# Residential Deep Energy Retrofits

Rachel Cluett and Jennifer Amann

March 2014

Report Number A1401



529 14th Street NW, Suite 600, Washington, DC 20045
Phone: (202) 507-4000 • Twitter: @ACEEEDC
Facebook.com/myACEEE • www.aceee.org

## Contents

## Acknowledgments

We would like to extend our appreciation to the organizations that funded this project, including Energy Trust of Oregon, National Grid, NYSERDA, Northeast Utilities, and United Illuminating. We are grateful for thorough and helpful reviews from members of these organizations, including Fred Gordon and Diane Ferington of Energy Trust of Oregon, Michael McAteer and Nicholas Corsetti of National Grid, Christine Gifford and Gregory Pedrick of NYSERDA, Vinay Anathachar of Northeast Utilities, and Sheri Borrelli and Marissa Westbrook of United Illuminating. We also thank Linda Wigington for her thorough review of this report. She has worked to make deep energy retrofit work a reality through the Thousand Home Challenge. Last, thank you to the following ACEEE staff for their input during the project: to Steve Nadel, for providing insights and comments at many stages, to Fred Grossberg for bringing clarity to our work through his editing expertise, to Eric Schwass for making the figures so clear and attractive, and to Patrick Kiker and Glee Murray for launching this report into the world.

## Executive Summary

This report explores energy efficiency programs that target deep energy savings through substantial improvements to existing residential buildings. As states and regions set targets for reducing building-sector energy consumption, it is increasingly critical to scale up deep energy retrofit work. Many energy efficiency programs such as Home Performance with ENERGY STAR™ already help homeowners reduce whole home energy use by an average of 20%. However strategies that reduce over half of the energy used in a home are not as well developed.

Deep energy retrofits aim to save 50% or more of the energy used on site in a home as compared to actual pre-retrofit usage or an estimate of energy use based on housing and climate characteristics. These savings are realized through improvements to the building shell including insulation and air sealing, and often through upgrades to high-efficiency heating, cooling, and hot water systems suited to the smaller energy load of the house.

One utility-scale deep energy retrofit program exists at present in addition to several research and development projects. Our analysis includes the following:

- National Grid Deep Energy Retrofit Pilot
- National Grid Deep Energy Retrofit Program (a utility-scale program)
- New York State Energy Research and Development Authority (NYSERDA) Advanced Buildings Deep Energy Retrofit Program
- U.S. Department of Energy Building America Residential Retrofits
- Thousand Home Challenge

### *FINDINGS*

This paper presents findings in four aspects of deep energy retrofits.

*Workforce.* Programs seek out contractors with prior deep energy retrofit experience. However since their familiarity with deep energy retrofit techniques is limited, they need technical assistance to ensure high performance and durability. We describe the types of contractors and trades undertaking deep energy retrofits, program strategies to find and enlist them, and the certifications used to qualify them.

*Retrofit measures*. Virtually all the retrofit cases we examined involve building enclosure improvement through insulation and air sealing, measures that may require contractors to learn new installation practices. Projects also may include replacement of HVAC equipment with more efficient units and new methods of distribution.

*Costs.* Project costs range from about $50,000 to well over $100,000, often including renovations or improvements that are not directly energy related. Some programs have reported the incremental cost of adding deep retrofit measures to already planned renovations such as a siding or roofing replacement.

*Savings*. Actual energy savings of 50% or greater are possible when building shell improvements are involved. Some projects collected actual post-retrofit energy use data to assess the performance of implemented measures.

### BARRIERS

A number of barriers stand in the way of scaled-up deep energy retrofit programs.

*Limited workforce capacity.* While deep energy measures can cost effectively piggyback on non-energy-related maintenance and improvement projects, the tradespeople who deliver these services are generally not qualified for deep energy retrofit work.

*Limited market interest and acceptance.* Homeowners do not know enough about deep energy retrofits and their value to consider undertaking them at the time of major home renovations. In addition, there is no clear channel for them to contract for a retrofit even if they wanted one.

*Financial limitations.* Deep energy retrofits require a large financial investment. Many homeowners do not have access to the necessary capital or financing.

*Cost effectiveness challenges.* High project costs are the result of administrative and contractor inefficiencies and a lack of competition. In addition, most of the common cost-effectiveness tests have difficulty demonstrating a positive cost-benefit ratio for whole building retrofit programs.

### RECOMMENDATIONS

We recommend a number of ways that a deep energy pilot program can overcome these barriers and lay the groundwork for a utility-scale program.

*Develop workforce capacity.* Encourage builders to document their high-performance work to prove eligibility for program participation. Offer technical assistance to help contractors properly sequence and install deep energy retrofit measures.

*Encourage better market valuation.* Energy efficiency programs should collaborate with realtors and appraisers to properly value deep energy retrofit work in the real estate market.

*Increase customer awareness and interest.* Increase consumer knowledge about deep energy retrofits through existing energy efficiency programs. Partner with organizations that distribute information on home maintenance such as insurance companies. These organizations can help introduce homeowners to retrofit opportunities during home repair from a natural disaster, including siding or roofing replacement, or the renovation of a flooded basement.

*Target the right customers.* Community organizations can provide contact with people who are committed to environmental issues. Other good targets include the highest energy consumers.

*Provide financing opportunities.* Programs can sponsor financing for homeowners who incorporate energy efficiency measures into renovations, thus encouraging them to consider deep energy work. Private bank loans might also be an option if deep energy retrofits had a higher market valuation.

*Measure energy performance.* Programs should monitor actual post-retrofit energy use to evaluate individual measures and entire projects.

*Develop a strategy for program development and evolution.* Utilities interested in deep energy retrofits should begin with a pilot, robustly evaluate initial results, and use this solid foundation to build a full-scale program.

## Introduction

Residential buildings account for 22% of the energy consumed in the United States as of 2009 (EIA 2009). The majority of this energy is used in the 78.5 million existing single-family homes, most of which are ripe for improvements in their building shell and mechanical systems to reduce their energy demand. While many programs address energy efficiency in existing homes, very few of them succeed in reducing home energy use by 50% or more. Nonetheless, a growing number of cities and states are setting energy-savings targets to help meet greenhouse gas emissions goals, and these targets will require reductions in the energy use of existing homes.

For example, California is calling for a 40% reduction in existing homes' energy use by 2020. This is an ambitious goal considering that the highest performing residential retrofit programs result in savings of between 10% and 20% (Brook et al. 2012). Yet while the goal is ambitious, it is feasible. A number of case studies show how energy use in an existing home can be cut by 50% or more. However, although the technology to get to this level of energy savings is there, other barriers must be addressed to achieve these savings at scale.

Programs addressing residential energy use have focused on individual appliances and equipment, basic shell measures (insulation or spot air sealing), or on more comprehensive home performance retrofits involving whole-home solutions. These programs rarely achieve savings greater than 15-30%. More significant energy savings can be realized by treating homes as whole systems rather than as a collection of individual components that do not interact.

This study reviews the latest research and experience and provides recommendations for deep energy retrofits that aim to save more than 50% of the energy used in the home. While initially focused on a relatively small market of the most committed homeowners, such programs have the potential to build workforce capacity, increase funding opportunities, and broaden consumer support for residential energy efficiency. Deep energy retrofit programs can fill a niche in a program portfolio by helping the most committed homeowners make significant energy improvements while laying the groundwork for more widespread improvements in coming years.

This report lays out the essential elements of deep energy retrofit programs. We review these programs and other concerted deep energy retrofit efforts to better understand the most promising opportunities in terms of technical and economic potential, and consumer and builder acceptance. Most of the programs are relatively new or operating on a small scale, so our research draws heavily on information from program staff and key participants. As we investigate the progress of deep energy retrofit programs, we explore lessons learned in individual cases, particularly relating to overcoming barriers including costs, contractor capabilities, and market interest and acceptance.

## Residential Building Retrofit Overview

While whole-house home performance programs are available to a host of utility customers around the country, the bulk of participation and savings currently come from programs that incentivize the installation of one or more appliance and/or equipment measures. Only a limited number of homes have undergone comprehensive retrofits including air sealing, insulation, and so on.

Energy efficiency programs have focused on single or small packages of measures to meet energy efficiency requirements, and they have relied on market forces to decide how many measures are installed at once. These programs may not do much to prime the market for more energy efficiency measures or more comprehensive retrofit work by homeowners, or to increase the ability and scale of the workforce necessary to make significant energy improvements.

To meet significant energy saving goals for existing homes, it will be increasingly necessary to leverage utility programs to overcome barriers to comprehensive deep energy retrofits and to prime the market for greater uptake of this work. Since homes use a good deal of energy and their energy efficiency could be greatly improved, there is a significant opportunity for savings in this sector.

### *THE POTENTIAL: EXISTING RESIDENTIAL BUILDING STOCK*

There are 113 million housing units in the United States, with 78.5 million of them classified as single-family detached or attached. Table 1 shows that among these buildings, site energy consumption and expenditures vary by climate region. Following the table, figure 1 shows the regions.

**Table 1. Residential energy characteristics by climate region**

| Climate region | Single family (attached and detached units) (million) | Average square footage for a single-family home | Site energy consumption per household (million Btu) | Energy expenditures per household (dollars) |
|---|---|---|---|---|
| Very cold/cold | 27.5 | 2198 | 111.5 | 2,129 |
| Mixed-humid | 24.4 | 2062 | 91.6 | 2,149 |
| Mixed-dry/hot-dry | 9.5 | 1631 | 67.0 | 1,627 |
| Hot-humid | 13.1 | 1685 | 65.9 | 2,070 |
| Marine | 4.1 | 1666 | 66.2 | 1,420 |

***Source:*** **EIA 2009**

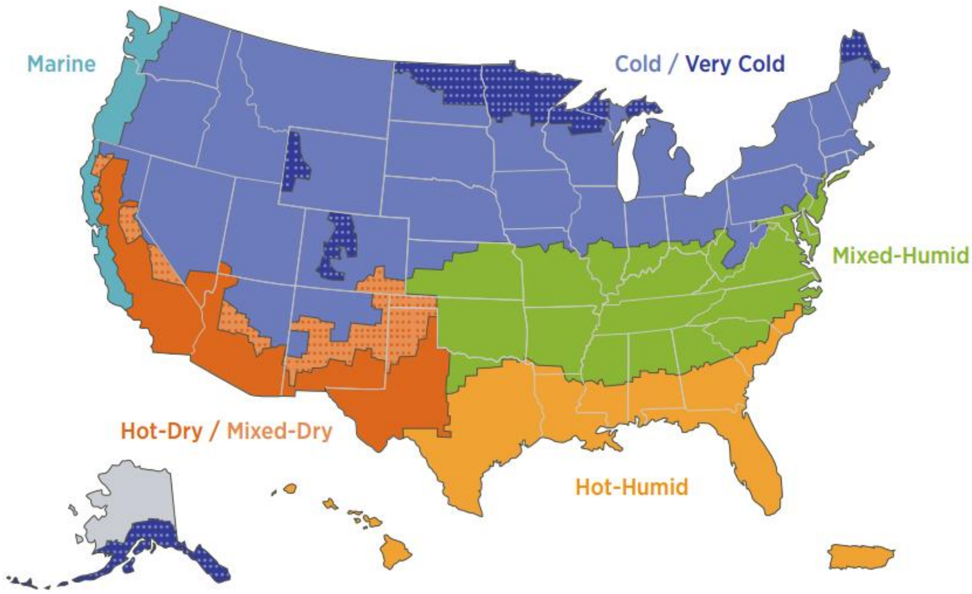


Figure 1. U.S. climate regions. *Source:* Building America 2013.

Energy is used differently in various climate regions. While some energy-saving methods can achieve savings in a variety of climates, variations in energy budgets in different regions must be considered when programs are designed and savings targets are set. For example, a program to incentivize measures that address space conditioning loads in a hot-humid climate would be less likely to reach 50% overall energy use savings than a program in a cold climate with high space conditioning energy loads. Figure 2 shows the differences in energy consumption by climate region.

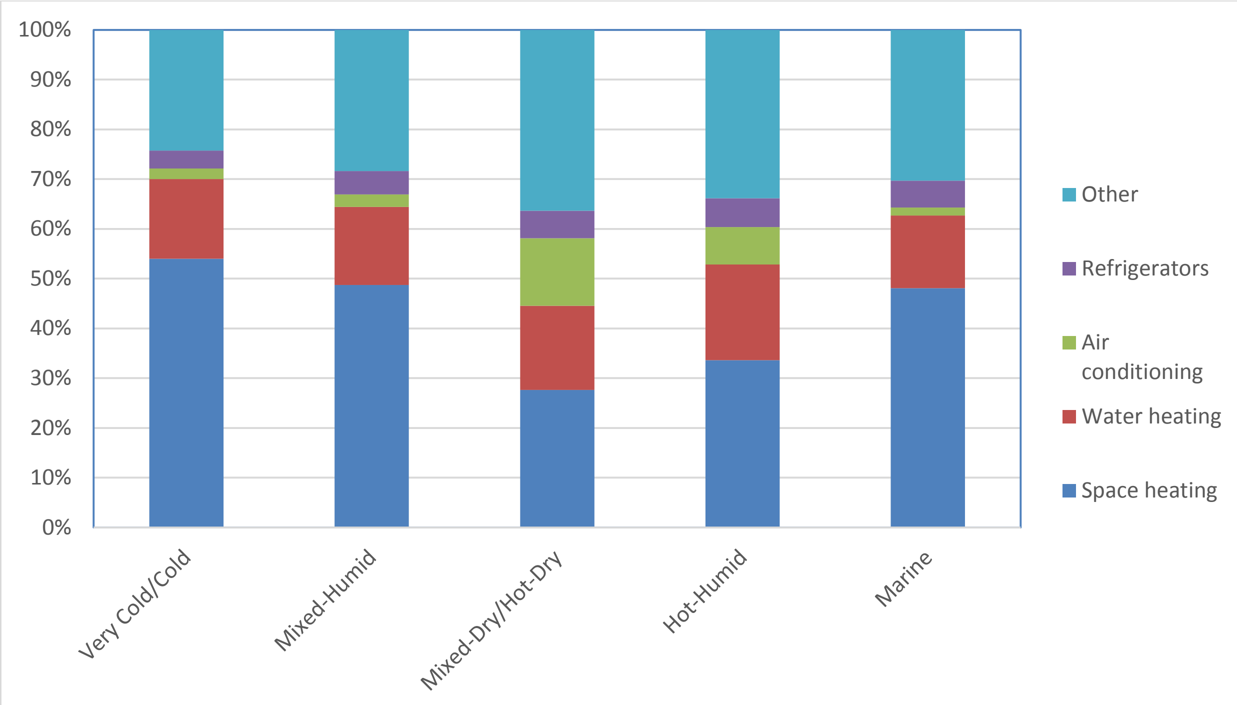


Figure 2. End-use percentage of total home energy consumption by climate region. "Other" includes appliances, electronics, and lighting. *Source:* EIA 2009.

Utility programs that incorporate more than individual measures will be essential to realizing greater energy savings. Utilities can improve the economic feasibility of an entire program by packaging the most cost-effective measures with deeper, more comprehensive options. This approach will also reduce the inefficiency of having multiple staff members (support staff, marketing and outreach, evaluation, measurement and verification) for separate programs (Brook et al. 2012). Bundling programs that cover multiple incentives into a more comprehensive strategy can be particularly well suited to regions where heating and cooling loads do not account for a majority of energy use, including mixed-dry, hot-dry, and hot-humid climates. Programs in these regions will never be able to cut residential energy consumption in half solely by focusing on air sealing, insulation, and HVAC improvements. In fact, comprehensiveness is key to achieving 50% household energy reduction in any region.

### *WHOLE HOME RETROFIT ACTIVITY*

Retrofit activity in the residential sector has grown in recent years, spurred by an increase in utility and state program activity, including programs supported by the American Reinvestment and Recovery Act (ARRA). However there is still significant opportunity for additional savings. In the residential sector, the Weatherization Assistance Program (WAP), which has been evolving since the late 1970s, has made significant contributions to the development of whole home programs and a skilled workforce. Home Performance with ENERGY STAR™ (HPwES) has become a national platform for comprehensive energy improvements in existing homes, aiming to save about 20% of the energy used in the home (ENERGY STAR 2011). The widespread HPwES program has also helped develop some of the workforce necessary to scale up deep energy retrofits, and it has shown consumers how they can pair certain purchasing decisions and home renovations with a deep energy retrofit.

More than 275,000 homes have been upgraded as a result of the HPwES program since 2002, with over 1,900 participating contractors (ENERGY STAR 2013). Along with widespread customer recognition of the ENERGY STAR brand, the platform is widely recognized among sponsors, contractors, and trade allies. While HPwES programs around the country are varied in size and have met with varied success, some programs have saved over 20% of total site energy used. In Austin, the HPwES program, which is locally sponsored by Austin Energy, used the whole-house approach to save 25-35% per home between 1998 and 2006, based on an analysis of actual energy use data from utility bills. This program included a home energy assessment that resulted in a set of recommendations with cost estimates. The owner could choose to implement only one or the complete set of measures (Belzer et al. 2007).

HPwES program designs can vary considerably. Differences are apparent in market strategies and tactics, types of consumer incentives (rebates and financing) offered, field inspection of measures, site energy saved, use of midstream incentives for contractors, and sponsor budgets and costs per project (Jacobsohn, Moriarta, and Khowailed 2013). While the highest performing HPwES programs are able to produce savings of 30% or greater, that rate varies considerably depending on program design and scope. As in the Austin approach, a commonly used model involves an energy audit that leads to recommendations for energy-efficient measures that the homeowner can then choose to undertake.

Other approaches have been developed as well. For example, Energize Connecticut uses an initial direct-install program followed by installation of deeper energy-efficient measures.[1] This approach results in lower-than-average energy savings per home: 16 million British Thermal Units (MMBtu) as opposed to the 20 MMBtu average across the whole HPwES program in 2013. On the other hand, Energize Connecticut reaches more consumers than other HPwES programs.

