U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

BUILDING TECHNOLOGIES PROGRAM

Challenges and Opportunities To Achieve 50% Energy Savings in Homes: National Laboratory White Papers

M.V.A. Bianchi, Editor

July 2011

Building America
U.S. Department of Energy

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Challenges and Opportunities to Achieve 50% Energy Savings in Homes: National Laboratory White Papers

Prepared for:

Building America

Building Technologies Program

Office of Energy Efficiency and Renewable Energy

U.S. Department of Energy

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July 2011

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Definitions

ACEEE	American Council for an Energy-Efficient Economy
ACI	Affordable Comfort Inc.
BPI	Building Performance Institute
CEE	Consortium for Energy Efficiency
DALY	disability adjusted life year
DIY	do-it-yourself
DOE	U.S. Department of Energy
HERS	Home Energy Rating System
HPWH	heat pump water heater
HUD	U.S. Department of Housing and Urban Development
HVAC	heating, ventilation, and air-conditioning
IAQ	indoor air quality
IECC	International Energy Conservation Code
in.	inch
kW	kilowatt
kWh	kilowatt-hour
LBNL	Lawrence Berkeley National Laboratory
MEL	miscellaneous electric load
NO_2	nitrogen dioxide
NREL	National Renewable Energy Laboratory
ORNL	Oak Ridge National Laboratory
PNNL	Pacific Northwest National Laboratory
PV	photovoltaic
QALY	quality adjusted life year
RESNET	Residential Energy Services Network
SIP	structurally insulated panel
TVA	Tennessee Valley Authority
VOC	volatile organic compound

Executive Summary

In 2010, researchers from four of the national laboratories involved in residential research (Lawrence Berkeley National Laboratory [LBNL], National Renewable Energy Laboratory [NREL], Oak Ridge National Laboratory [ORNL], and Pacific Northwest National Laboratory [PNNL]) were asked to prepare papers on the key longer term research challenges, market barriers, and technology gaps that must be addressed to achieve the longer term 50% saving goal for Building America to ensure coordination with the Building America industry teams who are focusing their research on systems to achieve the near-term 30% savings goal. Although new construction was included, the focus of the effort was on deep energy retrofits of existing homes.

Building America holds three annual planning meetings to develop and evaluate strategies to reach its goals for cost effective savings of 30%–50% in new and existing homes. These meetings generate public documents similar to this report that are used as resources to support the DOE planning process. The three annual meetings are:

- A fall research planning meeting to identify and evaluate technical gaps and barriers to long-term goals.
- A summer technology update meeting to review current year research progress.
- A spring stakeholder update meeting to review stakeholder needs and ensure that Building America research reports provide actionable results. Key stakeholders include other Building Technology program areas (Codes, Better Buildings, and Emerging Technologies), other government agencies, manufacturers, contractors, utilities, developers, builders, financial institutions, appraisers, and real estate agents.

The topics in this report were a result of lab discussions held at the fall 2010 research planning meeting. Presentations from past meetings and information on current meetings can be found at www1.eere.energy.gov/buildings/building_america/meetings.html.

Technology roadmapping, a form of technology planning, can identify and develop the technologies required to meet the mission of Building America. Its main benefit is that it provides information to make better technology investment decisions by identifying critical technologies and technology gaps and identifying ways to leverage R&D investments (Garcia and Bray 1997).

Two parts of this activity were initiated in the fall of 2010:

- National laboratory planning, long-term 50% or greater energy savings
- Overall industry team planning, near-term 30% energy savings.

To complete this task, the national laboratories focused on a strategic planning activity that included a meeting on November 2, 2010, and a group of white papers written by the laboratory researchers about specific areas to identify research opportunities. This report summarizes the key opportunities, gaps, and barriers identified in the national laboratory white papers.

The industry team portion of this planning exercise is documented.[1]

Building America currently has three major system integration research elements:

- System Evaluations
- Technology Pathways Analysis (BEopt)
- Test House and Pilot Community Evaluations

Barriers, Gaps, and Opportunities Identified by the National Laboratories

A few of the barriers, gaps, and opportunities identified by the national laboratories in their white papers are listed below. For a complete list, see the Appendix at the end of this report.

Summary of Longer Term Barriers and Gaps

- There is a general perception (but limited evidence) that software-based energy analysis of inefficient existing homes tends to overpredict pre-retrofit energy use and retrofit energy savings.
- Building characteristics and utility billing data from actual houses have not been available in large scale for comparing software predictions with metered data.
- Advanced heating, ventilation, and air-conditioning (HVAC) equipment has fewer oversizing performance penalties than do traditional ones. However, their long fan run times mean that their field performance may not live up to their rated performance in typical installations with ducts in unconditioned spaces.
- Homeowners choose not to spend their capital in energy efficiency retrofits.
- The International Energy Conservation Code (IECC) 2012 will increase performance requirements in enclosures and the building industry is not fully equipped to meet the requirements cost effectively.
- The heavy focus on air sealing without designed ventilation provisions will negatively affect health, safety, and durability unless precautions are taken.
- Multifamily and rental units need special attention vis-a-vis energy efficiency.
- A major barrier to retrofits is the relatively low cost of energy.
- Limited data from past energy retrofit efforts suggest long payback periods (25 to 50 years).
- Although energy retrofits can enhance comfort, indoor air quality (IAQ), and other desirable characteristics, very little research has been done to document and market these added benefits
- There is low value on unseen retrofits. Renovation focus is on appearance, adding amenities, convenience, comfort, and health, not on energy efficiency.
- The energy and IAQ performance of a high-performance home will be limited without advances in ventilation equipment and control systems.

[1] http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/meeting_summary_50675.pdf

- There is a lack of standards to realize a vision where miscellaneous electric load (MEL) devices cooperatively manage their energy use in a distributed manner.
- Building America research is not accessible in a format that is most useful to stakeholders.
- Building code information is not consolidated in a single location.

Opportunities

- Focus retrofit efforts on conserving resources for the next generations rather than saving money.
- Concentrate on energy efficiency measures that are associated with other benefits that the homeowner desires (enhanced comfort, improved IAQ, dust control, durability, etc.).
- Use empirical data from the field to assess and track the accuracy of reference software.
- Use a rigorous process to identify potential issues in building energy simulation tools using comparisons of predicted versus metered energy use and savings.
- Perform careful field data collection, HVAC model development, and computer simulation validation from multiple test sites and climates surrounded by whole-house performance measurements to generate well-characterized datasets.
- Establish successful deep energy retrofit projects spawned by homeowner needs.
- Conduct research to determine the health, safety, and durability of high-R enclosures, focusing on their moisture performance.
- Develop, evaluate, and deploy smart and robust ventilation and ventilation control technologies. Develop on-demand ventilation solutions that can sense the presence of occupants and the operation of unvented gas appliances, electric and gas dryers, and bath and kitchen exhaust fans.
- Conduct research on how to manage shared hot water equipment that is unique to multi-family homes.
- Investigate ways to address the distinction between those who can legally make changes to a rental property and those who accrue the energy savings.
- Participate in committees defining standards for interoperability of MELs communication and control.
- Use Building America documentation products to strengthen market allies and potential partners, such as trade organizations representing strategic elements of the building and remodeling industries; program implementers such as government agencies, utilities, and regional alliances; and educators.
- Form an ongoing market transformation working group within Building America.

1 Introduction

The U.S. Department of Energy (DOE) Building America Residential Integration Program holds three annual strategic planning meetings to evaluate stakeholder needs, review research progress, and identify system performance gaps. The Stakeholder Meeting is held in the spring, the Research Update Meeting is held in the summer, and the Research Planning Meeting is held in the fall.

The fall 2010 Research Planning Meeting focused on identifying technology gaps and research opportunities to achieve 30%–50% savings in existing and new homes. Before then, researchers from the national laboratories were asked to prepare papers on the key research challenges that must be addressed to achieve the longer term 50% saving goal and to leverage coordination with the Building America industry teams who are concentrating their research efforts on systems to achieve the shorter term 30% savings goal. This report summarizes the key opportunities, gaps, and barriers identified in the national laboratory white papers.

Technology roadmapping, a form of technology planning, can identify and develop the technologies required to meet the mission of Building America. Its main benefit is that it provides information to make better technology investment decisions by identifying critical technologies and technology gaps and identifying ways to leverage R&D investments (Garcia and Bray, 1997).

1.1 Overview of Building America Program

Building America is part of the DOE Office of Energy Efficiency and Renewable Energy (EERE), Building Technologies Program (BTP). Building America focuses on conducting the systems research required to improve the efficiency of the approximately 116 million existing homes, as well as of the 500,000–2,000,000 new homes built each year.

Research from this program accelerates the development of reliable and effective whole-house packages of measures for highly energy-efficient new and existing homes that are tailored for each major U.S. climate region. This research can be broadly implemented to reduce risks, increase durability, and provide a reasonable return on investment. These improvements are accomplished through multi-scale research, systems development, systems integration, large-scale field implementation and evaluation, and effective communication of key research results and system-based strategies. Recently, the near- and long-term Building America performance targets were updated to help guide the energy efficiency of homes past updated code requirements and current standard practices.

Since July 2010, the 15 Building America research partnerships have begun projects that help dramatically improve the energy efficiency of American homes. These highly qualified, multidisciplinary teams work to deliver innovative energy efficiency strategies to the residential market and address barriers to bringing high-efficiency homes within reach for all Americans.

Visit the Building America website for more information about Building America teams, projects, partners, and tools: www.buildingamerica.gov.

Building America currently has three major system integration research elements (Figure 1):

- Technology Pathways Analysis (BEopt)
- System Evaluations
- Test House and Pilot Community Evaluations.

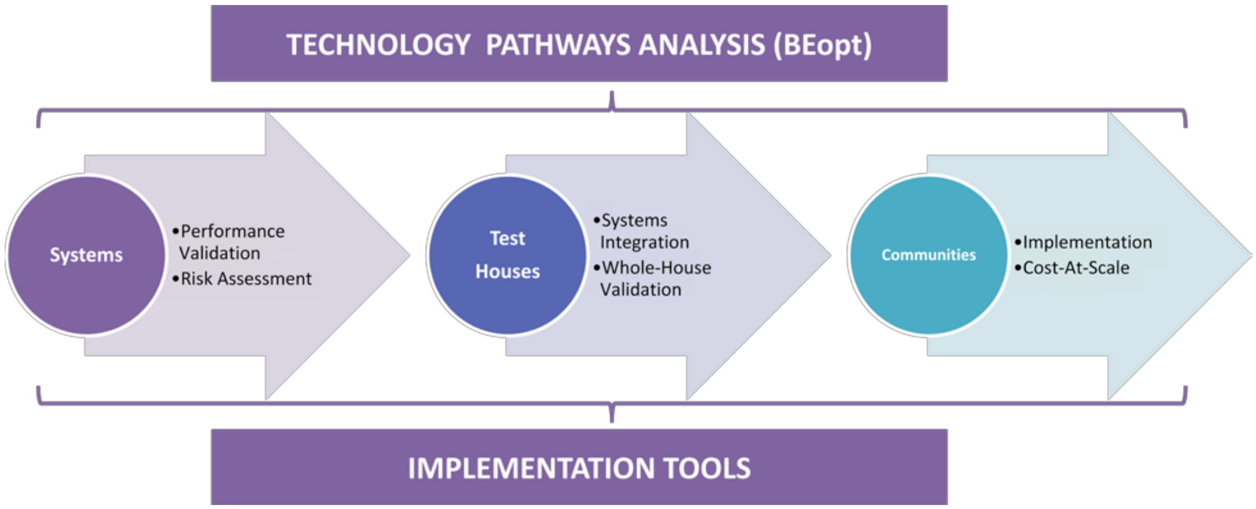

Figure 1. Building America program system integration research elements

1.1.1 Technology Pathways Analysis (BEopt)

1.1.1.1 Pathways Overview

Because numerous alternative designs can be considered and distinguishing between designs that improve cost/performance and designs that reduce cost/performance is difficult, Building America has developed a cost/performance optimization tool, BEopt. Pathway analysis provides the most cost effective packages for representative percentages of energy savings (e.g., 30% solution package).

1.1.1.2 Objective

The objective is to identify current best value/least cost efficiency packages for various energy savings levels and climates. These packages are then used as references for the participants to ensure their efforts focus on broad market rather than niche market solutions.

1.1.1.3 Technical Approach

A search optimization technique is used to identify a package of efficiency measures that provides the target level of whole-house energy savings with the least increase in cost relative to the base building. The user can select climate, building type (existing or new), building geometry, and efficiency measures to meet specific stakeholder needs.

This analysis effort is supported by research to improve residential software accuracy, including a national efficiency measures database, an empirical database for validation of audit software energy savings, the development of standard software methods of test, and the development of standard techniques for comparison of software predictions.

1.1.1.4 Key Results

Measures packages, improved software and audit tool accuracy, measures database, case studies, partnerships with software providers.

1.1.2 System Evaluations

1.1.2.1 System Performance Overview

This element uses laboratory and field testing to develop detailed performance maps of emerging residential building systems (e.g., the performance of air conditioners across a range of temperatures and relative humidities).

1.1.2.2 Objective

The objective is to differentiate between emerging systems that have the potential for broad market impacts or only niche market solutions, based on how well the system performs in various scenarios.

1.1.2.3 Technical Approach

In collaboration with manufacturers and utilities, laboratory tests are conducted using realistic operating conditions to develop highly accurate performance datasets that cover the range of expected operating conditions for all seasons and building types within major U.S. climate regions.

1.1.2.4 Key Results

Measures guidelines, system performance maps, case studies, and partnerships with manufacturers.

1.1.3 Test House and Pilot Community Evaluations

1.1.3.1 Test House Overview

Promising efficiency packages identified by Building America are evaluated in individual test homes and in multiple home pilot communities to ensure they meet contractor and builder requirements and can be successfully deployed.

1.1.3.2 Objective

The objective of evaluations in test homes and pilot communities is to verify that advanced efficiency packages developed by Building America can be successfully integrated with production, retrofit, and construction practices and meet overall comfort, usability, durability, safety, maintenance, quality installation, and commissioning requirements for use in homes.

1.1.3.3 Technical Approach

Research partnerships are developed with key stakeholders, including utilities, builders, contractors, program operators, and auditors to conduct field studies in test homes and pilot communities. All construction labor and material costs are provided as cost share by research partners with technical support from Building America teams.

1.1.3.4 Key Results

Case studies confirming cost-effective savings and benefits, residential data repository, case studies, and partnerships with utilities, appraisers, real estate groups, financial institutions, developers, contractors, and builders.

1.2 Reference

Garcia, M.L.; Bray, O.H. 1997. *Fundamentals of Technology Roadmapping*, Sandia National Laboratories Report, SAND97-0665, UC-900.

2 Assessing and Improving the Accuracy of Energy Analysis for Residential Buildings

Ben Polly, Neal Kruis, and Dave Roberts

National Renewable Energy Laboratory

2.1 Introduction

Whole-building energy analysis is used in the residential sector for many purposes:

- Design energy-efficient homes.
- Produce labels, scores, and ratings.
- Predict energy and cost savings from energy efficiency upgrades (retrofit measures).
- Determine cost and performance criteria for new energy-efficiency technologies.
- Provide quantitative analysis and data to support programmatic and policy-related decisions.

The success of energy-efficient design, labeling, scoring, rating, and retrofit efforts depends largely on the accuracy of the analysis performed for each task; stakeholders must be confident that the analysis approach can accurately predict relevant metrics such as energy use and energy savings. This chapter describes NREL's methodology to assess and improve the accuracy of whole-building energy analysis for residential buildings.

2.1.1 Mechanisms To Improve Energy Analysis Methods

A variety of approaches, including annual building energy simulation, statistical analysis based on empirical data, and spreadsheet calculations, can be used to perform whole-building energy analysis. This chapter focuses on improving whole-building energy analysis methods that employ annual building energy simulations. These methods involve inputting information about a building into a building energy simulation program and running the program to predict energy use. Key participants are energy assessors, building energy analysts, and software developers. NREL improvements to the accuracy of energy analysis methods are translated to industry through three primary mechanisms:

- Field data collection procedures. Published recommendations for collecting data from a house through measurement and observation.
- Simulation protocols. Published defaults and assumptions for simulation inputs that are not directly measured or observed in the field.
- Software test suites. Published suites of tests through which commercial vendors can compare their software results to those of reference software,[2] analytical solutions, and empirical data. Tests can be at the whole-building or isolated-component level.

Figure 2 shows how each mechanism relates to energy analysis in the field. NREL's overall approach for improving the accuracy of energy analysis methods for residential buildings leads to improvements in field data collection procedures, simulation protocols, and software test suites. The approach builds on previous work at NREL to develop a methodological foundation

[2] Detailed, hourly whole-building energy simulation engines such as EnergyPlus, DOE-2, and SUNREL®.

for evaluating the accuracy of whole-building energy simulation programs (ASHRAE 2007; Judkoff and Neymark 1995a, 1995b; Judkoff et al. 2010; Neymark and Judkoff 2004, 2008, 2009a), but also focuses on assessing and improving the accuracy of input data for residential energy analysis methods.

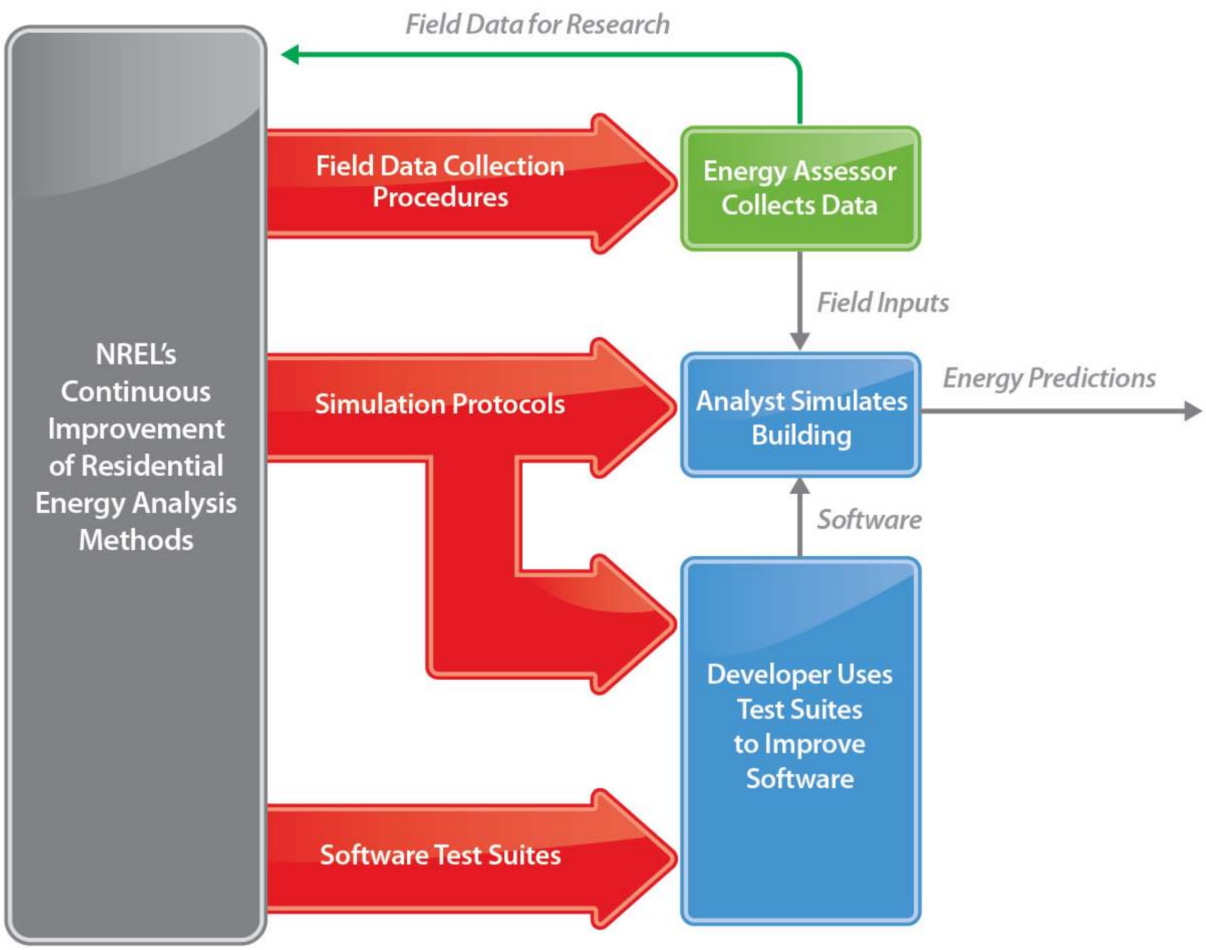

Figure 2: Mechanisms for improving energy analysis methods in the field

2.2 Motivation

Historically, DOE/NREL residential buildings research efforts have focused on high-efficiency designs for new homes. Software has been validated primarily in the context of such buildings. During the past few years, more emphasis has been placed on research related to improving the efficiency of existing homes. Anecdotal evidence and controlled studies have raised concerns about the accuracy of software-based energy analysis for existing homes, especially for energy-inefficient ones.

A general perception is that software-based energy analysis of inefficient existing homes tends to overpredict pre-retrofit energy use and retrofit energy savings. This perception hinders the efforts of companies, utilities, programs, and research institutions that depend on the accuracy of energy analysis predictions. One goal of NREL's overall research is to use empirical data from the field to assess and track the accuracy of reference software. A literature review of previous accuracy studies is presented by Polly et al. (2011) (Appendix A of their report), who showed that:

- Multiple studies confirm that analysis methods tend to overpredict energy use and savings in poorly insulated, leaky homes with older mechanical systems, that is, homes most needing energy retrofits.
- Determining the reason for discrepancies is difficult, because all error sources act simultaneously.
- Many metrics for accuracy are used in various studies and many possible causes of overprediction are described. A single reference containing definitions for error, potential sources of error, and accuracy, developed in the context of comparing simulated building energy use to measured energy use, would be beneficial.
- A method to improve the accuracy of energy use and savings predictions is needed.
- Definitions for error, sources of error, and accuracy are presented by Polly et al. (2011) (Appendix B of their report). These can be used to improve the consistency of calculations for errors and accuracy, which provides for easier comparisons across studies and reduces confusion that arises from having differing definitions in different sources.

Sources of error can be grouped into the following categories:

- Related to the analysis methods
    - Inputs
    - Software.
- External to the analysis methods
    - Processing utility data
    - Quality and consistency of retrofit contractor work.

The process described in this chapter focuses on reducing errors related to the analysis methods (inputs and software)—methods for reducing error external to the analysis methods are not described. A method for improving the accuracy of energy use and savings predictions is described in Section 2.3.

2.3 Method To Improve the Accuracy of Residential Energy Analysis Methods

A continuous process for improving the accuracy of energy analysis for residential buildings is illustrated in Figure 3 and is described in Sections 2.3.1–2.3.7. The first four subprocesses (Sections 2.3.1–2.3.4) improve field data collection procedures, simulation protocols, and software test suites to reduce software and input errors. The last three (Sections 2.3.5–2.3.7) track the impact of improving inputs and reference software by comparing analysis predictions to metered energy use in real homes.

