In Situ Furnace Performance"

Value \ Cost	L	M	H
H		X	
M			
L			

2.3: Validation Methodology – Accuracy Tests Based on Existing Empirical Data Sets

BA Enclosures		BA Hot Water	
Walls	x	Test Standards	
Roof/Ceiling	x	Distribution	
Foundations	x	Condensing/Tankless	
Moisture	?	Heat Pump Water Heater	
Windows	x	Combined Space and DHW Heating	
Other: __________________		Other:__________________	
BA Space Conditioning		**BA Miscellaneous Loads**	
Heating	x	Home Energy Management	
Cooling	x	Lighting	
Dehumidification	x	Large MELs (pools, etc.)	
Distribution	x	Small MELs (TVs, VCRs, etc.)	
Ventilation	x	Other: __________________	
Other: __________________			
Testing Methods/Protocols		**BA Implementation**	
House Simulation Protocol	x	Quality Control / Quality Assurance	x
Lab Test Methods		Training	
Field Test Methods	x	Documentation / Resources	
Analysis Methods/Tools		Needs Evaluation / Identification	
Analysis Tools	x	Other: __________________	
Strategic Analysis	x		
Other: __________________			

House Type	
New	x
Existing	x
Single Family	x
Multi-Family	x
DOE Emerging Technologies	
Walls and Windows	
Efficient Appliances	
Advanced Heating and Cooling Fluids	
Solar Heating and Cooling	
Geothermal Heat Pumps	
Solid State Lighting	
Bulk Purchase	
Onsite Renewables (Building-Integrated Photovoltaic, onsite cogen)	
DOE Deployment	
Labeling/Rating	x
Codes	x
Standards	x
Large Scale Retrofit (Better Buildings)	x

Problem Statement:
Predicted savings using simulation tools to model new or retrofit energy efficiency measures may not be accurate. Especially for inefficient (uninsulated, leaky, etc.) existing homes, there is a perception that some simulations may overestimate energy use by up to a factor of about 2; this results in over-prediction of savings associated with energy efficiency measures. Resolving this problem would lead to greater confidence in energy savings predictions, a more reliable financing basis, and less financial risk – potentially resulting in greater investment in energy efficiency measures that provide a satisfactory predicted level of investment return. If the barrier is not resolved, customers and stakeholders may have low confidence in energy cost savings predictions, resulting in less investment in energy efficiency measures. This concern applies in all climates.

Key Customers and Stakeholders:
Resolving this barrier will lead to improved confidence when investing in industry products and services, which is important to the following key customers and stakeholders:

- Homeowners: pay for retrofits, expect "advertised" return on investment in the form of lower energy costs
- Software developers: provide calculation tools
- Financial institutions/investors: provide financing for energy efficiency products and services
- Retrofit companies: install energy efficiency measures, use calculation tools to sell energy efficiency measures
- Manufacturers of energy efficiency measures: provide energy efficiency products

- Regulators: establish minimum requirements for energy efficiency measures (usually based on cost-effectiveness calculations)
- Energy utilities: rely on effective energy efficiency programs to displace need for additional power plants and/or distribution infrastructure, and to better serve customers in their service territories
- State/local agencies that support energy efficiency: rely on accurate cost effectiveness calculations to support public policy/funding decisions

Background Knowledge:
Several previous studies have shown that software tends to over-predict energy usage and savings in older, poorly insulated, leaky homes. A review of such studies can be found in Appendix A of Polly et al. [2011]. Currently, the most commonly used software tests are software-to-software comparative tests (such as ANSI/ASHRAE Standard 140 [ASHRAE 2007], HERS BESTEST [Judkoff and Neymark 1995], RESNET mechanical equipment tests [RESNET 2007], and BESTEST-EX [Judkoff et al. 2010]). While purely software-to-software comparative tests are effective for identifying and diagnosing software errors, they do not provide a direct empirical truth standard beyond previous empirical validation studies of reference programs used as the basis of results comparisons and example acceptance criteria. Therefore, the software development/research community has identified a need to develop tests applying comparison of software results to empirical data.

As any test case requires a test specification, it is necessary to assess the quality of building descriptions, utility data, weather data, and occupancy information that accompany an existing empirical data set, to answer the question: is a given data set of sufficient quality to be useful as the basis of an empirical validation test specification? Related issues (gaps/barriers/limitations) to be addressed:

- A listing of requirements for "test-worthy" data does not exist – this must be developed.
- A data set vetting process does not exist; this must be documented during initial analysis of potentially useful data sets.
- Non-laboratory (non-controlled) data typically have high noise (uncertainty in input descriptions based on audits, occupant behavior, weather data, etc., along with uncertainty in billing data used as the basis of results comparisons). High uncertainties lead to a situation where simulations with compensating errors may agree with utility bills, but it would be difficult (if it is possible) to diagnose such compensating errors. This is because diagnostics based on the sensitivity of variations to key parameters (where available) are likely to be weak because of, e.g., inconsistent base cases (no two pre-retrofit homes are likely to be the same) and inconsistency among parametric variations (specific retrofits).
- Controlled laboratory experiments (e.g., using side-by-side test buildings) could address consistency/uncertainty issues but are expensive. [Judkoff and Neymark 2006, ASHRAE Handbook of Fundamentals 2009].

System Considerations:
This barrier relates to other known gaps/barriers identified by the STCs:

- Accurate and fast energy assessments
- Tuning BESTEST-EX based on existing empirical data sets
- More test suites where software is compared to other software
- Full-scale empirical validation test facility.

Planned or Ongoing Research:

- NREL work to establish the Field Data Repository and investigate the possibility of using data sets from state/local residential energy efficiency programs to develop test cases based on empirical data from actual houses.

- Flexible Residential Test Facility Project (BA, FSEC). May provide data sets that can be used for empirical test suites. This test facility is representative of typically constructed existing buildings in a hot/humid space-cooling load dominated climate.
- PNNL has two side-by-side manufactured lab homes (http://labhomes.pnnl.gov/). According to the website, "the Baseline Home, will remain a control typifying an average existing home in the inland eastern Pacific Northwest region, and the other, the Experimental Home, will test a new technology. Occupancy in each home will be simulated to account for human activity." This project may also provide data sets that can be used for empirical test suites.
- In the Zebra Alliance project (four newer homes, ~50% more efficient than IECC 2006), ORNL is measuring approximately 250 data points per home and plans to compare EnergyPlus model predictions to measured data. Advanced systems such as geothermal heat pumps, structurally insulated panels, phase change materials, high-efficiency air-source heat pumps, and exterior insulation finish systems are present in some of the homes.
- LBNL has several deep retrofit projects where detailed end use data from 10 homes are being collected. The data includes descriptions of many home characteristics used for model input. This project is about 75% complete and forthcoming reports may have information useful for software validation.
- Appropriate data from other test facilities and field activities (e.g. Natural Resources Canada, Electricité de France, Boise St. Univ., ARBI, etc.) should also be reviewed. For example, ARBI is working to collect pre- and post-retrofit utility bill data for homes participating in the Energy Upgrade California Better Buildings Program.

BA research should supplement private industry's efforts by addressing this barrier because third party standardized software accuracy test development by a "reliable" non-biased source (e.g., a national laboratory) is perceived as more credible (less self-serving) than an individual software developer's (or software developer industry organization's) claims.

"Closing the Gap":
Goal: Quantify accuracy of software predictions versus existing empirical data sets.
Achievement Criteria and Metrics: The goal will be achieved when we are able to quantify the probability that the prediction of pre-retrofit base-case energy consumption and retrofit energy savings will fall within some reasonable percentage of actual energy consumption and savings.

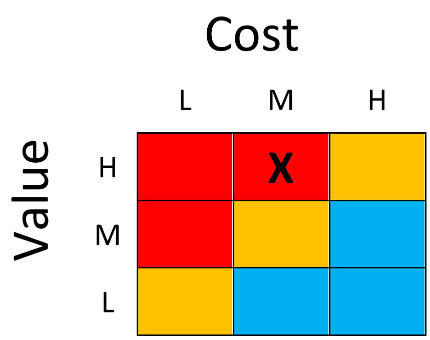
Stakeholders seem to want answers to two key questions:

1. How accurate is software as it is used in the field?
2. How can the accuracy of software be improved?

Existing empirical data sets (audit and utility bill data) could be used to answer the first question. The approach to answering the second question requires more detailed test diagnostics that may be somewhat achievable by applying statistical evaluation methods to existing empirical data and/or examining the possibility of empirically tuning the BESTEST-EX base case. Direct empirical-data based diagnosis of software inaccuracies may only be achievable by developing a whole-house laboratory test facility designed specifically for the purpose of empirical validation.

Timeline:
Mid-term.

Table 4: Cost-Value Matrix for "Validation Methodology – Accuracy Tests Based on Existing Empirical Data Sets"



Note: Research addressing this gap has high value if satisfactory existing data sets can be found. There is risk that existing data sets may not form a satisfactory basis for empirical validation.

References:

1. Polly, B.; Kruis, N., Roberts, D. 2011. *Assessing and Improving the Accuracy of Energy Analysis Methods for Residential Buildings*. Golden, CO: National Renewable Energy Laboratory. DOE/GO-102011-3243.
2. ANSI/ASHRAE. 2007. ANSI/ASHRAE Standard 140-2007, *Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs*. Atlanta, GA, USA: American Society of Heating, Refrigerating and Air-Conditioning Engineers.
3. Judkoff, R.; Neymark, J. 1995. *Home Energy Rating System Building Energy Simulation Test (HERS BESTEST)*. NREL/TP-472-7332a and TP-472-7332b. Golden, CO, USA: National Renewable Energy Laboratory.
4. RESNET 2007. *Procedures for Verification of International Energy Conservation Code Performance Path Calculation Tools.* RESNET Publication No. 07-003: September 2007. Oceanside, CA, USA: Residential Energy Services Network, Inc. http://www1.resnet.us/standards/iecc/procedures.pdf.
5. Judkoff, R.; Polly, B.; Bianchi, M.; Neymark, J. 2010a. *Building Energy Simulation Test for Existing Homes (BESTEST-EX).* NREL/TP-550-47427. Golden, CO, USA: National Renewable Energy Laboratory.
6. Judkoff, R.; Neymark, J. 2006. "Model Validation and Testing: The Methodological Foundation of ASHRAE Standard 140." *ASHRAE Transactions* 112(2):367–376. Atlanta, GA, USA: American Society of Heating, Refrigerating and Air-Conditioning Engineers.
7. *ASHRAE Handbook of Fundamentals.* 2009. Atlanta, GA, USA: American Society of Heating Refrigerating and Air-Conditioning Engineers.
8. http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/meeting_summary_50675.pdf
   "Develop method for validation of software to ensure accuracy, credibility, and capability. -facilities -houses not occupants -lots of field data of occupied homes" [pg 20] "Validation of software. Standards for DOE recognition of audit software tools. Define accuracy. Accuracy, credibility and capability." [pg 22] "Develop protocols for assessing common errors" [pg 7];

2.4: In Situ Air Conditioner Performance

BA Enclosures		**BA Hot Water**	
Walls		Test Standards	
Roof/Ceiling		Distribution	
Foundations		Condensing/Tankless	
Moisture	x	Heat Pump Water Heater	
Windows		Combined Space and DHW Heating	
Other: ________________		Other:________________	
BA Space Conditioning		**BA Miscellaneous Loads**	
Heating		Home Energy Management	
Cooling	x	Lighting	
Dehumidification	x	Large MELs (pools, etc.)	
Distribution		Small MELs (TVs, VCRs, etc.)	
Ventilation		Other: ________________	
Other: ________________			
Testing Methods/Protocols		**BA Implementation**	
House Simulation Protocol	x	Quality Control / Quality Assurance	
Lab Test Methods		Training	
Field Test Methods	x	Documentation / Resources	
Analysis Methods/Tools		Needs Evaluation / Identification	
Analysis Tools	x	Other: ________________	
Strategic Analysis			
Other: ________________			

House Type	
New	
Existing	x
Single Family	x
Multi-Family	x
DOE Emerging Technologies	
Walls and Windows	
Efficient Appliances	
Advanced Heating and Cooling Fluids	
Solar Heating and Cooling	
Geothermal Heat Pumps	
Solid State Lighting	
Bulk Purchase	
Onsite Renewables (Building-Integrated Photovoltaic, onsite cogen)	
DOE Deployment	
Labeling/Rating	
Codes	
Standards	
Large Scale Retrofit (Better Buildings)	

Problem Statement:
The in situ performance of air conditioning equipment (for both central and wall units) is not well characterized and, as a result, it is difficult to confidently assess the benefits of retrofitting a house with newer air conditioning equipment. Without proper characterization, contractors and energy analysts may be overstating or understating the value of air conditioning retrofits, which could ultimately result in unnecessarily high costs to the homeowner or unrealized energy saving potential.

Most often, a Seasonal Energy Efficiency Ratio (SEER) is used to rate air conditioner performance. However, the rated SEER alone is not enough to characterize the full performance of air conditioners over a wide range of operating conditions. The actual performance depends on several factors, including:

- Steady-state efficiency
- Cycling losses (at part load)
- Installation quality
- Refrigerant line length
- Performance degradation (refrigerant charge loss, coil fouling, etc.)