Deep energy retrofit projects show that technologies and techniques are available to reduce energy in a home while maintaining or improving durability, comfort, and indoor air quality. Such retrofits have been performed on homes for many years, but on a very small scale, mainly by those with strong personal interest and knowledge of energy consumption in residential buildings. To promote more widespread adoption, demonstration projects with small pools of participants and effective strategies and applications can help overcome barriers including upfront costs and lack of workforce expertise. While some of this work has been fairly well documented, projects have been inconsistently described and evaluated. This paper compares

[1] The Connecticut Energy Efficiency Fund offers two options for residential customers to learn about energy-saving opportunities: HPwES and the Home Energy Solutions program. Energy savings measures from both of these program offerings are counted as HPwES participation for accounting purposes (S. Borelli, Senior Business Dev., the United Illuminating Company. pers. comm., January 30, 2014).

these disparate efforts to lay the groundwork for larger scale cost-effective deep energy retrofit programs.

## Research Methodology and Scope

This report addresses barriers to scaling up deep energy retrofit programs in single-family residential buildings.[2] We draw on utility-sector program and pilot evaluations, but since few programs focus on deep energy retrofits, we also rely on case studies and interviews with contractors, architects, energy consultants, and program administrators to explore barriers and best practices. We also describe innovative best practices for program design, marketing, and implementation in other energy efficiency programs that could be applicable to deep energy retrofits.

We begin with definitions used by various projects and programs. Next, we outline the benefits of deep energy retrofits. Finally, we examine a number of small-scale demonstration projects and one-off case studies to highlight elements that contribute to a successful deep energy retrofit program.

## What Is A Deep Energy Retrofit?

A single, consistent definition of "deep energy retrofits" would make it easier to compare and scale up programs. The projects and programs we examine engage in one or more of the following practices to achieve home energy savings:

- Significant improvements to the building shell
    - Insulation improvements, usually to the walls, floors, roof, and attic surfaces that make up the thermal envelope
    - Attention to air sealing, particularly in areas that are harder to address without being paired with improvements to the insulation shell
- Upgrades to heating, cooling, and hot water systems
    - Upgrade to non-atmospheric vented combustion units that either vent directly outside or are electric only
    - Upgrade to units that are correctly sized for the heating and cooling load demands of an altered building
    - Improvement to or replacement of the existing distribution systems for heating, cooling, and/or hot water, including changes to ductwork, water piping, and wastewater heat recovery

Deep energy retrofit programs and projects have adopted a number of guidelines, detailed in table 2.

[2] Energy efficiency programs are often operated by utilities, as well as other organizations such as the New York State Energy Research and Development Authority (NYSERDA) and Energy Trust of Oregon.

**Table 2. Deep energy retrofit program definitions**

| Program/project | Energy savings target | Definition |
|---|---|---|
| National Grid Deep Energy Retrofit Pilot | 50% site energy | Program designed to target energy savings of at least 50% of total onsite energy use, or at least 50% better energy performance than a code-built or Federal Energy Yardstick home. |
| Thousand Home Challenge | 75% or more site energy | Includes improvement to the building shell, HVAC, and hot water systems. Renewable energy and behavioral measures can also be used to meet the measured savings goal. Homes must prove actual on-site energy savings of 75% or more to meet the challenge requirements, or meet an energy use target specifically designed for that house and the occupants. |
| NYSERDA Pilot Program | Phase 1: 60-75% reductions to heating load.[1]<br>Phase 2: 60-75% reduction in measured energy use | Significantly reducing energy consumption by installing insulation to the exterior, air sealing, and reduction in size of mechanical equipment. |
| LBNL Study Homes | 70% or more | Ten homes monitored for better understanding of energy use after improvements were done independently by homeowners. |
| SMUD's Energy Efficient Remodel Demo Program | 50% or more | Research and development program that works with local builders to employ advanced construction techniques and energy efficiency measures designed to reduce an existing home's energy use by 50% or more. |
| Building America PNNL/ORNL Deep Energy Retrofits | 30-50% modeled site energy savings | Reduction of 30-50% or more of whole-house energy use through a number of projects undertaken in marine, cold, and hot-humid climates, to demonstrate feasibility and characteristics of deep energy retrofits. |

[1] In the Northeast, where the NYSERDA projects are occurring, space heating is responsible for approximately 55% of total energy consumption in the home (EIA 2009).

Many of these programs define success differently and use different metrics to measure it. A majority of them are demonstration projects designed to assess various aspects of deep energy retrofit work. A comparison of pre and post energy use is not always possible because of a lack of pre-retrofit usage data. Additionally, a number of projects significantly alter the occupancy and/or footprint of the house, making comparison to the preexisting home less useful.[3]

The energy savings targets in table 2 also highlight a distinction that is critical to measuring the energy efficiency of a home and determining the success of a deep energy retrofit. The distinction is between *site energy*, which is the amount of energy used in a specific building as

[3] In a number of the deep energy retrofits we examined, improvements were frequently combined with major renovations, sometimes of previously unoccupied homes.

reflected by utility bills, and *source energy*, which takes into consideration the total amount of raw energy used, which includes all transmission, delivery, and production energy. Raw fuels used in a house such as oil and natural gas are primary energy sources which are not converted to create heat or electricity until they are in the home. On the other hand, electricity is a secondary energy source because it has been created from a raw fuel such as coal or natural gas. Substantial energy is expended in generating and transmitting electricity. For primary energy sources like natural gas, source energy is approximately the same as site energy, whereas for electricity, source energy may be three times greater than site energy.

Source energy can vary significantly by region, depending on the regional electric power fuel mix (Less, Fisher, and Walker 2012). Thus two identical homes in different regions could have very different source energy. Figure 3 shows the variation in carbon emissions of the electricity supply by state. These variations are due to states' varying use of non-fossil-fuel electricity generation such as nuclear, as well as renewables.

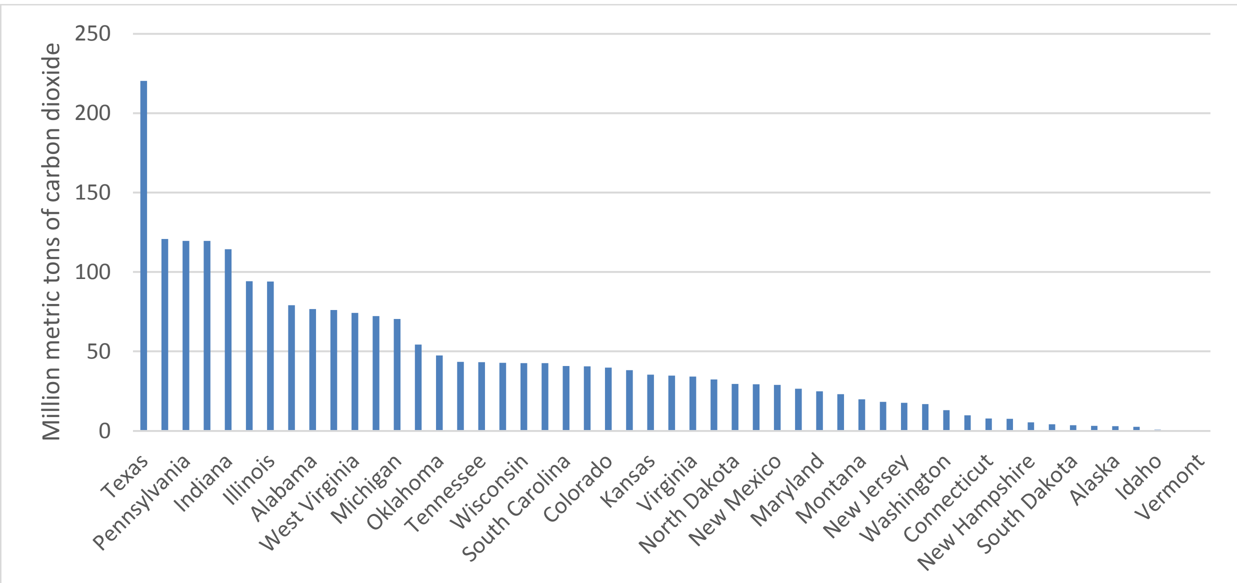


**Figure 3. Carbon intensity of the energy supply by state in 2010.** ***Source:*** **EIA 2013a.**

Many deep energy retrofit programs switch the home's fuel at the same time as they improve the building envelope. They most often switch to electric space and water heating using equipment that is smaller and better suited to serve the reduced energy loads in the home. Recent improvements to low-load electric space heating equipment (such as high-efficiency mini-split heat pumps) have made it suitable for use in a broader range of climate regions. But gains in site energy savings from fuel switching must be balanced against increased source energy costs. Table 3 compares the site and source efficiency of various heating equipment.

Table 3. Space heating efficiencies of heating equipment choices

| Equipment type | Site efficiency | Source efficiency |
|---|---|---|
| High-efficiency condensing gas furnace | 95% | 95% |
| Electric resistance furnace | 100% | 33% |
| Very high-efficiency electric heat pump | 265% | 88% |

Based on a 9.0 HSPF heat pump and a typical electric generator efficiency of 33%

It should be noted that the distinction between site and source energy might become less of a factor in the future, as more electricity is produced from low- and non-carbon sources as well as from on-site renewable generation. Electric space and water heating would then become more cost effective in terms of source energy as well as in terms of site energy.

For the present, since many deep energy retrofit programs incorporate fuel switching into projects, it can be misleading to track site energy without any consideration of source energy. Most retrofit programs and homeowners rely on site energy savings as the measure of a project's success, and there is value in continuing to use site energy savings because it is recognizable. But considering site energy alone can result in a situation where fuel switching is rewarded in ways that do not make sense. Utilities should also be aware that incentivizing fuel switching for space and water heating, even for a low-load home, can lead to increased peak demand.

The difference between site energy and source energy is particularly important for determining the success of a deep energy retrofit when designing programs to meet state energy and/or carbon emissions reduction goals. Utilities should track both site and source energy savings for homes involved in a pilot program to ensure that the program has the desired regional impact and does not just switch consumption to another part of the ledger. The distinction between site and source energy should also be factored into program definitions when creating policies and incentives. Otherwise the results could be detrimental to homeowners, utility peak loads, and atmospheric carbon dioxide levels.

Our analysis includes retrofit cases that aim to save 50% or more of the site energy used in a home as compared to pre-retrofit usage, or, if there is no pre-retrofit usage available, compared to an energy reduction target based on climate, occupancy, house size, and house type. The latter might be modeled on Option B in the Thousand Home Challenge baseline energy calculation. For projects that have tracked source energy, we also include those values.

## Benefits

There are many compelling reasons to incorporate deep energy retrofits into state and utility program portfolios. In addition to the benefits to states and utilities, a program seeking individual participants can articulate a number of benefits to homeowners.

### *BENEFITS FOR PROGRAMS*

Programs that focus on deep energy retrofits can incorporate more targeted and nuanced program design and reach niche markets of committed homeowners. Since these projects require considerable homeowner commitment and investment, it is important to target the right customers. They are worth reaching in order to maximize individual household savings. Instead of offering individual equipment rebates to a broad swath of homes, deep energy retrofits target fewer homes for more impactful upgrades.

While energy costs (and forecasts of future costs) have been declining in recent years, these trends could reverse due to market fluctuations and environmental regulations. Even if it is not cost effective today, deep retrofit programs are preparation for a possible future where efficiency is more highly valued. Retrofit programs can help prepare for future energy savings targets by increasing consumer knowledge, workforce experience, and technical capacity. They may also help reduce the future costs of deep energy retrofits by adding to workforce experience, improving processes, and developing competitive mechanisms.

Traditional residential efficiency programs generally have not promoted the installation of multiple measures at one time (Brook et al. 2012). They incentivize only the measures that pay back quickly and have the fastest return on investment. Some of these measures may not be the most beneficial in the long term and may miss opportunities for energy savings. For example, sealing a poorly designed attic duct system can yield some immediate savings for a customer. But this work might take the place of a project to redesign and/or relocate the distribution system, which, while more expensive, would likely produce greater long-term energy savings. As another example, the most cost-effective measure for a homeowner at present might be to insulate an attic only to a certain level despite the existence of more room for insulation. But, given the potential for rising energy costs and more stringent environmental regulations, fully insulating the attic might be the most cost-effective option in the long term (L. Wigington, Residential Energy Consultant, Linda M. Wigington & Associates, pers. comm. September 2013).

Utilities should develop a longer-term outlook in the planning and evaluation of efficiency programs. Their portfolios should include projects that prepare homes for deeper energy measures, or at least do not create a missed opportunity for them. Low hanging fruit like compact fluorescent lighting and low-flow water fixtures that are traditionally targeted by one-off retrofit measures should be packaged with deeper energy improvements such as insulation and air sealing (Brook et al. 2012).

### *Benefits for Homeowners*

Homeowners who have undertaken deep energy retrofits see benefits beyond saving money on energy. Due to the high cost of such retrofits, these homeowners are generally not motivated by the bottom line but by some other perceived value. Many of them cite a personal commitment to reducing their environmental footprint. They also may wish to enhance their home in terms of increased comfort, livable space, and/or long-term durability.

The fact is that lowering a home's energy use through a deep energy retrofit goes hand in hand with increasing its comfort and durability. While it is certainly possible to make a house more comfortable or more durable without reducing energy use (perhaps via an oversized heating system that runs all the time), deep energy retrofits generally increase comfort and durability at the same time as they reduce energy use. The result is a high performing house in all three respects.

Table 4 details some of the benefits cited by individual homeowners who have undertaken deep energy retrofits. We should note that not all of the non-energy benefits are exclusive to deep energy retrofits; many are also realized in energy weatherization upgrades.

Table 4. Non-energy benefits to homeowners from deep energy retrofits

| Benefit | Explanation | Example/case study | Value |
|---|---|---|---|
| Disaster preparedness. Increased earthquake and wind resistance | Reinforcing existing structure to code requirements dictated for "essential buildings" like schools | Thousand Home Challenge, Beeler case study, Petaluma, CA (Beeler 2011) | Homeowners protect the embodied resources of the home with relatively little extra structural cost when work is done during remodels that allow access to the home's structure. |
| Durability. Elimination of ice dams | Ice dams occur when conductive heat or warm air escaping from the roof melts snow, which then refreezes after running down the edge of the roof. This can cause water leakage into building assemblies, and can compromise entire roof sections when ice snaps off and takes a piece of the roof with it. | Two homes in MA, part of the National Grid Pilot: "Millbury Cape" and "Somerville Triple Decker" (Osser, Neuhauser, and Ueno 2012) | Repairs from leaks associated with ice damming can cost thousands of dollars. Repairs associated with larger roof damage, although less common, can cost significantly more. |
| Comfort | Making previously unusable portions of homes more comfortable; "comfort of a new house without the cost of one"[1] | Finishing the basement of a home, or adding an attic bedroom in conjunction with significant energy improvements to these spaces | Increased resale value of a home with greater amounts of living space |
| Preserving the embodied energy of existing housing stock | Rehabilitation of existing buildings instead of demolition and new construction saves embodied energy and resources used during production, distribution construction, etc., taking into account that energy consumed after a home is built is just part of its overall energy footprint. | Thousand Home Challenge, Beeler case study, Petaluma, CA (Beeler 2011). All homes that were previously uninhabitable and/or unoccupied (Keesee 2012). | Research to quantify life-cycle costs of building could help determine value. Value of occupying a home in a desirable location, close to amenities and public transportation. |
| Health and safety | Improving air quality by reducing moisture, particulates, dust, pests, etc. | Basement renovation, which addresses sources of pests, moisture, radon, etc. | Benefits to occupants with existing health conditions, such as asthma or allergies (Wigington 2010) |

[1] Increased comfort or use of a room that was previously uninhabited may also draw more energy as a result of increased use. The goal is to increase capacity and/or comfort while still reducing energy consumption in the entire home.

## Deep Energy Retrofit Programs

This section presents an overview of deep energy retrofit programs and projects that may help inform program development and the scaling up of further efforts. We focus on the program details and design strategies of a utility-scale energy efficiency program offered by National Grid that serves customers undertaking deep energy retrofit activities at market rate. We also give an overview of other programs and research efforts involving particular retrofit processes, technologies, and savings opportunities. Many of these programs document what works and what does not, focusing on elements of the design, planning, and construction process and the resulting energy use. However the types of projects are so different that there is limited consistency in how they are tracked and evaluated.

### *NATIONAL GRID DEEP ENERGY RETROFIT PILOT PROGRAM*

**Sponsor**: National Grid
**Location**: National Grid territory in Massachusetts and Rhode Island
**Program type**: Utility-run pilot program
**Retrofit work funded by**: Homeowners and utility incentives
**Measures included in projects**: Incentives covered insulation, air sealing, high-efficiency windows, and HVAC equipment. Additional incentive available post-retrofit for meeting advanced performance initiatives including the Thousand Home Challenge, Net Zero Energy, and Passive House.

The National Grid Deep Energy Retrofit Pilot Program is the first program ever developed for a utility's energy efficiency portfolio. It began as a research pilot to capture opportunities at the time of renovations including roof replacement, window replacement, re-siding, basement renovation, and remodel (Neuhauser 2012). Homes retrofitted during the pilot phase were closely evaluated, and as a result, more information is available for this pilot than for many of the other efforts described in this report.

#### PROGRAM DEVELOPMENT

The program was launched in 2009 in the utility's Massachusetts gas and electric territory, and then in 2011 in Rhode Island. It was developed as a response to Massachusetts Governor Deval Patrick's Zero Net Energy Task Force, which called for increased energy efficiency programming to "expand the current home energy weatherization rebate program to promote incremental super-insulation retrofits of existing homes" (MZNEB 2009). The task force's plan included the following recommendations:

- Expand current utility incentives to apply to additional building envelope and efficiency improvements not currently eligible for rebates.
- For consumers who undertake additional building improvements, offer an additional rebate based on measured building performance after a period of one year from the date of completed work.