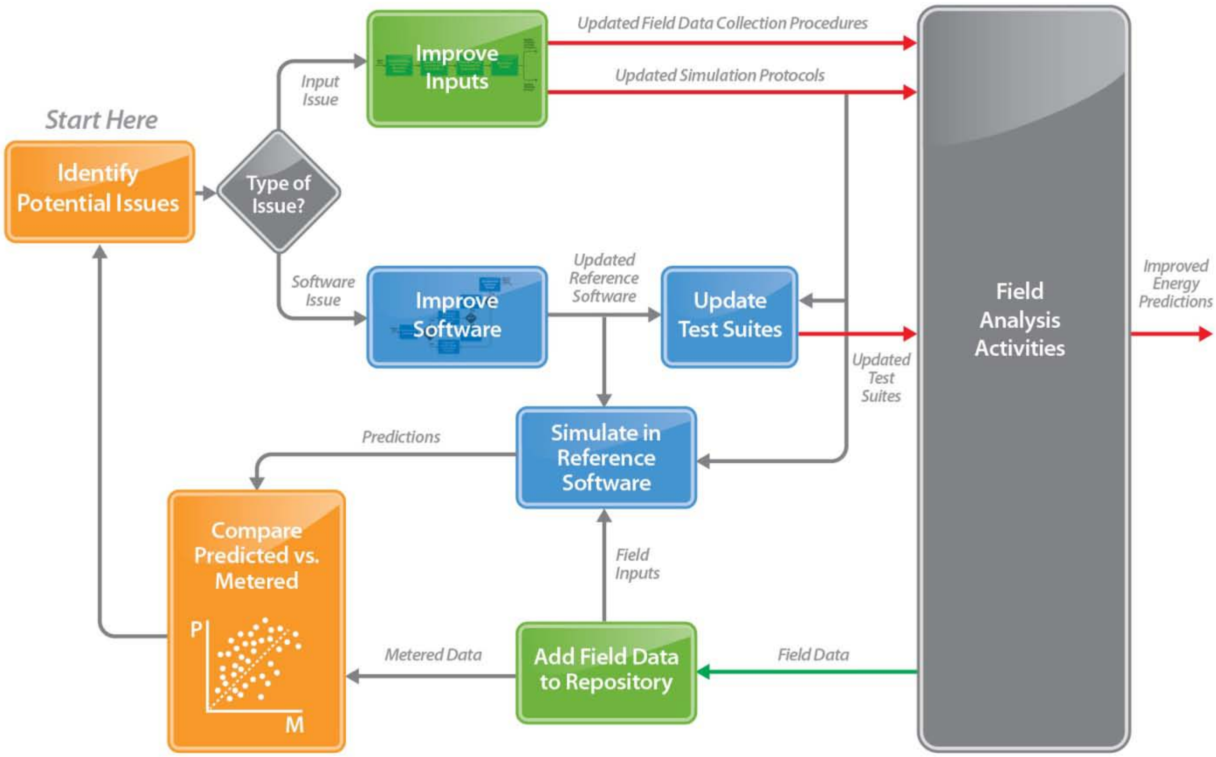

Figure 3: Continuous process for improving the accuracy of energy analysis for residential buildings

2.3.1 Identify Potential Issues

The method illustrated in Figure 3 involves incremental improvements to energy analysis methods by identifying, investigating, and correcting specific input and software issues. The first step is to identify potential issues based on:

- Comparisons of predicted versus metered energy use and savings. With large samples of predicted and metered energy uses, observation and statistical analysis of errors may identify certain building characteristics, occupant types, and building sites where energy analysis methods perform poorly.
- External methods. Hypotheses about specific issues may originate from consensus of modeling experts, field tests, comparative software tests, etc.

Issues with the greatest potential impact on energy use and savings predictions, as determined from the literature and preliminary sensitivity and uncertainty studies, are given priority. A selected issue is typically classified as either an input issue or a software issue. In some cases the classification may be difficult to determine. For example, if the potential issue is heat transfer through uninsulated wall cavities, one could hypothesize that (1) the default input for the air-gap thermal resistance is incorrect; or (2) the current wall heat transfer model in the reference software is not appropriate for uninsulated cavities. Because models define the necessary input values (in this example the 1-D conduction model in the software defines the need to input an air gap thermal resistance), the best approach is to first confirm the model is accurate and then verify that methods for defaulting, estimating, or measuring the relevant inputs are sufficient.

2.3.2 Improve Inputs

Potential input issues are investigated and resolved through a series of steps described by Polly et al. (2011) (Appendix C of their report). Improvements are documented in technical reports along with expected impacts on the accuracy and cost of energy analysis methods. Organizations that maintain field data collection procedures and simulation protocols can choose whether to adopt improvements depending on their specific accuracy requirements and cost limitations.

2.3.3 Improve Software

Potential software issues are investigated and resolved through a series of steps described by Polly et al. (2011) (Appendix D of their report). Software models and solution processes related to the issue are isolated in the code and then validated against empirical data from laboratory experiments and field tests. Improvements are documented in published technical reports, and when possible, implemented in reference software.[3] Improvements to reference software tend to be additions or alterations to the underlying source code and result in compiling updated reference software.

2.3.4 Update Test Suites

Figure 3 shows the overall process that results in improvements to reference software. Comparative test suites should be updated periodically so commercial software developers can verify they have implemented software improvements and simulation protocols correctly.[4] Updating comparative test suites involves:

Updating reference program results using improved reference software.

Modifying or adding test cases that are designed to determine whether specific improvements have been implemented correctly.

Software improvement efforts may also result in analytical and empirical test cases that can be included in software test suites to help developers improve their software.

2.3.5 Add Field Data to Repository

The subprocesses described in Sections 2.3.1–2.3.4 lead to improvements of energy analysis methods. To track their impact on the accuracy of analysis methods, NREL researchers compare analysis predictions to the performance of real homes. The first step is to collect empirical datasets from field analysis activities.

Field data for many residential buildings are collected and stored in a repository. The information collected in the field includes the building characteristics that are relevant to energy

[3] NREL researchers are directly involved in the development of EnergyPlus, which is the primary reference software tool supported by DOE. Improvements to other tools will be made at the discretion of those developing and maintaining the software. Recommendations for improved models and the expected benefits of adopting improvements will be documented and published in technical reports to aid software developers. When selecting reference tools for comparative test suites, NREL will consider tools that are actively implementing bug fixes and model improvements.

[4] Comparative test suites cannot be used to verify that recommended field data collection procedures are being followed.

analysis, as well as metered utility data. The range and resolution of the field data are determined according to established field data collection procedures from labeling, rating, scoring, and retrofit efforts. This information must cover a wide range of residential building types and occupants and span each DOE climate region. When energy improvements are made, building descriptions and utility bill data also cover pre- and post-retrofit conditions.

2.3.6 Simulate in Reference Software

Reference software is used to simulate the residential buildings in the repository. Inputs come from the collected field data, or where appropriate, are calculated or defaulted under the guidance of published simulation protocols. The simulations predict long-term energy use and energy savings for buildings and retrofit packages represented in the field data.

2.3.7 Compare Predicted Versus Metered

Reference software predictions of long-term energy use and energy savings are compared to the metered utility data in the repository. Utility bill analysis methods such as PRISM (Fels 1986) can be used to disaggregate the metered energy use into several estimated end-use bins. This method provides more meaningful and diagnostic comparisons between predicted and metered data.[5] The aggregate accuracy of the energy analysis method is quantified as described by Polly et al. (2011). Because the current versions of the reference software are used in conjunction with current simulation protocols and field data collection procedures, the predictions represent the current state of residential energy analysis methods. If current energy analysis methods are not accurate enough, other potential sources of inaccuracy must be investigated.

2.4 Ongoing Efforts

This section describes ongoing research efforts at NREL and how each effort supports the method presented in Section 2.3

2.4.1 Addressing Potential Issues

NREL has begun to identify, investigate, and correct input and software issues (see Figure 3). A preliminary list of potential issues was compiled and is presented by Polly et al. (2011) (Appendix E of their report). NREL is also engaging the Building America Analysis Methods and Tools Standing Technical Committee to help:

- Identify potential issues.
- Prioritize potential issues.
- Peer review proposed improvements.

A series of short NREL technical reports will document results and recommendations for individual issues. Others will summarize improvements to field data collection procedures, simulation protocols, and software test suites.

2.4.2 National Residential Efficiency Measures Database

In 2009, DOE tasked NREL to develop a National Residential Efficiency Measures Database[6] to create standard technical definitions for energy retrofit measures so software developers and

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[5] Direct comparison of predicted and measured energy use is not without challenges. Uncertainties associated with occupant behavior, weather normalization, and end-use disaggregation make direct comparison inexact. Reddy (2006) provides a good overview of these issues in the context of software calibration. Mills (2004) highlights limitations related to the availability and manipulation of measured data.

[6] See www.nrel.gov/ap/retrofits/index.cfm.

analysts would have access to consistent and vetted input information. The database is publicly available through a Web interface and XML (extensible markup language) feeds. Improvements to measure definitions will be made through scheduled database updates.

To further improve the database, NREL is collecting and organizing field data from residential retrofit programs. These characteristics, consumption, cost, and performance data will help evolve the public-facing, aggregate measure data. As described in Sections 2.3.5–2.3.7, NREL will use the field data repository to assess the accuracy of reference software under the current field data collection procedures and simulation protocols. NREL is striving to make field data available to commercial software developers so they can use large empirical datasets to track the impact of improvements on software accuracy.

2.4.3 Building America House Simulation Protocol

NREL will continue to maintain and improve the *Building America House Simulation Protocols*[7] (Hendron and Engebrecht 2010). Improvements will be documented in published updates, and can be adopted by other organizations that maintain simulation protocols.

2.4.4 BEopt Diagnostic Test Suite

To facilitate rapid comparison of research-level, whole-building simulation engines, NREL developed the BEopt Diagnostic Test Suite. BEopt is a building energy optimization tool that currently interfaces with two simulation engines: EnergyPlus and DOE-2.2. Because BEopt is designed to evaluate alternative energy efficiency options and retrofit measures in new home construction and existing buildings, respectively, a comprehensive range of building characteristics, site conditions, and occupant behavior can be simulated automatically and systematically. This tool enables NREL researchers to identify and understand differences between simulation engines by eliminating discrepancies caused by inputs. Discrepancies between simulation engines may indicate potential software issues where analytical verification and empirical validation are needed.[8]

2.4.5 Building Energy Simulation Test

NREL researchers have developed an overall building energy software validation methodology that includes analytical solutions, comparative testing, and empirical data (Judkoff and Neymark 2006). The methodology has been adopted by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 140 and is discussed in the ASHRAE Handbook of Fundamentals, along with the pros and cons of the analytical, comparative, and empirical methods (ASHRAE 2005). NREL researchers have written several building energy simulation test (BESTEST) suites (see Judkoff and Neymark 1995a, 1995b; Judkoff et al 2010; Neymark and Judkoff 2002, 2004, 2008, 2009a, 2009b; Neymark et al. 2005). Most have used comparative methods where software predictions are evaluated versus reference software predictions, and versus analytical solutions and verified numerical solutions when possible. These test suites have helped software developers diagnose and fix discrepancies caused by physical algorithms and coding. However, because there is no truth standard in comparative testing, such a suite is only as good as the reference software that is the basis for comparison. Also, analytical solutions and verified numerical solutions represent a mathematical truth

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[7] Previously called the *Building America Benchmark*.

[8] Agreement between two simulation engines does not ensure agreement with the true performance of buildings; some models and solution processes in both programs may be incorrect relative to the true physical behavior of the building system. Possible software issues are thus identified by applying other techniques in addition to comparative testing.

standard, but not necessarily a physical truth standard. NREL is therefore interested in addressing empirical validation, the third component of the overall validation method.

NREL will develop test suites that can be used to directly compare software predictions to empirical data. Classes of empirical data include:

- Laboratory and field test data for isolated building subsystems. Empirical datasets collected to validate software algorithms may be presented in a standardized form as empirical test cases. Such data, which are collected from highly controlled experiments designed to minimize input error, can be used to validate algorithms corresponding to different subsystems and the interactions of subsystems in building energy simulation programs.
- Building characteristics and utility bill data. Empirical datasets collected to support the National Residential Efficiency Measures Database may also be presented in a standardized form to aid software developers in the evaluation of their tools against measured data. This type of data, which are collected from field analysis activities where input errors are not tightly controlled, can be used to assess the performance of software as it is typically used in the field.

The purpose of developing software test suites is to provide tools for developers to improve the accuracy of their software. Therefore, test suites should be diagnostic (allow users to determine the sources of inaccuracy) and cover a range of building characteristics, site conditions, and occupant behaviors. NREL will periodically update BESTEST comparative suites to reflect improvements to simulation protocols and reference software (see Section 2.3.4).

2.4.6 Estimating Uncertainty in Energy Analysis Predictions

Whether an input is defaulted, estimated, or measured, there is some uncertainty as to how closely the input value matches the "true" value. These errors in input propagate through a building energy simulation program to produce errors in output. Because there will always be some uncertainty in input values, there will always be some uncertainty in software predictions.

In the process of addressing specific input issues, NREL will estimate the uncertainty of many input values for software. NREL is also exploring methods to estimate the uncertainty and natural variability in energy assessment data through controlled field studies. As more information is collected, NREL will use batch Monte Carlo simulation methods to estimate the overall uncertainty in predicted energy uses and savings for a variety of conditions. Understanding the variability and uncertainty in predictions will help establish expectations for software accuracy and identify the relative importance of each input parameter. Results from this research will lead to more accurate, streamlined, cost-effective energy assessments.

2.4.7 Field Testing

NREL and Building America field tests will collect data that can be used to validate software models (Section 2.3.3) and improve input collection methods (Section 2.3.2).

2.4.8 Thermal Test Facility Experiments

Measurements taken in the NREL Thermal Test Facility will be used to improve the accuracy of models and inputs for various HVAC and domestic hot water systems. For example, laboratory tests will yield performance maps for various new and existing air-conditioning systems, which will help us validate software models and improve default input parameters. These detailed performance characteristics will be added to the National Residential Efficiency Measures Database as they become available.

2.4.9 Field Data Measurement Technology Research and Development

In the process improving field data collection procedures (Section 2.3.2), gaps may be identified that demonstrate the need for measurement technology research and development. NREL plans to develop and test alternative measurement technologies that will lead to more accurate, more affordable, faster, and safer energy assessments.

2.5 Final Remarks

A method for improving the accuracy of residential energy analysis methods has been presented. Application of the method will result in improvements to:

- Field data collection procedures
- Simulation protocols
- Software test suites.

Energy assessors, analysts, and software developers can incorporate these improvements into their activities, resulting in more accurate energy analysis in the field. More accurate energy analysis methods will improve the success of energy-efficient design, labeling, scoring, rating, and retrofit efforts.

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3 Deep Retrofits

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3.1 Goal

This chapter supports the Residential Integration road mapping project for DOE's BTP and addresses residential building research needs in areas where ORNL has historically had a lead technical responsibility:

- Utility-led deep energy retrofits
- Heating, ventilating, and air-conditioning (HVAC)
- High-performance envelopes (roofs, walls, foundations, and moisture management)
- Envelope materials research
- Validation of computer-predicted versus measured energy consumption
- Materials characterization.

Also emphasized in these discussions are accelerated development of utility-led whole-house energy retrofits, thermal distribution, smart-grid-enhanced deep energy retrofits, and new maximum-high-performance residences exceeding anticipated IECC 2015 standards.

This material includes inputs from Tennessee Valley Authority (TVA), manufacturers of HVAC equipment, envelope materials, and energy management systems.

3.2 Background

ORNL has worked closely with TVA on two projects that have produced a wealth of information about residential energy efficiency: 3 research houses with simulated occupancy since June 2008 (the Campbell Creek houses), and 10 occupied deep-retrofit houses since March 2010. In both cases, the homes were selected after a TVA demographic analysis of its 9 million customers to determine the type, size, and characteristics of homes that are statistically near the average single-family residence. A most significant finding from analysis of the first year of very detailed performance data is that a 40% energy saving retrofit as defined by the Building America protocol for new houses (Hendron 2008) was attained at an incremental cost of $10,000 financed by a 10-year loan at 6% interest, which meets the Building America neutral-cash-flow criteria (energy cost savings exceeded the amortized cost of the loan). Loans with similar terms were available from the local utility that serves the Campbell Creek research houses at the time of this writing.

TVA has learned much as it expands its In-Home Energy Evaluation Program, and these lessons have strongly influenced this chapter by crystallizing the research that is needed to attain much greater energy savings from utility-led residential retrofits.

ORNL is also collaborating with PNNL on a 50-home energy retrofit project in humid, mixed-humid, and marine climates. Specifically, ORNL is leading the technical assistance and coordination for 10 homes that will undergo energy retrofits in the Atlanta area.

3.3 Summary of Research Needs Identified

3.3.1 Utility-Led Deep Energy Retrofits

Review Manual J and Manual D with respect to variable-capacity equipment now available for the residential market and prepare a report suggesting how to revise to cover this equipment.

- Duct Issues
    - Develop the technology to downsize abandoned ducts.
    - Conduct a broad search for duct sealing techniques, employ the top three techniques in well-characterized deep-retrofit houses, and measure performance for one year.
    - Develop a duct model for residential retrofit designers.
    - Instrument at least three well-characterized deep-retrofit houses with smart controls that have the potential to self learn, use homeowner input, and interface with the electric utility for demand-side management.
- Electric utility-sponsored home retrofits research.
    - Identify optimum whole-house retrofit packages for at least one generating electric utility based on data from research houses and document the approach for replication by other electric utilities.
    - Validate energy audit software with measured data. Use whole-house and submetered energy consumption data from occupied and simulated-occupancy homes to generate DOE Energy Home Score and Home Energy Rating System (HERS) values and compare to normalized measured energy savings.
- Pilot the DOE Home Energy Score Program in at least 5 of the 156 TVA distributors' service territories.
    - Implement for one full year a single major retrofit package in all three Campbell Creek research houses with simulated occupancy, and a matrix which reflects average, energy-saving, and energy-wasting occupants and average envelope, retrofitted average, and very-high-performance envelope houses will be filled out with the resulting energy savings.
    - Work with key manufacturers to gather the information needed for software developers to accurately reflect the performance of advanced technologies operating in the research houses in future revisions of audit and simulation tools commonly used by retrofit auditors.
    - Develop reliable partners from among stakeholders in the building and manufacturing industries, financial institutions, and real estate businesses to help validate annual and peak load energy savings for use in electric utility resource planning models.
    - Conduct home retrofit research to enhance the effectiveness of ongoing utility-sponsored programs, based on data from the Campbell Creek houses and the 20 occupied deep-energy retrofit houses.

- Identify needed data that utilities could collect before, during, and after retrofit.
    - Develop the protocol for local third-party case studies with homeowner satisfaction feedback before and after measured savings are shown to the homeowner to strengthen the effectiveness of marketing and incentives.
    - Include a home retrofit plan on the utility bill. This should include target energy savings, progress toward the final goal, and a reward when the goal is achieved. Use the data from the research houses to develop a method for generating this type of information for utilities to use for monthly feedback to homeowners.
    - Conduct research to provide interval data, smart meters, and in-home displays to enable "Customers as Partners" on systems goals (e.g., delaying the need for new generation capacity).
    - Provide the residential retrofit research to help expedite at least one utility's effort to "go through a program development process until you crack the code with the silver bullet solution." (Frank Rapley, TVA 2010).
    - Work with local government agencies to provide an electronic tool box on Chamber of Commerce websites, and develop a community residential energy retrofit savings competition with case studies documenting homeowner satisfaction with energy savings, comfort, and IAQ.
    - Considering house life-stage triggers requiring remodeling or system replacement, determine, once the life-stage trigger kicks in, how to deliver each major component of a whole-house retrofit faster, cheaper, and deeper to achieve greater peak and annual energy savings. Develop a method for generating customized home-retrofit plans to be included in monthly utility bills. A tool needs to be developed that can process the energy use, age and efficiency of major energy consuming systems, and the homeowners' remodeling desires, energy saving priorities, and financial situation and generate a phased whole-house energy retrofit plan.
    - Work with a manufacturer partner to develop low-cost enhanced control logic for air cycler controllers and demonstrate in research houses.

3.3.2 Research To Address Factors Affecting Availability of Commercially Viable Equipment With Variable-Capacity Compressors That Achieves Installed Performance That Meets DOE Goals for High Part-Load Efficiency and Dehumidification

- Conduct side-by-side field comparisons of variable-speed heat pump options with operation optimized for annual energy savings versus peak load reductions.
- Field test to compare advanced vapor compressive cycles to inverter technology with variable refrigerant flow to central single indoor units and multi-split systems.

3.3.3 Significant Envelope and Thermal Distribution Energy Savings Beyond IECC 2012 and IECC 2015

- Develop an industry-accepted protocol for establishing a National Opaque Wall Rating Label. Carry one envelope system through the procedure and present to DOE and the U.S. Environmental Protection Agency (EPA) for approval.

- Develop a structurally insulated panel (SIP) kit for a very-high-performance affordable new house that meets anticipated IECC 2015 standards.
- Develop a process for manufacturing exterior-applied retrofit SIP nail-base panels that meet anticipated IECC 2015 roof and wall requirements.

3.3.4 Foundations

- Develop a foam glass bottom-course insulated block system to minimize thermal shorts with above-grade exterior wall brick cladding.
- Conduct laboratory tests to characterize capillary wicking in concrete foundation walls, and use the data to develop a simple homeowner test kit to determine where interior insulation is appropriate.
- Perform side-by-side testing of interior basement insulation having very permeable facings in the mixed humid climate to generate validation data for hygrothermal foundation models and guidelines in the draft DOE *Foundations Design Handbook* (2011).
- Test Class 1 and 2 moisture retarders in below-grade walls in the field in mixed-humid climates and via modeling analysis.

3.4 Major Research Issues Associated With Deep Energy Retrofits

3.4.1 Utility-Led Deep Energy Retrofits

3.4.1.1 System Capacity

New high-efficiency HVAC systems with variable-capacity compressors are performing well in research houses. A very attractive feature of these systems is that they impose far smaller oversizing penalties than traditional systems do, and the HVAC installer can worry less about historic rightsizing issues. However, wasting retrofit funds on more HVAC capacity than necessary constitutes a barrier to achieving maximum affordable energy efficiency. To allow proper sizing of these advanced heat pumps in high-performance retrofits, Manual J and Manual S need to be revised to provide comprehensive guidance. Careful field data collection, heat pump model development, and computer simulation validation need to be conducted from multiple test sights surrounded by whole-house performance measurements to generate well-characterized datasets.

3.4.1.2 Duct Issues

The November 2–4, 2010, Building America planning meeting identified major space-conditioning gaps after whole-house retrofits as (1) design and installation of properly sized ducts, (2) moving ducts into conditioned space, and (3) guidelines for sealing inaccessible ducts. The "Space Conditioning and Hot Water" breakout named as its second-highest priority fixing ducts during whole-house retrofits by proper sizing.

- **Duct downsizing.** Even after extensive envelope improvements in both R-value and airtightness, and homeowners' investments in high-efficiency equipment, hard-to-reach ducts are being left in place. These ducts create the weak link in the chain. Could a system be developed that effectively downsizes these abandoned ducts, for instance by running a (puncture-resistant) balloon from the central plenum to the supply and return registers and selecting the degree of inflation according to a Manual D calculation? Injecting foam in the void between the properly sized balloon and the old duct could create a permanent down-sizing, allowing the balloon to be pulled out and used on the next job. Something similar is done to reline and insulate old steam lines in industrial facilities.

- **Duct sealing.** A large fraction of ducts in deep retrofits will be left in unconditioned spaces. We now understand that these ducts are rarely sealed properly in the traditional way with mastic. Instead, a lot of mastic tape is being used, and the tedious nature of in situ duct sealing makes it prone to lower quality work than is desirable. Duct blasters can diagnose leaks, but time spent on testing is time lost time for duct sealing. To address this problem, a survey of duct-sealing techniques should be done, followed by testing and performance measurement of several promising innovative systems in deep-retrofit houses. A mastic that turns blue if a high-velocity air film is nearby would be the type of real-time visual feedback that could promote consistently high-quality, effective duct sealing. Shrink wrap duct insulation would be another technical breakthrough.
- **Duct insulation.** Guidelines for duct insulation after envelope retrofits are also needed. To develop accurate guidance, it is necessary to develop a good duct model based on several of the Building America deep-retrofit houses and follow up with extensive monitoring to allow validation with measured data. Once calibrated, this tool should be the backbone for supporting the duct sealing and insulating guidelines.

3.4.1.3 Smart Grid and Home Automation

On March 22–23, 2010, ORNL held a meeting with more than 200 stakeholders to help plan the most promising building energy research for the next 10 years. Participants in the "Residential Whole Building Integration" breakout represented electric utilities, manufacturers of appliances, HVAC, and control systems, several national laboratories, Building America teams, and leading energy efficiency builders in eastern Tennessee. The most important project was "Inter-operability of smart energy devices (appliances, HVAC, lighting) with smart meters, need to characterize energy peaks," to focus on standardization, communication protocols, streamlined process for commissioning, national laboratories providing third-party testing in the research houses, and partnering with organizations working on automation standards.

The national laboratory representatives at the November 2010 Building America planning meeting also selected this project area as number one ("Smart Controls" with cooperative control of miscellaneous loads and self learning capabilities). The group indicated that to address this issue the test houses should be able to simulate different grid signals and interfaces to grid capabilities, and should be used for comparing communication protocols and developing a whole-house smart-grid interface. Partners that should be included are the Association of Home Appliance Manufacturers, trade associations in consumer electronics, ASHRAE (BacNet), the Electric Power Research Institute, TVA, the PV/inverter industry, the Society of Automotive Engineers, and manufacturers of home energy management systems.