The following two important research questions pertain to the in situ of air conditioners:

1. How can we best estimate the full range of performance parameters for air conditioners given a limited amount of information (e.g., climate, vintage, installation quality, name-plate information)?
2. How does air conditioner performance change over time and how can degradation be accurately modeled in simulations?

Key Customers and Stakeholders:
DOE Speed and Scale Programs (e.g. Better Buildings) – Accurate predictions of air conditioner performance will influence DOE programmatic decisions and are necessary to find the most cost-effective way to meet national energy saving targets.

Utilities – Accurate predictions of air conditioner performance will lead to suggesting more efficient replacement units which may reduce peak power demand.

Others (Air conditioner manufacturers, Energy retrofit contractors, Homeowners) - Accurate predictions of air conditioner performance will lead to suggesting appropriate, energy-saving, cost-effective retrofit measures.

Background Knowledge:
In general, air conditioning performance is difficult to describe. New air conditioners are rated based on the AHRI standard 210/240 definition of SEER, but this information was not standardized for much of the older equipment still found in homes. Air conditioner performance also varies significantly depending on the operating conditions of the equipment. Some manufacturers provide performance maps for new equipment (for the purpose of system sizing and selection), but this information is also not commonly available for older units.

The Building America House Simulation Protocols (HSP) currently describes a method (based on engineering judgment) to de-rate the Seasonal Energy Efficiency Ratio (SEER) of old equipment based on age and level of maintenance. However, the HSP does not describe the full range of inputs required to fully describe air conditioner performance, including all of the off-rated performance maps necessary to describe the full range of operation.

There are many factors that contribute to degradation of air conditioning system performance:

- Improper installation
- Over/undercharged refrigerant
- Incondensibles in refrigerant
- Wear and tear on the compressor
- Fouling of the heat exchangers

These factors are difficult to quantify for a specific system. There is a disconnect between the complexity of these problems encountered in the field and the simplicity of the models used to quantify the performance of the units they represent.

System Considerations:
In situ AC performance is also influenced by the performance of the air handler. Inefficiencies in the air handler can result in lower airflow over the evaporator and affect performance significantly.

There are several considerations that revolve around replacing an old AC, such as: downsizing the new equipment, replacing the air handler and furnace, and the effect replacement will have on meeting loads (improving capacity means the unit will be able to meet more of the load, and possibly use more energy).

Planned or Ongoing Research:
Ferris State University (BA) – FSU is under contract (through the CEER BA Team) to develop a standard test protocol for in situ performance testing of split-system AC units and perform tests on old air conditioners in the West Michigan area.

Field Diagnostic Services, Inc. (non-BA) – FDS has been monitoring systems and diagnosing problems in old residential air conditioners. They have a sizable database of system characteristics from around the United States.

Steven Winter Associates (BA) – SWA has developed a small EER test box that they have used on previous projects to measure the steady state EER of old air conditioners.

Davis Energy Group recently prepared a report for the Southern California Edison which evaluates the effectiveness of programmatic HVAC maintenance on the performance of systems[6]. This work is ongoing and looking specifically into providing a guideline for refrigerant charge and air flow issues.

It remains to be seen if data from these four efforts will be enough to provide a meaningful representation of the range of air conditioners encountered in the field.

There are several ongoing projects related to monitoring performance of current air conditioning equipment including: hybrid air-to-water heat pumps (ARBI), SEER 21 heat pumps (BA-PIRC), and mini-split heat pumps (BIRA).

"Closing the Gap":
Energy Analysis tools need to provide an accurate estimate of the performance of old air conditioning systems. From the modeling perspective, this means defining the as-used efficiency and performance maps of systems ranging in quality of installation, age, and level of maintenance.

The HSP should be updated to reflect a better understanding of in situ air conditioner performance. For a given installation, vintage, and maintenance level, the HSP should define typical:

- System efficiency (SEER, EER, COP, etc.)
- Cycling degradation
- Capacity degradation
- Performance maps
- Fan efficiency

As part of this process, sensitivity/uncertainty analysis should identify parameters (such as percent refrigerant charge, refrigerant line length, etc.) that have large impacts on simulation results and are not typically accounted for in simulation inputs. These identified parameters will inform what information is important to collect on the pre-retrofit HVAC system and what information should be defaulted based on best practice procedures (stated in the HSP).

Additionally, field measurement methods should be established to best capture the performance of specific units when necessary. This may include the need for improved tools for auditors to make simple yet meaningful measurements in the field related to air conditioner performance.

The accuracy of energy analyses after the HSP and analysis tools have been updated should be validated against field test data.

[6] Hunt, M., Heinemeier, K., Hoeschele, M., & Weitzel, E. (2010). HVAC Energy Efficiency Maintenance Study.

Timeline:
Mid-term.

Table 5: Cost-Value Matrix for "In Situ Air Conditioner Performance"

Value \ Cost	L	M	H
H		X	
M			
L			

2.5: In Situ Water Heater Performance

BA Enclosures		BA Hot Water	
Walls		Test Standards	
Roof/Ceiling		Distribution	
Foundations		Condensing/Tankless	x
Moisture		Heat Pump Water Heater	
Windows		Combined Space and DHW Heating	
Other: ___________________		Other: Tank Water Heaters	x
BA Space Conditioning		**BA Miscellaneous Loads**	
Heating		Home Energy Management	
Cooling		Lighting	
Dehumidification		Large MELs (pools, etc.)	
Distribution		Small MELs (TVs, VCRs, etc.)	
Ventilation		Other: ___________________	
Other: ___________________			
Testing Methods/Protocols		**BA Implementation**	
House Simulation Protocol	x	Quality Control / Quality Assurance	
Lab Test Methods		Training	
Field Test Methods	x	Documentation / Resources	
Analysis Methods/Tools		Needs Evaluation / Identification	
Analysis Tools	x	Other: ___________________	
Strategic Analysis			
Other: ___________________			

House Type	
New	x
Existing	x
Single Family	x
Multi-Family	x
DOE Emerging Technologies	
Walls and Windows	
Efficient Appliances	
Advanced Heating and Cooling Fluids	
Solar Heating and Cooling	
Geothermal Heat Pumps	
Solid State Lighting	
Bulk Purchase	
Onsite Renewables (Building-Integrated Photovoltaic, onsite cogen)	
DOE Deployment	
Labeling/Rating	
Codes	
Standards	
Large Scale Retrofit (Better Buildings)	

Problem Statement:
The in situ performance of water heaters is not well characterized and, as a result, it is difficult to confidently assess the benefits of retrofitting a house with newer water heaters. Without proper characterization, contractors and energy analysts may be overstating or understating the value of water heater retrofits, which could ultimately result in unnecessarily high costs to the homeowner or unrealized energy saving potential.

Most often, an Energy Factor (EF) is used to rate water heater performance. However, the EF alone is not enough to characterize the performance of water heaters over a wide range of operating conditions. The actual performance depends on several factors, including:

- Steady-state burner efficiency
- Tank insulation levels
- Controls
- Part-load performance
- Pilot light consumption
- Auxiliary electric consumption

The following two important research questions pertain to the in situ performance of water heaters:

1. How can we best estimate the full range of performance parameters for water heaters given a limited amount of information (e.g., climate, vintage, fuel type, name-plate information)?
2. How does water heater performance change over time and how can degradation be accurately modeled in simulations?

Key Customers and Stakeholders:
DOE Speed and Scale Programs (e.g. Better Buildings) – Accurate predictions of water heater performance will influence DOE programmatic decisions and are necessary to find the most cost-effective way to meet national energy saving targets.

Others (Water Heater manufacturers, Energy retrofit contractors, Homeowners) - Accurate predictions of water heater performance will lead to suggesting appropriate, energy-saving, cost-effective solutions.

Background Knowledge:
The current Building America House Simulation Protocols (HSP) describes a method (based on a single reference and engineering judgment) to de-rate the EF of water heaters based on age and level of maintenance. The HSP also relies on the EF as the only metric for performance and does not describe the full set of performance metrics for water heaters, such as recovery efficiency, tank insulation, draft-type, pilot light consumption, or draft fan efficiency. There are a couple of factors that may contribute to degraded performance of water heaters:

- Incomplete fuel combustion – either inadequate combustion air supply or inadequate fuel supply.
- Fouling/scaling of the burner – particularly relevant for tankless water heaters.

A good resource for information on water heaters is the following Technical Support Document provided by DOE:

http://www1.eere.energy.gov/buildings/appliance_standards/residential/waterheat_0300_r.html

System Considerations:
The characterization of the hot water distribution system will also influence the predicted hot water energy use of an older water heater.

Planned or Ongoing Research:
WAP – DOE's Weatherization Assistance Program has performed steady-state efficiency tests on a large number of water heaters. These results should be reviewed further to better understand degradation of water heater performance.

There are several ongoing projects related to monitoring performance of heat pump water heaters (ARBI, CARB).

"Closing the Gap":
Energy Analysis tools need to provide an accurate estimate of the in situ performance of water heaters. From the modeling perspective, this means defining the as-used performance of water heaters ranging in age and level of maintenance.

A survey of installed equipment could be conducted to better understand the causes and effects of water heater performance degradation under different maintenance scenarios.

The HSP could be updated to reflect a better understanding of in situ water heater performance. For a given vintage and maintenance level, the HSP could define typical:

- System efficiency (EF, recovery efficiency)
- Tank insulation
- Draft fan power
- Pilot light consumption.

As part of this process, sensitivity/uncertainty analysis should identify parameters (such as burner scaling and air-to-fuel ratio) that have large impacts on simulation results and are not typically accounted for in simulation models. These identified parameters will inform what information is important to collect on the pre-retrofit water heater system and what information should be defaulted based on best practice procedures (stated in the HSP).

The accuracy of energy analyses after the HSP and analysis tools have been updated can be validated against field test data.

Timeline:
Mid-Term.

Table 6: Cost-Value Matrix for "In Situ Water Heater Performance"

Value \ Cost	L	M	H
H			
M		X	
L			

2.6: High Efficiency Air-Conditioners and Heat Pumps

BA Enclosures		BA Hot Water	
Walls		Test Standards	
Roof/Ceiling		Distribution	
Foundations		Condensing/Tankless	
Moisture		Heat Pump Water Heater	
Windows		Combined Space and DHW Heating	
Other: ___________________		Other:___________________	
BA Space Conditioning		**BA Miscellaneous Loads**	
Heating	x	Home Energy Management	
Cooling	x	Lighting	
Dehumidification	x	Large MELs (pools, etc.)	
Distribution		Small MELs (TVs, VCRs, etc.)	
Ventilation		Other: ___________________	
Other: ___________________			
Testing Methods/Protocols		**BA Implementation**	
House Simulation Protocol	x	Quality Control / Quality Assurance	
Lab Test Methods		Training	
Field Test Methods		Documentation / Resources	
Analysis Methods/Tools		Needs Evaluation / Identification	
Analysis Tools	x	Other: ___________________	
Strategic Analysis			
Other: ___________________			

House Type	
New	
Existing	x
Single Family	x
Multi-Family	x
DOE Emerging Technologies	
Walls and Windows	
Efficient Appliances	
Advanced Heating and Cooling Fluids	
Solar Heating and Cooling	
Geothermal Heat Pumps	
Solid State Lighting	
Bulk Purchase	
Onsite Renewables (Building-Integrated Photovoltaic, onsite cogen)	
DOE Deployment	
Labeling/Rating	
Codes	
Standards	
Large Scale Retrofit (Better Buildings)	

Problem Statement:
As new, high efficiency vapor compression heating and cooling equipment enters the market, it is important to continually update and advance air-conditioner and heat pump modeling approaches and capabilities. The energy savings potential of high efficiency vapor compression cooling equipment cannot be accurately predicted without accurate, performance-based models. Additionally, it is important that users can easily enter specific air-conditioners into building simulation software (such as BEopt) in order to compare specific manufactured units not included in built-in component libraries.

The highest Seasonal Energy Efficiency Ratio (SEER) air-conditioning equipment available on the market incorporates variable speed technologies. Both mini-split heat pumps (MSHPs) and variable-speed central systems are examples of market-available high SEER cooling equipment. Building simulation tools' ability to accurately simulate MSHPs is unknown and research is needed to determine if current air-conditioner models can be applied to MSHP technologies.

Key Customers and Stakeholders:
DOE Speed and Scale Programs (e.g. Better Buildings) – Accurate predictions of air conditioner performance will influence DOE programmatic decisions and are necessary to find the most cost-effective way to meet national energy saving targets.

Utilities – Accurate predictions of air conditioner performance will lead to suggesting more efficient replacement units which may reduce peak power demand.

Others (Air conditioner manufacturers, Energy retrofit contractors, Homeowners) - Accurate predictions of air conditioner performance will lead to suggesting appropriate, energy-saving, cost-effective solutions.

Background Knowledge:
Current fixed-speed air-conditioner performance varies significantly with operating conditions (specifically indoor and outdoor temperatures). Manufacturers of single and two stage air-conditioners provide performance maps over a range of operating conditions that can be used to develop performance-based models for building simulation tools. Single stage air-conditioners cycle on and off to meet building cooling loads, whereas two stage air-conditioners can run at a reduced capacity to meet lower loads. Manufacturers of two stage air-conditioners typically provide performance data for both first and second stage operation.