The task force also recommended tracking the ongoing building performance of select homes involved in the utility pilot, including energy usage, indoor air quality, durability, temperature, humidity, and so on. They wanted to see whether the installed measures would produce significant energy savings without having a negative impact on indoor air quality and home durability (Neuhauser 2012). Quantifying the non-energy benefits of deep energy retrofits could help convince consumers to undertake them.

#### PROGRAM DETAILS

The pilot requirements, developed through a collaborative planning process led by National Grid, are detailed in table 5.

**Table 5. Program performance targets to support overall performance goal**

| Overview | Insulation | Air sealing | Windows and doors |
|---|---|---|---|
| Overall energy performance goal of 50% reduction in total energy use relative to a home built to standard code levels of performance[1] | Target effective R-value (overall performance)[2]<br>Roof: R-60<br>Above-grade wall: R-40<br>Below-grade wall: R-20<br>Basement floor: R-10 | Whole house sealed to achieve 0.1 CFM50/sq. ft. of thermal enclosure surface area (6 sides of surface area) with highly durable/long lasting materials.[3] | Target of R-5 thermal performance for the whole unit.<br>Air infiltration resistance performance of less than 0.15 CFM/sq. ft. (per AAMA11 standard infiltration test). |

[1] The standard energy code in Massachusetts (MA) at the time of development of this pilot was the MA Seventh Edition Building Energy code, which is unique to MA. MA has since adopted IECC 2009 with strengthening amendments for residential buildings (DOE 2013). [2] Effective R-value speaks to the overall R-value of each building component (wall, roof, basement wall, slab, etc.). This requires thermal bridging to be fully considered in thermal performance estimates (Neuhauser 2012). [3] 0.1 CFM50/sq. ft. corresponds to 1.2-1.7 ACH50 for the test homes in the pilot. *Source:* Adapted from Neuhauser 2012.

Program guidelines for safety and durability issues encompassed combustion safety, ventilation, and hazardous material mitigation. The guidelines also stipulated that "The project plan and implementation must demonstrate sound building physics as it relates to moisture management of the enclosure and effectiveness of the mechanical system configuration" (Neuhauser 2012).

Incentives were offered for up to 75% of the owner's net cost up to maximums based on the conditioned floor area (table 6).

**Table 6. Maximum incentive levels for single family homes**

| Conditioned sq. ft. floor area per unit | Maximum project incentive |
|---|---|
| <2000 | $35,000 |
| 2000-2500 | $38,000 |
| >2500 | $42,000 |

*Source:* Neuhauser 2012

Incentives ranged from $35,000 to $42,000 for detached single-family residences, and from $50,000 to $60,000 for duplexes. Multifamily buildings were also eligible for an incentive based on the number of units, ranging from $72,000 for a three-unit building to $106,000 for a building with ten or more units (Neuhauser 2012). Incentives for staged or partial deep energy retrofit (DER) work were also available on a case-by-case basis for measures that were consistent with DER project characteristics but did not address the entire building; these were required to have a detailed plan for completing the deep energy retrofit at a later date in order to qualify.

Incentives for high-efficiency heating and cooling were also available for up to 50% of the cost, up to a maximum of $4,000 for heating and $1,000 for cooling. In addition, reimbursement for replacement windows covered the cost of high-efficiency windows above the typical replacement cost of $15/sq. ft.

An additional incentive was available for projects achieving the advanced performance levels of initiatives such as the Passive House Institute EnerPhit program, the Thousand Home Challenge, or a Net Zero Energy retrofit. Performance was validated through the initiative's certification as well as through one year of operational energy-use data.

Technical assistance was a critical part of the pilot program to address the technical hurdles of complex retrofit work. National Grid offered technical assistance during field visits to oversee project planning and work products, and to verify implementation of measures that were eligible for incentives.

The timeline for projects under this program is detailed below (table 7). Project applications were not accepted after the end of March for a program beginning in January and spanning the calendar year, so that the project could be completed by the end of the same year.

**Table 7. Inspection timeline for National Grid Deep Energy Retrofit Pilot**

| Inspection time | Inspection task | Technical guidance opportunity |
|---|---|---|
| Pre-work inspection | After applicant has entered the formal application process, data are collected to supplement what has already been submitted on the application form. | Guidance about the retrofit plan is provided, Opportunity to amend solutions to identified problems, and/or to address issues that are not yet identified. |
| Verification of completed measures in the project plan | Site visits are conducted to ensure completion of measures eligible for incentives. Project teams and inspectors agree on packages of measures to be inspected at set times. National Grid pays incentives upon successful inspection. | Technical guidance regarding the implementation of various deep energy retrofit measures during inspections. |
| Final inspection | Performance testing is completed, including blower door air leakage testing and duct leakage testing (if applicable). Inspectors verify that all measures in the project plan have been implemented. | N/A. Site visits are arranged for various stages of each project to allow for verification of specific measures and assessment of challenges projects face with respect to continuity of thermal and air barriers, and proper exterior moisture/water management strategies (e.g., flashing around windows). |

*Source:* Neuhauser 2012

The pilot demonstrated the possibility of incorporating additional steps into a renovation or rehabilitation project that included roof replacement, siding replacement, and/or basement renovation to gain high energy savings. It ran from 2009 to the end of 2012, with 42 projects completed for a total of 62 housing units. Building Science Corporation was commissioned by the U.S. Department of Energy (DOE) to conduct a detailed analysis of the first 13 projects as detailed in Appendix A (Neuhauser 2012).

### *NATIONAL GRID DEEP ENERGY RETROFIT PROGRAM*

**Sponsor**: National Grid
**Location**: National Grid territory in Massachusetts and Rhode Island
**Program type**: Evaluated utility program
**Retrofit work funded by**: Homeowners and utility incentives
**Measures included in projects**: Incentives covered insulation and air sealing.

The full-scale program builds on experience from the pilot. Incentives for the program include (1) a base incentive per square foot of treated area that meets the specified thermal requirement (R-60 for roof, R-40 for exterior wall, and R-20 for basement), and (2) a performance incentive for the $CFM_{50}$ reduction level, based on pre and post blower door tests (table 8). Incentive levels are intended to cover most of the incremental cost of superefficient building envelope upgrades**.**

Table 8. Incentives for deep energy retrofit measures in National Grid Program

| Incentive type | Feature | Incentive amount |
|---|---|---|
| Base incentive | Roof/attic DER measure<br>Exterior wall DER measure<br>Basement DER measure | \$3.00 per square foot of treated area<br>\$3.50 per square foot of treated area<br>\$2.00 per square foot of treated area |
| Performance incentive | CFM50 reduction based on pre- and post-construction blower door testing | \$1.75 per cubic feet per minute reduced |

*Source:* National Grid 2013c

Rather than whole-home deep energy retrofits, this program encourages the inclusion of deep energy upgrades to already planned renovations to a home's roof, walls, or basement. It engages area builders, encouraging them to refer to the *Mass Save Deep Energy Retrofit Builder Guide* (developed based on lessons from the pilot) for details on incorporating DER measures into other renovations and rehabilitations. The guide is designed to cut back on the need for technical assistance.

Measures are inspected throughout the project, and energy performance testing is conducted before and after work is completed as well as during construction (NEC 2012). An external vendor is responsible for program management, including the following:

- Customer intake and application
- Training to promote DER, highlight its benefits, and recruit participating builders
- Delivery of materials to training attendees
- Administrative duties including scheduling energy performance and code compliance inspections
- Coordination of technical assistance
- Overall project management (NEC 2012)

The 2013 program year was the first year when energy savings from this program counted towards overall energy savings targets for the utility. The projected number of projects for 2013 included 10 roof-related, 6 wall-related, and 6 basement-related projects, with the understanding that some homeowners might choose to retrofit multiple areas.

Although the reach of the program is relatively limited, it is supplemented by a number of other residential efficiency program offerings (NEC 2012). Homeowner education on DER measures is also being integrated into other programs, verbally and in writing, and into the utility's high-volume home audit program, EnergyWise (NEC 2012).

Table 9 outlines the differences between the pilot and the full National Grid program.

**Table 9. Differences between deep energy retrofit pilot and full-scale National Grid program**

| Program element | Pilot | Program |
|---|---|---|
| Program scope | Significantly reduce energy use of residential homes by 50% or more by meeting target performance levels for building envelope. | Include deep retrofit measures in roofing, siding, or basement renovation activity. |
| Incentive structure | Base incentive up to 75% of owner's otherwise net cost of DER work. Overall incentive adjustment based on $CFM_{50}$ reduction level (i.e., additional incentives for meeting a threshold, and penalties on overall incentive package for failing to meet threshold).<br>Additional incentive for meeting eligible advanced performance initiatives. | Base incentive for square foot of treated area that meets the specified thermal requirement (R-60 for roof, R-40 for exterior wall, and R-20 for basement).<br>Additional performance incentive awarded for $CFM_{50}$ reduction based on pre and post blower door tests. |
| Technical assistance strategy | Considerable technical support from a building science vendor (Building Science Corporation). Multiple site visits for technical guidance and inspection. | Creation of DER builder guide to alleviate some need for technical assistance. Projects receive up to 5 hours of technical support from Building Science Corporation. |

*Source:* NEC 2012, Neuhauser 2012, National Grid 2013b, National Grid 2013c

### *NYSERDA ADVANCED BUILDINGS DEEP ENERGY RETROFITS*

**Sponsor**: NYSERDA
**Location**: New York State
**Program type**: Research and development program
**Retrofit work funded by**: Phase I funded completely by NYSERDA. Phase II funded by homeowners, NYSERDA incentives, and manufacturer donations.
**Measures included in projects**: Incentives covered insulation and air sealing.

The New York State Energy Research and Development Authority (NYSERDA) Advanced Buildings Program has undertaken a series of projects in existing homes in upstate New York to demonstrate and develop high-performance retrofit strategies that are of higher quality than regular practice today. The program involves two phases. Phase I, which has been completed, aimed to demonstrate significant energy savings in four home retrofits. Fully funded by NYSERDA, these retrofits focused on testing emerging insulating practices and construction techniques that could be applied on a larger scale. Each of them cost about $100,000 per home, much of which went to necessary home repairs in addition to deep energy retrofit measures (NYSERDA 2013).

Phase 2 of the NYSERDA project is using the expertise of home performance contractors around the state to undertake deep energy retrofits at market rate, with incentives from NYSERDA and manufacturer-donated materials provided to homeowners. Twenty-one homes are at various stages of the retrofit process, with approximately 5 performance contractor teams involved. Contractors report on installation materials and strategies, lessons learned, and performance testing results. The metrics used for comparing cost and performance across all projects are cost per shell square foot (ssf) and air tightness in cubic feet per minute at 50 pascals (CFM50) per ssf. Energy use in the four initially retrofitted homes has been monitored to evaluate the energy savings potential. These results are displayed in figure 4.

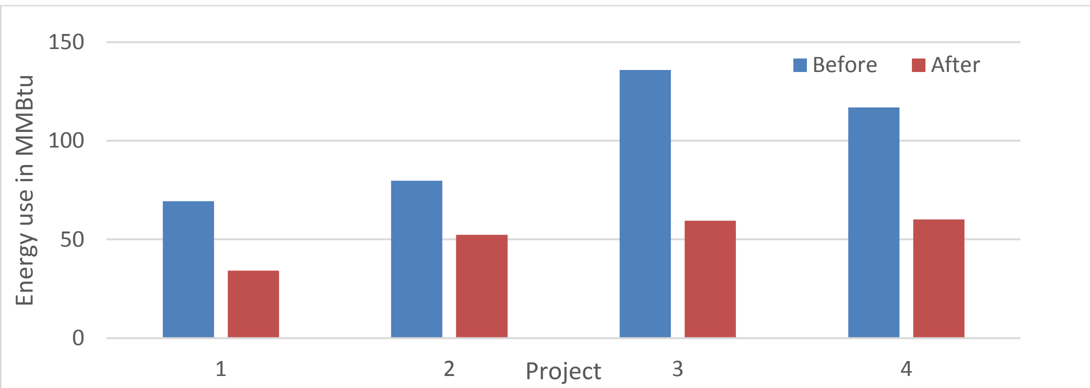


**Figure 4. Pre- and post-retrofit energy use for NYSERDA projects.** ***Source:*** **G. Pedrick, Project Manager, Buildings Research and Development, NYSERDA, pers. comm., October 2013.**

Phase 2 of the NYSERDA program provides a significant opportunity to evaluate how contractors with increasing experience can develop, perform, and refine cost-effective deep energy retrofit techniques (G. Pedrick, pers. comm., October 2013). Lessons learned and strategies for scaling up effective strategies are described in the Findings and Trends section below.

### *BUILDING AMERICA RESIDENTIAL RETROFITS*

**Sponsor**: DOE Building America Program, Pacific Northwest National Laboratory (PNNL), Oak Ridge National Laboratory (ORNL)
**Location**: Georgia, Texas, Florida, Washington, Oregon
**Program type**: Research and development program
**Retrofit work funded by**: Homeowners, affordable housing agencies, local governments
**Measures included in projects**: Included, but not limited to HVAC equipment, insulation, air sealing, duct sealing

This study aimed to demonstrate what it takes to achieve 30-50% energy savings while also improving comfort, combustion safety, durability, and indoor air quality in 50 residences in various climate zones (Chandra et al. 2012). Researchers were involved in recruiting homeowners as well as in pre-retrofit assessment and recommendations, and post-retrofit assessment. Homeowners were responsible for hiring contractors and going forward with deep energy retrofit work on their own. ORNL led nine completed deep energy retrofits in the Atlanta area; PNNL is leading the rest of the retrofits.

**PNNL DEEP ENERGY RETROFIT RESEARCH PROJECT** Researchers used various materials for marketing to the homeowners recruited by PNNL, including newsletter postings, emails to colleagues, and a website.[4] Based on various criteria, researchers chose homeowners and homes that were best suited to be a DER demonstration project. They then tested each home to document pre-retrofit conditions and energy performance. They based their audits on guidelines for home energy professionals including the Building Performance Institute (BPI) *Technical Standards for the Building Analyst Professional* and a draft of the DOE *Workforce Guidelines for Home Energy Upgrades* (Chandra et al. 2012).

Based on data collected through the audit, homes were modeled with one or more software programs including Energy Gauge, BeOpt, and REMRate, and models were calibrated with actual energy use from monthly utility bills. The most effective retrofit measures were chosen for each home and assembled into a package that would achieve source energy savings of 30-50% or more. Measure costs were based on the National Renewable Energy Laboratory (NREL) national measures database, on price quotes from local contractors, and on manufacturer literature (Chandra et al. 2012).

Once the research team discussed its recommendations with the homeowner, the latter was responsible for hiring a contractor to complete the retrofit. While the retrofit contract was nonbinding, researchers had taken care to engage homeowners who were likely to go through with the full process. Finding and selecting qualified contractors proved to be a hurdle and source of delay for the retrofits, and in many cases the research team had to help select qualified tradespeople and communicate the scope of work to them.

---

[4] The consumer-facing website is http://deepenergyretrofits.pnnl.gov/

Of the PNNL research cases, as of December 2011, 15 retrofits in hot-humid, marine, and cold climates had been completed (3 in San Antonio, 10 in Florida, 1 in Portland, and 1 in Dayton, WA), with 14 additional projects underway. Nine homes were completed in Atlanta under the guidance of ORNL. Figure 5 summarizes this progress.

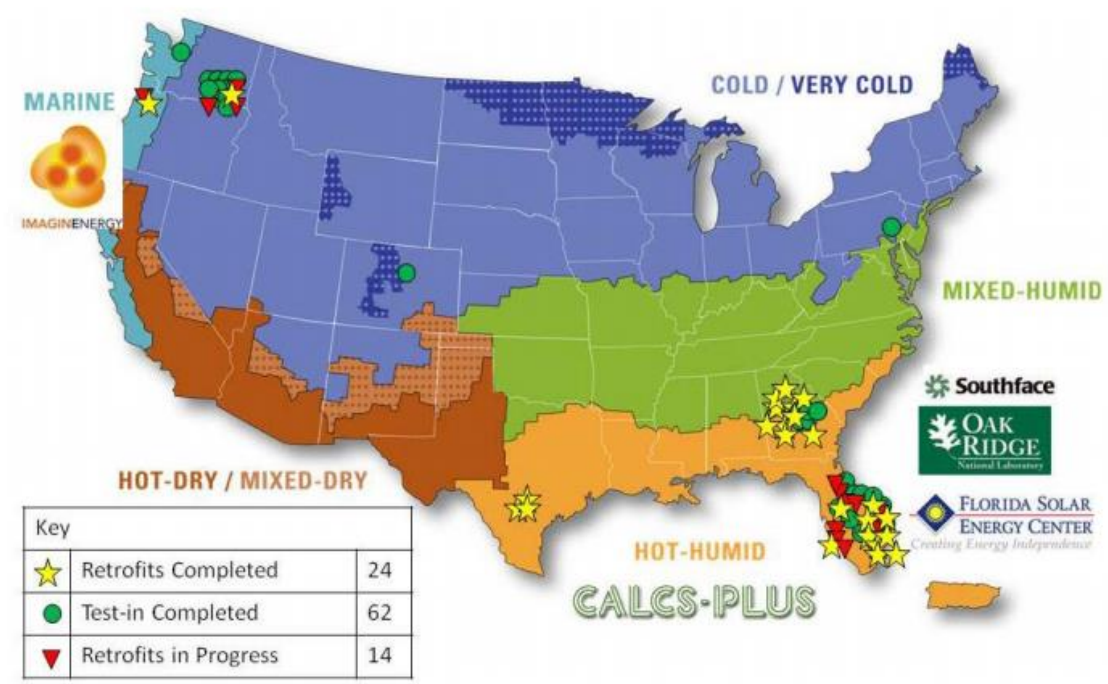


Figure 5. Status of deep energy retrofit homes in Building America program (as of December 2011). *Source:* Chandra et al. 2012.