3.4.1.4 Electric Utility-Sponsored Home Retrofits and Support of Integrated Resource Planning

After the federal boost to energy retrofits through the American Recovery and Reinvestment Act, the most likely industry to carry the momentum into a sustainable market for whole-house energy retrofits is the utilities. At a Building America expert meeting in Chicago on November 16, 2010, a key observation was that R&D is needed to lower the generating utilities' risk in engaging in home retrofit programs, particularly in light of their other options for providing reliable, safe, low-cost energy. In its 2010 Integrated Resource Plan (IRP), TVA considers achieving short-term energy efficiency and demand-response goals by expanding its residential retrofit incentive program to help attain 1400 MW of peak power savings by 2012, accelerating coal plant layups totaling 4730 MW by 2015, and delaying the need for the Bellefonte Nuclear Power Plant Unit 1 from 2018 to 2022. For energy efficiency to gain the confidence of utilities, energy savings predictions must be reliable. Several important research products are critical to addressing this need.

- **Balance of peak kilowatt and kilowatt-hour savings.** The business driver for electric generating utilities is to offset the revenue lost from selling fewer kilowatt-hours with the savings from not expending resources for future generation capacity. Utilities will have the strongest interest in incentivizing residential retrofits that accomplish this goal. What are the optimum retrofit packages for generating assured peak kilowatt savings to offset the lost revenue from kilowatt-hour sales? Research is needed to identify whole-house retrofit packages for at least one generating electric utility based on hourly submetered research homes, and to document the approach for other electric utilities to follow to generate optimum packages for their climates and economic markets.
- **Validation of energy audit software with measured data.** The area that drew the top seed in the tools breakout session of the November Building America planning meeting was: "Validation of Software Standards for DOE recognition of audit software tools. Define accuracy, credibility, and capability." A significant barrier to whole-house energy retrofits is lack of confidence in predicted energy savings due to large variances in modeled performance. Predicted energy savings from energy audit and design tools can predict annual energy consumption and savings quite accurately. However, when individual houses are evaluated on the basis of their as-built and installed energy efficiency characteristics ("asset-evaluated"), there is often considerable inconsistency between predicted and actual energy use. As the home energy retrofit industry is stimulated, homeowners' and investors' confidence in expected savings and return on retrofit investments must be established to promote long-term sustainability. Whole-house and submetered energy consumption data from occupied and simulated-occupancy homes should be used to provide Home Energy Score and HERS values, these values compared with normalized measured energy savings representative of asset performance, the sources of discrepancies identified.
- **TVA/ORNL pilot of DOE's Home Energy Score Program.** TVA and ORNL have worked together on residential research since 2002, aiming to scale up results from 18 test houses to have a major impact on the TVA portfolio of demand-response and energy saving options. Through the pilot of the Home Energy Score Program, TVA and ORNL propose to identify best practices to guide the program as it rolls out to other utility-led programs.

  TVA's In-Home Energy Evaluation Program home evaluators are certified by the Building Performance Institute (BPI), conduct a pre-retrofit walkthrough evaluation and post-retrofit inspection, currently collecting most of the 45 inputs needed to generate the Home Energy Score value of 1–10.

  The proposal is to generate Home Energy Scores before and after participating homes receive audits from the TVA In-Home Energy Evaluation Program. This score would be used as added incentive to encourage participation by more homeowners. The motivation to the homeowners is that they would have a certified national label, which TVA hopes will evolve into a recognized added value when the home is sold. This would mitigate homeowners' concerns about the value of their investments beyond the TVA incentives. It also would allow TVA to offer tiered incentives based on performance. Currently all eligible retrofits can be put toward the $500-per-house incentive. This proposal calls for the following:

- Organize and fund an educational event for contractors on TVA's Quality Contractor Network in the pilot area. This would include BPI training, systematic retrofit approaches, and presentation of results from the research houses under study by ORNL and TVA.
- Offer the Home Energy Score pilot to all five TVA distributors whose territories have DOE/TVA/ORNL deep-retrofit research houses under study by ORNL.
- Generate a predicted post-retrofit Home Energy Score during the initial evaluation and provide general information about how to attain a higher score by investing in a variety of retrofit packages.
- After the walkthrough inspection, change the model inputs to reflect the properly installed retrofits and generate the higher Home Energy Score.
- Leave the BPI-certified score with the homeowners and urge them to show this score to the real estate agents/appraisers before placing their home on the market.

TVA/ORNL will evaluate the pilot after one year, as follows:

- Evaluate the impact of tiered TVA incentives, ranging from $1000 for 3-point improvement to $2500 for 5 or more points in addition to the incentives for retrofits are already in place like $2000 per house that is likely to result in about 20% energy savings. This is the current opportunity in four of the largest TVA distributors in southwestern Kentucky. We propose that DOE help find the sweet spot to encourage homeowners to chase after 30%, 40%, and 50% savings. The goal would be to align this incentive with the utilities cost savings from avoided electric generation capacity and purchased power expenses from other utilities. At this time TVA uses $0.045/kWh saved for a 10- to 15-year period.
- Evaluate the increase in participation and retrofits from this expanded offering compared to current program.
- Compare predicted energy savings of participants in the pilot to measured post-retrofit savings, and to the 10 deep retrofits under study by ORNL/TVA in the same areas and housing markets.

  The three Campbell Creek research houses are providing great insight on prioritizing retrofit measures based on energy savings with average American energy-usage patterns. The experimental plan for this facility has always been to rotate simulated occupant energy behavior (wasting, average, and conserving) in each month. TVA and ORNL propose to provide a robust basis for predicting aggregate energy usage for utilities' integrated resource planning by implementing the same major retrofit package in the three Campbell Creek houses, measuring their performance for a full year, and providing the data to fill in the resulting energy savings in Table 1, which accounts for asset quality and occupant behavior.

Table 1. Matrix of Three Levels of Energy Performing Houses and Three Levels of Energy-Consuming Occupants

Occupancy/House Type	Builder	Retrofit	New High Performance
Energy waster	X	X	X
Typical homeowner	X	X	X
Energy conserver	X	X	X

These data would go a long way toward building a reliable model that would allow direct optimization of TVA's balance of supply capacity, energy demand, and savings investments. The research approach would be to build this model for at least one of TVA's major metropolitan distributors. After the approach is validated with DOE's assistance, the electric utility would likely provide funds to and scale up the model to all 155 distributors.

- Integrate next-generation technologies into energy audit and simulation software. Variable-capacity heat pumps, heat pump water heaters, ENERGY STAR® washers, horizontal geothermal loop systems, and advanced MELs are all examples of technologies that are in test houses but are not accurately modeled in audit and simulation tools. TVA/ORNL propose to work with GE, Daikin, Mitsubishi, and Trane to gather information to make performance data on these technologies available to software developers for inclusion in future revisions to whole-building simulation tools commonly used by retrofit designers.
- Develop reliable partners from among stakeholders in building and manufacturing industries, financial institutions, and real estate concerns to help validate Generating Electric Utility Resource Planning Models. Participation from such partners is essential to developing credible predictions of sustained energy savings that are scalable across an array of home types and energy use behavior representative of aggregated residential markets.
- Home retrofit research to enhance the effectiveness of ongoing utility-sponsored programs.
- Identify needed data that utilities could collect during the retrofit, not just before and after.
    - Determine how utilities could encourage more homeowner involvement. Develop the protocol for local third-party case studies with homeowner satisfaction feedback before and after data on savings are collected and shown to the homeowner. These case studies will strengthen the effectiveness of marketing and incentives.
    - Include a home retrofit plan on the utility bill. This should include target energy savings, progress toward the final goal, and some type of reward when the goal is achieved. Using the data from the research houses, develop a method for generating this type of information for utilities to use for monthly feedback to homeowners.

- Provide third-party interval data, smart meters, and in-home displays to provide customers with more information about their energy consumption and its relation to energy retrofits, enable direct communications from utilities, and create more choices. The goal of the research is to enable utilities to provide information that makes customers feel more like partners on systems goals such as accelerated retirement of old coal-fired power plants and delaying the need for new nuclear facilities.
- Provide the residential retrofit research to help accelerate at least one utility to "go through a program development process until you cracked the code with the silver bullet solution" (Frank Rapley, TVA 2010)
- Working with local entities:
  - Citizens' electronic residential retrofit tool box on Chamber of Commerce websites.
  - Community energy retrofit savings competition. The core of this effort is to generate local case studies with solid energy performance data and homeowner testimony of satisfaction with not only energy savings but comfort and IAQ.

3.4.1.5 Deep Energy Retrofit Projects Triggered by Homeowner Needs

R&D is needed to identify how to deliver each component of a whole-house retrofit faster, cheaper, and deeper (for greater peak and annual energy savings). The national laboratory brainstorm at DOE in November 2010 concluded that one of the three top-priority research projects was "the drive-by audit"—a low-cost, automated, accurate, diagnostic process and audit. The desired features of this audit focus on less inconvenience and more information and choices for the home owner and relaxing the tension between accuracy and expense.

Utility-sponsored in-home energy evaluations, retrofits, and inspections need to lead toward a phased, whole-house energy retrofit plan triggered by home life stages such as remodeling and system replacement, and matched to homeowners' available cash flow over a 3-5-year time horizon. Personalized retrofit plans should be included in homeowners' utility bills. A tool is needed that can process the energy use, age, and efficiency of all major energy-consuming features of the home along with the homeowners' remodeling desires, energy saving priorities, and financial situations, and generate a phased whole-house energy retrofit plan. Research is needed to determine a set of rules for optimizing the sequencing of individual retrofit steps phased to match homeowners and home life stages.

In addition to investigating approaches to providing a low-cost "drive-by" audit, home energy assessors need better diagnostic tools to adequately characterize home conditions. Presently, only qualitative assessments regarding the insulation level in walls can be made with infrared thermal cameras. These assessments serve as an added layer of data uncertainty in home energy analysis software, which helps to preclude the determination of accurate and reliable home energy consumption and saving potential. Therefore, research is needed to develop a diagnostic tool that can be used to deduce the R-value of walls in existing buildings. This tool could help provide for wall R-values what blower-door analysis has provided for envelope air infiltration.

To support utility integrated resource planning, utility home audits should be integrated with home energy ratings based on the rating system that provides the most reliable, meaningful, useful information. TVA is contemplating the adoption of the best home rating procedure to incorporate into its growing in-home energy evaluation program. The percentage energy savings measured at the three Campbell Creek houses correlated very well with the HERS Index developed for each house. Compared to the base-case builder house with a HERS rating of 101, the retrofit house with a HERS of 68 consumed 67% and the very-high-performance house with a HERS rating of 34 consumed 35% over a full year of detailed measured performance. All retrofit research houses should have home energy scores calculated and compared (on the basis of source energy savings) to other houses in the same climate bins.

3.4.1.6 Low-Cost, Enhanced Control Logic for Air Cycler Controllers

A major concern that has been uncovered in the very-high-performance (tight) houses under study is that their dryer ducts become plugged with lint more than those in conventional housing. The dryer sucks 150–250 cfm from the laundry room. If the surrounding space is very airtight, less air will be pulled into the dryer, which will result in slower velocities in the dryer duct and more lent depositing on the outlet vent. This finding begs for demand-enabled ventilation capabilities. When the electric or gas dryer or gas stove and all other gas appliances that are not pulling combustion air from outside the envelope are running, more mechanical ventilation is needed. Secondly, when the simple air cycler is used to open a motorized damper to bring in fresh air, it is totally dependent on the suction in the return plenum. Because suction can vary with variable-speed indoor fan motors, a feedback loop is needed to adjust the time of opening the fresh air damper depending on the HVAC indoor fan mode of operation. Continuous adjustment is needed to account for the varying amount of time the fan unit will be operating at high and low speeds. With a manufacturer partner develop low-cost, enhanced control logic for air cycler controllers.

3.4.2 Factors Affecting Availability of Commercially Viable Residential Heat Pumps and Air Conditioner Units for New and Retrofit Application With Installed Performance That Meets DOE Goals for High Part-Load Efficiency and Dehumidification Performance

This will specifically address variable-capacity compressors.

An informal session on variable-capacity heat pumps and AC units was held at the 2010 ACEEE conference. Manufacturers claim that variable-speed heat pumps and AC can be run to optimize overall annual efficiency, provide intelligent peak load reduction (e.g., modulating down to 75%), eliminate inrush current, and operate at a power factor near 1.0. This session of about 30 experts from HVAC manufacturers and electric utilities generated several research questions that address optimal selection metrics, whether this equipment should be optimized for full or part load, options and controls for its use for demand-response programs, and other issues.

3.4.2.1 Side-by-Side Field Comparisons

The most important action suggested by this knowledgeable group is conducting year-long, side-by-side field comparisons of several variable-capacity equipment options while operations are optimized for annual energy savings or for peak load reductions. Providing groups interested in maximum annual energy savings and peak savings with well-characterized field site data will go a long way toward answering these questions and ensuring that optimized HVAC units will be available to meet the near-term demand expected from a rapidly expanding retrofit market.

3.4.2.2 Zoned Concept

The research results from the first year of detailed measurements in the Campbell Creek test houses show that the zoned concept (one unit servicing each floor) controls temperature and humidity well. Smaller single-unit central air systems with zoned ducts are not showing first-cost savings; they also are having higher maintenance costs. Additional field testing is needed to compare advanced vapor compressive cycles to inverter technology with variable refrigerant flow to both central single indoor units located in mechanical rooms feeding central duct systems, and ductless multi-split systems with individual indoor units distributed in each zone of the house.

Research findings from the Campbell Creek houses have lead to a retrofit of a 7-indoor-unit, single-outdoor-unit multi-split. Continued testing is needed to explore the tradeoffs of various optimized distributed space conditioning strategies. This need was voted the top research opportunity by the "Space Conditioning and Hot Water" breakout session at the November 2010 Building America planning meeting.

3.4.3 Envelope and Thermal Distribution Energy Savings Beyond IECC 2012 and IECC 2015 Code Goals for New Housing and Deep Energy Retrofits

Envelope research opportunities for high-R walls, roofs, and foundations: IECC 2012 will increase wall R-values in Zones 3 and 4 from R-13 to R-20, in Zone 5 from R-19 to R-20, in Zone 6 from R-19 to R-20+R-5, and in Zones 7 and 8 from R-21 to R-20+R-5. In addition 2012 IECC will require all homes to have blower door testing and the air leakage not to exceed 5 ACH50 (air changes per hour at 50 Pascal) for climate zones 1–3 and 3 ACH50 for all other climate zones. The most advanced framed house at Campbell Creek meeting all the standards for "Fully Aligned Air Barriers and Air Sealing" in EPA's ENERGY STAR Homes checklist, measuring just under the limit with 2.4 ACH50. If DOE and partners are successful in proposed changes for IECC 2015 these required R-values and airtightness requirements are likely to climb even higher. The research needed to generate energy savings beyond these levels fall into two areas: moisture management and advanced envelope systems.

3.4.3.1 Moisture Research and Other Research Needs Affecting the Health, Safety, and Durability of High-R Envelopes, Including The Need To Expand the Scientific Basis for These Areas

- **Moisture management research.** Although since the late 1970s building efficiency brainstorming sessions around the world have emphasized the need for hygrothermal models for efficient use with commonly used building simulation tools, it has still not been accomplished, particularly for foundation analysis. The word moisture was mentioned in the November 2010 Building America brainstorming session 21 times. WUFI needs to be seamlessly linked with EnergyPlus.

  Spray foam for attics, crawlspaces, and basements is taking off with much success across the country, yet failures typically leading to moisture management issues are popping up and need to be analyzed, categorized, generic faults identified, and all documented in best practice guidelines and sprayer certification training.

  External envelope solutions that enhance moisture control need to be developed.

- **Health, safety, and durability of high-R envelopes.** The heavy focus on air-sealing existing homes will affect health and safety unless precautions are taken. The solutions for radon problems in new homes have been developed, but this problem is more difficult to manage in existing homes. One idea that needs further research and development is a solar-powered sub-crawlspace, membrane depressurization fan.

On-demand ventilation needs further development. To attain the high performance required beyond the 50% solution suggested for IECC 2015 will most likely require demand ventilation that can sense occupants and the operation of unvented gas appliances, electric and gas dryers, and exhaust fans.

Research is also needed to address fire and flame spread issues in attics, crawlspaces, basements, and external walls.

- **Expanding the scientific basis for developing high-performance foam materials for building envelopes.** We are not far away from banning from our building materials all compounds with the potential to cause global warming. These fourth-generation products need early field testing to avoid problems of shrinkage, lower R-values per inch, and more restrictive acceptable application temperatures.

Properties of foam insulation must be optimized differently depending on whether they are used for attics, walls, or foundations. Designer foam is needed that can apply customized properties from a single nozzle: conductivity, fire resistance, structural, and permeability to vapor and air.

3.4.3.2 Advanced Envelope Material And System Performance Targets and Specifications for Fire Resistance (Typically Covered by the Manufacturer), Permeability, Durability, Termite Resistance (ORNL Has Conducted Limited Termite Resistance Testing, but This Is Typically a Manufacturer Covered Expense), Thermal Resistance, Etc.

- An expanded materials and systems characterization program with DOE goals to exceed the proposed 2015 IECC of whole-house savings of 50% above IECC 2006 at installed costs 15% less than advanced framing with a continuous air barrier, insulated headers, insulated corners, sill-plate sealing, top-plate sealing, and wind baffles, and commercially available insulated sheathings and cavity insulations can provide.

- A systematic building materials and systems evaluation protocol, similar to the DOE Lighting Caliper program. In 1995 ORNL first proposed a National Opaque Wall Rating Label, (J.E. Christian and J. Kosny, Towards a National Opaque Wall Rating Label, U.S. DOE Building Thermal Envelope VI Conference, 1995). Today all the tools and standard measurement protocols are available to completely cover envelope system, durability, thermal resistance, and airtightness, and ORNL proposes to perform a series of laboratory tests concurrent with the construction of a single demonstration house to establish an industry-accepted protocol for attaining a National Opaque Wall Rating Label. One envelope system will be carried through the full procedure and presented to DOE and EPA for approval.

- 2015 New House Now! Increasingly stringent energy standards are likely to pose compliance challenges, particularly to smaller builders that simply cannot construct 50% more efficient houses using traditional construction techniques. This will create the need for premanufactured roof, wall, and foundation panel systems such as SIPs for above- and below-grade applications. Potentially SIP kit houses could be shipped precertified to exceed IECC 2015 standards. ORNL's studies of the four Wolf Creek houses have shown that SIPS could be constructed faster; attain better airtightness, and save more energy than three other houses with advanced envelope systems. A great deal has been learned and SIP clearly outperforms optimal-value wood-frame construction in airtightness, energy savings, and speed of construction. Every SIP house that ORNL has been involved in since 2002 has measured airtightness below 2 ACH@50. None of the crews have been "experienced" SIP installers.

The only category that SIP construction historically struggles with is installed first cost compared to advanced framing systems, but this was with much lower R-value and airtightness requirements than those needed to go beyond IECC 2015. Custom SIP houses require in most areas a structural engineer's design and stamp, but an affordable SIP kit with a complete open floor plan, factory-installed electric wiring, home-run plumbing, and central utility wall removes that barrier. With results and structural analysis from shaker table experiments completed, a design and cost report will be completed for a single 1600–2000-ft2 SIP kit house that will satisfy 130-mph wind and seismic criteria for construction permit approval. Construction-ready design drawings were previously completed under DOE research funding.

A strong network of industry partners has been built as a result of DOE-funded research spanning from 2002 to 2011. A set of electronic, downloadable housing designs and cost reports for affordable SIP/insulating concrete form (ICF) kit housing for new and retrofit applications could help educate small builders and perhaps help them to recover from the housing recession. ICF foundation systems are ideal for setting SIP above-grade walls because they offer kit-type solutions that attain the high R-values, airtightness, and moisture management required to go beyond the IECC 2015 50% solution. Private industry will obviously develop plan variations once, with DOE's help, a near-optimum package for a very utilitarian house plan is developed, built, and tested. The construction of the house would be financed by an already-identified partner.

3.4.3.3 High-Performance Retrofit Panel

House retrofits that need new siding or additions are great candidates for SIPs. A process will be developed for creating high-performance panels for the exterior of deep-retrofit houses that strive to meet IECC 2015 standards for new house energy performance, which will transform a GIS picture into panel cut drawings.

3.4.3.4 Foundations

The Building America Foundations Expert Panel in 2009 generated a list of research needs that have yet to be addressed. ORNL was an active participant in the DOE Building America November 2010 Planning Meeting foundations breakout team.

- Foundation insulation detail with above-grade exterior-wall brick cladding that avoids the thermal short like an insulated bottom course of insulated block. All exterior insulation must be insect and moisture resistant. Foam glass has been discussed for years as a first course for brick-clad buildings.
- Laboratory measurements are needed to determine capillary wicking from footers in water and wet soil into foundation walls. Testing is also needed of various types of concrete masonry units (CMUs) and poured concrete, with and without a capillary break between the footer and the foundation wall. Simple homeowner testing kits are needed to determine where interior insulation is appropriate for the foundation, especially for retrofit situations.

- Basement insulation systems have been installed successfully with very permeable facings, yet Smegal and Straube (2010) decline to suggest these systems for northern climates, stating that, "…vapor diffusion will be higher both ways, and air leakage condensation will be significantly greater across a perforated facer than a non perforated facer." Side-by-side testing of systems has been conducted by the Consortium for Advanced Research Buildings (CARB) and the University of Minnesota, but testing is needed in the mixed humid climate, where more drying to the interior is possible, to generate solid validation data for hygrothermal models and ultimately the foundation retrofit electronic handbook on ORNL's website.
- Smegal and Straube (2010) show convincingly that Class 1 and 2 moisture retarders in below-grade walls on typical fiberglass-insulated walls will have unacceptable moisture problems. But more permeable facings such as drywall with latex paint will allow some drying to the inside. These systems need to be more carefully studied both in the field in mixed humid climates and via modeling analysis. Measurements are needed to determine whether EPS would work as well as XPS in foundation insulation moisture control systems, And to test 2-in. × 4-in. framing offset from the foundation wall by 1 in. to 2 in. and sprayed solid with open-cell foam insulation.

3.5 References

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4 Deep Energy Upgrades and Improvements

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4.1 Problem Summary

4.1.1 Problem Statement

We need to reduce the energy used in residential buildings by at least 50%.

4.1.2 Solution—Upgrade and Improve Existing Homes

- Create a brand. The DOE BLUE SHEET for deep retrofits and the DOE ORANGE SHEET for normal retrofits. These sheets list the target values for various aspects of the homes (e.g., wall insulation, window performance, heating and cooling equipment efficiency, envelope and duct leakage, duct insulation, water heater EF, etc.) that will be required to meet deep retrofit requirements. These values will vary by climate/building location. The intent is to remove some of the guesswork from the process and to give contractors and homeowners something straightforward and simple to refer to that is endorsed by DOE.
- Keep it simple: low transaction costs.
- Use available technology; for example, highest Consortium for Energy Efficiency (CEE) tiers.
- Address technology gaps.
- Ensure that health, safety, durability, and IAQ issues are addressed.

This problem has several categories:

- **Technical.** We need to find more efficient ways to provide heat, hot water, cooling, lighting, cooking, cleaning, bathing, security, healthy environments, etc. We need only a few new technologies. Deficient areas are ventilation controls, dehumidification in humid climates, and eliminating vampire loads. We need to provide low-energy entertainment, because this is an expanding field of household energy use. We need to expand technical efforts to include multifamily homes and rental properties. Some technical issues such as shared hot water equipment are unique to multifamily homes. Rental properties require a distinction between those who can legally make changes to the property and those who accrue the savings.
- **Behavioral.** A deeply retrofitted home has a tight envelope, energy-efficient lighting, and an efficient and reliable hot water source, so the remaining energy use is discretionary. To address this issue, we need to ask whether people can maintain their lifestyles and save energy. We need to ask the following fundamental questions about discretionary energy use:
    - Which appliances can be turned off when they are not in use?
    - How can occupants change their behaviors? Marketing and behavioral studies need to be performed to address this.

- Should the focus be on the mass market or on innovators? Innovators are active in home retrofits; the mass market will likely follow several years later. Short-term requires approaches that appeal to a wide audience. Specialized groups such as fixed-income retirees need to be targeted.