Variable-speed air-conditioners adjust the compressor speed to meet the cooling load without cycling on and off. Thus, in addition to indoor and outdoor temperatures, the system performance is dependent on the compressor speed (or cooling load). Manufacturers typically do not publish performance data for an adequate number of speeds, making it impossible to develop accurate performance-based models. NREL recently published laboratory test results for two MSHPs that can potentially be used to develop MSHP performance-based models[7]. BA-PIRC published a report on the performance of SEER 21 variable-speed heat pump in December 2011[8] that can potentially be used to aid in the development of a variable-speed heat pump model.

MSHPs are typically installed to meet the cooling and heating loads for a single room, space, or zone using one or several indoor heat exchangers. They are available at smaller capacities than typical forced air, split systems, making them potential solutions for high efficiency, low load homes. The zone control capabilities of MSHPs may lead to additional energy savings over forced air systems. Single zone building models may not allow for accurate modeling of zoned MSHP systems.

System Considerations:
MSHPs are point-source heating and cooling devices and do not condition the entire house in the same way as a typical forced air system. The way occupants operate MSHPs and their effect on thermal comfort is largely unknown.

The installation of a high-efficiency split air-conditioner may require modifications to the existing duct system. If the high-efficiency system is being installed in an attic, opportunities may exist to improve the duct system. Furthermore, as higher efficiency systems are installed in homes, it will be important to understand the impact those systems have on moisture levels.

Planned or Ongoing Research:
Building America teams are planning to research various issues associated with high efficiency air-conditioners and heat pumps. Fraunhofer CSE is investigating thermal comfort and cooling and heating performance of two

[7] Winkler, J. (2011). Laboratory Test Report for Fujitsu 12RLS and Mitsubishi FE12NA Mini-Split Heat Pumps. NREL: Golden, CO.
[8] Cummings, J. and Withers, C. (2011). Energy Savings and Peak Demand Reduction of a SEER 21 Heat Pump vs. a SEER 13 Heat Pump with Attic and Indoor Duct Systems. BA-PIRC and FSEC: Cocoa, FL.

MSHP configurations in two climates. BA-PIRC plans on continuing their study on the performance of high-efficiency, variable-speed heat pump.

Oak Ridge National Lab is currently field monitoring several MSHPs.

NREL recently revised the BEopt air-conditioner and heat pump models using updated manufacturer's data. The updated performance curves will improve the consistency in predicted energy usage across different SEER levels, and the revised category structure will allow users to easily add new air-conditioner options into the BEopt library. NREL has included centrally-ducted, variable speed air-conditioner and heat pump options into BEopt using suitable data from a single manufacturer. Ideally, performance data for variable-speed units from various manufacturers would be used to develop a generalized set of BEopt inputs.

The MSHP test data recently published by NREL[6] was attained through a subcontract with Purdue University. Two MSHPs have been tested and three more will be tested by fall 2012. In total, five MSHPs will be experimentally performance mapped. NREL has also acquired detailed MSHP field test data through Ecotope Inc. from the Northwest Energy Efficiency Alliance (NEEA) and Bonneville Power Authority (BPA) for approximately 100 homes located throughout the Pacific Northwest.

BA-PIRC is working with NEEA and BPA to monitor 10 additional homes containing electric forced-air furnaces retrofit with ductless MSHPs.

NEEA is currently collecting utility bill data for nearly 4,000 homes with MSHPs. This data might help with model validation but the usefulness of this data in meeting this particular gap is unknown.

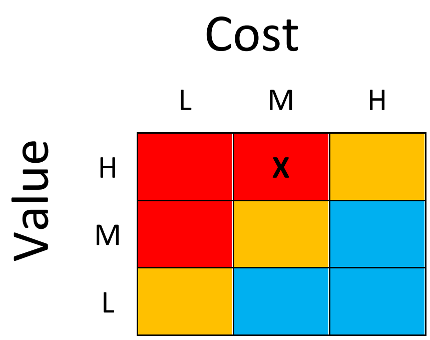
"Closing the Gap":
Energy analysis tools should accurately predict the performance of high efficiency air-conditioning and heat pump systems.

Four main issues need to be resolved prior to accurately modeling MSHP systems:

1. Experimental performance data:
    a. Currently, manufacturer-provided data for variable speed equipment are not suitable for developing accurate performance-based models.
    b. Field testing is unlikely to cover the necessary range of operating conditions for model development; thus laboratory testing is needed.
    c. It is important to test a variety of systems to accurately represent the market landscape.
2. Component modeling: Can current building simulation tool air-conditioner models be extended to MSHP systems? If so, how accurately can MSHP systems be modeled using current approaches?
3. Point-source heating and cooling: Can/should MSHP systems be modeled using a single living zone building model?
4. Operation: How are MSHPs operated by occupants?

Timeline:
Mid-term.

Table 7: Cost-Value Matrix for "High Efficiency Conditioners and Heat Pumps"



Resolution (partial):

As noted in the "Planned and Ongoing Research" section, in January of 2012 BEopt air-conditioner and heat pump models were updated using updated manufacturer's data. The updated performance curves will improve the consistency in predicted energy usage across different SEER levels, and the revised category structure will allow users to easily add new air-conditioner options into the BEopt library. NREL has included centrally-ducted, variable speed air-conditioner and heat pump options into BEopt using suitable data from a single manufacturer.

2.7: Wall Cavities

BA Enclosures		BA Hot Water	
Walls	X	Test Standards	
Roof/Ceiling		Distribution	
Foundations		Condensing/Tankless	
Moisture		Heat Pump Water Heater	
Windows		Combined Space and DHW Heating	
Other: ___________________		Other:___________________	
BA Space Conditioning		**BA Miscellaneous Loads**	
Heating	X	Home Energy Management	
Cooling	X	Lighting	
Dehumidification		Large MELs (pools, etc.)	
Distribution		Small MELs (TVs, VCRs, etc.)	
Ventilation		Other: ___________________	
Other: ___________________			
Testing Methods/Protocols		**BA Implementation**	
House Simulation Protocol		Quality Control / Quality Assurance	
Lab Test Methods		Training	
Field Test Methods		Documentation / Resources	
Analysis Methods/Tools		Needs Evaluation / Identification	
Analysis Tools	X	Other: ___________________	
Strategic Analysis			
Other: ___________________			

House Type	
New	
Existing	X
Single Family	
Multi-Family	
DOE Emerging Technologies	
Walls and Windows	
Efficient Appliances	
Advanced Heating and Cooling Fluids	
Solar Heating and Cooling	
Geothermal Heat Pumps	
Solid State Lighting	
Bulk Purchase	
Onsite Renewables (Building-Integrated Photovoltaic, onsite cogen)	
DOE Deployment	
Labeling/Rating	
Codes	
Standards	
Large Scale Retrofit (Better Buildings)	

Problem Statement:
Some analysts believe that uninsulated wall assemblies perform better than predicted by current building energy simulation models. Uninsulated wall assemblies are typical in older homes, as many were built before building codes required insulation. Most whole-building energy simulation tools currently use simplified, 1-D characterizations of building envelopes and assume a fixed thermal resistance of the assembly that does not vary over a building's temperature range. Most tools also neglect both moisture transfer and the interaction of wall heat transfer with air infiltration. This may lead to inaccuracies in building energy use predictions. Building engineers need to understand the thermal performance of these assemblies as they consider home energy upgrades if they are to properly predict pre-upgrade performance and, consequently, prospective energy savings from the upgrade. Addressing this issue has the potential to improve the accuracy of building energy simulation tools applied to older homes.

Key Customers and Stakeholders:
Software Developers: Implement modeling improvements and would benefit from more accurate predictions.

Retrofit Contractors: Upgrade empty cavity walls and would benefit from more accurate predictions of energy use and savings for wall insulation retrofit measures.

Insulation Manufacturers: Produce wall insulation retrofit products and would benefit from accurate modeling of products relative to other energy efficiency measures.

Homeowners: Purchase wall insulation upgrades and would benefit from more accurate software recommendations.

Background Knowledge:
A brief literature review on uninsulated wall assemblies is described in the following paragraphs:

Researchers at the NRCC performed experimental studies evaluating the thermal performance of wood-framed walls with empty and partially filled cavities (Handegord and Huntcheon, 1952; Rousseau and Brown, 1995). Data was provided in terms of temperature profiles, heat flux along the wall, and thermal resistance of the assembly for a fixed or a limited number of indoor and outdoor conditions. The operating conditions considered were not sufficiently diverse to show the applicable range of thermal resistance trends.

Calibrated hot box tests of uninsulated masonry wall cavities were conducted at ORNL by Van Geem (1984). These tests provided data on the heat transmission characteristics of full-sized wall assemblies under steady-state and dynamic temperature conditions. Limited operating conditions were tested and the data presented can be used to validate numerical models. Park et al. (1986) focused on building enclosures and performed 2-D, finite difference simulations to investigate the heat transfer through a standard residential uninsulated stud wall structure. Indoor and outdoor air temperatures were fixed at 294 K (70°F) and 300 K (80°F), respectively. The results showed that thermal radiation is an important transport mechanism in uninsulated walls, even with modest temperature differences: adding a reflective layer (foil liner) on one inner surface of the cavity reduced the predicted heat transfer by 50%. Calculated heat transfer rates through the wall were within 3% of the values published in the 1977 ASHRAE Handbook of Fundamentals.

ASHRAE (2009) provides a table (Table 3, Chapter 26) listing thermal resistance values for enclosed air spaces under various conditions, depending on cavity surface emissivity. These values are for well-sealed cavities and selected combinations of mean temperatures and temperature differences. Most of the presented temperature combinations do not represent a typical building's operating conditions. For uninsulated 2 × 4 walls, the table shows slight variations in cavity resistance with the mean temperature and temperature difference.

Ridouane and Bianchi (2011) developed 2D and 3D computational fluid dynamics (CFD) models for evaluating the thermal performance of well-sealed, uninsulated walls in existing homes. In this recent study, variable material properties (such as the density and thermal conductivity of wood and air) were found to have a significant impact on the thermal resistance of the assembly. The assumption of *constant* properties resulted in up to a 5.4% over-prediction of heat flux for colder ambient temperatures (0°F). The constant value of conductance used in EnergyPlus resulted in an over-prediction of 6.5% at 0°F. Three-dimensional flow structures induced by the wood framing elements were identified, but they led to only minor differences from 2D predictions of the total heat flux through the wall. This indicates that a 2D model with variable material properties may be sufficient to improve the prediction of the thermal resistance of uninsulated wall assemblies.

The literature review uncovered a potential source of inaccuracy in determining the thermal resistance of uninsulated cavities. Further examination and consolidation of data from Europe is needed. Data for steel-framed walls with empty cavities may also be needed.

System Considerations:

- The performance of uninsulated wall assemblies is directly related to infiltration heat recovery.
- Inaccurate modeling of uninsulated wall assemblies can lead to incorrect equipment sizing.
- Other considerations that revolve around envelope performance include: thermal comfort, acoustics, and fire safety.
- Furniture, wall hangings, cabinets, and closets provide additional insulation for exterior surfaces that usually is not accounted for in building models, and this effect could be significant for homes with empty cavity walls.

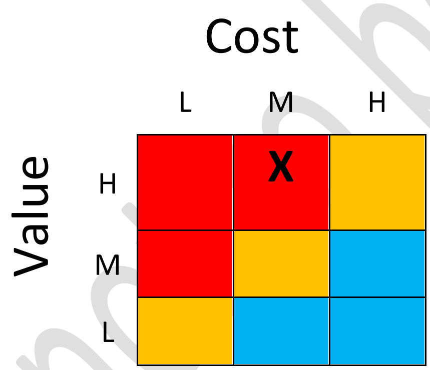
Planned or Ongoing Research:
No planned or ongoing research projects were identified.
"Closing the Gap":
Goal: Identify models that accurately predict heat and moisture transfer through uninsulated cavities and implement the model output into BES programs. Guarded hot box testing such as the capabilities available at Fraunhofer and ORNL may be used to test uninsulated wall assemblies and verify the numerical models.

Future work could include the use of model results to develop correlations that can be used in building energy simulation tools and modifying models to address air infiltration and moisture transfer through the uninsulated assemblies.

Achievement Criteria: A specified level of agreement between building energy simulation model predictions, predictions using detailed CFD models, and laboratory/field test measurements of heat and moisture transfer through uninsulated wall assemblies.

Timeline:
Mid-term.

Table 8: Cost-Value Matrix for "Empty Cavity Walls"



References:

ASHRAE. 2009. ASHRAE Fundamentals Handbook. Atlanta: American Society of Heating Refrigeration and Air-Conditioning Engineers, Inc.

Handegord, G.O., and Huntcheon, N.B. 1952. Thermal Performance of Frame Walls. Reprint of a paper presented at the 58th Annual Meeting of the American Society of Heating and Ventilating Engineers, January 28-30.

Park, J.E., Kirkpatrick, J.R., et al. 1986. Calculation of Heat Flux through a Wall Containing a Cavity: Comparison of Several Models. Oak Ridge Gaseous Diffusion Plant, TN, DE86010348.