Based on the energy models developed, estimated energy savings were calculated for the 15 completed PNNL retrofits. For seven additional homes in the Pacific Northwest, the differences between estimated and actual savings were assessed to address the possibility of a discrepancy between modeled and actual energy usage.[5]

Of the 15 completed PNNL retrofits, only one home was occupied during renovations; the others were vacant and in poor shape when the projects started. Individual homeowners paid for only three of the retrofits. Funding secured by local cities financed four projects, and Habitat for Humanity affiliates in Florida funded the rest (Chandra et al 2012). All the projects in the Southeast were undertaken by institutions or organizations, whereas the Pacific Northwest retrofits depended on individual homeowners. In these latter projects, it was challenging to turn test-in audits and evaluations into retrofit work. Homeowners tended to be more concerned about the short-term cost effectiveness and the capital cost of each measure than were organizations, which took a longer-term view of improvements (Chandra et al 2012). By including independent homeowner financing, the PNNL program more closely reflected the

[5] For more information about the differences between modeled and actual energy use, see http://deepenergyretrofits.pnnl.gov/resources/ActualvEstimated.pdf

actual market and its barriers than other pilots where financing was not up to the individual owner.

An energy auditor did the initial home test-in and assessment, devised a scope of work, and communicated it to qualified contractors. Table 10 summarizes the measures recommended for a number of the homes. Air sealing and insulation were not nearly as prevalent as in other deep energy retrofits. Instead, these projects focused on equipment as the most cost-effective improvement. This discrepancy may be explained by differences in energy budgets corresponding to climate zone and the fact that energy modeling programs are likely to recommend HVAC systems.

Table 10. Common measures by region

| Pacific Northwest (marine) | Southeast (mixed-humid)[2] | South (hot-humid)[3] |
|---|---|---|
| 1. High-efficiency heat pumps commonly replaced electric furnace or baseboard heat.<br>2. Some additional air sealing and insulation specified, but substantial shell improvements were uncommon. | 1. HVAC upgrade was the most common upgrade in the Atlanta, GA retrofits<br>2. A majority of homes had at least one specific part of the home air sealed, such as the attic or attic floor, crawlspace, or subfloor. | 1. Upgrade of HVAC system to at least SEER 14.5 unit, and ensure proper sizing of unit. If not replacing unit, service to ensure proper functioning of major system components.<br>2. Duct sealing and flex duct improvements to improve airflow.<br>3. Whole house air sealing<br>4. Replacing/refinishing roof with reflective finish.<br>5. Attic insulation |

*Sources:* For Pacific Northwest, Chandra et al. 2012; for Southeast, Jackson et al. 2012; for South, McIlvaine, Sutherland, and Beal 2013.

### *THOUSAND HOME CHALLENGE*

**Sponsor**: Independent effort of Linda Wigington, originally begun as an initiative of the Affordable Comfort Institute
**Location**: Nationwide
**Program type**: Voluntary home certification
**Retrofit work funded By**: Homeowners
**Measures included in projects**: Air sealing and insulation, mechanical equipment and/or system redesign, renewable energy

The Thousand Home Challenge (THC) has reduced home energy consumption with current technology and methods in one of the largest sets of homes of any current program. Begun as an initiative of Affordable Comfort Inc. (ACI), the Challenge is a voluntary program designed to demonstrate the possibility of greater than 70% reductions in 1,000 existing homes. The Challenge is unique in that it does not use any particular equipment, technology, or materials performance requirements to meet its goals. Instead, homes can meet the challenge by demonstrating a 75% reduction in site energy use over previous usage levels, or by meeting a customized energy allowance for the amount of annual site energy used. This approach is unique in that it requires tracking of actual total energy use, not just modeled energy use.

Developed by Linda Wigington and Michael Blasnik, the customized allowance estimates the energy needed for a very high performance house based on climate, house size, whether the house is detached or attached, heating fuel type, and the number of occupants. THC energy reduction targets are meant to be challenging for everyone, and are designed to inspire creativity in how to reach the targets. The most obvious route is through systems and structural improvements, e.g., in how hot water is distributed and HVAC distribution is set up. But unlike most demonstration projects, THC assumes that there are other ways to save energy in a home besides technical improvements to equipment, systems, and shell. Behavioral choices, renewables, and community solutions are all considered pathways to reduced consumption. Thus about half the people meeting or working towards meeting the THC allowance are focusing on deep energy reductions instead of retrofits. They are reassessing what is comfortable and required for day-to-day operations and exploring what is possible in terms of behavioral adjustment, going beyond just turning down the heat and putting on a sweater (Wigington 2013). These behavioral strategies are a good complement to traditional retrofit measures.

THC currently has 89 projects underway (figure 6). To meet the challenge, homeowners must collect one year of actual energy use data. Results are not normalized for temperature, mainly to keep the metrics simple and understandable for all involved. Figure 7 summarizes energy use data of homes currently meeting the THC.

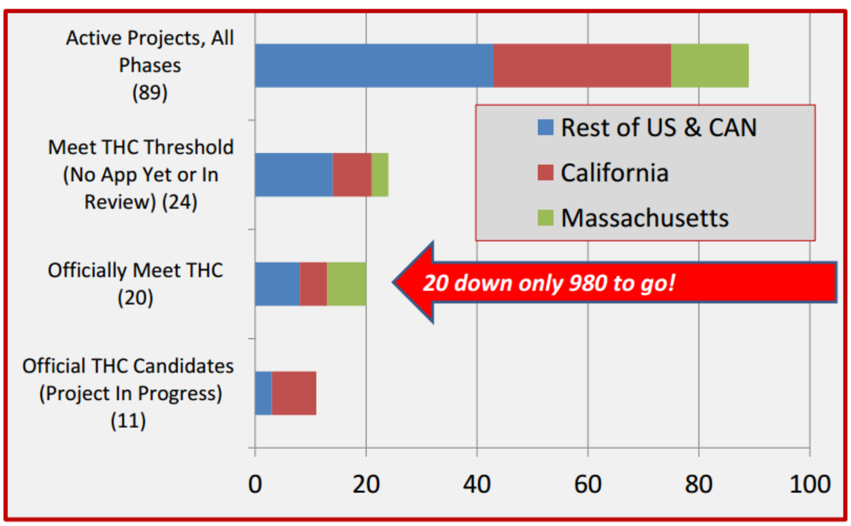


Figure 6. Number of homes participating in the Thousand Home Challenge *Source:* Linda Wigington, pers. comm., January 2014.

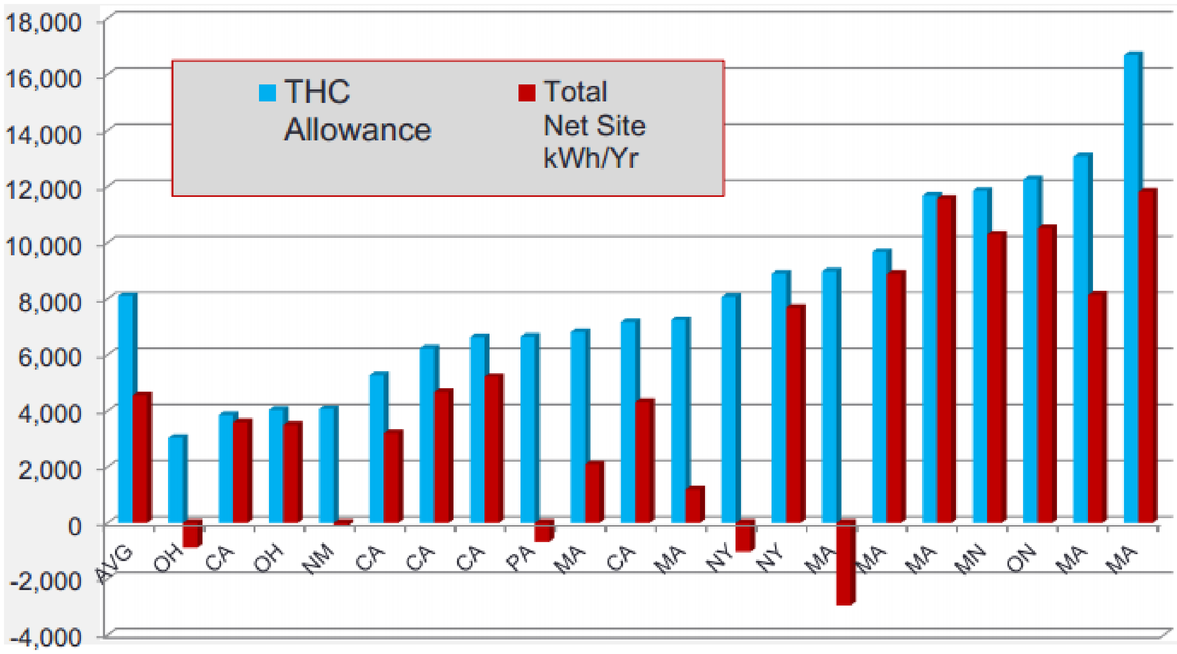


Figure 7. Homes that meet the Thousand Home Challenge. Includes site renewable energy production; *Source:* Linda Wigington, pers. comm., January 2014.

## Findings and Trends

### *WORKFORCE*

This section describes the workforce carrying out deep energy retrofit work, including the types of contractors and trades, how programs are seeking out qualified contractors, and the certifications being used to show workforce qualifications. We also explore contractor strategies to increase installation efficiency.

Energy efficiency improvements and retrofits typically benefit from workforce alliances. Independent assessors and subcontractors often work together to recommend and bring services to homeowners. One contractor generally acts as the project manager and is responsible for verifying whole-house performance metrics.

This approach has been championed by the Residential Energy Services Network (RESNET) through their EnergySmart Home Performance Team program. Members of allied teams provide each other with referrals and also sometimes engage in co-marketing. Retrofits are developed, completed, and verified collectively, with one team member serving as the project manager.

Two other workforce strategies characterize energy efficiency upgrades. First, existing trades (most commonly HVAC contractors) have expanded their services to include whole-house assessments and implementation (McIlvaine et al. 2013). Second, efforts like the National Grid program relied on builders with experience in high-energy performance building and renovation, particularly with homes to be certified or rated green buildings.

Table 11 shows the professionals involved in some deep energy retrofit programs.

**Table 11. Workforce undertaking deep energy retrofits**

| Organization | Workforce |
|---|---|
| Sacramento Municipal Utility District (SMUD) and National Renewable Energy Laboratory (NREL) Research and Development Program on Deep Energy Retrofits | SMUD worked with various partners for retrofit work. NREL contributed the energy analysis for each home, including aiding in the selection of measures. One project was done through a local home performance contractor, while others were carried out through affordable housing organizations. |
| New York State Energy Research and Development Authority (NYSERDA) | The program has contracted a number of building performance contractor groups to track and assess development of retrofit techniques. |
| Vermont Energy Investment Corporation (VEIC), Champlain Housing Trust (CHT) | For projects that were large enough to employ a general contractor, contracts specified insulation and air sealing contractors that were BPI certified or equivalent (based on past work performance). |
| National Grid Deep Energy Retrofit Pilot Homes | National Grid provided technical support through Building Science Corporation. All contractors eligible to work through program were qualified by National Grid. Specifics of the National Grid qualifications are detailed below. |
| Lawrence Berkeley National Laboratory (LBNL) | Each project in this study was completed independently, before the homes were selected for the LBNL study. No concerted strategy. |

**Workforce Qualifications**

Energy efficiency programs often rely on certification to indicate contractor competency. National Grid specified the following qualifications for contractors in their pilot:

- At least 2 years of experience as a building or remodeling contractor or designer
- Massachusetts Home Improvement Contractor license
- Prior deep energy retrofit related experience, which may include:
    - ENERGY STAR certified homes with HERS scores that are 60 or below, and/or remodeling with HERS below 70
    - Net Zero Energy or Passive House projects
    - Remodeling projects involving super insulation and extensive blower door verified air sealing. (Neuhauser 2012)

Both the Net Zero Energy and Passive House projects also involve certifications that can be verified.[6] Passive House requires projects to be built to a defined standard that is verified through detailed examination and testing. The Net Zero Energy Building Certification requires adherence to and documentation of a number of requirements for each project. Both new construction and existing building renovation can meet the Net Zero Energy and Passive House standards.

None of these building certification models requires that builders themselves be certified. Instead, they require third-party verification of building standards compliance by certified raters. Although not required, Passive House also offers certification for builders.[7]

### Technical Assistance for Workforce Development

The National Grid pilot program provided technical assistance to builders: advisors regularly assessed work and offered input. They also developed the *Mass Save Deep Energy Retrofit Builder Guide* which details the building and installation techniques eligible for incentives (see Appendix A). In addition, technical support in the early pilot assessed whether the contractor eligibility requirements were good indicators of the skills necessary for DER work.

It is unclear whether technical assistance was critical to the success of early projects, or whether the capacity of the participating contractors would have been sufficient. In any case, such in-depth technical assistance is unlikely to be feasible, or even necessary, in a full-scale evaluated program. Eligibility requirements that are good indicators of contractors' ability to carry out DER work should be sufficient.

### Development of Efficient Installation Methods

NYSERDA developed an innovative model to encourage and assess workforce development. They had the same contractor group retrofit four Ithaca homes one after another, document their best practices, and articulate how the lessons they learned in one project influenced their work in the next. This program shows how DER project documentation and increasing experience can lead to more efficient and higher quality work. Many of the lessons learned by the NYSERDA contractors are included in the "Common Measures for Deep Energy Retrofits" section above.

---

[6] More information on the Net Zero Energy Building Certification through the International Living Future Institute is available here: http://living-future.org/netzero. For more information about the Passive House standard: http://www.passivehouse.us/passiveHouse/PassiveHouseInfo.html

[7] A list of qualified Passive House Builders is maintained at http://www.passivehouse.us/passiveHouse/PHIUS_Certified_Builders.html

## *TECHNOLOGY: COMMON MEASURES FOR DEEP ENERGY RETROFITS*

This section describes deep energy retrofit measures, especially those that have been successful in addressing air sealing, insulation, and moisture control issues.

### Building Shell

Building shell improvements are crucial to a high performing retrofit. The tools and materials that can lead to energy savings are not new, but they are not common practice among contractors. This section on building shell improvements focuses on insulation and air sealing techniques, particularly how they perform in terms of water, airflow, vapor, and thermal control (Neuhauser 2012). It summarizes current strategies, notes how they may differ based on climate region, and discusses the evolution of techniques to increase efficiency. Table 12 lists the targets for air sealing and insulation.

**Table 12. Building shell elements addressed with air sealing and insulation**

| Building shell elements |
| --- |
| • Attic/roof<br>• Above-grade walls<br>• Basement and/or crawl-space walls<br>• Rim joists<br>• Basement and/or crawl-space floor<br>• Windows, including proper window installation |

### Attic/Roof

Deep energy retrofits may involve conditioned or unconditioned attics. For conditioned attics, the roofline is insulated and air sealed to bring the attic into the conditioned space of the building. For unconditioned attics, insulation and air sealing efforts are focused on the attic floor. Both approaches are common in cold climates. The National Grid Pilot Program more frequently undertook a conditioned attic approach in order to use attic space for storage or to enclose HVAC equipment in conditioned space.

Table 13. Two approaches to attic/roof retrofit

| Unconditioned attic (vented) | Conditioned attic (unvented) |
|---|---|
| Air sealing: spray foam is used to seal minor gaps in attic floor, including top plate seams between framing and drywall, wire and pipe penetrations, etc. Large gaps are sealed with spray foam or other adhesive and blocking. All hatch access points to attic are well sealed. | Air sealing and insulation: spray foam is commonly applied between unfinished roof rafters, forming the primary airflow control layer as well as an insulation layer. Many homes have an additional layer or more of rigid foam insulation between roof sheathing and roof cladding/water membrane. |
| Insulation: cellulose insulation is applied to attic floor. | Exterior roof insulation is desirable because it controls for air and moisture from the outermost point. Some cases have used netted cellulose insulation in roof cavities, or unfaced fiberglass insulation instead of spray foam. |
| Example: NYSERDA test homes, Ithaca, NY | Example: National Grid Pilot Program homes |

*Sources:* G. Pedrick, pers. comm., October 2013; Neuhauser 2012

### Lessons Learned: Extensive Attic Air Sealing

In three retrofits conducted in Ithaca through the NYSERDA program, the contractor cleaned dirt, debris, and old insulation from the attic with an industrial vacuum before air sealing. This technique prepared for the inspection and sealing of air leaks "in accordance with best practices for new construction"(Tatiem Engineering 2013). While it may be possible to access large chases by leaving existing insulation, small leaks cannot be successfully sealed when covered by insulation, dirt, and debris. Adding new cellulose insulation to replace the old insulation that has been removed is not likely to result in a significant cost increase.

### Above-Grade Wall

Deep energy retrofits may upgrade above-grade wall assemblies, often removing existing siding to air seal and insulate. Table 14 details approaches to above-grade wall insulation and air sealing.

Table 14. Common approaches to above grade wall insulation and air sealing

| Wall cavity | Water control layer | Exterior insulation | Siding |
|---|---|---|---|
| Wall cavities are commonly filled with blown cellulose insulation, blown fiberglass, or less frequently, spray foam. Obstructions in wall cavities that may hinder comprehensive insulation must be addressed to fully seal home. | When siding is removed to add exterior insulation, house wrap (generally Tyvek, or sometimes a self-stick membrane) is applied to the existing board sheathing (commonly OSB, wood slats, etc.). Sheathing replacement is generally required only if water damage is apparent. In many examples, the exterior face of the foam board is detailed as the primary water and airflow control layer.[3] | Foam board insulating sheathing is attached to existing sheathing. Most commonly utilized material is polyisocyanurate, a thermosetplastic which has the highest R-value out of three primary foam sheathing insulations (XPS, EPS, polyiso.), and tends to be the most stable compound.[1] Two layers of foam are often used to reach desired wall R-value, to allow for staggering of seams. One layer of foam board installed with attention to seam detailing is sufficient in some applications. Seams are sealed with tape, Attention is paid to air and moisture sealing details for exterior foam board. | Vertical wood strapping is attached over insulating sheathing and attached to wall framing using long screws. Exterior siding is attached to wood strapping. In some applications, existing siding has been reused. This process takes attention to detail during removal of siding, and significantly more re-installation time than would be expected for work with new vinyl siding.[2] |

*Sources:* [1] BSC 2007. [2] Tatiem 2012. [3] Osser, Neuhauser, and Ueno 2012. [4] G. Pedrick, pers. comm., October 2013.