- **Cheap energy (and carbon).** Energy bills and devices that show homeowners the costs of specific end uses may be deceptive. Energy bills tend to be low in moderate and temperate climates, but high elsewhere. Air-conditioning in Florida and oil heat in New England are expensive, especially in older homes. Rather than focusing on saving money, we should probably craft messages about conserving resources for the next generations.

- **Resource allocation.** About $150–$250 billion is spent in the United States each year to renovate homes. The range is the result of data from different sources: National Association of Home Builders and Remodeling Magazine. To get an idea for the financial scope of some popular retrofits see Table 2 (data from *Remodeling Magazine*, November 2010). Given this potentially huge resource, we need to provide contractors and homeowners information so they can reduce premiums and tradeoffs for adding energy efficiency to these renovations. One strategy would be for DOE to regularly provide content about innovations and American Recovery and Reinvestment Act funding to industry publications such as *Remodeling Magazine* and *Home Energy Magazine*. Each Building America team should provide content and DOE should include expert comments.

Table 2. National Averages of Remodel Costs in 2010
(values from *Remodeling Magazine*, November 2010)

Type of Remodel	Average Cost
Attic bedroom	$51,428
Basement remodel	$64,519
Bathroom remodel	$16,634
Family room addition	$85,740
Major kitchen remodel	$58,367
Minor kitchen remodel	$21,695
Roofing replacement	$21,488
Siding replacement (vinyl)	$11,357
Window replacement (wood)	$18,226

- **Partnerships.** LBNL is initiating a partnership with Google and several Bay Area cities. Google is providing 50 TED5000 power meters to LBNL, which will coordinate with local communities to have them installed in homes that are retrofitted with Recovery Act funding. LBNL is also working with Google to beta test application programming interfaces that will enable LBNL to access and download the power meter data directly. To extrapolate, DOE may eventually have access to energy use data in many thousands of homes to better direct research plans and public policy.

- **Changing the construction industry.** We may need to be more aggressive with the industry. New players such as Google and Microsoft are measuring energy use in homes, analyzing the data, and connecting to occupants, industry groups, utilities, and well-connected contractors. They will change the relationship between homeowners, utilities, and energy use. DOE needs to understand the complexities of this process (Figure 4) and find ways to streamline it. Two possible approaches may be helpful:

- Encourage contractors to combine envelope and window upgrades with HVAC improvements, either by partnering with other contractors or by expanding the skill sets of their own employees. For example, technicians may be trained to seal ducts and envelopes and install furnaces.
- Learn how to motivate homeowners to do retrofits and use less energy.

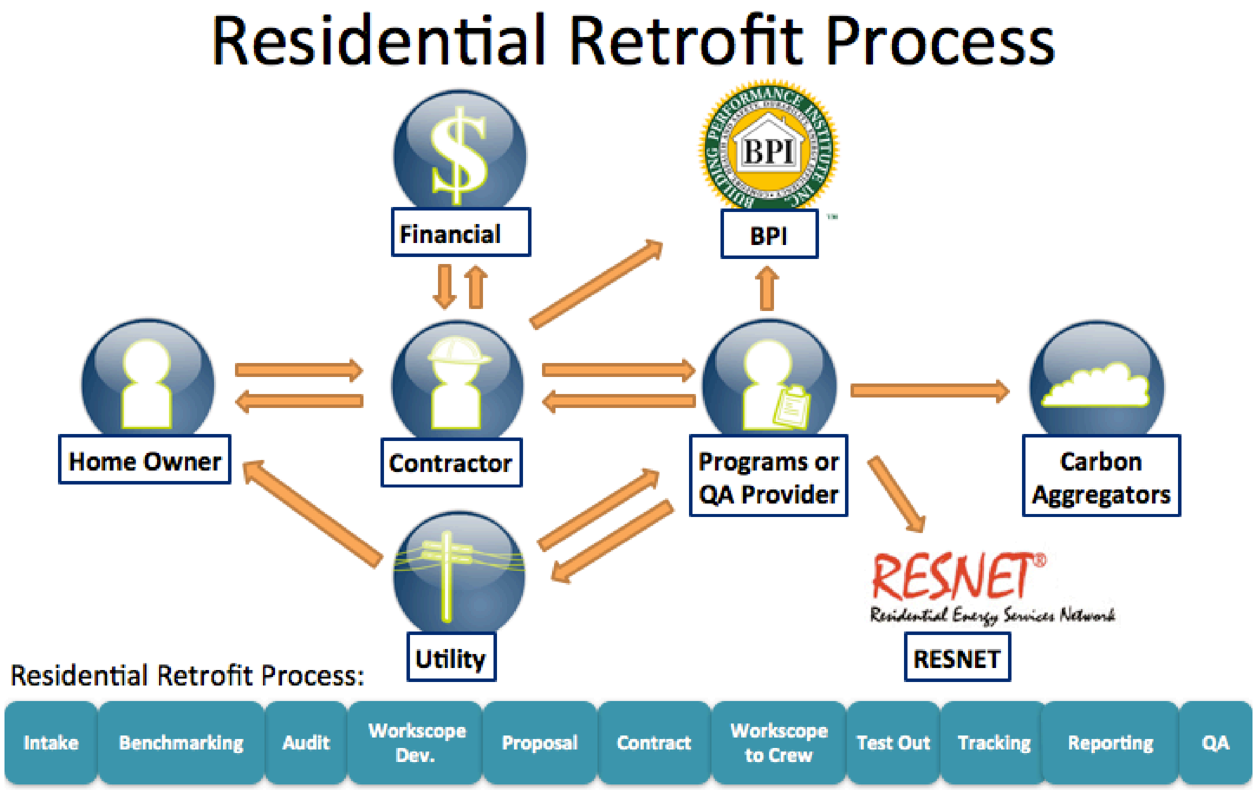

Figure 4. Example of interactions required for retrofit
(Credit: Greg Thomas, Performance Systems Development)

We need to partner with contractors and others who have direct contact with homeowners. This is beginning to happen with the Residential Energy Network's (RESNET) collaboration with The Home Depot, for example. The key here is to use the homeowner contact infrastructure, including contractors, big box retailers, and new entrants such as Microsoft and Google to deliver DOE's message. We need to recognize that almost no home improvements are based on a cost-effectiveness approach, but are done for appearance, utility, comfort, health, etc. We need to provide homeowner contacts with information and advice about how to include energy savings measures in all their activities, particularly when the incremental costs are low. So, for example, if a wall is open because the interior finish is being replaced, the additional cost to insulate the empty cavity is low.

4.2 Identifying Challenges for Home Builders and Renovators

Moisture, lead and asbestos, knob and tube electrical wiring, historic buildings, combustion safety versus airtightness, home type, and climate are among the challenges homebuilders and renovators face.

4.3 Identifying Challenges for Contractors

To help contractors make the transition to deep energy upgrades, DOE should provide them the opportunity to upgrade their skills. This would include qualifications and certifications, training on the use of diagnostic equipment and how to market energy reduction concepts. This includes the ability to debunk energy myths and extravagant claims that homeowners are continuously bombarded with.

4.4 Identifying Challenges for Homeowners

DOE needs to connect to this market so every renovation has energy upgrades included to minimize costs. DOE should develop good advice and recommendations about the costs of energy audits, credit and market misinformation, energy efficiency claims, etc. This advice should be presented as targets (BLUE and ORANGE sheets) and techniques for achieving targets (which have details similar to the guides for new construction already produced by Building America). We should explore ways to persuade owners to upgrade rental homes, given that occupants rather than owners benefit from energy cost reductions.

4.5 Identifying Challenges for the Market

Creating a robust deep retrofit market requires us to address:

- Limited awareness by owners, inspectors, appraisers, realtors
- Credibility gap on energy savings
- Low value of unseen retrofits
- Appearance, convenience, comfort, and health.

To address these issues requires that credible energy savings data, protocols, and demonstration tools be developed that contractors can use to sell jobs.

The current message for selling energy efficiency tends to focus on monetary savings that are often hard to justify or achieve given low energy costs. To broaden the appeal, we need to change (broaden) the energy conservation message. For example, the new message could be: "We'll fix your comfort problem and save you $XX/year and save on pollution, reduce resource consumption."

Contractors and homeowners identified the complexity of deep retrofit work as a key barrier, so anything that simplifies decision-making or planning processes is valuable. One example is the effort required to realize rebates for both homeowners (who are recieving the benefit) and program administrators. An approach that deals with this issue is to provide rebates to equipment, lighting, and appliances at the dealer/distributor level. This is much more cost effective for program administrators due to much lower overheads; they only need to touch 20 people nationally, not 20 million individuals. This approach also puts the money savings up front so there is no delay between installation and rebate as with current programs. For contractors, instant savings are easier to sell to a homeowner than something that has to be applied for later. This approach also makes it much simpler: there is less time, effort, disruption, uncertainty, and paperwork for the homeowner.

Another step on the path to simplicity, scale and ease of use is to have a national energy code for homes. To overcome resistance at the state and local levels, we could make federal stimulus funds dependent on adopting a national energy code for buildings. DOE could develop a simple low-level prescriptive code for the current stimulus package that will also be useful in the future for other federal programs.

Lastly, there is the issue of quality control and regulation. Good contractors currently face the difficulty of competing against those who are allowed to get away with poor work. There needs to be a national system of testing and inspection to remove the low cost – bad performance option. This should be developed in coordination with certification programs such as the BPI.

4.6 Identifying Challenges for Weatherization and Utility Programs

Many challenges for weatherization and utility programs are based on industry-accepted myths and half-truths. For example, the cost (in time and effort) of testing for envelope leakage is raised repeatedly. In reality, the time is in preparing the envelope and installing the equipment. Once the blower door is installed it is a diagnostic tool for finding air leaks (with smoke), finding disconnected ducts (with a pressure pan), and guiding air sealing (so a contractor knows when the big holes are filled and if further tightening can be reasonably achieved). We need to emphasize that measuring envelope leakage (and duct leakage) is one of the very few things we can do for an energy audit that results in some accuracy in the input data.

4.7 Changing the Metrics

DOE needs to focus on energy use instead of on measures such as efficiency and energy use per square foot. This removes the penalty for having a small low energy use home and discourages high energy use but low energy density housing that is characteristic of new U.S. construction (Figure 5). The terminology used to describe metrics (the lexicon of energy use) also needs to be changed to project a more positive image and send the right message.

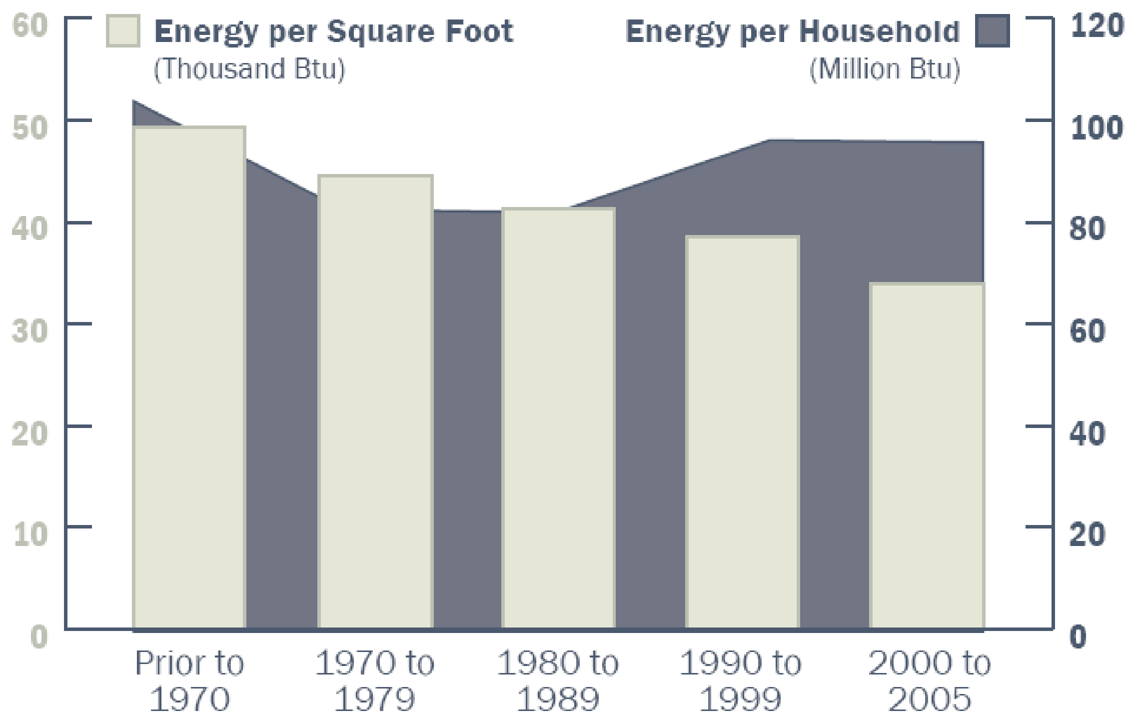

Figure 5. Energy per square foot versus energy per household
(National Renewable Energy Laboratory 2006. The Potential Impact of Zero Energy Homes. Golden, CO: by NAHB Research Center, Upper Marlboro, MD. www.toolbase.org/PDF/CaseStudies/ZEHPotentialImpact.pdf)

4.8 R&D Questions

1. **How should we provide guidance to contractors?** DOE needs to create simple basic specifications that are the targets for deep retrofits—the DOE BLUE SHEETS (see Figure 6). This simplifies the sale of retrofits, reduces paperwork, etc. These specifications can include diagnostic testing such as setting and achieving an airtightness level, setting and achieving a duct leakage level, and using CEE highest tier specifications for equipment. This is also needed for non-deep retrofits. Another idea is to produce two sheets: BLUE for deep retrofit (>70% + threshold) and ORANGE for normal retrofit (>35%). BLUE would be more advanced and ORANGE might upgrade home to IECC 2009 specifications. The ORANGE sheet should be developed such that efforts undertaken to achieve its goals do not preclude moving up to the BLUE level at a later date.
2. **How should we partner with large corporations?** DOE needs to connect to new large corporate entities entering this market: Google, Microsoft, and large retailers such as Lowes and The Home Depot, which will advertise these technologies and reach the large number of homes required for significant national energy savings and fossil fuel reductions. DOE should provide technical information and analyses and protect consumers. In return, DOE will be able to access large numbers of data on home performance to direct research and public policy.

CZ6 DOE BLUE SHEET

R5 windows
R10 slab
R20 below-grade wall
R40 above-grade walls
R60 roof/attic
0.25 cfm50 / s.f. floor area
ASHRAE 62.2 Mechanical Ventilation

CEE Tier 2 Storage water heater
CEE Tier 1 Tankless water heater
95% AFUE Furnace
90% AFUE Boiler
16 SEER A/C
10 HPSF heat pump
< 5%Duct leakage
R8 Duct insulation

ENERGY STAR Dehumidifier
Highest CEE Tier for all appliances
All combustion appliances inside conditioned space are to be sealed combustion

Figure 6. Example of BLUE SHEET

3. **How should we provide training for contractors?** DOE should provide technical support to organizations such as ACI, BPI, and RESNET. DOE should review these programs to ensure they provide good technical information and some consumer protection, as well as technical support for revisions, reviews, and improvements.
4. **What technologies do we need?** Although all the technology for deep retrofits is available, improvements can still be made.
    a. *Ventilation control.* Because healthy, durable homes with good IAQ form the core of deep retrofits, mechanical ventilation is essential. The energy required to condition ventilation air becomes 70%–80% of building load. Technologies are needed to control ventilation systems so IAQ levels are met. At the same time, they need to prevent overventilating and take advantage of incidental mechanical ventilation from kitchen and bath exhausts and clothes dryers.
    b. *Hot water storage.* Well-insulated tanks can be used to store solar-heated water. Tanks can be retrofitted to improve their insulation.
    c. *Cavity insulation.* Cavity-filling methods need to be refined to completely fill cavities without leaving voids and to cause less damage to walls (e.g., by using smaller holes to inject insulation into cavities). These will reduce costs, minimize damage, and increase appeal. Some methods may be able to use holes about 0.4 in. diameter to fill cavities. Research is needed to evaluate this.

d. *Window improvement (not just replacement).* A few methods are available to retrofit windows. These include rebuilding windows to improve air sealing and using interior and exterior storm windows. Research is needed to assess the effectiveness of these window treatments and to develop improved methods for flexible/adjustable frames, nonglass glazings, etc.

e. *Humidity control.* In a conventional home in a humid climate, the sensible cooling system can be used to control humidity. Efficient homes, however, have smaller sensible loads, resulting in lower capacity air conditioning systems that have insufficient latent capacity. This can lead to excess humidity levels in humid climates or cases of high occupancy. The solution is to use dedicated humidity control systems and research is needed to develop more efficient, cost-effective dehumidification systems.

f. *Improved diagnostics.* The retrofit industry focuses on envelope and duct airtightness, but also needs to consider insulation levels and window performance. A new area for measurement and verification is for ventilation system air flows, particularly as all deep retrofits will require mechanical ventilation systems and work is currently underway to include this in RESNET and other standards. Work is required to document the relative efficacy of possible ventilation air flow measurement techniques, including passive and active flow hoods and bag filling techniques.

5. How can we avoid IAQ and moisture problems? DOE should have a program that measures pollutants in homes and does pre- and post-retrofit analyses combined with field evaluation of new approaches and technologies such as formaldehyde (HCHO) scrubbers. Researchers also study the transfer of polluted garage air into homes to determine whether attached garages should be banned or strict requirements placed on garage to house air leakage and placement of HVAC systems in garages.

6. What is the new lexicon? Fuller et al. (2010) showed that words need to be chosen carefully to reach the mass market. For example, audit and retrofit have negative connotations. DOE should talk to behavioral scientists who understand the power of language to develop a new lexicon.

7. How should we deal with externalities? Many aspects of existing homes—knob and tube wiring, lead paint, asbestos, poor air sealing and insulation, historic preservation, and occupant aesthetics—complicate improvements. DOE should examine these aspects and work with contractors to resolve the attendant issues.

8. How should we use information technologies such as smart meters and Google power meters?

   a. Can we access these data streams to help make research plans and policy? DOE should develop a national database of home performance based on these measured data to make informed decisions about R&D and policy making.

   b. Can we expand LBNL's efforts with Google to all Google power meter homes?

   c. Does DOE want to partner with Google?

d. What useful information can we extract from the 15-minute data: identify high energy users, identify some large energy uses (e.g., heating and cooling), identify high baseline (e.g., outdoor lights at night).

Commercially available information technologies focus on electricity consumption. In the long term, when all-electric homes are the norm, this is fine, but in the short term, we will continue to consume natural gas for heating and hot water. LBNL's deep energy retrofit work for FY 2011 focuses on how to couple gas metering to Google power meter and other technologies. More work is needed on small and easily installed gas meters, because current meters are too unwieldy and intrusive to be practical.

4.9 Current Status—LBNL Efforts in FY 2011

4.9.1 Deep Retrofits

The LBNL project monitors deeply retrofitted homes to demonstrate the feasibility of deep retrofits and identify key issues that need to be resolved to meet the energy saving goals. A deep retrofit aims at reducing energy use by more than 75% and meeting the definition used in Affordable Comfort Inc.'s (ACI) "1000 Home Challenge," which includes a threshold energy use for homes that are already low energy users. Current activities include the development and demonstration of ways of measuring and monitoring the individual end uses for energy, performing diagnostic testing to characterize the buildings, learning about what motivates homeowners, and which approaches/technologies work well (and which do not).

4.9.2 Hazard and Risk Mitigation

LBNL is working with other national laboratories to develop guidelines for knob and tube wiring, asbestos, lead paint, combustion appliances, and effective, climate-appropriate ventilation. This consists of reviewing codes, standards, and literature and providing summary and guidance information to NREL, which is leading and coordinating this effort. Specifically, LBNL is coordinating with other LBNL researchers, BPI, RESNET, the DOE labeling team, and the NREL modeling team on airtightening issues. These include:

- Setting tightness limits for backdrafting
- Making recommendations for codes and standards, including California Title 24, U.S. Department of Housing and Urban Development (HUD), and deep retrofits
- Teaching contractors that they should not airtighten to a limit.

4.9.3 Ventilation Strategies

LBNL's activities in this area include:

- Assessing night vent strategies for precooling hot/dry, mixed dry, and cold climates.
- Working with NREL to produce a technical report that documents the potential energy savings of this strategy and examine the effectiveness of reducing ventilation energy use in compliance with ASHRAE 62.2. This work will use LBNL's REGCAP ventilation software to examine active, passive, and hybrid systems. This task will be performed in collaboration with another LBNL project, Residential Ventilation and Indoor Pollution.
- Working with NREL to develop advanced controls for residential buildings by developing a prototype residential ventilation controller that communicates with other mechanical systems to reduce overventilation and its associated energy penalty, reduce the entry of outdoor pollutants during high pollutant events (e.g., high ozone levels), and

allow time shifting of ventilation to off-peak times (saving on energy bills, avoiding brown-outs and new installed generating capacity). This work includes developing new control algorithms and combining field testing and energy modeling of controllers to enhance the algorithms and provide enough information to create a marketable product.

- Collaborating with the Haas School of Business at the University of California–Berkeley to find an industrial partner to bring the controller to market.
- Providing technical assistance on the development of retrofit quality management procedures and protocols. LBNL is working with ASHRAE to change Standard 62.2 (and other relevant standards) to be more easily applicable to all housing, specifically to retrofits. LBNL is also developing new industry standards with RESNET, BPI, ACI, and DOE's building labeling (auditing and modeling) efforts. This work focuses on addressing health, safety, comfort, and IAQ issues, and is an essential part of making major energy savings acceptable to the industry and homeowners.

4.9.4 Improve Software Used in Analyses

The national laboratories are collaborating with a team of experts to create a software evaluation for the ACI meeting in April.

4.10 FY 2012 Issues—Continuation of FY 2011 Work

4.10.1 Deep Retrofits

- Continue to monitor deep retrofit homes to better identify dependence on weather and occupancy effects.
- Add homes in more climates that meet a stricter definition of deep, such as "at least 75% energy savings."
- Refine the end point for deep retrofits and energy savings (include information from 1000 home challenge that has fractional savings and a low-energy threshold). This would be the same as the "BLUE SHEET" but with the target end points revised to be a threshold.
- Study solutions for large energy end uses such as swimming pools and spas that are not directly part of the structure. This is a topic of debate at rating organizations such as RESNET, and for contractors who sell energy savings. RESNET is specifically seeking more input from the national laboratories in this area.
- Refine diagnostic and long-term monitoring techniques.
- Facilitate the sharing and combining of field data between national laboratories and Building America teams.

4.10.2 Hazard and Risk Mitigation

Although substantial progress will be made in FY 2011, continued efforts to update standards and provide input to DOE guidance documents will be required in FY 2012.

4.10.3 Ventilation Strategies

The advanced ventilation controller is expected to require construction and field testing of several prototypes in collaboration with an industrial partner as a prerequisite to full market acceptance. These additional efforts should occur in FY 2012; the goal is to have a final product at the end of FY 2012.

LBNL will provide technical assistance for developing retrofit quality management procedures and protocols. LBNL will continue to address health, safety, comfort, and IAQ issues through collaborations with ASHRAE, ASTM, RESNET, BPI, ACI, and DOE's building labeling (auditing and modeling) efforts.

4.11 New for FY 2012

4.11.1 Create DOE BLUE/ORANGE Sheets

These sheets should list the simplest level of requirements that will generally result in 75%/35% savings.

4.11.2 Connect to Google and Others for Information, Feedback, and Social Changes

Google expects to have power metering in many homes, and DOE may acquire access to this database in return for analysis expertise. Privacy concerns are paramount: We must ensure that individuals cannot be identified in the results. Utilities are reluctant to share customer data, even with customer permission. However, some utility commissions, at least in California, are exploring ways to systematically provide privacy, address legal issues for utilities, and allow access to large numbers of data to promote solid research and form a much better basis for policy recommendations for DOE, state, and local authorities.

4.11.3 Develop a New Lexicon and Energize for the Future

DOE should always promote a positive message and a leadership vision. Communications and outreach are critical to persuading industry that change is inevitable and desirable.

4.11.4 Listen to Experts

DOE should engage companies such as ReCurve, Performance Systems Development, and Greenhomes America, which are engaging the industry and consumers. The national laboratory teams should include the experiences of their contractors on the field demonstrations of deep retrofits.