Ridouane, E.H., and Bianchi, M.V.A. 2011. 3D Numerical Evaluation of Thermal Performance of Uninsulated Wall Assemblies. Accepted for Publication. Proceedings of the ASME 2011 International Mechanical Engineering Congress & Exposition, Denver, CO: November 11-17.

Rousseau, M.Z., and Brown, W.C. 1995. Research Update on Heat, Air and Moisture Flows in Exterior Walls. NRCC-48645.

Van Geem, M.G. 1984. Calibrated Hot Box Test Results, Data Manual – Volume 1. ORNL/SUB/79-42539/4.

2.8: Multi-family Window-to-Wall Ratio

BA Enclosures		BA Hot Water	
Walls		Test Standards	
Roof/Ceiling		Distribution	
Foundations		Condensing/Tankless	
Moisture		Heat Pump Water Heater	
Windows		Combined Space and DHW Heating	
Other: __________________		Other:__________________	
BA Space Conditioning		**BA Miscellaneous Loads**	
Heating		Home Energy Management	
Cooling		Lighting	
Dehumidification		Large MELs (pools, etc.)	
Distribution		Small MELs (TVs, VCRs, etc.)	
Ventilation		Other: __________________	
Other: __________________			
Testing Methods/Protocols		**BA Implementation**	
House Simulation Protocol	x	Quality Control / Quality Assurance	
Lab Test Methods		Training	
Field Test Methods		Documentation / Resources	
Analysis Methods/Tools		Needs Evaluation / Identification	
Analysis Tools	x	Other: __________________	
Strategic Analysis			
Other: __________________			

House Type	
New	x
Existing	
Single Family	
Multi-Family	x
DOE Emerging Technologies	
Walls and Windows	
Efficient Appliances	
Advanced Heating and Cooling Fluids	
Solar Heating and Cooling	
Geothermal Heat Pumps	
Solid State Lighting	
Bulk Purchase	
Onsite Renewables (Building-Integrated Photovoltaic, onsite cogen)	
DOE Deployment	
Labeling/Rating	
Codes	
Standards	
Large Scale Retrofit (Better Buildings)	

Problem Statement:
More real world data is needed on typical window areas of multi-family buildings. The B10 Benchmark definition set by the Building America House Simulation Protocols (HSP) specifies a window-to-total-exterior-wall ratios (WWR) of 0.15 for single family housing (includes duplexes and townhomes) and 0.30 for "multi-family" housing, which is defined by the HSP as a building with three or fewer stories and at least five housing units, each of which must share at least a floor or ceiling with another unit. These values may be unrealistic considering that there is a spectrum of housing types (duplexes, townhomes) rather than a distinct line between single family and multi-family housing. The ambiguity could lead to confusion or inconsistencies in the use of the Benchmark.

Key Customers and Stakeholders:
Building America teams, homeowners, and contractors benefit from having a good benchmark that represents typical new construction circa 2010.

Background Knowledge:
While the 0.15 WWR for benchmark single family homes is based on the International Energy Conservation Code (IECC) 2009, the 0.30 WWR for benchmark multi-family buildings was derived from an interpretation of NREL's Commercial Benchmark (2009) for mid-rise apartment buildings. The 0.30 WWR is not necessarily representative of the full spectrum of multi-family buildings; in some cases, there is a fine line between attached single family and multi-family buildings. In general, a more detailed WWR calculation method based on real world data is needed.

Another approach would be to specify a window to floor area ratio (WFR), such as the 8% minimum specified by the International Building Code (Section 1205.2). The Building America Benchmark formerly used WFR to determine window area, but required modifications for attached walls (e.g. garage) and did not handle various wall heights and aspect ratios very well. However, using WFR may be more appropriate for multi-family buildings. Since the WFR is based on *habitable* floor area, it requires additional input information (floor area for hallways, closets, etc.) that is currently not collected by BEopt.

A third approach would be to have the benchmark building use the prototype window area, but impose a maximum cutoff WWR or WFR. This is similar to the prescribed maximum 0.50 WWR approach used by ASHRAE 90.1.

Another point of reference is the HERS rating system, which specifies a WFR of 18% for the reference building used in determining a home's HERS rating.

System Considerations:
This gap/barrier is related to the effort to add multi-family modeling to BEopt; the benchmark window area calculation must be able to be easily implemented in BEopt. It is also related to the need for better characterization of the U.S. housing stock.

Planned or Ongoing Research:
CARB: In May 2011, CARB published a Building America Technical Report "Window to Wall Ratios for Attached and Multi-Family Housing" that surveyed 30 unique plans of various attached housing types (duplexes, townhomes, and multi-family buildings) in the Mid-Atlantic and Northeast region and suggested revising the WWRs for the B12 Benchmark. The report acknowledged that it looked at a limited sample of plans and that further research would be necessary to establish trends. Specifically, data is needed for attached and multi-family buildings from other regions of the United States.

The suggested WWR specifications from CARB's report are listed below. Although the results of this study were conclusive, a deeper analysis of multi-family building styles may reveal other trends that could not be investigated in this limited study.

CARB suggested that the window areas specified should use the following equations:

For duplexes, townhome end units, and multifamily garden apartments:

$$A_{windows} = 0.15 \times A_{ExteriorWalls}$$

For townhome middle units:

$$A_{windows} = 0.18 \times A_{ExteriorWalls}$$

For multi-family urban low-rise units:

$$A_{windows} = 0.25 \times A_{ExteriorWalls}$$

CARB provided two separate multipliers depending on a housing type characterization as a garden apartment or an urban low-rise unit. CARB has proposed to evaluate 20 additional multi-family site plans in the Mid-Atlantic and Northeast region, to validate a single equation for the WWR of all multifamily buildings:

$$A_{windows} = ((-0.33 \times A_{EWFR}) + 0.31) \times A_{ExteriorWalls}$$

where A_{EWFR} = total exterior wall area (ft^2)/ total floor area (ft^2).

NorthernSTAR: A state-funded multi-family characterization project in Minnesota will be completed over the next 18 months (2012 to mid 2013).

BA-PIRC is working on a project with Orlando Utilities Commission where MF WWR could be collected for five apartment complexes. They will also have a project analyzing multifamily upgrades under Florida's Weatherization Assistance Program.

BSC and Southface (NAHB) also have multi-family projects underway.

"Closing the Gap":
1. Building America teams will deliver data on a representative sample of real world multi-family buildings. At the least, 12 buildings (new or recently constructed) in each of the remaining three U.S. Census Bureau regions (Midwest, South, West) are needed to determine if the trended notes in CARB's report carry over to those regions. NREL will send a form with the desired information out to the BA teams. The form will specify what information is needed and from which types of homes.

2. The goal is to characterize window-to-exterior-wall ratios (WWR) for multi-family buildings, including townhomes and duplexes, so that the ratios specified by the Building America Benchmark will be more realistic.

3. As the HSP is a consensus-based document, any changes made by NREL will be approved by technical leaders from Building America teams and National Laboratories.

Timeline:
Short-term.

Table 9: Cost-Value Matrix for "Multi-family Window-to-Wall Ratio"

Value \ Cost	L	M	H
H			
M		X	
L			

2.9: Ground Source Heat Pumps

BA Enclosures		**BA Hot Water**	
Walls		Test Standards	
Roof/Ceiling		Distribution	
Foundations		Condensing/Tankless	
Moisture		Heat Pump Water Heater	
Windows		Combined Space and DHW Heating	
Other: ___________________		Other: Desuperheater	x
BA Space Conditioning		**BA Miscellaneous Loads**	
Heating	x	Home Energy Management	
Cooling	x	Lighting	
Dehumidification		Large MELs (pools, etc.)	
Distribution		Small MELs (TVs, VCRs, etc.)	
Ventilation		Other: ___________________	
Other: ___________________			
Testing Methods/Protocols		**BA Implementation**	
House Simulation Protocol		Quality Control / Quality Assurance	
Lab Test Methods		Training	
Field Test Methods	x	Documentation / Resources	
Analysis Methods/Tools		Needs Evaluation / Identification	
Analysis Tools	x	Other: ___________________	
Strategic Analysis	x		
Other: ___________________			

House Type	
New	
Existing	x
Single Family	x
Multi-Family	x
DOE Emerging Technologies	
Walls and Windows	
Efficient Appliances	
Advanced Heating and Cooling Fluids	
Solar Heating and Cooling	
Geothermal Heat Pumps	x
Solid State Lighting	
Bulk Purchase	
Onsite Renewables (Building-Integrated Photovoltaic, onsite cogen)	
DOE Deployment	
Labeling/Rating	
Codes	
Standards	
Large Scale Retrofit (Better Buildings)	

Problem Statement:
There are several limitations on ground source heat pump (GSHP) modeling capabilities in existing software tools. In DOE-2, there have been concerns that the horizontal trench (slinky loops) model results in daily/monthly temperature swings similar to vertical bore heat exchangers, causing over-prediction of energy savings for the horizontal trench. However, some BA teams' past modeling and calibration work showed matching results for the horizontal trench. [1] In EnergyPlus, neither horizontal trench nor domestic hot water desuperheaters can be modeled.

Both DOE-2 and EnergyPlus have algorithms to model vertical bore ground heat exchangers. The biggest known modeling issue, however, is related to EER/COP user inputs. Using manufacturer published EER/COP at rated conditions (AHRI/ASHRAE ISO 13256-1) does not properly address the in situ fan and pump operating energy consumption. Additionally, while there has been a considerable amount of GSHP modeling and installation work conducted on both residential and commercial buildings, a literature search indicated minimal detailed measurement and verification (M&V) follow-up.

Key Customers and Stakeholders:
Building Science Community – Proper modeling, design, commissioning, monitoring, and analysis
Homeowners – Making the right decision, understanding energy, cost and environmental impacts
Manufacturers – General interest in understanding comparisons between technologies
Utilities – Deployment on a territory or community scale
Policy Makers – National level policy making for GSHPs

Background Knowledge:
GSHP products normally come with a cooling EER in the range of 15-25 and a heating COP of 4.0-5.0, but their performance varies across different operating conditions. Manufacturers publish GSHP performance maps over a wide range of entering water temperatures and air wet bulb temperatures. However, local installed conditions such as soil conductivity, soil diffusivity, ground heat exchanger size, bore grout conductivity, and pump size all affect GSHP energy consumption.

Generally speaking, it should be expected that the operating parameters on outdoor pump and indoor fan can vary significantly from AHRI/ASHRAE/ISO 13256-1 certified performance testing. Multiple continuous field monitoring studies conducted in Germany and US sites indicated field average COPs from 3.4-3.8.[2,3,4,5,6] DOE-2 and EnergyPlus both count the indoor fan and ground loop pump energy separately, but the manufacturer rated cooling EER and heating COP come bundled with fan and pump power at zero external pressure drops. [7] Simply inputting the manufacturer rated EER/COP without proper adjustment can result in inaccurate GSHP energy consumption. RESNET recently adopted new amendments on Auxiliary Electric Energy of Ground Source Heat Pumps.[8]

There has been some monitoring on GSHP installations to understand GSHP systems performance against their rated performance in terms of COP comparisons and ground entering water temperature comparisons. [5,6] However, the majority of the GSHP modeling work has been on the design phase, without much detailed M&V following the installation to validate the energy models.

Similar to other air conditioning equipment, there are GSHP modeling issues related to understanding cycling, capacity and efficiency degradation, and performance maps. GSHP performance degradation can become more significant in unbalanced climates.

Horizontal trench heat exchanger modeling algorithms need to be added in DOE-2 and EnergyPlus. A desuperheater option needs to be added in EnergyPlus. GSHP options need to be included with other technologies in objective cost/value evaluations.

System Considerations:
Properly understanding GSHP performance and cost effectiveness is important in residential buildings research. This is necessary to identify optimal space conditioning and domestic hot water systems in whole-building energy analysis. Additionally, emerging foundation GSHP systems closely interact with building foundations, so additional modeling capabilities may be needed to properly account for this interaction.

Planned or Ongoing Research:
Many BA teams (DEG, BSC, CARB [6], NAHB, BA-PIRC, IBACOS, FSEC[9]) and ORNL[5] have been and are performing continuous monitoring, modeling, and data gathering of existing GSHP installations.

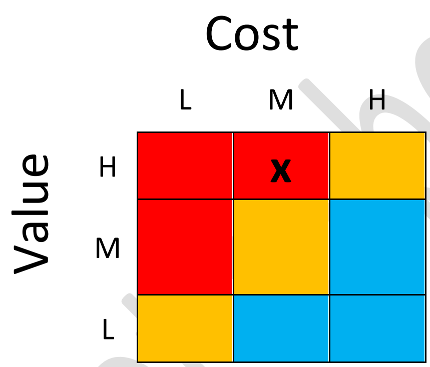
NREL has added GSHP options in BEopt 1.2. Closed loop vertical bore field is autosized in BEopt 1.2 according to *IGSHPA Design and Installation Guide* [10], taking into account soil and grout thermal conductivities, system EER/COPs, and climate peak conditions and annual ground load unbalance. With this capability, these GSHP technologies can be evaluated objectively and documented against other HVAC technologies in terms of cost/energy savings metrics. An area requiring further research is the proper modeling of two-stage ground source heat pump operation in building simulation tools.

EnergyPlus teams are working on implementing horizontal trench and desuperheater options for GSHP systems.