### Lessons Learned: Exterior Wall Insulation

Exterior rigid foam board is an increasingly common solution because it serves as a robust air barrier in addition to providing insulation. Using two layers provides greater air and moisture sealing and allows staggering of the seams to combat possible foam board shrinkage. However two layers may not be the most cost-effective solution, particularly as insulation compounds are improved and become less prone to shrinking. Three consecutive NYSERDA retrofits performed by the same contractor in Ithaca used only one carefully detailed 2.5" layer instead of two, resulting in low levels of air leakage and less time spent by the crew.

The retrofits also used creative strategies to help reduce invasive and costly modifications to the building shell. To avoid narrow clearances around a window and door, one section of a home was insulated with closed-cell spray foam in the wall cavity rather than with cellulose and rigid foam board exterior. To avoid extending roof overhangs to accommodate for thicker wall insulation, a small section of the gable end of a roof was insulated with 1″ rigid foam board instead of 2.5″. In addition, contractors found that the manufacturer’s specification for attaching foam insulating sheathing to a wood frame exterior wall called for more fasteners than necessary for the application. They reduced the number of fasteners per sheet from 28-30 to approximately 12 (Tatiem Engineering 2012).

An early deep energy retrofit case study by Building Science Corporation also illustrated the importance of choosing foam type carefully: shrinkage is much more of an issue for expanded polystyrene (EPS) than it is for extruded polystyrene (XPS) and polyisocyanurate. In addition, the way in which seams are sealed between foam board pieces is crucial to performance. In the Building Science Corporation experiment, seams sealed with mastic and mesh dried out and cracked over 16 years, resulting in considerable air leakage, while peel-and-stick tape used on another portion of the house held strong (Lstiburek 2012). While using two layers of foam board can ameliorate leakage and shrinking problems, the right type of insulation and sealing material targets the direct culprits to ensure foam board life and performance.

### Foundation Wall/Slab

Full basements are commonly included in the thermal enclosure of a home, both for additional space and to house equipment. The National Grid program found that including the basement in the thermal enclosure resulted in better energy performance (Osser, Neuhauser, and Ueno 2012). Table 15 describes common approaches.

**Table 15. Common approaches to foundation wall/slab insulation and air sealing**

| Foundation wall | Basement/crawl slab |
|---|---|
| Foundation walls are commonly insulated with either closed-cell spray polyurethane foam or rigid polyisocyanurate foam board. | Some retrofits install rigid foam insulation under a new slab when the existing slab is dug up to address drainage issues. Others install rigid foam insulation over an existing slab and finish the application with flooring to protect foam. |
| Spray foam insulation is often used to air seal and insulate rim joists. | Not all deep energy retrofits treat the basement floor with insulation. National Grid Pilot evaluations indicate insulation of basement floor does not affect heating/cooling loads significantly (Neuhauser 2012). Some projects with a combination of full basement and crawl space have focused efforts on crawl spaces to insulate the slab that is most exposed (i.e., further above ground). |

*Sources:* Neuhauser 2012, Tatiem 2013

### Windows

Existing windows are sometimes replaced with highly insulated windows with an R value of 7 or more. Because of the prohibitive price of new windows, many projects keep and reinstall existing windows if they are moderately well performing (e.g., double paned with insulated frames). New window installation may also involve adding wall thickness and air- and water-control detailing. Window installers may not be familiar with these practices.

Project managers should pay particular attention to window installation, especially if window companies unfamiliar with the integration of windows with deep energy retrofit wall components are involved. Installers need to focus on air and water control when integrating windows with a DER wall. Proper window air and water sealing detail jobs are done in accordance with Building Science Corporation recommendations, focusing on integrating the drainage plane into window installation to direct water away from the window frame.[8] For existing windows, new framing and sill extensions can be built outboard of the existing trim.

### Mechanical Systems

Improving or replacing a home's equipment can meet the smaller energy demands of a low-load house, allow for sealed combustion in more airtight homes, improve distribution systems, and reduce the energy use of the heating equipment itself. There is no one clear path or technology for deep energy retrofit heating and cooling applications. The nature of the work depends on the extensiveness of the retrofit, the existing HVAC system and its location, and the existing venting strategy (i.e., atmospheric versus direct venting to outside).

Deep energy retrofits use the following measures to ensure safe indoor air quality and energy savings:

- Location of all HVAC equipment and distribution systems within the conditioned space of the home
- Closed combustion, direct-vented fuel-burning appliances when located within the conditioned building envelope, to maintain healthy indoor air quality and minimal air leakage to the outside
- Mechanical ventilation, most commonly HRVs or ERVs to provide fresh air for occupants while minimizing loss of heating or cooling energy. Some deep energy retrofits rely on the less-costly option of exhaust-only fans for cycling air through the home.

In conjunction with significantly lower energy loads, some retrofits install new HVAC equipment and distribution systems with significantly lower capacity. Table 16 provides examples of a number of projects that have installed lower-capacity heating equipment.

---

[8] See Info-302: Pan Flashing for Exterior Wall Openings: http://www.buildingscience.com/documents/information-sheets/pan-flashing-for-exterior-wall-openings, Info-303: Common Flashing Details: http://www.buildingscience.com/documents/information-sheets/common-flashing-details/, and Info-406: Air Sealing Windows for Building Science Corporation Methods: http://www.buildingscience.com/documents/information-sheets/air-sealing-windows.

Table 16. Deep energy retrofit projects using low load heating equipment

| Program/project | Existing equipment | Replacement |
|---|---|---|
| THC: Ohio[1] | Propane boiler | 9,000 Btu ductless mini-split heat pump |
| THC; New Mexico[1] | Gas furnace located in an unconditioned crawlspace | 2 ductless mini-split heat pumps: one 9,000 Btu and one 12,000 Btu unit |
| THC; Pennsylvania[1] | Unknown | 2 ductless heat pumps, each 9,000 Btu |
| THC; Ohio[1] | All-electric forced air furnace | 9,000 Btu ductless heat pump |
| NYSERDA; Utica[2] | 250,000 Btu forced-air natural gas furnace | Fan coil (45,000 Btu) supplied by hot water loop from home's tankless natural gas water heater |
| National Grid DER; Millbury Cape[3] | 30+ year-old oil boiler and 4 window AC units | Ductless mini-split heat pump (size unknown) |

*Sources:* [1]Thousand Home Challenge 2013. [2]NYSERDA 2013. [3]Osser, Neuhauser, and Ueno 2012.

HVAC professionals need to be educated about the proper placement, installation, and maintenance of mechanical ventilation that provides fresh air throughout the house (Wigington 2013). Deep energy retrofits may also make use of new technology for low-load homes. For instance, recent advances in heat pump technology have allowed ductless mini-split pumps to be viable in cold weather conditions as a legitimate space heating option for the Northeast and Mid-Atlantic (NEEP 2013).[9]

### Water Heating and Distribution

Water heating upgrades focus on replacing existing water heaters with more efficient models, including non-atmospherically-vented or electric heat-pump units. Recent developments in heat-pump water-heater technology, particularly those designed for northern climates, can mean significant savings for homes with aging electric tank water heaters.[10] Overall hot water system efficiency can also be increased by integrating drain-water heat recovery and reconfiguring water distribution systems, e.g., by positioning the water heater according to highest use areas or using point-source water heaters for particularly distant fixtures. However

[9] A recent NEEP report characterizes the opportunity for residential air-source heat pumps, identifies market barriers to their adoption, and recommends near- and long-term strategies for the Northeast and Mid-Atlantic. The report is available at: http://www.neep.org/efficient-products/emerging-technologies/Air-Source-Heat-Pumps/index

[10] The Northwest Energy Efficiency Alliance (NEEA) has been collaborating with utility partners to influence manufacturers to develop heat-pump water-heater products that perform well in northern climates. More information on NEEA's work, including a specification for heat pump water heaters installed in northern climates is available here: http://neea.org/northernclimatespec/

few deep energy retrofits have made such improvements to date. In addition, while water heating system components (e.g., water heaters, showerheads, and faucet aerators) have become more efficient, plumbing codes have not been modified to reflect new flow patterns. For instance, the larger homes built today often have longer pipe runs that make efficient hot-water delivery more challenging (Wigington 2010).

### Additional Energy Loads

Deep energy retrofit programs generally focus on the performance of the structure of the house and its primary systems (heating, cooling, hot water). However, the way energy is used in homes is changing, and the loads associated with lighting, appliances, mechanical ventilation, and electronics should also play a role in energy reduction. In 1993, 24% of home energy was used for appliances, electronics, and lighting. By 2009, these applications used 34.6%. Figure 8 shows the change. While it will be useful to address these loads in all climates, focusing on appliances, electronics, and lighting will be particularly worthwhile in milder climate zones where heating and cooling loads are limited.

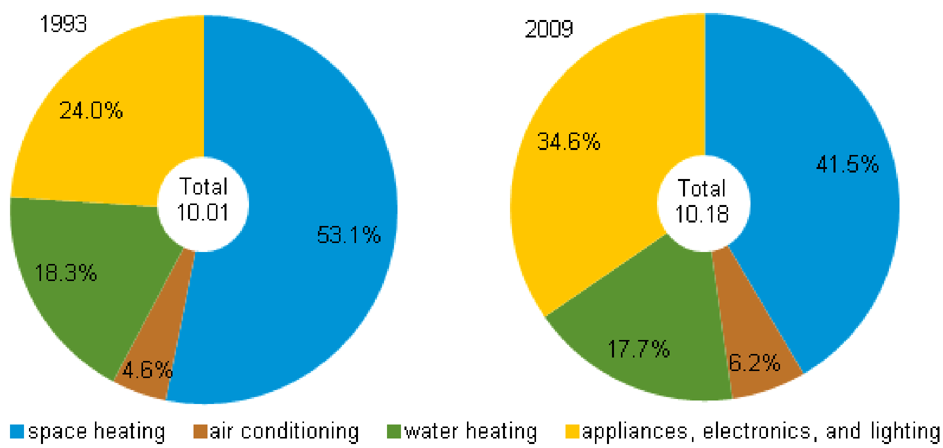


Figure 8. Energy consumption in homes by end use in quadrillion Btu and percent. *Source:* EIA 2013b.

## *COSTS*

A typical deep energy retrofit costs about the same as a kitchen renovation or room addition.[11] While material costs are a significant component, the greatest potential for cost savings lies in increasing a project's efficiency and working deep energy improvements into planned upgrades.

For most of the measures in the National Grid pilot, deep energy retrofit improvements cost more than typical maintenance jobs such as replacing siding or a roof. Table 17 shows the details.

---

[11] Major kitchen model national average for a midrange project is $53,931; an attic room addition average cost is $47,919 (Remodeling 2013).

Table 17. Incremental improvement costs for measures in the National Grid pilot program

| Component | Total measure cost (per sq. ft.) | Incremental performance improvement cost (per sq. ft.) |
|---|---|---|
| Roof/attic: unvented attic with closed-cell spray foam | $17.75 | $5.19 |
| Roof/attic: exterior insulation and framing cavity insulation | $22.22 | $7.44 |
| Above-grade wall: rigid foam insulating sheathing with air permeable framing cavity insulation | $10.41 | $4.46 |
| Above-grade wall: rigid foam insulating sheathing with ccSPF cavity insulation | $17.73 | $11.59 |
| Foundation wall: ccSPF insulation | Project A: $3.77<br>Project B: $5.80 | Project A: $2.15<br>Project B: $4.00 |

Measure costs reflect builder proposals and estimates prior to construction. *Source:* Neuhauser 2012.

The typical costs of standard home improvements as reported in *Remodeling Magazine* provide a useful comparison to high-performance measures. In 2013, the average cost for a roofing replacement in the United States was $18,488, with upscale projects costing an average of $33,880. The average cost of siding replacement in 2013 was $11,192 for vinyl siding and $13,083 for fiber-cement siding.[12] In 2011, the average cost of improving a roof was $6,540, with a total of 3 million homeowners undertaking improvements on some scale; an average of $6,101 was spent on siding improvements by 720,000 homeowners. In comparison, measure prices from some NYSERDA case study homes that had exterior wall insulation installed are shown in Table 18.

[12] Values are based on an average of 1,250 sq. ft. of siding replacement.

**Table 18. Cost of deep energy improvement for walls from NYSERDA case studies**

| Home ID | Wall improvement details | Total cost of wall improvement | Cost/sf |
|---|---|---|---|
| IBACOS #1 | R-28 (Frame-out of exterior walls, cc sf installed, sheathing, and new siding) | $25,560 | $17 |
| West Hill | R-30 (dense packed walls with cellulose insulation, 2.5" THERMAX board installed, reinstalled existing vinyl siding) | $29,569 | $21.74 |
| Hawthorne | R-30 (cellulose filled walls, exterior sheathing 2.5" THERMAX) | $19,681 | $12.85 |

Actual costs once work was completed. A majority of cost estimates in builder proposals were underestimates, with final values being higher.
*Sources:* Herk et al. 2012, Tatiem 2013.

Table 19 provides the overall project costs for the deep energy retrofits examined in this report.

**Table 19. Overall project costs of deep energy retrofits**

| Organization | Costs |
|---|---|
| Sacramento Municipal Utility District (SMUD) and National Renewable Energy Laboratory (NREL) Research and Development Program on Deep Energy Retrofits | Total project costs ranged from $66,500 to $141,000, with an average cost of $112,489. The energy efficiency upgrade costs ranged from $16,957 to $40,800, with an average cost of $29,360, 26% of total project cost. |
| New York State Energy Research and Development Authority (NYSERDA) | Total project costs ranged from approximately $67,000 to $144,000. The homes involved in the Pilot Phase I were fully funded by NYSERDA, for about $100,000 per home. |
| Vermont Energy Investment Corporation (VEIC), Champlain Housing Trust (CHT) | Project costs range from $58,000 to $218,000. Energy efficiency upgrade costs range from $7,500 to $16,500. |
| National Grid Deep Energy Retrofit Pilot Homes | Projects ranged from $50k to $180k, with an average of about $40/sf. |
| Lawrence Berkeley National Laboratory (LBNL) | Unknown |

*Sources:* Keesee 2012, Tatiem 2013, Herk et al. 2012, G. Pedrick, Project Manager, Buildings Research and Development, NYSERDA, pers. comm., October 2013, N. Kuhn, Senior Consultant, Vermont Energy Investment Corporation, pers. comm., October 2013, Neuhauser 2012.

Many homeowners consider the impact on resale value when they renovate their house. Table 20 shows the resale value of some standard improvements.

Table 20. Job cost and resale value for standard home improvements

| Project | Job cost | Resale value | Cost recouped |
|---|---|---|---|
| Roofing replacement | $18,488 | $11,633 | 62.9% |
| Siding replacement (vinyl) | $11,192 | $8,154 | 72.9% |
| Basement remodel | $61,303 | $43,095 | 70.3% |
| Attic bedroom | $47,919 | $34,916 | 72.9% |

*Source*: Remodeling 2013

Although incorporating high-performance retrofit measures into an attic addition, basement renovation, or siding or roofing replacement may increase the cost of the project, it may also add a premium to the resale value given the higher prices buyers are willing to pay for energy-efficient homes. Research has indicated that homes with labels indicating that they have been designed and built to use energy efficiently sell for 9% more than comparable non-labeled homes (Kok and Kahn 2012).

### *ENERGY SAVINGS: WHAT IS POSSIBLE?*

Actual energy use data have been collected on the post-retrofit energy use of a number of deep energy retrofits. Pre- and post-retrofit data show that comprehensive retrofits that undertake shell improvements can result in actual energy savings of over 50%. Figure 9 focuses on projects that have measured post-retrofit energy use. Pre-retrofit energy use data are also available for many of these projects.

Not included in figure 9 are energy use data for seven homes in the Pacific Northwest that were retrofitted as a part of the Building America PNNL project. Researchers collected actual post-retrofit energy use data in these homes to compare energy modeling estimates with measured energy use. They found a discrepancy between actual and estimated energy use (Osser, Neuhauser, and Ueno 2012).

This discrepancy is an issue because utilities need to use modeling software to predict and determine the energy savings of particular deep retrofit measures, as well as how those measures interact with the rest of the home energy system. Although many modeling tools are available to assess home energy savings, the inaccuracy of their predictions (compared to actual energy use measurements) limits their usefulness (Osser, Neuhauser, and Ueno 2012). Pilot programs should monitor actual energy savings to evaluate project impact and help calibrate estimation tools.