4.11.5 Get Away From Cost-Effectiveness Issues

Homeowners are much less interested in cost effectiveness than they are in improved appearances, improved comfort and room layout, and health. They are less concerned about payback periods than about deriving a sense of investing in their homes. Most home upgrades, including those for energy, add value to a home. We therefore need to engage homeowners on the bases of comfort, health, and additional features to reduce energy use. One possibility is to focus less on what the retrofits should be and instead define what the targets are that a building needs to reach. This can simplify discussions with contractors and homeowners and make it easier to administer and show compliance with various federal, state, and utility programs.

4.11.6 Develop Diagnostic Tools

DOE should survey users and performers to address the debate about the value of air leakage testing for envelope and duct systems. This will provide information about how much time and effort the tests require and how users value the testing. It could lead to improved test methods and alternative techniques. DOE should also provide guidance on ventilation air flow verification, which will be required in any reasonable home retrofit. A study is needed that performs field evaluations of a range of ventilation air flow measurement techniques to provide input to industry standards. A secondary issue relates to utility and government rebates that require proof of home improvement and RESNET/BPI standards, where tests such as infrared scanning to evaluate insulation installation would be performed in addition to air leakage testing.

4.12 Multi-Year Milestones

4.12.1 FY 2012

- Identify the number of homes to deeply retrofit in 2, 5, and 10 years. DOE has no control, but can help craft the framework.
- Industry adopts new lexicon during 2011. Coordinate with RESNET, BPI, Efficiency First, CEE, ACEEE, EPA, Weatherization, product manufacturers.
- Create DOE BLUE/ORANGE sheets.
- Pilot studies with Google, Microsoft, and other new buildings industry entrants. Engage enthusiastic people.

4.12.2 FY 2012/2013

- Coordinate with Affordable Comfort 1000 home challenge to get 1000 deep retrofits over next two years. Document energy savings and retrofit activities.
- Link to DOE's labeling effort. Define a clear separation between a simple label and an audit related to home upgrades. Focus this effort on the end point, not necessarily on energy changes.
- Develop new technology for dehumidification.

4.12.3 FY 2012/2013/2014

- Have competitions to raise public awareness. Have a prize to leverage private investment and ego.
- Change building codes to make low-energy homes easier to permit (build/rebuild/renovate). Hard to set timeline, but three years for the entire United States seems reasonable.
- Continue to support revisions to industry standards; BPI, RESNET, ASHRAE, ASTM, ACCA.

4.13 Reference

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5 Residential Planning for Healthy, Efficient Homes Research

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5.1 Problem Summary

The United States is ramping up efforts to improve the energy efficiency of residential buildings. One key strategy is to reduce uncontrolled air leakage to reduce thermal energy loads. Absent other measures, reducing outdoor air exchange will lead to increased concentrations of pollutants emitted continuously from indoor finishing and furnishing materials and from intermittent activities such as cooking, candle use, and cleaning. Americans spend about two thirds of their time at home (Klepeis et al. 2001), so these exposures can have important health impacts.

A recent LBNL hazard assessment found that at least 31 chemical air pollutants have been measured at potentially hazardous levels in a large fraction of thousands of homes sampled over the past two decades (Logue et al., in press). Formaldehyde commonly exceeds standards for noncancer effects and at levels that present cancer risks in excess of 10-5 for chronic exposure over a 10-year period. LBNL analysis indicates that most of the quantifiable population health risk from air pollutant exposure indoors is associated with fine particles, nitrogen dioxide (NO_2), and acrolein; formaldehyde risk depends heavily on the unit risk estimate values used. According to the World Health Organization, more than 41 million disability adjusted life years are incurred annually in the United States from illness and injury. An LBNL scoping analysis of these and other pollutants finds that about 10% of this could result from inhaling pollutants in residences. Preliminary modeling indicates that the health burden caused by volatile organic compounds (VOCs) can be cut almost in half with balanced mechanical ventilation; exhaust-only ventilation would cut the health burden of these chemicals by 40% with less than half the incremental energy input. Formaldehyde is emitted primarily from material particles, but NO_2 and acrolein are produced from intermittent activities such as cooking, cleaning, and candle burning, and enter with outdoor air. Increasing ventilation without mitigating outdoor air pollutants could increase health risks. Careful analysis of these questions is critical to planning efficient and effective ventilation.

The analyses examined chemicals with established health standards. New chemicals that are core components or production by-products of new materials and changing consumer product formulations represent an additional, undetermined hazard. For example, there is a growing awareness of the potential (and in some cases established) hazards of flame retardants and other semivolatile organic compounds that spread from their source materials to other surfaces and contaminate indoor environments for decades. Many products related specifically to energy efficiency, such as spray foam and other types of insulation, are used increasingly; they may present exposure issues to home performance contractors and occupants. An additional but highly uncertain level of risk is associated with the ever-changing formulations of household products and materials. We lack the information needed to estimate the magnitude and distribution of indoor environmental health risks. The EPA (www.epa.gov/iaq/homes/retrofits.html) can be a good source of information.

Residential pollutant exposures can be mitigated by source control, air cleaning, and ventilation. Emission source reduction is often preferred, but it requires consideration of a vast array of materials, products and activities. Air cleaning—which can include improvements in filtration for forced air heating and cooling systems and room-scale devices—can be helpful, but most technologies carry steep energy costs and may not be practical in a residential environment. Advances are ongoing, but new technologies must be validated and assessed for undesirable side effects such as ozone formation by ion generator particle collectors.

ASHRAE Standard 62.2 includes provisions for local and overall ventilation. The overall ventilation rate, specified as a continuous or equivalent intermittent mechanical ventilation rate, ostensibly is set to ensure acceptable IAQ. This rate and other aspects of the standard are not explicitly tied to specific health-protection targets. The standard provides no guidance for the most energy efficiency strategies to meet the requirements and only limited equipment performance standards. For example, there is no standard for kitchen exhaust removal efficiency. The standard is, nevertheless, widely regarded as best practice for protecting occupant health. Updating this standard and associated guidance is an established path to ensure research results are incorporated into professional practice. We need to understand the typical and expected contaminants in the residential environment and develop reasonable minimum strategies for their control. This requires research or the coupling of research on emission, transport, exposure, and control technologies.

Reducing uncontrolled air leakage is essential to improving building efficiency. The energy cost to fully thermally condition the current stock of U.S. homes (e.g. before implementing Better Buildings) has been estimated as a few quads per year. Aggressive air tightening theoretically could cut this by as much as a factor of three. Realized energy benefits will be lower as some energy is used to ensure adequate ventilation and some cost savings are reinvested to improve comfort. A rough estimate of the magnitude of potential savings from aggressive tightening is therefore about 1 quad.

5.2 R&D Questions

Three broad areas of R&D questions need to be answered to inform policy and planning to achieve a healthy, energy-efficient housing stock:

- Characterize the baseline conditions of ventilation-related energy uses and health risks. This will inform ranking of near-term research and deployment efforts. Many elements of this situation are unknown but could be resolved with compilation and analysis of available data and targeted new data collection efforts. An important subset of questions focuses on preliminary assessment of potential health risks that have been underexplored, even though they could drive overall risk profiles.
- Examine the costs and benefits of various technology and policy implementation pathways. These questions must be addressed by well-designed simulation that is based on data and physical processes. The goal is not to precisely predict reality, but rather to advance understanding of the relative impacts of potential energy and IAQ strategies.
- Find opportunities for technology development, standards, and regulations to achieve healthy, efficient homes.

R&D questions related to characterizing baseline ventilation energy and health risk follow:

- What health impacts and costs (associated with residential chemical air pollutant exposures) can be mitigated?

- What are current and projected indoor air pollutant source profiles in U.S. homes? How do these vary between new high-performance, new conventional, retrofitted, and existing homes?
- Are any materials being used in construction of energy-efficient new homes or retrofits that introduce chemicals at hazardous levels?
- How do we reduce the likelihood of materials introducing new hazards, when standards and health effects are unknown?
- How do formaldehyde and other materials-based VOC concentrations and emissions respond to increased ventilation? Many classes of contaminants do not respond simply because of material storage, chemistry, or low volatility. Formaldehyde—one of the most important VOCs for indoor exposure—exhibits this behavior.
- What are the baseline ventilation conditions (windows, fan use, effect of mechanical systems, etc.) in U.S. homes? Are there substantial differences by region, ethnicity, income level, housing type, urban versus rural, etc.? What is the relationship between outdoor temperature and window use? How frequently do people use windows and fans during pollutant-generating activities?

R&D questions about costs and benefits of ventilation and other options to reduce risk follow:

- What benefits are likely to be achieved by requiring mechanical ventilation? Are substantial variations in benefits achieved by balanced exhaust only, and supply only mechanical ventilation systems? How do these vary with airtightness?
- What are the energy costs and cost-benefit relationships of each system type? How do these vary with airtightness?
- How is health risk divided among indoor air pollutants? Which pollutant sources contribute the greatest risk? What risk is associated with preventable exposures from gas cooking burners and other pollutants that could be removed by a kitchen exhaust fan? Should homes consider restaurant-style exhaust principles?
- What are the potential costs and benefits of cooking exhaust requirements, based on equipment performance?
- What are the costs and benefits of incorporating available air treatment technologies in new or retrofitted energy-efficient homes?

R&D questions about potential of specific measures to improve energy and health follow:

- What are the potential benefits and costs of kitchen exhaust performance standards?
- What factors inhibit the use of kitchen exhaust? What benefits could be achieved by automated systems?
- What are the potential benefits of smart ventilation systems that account for all mechanical systems and potentially window opening to provide mechanical ventilation only when needed?
- What technology developments are needed to provide smarter, lower cost, and more robust mechanical ventilation systems?

5.3 Current Status

DOE, EPA, and HUD are collaborating to support LBNL research on the intersection of residential energy efficiency, ventilation, indoor environmental health risks, and mitigation options. The broad objectives are to inform the setting of a health risk-based residential ventilation standard and to advance understanding of the energy impacts of various ventilation and other risk mitigation approaches, including source control.

This research is being conducted through modeling and simulation; data compilation, collection and analysis; and controlled experimentation. These are described below.

The interagency research program initially focused on hazard identification and baseline health risk assessment. Toward this end, LBNL identified and analyzed published data from more than 70 studies on measured indoor air pollutant concentrations relevant to U.S. residences (Logue et al. 2010).

To identify hazards and support the modeling, LBNL conducted a search to identify publicly available information about chemical emissions from residential construction, finishing, and furnishing materials (Willem and Singer 2010). Concern about chemical emissions has led to an explosion of products claiming to be "green" or "low emissions." Many such claims are verified by standards and certifications of varying transparency and provenance (some were created or heavily influenced by industry associations or stakeholders). Information about resulting chemical emission rates from products is not typically available. Federal guidance on what manufacturers need to supply and when would be appropriate.

Hazard identification is also being pursued through detailed chemical analysis of air samples collected in new homes. A detailed examination of gas chromatography/mass spectrometry chromatograms from air samples collected during the California New Home Study is underway; this will provide a picture of VOCs in moderately energy-efficient homes built to California Title 24 standards between 2002 and 2005. A similar review will be conducted on air samples collected in more recently built California houses. This approach will be extended to air samples collected from high-performance new homes and non-California conventional new homes through collaborations with Building America teams across the United States.

The health impacts from indoor air pollutants can be considered in several ways. The hazard assessment examined the frequency of exceeding chronic or acute health-based guidelines or standards. Another approach is to translate pollutant exposures to health impacts through the metric of quality adjusted life years (QALYs) or disability adjusted life years (DALYs). LBNL is translating the exposure levels identified in the hazard assessment to total QALYs and to attribute the QALY burden by pollutant. Preliminary results indicate that most health risk is associated with fine particles, NO_2, acrolein, and formaldehyde (Logue et al., in preparation).

The goal of current modeling and simulation activities is to develop and apply frameworks for projecting and analyzing energy and IAQ impacts of various technologies and design approaches to building energy-efficient, healthy homes. The intent is to understand the cumulative impacts (in terms of quads of energy and QALYs saved) and their distribution. Preliminary efforts focused on California because it is the only state with enough data to conduct an analysis. The California Energy Commission funded two studies of ventilation and IAQ in new homes. A mail-out questionnaire focused on occupant-controlled ventilation and attitudes about ventilation and IAQ. A follow-up field study included measurements of home ventilation characteristics (including airtightness and equipment performance), outdoor air exchange, air pollutant concentrations, and ventilation.

LBNL developed the first modeling framework to analyze the health and energy impacts of central mechanical ventilation. This initial effort focused on time-averaged emissions of VOCs, including formaldehyde, but did not include fine particles. The analysis examined health costs of baseline conditions and health benefits and energy costs of exhaust only (most typical system used today) and balanced mechanical ventilation at the rates currently specified in ASHRAE 62.2. We will complete and report on this analysis in FY 2011.

The modeling framework needs to be expanded and further developed to include elements that have major impacts on health and energy, such as time-varying ventilation, pollutant emissions from intermittent sources, entry of particles from outdoors, and effects of pollutant removal indoors and in HVAC systems.

Data are needed for the rest of the United States, for high-performance homes, and for retrofits. LBNL has designed and constructed an updated version of the national air leakage database and is conducting national outreach efforts to obtain and incorporate air leakage measurements into this database. An initial analysis of the acquired data will be conducted in FY 2011. The database will continue to be expanded and analyzed.

In FY 2011, LBNL is developing a draft plan for a tiered national data collection effort, including questionnaires, short home visits for characterization, sampling of IAQ, and monitoring of window and fan use.

Also in FY 2011, LBNL is conducting pilot experiments to isolate and measure the effect of air exchange rate on formaldehyde, (HCHO) concentrations and inferred emissions in residential rooms. LBNL is also conducting laboratory experiments to assess the potential for HCHO transfer across energy recovery ventilators.

With funding from the California Energy Commission, LBNL initiated research into the as-installed and potential performance of residential cooking exhaust fans and range hoods, and will develop a framework for analyzing the energy and health implications of increasing use of installed systems, of the potential benefits of deploying best-in-class technologies, and of the potential benefits of energy-efficient, effective pollutant removal designs.

5.4 Opportunities, Gaps, and Barriers

There are many potential opportunities and some substantial barriers to protecting health as we work to dramatically improve the energy efficiency of U.S. homes; applied research and demonstration projects can advance these goals. This section focuses on pertinent RD&D needs extending beyond those being addressed in the FY 2011 work scope.

- Apply energy and health risk modeling framework to evaluate the benefits and costs of ventilation, source control, and other IAQ-related technologies and strategies. Preliminary simulations will use data (e.g., from California studies) that are not fully resolved or region-specific to generate initial estimates of baseline conditions and the effects of various technology and design options. These applications may be parametric or distributional. One outcome will be prioritization of data collection efforts.

- Compile, collect, and analyze data to support modeling of ventilation energy and indoor air-related health risks throughout the United States. The data collection effort will be guided by prioritized needs from preliminary modeling and include several levels of data collection: survey only, limited measurements and monitoring, and intensive monitoring. To the greatest extent feasible, information from EPA, the National Institute of Science and Technology, and others and new data being collected in concurrent studies from the National Children's Health Study and the Centers for Disease Control Green Housing Study should be used. However, since many key parameters are not being monitored in these studies, the need will remain for substantial dedicated data collection. For example, only limited information is available nationally about how people use windows, fans, and other equipment that contributes to ventilation. California data indicate that many people do not open windows regularly.

- Develop, evaluate, and deploy smart and robust ventilation and ventilation control technologies. The energy and IAQ performance of a high-performance home will be limited without advances in ventilation equipment and control systems. LBNL's patented control technology can integrate the operation of multiple mechanical systems for highly efficient and predictable ventilation control. Deployment and continuing development of this system will improve operation of ventilation systems to maximize IAQ benefits with minimal overall ventilation-related energy use. LBNL is partnering with Panasonic to study innovative ventilation systems. One potentially valuable development will be to integrate ventilation controls with online data from outdoor air quality monitoring stations; such an advance would capture the benefits of ventilation to reduce indoor sources and mitigate undesired pollutants from the outdoors. The University of California at Berkeley Haas School of Business has adopted this technology for a development project. Additional partnerships are thus likely.
- Develop, deploy, and field test advanced kitchen and bath exhaust systems. Efficient local removal of air contaminants and excess moisture are key elements in an efficient overall ventilation system. Some cooking exhaust fans effectively remove pollutants before they mix throughout the air, but many—including the most widely installed designs—are not. The lack of any industry standard performance test for capture efficiency of residential kitchen exhaust systems is a critical gap. Lack of awareness about pollutants generated during cooking is a substantial barrier to progress. There is a potentially large synergy in combining several developments, namely improved capture efficiency, quieter fans, and public education about the potential hazards associated with cooking and gas burners. Automatic exhaust fan operation initiated by a cooking burner in a kitchen and humidity or motion sensing in a bathroom also have great promise. Should these new systems prove beneficial, LBNL would work with the home ventilating industry to transfer this technology to enable the development of market products.
- Incorporate energy efficiency guidance and equipment performance standards into the ASHRAE residential ventilation standard. Current ASHRAE ventilation standards do not differentiate between new and existing homes, even though pollutant profiles can differ substantially. Likewise, ventilation needs and optimum systems can vary by region and location. For example, concerns about the timing of ventilation vis-à-vis outdoor air pollution and heat island effects are important in many urban locations, but less critical in suburban or rural sites. The energy efficiency characteristics of ventilation and air cleaning technologies and strategies can be addressed for specific circumstances. Energy

impacts of air leakage are being dealt with through ASHRAE Standard committees 90.2 and 119, which have multi-laboratory and multi-manufacturer involvement.

- Provide guidance on energy-efficient, effective filtration and air cleaning for residential applications. Increasing concerns about IAQ have led to increased use of residential air cleaning and filtration in portable and stand-alone applications and as components integrated with central HVAC systems. Such devices and systems may improve energy efficiency by reducing the amount of outside air needed to dilute or remove emitted pollutants, depending on how effectively they are deployed. Analysis of the energy and health impacts of these devices is relevant to this research topic and to residential miscellaneous electric loads (MELs).
- Develop equivalence paradigms for energy-efficient alternatives to ventilation. This approach may be most valuable for new homes, which would typically require higher ventilation rates that could be reduced with material source control measures. Such approaches are quite different than the more prescriptive approaches currently used. These approaches are performance based by specifying the appropriate IAQ-related targets and enabling innovative solutions to show equivalence.
- Evaluate needs, strategies, and technologies for humidity control and innovative dehumidification. In high-performance homes, humidity control is important to maintain good IAQ. The issue needs to be evaluated because few good data are available. Innovative technologies need to be developed to address dehumidification energy efficiently.
    - *Diagnostics.* The need to develop new test methods and standard practices to support retrofit and new technologies will increase. This could include advanced envelope and duct leakage testing procedures. A collaborative effort that includes many Building America participants and teams is required.
    - *Technology evaluation.* As the industry and R&D organizations develop new technologies for energy-efficient IAQ control, they will continue to need field and theoretical evaluations to facilitate market acceptance. The current year effort of evaluating energy recovery ventilators for formaldehyde performance is a good example. New technologies will continue to require such evaluations.
- Advance understanding of energy and IAQ impacts of garages, basements, and attics within the air-sealed building envelope. Attached buffer spaces, particularly garages, can be a major source of contaminants, but are not well understood. The value from an energy and an IAQ perspective of garage compartmentalization needs to be explored and its impact on standards and best practices reviewed.

5.5 Multi-Year Milestones

The following are adapted from LBNL’s FY 2011 annual operating plan:

- Identify data needs to support analysis of a health risk-based ventilation standard.
- Complete a modeling framework design to analyze health and energy impacts of mechanical ventilation and other health risk mitigations.
- Quantify the baseline health impacts of airtightening without ventilation, and the health benefits and energy costs of exhaust and balanced mechanical ventilation.

- Characterize new home VOC profiles and differences between conventional and high-performance new homes.
- Compile sufficient data for national and regional analysis of airtightness data.
- Complete pilot experiments to assess the effect of ventilation rate on formaldehyde levels in new residential rooms.
- Propose scope and methods for a national data collection effort.

FY 2012 milestones:

- Write detailed protocols for national field data collection effort.
- Pilot data collection efforts for all field study components.
- Upgrade modeling framework to handle intermittent sources and particle dynamics.
- Develop (with stakeholder input) appropriate test methods for assessing pollutant capture performance of cooking exhaust fans.
- Evaluate options (filtration, intermittency) to ensure that increased ventilation does not adversely affect IAQ when outdoor air pollution is high.
- Identify technology development needs for smart ventilation systems.
- Analyze costs and benefits of advanced kitchen and bath ventilation.
- Initiate data collection efforts.
- Support incorporation of findings to ASHRAE standards and relevant codes.
- Publish results in archival journals and make available to public as LBNL reports.

FY 2013-2014 milestones:

- Complete data collection efforts.
- Conduct a national analysis of energy and health implications of ventilation strategies and technologies.
- Publish results in archival journals and make available to public as LBNL reports.
- Publish ASHRAE Standards (62. 2-2013, 90.2-2013, 119-2013 and 136-2013).
- Publish ASTM test methods to support diagnostics.
- Provide policy analyses to DOE.

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6 Residential Miscellaneous Electric Loads R&D Agenda

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6.1 Problem Summary

MELs are about 20% of residential primary energy use today and projected to grow to about one third of energy use in the next 20 years (DOE 2009). The most recent residential survey data from EIA also show that the increased saturation of consumer electronics may be offsetting efficiency gains in major appliances (DOE 2011). In low-energy homes, MELs can be 40% or more of whole-house energy use, which means that to achieve DOE's goals of 50% or greater whole-house energy savings, the MELs end use must be addressed along with the traditional end uses (Brown et al. 2006).

MELs energy use tends to be spread among many devices in a given home (50–100 plug-in devices in a home is typical); the services provided and the drivers of energy use vary greatly between the end uses within MELs (e.g., from home entertainment, to cooking, to power tools). The largest clusters of MELs energy use in homes, and the areas of greatest growth, are home offices and home audiovisual systems, where electronic devices predominate. This poses a problem for developing policies to address this energy use because electronic products tend to change rapidly, which makes it hard to develop energy use reduction strategies, which may not be effective across successive generations of products as new features and functionality are introduced. In addition, many MELs (particularly electronics) have power supplies that introduce losses in active use and in standby.

For most MELs devices, the largest uncertainty and variation in energy use is due to occupant energy use patterns, not variation in device energy use under test conditions. Moreover, for many MELs devices, their presence and energy use in a given house are closely associated with occupant tastes, preferences, and behaviors. Nevertheless, occupants rarely have any information about how much energy the MELs, collectively and individually, are consuming in their homes.

6.2 R&D Questions

Given the energy challenge posed by MELs, we need to develop a comprehensive set of technologies and policies to reduce their energy use. The ultimate goal is to enable a MELs end-use that consumes the least energy possible while still meeting occupant needs. Research is needed in the following areas:

- Better understand the diffuse and varied MELs end-use.
    - How do we collect meaningful energy use data on MELs in actual use?
    - What are the high priority MELs devices to address?
    - What usage modes account for most of the energy use?
    - How much do MELs contribute to peak loads?
    - What is the potential for controls (whole-house and device level) to reduce MELs energy use?
    - What are the drivers of MELs device proliferation (what energy services are driving increased saturation of MELs)?

- Develop component and system designs that efficiently deliver MELs services.
    - What functions and components of MELs devices drive energy use (power conversion, displays, etc.)?
    - In a given MELs device category, what technologies and design strategies can make that device, and its components, more efficient?
    - What information, training, and incentives would effectively persuade MELs device manufacturers to design more efficient products?
    - Are there ways to limit the proliferation of MELs devices (e.g., multifunction devices)?
    - How do we influence the purchase of MELs devices in an energy retrofit or new construction situation?
- Develop controls that more closely match delivered energy services to occupant needs.
    - In a given MELs device category, what control technologies and strategies can make that device more efficient (e.g., occupancy and ambient light sensing, interdevice control)?
    - What technologies and standards need to be developed to realize a vision where MELs devices cooperatively manage their energy use in a distributed manner, so their energy consumption is proportional to the services being delivered?
    - How effectively can energy use feedback systems affect MELs energy use? What other information is needed to educate homeowners about MELs energy use and make it easy to reduce that energy use?
    - How can usability of MELs be improved to encourage energy savings?
    - Should MELs interact with the electricity grid? If so, how and how do we optimize the interaction to reduce energy consumption and bills?