“Closing the Gap”:
The gap will be closed when the above-identified issues are resolved. Metrics for identifying achievement of this gap/barrier include inclusion of default GSHP options in BA analysis tools such as BEopt and demonstration of agreement within a particular level of accuracy between predicted and measured energy usages for GSHP systems.

Timeline:
Although modeling capabilities will be added to EnergyPlus and BEopt in the short-term, the timeline for the overall gap/barrier (including verification and validation of model predictions) is long-term.

Table 10: Cost-Value Matrix for “Ground Source Heat Pumps”



Resolution (partial):
As noted in the “Planned or Ongoing Research” section, GSHP options were added with the release of BEopt 1.2 in January, 2012. Language in the original draft of this gap summary, noting the need for BEopt GSHP options, has been deleted.

References:

1. Davis Energy Group, Inc. Calibration of the DOE-2.2 Ground-Coupled Heat Pump Model With Monitored Data, Report for PG&E GeoExchange project task 2.3, May 1999
2. Norton, P., et al. The Hathaway “Solar Patriot” House: A Case Study in Efficiency and Renewable Energy. *NREL/TP-550-37731*, May 2005.
3. Hendron, R., et al. Field Evaluation of a Near Zero Energy Home in Oklahoma. *Proceedings of Energy Sustainability Conference*, June 2007.
4. Analysis and Evaluation of Heat-Pump Efficiency in Real-Life Conditions, Marek Miara et. al. Fraunhofer Institute for Solar Energy Systems, ISE, August 2011.
5. ZEBRALLIANCE Ground Source Heat Pumps, Jeffrey D. Munk, Dr. et. al. Presented at BA Summit, July 2010
6. Residential Ground-Source Heat Pumps: In-Field System Performance and Energy Modeling, Srikanth Puttagunta et.al. GRC Transactions, Vol. 34, 2010
7. ASHRAE ISO Standard 13256-1: 1998, Water-source heat pumps – testing and rating for performance- Part 1: water to air and brine to air heat pumps, 1998
8. RESNET Amendment: Auxiliary Electric Energy of Ground Source Heat Pumps, Section 303.5 and 303.7, 2011

9. Performance of Four Near Zero Energy Homes, Lessons Learned, Sherwin J. et. al. FSEC PF 452-10, December, 2010
10. Ground Source Heat Pump Residential and Light Commercial, Design and Installation Guide, International Ground Source Heat Pump Association, Oklahoma State University, 2009

2.10: Heat Pump Water Heaters

BA Enclosures		**BA Hot Water**	
Walls		Test Standards	
Roof/Ceiling		Distribution	
Foundations		Condensing/Tankless	
Moisture		Heat Pump Water Heater	x
Windows		Combined Space and DHW Heating	
Other: __________________		Other:__________________	
BA Space Conditioning		**BA Miscellaneous Loads**	
Heating		Home Energy Management	
Cooling		Lighting	
Dehumidification		Large MELs (pools, etc.)	
Distribution		Small MELs (TVs, VCRs, etc.)	
Ventilation		Other: __________________	
Other: __________________			
Testing Methods/Protocols		**BA Implementation**	
House Simulation Protocol		Quality Control / Quality Assurance	
Lab Test Methods		Training	
Field Test Methods		Documentation / Resources	
Analysis Methods/Tools		Needs Evaluation / Identification	
Analysis Tools	x	Other: __________________	
Strategic Analysis			
Other: __________________			

House Type	
New	x
Existing	x
Single Family	x
Multi-Family	x
DOE Emerging Technologies	
Walls and Windows	
Efficient Appliances	
Advanced Heating and Cooling Fluids	
Solar Heating and Cooling	
Geothermal Heat Pumps	
Solid State Lighting	
Bulk Purchase	
Onsite Renewables (Building-Integrated Photovoltaic, onsite cogen)	
DOE Deployment	
Labeling/Rating	
Codes	
Standards	
Large Scale Retrofit (Better Buildings)	

Problem Statement:
Integrated Heat Pump Water Heaters (HPWHs) are rapidly entering the mainstream market after being introduced by major manufacturers. With energy factors (EFs) upwards of 2.0, HPWHs promise to significantly reduce energy consumption for domestic hot water over standard electric resistance water heaters. However, it is important to account for the cooling effect that HPWHs provide when located in conditioned space, as this is a benefit in warmer climates and a detriment in cooler climates. A new federal water heater standard that becomes effective in 2015 mandates EFs around 2.0 for all new electric storage water heaters with capacities greater than 55 gallons, effectively mandating installation of HPWHs in applications with large hot water demands. Additionally, the water heater EF rating does not accurately capture all aspects of real-world HPWH performance. This necessitates accurate HPWH analysis methods that can evaluate their performance across various conditions.

This gap has been substantially resolved by the release of BEoptE+ 1.2, which includes a HPWH model that is based on NREL's laboratory evaluation and validated with Building America field evaluations.

Remaining needs include:

- Simplified (spreadsheet-based) HPWH model? (CARB)
- Better draw profiles for testing and Energy Factor rating HPWHs (ASHRAE SPC 118.2 is working on this)
- How are HPWHs operated by occupants? (especially in response to running out of HW) (CARB and BA-PIRC have relevant projects)
- Better understanding/modeling unconditioned basement humidity and air exchange with conditioned space, for HPWHs in basements
- HPWH performance in enclosed/semi-enclosed spaces (e.g. louvered closet door) (BA-PIRC)
- Additional field validation of HPWH model and DHW Event Schedule Generator draw profiles.

Key Customers and Stakeholders:
Building America teams, homeowners, and contractors will benefit greatly from the ability to accurately model HPWHs, particularly the interaction of the unit with the space conditioning equipment. The ability to model these systems will allow for a greater understanding of the appropriate applications for HPWHs in residential settings. Additional stakeholders are the manufacturers of HPWHs, software developers that will be able to include the model in their simulation tools, and other users of energy simulation tools.

Background Knowledge:
The DOE-2 simulation engine has a HPWH model, but does not model the effect of HPWHs on the zone. Other simulation tools (EnergyPlus and TRNSYS) can model HPWHs, but require the use of sub-hourly time steps in order to capture short-term transient effects. Released in January 2012, BEoptE+ 1.2 includes a HPWH model that overcomes the limitations of other simulation tools.

A useful summary of past and ongoing HPWH testing and modeling efforts can be found in the "Heat Pump Water Heater Technology Assessment" prepared by Davis Energy Group for Pacific Gas and Electric Company.[9]

System Considerations:
This gap/barrier is closely tied to the Water Heating Standing Technical Committee, where isolating behavior impacts on HPWH performance and validating HPWH models with lab/field data have been identified as an important gap/barrier.

The Space Conditioning STC has a gap/barrier titled "Integration of HPWH into whole home comfort systems." Modeling work should be conscious of this effort to direct a HPWH's space cooling capacity to where it is needed using ducts.

A method of accounting for the short-term transient effects of discrete DHW draws while keeping an hourly time step may also be used to improve tankless water heater modeling, which BEopt models with a constant derate due to cycling.

Planned or Ongoing Research:
NREL has conducted extensive laboratory evaluation of five new HPWHs. This test data includes performance mapping and has been used to develop and validate a HPWH model that can be used with hourly time steps. A TRNSYS model has been created based on the lab test performance mapping. This model has been used to conduct a cost-benefit analysis across climates. Based on the lab testing and TRNSYS simulations, NREL has

[9] Davis Energy Group. "Heat Pump Water Heater Technology Assessment" Technology Assessment Report #PGEZNE2010-01. Prepared for Pacific Gas and Electric Company Zero Net Energy Program (publication pending).

created an EnergyPlus-based based model, for use with BEoptE+, that is fully integrated with building energy simulation.

There are several ongoing HPWH field monitoring studies. CARB is collecting long term performance data at 14 sites in Massachusetts and Rhode Island. Measurements are being taken at 15-minute intervals for at least 12 months at all sites to establish the efficiency and performance of each unit. This field data is being used to develop and validate NREL's HPWH model.

BSC presented HPWH field testing results for one site at the Summer 2011 ASHRAE Conference.[10]

FSEC (BA-PIRC) performed laboratory testing on one HPWH using ASHRAE and BA HSP draw profiles. Preliminary results are available and more will be available in March 2012. Another BA-PIRC project involves 700+ GE HPWHs installed in multi-family buildings in Florida (Atlantic Housing). Two of these units will be monitored for TO3. Maintenance staff at the buildings have been surveyed on resident satisfaction and setpoints. A third BA-PIRC project has just started taking field data on a GE HPWH in a Habitat for Humanity house in Florida.

ORNL is monitoring HPWHs in multiple test homes to a degree that may provide data for model validation. One test home is occupied (Retrofit Home) and two test homes have simulated occupancy (Zebra Alliance, Campbell Creek).

ARBI has a multi-family complex project, the"West Village Community," that has a central HPWH system.

PNNL has side-by-side lab homes. They will be testing a HPWH in one home while the other serves as a control.

Outside of Building America, EPRI has conducted laboratory tests at conditions similar to the DOE test procedure, but with some important differences, such as varying inlet and outlet temperatures. EPRI is also conducting a monitoring study of 200 new residential heat pump water heaters.

"Closing the Gap":
The primary goal of an accurate HPWH integrated with building energy simulation was resolved. There are additional needs that remain:

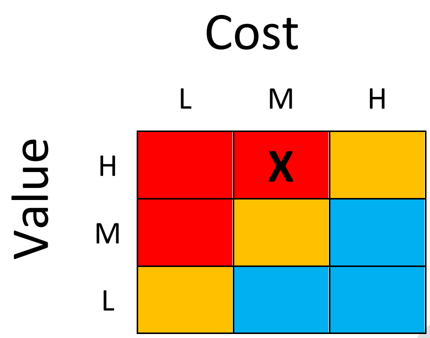
- It remains important to investigate the feasibility of developing simpler models that don't require hourly simulation and to understand the trade-offs between analysis time and accuracy. CARB is working on this.
- ASHRAE SPC 118.2 is working on better draw profiles for testing and rating HPWHs.
- CARB and BA-PIRC are working on the issue of occupant satisfaction and how HPWHs are operated.
- BA-PIRC is working on evaluating HPWH performance in enclosed/semi-enclosed spaces (e.g. louvered closet door).

[10] Ueno, K., Straube, J. "San Francisco Bay Area Net Zero Urban Infill" Research Report – 1102 Building Science Corporation. Presented at 2011 ASHRAE Annual Conference and available from Building Science Press: http://www.buildingscience.com/documents/reports/rr-1102-san-francisco-net-zero-urban-infill/view

- As part of the NREL Field Test Best Practices online resource, NREL will work with Building America teams to define a standard set of HPWH field test measurements that are useful for ongoing model validation.

Timeline:
Mid-term.

Table 11: Cost-Value Matrix for "Heat Pump Water Heaters"



Resolution (partial):
In January 2012, after six months of research effort, NREL released BEoptE+ 1.2, which includes a HPWH model that does not significantly increase simulation run time. This resolved the major portion of this gap/barrier, which was that existing analysis tools cannot accurately model HPWHs with reasonable runtime.

Building America's role in resolving this gap/barrier includes NREL laboratory evaluation, field evaluation from CARB, and model development by NREL. Although the model was just released, it can be concluded that industry has benefited since HPWH was a frequently requested feature for BEopt. Remaining needs for this topic are listed in the "Problem Statement".

2.11: Data Transfer Standard

BA Enclosures		**BA Hot Water**	
Walls		Test Standards	
Roof/Ceiling		Distribution	
Foundations		Condensing/Tankless	
Moisture		Heat Pump Water Heater	
Windows		Combined Space and DHW Heating	
Other: __________________		Other:__________________	
BA Space Conditioning		**BA Miscellaneous Loads**	
Heating		Home Energy Management	
Cooling		Lighting	
Dehumidification		Large MELs (pools, etc.)	
Distribution		Small MELs (TVs, VCRs, etc.)	
Ventilation		Other: __________________	
Other: __________________			
Testing Methods/Protocols		**BA Implementation**	
House Simulation Protocol		Quality Control / Quality Assurance	X
Lab Test Methods		Training	X
Field Test Methods		Documentation / Resources	X
Analysis Methods/Tools		Needs Evaluation / Identification	X
Analysis Tools		Other: __________________	
Strategic Analysis	X		
Other: __________________			

House Type	
New	X
Existing	X
Single Family	X
Multi-Family	X
DOE Emerging Technologies	
Walls and Windows	
Efficient Appliances	
Advanced Heating and Cooling Fluids	
Solar Heating and Cooling	
Geothermal Heat Pumps	
Solid State Lighting	
Bulk Purchase	
Onsite Renewables (Building-Integrated Photovoltaic, onsite cogen)	
DOE Deployment	
Labeling/Rating	X
Codes	X
Standards	X
Large Scale Retrofit (Better Buildings)	X

Problem Statement:
Presently, no widely-adopted data transfer standard exists for the home performance industry. This gap increases the burden on home performance companies working across multiple programs: assessors and analysts must be trained and retrained to process data into formats appropriate for various tools; data cannot be easily integrated into business tracking systems; quality assurance cannot be standardized.