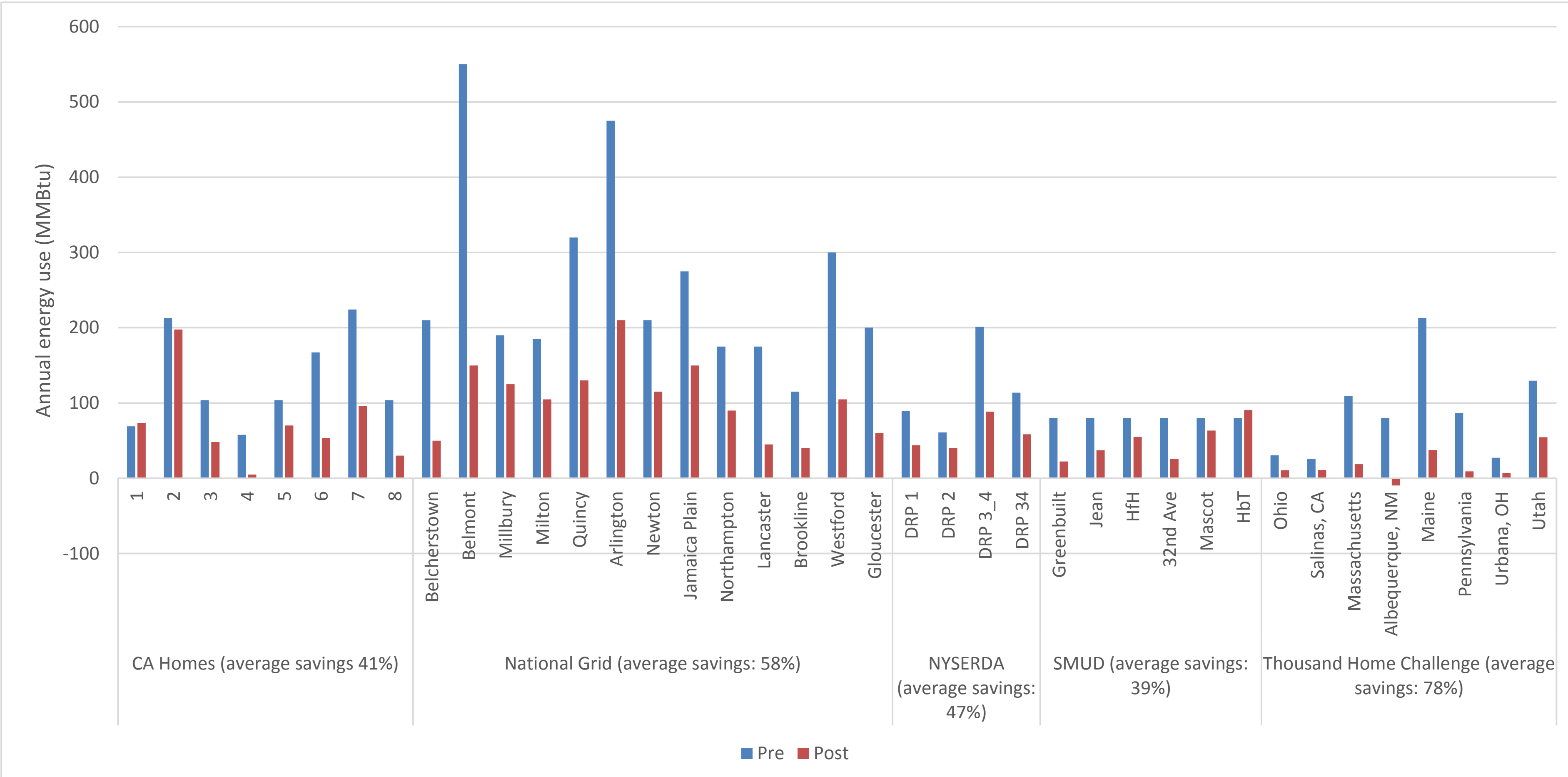


Figure 9. Measured energy data from deep energy retrofits. NYSERDA and THC home energy use is reported as site energy; in all other homes energy is reported as source energy. THC post-retrofit examples may include renewable energy production. Pre-retrofit usage for SMUD homes is an energy-use average calculated for homes in the utility territory, not actual energy usage for each home.

### Utility Program Energy Calculation Considerations

In the National Grid Pilot, program operators considered various approaches to predicting and recording savings, including:

- Assigning savings from prescriptive values associated with prototypical models
- Pre and post monitoring of project energy use
- Pre and post Home Energy Rating System (HERS) rating of the building

Following the National Grid Pilot, consultants calculated energy savings for partial DER projects (which were incentivized in the 2013 program) to support the energy efficiency program plan regulatory filing. They estimated savings for projects that covered a home's attic, above-ground walls, windows, and basement walls. They set up the characteristics of a baseline model house by assessing the pre-existing conditions of homes that participated in National Grid's DER pilot project. They developed two baseline scenarios: a "worst existing condition" assuming little pre-existing insulation, and a "better existing condition" assuming better insulation. Homes were modeled for upgrades corresponding to the DER insulation targets for National Grid's program (Takahashi, et al. 2012).

National Grid used the *Rhode Island Technical Reference Manual for Estimating Savings from Energy Efficiency Measures* (2013 and 2014 program years) to guide them in evaluating the National Grid Deep Energy Retrofit Program. In this model, the project savings are the difference between the baseline efficiency (the performance of the house before participation in the program) and the high-efficiency case (the post-retrofit performance). The program implementer calculates this value and provides it to National Grid. Project-specific information is used to estimate energy and demand impacts from DER installations. Gross savings per project in kWh are calculated for the basements, walls, and roofs (through the same work as for the regulatory filing). Savings for air infiltration reductions must be calculated by the program implementer (National Grid 2013a).

## Barriers to Scaling Up Deep Energy Retrofits

Deep energy retrofit case studies show that existing technology and practices can result in energy savings of 50% or more. However there are still many barriers to adoption and delivery on a large scale.

### *WORKFORCE*

One of the barriers to implementing deep energy retrofit measures is access to a workforce with the right skills. Energy efficiency services currently reach homeowners through (1) independent assessors or consultants, (2) subcontractors in energy-related trades (e.g., HVAC), (3) general remodeling contractors, or (4) home performance contractors (McIlvaine 2013). While all of these pathways can provide an entry for deep energy retrofit work, none of them currently does so on a large scale.

Home upgrades such as re-roofing, re-siding, finishing a basement, finishing an attic, and building an addition all provide opportunities to implement additional measures that save energy. The problem is that the tradespeople who deliver these services are usually not qualified to undertake deep energy retrofit measures at the time that they could be done for least cost to the homeowner.

Retrofits often involve multiple measures affecting various parts of the house. However the trades involved in upgrades are usually compartmentalized. The professionals homeowners call to insulate an attic are not the same ones who do roofing or siding upgrades. In addition, these specialized contractors may not be qualified to consider how improvements might react with each other. Sometimes homeowners call the wrong person altogether. For example, they may call an HVAC contractor to address a comfort issue like uneven heating when an air sealing and insulation contractor would be best suited to fix the problem.

Deep energy retrofits call for several different contractors. But it is difficult to keep a staff employed full time who are specialized in all the necessary trades. Some home performance contractors have taken on the role of energy consultant/assessor and put together teams as needed. They perform assessments, develop work scopes, coordinate multiple contracts, and sometimes do air sealing and insulation work themselves.

### *MARKET INTEREST AND ACCEPTANCE*

Getting homeowners to undertake deep energy retrofits at the time of major home renovations is a promising opportunity. But not only is there no clear channel for the delivery of these retrofits, homeowners know little about them. "Deep energy retrofit" is not a commonly recognized term.

In fact the percentage of homeowner spending on remodeling projects that include an energy efficiency measure has climbed in recent years, from 25% in 2009 to 32% in 2012 (JCHS 2013, McIlvaine et al. 2013). Most of these efficiency improvements involve single measures (window or HVAC replacements, insulation installations, and so forth), but at least an increasing number of homeowners are motivated to make them.

Despite growing interest in energy efficient home improvements, there is a lot of conflicting information about the magnitude of energy savings from different measures (McIlvaine et al. 2013). There is no one prescription for achieving deep savings in a home or agreement as to what those savings are. Some projects aim to save 30%, while others aim to save 75% of pre-retrofit energy use. As a result, the extent of improvements, and the costs, vary widely.

To gain market acceptance, it would help to develop a package of solutions that have been tested and proven to save energy in a variety of applications. Homeowners need a clear picture of what can save them energy, how much improvements cost, and what other benefits the work provides. They need more information on what improvements are most effective for energy use reduction, and which ones are best addressed at the time of other renovations. The industry needs to be more transparent about the energy savings that are possible from deep energy retrofits. Programs incentivitizing retrofits should report actual energy use. Finally, we need to quantify the non-energy benefits of deep energy retrofits, including increased home durability, greater comfort, and better indoor air quality, in order to articulate these benefits to homeowners who are motivated by more than energy savings.

### *FINANCIAL BARRIERS*

It is difficult to complete a deep energy retrofit that saves more than 50% of the energy used in a home without significant financial investment. Costs are high for these projects relative to other home improvements and renovations. In 2011, over $145 billion was spent on professional home improvements, with an average project cost of $9,062 (JCHS 2013). Homeowners spend an average of $33,940 on kitchen additions and alterations, the most costly home improvement project. The total cost of a deep energy retrofit (which includes energy and non-energy measures) can set the homeowner back significantly more. The first National Grid projects in the pilot ranged from $50,000 to $180,000 (Neuhauser 2012). A number of these homes also underwent significant home maintenance and repair in conjunction with deep energy retrofit work.

Many homeowners cannot afford the upfront capital investment necessary for deep energy improvements. Although the situation is improving, many are underwater on their mortgages, owing more than their home is worth. As of the end of 2013, about 20% of homeowners were in this situation (Carlyle 2013). In addition, many homeowners do not have enough savings to spend on costly home improvements. About 50% of Americans have less than three months' savings to cover their expenses in an emergency, and 27% have no emergency savings at all (Bankrate 2013). These financial situations do not leave a lot of capital for energy-efficient home renovations. This is especially true for consumers who spend a higher percentage of their budget on energy than most. While they could benefit most from lower energy costs, they are unlikely to have the resources to undertake a deep energy retrofit.

All of these factors suggest a role for financing options. In addition, programs should develop strategies to streamline administration, simplify contractor procedures, and create sufficient competition so that the per-site costs go down.

### *COST EFFECTIVENESS*

Cost effectiveness is a challenge for utility programs involving deep energy retrofits. We need more data from completed projects to assess the cost effectiveness of comprehensive energy retrofits as well as individual measures. As currently applied, most of the common cost-effectiveness tests have difficulty demonstrating a positive cost-benefit ratio for whole building retrofit programs; as a result, regulators are reluctant to support utility investments in these programs (Brook et al. 2012). Many cost-effectiveness tests use inappropriate discount rates and measure lifetimes, and they inadequately address the full range of avoided costs, non-energy impacts, and market transformation effects like free riders and spillover (Amann 2006, Woolf et al. 2012).

Of these shortcomings, the failure to account for non-energy impacts is particularly problematic for whole-home retrofit programs. Non-energy benefits associated with home retrofits (e.g., improved comfort, indoor air quality, safety and durability) are highly valued by customers and are often the primary drivers of investment in retrofit projects (Lutzenhiser 2004). Rarely does a homeowner start a retrofit solely to reduce energy consumption.

As a first step to overcoming this barrier, table 21 below attempts to show the impact of non-energy benefits on cost effectiveness by incorporating them into an existing study. To give some background, Building Science Corporation performed a cost-effectiveness evaluation on five test homes in the National Grid program, using energy modeling software and cost information from the pilot program application forms (Neuhauser 2012). They based their evaluation on actual pre-existing home conditions, but did not include actual measures implemented or actual final cost data or energy use. They modeled measures applied in earlier retrofits and new construction (Neuhauser 2012).

Table 21 adds non-energy benefits to this study. Data on non-energy benefits from residential retrofits show values ranging from 0.5 to 1.5 times the value of energy cost savings (Amann 2006). We split the difference and assume that non-energy benefits provide a value equal to the energy cost savings.

**Table 21. Cost effectiveness of deep energy retrofits**

| Project | Total project cost | Yearly cost savings | Cost savings over 25 years[1] | Cost savings over 25 years from energy and non-energy benefits[2] | Benefit/cost ratio |
|---|---|---|---|---|---|
| Test home 1 | $156,762 | $1,710.06 | $43,161.99 | $86,323.98 | 0.55 |
| Test home 2 | $150,329 | $1,802.68 | $45,499.69 | $90,999.39 | 0.61 |
| Test home 3 | $233,055 | $9,072.14 | $228,980.91 | $457,961.83 | 1.91 |
| Test home 4 | $191,343 | $1,350.88 | $34,096.26 | $68,192.52 | 0.36 |
| Test home 5 | $155,339.00 | $2,139.27 | $53,995.25 | $107,990.50 | 0.70 |

[1] Cost savings estimates based on calculated use and energy expenditures of an average household of $22.59/MMBtu (EIA 2009). Lifetime cost savings based on an overall increase of 2% over 25 years. Based on a measure lifetime of 25 years. [2]Assuming non-energy benefits equal the yearly cost savings of energy reduction.

By way of comparison, figure 10 shows the energy-savings cost effectiveness of each project relative to the approximate cost of a residential-scale PV system designed to reduce source energy. Each home was modeled to determine the cost effectiveness of individual measures using measure-cost data from a number of sources. This method did not apportion costs for energy savings and non-energy benefits, even though energy savings are rarely the only benefit that results from a high-performance measure.[13]

[13] Results from energy modeling for five test homes that explores the cost effectiveness of individual measures are available at http://www.nrel.gov/docs/fy12osti/53684.pdf

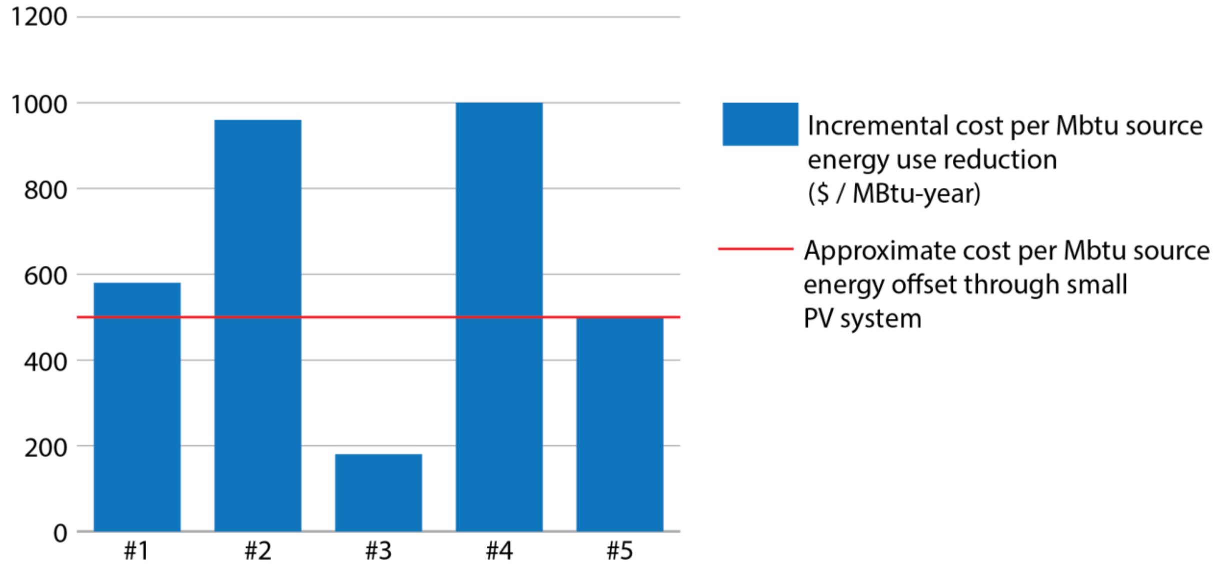


Figure 10. Incremental project cost for energy performance measures in 5 homes relative to predicted source energy use reduction. *Source:* Neuhauser 2012.

## Recommendations

Although not optimal for all homes and homeowners, deep energy retrofits are a suitable offering to the small subset of utility customers who are willing to undertake significant renovations to a home and who are committed to reducing their energy footprint. Eventually DER programs will appeal to and benefit a broader audience as the workforce gains more experience, processes are improved, and delivery mechanisms are developed.

The suggestions in this section apply to deep energy retrofit pilot programs rather than full-scale utility programs. Pilot programs can overcome barriers and lay the foundation for large-scale efforts as they help deep energy retrofits to become more widely known and less costly for homeowners, and more cost effective for utilities.

### *DEVELOP WORKFORCE CAPACITY*

Pilot programs can access qualified builders by seeking out contractors who have worked on high-efficiency renovations or new construction that achieved ratings or certifications described in the Findings section of this report. While a small subset of homes have achieved Passive House or Net Zero Energy certification, an increasing number of builders are familiar with HERS ratings as a result of the ENERGY STAR for New Homes program. They may also be aware of the increasingly available option of using HERS to demonstrate code compliance. Programs should encourage builders to document high-performance work to prove their eligibility for program participation.

The most critical elements of deep energy retrofit projects are often details and installation techniques that are not widespread in the building and renovation industry. Technical assistance to builders can help address the challenges of proper installation and measure sequencing, and they can also be tailored to the region and its housing stock. For example, the National Grid pilot program provided technical assistance by adopting elements of a code inspection process that is normally carried out for substantial renovations or new construction. Building scientists inspected projects to ensure proper installation of retrofit measures, particularly those that were incentivized. They also provided technical guidance through multiple visits to the worksite and through the *Mass Save Deep Energy Retrofit Builder Guide*, a compilation of lessons learned on material application and sequencing from the first projects in the National Grid pilot program.[14] As programs scale up, documents like this can provide information to a wider audience using less staff time.

Additionally, programs can encourage the participation of contractors who offer a wider range of in-home services by offering training on DER measures. They can also show contractors who are in more narrowly focused trades how deep energy retrofit work can fit into what they do. Training sessions can also be a way to recruit qualified contractors.

### *ENCOURAGE BETTER MARKET VALUATION OF DEEP ENERGY RETROFITS*

Energy efficiency program administrators and the real estate and appraisal industries can help realtors and appraisers better value deep energy retrofits and benchmark them against homes of similar vintage and footprint that have not been retrofitted. Homeowners commonly take on home renovations to increase the sale price of their home. If realtors and appraisers highlight the value of efficient homes, they will encourage homeowners to invest in efficiency improvements as a way to add value. Programs should develop continuing education classes to educate appraisers and realtors on the non-energy benefits of deep energy retrofits.