6.3 Current Status

With the growth of the MELs end use over the last 20 years has come increased activity to better understand and address this energy use. The most comprehensive information about the MELs end use is from the national RECS survey of a few thousand residential buildings, in which housing characteristics and monthly, whole-building utility bills are collected. These monthly bills are then statistically disaggregated to estimate end use energy consumption, using building characteristics, equipment ownership, and exogenous factors such as weather to explain variation in energy use. In these models, miscellaneous and electronic loads are included in the "Other" end use category, which is simply a statistical residual that cannot be attributed to one of the traditional end uses (heating, cooling, lighting, etc.), and is therefore subject to errors that result from data collection or model specification. RECS collects very few data about the presence and characteristics of MELs devices in the study homes, so very little can be said about which devices are responsible for the Other energy use.

To help identify the large energy users in the MELs end use, researchers began supplementing the top-down RECS data with bottom-up estimates of MELs energy use by device, based on energy consumption data from controlled, laboratory conditions. These bottom-up studies provide a high-level estimate of how energy is used in the residential sector, and what types of devices may be most responsible for that energy use. The shortcomings of these studies, however, are that they nearly always study the devices in isolation (i.e., device by device) rather than as a collection of devices in a building (thereby missing the correlation between device uses). Moreover, the laboratory data on MELs energy use is collected under simulated use conditions, which may not accurately represent the field use patterns that actually drive energy use.

To overcome this analytical uncertainty, researchers typically employ field metering, usually conducted at the branch-circuit level to identify large individual loads such as heating, cooling, and water heating. Because MELs devices tend to be spread among the branch circuits and their use is aggregated with other devices, the traditional field metering techniques have limited value for quantifying MELs energy use. With improvements in electrical metering technology over the last several years, a more intensive type of metering—at the device level—has been developed. These field studies have shown promising results but have been conducted on only a very small sample of buildings, and only a small sample of devices within these buildings, because the cost of metering equipment is high and the activity is labor intensive.

6.3.1 U.S. Department of Energy Activities

LBNL undertook the first studies to quantify the MELs end use in the 1980s and 1990s (Meier 1987, Meier et al. 1992, Sanchez et al. 1998). Beginning in the late 1990s, the DOE Building Technologies Program commissioned a series of analyses to better understand electronics and miscellaneous device energy use and savings potential, to inform both program design and the Annual Energy Outlook forecasts (Roth et al. 2002, Roth et al. 2007, Roth and McKenney 2007, Roth et al. 2006, Zogg and Alberino 1998). These studies were all bottom-up estimation studies.

Recognizing that the lack of field energy use data is a significant barrier to better understanding the MELs end use, LBNL has been developing field methods for measuring device-level energy use (Brown et al. 2011). They used small, relatively inexpensive wireless power meters to develop an improved method for collecting device-level energy and power data. These meters form a mesh network based on Internet standard protocols and can form networks of hundreds of metering points in a single building. Because the meters are relatively inexpensive (<$100 each) and do not require manual data downloading, they can be left in the field for months or years to collect long time-series energy use data. LBNL has also developed a field protocol to collect comprehensive, robust data about the characteristics of MELs devices in a home.

To complement the direct energy measurements using wireless meters, the Fraunhofer Center for Sustainable Energy (FhCSE, under contract to LBNL) has also been exploring whole-house non-intrusive load monitoring (NILM) techniques, in which individual appliance power consumption information is disaggregated from single-point measurements. The goal of this work is to develop techniques that can reliably measure MELs energy use for much lower cost than individual device meters, which will allow much larger field studies and less expensive energy-use feedback systems. The initial work reviewed the literature in the NILM field from last 30 years and published a review paper at an IEEE conference (Zeifman and Roth 2011). The NILM techniques that have been tried in the past fall into two sampling rate regimes: low-frequency (~1Hz) or high-frequency (>10kHz). In general, the low-frequency algorithms are not suitable for MELs, and the best high-frequency algorithms successfully identify the energy use of individual appliances only about 75% of the time. This indicates more algorithm development is needed for accuracy. Fraunhofer also tested improved signal processing algorithms in the laboratory and found that combined classification algorithms show promise. This research is currently being documented and the study team plans to publish the findings in the open literature during summer 2011.

To begin to address the energy use of MELs and other end uses, NREL has conducted laboratory and field assessments of commercially available Automated Home Energy Management (AHEM) systems.

The DOE appliance standards program is currently conducting rulemakings or developing test procedures for several MELs products: Battery Chargers & External Power Supplies (this will significantly reduce standby loads in many electronic products), Ceiling Fans and Ceiling Fan Light Kits, Cooking Products, Dehumidifiers, Pool Heaters, Television Sets, and Torchieres. DOE is also considering rulemakings for several electronic products such as computers, displays, and set-top boxes. To support these rulemakings, LBNL is developing a database of short-term field metering data for MELs devices.[9]

6.3.2 ENERGY STAR

ENERGY STAR continues to maintain and update its specifications for a wide variety of MELs devices (see Table 3). For some products, DOE is now helping develop test procedures in collaboration with EPA.

Table 3. Residential MELs Product Categories With ENERGY STAR Specifications

Electronics	Miscellaneous Devices
Existing Products	
Computers*	Vent fans (includes range hoods)*
Displays* (includes computer monitors and digital picture frames)	Ceiling fans*
Set-top boxes and cable boxes*	Decorative light strands (e.g., holiday lights)
Imaging equipment (printers)*	Water coolers
Televisions*	Dehumidifiers*
Audio/video equipment*	Room air cleaners and purifiers
Battery chargers*	
Cordless phones	
New or Possible Future Products	
Small network equipment (e.g., wireless access points)*	Countertop appliances (e.g., toasters)
Game consoles*	Spa baths
Uninterruptible power supplies*	Security systems
Projectors	Garage door openers
Home storage	

*ENERGY STAR specification for this product category is being updated or under development in FY 2011.

[9] http://minotaur.lbl.gov/aeud/

6.3.3 Other Activities

CEE (www.cee1.org/resid/rs-ce/rs-ce-main.php3) has formed an electronics committee for its member utilities around the country to coordinate its programs that address electronics products. These utility programs have mainly focused on efficient televisions, patterned after the ENERGY STAR specification. Some programs have tried to address collections of devices using smart plug strips, with mixed success (O'Neil et al. 2010).

The California Energy Commission Public Interest Energy Research (PIER) program has funded a series of studies to better quantify the energy use of MELs and develop technologies to reduce this energy use. Beginning around 2000, PIER funded a study to quantify the impact of low-power mode (standby) energy use in California homes (Nordman and McMahon 2004), and a related study that quantified the overall impact of residential MELs in the state (Porter et al. 2006). Based on these studies, PIER concluded that networking and consumer electronics were large drivers of MELs energy use, and subsequently funded work by LBNL to begin to address the impact of digital networks (Lanzisera et al. 2010), and work by Ecos to identify technologies for reducing electronics energy use (Moorefield and Calwell 2011).

Finally, a significant field study of MELs energy use was conducted last year in Minnesota (Bensch et al. 2010). This study found that MELs energy use was spread across a broad range of devices, but concentrated in the home entertainment and home office area. They found a significant potential for energy reduction using simple control technologies built into products, such as computer power management and automatic brightness control in televisions.

6.3.4 Industry Activities

In 2007 the information technology industry started the Climate Savers Computing Initiative (www.climatesaverscomputing.org) to promote efficient design of computers and enabling of power management features. It focuses primarily on commercial end users, but also has strong element of consumer outreach and education. The Consumer Electronics Association (CEA) also has a consumer education campaign about energy use in electronics, but it is buried in a website designed to promote the benefits and purchase of consumer electronics (http://digitaltips.org/green). The Northwest Energy Efficiency Alliance also has a consumer education campaign about efficient electronics (http://energyefficientelectronics.org).

A few voluntary technology standards address MELs energy use. For instance, CEA maintains test procedures for set-top box and audiovisual equipment energy use (CEA-2013-A, CEA-2022, and IEC 62087).

6.4 Opportunities, Gaps, and Barriers

Based on the studies described and LBNL's experience in studying MELs, solving the "MELs problem" will require a collection of many strategies, ranging from efficient product components (e.g., efficient power supplies) to efficient products (e.g., PC power management) to managing groups of connected devices (e.g., home theater or home office) to whole-house control (e.g., automated home energy management and occupant feedback). A portfolio of research activities is needed, in three general areas: 1) Better understanding the diffuse and varied MELs end-use, 2) Developing component and system designs that efficiently deliver MELs services, and 3) Developing controls that more closely match delivered energy services to occupant needs.

Market trends indicate that networking and communication capabilities will be added to essentially all residential products over the next decade, primarily for convenience and functionality, but also due to Smart Grid initiatives. While these connectivity functions have the potential to enhance energy efficiency, they are primarily being added to products for other reasons and therefore will likely impede energy efficiency without intervention by the energy efficiency community. The key to realizing the energy savings potential of networking and communications are energy-aware technology standards for device interoperability and usability. Because communication capabilities are already being added to devices, stand-alone energy control systems probably will not be viable in residences, for cost and consumer acceptance reasons. Consumer acceptance of stand-alone control systems is a problem because the only control method generally available to these systems is to turn off the power to the device, which makes products behave unpredictably (e.g., "on" switches are disabled). On the other hand, "distributed" control that is built into devices using the native control interfaces is most likely to succeed in the market. The technologies for achieving this type of distributed, cooperative control have not been fully proven, however. This research need was identified as a top priority at the Building America Fall 2010 planning meeting, "Smart cooperative controls for MELs" (NREL 2011).

A significant development in the MELs area has been the decision by the DOE Appliance Standards Program to pursue rulemakings for several types of MELs devices in the coming years. To support this standards process, research is needed to better characterize the energy use of MELs devices to identify the best targets for standards and variability across the housing stock, as well as collect better data on the performance of efficiency technologies for MELs. For instance, LBNL is considering applying the MELs field protocols described previously to collect energy consumption data on electronic devices from a larger sample of homes, for use in standards rulemakings.

An important industry standard (ECMA-393) was recently adopted that will allow sleeping PCs to maintain their network presence, thus eliminating a significant barrier to saving 50% or more of PC energy use. To encourage adoption of this standard, it needs to be demonstrated in a variety of applications so its savings potential can be accurately verified.

6.5 Multi-Year Milestones

6.5.1 FY 2011 Milestones

- Complete long-term field metering of MELs in three homes and publish results.
- Publish NILM algorithm development and testing results.
- Develop an R&D plan, to include identifying key MELs with further research, candidate efficiency technologies to investigate, ways to work with manufacturers to encourage more efficient products, and communication and control standards that are needed.

6.5.2 FY 2012 Milestones

- Participate in committees defining standards for interoperability of MELs communication and control.
- Develop and demonstrate networked management of MELs using "native" control interfaces.
- Conduct field demonstration to quantify savings from PC network proxying (ECMA-393).

- Work with industry to improve MELs product design process (e.g., identify what incentives are needed for highly efficient mobile electronic designs to be used for AC-powered devices).
- Test commercially available networked plug-load controls (e.g., Modlet).
- Continue to develop and field test NILM methods.
- Assess usability of MELs energy control user interfaces.
- Assess consumer response to information about MELs energy use for purchase and operation.
- Field test MELs packages with efficient devices and improved controls.
- Develop and refine energy test procedures to cover additional types and operational modes of MELs products (e.g., participate in IEC committee developing test procedures for "network standby" modes).

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7 Research Needs for Achieving Cost-Effective Deep Energy Retrofits (Site Built and Manufactured Housing) and High-Performance New Manufactured Housing

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7.1 Context

The specific scope of work for this chapter is to identify:

- Research needs to achieve cost-effective deep energy retrofits for site built and manufactured housing
- Strategies to reduce risks to occupants from health and safety issues that could be caused during and by the deep energy retrofits.
- Strategies to reduce risks to house durability caused by deep energy retrofits.
- Research needs for retrofitting manufactured housing and identify research needs to achieve high-performance, cost-effective new manufactured housing.
- The need for computer modeling accuracy versus cost, time, and accuracy required for input data.

7.2 Introduction

At more than 20% (Table 1.1.3 of the *Buildings Energy Data Book* [BEDB] 2009) (http://buildingsdatabook.eren.doe.gov/), residential energy use is a significant part of U.S. energy use and greenhouse gas emissions. Accordingly, DOE is investing significant resources to reduce residential energy use and develop the technical and scientific capability for deep energy retrofits. Building America has more than 15 years experience and demonstrated success in conducting systems engineering and research to cost-effectively improve the energy efficiency, IAQ, comfort, and durability of new housing. It has only recently, however, started similar systems-based research for deep retrofits in existing homes. One goal of Building America is to document strategies to cost-effectively reduce whole-house energy use in existing homes by 30% in all climates by 2014 (Lee 2010).

Deep retrofits in existing homes are not cheap, easy, or common. A few inspired individuals have completed serious deep retrofits that aim to save more than 70% of pre-retrofit energy use. Some of these homes are net power producing. Case studies or data from six of these homes, five in cold climates and one in Florida, are available from links cited in the Reference section. There are, of course, more examples of case studies of deep retrofits of individual homes that achieve the more modest goal of 30% or higher savings (McIlvaine et al. 2010).

Community-scale case studies of retrofits, with varying levels of savings, have also been completed. For example, Shonder et al. (1998) documented 32% savings in 200 apartments in Fort Polk, Louisiana, through lighting retrofits, low-flow showerheads and replacing the air-source heat pumps with ground-source heat pumps with desuperheaters. Fuller et al. (2010) completed a comprehensive review of large-scale retrofit efforts over the past 30 years: "… there is no proven formula—and only limited success to date with reliably motivating large numbers of Americans to invest in comprehensive home energy improvements, especially if they are being asked to pay for a majority of the improvement costs…"

Persistence of savings and cost effectiveness are other major challenges. As documented by Fuller (2010), in the Bonneville Power Administration weatherization efforts in the Pacific Northwest (which ultimately weatherized 900,000 homes in the 1980s and early 1990s), "savings per household (relative to non-participants) declined over the course of the Long-Term Weatherization Program, from 3,060 kWh/home in 1986 to 2,180kWh/home in 1988 and 1,330 kWh/home in 1989."

The lack of cost effectiveness is shown in two examples. In the recent Clean Energy Works Portland project (Peters et al. 2010) the annual savings estimated in 64 homes that completed retrofits in 2009 and 2010, ranged from $28 to $650/yr with a median value of $216/yr. The median loan amount for similar projects was $12,633. The average median simple payback is thus about 50 years. Earlier, in the 1980s, for the Hood River Conservation Project that implemented extensive retrofits in over 80% of all eligible homes in an Oregon community, the cost was $1.70 per initial saved kilowatt-hour (Fuller et al. 2010). That translates to a simple payback of more than 25 years, given the low cost of electricity in the Pacific Northwest.

These examples also show that a major barrier to retrofits is the relatively low cost of energy. The average "energy burden" for households that are ineligible for federal assistance is only 2.3% of household income (Table 2.3.15 of BEDB 2009) and in many cases lower than phone and cable bills. Thus, home energy costs do not seem to strongly motivate most Americans.

This discussion suggests that a fruitful area for research will be to lower the cost of deep retrofits and weatherization through systems engineering and documenting the cost effectiveness of energy retrofits and the attendant potential value added through enhanced comfort, IAQ, building durability, and improved aesthetics. In other words, the same fundamental Building America approach that has worked for new housing has the potential to be successful for retrofits. The following research needs spring from that fundamental philosophy.

7.3 Research Needs

The research needs are identified in four categories

- Site-Built and Manufactured Housing Retrofits
- Manufactured Housing Retrofits
- Manufactured Housing New Construction
- Software.

7.4 Site-Built and Manufactured Housing Retrofits

7.4.1 Pilot Deep Energy Retrofits

- Continue the PNNL/ORNL team approach of achieving and monitoring pilot deep retrofit homes that began in 2010. Initiate new pilots that achieve savings in all climates and cover single and multifamily applications. These pilots will be used to document the costs, savings, and challenges associated with deep energy retrofits.

The PNNL team approach focuses on systems engineering during equipment replacement or ownership changing events. For instance, if the HVAC equipment is to be replaced, rightsize the equipment, incorporate return air transfers if needed, ensure airtight ductwork, and install an outdoor air ventilation system simultaneously. If roofing is to be replaced (a more than $14 billion/yr industry per table 2.6.2 of BEDB 2009), explore opportunities to remove some roof sheathing to access normally inaccessible attic areas and seal the ducts, air tighten the ceiling plane, fix leaky can lights, and add ceiling insulation. Explore adding wall insulation if siding is to be replaced (more than $5 billion/yr per BEDB, 2009) or complete interior painting is to be done. If a foreclosed home is being renovated by a county under the HUD neighborhood stabilization program, conduct a full systems engineering analysis to identify and implement all cost-effective options subject to available budget. Early success with this approach was documented by McIlvaine et al. (2010). They document 10 completed renovations that have simulated energy savings of 9%–48% (average 31%).

- Instrument and monitor these homes to determine actual energy savings and improvements in IAQ and comfort. Interview and otherwise engage the occupants to evaluate their comfort and satisfaction with the retrofits and document any lessons learned.
    - *Reduce retrofit-related health, safety, and durability risks.* In cooperation with other laboratories and organizations such as Gas Technology Institute and BPI, develop a simple-to-use, well-illustrated checklist that a home energy professional can use to identify risks and recommend strategies to mitigate. Examples may include how to use an infrared camera to identify thermal shorts, how to use moisture meters to identify wood moisture levels in critical areas, how to check for defective or worn out electrical wiring, and how to assess whether fireplaces and atmospherically vented combustion equipment are likely to cause health and safety issues.
    - *Laboratory home 50%+ deep grid-friendly retrofits.* In cooperation with smart-grid researchers at PNNL, retrofit one of the two side-by-side PNNL laboratory homes in Richland, Washington, to research and showcase a grid-friendly 50%+ retrofit package for cold climates. Include water conservation measures. Partner with General Electric and other manufacturers that are introducing grid-friendly appliances.
    - *Integrate ductless heat pumps.* Monitor the performance of these systems with or without forced air systems in the PNNL laboratory homes and elsewhere to quantify the energy performance and room-to-room comfort. Develop air distribution and mixing strategies if significant room-to-room temperature differences are found. Engage with BPA and other utilities that are also interested in this area. Evaluate combined ductless heat pump and heat pump water heater (HPWH) strategies in various climates and home types.
    - *Retrofit HPWHs.* Conduct prototype HPWH retrofits in cooling climates to quantify the interactions with air-conditioning and domestic hot water and impacts on relative humidity issues. In heating climates, investigate HPWH integration with exhaust ventilation system to lower the negative impacts on heating energy consumption. Work with HPWH manufacturers. Evaluate strategies in the PNNL laboratory homes. Publish guidelines for retrofits after cost and performance data are obtained by performing several prototype retrofits in the field in several climates and by monitoring their performance.

- *Replace water supply line.* This offers the opportunity to switch to a structured or home run piping layout. Common practice is "like and kind" replication of pipe runs. Low-flow fixtures, WaterSense rated toilets, and tankless gas/heat pump water heaters would be included in more comprehensive retrofits. Floor air-sealing, floor (or crawlspace wall) insulation, and duct sealing are not directly related to the plumbing replacement, but could synergistically improve energy and water efficiency.

7.5 Manufactured Housing Retrofits

- Repair leaky ducts. Work with leading factory-built home manufacturers to develop and field test effective strategies for repairing leaky duct systems. Sealing high-pressure duct joints, sealing torn areas of the belly effectively and permanently to bring leaky floor ducts into closer coupling with the conditioned space, and creating interior duct systems in homes with vaulted ceilings to bypass inaccessible and leaky attic ducts are good strategies. Publish guidelines for retrofits after cost and performance data are obtained by performing several prototype retrofits in the field in several climates and monitoring their performance.

- Replace exterior insulating sheathing and windows. Manufactured homes typically have 6-in. to 12-in. overhangs, and windows are rarely flashed (typically they are just caulked after being nailed in). This presents unique opportunities and challenges for insulating poorly insulated walls and replacing leaky, poorly performing windows. Evaluate several strategies in laboratory homes. Publish guidelines for retrofits after cost and performance data are obtained by performing several prototype retrofits in the field in several climates and monitoring their performance.

7.6 Manufactured Housing New Construction

- Beyond code and ENERGY STAR compliance guidelines. Evaluate and analyze the proposed new code for manufactured housing that is expected to be released by January 2012 and compare to ENERGY STAR for Homes version 3 standards. Develop a guide for home manufacturers on cost-effective ways to meet beyond code performance levels.

- High-performance modular homes. Work with International Builders Show Village sponsors to demonstrate innovative envelope, equipment, and solar technologies incorporated in factory-built homes for International Builders Show 2012 and 2013.

7.7 Software Needs

- Assess energy retrofit software usefulness. Several software tools are in use by energy auditors and home performance contractors. Interview a dozen or more auditors to assess the tools they use and how satisfied they are with ease of use, accuracy, and general usefulness. Summarize the information so it is useful to software developers and auditors.

- Use Google SketchUp applications. Value generally needs to be added beyond energy efficiency to achieve large-scale market penetration of energy-efficient products and services. Software that uses the Google SketchUp or a similar platform should be developed to show homeowners how attractive some visible energy conservation items can look (e.g., interior ducts or added exterior insulation combined with window replacements).

7.8 Conclusions

For the last 15 years Building America has successfully increased the market share of new energy-efficient, high-performance homes by working with builder partners to increase their profits and customer satisfaction through systems engineering. The results have been communicated to other builders and stakeholders through market transformation and communications efforts led by the PNNL/ORNL team. Sustained guidance and support from DOE should enable the proposed research activities and market transformation activities to lead to an increased market share of deep energy retrofits of existing homes.

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Links with Case Study and/or Data for Very Deep Energy Retrofits (>70% savings)

http://infomonitors.com/dpr/ (Florida example).

www.affordablecomfort.org/initiatives.php?PageID=16 (four case studies in cold climates available at this link).

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8 Building America Market Transformation Opportunities

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8.1 Problem Summary and Introduction

Building America is a significant contributor to residential building science with an emphasis on energy efficiency. The knowledge produced by the program is of high value to builders, remodelers, industry allies, and managers of residential efficiency programs. However, several issues complicate the dissemination of consistent and meaningful information to the program's target audiences in a way that will transform markets. Building America:

- Has a complex structure. This is becoming more so with the addition of 10 research teams to the current five, and with a greater emphasis on existing homes in addition to new construction. The more teams and products, the greater the difficulty in maintaining consistent technical and informational content, products, and vocabulary. The need has never been greater to explain potentially conflicting research results from a program perspective.
- Emphasizes systems engineering. Achieving energy savings through systems engineering requires that many technologies, techniques, and models be applied. The fundamental programmatic message to builders is to follow the approach, not simply to adopt specific technologies. Describing and selling an abstract approach is more difficult than selling a specific technology (such as compact fluorescent lamps, PV, or high-R windows).
- Is a player in a crowded market. The program's outreach to builders must strengthen and leverage the good work from other programs.

The Home Energy Score is a key new tool and activity intended to improve information delivery to consumers. Vice President Joe Biden and DOE Secretary Steven Chu announced the launch of the Home Energy Score Pilot program on November 9, 2010. The Home Energy Score is presented on a label as a quick way for homeowners to understand how their home's energy performance compares to that of others in the same region (DOE 2010). In developing this strategy, the Vice President's Middle Class Task Force (2009) noted that: "Consumers do not have access to straightforward and reliable information on home energy retrofits that they need to make informed decisions."

The launch of this activity emphasizes DOE's commitment to improving information delivery and the priority given to renovating homes. Supporting and coordinating with this program will be important objectives for Building America market transformation activities.

The great strengths that Building America brings to market transformation are its recognition as an important source of tested and documented information and the relationships that the DOE managers, laboratory researchers, and Building America teams have developed with specific builders and other industry players over years of interactions and accomplishments. The program has paid less attention to reaching the broader population of builders that have not received direct intervention from a Building America team. Building America must do a better job of leveraging the strengths to reach the broader market and have greater impact on the speed and scale of the adoption of energy efficient construction and renovations.

Building America has held two all-team meetings since selecting 15 teams to participate in the program. Both meetings have resulted in substantial team input related to market transformation activities. Many perceptions shared in the team meetings are consistent with the issues raised in the preceding paragraphs.