Key Customers and Stakeholders:

- Home performance companies – reduces costs associated with training and systems integration.
- Audit software vendors – reduces demand for custom solutions by facilitating a common language of communication between software.
- EE program sponsors – reduces costs associated with program design, implementation and evaluation.
- EE program evaluators – reduces costs associated with program evaluation.
- Financial institutions – reduces risk by providing foundation for standardized source of empirical evidence of efficacy of energy efficiency (EE).
- Researchers – provides foundation for standardized empirical data for researching EE efficacy, software accuracy, etc.
- U.S. DOE – provides foundation for standardized empirical data for policy decisions.

Background Knowledge:
RESNET has a data collection standard, but no data transfer standard. BPI is developing a data collection standard as well. In addition to the data collection standard, BPI is developing a complementary data transfer standard – Home Performance XML (HPXML). Existing building-energy-related data transfer standards include Green Building XML (gbXML) and Integrated Energy Project (IEP) Model. gbXML, was developed to facilitate

the transfer of building information stored in CAD building information models, enabling integrated interoperability between building design models and a wide variety of engineering analysis tools and models available today. The schema was largely developed in the context of non-residential buildings, and the terminology is DOE-2-centric. IEP Model is a common language for software applications – it provides a comprehensive, standardized definition of an EE/DR+PV project, as well as information about how stakeholders can communicate between each other about those projects. A brief review of IEP Model identified a few missing data elements for this industry, the Model is worth exploring as a solution.

ASHRAE Standard 205, currently under development, is a related effort. According to the ASHRAE website[11]: "*This standard specifies data exchange protocols for HVAC&R equipment performance data for automated use by energy simulation applications.*" With respect to residential analysis, this standard may be useful in the context of feeding performance characteristics of HVAC&R equipment from the National Residential Efficiency Measures Database to residential simulation tools.

System Considerations:
Data transfer standards will facilitate aggregation of empirical data to "prove" efficacy of EE measures and programs. Data transfer standards will also provide a common platform for combining audit data with other data sources (data mining/data fusion). Large data sets in a standardized format may also help to characterize of the U.S. housing stock.

Planned or Ongoing Research:
BPI is currently developing data collection and transfer standards via ANSI standard development process.

"Closing the Gap":
The key milestone is the release of an industry-consensus standard for data transfer. It will require widespread adoption of the standard to actually close the gap. Support for piloting standards will help achieve widespread adoption.

Timeline:
Mid-term.

Table 12: Cost-Value Matrix for "Data Transfer Standard"

Value \ Cost	L	M	H
H		X	
M			
L			

11 http://spc205.ashraepcs.org/

2.12: Storm Windows

BA Enclosures		BA Hot Water	
Walls		Test Standards	
Roof/Ceiling		Distribution	
Foundations		Condensing/Tankless	
Moisture		Heat Pump Water Heater	
Windows	X	Combined Space and DHW Heating	
Other: ___________________		Other:___________________	
BA Space Conditioning		**BA Miscellaneous Loads**	
Heating		Home Energy Management	
Cooling		Lighting	
Dehumidification		Large MELs (pools, etc.)	
Distribution		Small MELs (TVs, VCRs, etc.)	
Ventilation		Other: ___________________	
Other: ___________________			
Testing Methods/Protocols		**BA Implementation**	
House Simulation Protocol		Quality Control / Quality Assurance	
Lab Test Methods	?	Training	
Field Test Methods	?	Documentation / Resources	
Analysis Methods/Tools		Needs Evaluation / Identification	
Analysis Tools	X	Other: ___________________	
Strategic Analysis			
Other: ___________________			

House Type	
New	
Existing	X
Single Family	
Multi-Family	
DOE Emerging Technologies	
Walls and Windows	
Efficient Appliances	
Advanced Heating and Cooling Fluids	
Solar Heating and Cooling	
Geothermal Heat Pumps	
Solid State Lighting	
Bulk Purchase	
Onsite Renewables (Building-Integrated Photovoltaic, onsite cogen)	
DOE Deployment	
Labeling/Rating	
Codes	
Standards	
Large Scale Retrofit (Better Buildings)	

Problem Statement:
Storm windows are very a well established energy conservation measure used in many existing homes in cold climates. However, many of the building energy analysis tools that are commonly used for research and design purposes do not enable the inclusion of storm windows in the analysis. Thus, we have a gap in our ability to assess the benefits of this important option. For existing homes that have storm windows, the omission of this feature in the analysis is a likely cause of over-prediction of energy use and energy savings. For planning retrofits in homes that do not already have storm windows, the omission of this option is a significant lost opportunity.

Key Customers and Stakeholders:

- Software Developers: Implement models and benefit from having more accurate and comprehensive software.
- Energy Contractors: Recommend efficiency measures and benefit from more accurate and comprehensive software recommendations.
- Window Manufacturers: Produce storm windows and benefit from having storm window technologies evaluated against other energy efficiency measures.
- Utilities: Potentially provide energy efficiency incentives and benefit from understanding the impact of storm windows on utility demand (overall and peak).
- Homeowners: Purchase storm windows and benefit from accurate predictions of energy savings.
- Historic Building Preservation Planners: Evaluate energy efficient options that preserve historic architectural features.

Background Knowledge:
Storm windows may be installed on the interior or exterior side of an existing window; exterior placement is more common in homes. In addition to adding a layer of glazing, they also cover all or part of the window frame and crack area. Thus, storm windows significantly reduce heat losses through the glass, frame, and infiltration. On the contrary, the additional glazing somewhat reduces solar gains that offset heating loads; however this effect is small compared to the benefits. Low-e storm windows, which further reduce heat losses through the assembly, are now available [1, 2], and at least one manufacturer offers storm windows that are tinted for control of solar gains. Occupants may alternate storm windows with insect screens on a seasonal basis; alternatively, operable storm windows may be installed permanently.

Many window products are rated by the National Fenestration Rating Council (NFRC). However, because the performance of a storm window is very sensitive to the type of window on which it is installed, the condition of that window, and the method of mounting, there is currently no clear pathway to an NFRC rating procedure for storm windows [22].

Modeling. The LBNL WINDOW software suite (including Optics and THERM) can resolve the complex thermal and optical properties of a storm window assembly [3]. Then, those thermal and optical properties (U-value and SHGC) can be translated into EnergyPlus or DOE-2 inputs using an algorithm developed by Arasteh et al. [4].[12] This method does not include the effect of the storm window on infiltration. Klems [19] concluded, "Regardless of climate, the heat loss attributable to infiltration through the window unit is small compared with that incurred as a result of direct transmission of heat through the window."[13] Additional modeling details to be addressed include seasonal variation of window properties within the simulation engines, occupant behavior regarding seasonal deployment of storm windows and insect screens, and interference with natural ventilation. However, these modeling complexities would not apply in the case of operable storm windows, which are now readily available. The National Residential Efficiency Measures Database [5] cites U-values and SHGCs from Klems, who measured the thermal performance improvement from installing low-e exterior storm windows outside existing single pane windows in winter conditions [6]. Also, plans for the development of the database include adding cost data for storm windows in the next version [7]. Overall, it should be possible with a moderate level of effort to include some typical storm window assemblies as options in building energy analysis software such as BEopt.

Validation. Model results should be checked against measured performance data. A very preliminary literature search has identified some promising references as a starting point for a more thorough literature review [6, 8-18]. After reviewing the usefulness of the data reported in the literature for model validation purposes, the need for additional laboratory and field testing can be assessed.

System Considerations:

- Validation and testing of software
- [placeholder for gaps/barriers identified by other STCs]

[12] This algorithm is embedded within EnergyPlus, so window assembly optical and thermal properties can be input directly using the Simple Window Model. The same algorithm has been implemented in BEopt for compatibility with DOE-2.
[13] Desjarlais et al. [20] measured air leakage through windows with and without storms.

Planned or Ongoing Research:

- Storm-window model development for BEopt was identified as a need and is in the queue of possible enhancements.
- Work is in progress for the National Residential Efficiency Measures database to document cost data and provide effective U-value and SHGC for various overall window assemblies that employ storm window technology.
- U.S. Department of Energy funded research project, "Low-E Retrofit Demonstration and Educational Program", Award # DE-EE0004015, Quanta Technologies Inc., Program Manager: Thomas D. Culp, Ph.D., August 2010-2013.

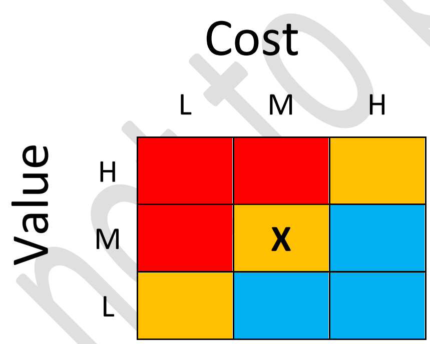
"Closing the Gap":

- Building energy analysis software will accommodate storm windows.
- Storm window models will be validated against lab and field test data.
- Studies will evaluate recommended retrofit packages, including storm windows as an option.

Timeline:

Short term.

Table 13: Cost-Value Matrix for "Storm Windows"



References:

1. Window Retrofit Option / Exterior Low-e Storm Windows. June 2011. http://www.windowattachments.org/fact-sheets/exterior-attachments/?aid=44&pid=10&sa=1
2. High Performance Windows Volume Purchase Program. http://www.windowsvolumepurchase.org/. http://www.windowsvolumepurchase.org/docs/specifications_requirements_phase2.pdf
3. THERM 6.3 / WINDOW 6.3 NFRC Simulation Manual, Section 8.4. LBNL, May 2011. http://windows.lbl.gov/software/NFRC/SimMan/NFRCSim6.3-2011-Manual.pdf.
4. Modeling Windows in EnergyPlus with Simple Performance Indices. Dariush Arasteh, Christian Köhler, and Brent Griffith. LBNL-2804E, October 2009. http://gaia.lbl.gov/btech/papers/2804.pdf.
5. National Residential Efficiency Measures Database (accessed 8/8/11). http://www.nrel.gov/ap/retrofits/index.cfm.
6. Measured Winter Performance of Storm Windows, J. H. Klems, Windows and Daylighting Group, Building Technologies Department, Lawrence Berkeley National Laboratory, Berkeley, California 94720-8134. http://www.parks.ca.gov/pages/1054/files/berkeley%20storm%20window%20research.pdf
7. Private communication with Sean Casey, 8/4/11

8. Field Evaluation of Low-E Storm Windows. S. Craig Drumheller, Christian Köhler, and Stefanie Minen (2007). http://www.ornl.gov/sci/buildings/2010/Session%20PDFs/22_New.pdf
9. Testing the Energy Performance of Wood Windows in Cold Climates, A Report to the State of Vermont Division for Historic Preservation Agency of Commerce and Community Development, August 30, 1996, Brad James, Andrew Shapiro, Steve Flanders, Dr. David Hemenway. http://www.kshs.org/preserve/pdfs/001_pdfsam_wood_window_study.pdf
10. Making Windows Work Better, Environmental Building News, Vol. 20, No. 6. http://www.buildinggreen.com/auth/article.cfm/2011/6/1/Making-Windows-Work-Better/.
11. Case Study National Grid Deep Energy Retrofit Pilot Program: Clark Residence (2010) http://www.wright-builders.com/images/residential/MA_NGrid_DER_Case_Study.pdf.
12. NFRC 102: Test Procedure for Measuring the Steady-State Thermal Transmittance of Fenestration Systems (2002). http://www.nfrc.org/documents/NFRC_102-2001.pdf.
13. ANSI/AAMA Standard 1002.10-93. Voluntary Specification for Insulating Storm Products for Windows and Sliding Glass Doors. American Architectural Manufacturers Association. (Document not yet found.)
14. Highly Insulating or LowE Storm Windows Energy Savings Estimator / Functions and Assumptions: http://haddonwindows.com/pdfs/Window_Savings_Estimator_Manual.pdf.
15. The Effects of Energy Efficiency Treatments on Historic Windows, Larry Kinney and Amy Ellsworth, Center for ReSource Conservation, Jan. 24, 2011. http://conservationcenter.org/.
16. Weatherization Measures for Existing Windows, Efficient Windows Collaborative, http://efficientwindows.org/weatherization2.cfm.
17. Window Technologies: Low-E Coatings, http://efficientwindows.org/lowe.cfm.
18. Association for Preservation Technology International, http://www.apti.org/.
19. Klems, J. H. (1983). "Methods of Estimating Air Infiltration throught Windows." Energy and Buildings 5: 243-252.
20. Desjarlais, A.O.; Childs, K.W.; Christian, J.E. (1998). To Storm or Not to Storm: Measurement Method to Quantify Impact of Exterior Envelope Airtightness on Energy Usage Prior to Construction. ASHRAE/DOE/BTECC Conference on the Thermal Performance of the Exterior Envelopes of Building VII, Clearwater Beach, FL, American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE).
21. Craven, C.; Garber-Slaght, R. (2011). "Evaluating Window Insulation." Fairbanks, AK: Cold Climate Housing Research Center. http://www.cchrc.org/docs/reports/window_insulation_final.pdf (accessed 1/27/12).
22. Private communication with Ray McGowan, Senior Program Manager at NFRC, 1/9/12.
23. N. Smith, "A Cost Benefit Analysis of Secondary Glazing as a Retrofit Alternative for New Zealand Home", Masters Thesis, School of Architecture, Victoria University of Wellington, New Zealand, 2009.