Realtors and appraisers are already developing tools and strategies to highlight the value of energy efficiency. For example, the Appraisal Institute has developed the *Residential Green and Energy Efficient Addendum* to supplement the widely used form for mortgage lending appraisals and provide a framework for evaluating energy-efficient homes. In addition, realtors have been active in the *Green the MLS* movement, which is supported by the National Association of Realtors. This program highlights the features and performance of energy-efficient homes by including verifiable metrics in home listings. A recent report, *Unlocking the Value of an Energy Efficient Home*, provides a blueprint for program sponsors and energy efficiency organizations who wish to integrate information about retrofitted homes into real estate transactions.[15]

Comparing homes using energy scores such as the Energy Performance Score (EPS) and the Home Energy Score (HES) will also highlight the value of deep energy retrofits. In addition, energy scoring can help track the progress of homes that are doing deep energy retrofit work in increments.

---

[14] The *Mass Save Deep Energy Retrofit Builder Guide* is available here: http://www.buildingscience.com/documents/guides-and-manuals/gm-mass-save-der-builder-guide

[15] *Unlocking the Value of an Energy Efficient Home* is available at the Elevate Energy (formerly CNT Energy) website: http://www.elevateenergy.org/wp-content/uploads/2014/01/Unlocking_the_Value_an_Energy_Efficient_Home.pdf

### *INCREASE CUSTOMER AWARENESS AND INTEREST*

Program administrators can leverage existing energy efficiency programs to educate consumers about deep energy retrofits. For example, National Grid has integrated information about deep energy retrofit measures into their high-volume home audit program, both verbally and in writing (NEC 2012).

Program administrators should also collect data about home conditions and customer needs, for example, the date of the last roof or siding replacement, or homeowner plans for attic renovation, home additions, and/or basement renovations. Knowing these things, program administrators can send targeted marketing materials about deep energy retrofits to the homeowners who are most likely to undertake such work.

Programs can also partner with existing organizations, such as insurance companies, who distribute information on home maintenance. For example, these groups could inform homeowners about deep energy retrofit measures they might undertake when replacing roofing damaged in a natural disaster or renovating a flooded basement. This is also an opportunity to show homeowners how to improve resilience and durability to prevent storm damage.[16]

### *TARGET THE RIGHT CUSTOMERS*

Since deep energy retrofits take time and money, pilot programs should target the most highly motivated end users. Homeowners who undertake DERs are motivated by a variety of factors. They may want to reduce their long-term energy spending, update aging or previously unoccupied homes, make their homes more comfortable, ensure their future energy security, and/or help the environment. Finding individuals motivated by strong personal values is key to recruitment. Local environmental organizations and local chapters of national organizations such as the Sierra Club can put programmers in contact with people who are committed to environmental issues.

Programs can narrow marketing to the best candidates by collecting and consolidating data on environmentally conscious consumers, high-volume energy users, and planned upgrades and improvements. Data on the local housing stock and its energy use can help programmers set realistic energy savings goals and give consumers confidence that their home can realize the desired energy savings. Programs can hone program design and messaging as they focus on committed homeowners. This experience will lead to more successful targeting of broader audiences as the program scales up.

---

[16] A homeowner who participated in the Thousand Home Challenge implemented deep energy retrofit measures with the help of insurance settlement funds after storm damage to roof and siding necessitated repairs (Thousand Home Challenge 2013). More information on this particular Thousand Home Challenge case study can be found at http://thousandhomechallenge.com/sites/default/files/user-files/Mackey_THC_Case_Study.pdf

### *PROVIDE FINANCING OPPORTUNITIES*

Some energy efficiency programs are already offering financing to help participants complete retrofits without significant upfront costs.[17] Both rebates and financing are available in some Home Performance with Energy Star (HPwES) programs. A survey of HPwES sponsors indicated that 16 out of 44 offered financing. The most common was low-interest financing, while some also offered on-bill financing. Sponsors that offered financing completed 84% of all HPwES projects in 2012 (Jacobsohn, Moriarta, and Khowailed 2013).

Program-sponsored financing appeals to homeowners who want to do renovations but cannot afford the work otherwise. Once they incorporate energy efficiency measures into renovations, they gain access to financing that otherwise might not have been available. Bank loans may also become a viable option when deep energy retrofits gain a higher market valuation.

### *MEASURE ENERGY PERFORMANCE*

Measurement and verification of actual energy use pre- and post-retrofit can be used to evaluate pilot efforts and drive the design of programs that achieve the highest savings, particularly at the early stages of program development. Initial results can be used to inform more cost-effective full-scale programs. Program operators can also use these data for incentives based on energy-use reduction.[18] By targeting reduced plug loads, programs can leverage additional savings from early DER adopters, many of whom are committed to reducing their environmental impact.

### *DEVELOP A STRATEGY FOR PROGRAM DEVELOPMENT AND EVOLUTION*

Deep energy retrofit pilots require more planning and technical assistance than traditional home performance programs. Figure 10 uses a mock project timeline to compare these two program types.

---

[17] For more information on utility financing programs for energy efficiency, refer to the ACEEE series on energy efficiency financing, including: http://aceee.org/white-paper/energy-efficiency-finance-101, http://aceee.org/research-report/u115, and http://aceee.org/research-report/e118

[18] The National Grid Deep Energy Retrofit Pilot used actual data from retrofitted homes to determine energy savings in the first full-scale year. It also offered participants an additional incentive on top of the one for structural improvements if the home qualified for the Thousand Home Challenge, which required measured home performance data.

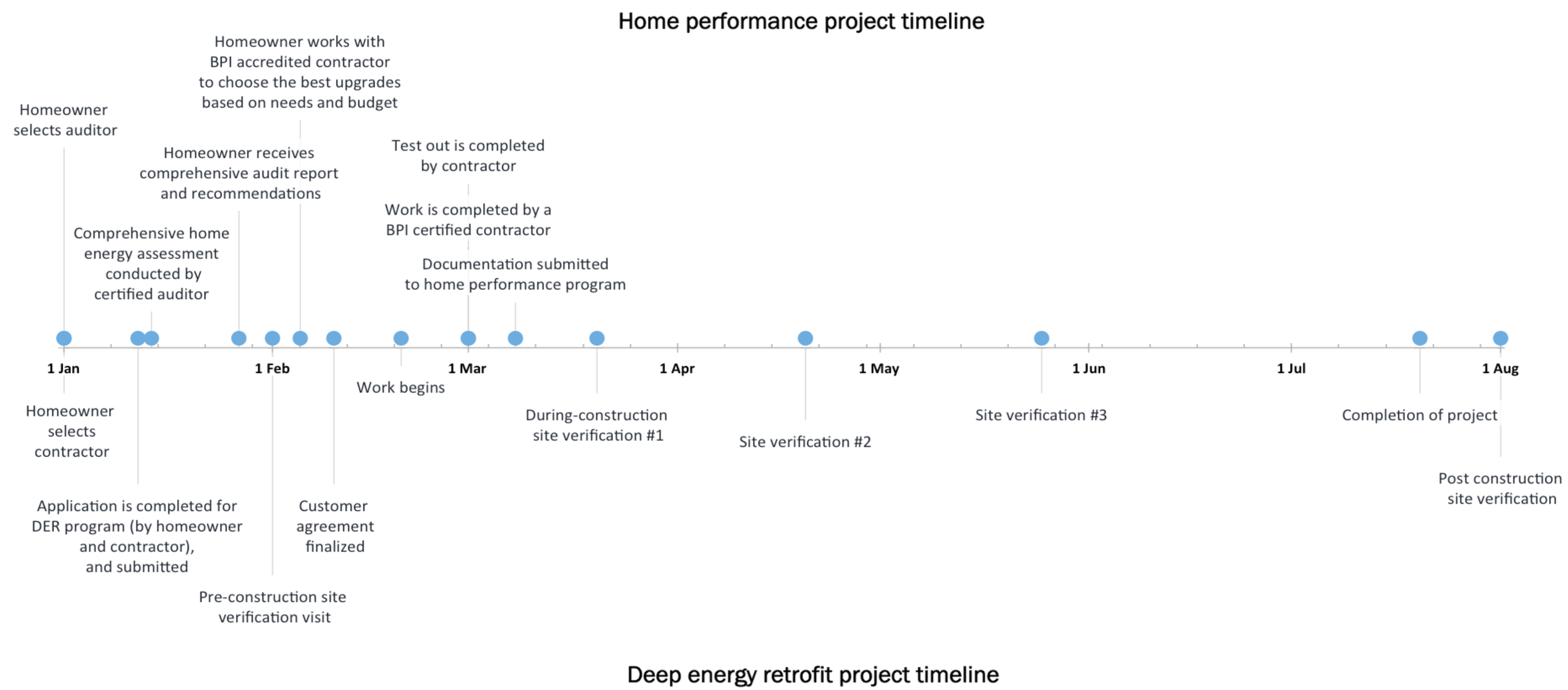


Figure 11. Home performance and deep energy retrofit program timelines. *Source*: EPA 2011, Neuhauser 2012.

Pilot program strategies will look different from those used in a more developed program that has to withstand regulatory evaluation. Pilot strategies are not necessarily meant to be replicated in full-scale programs; they are designed to build capacity for future efforts. For instance, pilots should aim to transform value chain elements that are critical to scaling up deep energy retrofits. As one example, programs may be able to incentivize work though channels connected to re-siding, re-roofing, additions, basement remodels, and attic conversions.

Program operators do not always have clear messaging that articulates the relative impact of measures on energy savings. Although offering a large number of equipment replacements in a single program may maximize near-term energy savings, unclear messaging can make customers less likely to undertake improvements in the future. A clear program development strategy can help guide the transition to a more comprehensive program that gives consumers a complete picture of the relative impact of various energy efficiency measures.

**Roadmap for deep energy retrofit program evolution**

**Pilot program**

- Goals: Prove energy savings potential of deep retrofit measures, develop workforce, increase public awareness
- Overview: Retrofit a small number of homes (e.g., 5-10) of committed homeowners
- Elements:
  - Create well-documented case studies that capture retrofit measures, pre and post energy use, and lessons learned during construction.
  - Provide technical assistance to ensure durable deep retrofit measures and do not negatively impact homes. To promote future retrofit work, maintain quality, durability, health, and safety.
  - For use in the full-scale program, develop a guide to deep energy retrofit measures tailored to the utility service region

**Program 1.0**

- Goals: Continue to develop workforce, increase public awareness of retrofit measures
- Overview: Moderately scale up number of homes involved in program from initial pilot
- Elements:
  - Maintain the opportunity for technical assistance, but wherever possible use technical guidance documents in lieu of onsite person hours.
  - Have at least one onsite inspection to confirm proper installation.
  - Engage additional contractor partners through trainings, including nontraditional partners such as roofers and siders.

**Program 2.0**

- Goals: Higher levels of participation, particularly by leveraging times of existing renovation, potential development and/or link to financing options for large-scale projects
- Overview: Continue to increase of homes involved in program, building on Program 1.0
- Elements:
  - Involve wider spectrum of homes by leveraging occasions such as improvement of basement, roof, siding, addition
  - Include incentives for additional household energy consumers such as appliances

### *WORK IN KEY AREAS*

Work still needs to be done in the following areas before deep energy retrofit programs can be brought to scale:

- Educate contractors about deep energy retrofit measure opportunities during other renovations and home improvements.
- Make homeowners aware of deep energy retrofit opportunities.
- Reduce high upfront costs and the uncertainty surrounding them.
- Include non-energy benefits in cost-effectiveness estimates.
- Establish the market value of deep energy retrofits to spur bank lending and better valuation at the time of sale.
- Factor actual energy use into the evaluation of projects and individual measures.

Systematic efforts in these areas could make deep energy retrofits a key strategy in energy efficiency programs.

## References

Amann, J. 2006. *Valuation of Non-Energy Benefits to Determine Cost Effectiveness of Whole House Retrofit Programs: A Literature Review*. Washington, DC: American Council for an Energy Efficiency Economy. http://www.aceee.org/research-report/a061

Anthony, A. and W. Ferguson. 2012. "Putting the Pieces in Place to Make Giant Leaps in Efficiency Investment: The Rhode Island Experience." In *Proceedings of the ACEEE 2012 Summer Study on Energy Efficiency in Buildings*. 8:1-13. Washington, DC: ACEEE. http://www.aceee.org/files/proceedings/2012/data/papers/0193-000255.pdf

Bankrate. 2013. "June 2013 Financial Security Index Charts." Accessed January 15, 2014. http://www.bankrate.com/finance/consumer-index/financial-security-charts-0613.aspx

Beeler, G. 2011. *Ellen and George Beeler Live/Work Building Rehabilitation. 1940 Vintage: Petaluma, CA Case Study.* Prepared for the Thousand Home Challenge. http://thousandhomechallenge.com/sites/default/files/user-files/beeler_thc_case_study.pdf

Belzer, D., G. Mosey, P. Plympton, and L. Dagher. 2007. *Home Performance with ENERGY STAR: Utility Bill Analysis on Homes Participating in Austin Energy's Program*. Golden, CO: National Renewable Energy Lab. http://www.nrel.gov/docs/fy07osti/41903.pdf

Brook, M., C. Collopy, D. Eden, T. Ferris, C. Graillat, H. Lam, S. Lerman, R. Menten, B. Pennington, J. Regnier, K. Roberts, and J. Wu. 2012. *Comprehensive Energy Efficiency Program for Existing Buildings Scoping Report.* California Energy Commission. http://www.energy.ca.gov/ab758/documents/

BSC (Building Science Corporation). 2007. *Guide to Insulating Sheathing.* Prepared for Building America, U.S. Department of Energy. Washington, DC: Building Science Corporation. http://www.buildingscience.com/documents/guides-and-manuals/gm-guide-insulating-sheathing

Building America. 2013. *Building Science Based Climate Maps*. Washington, DC: U.S. Department of Energy. http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/4_3a_ba_innov_buildingscienceclimatemaps_011713.pdf

Carlyle, E. 2013. "Study Finds 6.4 Million U.S. Homes Still Have Underwater Mortgages." *Forbes*, December 17. http://www.forbes.com/sites/erincarlyle/2013/12/17/6-4-million-still-have-underwater-mortgages-as-of-q3-2013-says-corelogic/

Chandra, S., S. Widder, G. Parker, S. Sande, J. Blanchard, D. Stroer, J. McIlvaine, D. Chasar, D. Beal, and K. Sutherland. 2012. *Pilot Residential Deep Energy Retrofits and the PNNL Lab Homes.* Richland, WA: Pacific Northwest National Laboratory.

DOE (United States Department of Energy). 2013. *Building Energy Codes Program: Massachusetts.* Washington, DC: DOE. http://www.energycodes.gov/adoption/states/massachusetts

EIA (United States Energy Information Administration). 2009. *Residential Energy Consumption Survey (RECS) Overview.* Washington, DC: DOE. http://www.eia.gov/consumption/residential/

———. 2013a. *State Level Energy Related Carbon Dioxide Emissions: 2000-2010*. Washington, DC: EIA. http://www.eia.gov/environment/emissions/state/analysis/

———. 2013b. "Heating and Cooling No Longer Majority of U.S. Home Energy Use." March 7. Washington, DC: EIA. http://www.eia.gov/todayinenergy/detail.cfm?id=10271

ENERGY STAR. 2011. *Home Performance with ENERGY STAR: A Cost-Effective Strategy for Improving Efficiency in Existing Homes.* Washington, DC: Environmental Protection Agency and DOE. http://www.energystar.gov/ia/home_improvement/HPwES_Utility_Intro_FactSheet.pdf

———. 2013. *Home Performance with ENERGY STAR*. Accessed January 15, 2013. http://www.energystar.gov/index.cfm?fuseaction=hpwes_profiles.showsplash

EPA (Environmental Protection Agency). 2011. *Home Performance with ENERGY STAR Sponsor Guide. Version 1.1.* Washington, DC: EPA http://www.energystar.gov/ia/home_improvement/HPwES_Sponsor_Guide.pdf

Herk, A., R. Baker, D. Abrey, and J. Todd. 2012. *NYSERDA Deep Energy Retrofits: House 1 Report: Exterior Spray Foam Retrofit Strategy*. Pittsburg: IBACOS.

Jackson, R., P. Boudreaux, E. Kim, and S. Roberts. 2012. "Advancing Residential Energy Retrofits." In *Proceedings of the ACEEE 2012 Summer Study on Energy Efficiency in Buildings.* 1:127-140. Washington, DC: ACEEE. http://www.aceee.org/files/proceedings/2012/data/papers/0193-000032.pdf

Jacobsohn, E., C. Moriarta, and G. Khowailed. 2013. *Home Performance with ENERGY STAR 2012 Annual Data Report Summary of Findings.* Washington, DC: DOE. http://www.energystar.gov/ia/home_improvement/downloads/2012_Annual_Report.pdf

JCHS (Joint Center for Housing Studies of Harvard University). 2013. *The U.S. Housing Stock: Ready for Renewal.* Cambridge: Harvard University. http://www.jchs.harvard.edu/sites/jchs.harvard.edu/files/harvard_jchs_remodeling_report_2013.pdf

Keesee, M. 2012. "Deep Energy Retrofits: Six Real World Examples and Lessons Learned: Sacramento Municipal Utility District." In *Proceedings of the ACEEE 2012 Summer Study on Energy Efficiency in Buildings.* 1:141-152. Washington, DC: ACEEE. http://www.aceee.org/files/proceedings/2012/data/papers/0193-000006.pdf

Kok, N. and M. Kahn. 2012. *The Value of Green Labels in the California Housing Market.* Berkeley and Los Angeles: University of California. http://www.builditgreen.org/_files/Marketing/ValueofGreenHomeLabelsStudy_July2012.pdf

Less, B., J. Fisher, and I. Walker. 2012. *Deep Energy Retrofits: Eleven California Case Studies*. Berkeley: Lawrence Berkeley National Laboratory. http://eetd.lbl.gov/publications/deep-energy-retrofits-eleven-california-case-studies

Lstiburek, J. 2012. "Foam Shrinks, and Other Lessons." *Fine Homebuilding*. February/March 2012. http://www.finehomebuilding.com/design/articles/foam-shrinks-and-other-lessons.aspx

Lutzenhiser Associates. 2004. *Final Evaluation Report: California Building Performance Contractors Association Comprehensive Whole House Residential Retrofit Program.* Portland: Lutzenhiser Associates.