The following key findings from participants at the July and November 2010 Building America meetings[10] included multiple gaps that relate to market transformation:

- Building America research is not accessible to stakeholders.
- Metrics and the number and quality of data collected need to be standardized.
- Consumers do not see the value in efficiency—we need to educate consumers and homeowners.
- We need to explore ways to deal with the unpredictable (confidence in energy savings, simulated occupancy).
- Data must be transparent and peer reviewed.

Building America is a successful research program and has made a difference in the market for new homes. Building America technical information and builder training has done much to strengthen deployment programs such as ENERGY STAR for New Homes. For example, builders participating in both ENERGY STAR and Building America build a disproportionate number of new ENERGY STAR homes in key markets as opposed to builders that participated in ENERGY STAR only. Thus builders participating in both programs helped to improve ENERGY STAR's penetration rate (Baechler et al. 2006). DOE's companion program to Building America, the Builders Challenge, continues to recruit builders and label new high-performance homes. Also, a private-sector service offered by Masco developed with technical assistance from Building America warranties energy performance for consumers and helps ensure building science principles are properly applied in hundreds of thousands of new homes.

Building America can help to fill gaps and needs, including outreach to new home builders who do not work with a Building America team and to contractors, remodelers, and installers working on existing homes, which Building America has recently turned its attention to. Building America is not alone in recognizing and attempting to transform these markets. The following sections describe strategies that Building America can follow to leverage its own strengths, and those of market allies, to have an even greater impact on both new and existing homes.

8.2 Building America Market Transformation Strategies

"The term *market transformation* refers to the strategic process of intervening in a market to create lasting change in market behavior by removing identified barriers or exploiting opportunities to accelerate the adoption of cost-effective energy efficiency as a matter of standard practice" (ACEEE 2010).

Building America's focus on new construction has developed strong relationships with builders and the building industry. Its emphasis on field applications has won over the nation's largest builders who have worked directly with Building America teams to improve the energy

[10] At the November team meeting, team and laboratory members participated in a brainstorming session on implementation. The gaps and needs identified in the July meeting were expanded. Findings were presented in Bianchi (2010).

efficiency, quality, and value of their houses. Building America has also developed strong industry allies, or at least set the foundation for growing these relationships. As Building America (and the entire Building Technologies Program) ramps up retrofit activities, these relationships must be replicated for new construction and renovations.

DOE's ambitious goal is to retrofit 1.3 million homes by the end of 2013 and to continue to aggressively enhance the energy and value performance of new homes. To substantially contribute to these goals in a timely way, Building America must find a way to reach, educate, and motivate contractors and builders who will not be directly touched by Building America teams. The program needs to continue creating and documenting research findings and design solutions. That information must be presented using consistent language and media directed to the identified target audiences. However, current approaches will not be enough to engage non-partner builders and contractors.

Residential construction and renovation involves many small contractors working in local markets (Will and Baker 2007). In 2008 there were a reported 270,000 building construction contractors and an unknown number of self-employed individuals (Bureau of Labor Statistics 2010). The Joint Center for Housing Studies at Harvard used data collected in the 2002 Economic Census of Construction to estimate more than 500,000 remodeling businesses that year, including the self-employed (Will and Baker 2007). The 2005 remodeling market value amounted to $280 billion (Will and Baker 2007). For a sense of scale, this accounted for nearly 40% of residential construction in 2005 (Bendimerad 2008).

Building America is not alone in trying to reach this market. Table 3 identifies opportunities and barriers related to this market. The strategies described in this chapter use the strong technical information and builder relationships developed by Building America to reach out to a broader audience of builders, renovators, and installers and to better coordinate with multiple deployment programs. The following strategy recommendations include brief descriptions of specific actions needed to pursue the strategy and a qualitative sense of the required budget above and beyond existing activities.

8.2.1 Strategy 1: Use Building America Documentation Products To Strengthen the Building America Brand and Market Allies

Building America should continue to develop programmatic-level documentation. Building America has developed a strong library of technical publications, including technical reports from the teams, Best Practices documents, and case studies that transcend individual team efforts to provide a programmatic perspective on efficient home design packages. Although individual team recommendations and documentation may vary in approach and depth, the programmatic documents place these differences in the context of overall program research. Whereas a single team may focus on a particular solution or viewpoint, the programmatic documents can present that solution as one of multiple approaches.

This documentation helps to ensure a consistent program vocabulary and brand. A common lexicon is important to avoid market confusion. To help ensure consistency, DOE requested that PNNL prepare outlines for case studies to be developed under the program. These outlines were prepared last summer (2010) and were used in developing task orders for the new Building America teams.

- Make Best Practices and other documentation available to all market allies. Potential allies who use the information include:

    - The Appraisal Institute, to develop new training materials for appraisers to include the value of energy efficiency in its appraisals.
    - The State of Wisconsin, to develop a new website for its new construction program promoting ENERGY STAR and Builders Challenge.
    - The American Institute of Architects, in support of training materials for solar design.
    - The DOE Codes Program, to help populate the Codes Resource Center.
- Pursuing this action is straightforward.
    - Continue to develop Best Practices and other deployable documentation.
    - Work with DOE management to develop clear and simple guidelines for when graphics and manuscripts can be released.
    - Reach out to critical organizations such as BPI, the Appraisal Institute, real estate professionals, home builders associations, educators, and others to use the material.
    - Respond to requests promptly for high-resolution materials.

The cost to pursue this strategy is low. Some additional time will be needed to coordinate across teams and laboratories tasked with maintaining communication with market allies, but materials are already being produced and are included in the budget.

8.2.2 Strategy 2: Form an Ongoing Market Transformation Working Group Within Building America

Building America teams have shown tremendous interest in market transformation activities. Invite each team and participating national laboratory to participate in a market transformation working group. This group can provide input into communications products and tools, as well as organizations and programs that should be targets of Building America outreach. This working group would be instrumental in working with DOE to form and implement a market transformation plan and assigning roles to implement the plan. However, the group will require leadership to focus on those activities best suited to Building America and its mission as opposed to the transformation of the entire residential construction market.

The cost of participating in meetings and calls would be low if meetings are conducted in combination with team meetings.

8.2.3 Strategy 3: Continue To Support Standard-Setting Organizations

Work began last year to directly support standard setting organizations. The first organization to receive support is BPI. PNNL is establishing a Web-based system to accept and track comments on BPI's proposed standards. BPI has requested additional help in responding to comments. PNNL is providing limited help with responses as an extension of the Web-based system designed to track comments. The system is transparent to users placing comments or questions. To their eye, the system is linked to the standard-setting organization, such as BPI. The primary investment in this system was made in FY 2010. Support to standard-setting organizations enables Building America to target its information and technology where it will most effectively influence industry practices. The support essentially leverages the volunteer efforts that industry leaders put into technical review panels, boards, and committees. The system will be validated with BPI and can then offered to other organizations attempting to set energy efficiency standards or protocols. The system can be expanded to provide technical assistance to any practitioner who wishes to submit a question to the standard-setting organization, whether related to a standard or not. Establishing standards and supporting the organizations that create them help to create workforce capabilities that are critical to quality management and give builders and contractors access to the tools and information they need to implement energy efficiency technologies.

The cost to develop this capability was covered in FY 2010. Additional costs would be modest to reach out to other organizations and coordinate with their standard-setting activities.

8.2.4 Strategy 4: Leverage Relationships With Builders To Establish a More Formal Organization of Builder Partners

There are several ways to do this:

- Formally make Building America partner builders a part of the program. To date most builder interaction has been exclusively done through the teams.
- Establish an organization that builder partners can join to share information. The organization may be structured to address new construction and renovation contractors. The organization may also be structured around topics such as quality management, Builders Challenge, ENERGY STAR, or technical issues.
- Allow all builders with an interest to join this voluntary, information-sharing organization.
- Use this builder partners organization as a sounding board to determine the tools that builders need to achieve better energy performance and to review or evaluate Building America products.
- Support the organization by preparing technical specifications, volume purchases, and demonstrations of new technologies.
- Use the builder organizations to engage manufacturers and vendors. For example, at national meetings such as the International Builders Show, organize speed dating opportunities where builders can learn about energy efficiency technologies and techniques. Invite service providers such as quality management consultants, raters, warranty programs (Masco's Environments for Living), and energy efficient mortgage (EEM) providers to participate in the speed dating. Invite branding programs such as ENERGY STAR and Builders Challenge to participate as well. This organization could serve as an important platform for training builders and renovation contractors in the use of the Home Energy Score label and the Scoring Tool.

Initial costs are low for inviting in builder partners. Coordinating the organization by maintaining e-mail lists, setting up conference calls, organizing events, and establishing other means of communication would entail higher costs. Organizing meetings at the IBS and inviting vendors would require coordination time. Higher costs could include conducting surveys, developing specifications for new products, organizing volume purchases, and other forms of assistance. However, establishing the builder partner organization does not create a specific commitment to complete more expensive forms of assistance and research. Those projects could be decided individually.

8.2.5 Strategy 5: Reach Out to Manufacturers and Vendors

Most manufacturers and vendors sell highly efficient and standard equipment. Unfortunately, most consumers cannot tell the difference and often must make very quick decisions about replacement or repair. We need to persuade this group to make the upsell for efficient equipment and to develop a systems perspective. "If Building America can help manufacturers of replacement equipment like heat pumps, air conditioners, windows, water heaters, siding, etc. to develop a systems approach to replacements and educate them on the possibilities, they may start including air sealing, duct sealing and insulation as part of replacement projects.

Moderate costs are expected to establish these relationships and maintain e-mail lists, set up conference calls, and organize speed dating activities. Ongoing education will be required to achieve success with the systems approach. Building America should coordinate with other organizations such as the Codes Program, Emerging Technologies, ENERGY STAR, BPI, and RESNET, which also seek to maintain relationships with manufacturers and vendors.

8.2.6 Strategy 6: Reach Out to Other Programs

Work with other programs such as ENERGY STAR, the Codes Program, Emerging Technologies, BPI, RESNET, CEE, state and regional programs, and others to share mailing lists, invite builder participants, and share programs.

This strategy is likely to reduce overall costs, although it will require time to establish relationships and coordinate resources.

Each of these strategies approaches the market from different perspectives. The strategies are intended to reinforce each other. They would work best if implemented in tandem. However, individual strategies, or even specific activities within the strategies, could be implemented.

8.3 Summary of Residential Construction Market Transformation Opportunities and Barriers

Table 4 summarizes market opportunities and barriers. The column "Building America Strategies" suggests ongoing (shown with a dash [-]) and new activities (shown with an asterisk [*]) that address each market barrier or opportunity.

Table 4. Summary Table of Building America Strategies for Market Barriers and Opportunities

Market Barriers and Opportunities	General Strategies	Building America Strategies[1]
New Construction – Leveraging Opportunities for Energy Efficiency		
Documentation and Resource Development	Disciplined program branding and messaging reduces confusion and enhances communication.	- Continue to develop documentation to consistently present program goals, encourage (or enforce) common lexicon, and present all team research perspectives.
Team participation indicates high interest and motivation in market transformation activities.	Establish market transformation and communication standing committee	* Establish a standing market transformation and communication committee to harness team experience and insight.
Builder partners are highly motivated and a strong resource, but few data have been collected to identify needs and understanding.	Gather information about technology gaps, training needs, branding preferences, business models, and other factors.	* Question teams and builder partners about the information, products, and approaches that work best for them and identify the gaps.
Branding differentiates efficient houses: ENERGY STAR for New Homes offers a well established and recognized brand for new construction Builders Challenge offers a consumer label that allows for the comparison of energy performance in homes	Consumers are willing to pay more for certified, branded, green, energy-efficient homes. The Builders Challenge label allows for energy performance comparison across houses as well as indication of specific performance and quality measures. Branding helps builders differentiate their product.	- Continue to support the Builders Challenge program. * Develop a “builder’s working group” that builders can participate in even if they are not part of partnerships. Target documentation products for these members such as catalogs of technologies. * Coordinate with the EPA to reach out to ENERGY STAR builders for speed dating and builder’s alliance.
Masco Environments for Living uses Building America principles to offer guaranteed energy performance that builders subscribe to and offer to consumers	Branding and performance guarantee.	Continue to provide team access and documentation as a building block for these types of programs.
Regional, state, and utility programs.	Sponsored programs often include incentives and aggressive recruitment and education activities. CEE includes many utility and other sponsors.	Coordinate with regional, state and utility programs
Energy Efficient Mortgages	All national secondary mortgage markets and federally insured programs offer energy mortgages at point of home sale (Baden 2010). EEMs are poorly understood in the market (Mann 2009).	* Encourage contractors to promote EEMs. * Encourage real estate professionals to promote EEMs. * Develop case studies emphasizing EIMs and EEMs * Invite HUD and other providers to builder speed dating. - Include information about energy efficient

Market Barriers and Opportunities	General Strategies	Building America Strategies[1]
		mortgages in builder and consumer documentation.
Energy efficient training such as “Houses that Work”	Provide training and training materials.	- Encourage the Energy Efficient Building Association and other training providers to use Building America resources and lexicon.
Quality management programs and awards.	Packaged programs and award programs exist but builder participation is limited and builder confusion is high.	- Continue to develop quality management tools and documentation * Develop a quality management website that provides introductory information and resource links. * Encourage vendors to participate in speed dating events. * Expand energy efficiency certification programs (BPI, RESNET, apprenticeships) to reach new construction trades.
Recognize exemplary builders using the Energy Value Housing Awards and Builders Challenge awards.	Recognize and award excellence.	Continue to support Energy Value Housing Awards and Builders Challenge award programs.
Encourage communication and sharing across university and college programs.	University outreach and coordination	- Continue to sponsor coordinating events and support teams and laboratories to work with universities and colleges.
Emerging Technology Programs	Technology purchases and new product specification	- Encourage builders to use volume purchase opportunities and join user groups. A current example is the High-R Windows volume purchase. * Product specifications for new generations of technologies are tested in more commercial buildings. Existing building partners and a new builder’s alliance could be used to identify technology gaps where specifications and solicitations could be useful. * Invite user groups to join “builder’s alliance.”
Energy Codes Resource Center	Technical assistance to builders Enforcement of code standards	- Populate codes resource center with Building America documents and resources. * Use e-mail lists generated by the codes program to invite builders to join the Building America builder organization. *Publicize Building America activities on the codes website, which receives 3 million hits per month.

Market Barriers and Opportunities	General Strategies	Building America Strategies[1]
New Construction – Reducing Barriers to Energy Efficiency		
Builders who are not partners have limited access to information about building science, new technologies, and Building America findings.	Develop education programs for builders and product distributors. Develop Golden Carrot[2] Programs to promote specific technologies. Develop technology purchase programs to increase awareness and drive down costs. Develop certification for specific trades.	- Continue to develop Best Practices and case studies, and participate in builder conferences. * Develop a builder's alliance that builders can participate in even if they are not part of partnerships. Target documentation products for these members such as catalogs of technologies. * Sponsor speed dating events to allow vendors to meet builders and distributors. * Expand energy efficiency certification programs (BPI, RESNET, apprenticeships) to reach new construction trades.
Appraisers do not value energy efficiency.	Improve appraiser standards and practices.	- Continue to provide training materials to trade organizations. * Engage trade organizations aggressively to require training and to develop training curricula and other documentation.
Real estate sales professionals do not sell energy efficiency.	Develop business cases showing improved sales and profit for real estate professionals. Consumers are willing to pay more for certified and branded, green, energy-efficient homes.	* Continue to provide training materials to trade organizations. * Engage trade organizations aggressively to require training and develop training curricula and other documentation.
Emerging Technology Programs	Technology purchase and new product specifications	* Promote the program through the builder alliance * Create new volume purchases and product specifications to fill gaps in product selection.
Renovation – Leveraging Opportunities for Energy Efficiency		
Documentation and Resource Development	Disciplined program branding and messaging reduces confusion and enhances communication.	Continue to develop documentation to consistently present program goals, encourage (or enforce) a common lexicon, and present all team research perspectives.
Home Performance With ENERGY STAR	This program offers a template for state and local programs to implement. The program is marketed to sponsors, not to remodelers.	- Prepare case studies on program experience. * Develop planned business case document for contractors. * Share technical support documentation to inform consumers and contractors.
Home Energy Score and other labeling programs for existing homes	Branding and informational labeling programs enable consumers to compare energy performance across houses and	* Develop planned business case document for contractors. * Develop quality criteria and support

Market Barriers and Opportunities	General Strategies	Building America Strategies[1]
	may indicate specific performance and quality measures.	documentation for installations. * Provide documentation to support training and communication. * Work with a builder partner organization to train builders and contractors.
Certification organizations (BPI, RESNET, Appraisal Institute) are establishing professional certifications and installation standards.	Certification and standards establish professional protocols and criteria to enhance credibility and quality management.	- Continue to develop infrastructure to support standard setting. - Continue to provide documentation to aid in training programs * Provide technical support to those offering comments. * Provide technical support for non-standard based questions and comments.
Energy Improvement Mortgages (EIMs) such as Power Saver loans (HUD 2010).	All national secondary mortgage markets and federally insured programs offer energy mortgages at point of home sale (Baden 2010). EEMs and EIMs are poorly understood in the market (Mann 2009).	* Encourage contractors to promote EEMs. - Encourage real estate professionals to promote EEMs. * Develop case studies emphasizing EIMs and EEMs.
Emerging Technology Programs	Technology purchases and new product specifications	* Welcome all interested contractors in a voluntary builders working group. * Promote programs through the builder working group. * Create new volume purchases and product specifications to fill gaps in product selection.
Home Energy Magazine	Magazine for energy performance professionals	* Sponsor and create Building America column that builds on previous articles incorporated in the magazine.
Energy Codes Resource Center	Technical assistance to builders Enforcement of code standards	- Populate codes resource center with Building America documents and resources. * Use e-mail lists generated by codes program to invite builders to join the Building America builder organization. * Publicize Building America activities on the codes website, which receives 3 million hits per month.
Renovation – Reducing Barriers to Energy Efficiency		
Home performance renovators have limited access to information about new	Develop education programs for builders and product distributors.	- Continue to develop Best Practices and case studies, and participate in builder conferences.

Market Barriers and Opportunities	General Strategies	Building America Strategies[1]
technologies and Building America findings.	Develop Golden Carrot[2] Programs to promote specific technologies. Develop technology purchase programs to increase awareness and drive down costs. Develop certification for specific trades.	* Develop a builder's working group that builders can participate in even if they are not part of partnerships. Target documentation products for these members such as catalogs of technologies. * Sponsor speed-dating events to allow vendors to meet builders and distributors. * Expand energy efficiency certification programs (BPI, RESNET, apprenticeships) to reach new construction trades.
Fragmented industry installers focus on piecemeal installations (roofers, plumbers, HVAC, painters)	When equipment fails or requires maintenance consumers must make decisions very quickly based on available funding. Sales opportunities based on routine maintenance and replacement does not upsell efficiency.	* Develop home performance business cases and training for installers. * Develop labels or other products to leave with homeowners that alert them to replace failed equipment with high-efficiency products. * Work with local sponsors to provide coupons and hotlines for efficient products. * Target property management firms for these materials.
Appraisers do not value energy efficiency.	Improve appraiser standards and practices.	- Continue to provide training materials to trade organizations and the Appraisal Institute. * Engage trade organizations aggressively to require training and develop training curricula and other documentation.
Real estate sales professionals do not sell energy efficiency.	Develop business cases showing improved sales and profit for real estate professionals. Consumers are willing to pay more for certified and branded, green and energy-efficient homes.	* Continue to provide training materials to trade organizations. * Engage trade organizations aggressively to require training and to develop training curricula and other documentation.

[1] Ongoing activities are shown with a dash (-) at the beginning of each strategy; new activities are shown with an asterisk (*).
[2] Golden Carrots are prizes offered in energy-efficient design competitions.

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Appendix – Barriers, Gaps, and Opportunities Identified by the National Laboratories

NREL – Assessing and Improving the Accuracy of Energy Analysis for Residential Buildings

Barrier or Gap	Opportunity	Area
There is a general perception that software-based energy analysis of inefficient existing homes tends to over predict pre-retrofit energy use and retrofit energy savings.	Use empirical data from the field to assess and track the accuracy of reference software.	Technical Pathway Analysis
Many metrics are used to assess the accuracy of software predictions and therefore comparing metrics across studies can be difficult.	Develop a single reference containing standardized definitions for error, potential sources of error, and accuracy.	Technical Pathway Analysis
Potential issues with software tools and their inputs are only partially identified.	Use a rigorous process to identify potential issues by comparing predicted versus metered energy use and savings. Gather modeling experts, assemble field test results, and conduct comparative software tests to identify potential issues.	Technical Pathway Analysis
As software tools are improved, reference software results in published comparative test suites become outdated.	Update reference program results using improved reference software. Modify or add test cases that are designed to determine whether specific improvements have been implemented correctly.	Technical Pathway Analysis
Building characteristics and utility billing data from actual houses have not been available in large scale for comparing software predictions with metered data.	Collect empirical datasets from field analysis activities so they can be used to evaluate the accuracy of analysis methods.	Technical Pathway Analysis
Potential issues with software tools and their inputs, even when identified, are not prioritized.	Prioritize potential issues based on estimates of potential impact.	Technical Pathway Analysis
Uncertainty in input values used by software tools to predict energy use is not fully known.	Create a process to estimate the uncertainty of input values for software tools. Measure the variability in energy assessment data through controlled field studies.	Technical Pathway Analysis
New or improved measurement technology may be needed for energy assessments.	Improve measurement technology and develop new measurement technology that will lead to more accurate, affordable, and safer energy assessments.	Technical Pathway Analysis

ORNL – Deep Retrofits

Barrier or Gap	Opportunity	Area
Variable-capacity compressors have fewer oversizing performance penalties, so requiring ACCA Manual J to rightsize the air conditioner may be unnecessary.	Carefully collect field data, develop heat pump models, and validate computer simulations from multiple test sites surrounded by whole-house performance measurements to generate well-characterized datasets. Investigate if there are better metrics than Seasonal Energy Efficiency Ratio (SEER) and heating season performance factor (HSPF). Conduct side-by-side comparisons for a full year of operation of different variable-speed options with various sequences of operation. Provide well-characterized field site data to groups that are interested in maximum annual energy savings and peak savings.	System Evaluations
During energy efficiency retrofits, even extensive ones, air distribution ducts are usually not replaced.	Develop procedures and possible technologies for downsizing installed air ducts according to ACCA Manual D.	Measure Guidelines
Air distribution ducts are left in unconditioned spaces after deep energy retrofits; the traditional way of sealing ducts with mastic often is still not effective.	Develop air sealing techniques that are self diagnosing (color change tape, for example) or error proof.	Emerging Technologies
A good duct model based on deep energy retrofits is not available, but is necessary to create guidelines for duct insulation.	Develop a good duct model based on deep retrofit houses.	Technology Pathway Analysis
Guidelines for duct insulation after an enclosure retrofit are not available.	Develop guidelines for duct insulation organized by duct location.	Measure Guidelines
Smart energy devices, such as appliances, HVAC, and lighting are not interoperable with smart meters.	Develop standardization, communication protocols, streamlined process for commissioning so the benefits of connecting smart energy devices with smart meters. Test devices in occupied and simulated occupied research houses.	Measure Guidelines Test House and Pilot Community Evaluations

Barrier or Gap	Opportunity	Area
The most likely industry to develop a sustainable market for whole-house energy retrofits is energy utilities, but there are perceived risks in utility engagement.	Develop software tools so the energy savings predictions are reliable.	Technical Pathway Analysis
	Develop reliable utility, building, and manufacturing partners, financial institutions, and real estate stakeholders to help validate utility electrical capacity resource planning models.	Stakeholder Need Evaluation
	Develop research-driven, electric utility-sponsored home retrofit programs.	Partner Program Development
A significant barrier to whole-house home energy retrofits is the lack of confidence in predicted energy savings.	Validate energy audit software with measured energy use.	Test House and Pilot Community Evaluations
	Quantify energy savings from prioritized lists of retrofit measures.	Technical Pathway Analysis
	Integrate next-generation technologies into energy audit and simulation software. This includes variable capacity heat pumps, heat pump water heaters, hot water savings from ENERGY STAR washers, horizontal geothermal systems, and advanced miscellaneous electric loads.	Technical Pathway Analysis
Homeowners choose not to spend their capital in energy efficiency retrofits.	Establish successful deep energy retrofit projects spawned by homeowner needs.	Test House Evaluations
	Develop energy retrofit plans that take place when equipment fails and in case of weather event damage.	Measure Guidelines
There is no knowledge about how to deliver each component of a whole-house retrofit faster, cheaper, and deeper.	Develop a low-cost, automated, integrated, and accurate diagnostic and audit tool that is less intrusive.	Technology Pathways