2.13: Enhancing Documentation, Training, and Education for Building America Analysis Tools

BA Enclosures		**BA Hot Water**	
Walls		Test Standards	
Roof/Ceiling		Distribution	
Foundations		Condensing/Tankless	
Moisture		Heat Pump Water Heater	
Windows		Combined Space and DHW Heating	
Other: __________________		Other:__________________	
BA Space Conditioning		**BA Miscellaneous Loads**	
Heating		Home Energy Management	
Cooling		Lighting	
Dehumidification		Large MELs (pools, etc.)	
Distribution		Small MELs (TVs, VCRs, etc.)	
Ventilation		Other: __________________	
Other: __________________			
Testing Methods/Protocols		**BA Implementation**	
House Simulation Protocol	X	Quality Control / Quality Assurance	X
Lab Test Methods		Training	X
Field Test Methods		Documentation / Resources	
Analysis Methods/Tools		Needs Evaluation / Identification	
Analysis Tools	X	Other: __________________	
Strategic Analysis			
Other: __________________			

House Type	
New	
Existing	
Single Family	
Multi-Family	
DOE Emerging Technologies	
Walls and Windows	
Efficient Appliances	
Advanced Heating and Cooling Fluids	
Solar Heating and Cooling	
Geothermal Heat Pumps	
Solid State Lighting	
Bulk Purchase	
Onsite Renewables (Building-Integrated Photovoltaic, onsite cogen)	
DOE Deployment	
Labeling/Rating	X
Codes	
Standards	
Large Scale Retrofit (Better Buildings)	X

Problem Statement:
Existing documentation, training, and education materials for Building America energy analysis tools could be enhanced. Currently, in-depth understanding and facility with a given tool is usually achieved only by highly motivated engineers who can access a network of experts, including staffs that develop and maintain the tools. Although the fall 2011 release of the BEopt(www.beopt.nrel.gov) website has addressed significant gaps in this area, more structured, indexed, and modularized documentation, training, and educational materials are still needed, especially for other BA analysis tools such as:

- Building America Analysis Spreadsheets
- Domestic Hot Water Even Schedule Generator.

Key Customers and Stakeholders:

- Development staff who support the packages/tools
- Building America researchers
- Engineering faculty and students
- Residential audit delivery practitioners

DOE has invested significant resources in developing a suite of analysis and modeling tools to support their programmatic goals to reduce overall energy consumption. One of the barriers to wider adoption of these tools is the lack of comprehensive documentation, training, and educational materials. By bridging this gap, the tools will gain wider acceptance in the community.

The development staff that supports the packages must spend a considerable amount of time answering questions about the capabilities and limitations of these packages. By having a more-comprehensive suite of training and education materials, development staff will have fewer calls from the field and will have a place to refer callers for basic questions related to capabilities and limitations. Development staff can still be available for particularly complex or unusual issues.

Having a common set of training materials will help interaction among the BA research teams by helping foster a sense of common language and purpose. The training will also help increase the reliability of the research by assuring consistency of usage throughout the research community.

Engineering faculty and students will benefit by having these materials available to be incorporated into new or existing classes. Specifically, educational materials are needed that can be used to assess the abilities and understanding of new modelers.

Background Knowledge:
In the fall of 2011 NREL went live with the www.beopt.nrel.gov website. The website allows users to:

- Read about the basic features of BEopt
- Download BEopt
- Access the indexed software help content that was previously only available in the BEopt program itself
- View series of training video lessons, developed by the BARA , that provide information on the basic functionality of the software, as well as highlighting a few advanced topics
- View BEopt and related publications
- Have read-only access to BEopt's internal ticket system, which houses feature requests and bug reports (tickets) for both modeling work and interface development, and
- Contact the BEopt developers with questions and requests.

Examples files are included in the BEopt download, the contents of which could form the basis of additional guided training materials. Help files could also be improved to provide more detailed information regarding underlying assumptions.[14] Examples of training approaches and materials related to EnergyPlus can be found here:
http://apps1.eere.energy.gov/buildings/energyplus/energyplus_training.cfm.

The Building America Analysis Spreadsheets are companions to the House Simulation Protocols, and can assist with many of the calculations and look-up tables found in the report. NREL recorded one presentation about using this BA Analysis Spreadsheets, but this presentation has not been modularized or published and further materials are needed.

The Domestic Hot Water Event Schedule Generator can be used to generate custom year-long hot water event schedules consistent with realistic probability distributions of start time, duration variability, flow rate variability, clustering, fixture assignment, vacation periods, and seasonality. A paper[15] has been published that describes the tool and its development, but additional materials are needed.

[14] The Solar Advisor Model and eQUEST may be good examples of the level of detail desired by the users:
https://www.nrel.gov/analysis/sam/
http://doe2.com/equest/
[15] http://www.nrel.gov/docs/fy10osti/47685.pdf

Simulation test suites such as BESTEST-EX may be a good starting point for developing educational materials that assess the abilities and understanding of new modelers: http://www.nrel.gov/docs/fy11osti/52414.pdf.

System Considerations:

The Analysis Methods and Tools STC has identified various gaps and barriers regarding the limitations of BEopt. It is hoped that a clearer and more widespread understanding of the program, its applications, its capabilities and its limitations, will lead to clearer understanding of the gaps and better direction for activities that will bridge them.

Planned or Ongoing Research:

By default, the BEopt developers continue to support the program, providing answers to user questions while adding to the BEopt capabilities. Some of the largest non-modeling limitations will be addressed by the release of BEopt 2, so it will be important to document enhanced capabilities in training and education materials.

"Closing the Gap":

The goal is to have a comprehensive suite of documentation, training, and education materials including videos, slide shows, lecture notes, examples and assessment/evaluation material that are organized in modules according to learning outcomes that clearly define the prerequisite expectations for each module. These can be used as stand-alone and self-paced training or can be incorporated into university lecture courses.

Metrics of success will be the number of individuals trained on BA Analysis Tools, the level of competence and the number of university level courses incorporating the materials.

Timeline:

Mid-term.

Table 14: Cost-Value Matrix for "Enhancing Documentation, Training, and Education for Building America Analysis Tools"

Value \ Cost	L	M	H
H			
M		X	
L			

Resolution (partial):
As noted in the "Planned or Ongoing Research" section, in the fall of 2011 the www.beopt.nrel.gov website went live. The website allows users to:

- Read about the basic features of BEopt
- Download BEopt
- Access the indexed software help content that was previously only available in the BEopt program itself
- View series of training video lessons, developed by the BARA , that provide information on the basic functionality of the software, as well as highlighting a few advanced topics
- View BEopt and related publications
- Have read-only access to BEopt's internal ticket system, which houses feature requests and bug reports (tickets) for both modeling work and interface development, and
- Contact the BEopt developers with questions and requests.

2.14: Supplemental Dehumidification Modeling

Originally Prepared by: Roselin Osser, Building Science Corporation.

BA Enclosures		**BA Hot Water**	
Walls		Test Standards	
Roof/Ceiling		Distribution	
Foundations		Condensing/Tankless	
Moisture		Heat Pump Water Heater	
Windows		Combined Space and DHW Heating	
Other: __________________		Other:__________________	
BA Space Conditioning		**BA Miscellaneous Loads**	
Heating		Home Energy Management	
Cooling		Lighting	
Dehumidification	X	Large MELs (pools, etc.)	
Distribution		Small MELs (TVs, VCRs, etc.)	
Ventilation		Other: __________________	
Other: __________________			
Testing Methods/Protocols		**BA Implementation**	
House Simulation Protocol		Quality Control / Quality Assurance	
Lab Test Methods		Training	
Field Test Methods		Documentation / Resources	
Analysis Methods/Tools		Needs Evaluation / Identification	
Analysis Tools	X	Other: __________________	
Strategic Analysis			
Other: __________________			

House Type	
New	**X**
Existing	**X**
Single Family	**X**
Multi-Family	**X**
DOE Emerging Technologies	
Walls and Windows	
Efficient Appliances	
Advanced Heating and Cooling Fluids	
Solar Heating and Cooling	
Geothermal Heat Pumps	
Solid State Lighting	
Bulk Purchase	
Onsite Renewables (Building-Integrated Photovoltaic, onsite cogen)	
DOE Deployment	
Labeling/Rating	
Codes	
Standards	
Large Scale Retrofit (Better Buildings)	

Problem Statement:
Supplemental dehumidification is an area of ongoing research and interest for the Building America program. Studies have shown that supplemental dehumidifiers can help achieve thermal comfort during periods of high humidity when dry bulb cooling is not needed. This technique is most relevant in hot, humid climates but can also improve comfort during swing seasons in colder areas. Supplemental dehumidification may also be necessary in high efficiency homes during periods when cooling occurs, but due to reduced sensible loads the air conditioning system does not run enough to adequately address latent loads. In order to better study this measure for various projects, it is necessary to model the energy use required to maintain desired setpoints within hourly energy modeling tools such as BEopt. The additional heat rejected by the operating dehumidifiers should also be accounted for. Setpoint inputs would allow the software to determine when supplemental dehumidification is needed independent of cooling.

Besides modeling these dehumidifiers in very airtight homes, it would also be useful to model the energy use of a dehumidifier in an uninsulated basement, a typical pre-retrofit scenario. However, this is more challenging because it requires accurate modeling of foundation moisture load which is dependent on a variety of factors. The integration of an accurate dehumidification model may also be difficult to integrate with assumptions about occupants opening windows.

The Building America House Simulation Protocols (HSP) require the modeling of humidity control for all new homes. Because humidity control cannot be modeled using the DOE-2.2 version of BEopt, this essentially requires that all new homes are modeled using the EnergyPlus version of BEopt. Although the HSP requires humidity control to be modeled for existing homes where humidity is controlled, the HSP does not specify when it is required to add humidity control to existing homes post-retrofit. Additional language is needed in the HSP to A) clarify whether there are any cases in which new homes can be modeled using BEopt/DOE-2.2 (e.g., hot dry climates where humidity is of less concern) and B) specify that the analyst is responsible for determining when humidity control should be added to post-retrofit homes.

Key Customers and Stakeholders:
The key customers and stakeholders include homeowners, builders, building consultants, researchers, and manufacturers of supplemental dehumidification systems. The ability to model this element allows examination of the relative costs and benefits of the system. Additionally, utility bills can be better-compared to models to understand energy use breakdown.

Background Knowledge:
Supplemental dehumidifiers can be either standalone units or integrated into the central air supply system. They can employ traditional approaches (cooling to the dew-point temperature to remove moisture and then reheating) or alternative approaches such as desiccant-based dehumidification.

In homes with high performance thermal enclosures, the sensible load is significantly reduced, making the latent load proportionally larger. Conventional cooling systems cannot effectively handle this latent load because they sense only dry bulb temperature. Additionally, over-cooling to remove excess moisture is not desired. Most residential energy modeling programs do not include the ability to model supplemental dehumidification. The following papers can be considered relevant background knowledge for this area:

Rudd, A., J. Lstiburek, and K. Ueno 2005. "Residential dehumidification systems research for hot-humid climates." U.S. Dept. of Energy, Office of Energy Efficiency and Renewable Energy, NREL/SR-550-36643. www.nrel.gov/docs/fy05osti/36643.pdf.

Rudd, A. 2004. "Supplemental Humidity Control Systems." Results of Advanced Systems Research, Project 3, 5.C.1 Final Report to U.S. Dept. of Energy under Task Order number KAAX-3-32443-05. Midwest Research Institute/National Renewable Energy Laboratory, Golden, CO. October.

Rudd, Armin, Joseph Lstiburek and Kohta Ueno, 2003. "Residential dehumidification and ventilation systems research for hot-humid climates," Proceedings of 24th AIVC and BETEC Conference, Ventilation, Humidity Control, and Energy, Washington, US, pp.355–60. 12-14 October. Air Infiltration and Ventilation Centre, Brussels, Belgium.

Rudd, Armin, Hugh Henderson, Jr., 2007. "Monitored Indoor Moisture and Temperature Conditions in Humid Climate U.S. Residences." ASHRAE Transactions (17, Dallas 2007). American Society of Heating Refrigeration and Air-Conditioning Engineers, Atlanta, GA.

Additional information related to modeling moisture in buildings:

- IEA Annex 41: http://www.ecbcs.org/annexes/annex41.htm#p
- ORNL website for WUFI software: http://www.ornl.gov/sci/ees/etsd/btric/wufi.shtml
- NREL Technical Report: http://www.nrel.gov/docs/fy11osti/49899.pdf

System Considerations:
This gap relates to the overall need for accurate moisture balance modeling. Comparisons of EnergyPlus to WUFI may be useful. A supplemental dehumidifier can be integrated into the central air distribution system. Also, supplemental humidification modeling is a related need.

Planned or Ongoing Research:
NREL recently completed the EnergyPlus version of BEopt that contains stand-alone supplemental dehumidification with auto-sizing capabilities.

GTI has been doing performance mapping through PNNL looking at regeneration of desiccants and renewable sources.

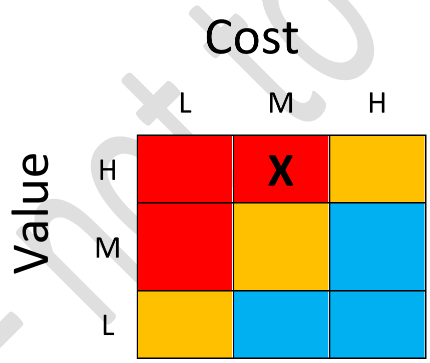
Enhancements to EnergyPlus modeling capabilities for residential integrated dehumidification systems may be needed before these systems can be added to BEopt. Forthcoming “Functional Mockup Interface” capabilities in EnergyPlus and may be useful for this.

“Closing the Gap”:
N/A; see previous.

Timeline:
NREL recently completed the Energy Plus version of BEopt that contains stand-alone supplemental dehumidification.

Estimated timeline for modeling integrated supplemental dehumidification systems: mid-term.

Table 15: Cost-Value Matrix for “Supplemental Dehumidification Modeling”



Resolution (partial):
As noted in the “Planned or Ongoing Research” and “Timeline” sections, the release of BEoptE+ 1.2 includes standalone supplemental dehumidification with autosizing capabilities, partially resolving this gap.

Appendix A:
Change Log

Record of additions and modifications to the summary sheets.

Date	Version of Plan (updated version #)	Title of Gap/Barrier/Need	Description of Change
2/2012	2012a	All	Responded to feedback from the October Building America Planning meeting. Added Strategic Goals to introductory section. Updated content based on research accomplishments since previous draft.

Appendix B:
Past Research – Resolved Gaps, Barriers and Needs

When gaps or barriers are resolved a brief summary is appended to the strategic planning document as a running record of Building America achievements.

Appendix C: Contributors

The committee as a whole reviewed the 2-pagers and the following committee members were lead authors of the 2-pagers:

- Dennis Barley
- Xia Fang
- John Gardner
- Neal Kruis
- Joel Neymark
- Roselin Osser
- Ben Polly
- El Hassan Ridouane
- David Roberts
- Carl Shapiro
- Eric Wilson
- Jon Winkler

Appendix D:
List of Gaps/Barriers and Survey Results

An online spreadsheet was used to develop an initial list of gaps/barriers. The committee was asked to identify gaps/barriers in the following categories:

- Validation and Testing
- Existing Methods and Tools
- New Methods and Tools
- Field Data and Audits
- House Simulation Protocols
- Other

An online survey was used to prioritize the gaps/barriers. For each topic in Table 17, respondents were asked to estimate the cost (high, medium, or low) and value (high, medium, or low). Responses were converted into a numerical "Survey Score" using the following weighting scheme:

Table 16: Cost-Value Matrix Weighting Factors

		Cost		
		L	M	H
Value	H	6	5	4
	M	5	4	3
	L	4	3	2

The topics in Table 17 are listed in decreasing order of the average survey score. Topics in the "Existing Methods and Tools Category" include a "general" or "BEopt specific" designation at the end of the topic description. For the BEopt specific topics the committee decided it was not necessary to develop detailed 2-page descriptions, but rather these topics should be tracked at a high level in the Strategic Plan (i.e., the list in Table 17 should clearly indicate which topics are BEopt specific).

Table 17: List of Gaps/Barriers and Survey Results

ID	Topic	Survey Score	Category
10	General--HVAC equipment autosize feature (BEopt specific)	5.08	Existing Methods and Tools
25	Pre-retrofit--HVAC sizing (BEopt specific)	5.00	Existing Methods and Tools
45	Multi-family--If modeling one unit in a multi-family or one home sharing a wall with another, the ability to model party walls through which no heat transfer occurs (BEopt specific)	5.00	Existing Methods and Tools
6	Sensitivity Analysis: Analysis is needed to determine most influential models and associated inputs.	4.91	Validation and Testing
22	Pre-Retrofit--Old furnaces (general)	4.90	Existing Methods and Tools
2	Validation Methodology: Accuracy tests based on existing empirical data sets are needed.	4.82	Validation and Testing
21	Pre-Retrofit--Old air conditioners (general)	4.82	Existing Methods and Tools
23	Pre-Retrofit--Old water heaters (general)	4.80	Existing Methods and Tools
50	Savings Calculations--Energy savings for different SEER rated AC systems (BEopt specific)	4.80	Existing Methods and Tools
52	Cost Selector/Option Editor--Increase the number of wall systems that can be added to the library (BEopt specific)	4.80	Existing Methods and Tools
29	Current Technologies--High-SEER air conditioners (general)	4.75	Existing Methods and Tools
49	Savings Calculations--Reference building profiles for IECC 2009 (BEopt specific)	4.75	Existing Methods and Tools
24	Pre-Retrofit--Empty cavity walls (general)	4.73	Existing Methods and Tools
30	Current Technologies--Ability to model air conditioners and heat pumps with performance ratings other than defaults (BEopt specific)	4.73	Existing Methods and Tools
67	Multi-family window to wall ratio: Minimal data for window to wall ratio in multi-family buildings. Current equation needs work.	4.73	House Simulation Protocols
51	Savings Calculations--Monthly energy use over specific time periods (BEopt specific)	4.70	Existing Methods and Tools
31	Current Technologies--Ground-source heat pumps (general)	4.67	Existing Methods and Tools
35	Current Technologies--Two-stage ACs or modulating furnaces/boilers (general)	4.64	Existing Methods and Tools
32	Current Technologies--Heat pump water heaters (general)	4.62	Existing Methods and Tools
62	Data Collection Standard: Standards and protocols for data collection and exchange (data fusion, data mining, and data granularity) are needed to better predict savings and improve tools.	4.62	Field Data and Audits
27	Retrofit Measures--Storm windows (general)	4.60	Existing Methods and Tools

77	Education/Training: Comprehensive, updated and evaluated training materials are needed to help train engineers on the use of the DOE modeling tools.	4.57	Other
53	Cost Selector/Option Editor--Allow for easier sharing of costs and options - save cost and option data with actual .bpj file? (BEopt specific)	4.56	Existing Methods and Tools
54	Cost Selector/Option Editor--Allow for easier sharing of costs and options - import partial libraries (BEopt specific)	4.56	Existing Methods and Tools
33	Current Technologies--Mini-split ACs and heat pumps (general)	4.55	Existing Methods and Tools
36	Current Technologies--Dehumidifiers (BEopt specific)	4.55	Existing Methods and Tools
70	Air Conditioner/Furnace Watt Draw: The 0.365 W/cfm used for ANSI/AHRI Standard 210/240 is not representative of values found in the field.	4.50	House Simulation Protocols
73	CFL vs. LED Lighting: LEDs have a lower efficacy than CFLs, according to the HSP, therefore LEDs put out less lumens than CFLs, and the lumen level is maintained at a certain level, thus resulting in more LEDs than CFLs, which consumes more energy.	4.50	House Simulation Protocols
1	Validation Methodology: Additional comparative tests are needed.	4.45	Validation and Testing
13	General--Different wall assemblies in BEopt (BEopt specific)	4.45	Existing Methods and Tools
26	Retrofit Measures--Costs (general)	4.44	Existing Methods and Tools
55	Cost Selector/Option Editor--Allowing for comparison for different system types in Optimization Mode (BEopt specific)	4.44	Existing Methods and Tools
5	Calibration: A standard method to calibrate software is needed (utility bills, smart meter data).	4.40	Validation and Testing
60	Customer interaction and feedback tools--better tools are needed (e.g., create a standardized homeowner survey and online database for inputting/collating results?)	4.40	New Methods and Tools
14	Heat Transfer--Better infiltration modeling (BEopt specific)	4.38	Existing Methods and Tools
48	Savings Calculations-- Add Benchmark costs for comparison (BEopt specific)	4.38	Existing Methods and Tools
68	Hot Water Draw Profiles for Modeling HPWHs: HW draw profiles (continuous, low volume) cause HPWH models to perform better than they would with realistic draws.	4.36	House Simulation Protocols
47	Savings Calculations--Incorporation of tiered rate structures and time of use rates for utility cost calculations (general)	4.33	Existing Methods and Tools
43	Multi-family--"multi-family housing (duplexes, townhouses, apartment buildings) should be included - not just single family new and retrofits." (BEopt specific)	4.31	Existing Methods and Tools
19	Heat Transfer--Energy recovery (BEopt specific)	4.30	Existing Methods and Tools

56	Cost Selector/Option Editor--Allow for any order of options in the library for Optimization Mode (BEopt specific)	4.30	Existing Methods and Tools
72	MEL Assumptions: MEL annual figures may not scale correctly for small homes (studios) and apartments.	4.30	House Simulation Protocols
15	Heat Transfer--Infiltration heat recovery (general)	4.27	Existing Methods and Tools
39	Current-Technologies--Combination space and domestic hot water heaters (BEopt specific)	4.27	Existing Methods and Tools
69	Air Conditioner Performance: Field studies have shown that air conditioners do not operate at rated performance due to a number of defaults including improper installation, lack of commissioning, etc. Specifically, poor performance can be attributed to improper refrigerant charge, low air flow, high duct pressure drops, and oversized units. In California, credit is provided under the energy code for measuring and verifying correct installation, and if not, the EER used in modeling is degraded accordingly. This may more realistically represent the energy use of systems.	4.25	House Simulation Protocols
34	Current Technologies--Evaporative cooling technologies (general)	4.20	Existing Methods and Tools
46	Dual Fuel--"Accurate modeling of dual fuel" (general)	4.20	Existing Methods and Tools
71	Thermal Bypass: Many national energy efficiency programs (ENERGY STAR, LEED for homes) and local programs require a thermal bypass inspection to minimize thermal bypass and ensure specific thermal performance from insulation. There is no mechanism in the HSP to credit performance of these homes over others (more detailed models or degradation factors are needed).	4.20	House Simulation Protocols
20	Heat Transfer--Multiple wall-types in BEopt (BEopt specific)	4.18	Existing Methods and Tools
57	Humidity Control--Allow for humidity control in BEopt (BEopt specific)	4.18	Existing Methods and Tools
63	Cost effective and accurate "Drive-by-Audit": is needed and the most important home attributes to accurately model should be identified (e.g., blower door or no blower door?).	4.18	Field Data and Audits
11	General--Retrofits changing size of home (BEopt specific)	4.17	Existing Methods and Tools
3	Validation Methodology: Tuning BESTEST-EX based on empirical based accuracy tests is needed.	4.14	Validation and Testing
65	Auditor Handbook: is needed to ensure consistency between different energy auditors.	4.09	Field Data and Audits
7	General--Internal temperature distribution (general)	4.08	Existing Methods and Tools
8	General--Mean radiant temperature (general)	4.08	Existing Methods and Tools
38	Current-Technologies--Hydronic systems (heating and cooling) (general)	4.08	Existing Methods and Tools
17	Heat Transfer--Foundation heat loss (general)	4.07	Existing Methods and Tools
37	Current Technologies--Air-to-water heat pump (general)	4.00	Existing Methods and Tools

16	Heat Transfer--Accounting for insulation performance degradation over time (general)	3.92	Existing Methods and Tools
28	Retrofit Measures--Window films (general)	3.90	Existing Methods and Tools
66	Many aspects of take back are not addressed: After a home has been retrofit, there are many forms of take back than can occur (e.g., heating and cooling set point, hot water use from low flow shower heads, and lighting use). The HSP lacks the ability to address many of these occurrences due to lack of data.	3.90	House Simulation Protocols
18	Heat Transfer--Slab heat loss (BEopt specific)	3.82	Existing Methods and Tools
64	Self Assessment Tools: there is a need for accurate, whole-house analysis that is doable by the average homeowner.	3.82	Field Data and Audits
76	Lighting: There is a need to better-understand the relationship between occupants and lighting.	3.82	House Simulation Protocols
59	Macro/community scale model: A model is needed for neighborhood/community scales to identify how much energy savings are available for certain homes to reach an overall goal.	3.77	New Methods and Tools
75	MELs: There is a need to better-understand the relationship between occupants and MELs.	3.77	House Simulation Protocols
74	Occupant Behavior: There is a need to validate assumed standard occupant use profiles.	3.69	House Simulation Protocols
4	Validation Methodology: A custom empirical validation facility is needed.	3.67	Validation and Testing
44	Multi-family--If modeling an individual unit rather than the whole MF building, the ability to model a central plant and its interaction with the individual unit. (general)	3.64	Existing Methods and Tools
61	Bridge between current whole building energy simulation tools and CFD technology--is needed to better understand the physical details of forced and buoyancy-driven air flow patterns within building enclosures, along with the resulting impact on associated heat flow, temperature, and moisture distributions.	3.47	New Methods and Tools
12	General--Window placement (BEopt specific)	3.46	Existing Methods and Tools
58	Site--Ability to draw neighbors in BEopt (BEopt specific)	3.36	Existing Methods and Tools
9	General--Furniture/interiors (general)	3.25	Existing Methods and Tools
41	Emerging Technologies--Electrochromic windows (general)	3.08	Existing Methods and Tools
40	Current Technologies--Micro CHP systems (general)	3.00	Existing Methods and Tools
42	Emerging Technologies--PCMs (phase change materials) (general)	3.00	Existing Methods and Tools
N/A	Characterization data for the U.S. housing stock (added after survey was completed).	N/A	Field Data and Audits