Barrier or Gap	Opportunity	Area
	Develop a tool that can process the energy use, age, and efficiency of all the home's major energy-consuming features with the homeowner's remodeling desires, energy savings priorities, and financial situation. The tool needs to generate a phased whole-house energy retrofit plan and respect privacy issues.	
Dryer ducts in high-performance homes are easily plugged with lint.	Develop demand-enabled ventilation capabilities.	Emerging Technologies
There is a desire to eliminate ducts in unconditioned spaces that will drive the increased use of multi-splits. This will generate more holes in airtight enclosures. Continuous fan operation may lead to high energy consumption and humidity control issues in some climates.	Testing of mini-splits in well-controlled houses is necessary to explore the tradeoffs of various optimized distributed space conditioning strategies.	Test House and Pilot Community Evaluations
The International Energy Conservation Code (IECC) 2012 will increase R-value requirements in enclosures. If DOE and its partners successfully propose changes for IECC 2015, these values are likely to increase even further. The building industry is not fully equipped to meet the requirements cost effectively.	Conduct moisture research to determine health, safety, and durability of high-R enclosures.	System Evaluations
	Determine advanced enclosure material performance targets for fire resistance, permeability, durability, termite resistance, thermal resistance, etc. This includes establishing an expanded materials characterization program and a systematic building materials evaluation protocol similar to the DOE Lighting Caliper program.	System Evaluations
	Conduct research on pre-manufactured externally applied roof and wall panel systems that can comply with the stringent energy standards.	System Evaluations
	Support ASTM whole wall analysis standard for single- and multi-family housing.	Measure Guidelines
	Develop foundation insulation detail with above-grade wall exterior brick cladding that avoids the thermal short.	Measure Guidelines
	Conduct a series of laboratory measurements to determine capillary wicking in foundation walls and footers.	Test House and Pilot Community Evaluations
	Measure the performance of permeable facings over interior foundation insulation in mixed humid climates.	Test House and Pilot Community

Barrier or Gap	Opportunity	Area
		Evaluations
	Test the performance of expanded polystyrene (EPS) in foundation insulation moisture control systems and compare it with that of XPS	Test House and Pilot Community Evaluations
	Test 2 × 4 frame offset from foundation wall 1-2 in. sprayed solid with open cell foam insulation.	Test House and Pilot Community Evaluations
Increase of spray foam application in attic, crawlspaces, and basements leads to moisture management issues.	Develop best practice guidelines for spray foam application.	Measure Guidelines
The heavy focus on air sealing will affect health and safety unless precautions are taken. Radon is still a problem and solutions for existing houses are not yet fully available.	Develop solutions for radon issues in existing homes. An example is a solar-powered radon sub-crawlspace membrane depressurization fan.	Measure Guidelines
	Develop on-demand ventilation solutions that can sense the presence of occupants and the operation of unvented gas appliances, electric and gas dryers, and bath and kitchen exhaust fans.	Emerging Technologies
All global warming potential compounds in building materials may be banned in the near future. The building industry does not have replacements fully vetted yet.	Laboratory and field test the next generation of building materials to avoid issues when applied to enclosures (for example, shrinkage, lower R-values, and more restrictive application temperatures)	System Evaluations

LBNL –Deep Energy Upgrades and Improvements

Barrier or Gap	Opportunity	Area
The energy use in residential buildings needs to be reduced by at least 50% and packages of measures are not properly documented.	Create brand: the DOE Blue Sheet for deep retrofits and the DOE Orange Sheet for normal retrofits.	Measure Guidelines
Entertainment systems are not low energy.	Develop equipment and controls to reduce energy consumption from entertainment systems.	System Evaluations
Multifamily and rental units need special attention to energy efficiency.	Conduct research on how to manage shared hot water equipment that is unique to multifamily homes.	System Evaluations
	Investigate ways to address the distinction between those who can legally make changes to a rental property and those who accrue the energy savings.	Measure Guidelines
A deeply retrofitted home has a tight envelope, energy-efficient lighting, and an efficient and reliable hot water source, so the remaining energy use is discretionary.	Conduct research on how to address occupant behavior to reduce energy use in homes.	Test House and Pilot Community Evaluations
	Determine which appliances can be turned off when they are not in use.	System Evaluations
	Perform marketing and behavioral studies to address how occupant behavior can change to reduce energy use.	Test House and Pilot Community Evaluations
	Conduct research on mass market and innovations to determine how to deploy energy efficiency improvements.	Measure Guidelines
About $150-$250 billion are spent in the United States each year to renovate homes with little emphasis on energy use. Some experts indicate that the premium and tradeoff would be negligible for intelligent renovations that save more energy.	Generate documentation about Building America research findings to industry publications such as *Remodeling Magazine* and *Home Energy Magazine*, including expert comments.	Measure Guidelines
New energy use data holders measure energy use in homes, analyze the data, and connect to occupants, industry groups, utilities, and well-connected contractors. They will change the relationship between homeowners, utilities, and energy use. The retrofit industry is not fully aware of this development.	Develop partnerships with energy use data holders (for example, Google) and local jurisdictions to obtain energy use data from a large number of houses.	System Evaluations
	Encourage contractors to combine envelope and window upgrades with HVAC improvements, either by partnering with other contractors or by expanding the skill sets of their own employees. For example, technicians may be trained to seal ducts	Test House and Pilot Community Evaluations

Barrier or Gap	Opportunity	Area
	and envelopes and install furnaces.	
	Investigate how to motivate homeowners to do retrofits and use less energy.	Test House and Pilot Community Evaluations
	Partner with contractors and others who have direct contact with homeowners, recognizing that almost no home improvements are based on a cost-effective approach, but are done for appearance, utility, comfort, health, etc. Provide homeowner contacts with information and advice about how to include energy savings measures in all their activities, particularly when the incremental costs are low.	Measure Guidelines
Homebuilders and renovators face many challenges when working in homes: moisture, lead and asbestos, knob and tube electrical wiring, historic buildings, combustion safety versus air tightness, home type, and climate.	Create opportunities for builders and renovators to upgrade their skills, including qualifications, certifications, and training, so they can make the transition to deep energy upgrades.	Better Buildings/Workforce Guidelines
There is limited energy efficiency awareness.	Develop good advice and recommendations about the costs of energy audits, credit and market misinformation, energy efficiency claims, etc. This advice should be presented as targets (blue and orange sheets) and techniques for achieving targets.	Measure Guidelines
	Explore ways to persuade owners to upgrade rental homes.	Measure Guidelines
	Investigate offering rebates on equipment, lighting, and appliances at the dealer/distributor level.	ENERGY STAR Appliances
There is a credibility gap on energy saving predictions.	Develop credible energy savings data, protocols, and demonstration tools.	Technical Pathway Analysis
There is low value on unseen retrofits. Renovation focus is on appearance, convenience, comfort, and health.	Focus on energy efficiency measures that are associated with other benefits that the homeowner is looking for.	Measure Guidelines
There is no common minimum energy code in the United States.	Make federal awards be dependent on adopting a national energy code for buildings. Develop a simple low-level prescriptive code to be used with current awards.	Building Codes

Barrier or Gap	Opportunity	Area
Good contractors currently face the difficulty of competing against those who are allowed to perform poor work.	Develop a system of testing and inspection to identify the low cost-bad performance contractors.	Better Buildings
High energy use but low energy density housing is characteristic in new U.S. construction.	Focus on energy use instead of energy efficiency (energy use per area, for example).	Technical Pathway Analysis
Improvements in technology are needed to deliver deep energy retrofits.	Develop technologies to control ventilation systems so IAQ levels are met. At the same time, they need to prevent overventilating and take advantage of incidental mechanical ventilation from kitchen and bath exhausts and clothes dryers.	System Evaluations
	Develop retrofit insulation for hot water storage tanks.	Measure Guidelines
	Conduct research on cavity insulation methods that completely fill cavities without leaving voids using holes as small as 0.4 in. in diameter.	System Evaluations
	Conduct research to assess the effectiveness of new window treatments to improve air sealing and using interior and exterior storm windows. Research is also needed to assess the effectiveness of these window treatments and to develop improved methods for flexible/adjustable frames, non-glass glazing, etc.	System Evaluations
	Develop efficient, cost-effective dehumidification systems for high-performance homes.	System Evaluations
	Improve diagnostics of insulation levels, window performance, and ventilation system airflow.	Measure Guidelines
Airtight houses are more prone to moisture and IAQ problems.	Develop a program to measure pollutants in homes pre- and post-retrofit combined with field evaluation of new approaches and technologies.	Test house and Pilot Community Evaluations
	Conduct research to study the transfer of polluted garage air into homes to create recommendations	System Evaluations

Barrier or Gap	Opportunity	Area
	on attached garages.	
Audits and retrofits have negative connotations.	Ask behavioral scientists who understand the power of language to develop a new lexicon to reach the mass market.	Better Buildings
Information technologies, such as smart meters, are not currently used for energy efficiency programs.	Develop a national database of home performance based on the measured data to make informed decisions about R&D and policy making. Conduct research to determine the useful information that can be extracted from the 15-minute data, such as high energy users, large energy uses, and high baseline. Determine how to couple gas metering to electricity smart meters and other technologies.	Test House and Pilot Community Evaluations

LBNL – Residential Planning for Healthy, Efficient Homes Research

Barrier or Gap	Opportunity	Area
There is a lack of data on ventilation energy and indoor air-related health risks in the United States.	Apply energy and health risk modeling framework to evaluate the benefits and costs of ventilation, source control, and other IAQ-related technologies and strategies.	Technical Pathway Analysis
	Compile, collect, and analyze data to support modeling of ventilation energy and indoor air-related health risks throughout the United States.	Test House and Pilot Community Evaluations
The energy and IAQ performance of a high-performance home will be limited without advances in ventilation equipment and control systems.	Develop, evaluate, and deploy smart and robust ventilation and ventilation control technologies.	System Evaluations
Some cooking exhaust fans effectively remove pollutants before they mix throughout the air, but many—including the most widely installed designs—do not. The lack of any industry standard performance test for capture efficiency of residential kitchen exhaust systems is a critical gap. Lack of awareness about pollutants generated during cooking is a substantial barrier to progress.	Develop, deploy, and field test advanced kitchen and bath exhaust systems.	System Evaluations
Current ASHRAE ventilation standards do not differentiate between new and existing homes, even though pollutant profiles can differ substantially. Likewise, ventilation needs and optimum systems can vary by region and location.	Incorporate energy efficiency guidance and equipment performance standards into the ASHRAE residential ventilation standard.	Measure Guidelines
Increasing concerns about IAQ have led to increased use of residential air cleaning and filtration in portable and stand-alone applications and components integrated with central HVAC systems.	Provide guidance on energy-efficient, effective filtration and air cleaning for residential applications.	Measure Guidelines
	Develop equivalence paradigms for energy-efficient alternatives to ventilation.	Technical Pathway Analysis
Few good data are available on humidity control and innovative dehumidification in high performance homes.	Evaluate needs, strategies, and technologies for humidity control and innovative dehumidification.	System Evaluations
	Develop new test methods and standard practices to support retrofit and new technologies.	Measure Guidelines
	Evaluate new technologies for energy-efficient IAQ control.	System Evaluations
Attached buffer spaces, particularly garages, can be a major source of contaminants, but are not well understood.	Advance understanding of energy and IAQ impacts of garages, basements, and attics within the air-sealed building envelope.	System Evaluations

LBNL – Residential Miscellaneous Electric Loads R&D Agenda

Barrier or Gap	Opportunity	Area
MELs are about 20% of residential primary energy use today and projected to grow to about 1/3 of energy use in the next 20 years. In low-energy homes, MELs can be 40% or more of whole-house energy use, which means that to achieve DOE's goals of 50% or greater whole-house energy savings, MELs end uses must be addressed along with the traditional end uses.	Conduct long-term field metering of MELs in several homes.	Test House and Pilot Community Evaluations
	Develop and publish whole-house nonintrusive load monitoring techniques, in which individual appliance power consumption information is disaggregated from single-point measurements.	Test House and Pilot Community Evaluations
	Develop an R&D plan to identify key MELs, focus on further research, investigate candidate efficiency technologies, identify ways to work with manufacturers to encourage more efficient products, and develop communication and control standards.	System Evaluations
	Assess the usability of MELs energy-control user interfaces.	System Evaluations
The largest clusters of MELs energy use in homes, and the areas of greatest growth, are home offices and home audiovisual systems, where electronic devices predominate. This poses a problem for developing policies to address this energy use because electronic products tend to change rapidly, which makes it hard to develop energy-use reduction strategies, and strategies may not be effective across successive generations of products as new features and functionality are introduced.	Develop and demonstrate networked management of MELs using "native" control interfaces.	System Evaluations
	Conduct field demonstration to quantify savings from use of network-presence proxies in PC networks.	Test House and Pilot Community Evaluations
	Work with industry to improve MELs product design process (e.g., identify incentives for highly efficient mobile-electronic designs to be used for AC-powered devices).	System Evaluations
For most MELs devices, the largest uncertainty and variation in energy use is due to occupant use patterns, not to variations in device energy use under test conditions. Moreover, for many MELs devices, their presence and energy use in a given house are closely aligned with occupant tastes, preferences, and behaviors. Nevertheless, occupants rarely have any information about how much energy the MELs, both collectively and individually, are consuming in their home.	Assess consumer response to information about MELs energy use, both for purchase and operation.	Test House and Pilot Community Evaluations
There is a lack of standards to realize a vision where MELs devices cooperatively manage their energy use in a	Participate in committees defining standards for interoperability of MELs communication and control.	Emerging Technologies

Barrier or Gap	Opportunity	Area
distributed manner.	Test commercially available networked plug load controls.	Test House and Pilot Community Evaluations
	Field test MELs packages with efficient devices and improved controls.	Test House and Pilot Community Evaluations
	Develop and refine energy test procedures to cover additional types and operational modes of MELs products (e.g., participate in IEC committee developing test procedures for “network standby” modes).	Test House and Pilot Community Evaluations

PNNL – Research Needs for Achieving Cost-Effective Deep Energy Retrofits (Site Built and Manufactured Housing) and High-Performance New Manufactured Housing

Barrier or Gap	Opportunity	Area
Deep retrofits in existing homes are not cheap, easy, or common. Persistence of savings and cost effectiveness of deep energy retrofits are major challenges.	Initiate, instrument, and monitor pilot deep retrofit homes to document the costs, savings, and challenges associated with deep energy retrofits.	Test House and Pilot Community Evaluations
	Publish guidelines for retrofits after cost and performance data are obtained by performing several prototype retrofits in the field in several climates and monitoring their performance.	Measure Guidelines
A major barrier to retrofits is the relatively low cost of energy.	Focus on systems engineering during equipment replacement or ownership changing events.	Measure Guidelines
There are retrofit-related health, safety, and durability risks.	Develop a simple-to-use, well-illustrated checklist that a home energy professional can use to identify risks and recommend strategies to mitigate.	Measure Guidelines
Ductless heat pumps are available, but their performance is not well documented in real houses.	Monitor the performance of ductless heat pump systems with or without forced air systems in test homes, to quantify the energy performance and room-to-room comfort.	Test House and Pilot Community Evaluations
	Develop air distribution and mixing strategies if significant room-to-room temperature differences are found.	System Evaluations
	Engage with utilities that are also interested in ductless heat pumps area.	Stakeholder Partner Program
	Evaluate combined ductless heat pump and heat-pump water heater (HPWH) strategies in various climates and home types.	Test House and Pilot Community Evaluations
HPWHs are available, but their performance is not well documented in real houses.	Conduct prototype HPWH retrofits in cooling climates to quantify the interaction with air-conditioning and domestic hot water and impact on relative humidity issues. In heating climates, investigate HPWH integration with exhaust ventilation system to lower the negative impacts on heating energy consumption.	Test House and Pilot Community Evaluations
	Publish guidelines for retrofits after cost and performance data are obtained by performing several prototype retrofits in the field in several climates and monitoring their performance.	Measure Guidelines
Water supply line replacements occur but deep retrofit opportunities are unrealized	Investigate replacing water supply line, offering the opportunity to switch to a structured or home run piping	Test House and Pilot Community

Barrier or Gap	Opportunity	Area
	layout.	Evaluations
Many manufactured homes have leaky ducts. Effective strategies to fix leaks and bringing ducts into conditioned spaces are needed	Investigate repairing leaky ducts in manufactured housing retrofits. Work with leading factory-built home manufacturers to develop and field test effective strategies for repairing leaky duct systems and bringing them inside conditioned spaces.	Test House and Pilot Community Evaluations
Manufactured homes with their small overhangs and poorly flashed windows present unique wall and window retrofit opportunities	Investigate replacing exterior insulating sheathing and windows in manufactured houses. Evaluate several strategies in laboratory homes.	Test House and Pilot Community Evaluations
	Publish guidelines for retrofits after cost and performance data are obtained by performing several prototype retrofits in the field in several climates and monitoring their performance.	Measure Guidelines
The upcoming new energy code for manufactured housing is likely to be much more stringent. Manufacturers need cost-effective compliance paths to meet the new code.	Evaluate and analyze the proposed new code for manufactured housing that is expected to be released by January 2012 and compare to ENERGY STAR for Homes version 3 standards. Develop a guide for home manufacturers on cost-effective ways to meet beyond code performance levels.	Measure Guidelines
Innovative energy savings technologies are not appreciated until they can be readily seen and touched.	Work with International Builders Show Village sponsors to demonstrate innovative enclosure, equipment, and solar technologies incorporated in factory-built homes for International Builders Show 2012 and 2013.	Show Home Demonstration and Case Study
There is a credibility gap on energy saving predictions.	Assess energy retrofit software usefulness. Interview a dozen or more auditors to assess the tools they use and how satisfied they are with ease of use, accuracy, and general usefulness. Summarize the information so it is useful to software developers and auditors.	Technical Pathway Analysis
Energy saving retrofits need to be attractively displayed to clearly articulate the nonenergy benefits and the enhanced value added.	Use Google SketchUp applications. Value generally needs to be added beyond energy efficiency to achieve large-scale market penetration of energy-efficient products and services. Software that uses the Google SketchUp or similar platform should be developed to show homeowners how attractive some visible energy conservation items can look (e.g., interior ducts or added exterior insulation combined with window replacements).	Measure Guidelines

PNNL – Building America Market Transformation Opportunities

Barrier or Gap	Opportunity	Area
Building America research is not accessible to stakeholders.	Use Building America documentation products to strengthen market allies.	Measure Guidelines
	Form an ongoing market transformation working group within Building America	Better Buildings
	Continue to support standard-setting organizations.	Building Codes
	Leverage relationships with builders to establish a more formal organization of builder partners.	Stakeholder Partner Program
	Reach out to manufacturers and vendors.	Stakeholder Partner Program
	Reach out to other programs.	Stakeholder Partner Program
	Sponsor and create a Building America column for Home Energy Magazine that builds on previous articles incorporated in the magazine.	Stakeholder Partner Program
	Develop a “builder’s working group” that builders can participate in even if they are not part of partnerships.	Stakeholder Partner Program
	Target documentation products for these members such as catalogs of technologies.	Stakeholder Partner Program
	Coordinate with the EPA to reach out to ENERGY STAR builders for speed dating and builder’s alliance.	Stakeholder Partner Program
	Encourage builders to use volume purchase opportunities and join user groups. A current example is the High-R Windows volume purchase.	Emerging Technologies/ Volume Purchase
	Product specifications for new generations of technologies are tested in more commercial buildings. Existing building partners and a new builder’s alliance could be used to identify	
	Coordinate with regional, state, and utility programs.	Stakeholder Partner Program
Disciplined program branding and messaging reduces confusion and enhances communication.	Continue to develop documentation to consistently present program goals, encourage (or enforce) common lexicon and present all team research perspectives.	Measure Guidelines
	Establish common vocabulary and publishing rules for Building America teams and labs.	

Barrier or Gap	Opportunity	Area
Team participation indicates high interest and motivation in market transformation activities, but activities need better coordination.	Establish market transformation and communication standing committee. Establish a standing market transformation and communication committee to harness team experience and insight.	Better Buildings
Builder partners are highly motivated and a strong resource, but few data have been collected to identify needs and understanding.	Gather information about technology gaps, training needs, branding preferences, business models, and other factors. Question teams and builder partners about the information, products, and approaches that work best for them and identify the gaps.	Stakeholder Partner Program
Energy efficiency mortgages (EEMs) and energy improvement mortgages (EIMs) are poorly understood in the market.	Encourage contractors and real estate professionals to promote EEMs. Develop case studies emphasizing EIMs and EEMs. Invite HUD and other providers to builder speed dating. Include information about EEMs in builder and consumer documentation. Provide training and training materials to energy efficiency professionals. Encourage the Energy and Environmental Building Association, BPI, RESNET, and other training providers to use Building America resources and lexicon.	Stakeholder Partner Program
Packaged quality management programs and award programs are available, but builder participation is limited and builder confusion is high.	Continue to develop quality management tools and documentation. Develop a quality management website that provides introductory information and resource links. Encourage vendors to participate in speed dating events. Expand energy efficiency certification programs (BPI, RESNET, apprenticeships) to reach new construction trades. Continue activities of the Quality Management Working Group within the Building America committee structure. Continue to support Energy Value Housing Awards and other award programs.	Stakeholder Partner Program
Communication and sharing across university and college programs with Building America are limited.	Continue to sponsor coordinating events and support teams and laboratories to work with universities and colleges.	Stakeholder Partner Program
Code information is not well integrated with Building America documentation.	Continue to populate codes resource center with Building America documents and resources. Use e-mail lists generated by the codes program to invite builders to join the Building America builder organization. Publicize Building America activities on the codes website, which receives 3 million hits per month.	Stakeholder Partner Program

Barrier or Gap	Opportunity	Area
Builders who are not partners have limited access to information about building science, new technologies, and Building America findings.	Continue to develop Best Practices and case studies, and participate in builder conferences. Develop a builder's alliance that builders can participate in even if they are not part of partnerships. Target documentation products for these members such as catalogs of technologies. Sponsor speed dating events to allow vendors to meet builders and distributors. Expand energy efficiency certification programs (BPI, RESNET, apprenticeships) to reach new construction trades.	Stakeholder Partner Program
Appraisers do not understand or value energy efficiency. This limits lenders' ability to fund energy efficiency.	Improve appraiser standards and practices. Continue to provide training materials to trade organizations. Engage trade organizations aggressively to require training and to develop training curricula and other documentation.	Stakeholder Partner Program
Real estate sales professionals do not understand or sell energy efficiency.	Develop business cases showing improved sales and profit for real estate professionals. Consumers are willing to pay more for certified and branded, green, energy-efficient homes. Continue to provide training materials to trade organizations. Engage trade organizations aggressively to require training and develop training curricula and other documentation.	Stakeholder Partner Program
Home Performance with ENERGY STAR is marketed to sponsors, not to remodelers.	Prepare case studies on program experience. Develop planned business case document for contractors. Share technical support documentation to inform consumers and contractors.	Stakeholder Partner Program
Home Energy Score and other labeling programs for existing homes are not well known.	Develop planned business case document for contractors. Develop quality criteria and support documentation for installations. Provide documentation to support training and communication. Work with a builder partner organization to train builders and contractors.	Stakeholder Partner Program
Certification and standards establish professional protocols and criteria to enhance credibility and quality management.	Continue to develop infrastructure to support standard setting. Continue to provide documentation to aid in training programs	Stakeholder Partner Program

Barrier or Gap	Opportunity	Area
	Provide technical support to those offering comments. Provide technical support for non-standard based questions and comments.	
Fragmented industry installers (roofers, plumbers, HVAC, painters) focus on piecemeal installations. When equipment fails or requires maintenance consumers must make decisions very quickly based on available funding and information.	Develop home performance business cases and training for installers. Develop labels (scannable and traditional) or other products to leave with homeowners that alert them to replace failed equipment with high-efficiency products. Work with local sponsors to provide coupons and hotlines for efficient products. Target property management firms for these materials.	Stakeholder Partner Program

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U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

DOE/GO-102011-3242 ▪ July 2011

Printed with a renewable-source ink on paper containing at least 50% wastepaper, including 10% post-consumer waste.