McIlvaine, J., S. Saunders, E. Bordelon, S. Baden, L. Elam, and E. Martin. 2013. *The Next Step Toward Widespread Residential Deep Energy Retrofits*. Golden, CO: Building America. http://www.fsec.ucf.edu/en/publications/pdf/FSEC-CR-1954-13.pdf

McIlvaine, J., K. Sutherland, and D. Beal. 2013. *Current Best Practices for High Performance, Deep Energy Retrofits in Florida Affordable Housing.* Cocoa, FL: Florida Solar Energy Center. http://www.fsec.ucf.edu/en/publications/pdf/FSEC-RR-444-13.pdf

MZNEB (Massachusetts Zero Net Energy Buildings Task Force). 2009. *Getting to Zero: Final Report of the Massachusetts Zero Net Energy Buildings Task Force*. Boston: Governor's Executive Office of Energy and Environmental Affairs. http://www.mass.gov/eea/docs/eea/press/publications/zneb-taskforce-report.pdf

National Grid. 2012a. *2011 Gas Energy Efficiency Annual Report*. Waltham, MA: Boston Gas Company and Colonial Gas, d/b/a National Grid. http://www.nationalgridus.com/non_html/eer/ma/11_MA_G_EEAR_Pt_1.pdf

———. 2012b. 2011 *Electric Energy Efficiency Annual Report*. Waltham, MA: Massachusetts Electric Company and Nantucket Electric Company, d/b/a National Grid. http://www.nationalgridus.com/non_html/eer/ma/11_MA_E_EEAR_Pt_1.pdf

———. 2013a. *Rhode Island Technical Reference Manual for Estimating Savings from Energy Efficiency Measures. 2014 Program Year.* http://www.nationalgridus.com/non_html/eer/ri/RI%20PY2014%20TRM.pdf

———. 2013b. "Services and rebates: Deep energy retrofit." Accessed January 15, 2014 https://www1.nationalgridus.com/DeepEnergyRetrofit-MA-RES

———. 2013c. "2013 Deep Energy Retrofit Measure Guidelines." Accessed January 15, 2014. https://www1.nationalgridus.com/Files/AddedPDF/POA/2013_Deep_Energy_Retrofit_Measure_Guidelines_20131217.pdf

———. 2013d. *2012 Energy Efficiency Year End Report*. Waltham, MA: Massachusetts Electric Company and Narragansett Electric Company, d/b/a National Grid. http://www.ma-eeac.org/Docs/5.1_Annual%20Reports/2012/Electric/National%20Grid_Electric_2012%20Annual%20Report%20with%20Attachments%20no%20TRM.pdf

NEC (Narragansett Electric Company). 2012. *Energy Efficiency Program Plan for 2013: Settlement of the Parties.* http://www.nationalgridus.com/non_html/eer/ri/2013%20EEPP%20Final%20w%20Rev%20Att%205%2020121204.pdf

———. 2013. *2012 Energy Efficiency Year End Report.* http://www.ripuc.org/eventsactions/docket/4295-NGrid-2012YrEnd-Rept(5-30-13).pdf

NEEP (Northeast Energy Efficiency Partnerships). 2014. *Northeast/Mid-Atlantic Air-Source Heat Pump Market Strategies Report.* Lexington, MA: NEEP. http://www.neep.org/Assets/uploads/files/market-strategies/emerging-tech/ASHP/ASHP%20Report_FINAL%20(2).pdf

Neuhauser, K. 2012. *National Grid Deep Energy Retrofit Pilot.* Somerville, MA: Building Science Corporation. http://www.nrel.gov/docs/fy12osti/53684.pdf

NYSERDA (New York State Research and Development Authority). 2013. "Field Documentation of Deep Energy Retrofits." Accessed January 15, 2014. https://www.nyserda.ny.gov/Energy-Innovation-and-Business-Development/Research-and-Development/Buildings-Research/Advanced-Residential-Buildings/Deep-Retrofit.aspx

Osser, R., K. Neuhauser, K. Ueno. 2012. *Proven Performance of Seven Cold Climate Deep Retrofit Homes.* Somerville, MA: Building Science Corporation. http://www.nrel.gov/docs/fy12osti/54205.pdf

Pettit, B., K. Neuhauser, C. Gates. 2013. *Mass Save Deep Energy Retrofit Builder Guide*. Somerville, MA: Building Science Corporation. http://www.buildingscience.com/documents/guides-and-manuals/gm-mass-save-der-builder-guide

Remodeling. 2013. "2013 Cost vs. Value Report." *Remodeling*. Washington, DC: Hanley Wood Media, Inc. http://www.remodeling.hw.net/2013/costvsvalue/national.aspx

Takahashi, K., W. Steinhurst. M. Duclos, D. Legg. 2012. *A Preliminary Analysis of Energy Impacts from Partial Deep Energy Retrofit Projects in National Grid's Jurisdiction*. Cambridge, MA: Synapse Energy. http://www.synapse-energy.com/Downloads/SynapseReport.2012-06.NGRID.Energy-Impacts-from-Partial-DER-Projects.12-007.pdf

Taitem (Taitem Engineering and Snug Planet). 2012. *Optimized Strategy for Scaling Up Deep Energy Retrofit: West Hill House*. Ithaca, NY: Taitem Engineering and Snug Planet. https://www.nyserda.ny.gov/BusinessAreas/Energy-Innovation-and-Business-Development/Research-and-Development/Buildings-Research/Advanced-Residential-Buildings.aspx

———. 2013. *Optimized Strategy for Scaling Up Deep Energy Retrofit: Hawthorne House*. Ithaca, NY: Taitem Engineering and Snug Planet.

Thousand Home Challenge. 2013. "Thousand Home Challenge Case Studies." Accessed January 15, 2014. http://thousandhomechallenge.com/case-studies

Wigington, L. 2010. "Staged Approaches for Deep Energy Reductions in Existing Homes." In *Proceedings of the ACEEE 2010 Summer Study on Energy Efficiency in Buildings.* 2: 339-354. Washington, DC: ACEEE. http://aceee.org/files/proceedings/2010/data/papers/2299.pdf

Woolf, T., W. Steinhurst, E. Malone, K. Takahashi. 2012. *Energy Efficiency Cost-Effectiveness Screening. How to Properly Account for 'Other Program Impacts' and Environmental Compliance Costs*. Cambridge, MA: Synapse Energy Economics, Inc.

## Appendix A: National Grid Pilot Program Evaluation

This section draws from National Grid's evaluation and Building Science Corporation's in-depth analysis of National Grid's deep energy retrofit pilot program.

### *PILOT PERFORMANCE ASSESSMENT*

National Grid collected extensive energy use data from the first 13 homes in the deep energy retrofit pilot to assess the success of the program in achieving deep energy reductions. Work in these homes focused on reducing heating and cooling loads, which account for approximately 60% of total energy use for a household in this region (EIA 2009). Pre- and post-retrofit energy use for these homes was compared to regional source energy use, where households use an average of 174 MMBtu/year. When compared with a threshold of 50% of the regional average (87 MMBtu/yr), 6 out of the 13 homes profiled were below or very close to using half the energy of an average home in the region (figure A1).

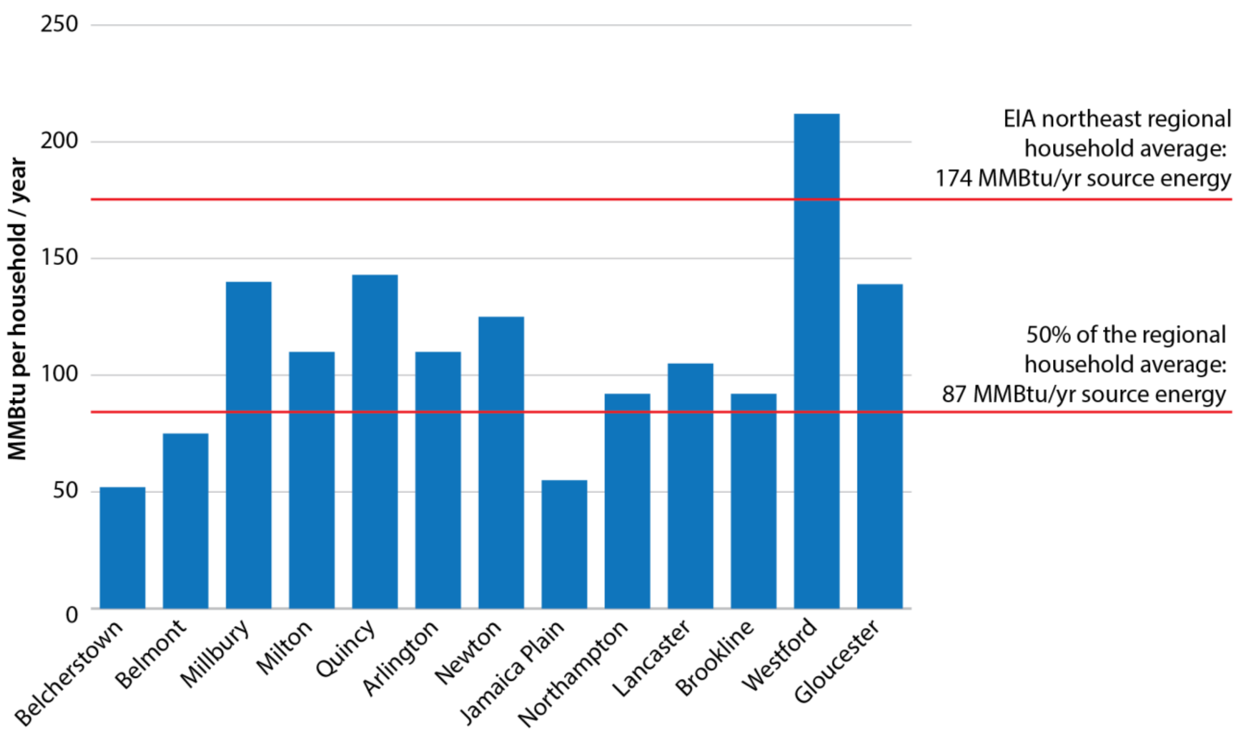


Figure A1. Post-retrofit energy use for 13 New England retrofits. *Source:* Recreated from Neuhauser 2012.

Of the 13 homes included in the evaluation, 8 homes succeeded in reducing overall measured energy consumption by 50% or more (figure A2).

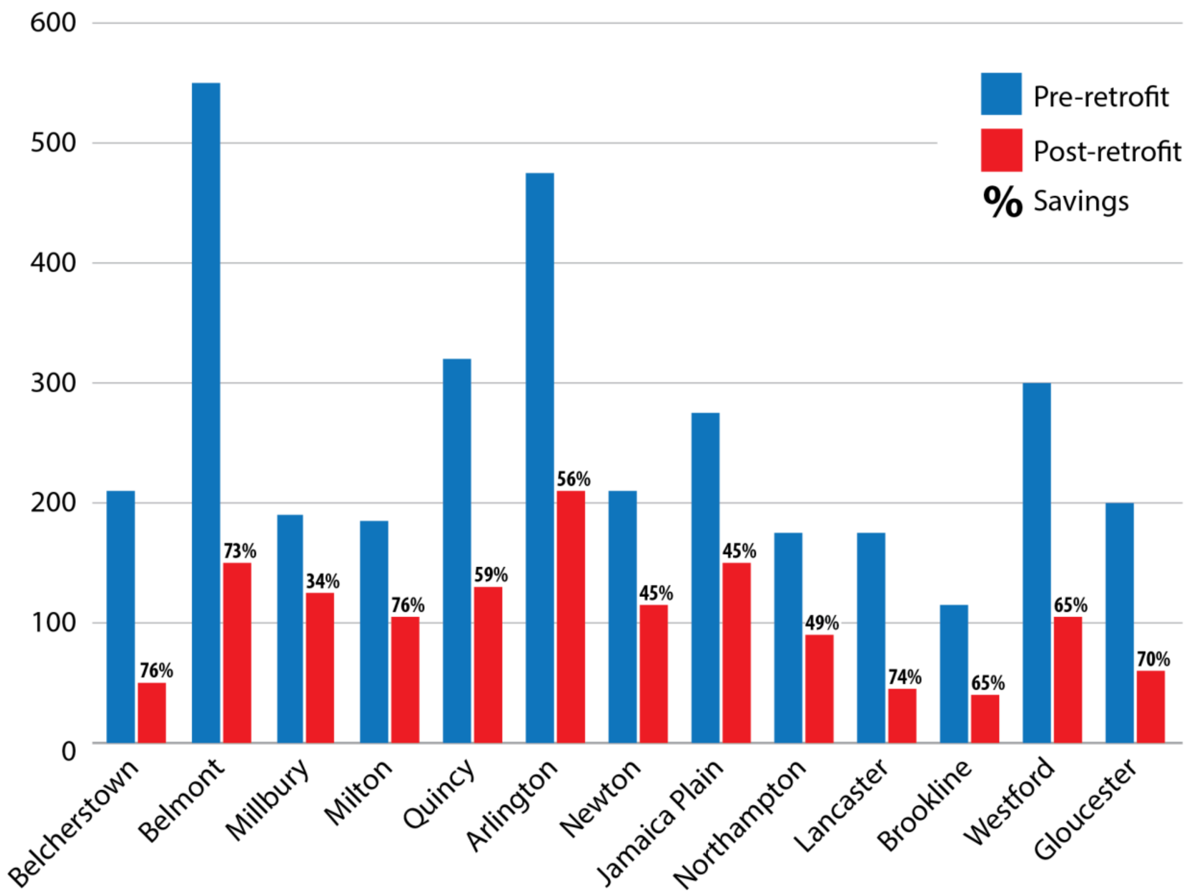


Figure A2. Energy savings in MMBtu in National Grid pilot program homes. *Source:* Recreated from Neuhauser 2012.

Air leakage reduction was also explicitly incentivized through the pilot. The air infiltration target was set at 0.1 $CFM_{50}$/sq. ft. of thermal enclosure surface area (all 6 sides of the house), which corresponds to 1.2 to 1.7 $ACH_{50}$ for the pilot homes evaluated. Nine of 13 of the homes evaluated reduced air infiltration to 1.7 $ACH_{50}$ or lower (figure A3).

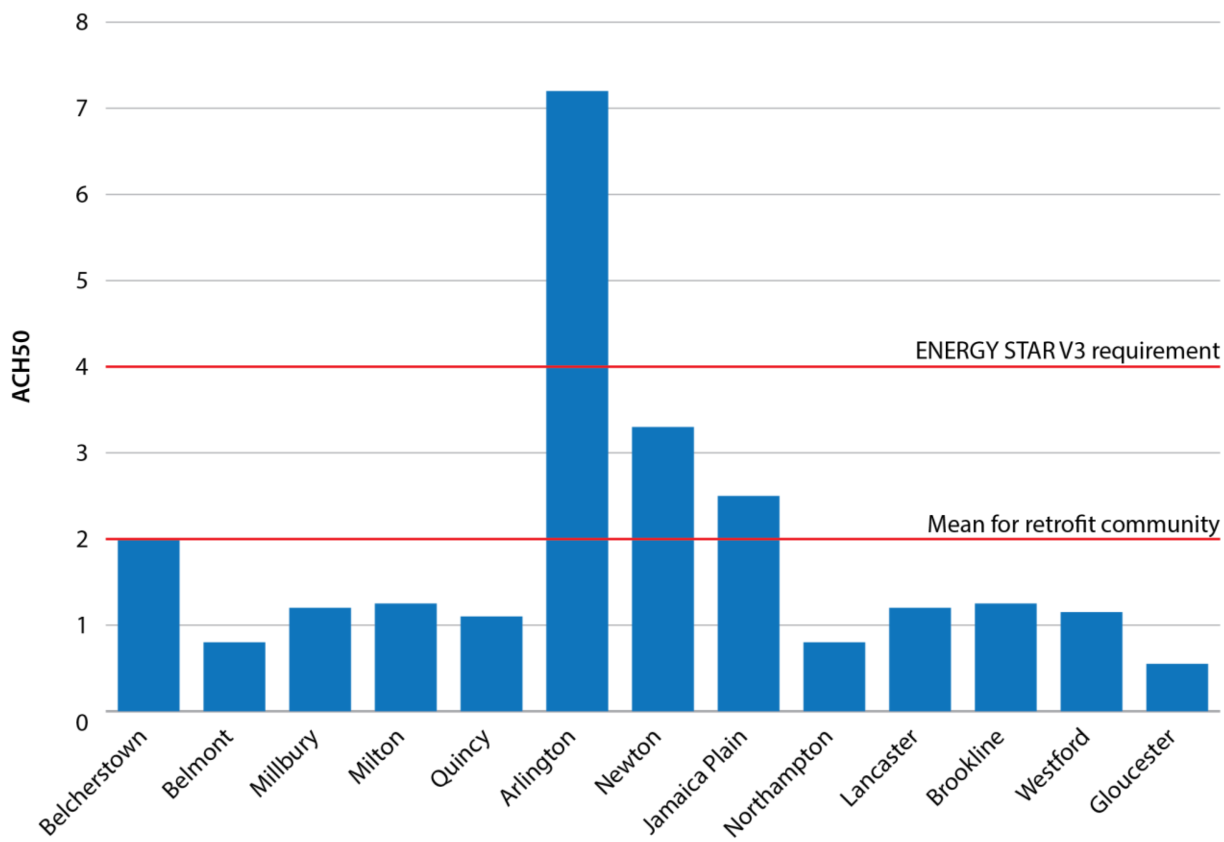


Figure A3. Air changes per hour at a pressure of 50 Pascals (ACH50) in 13 New England retrofits. *Source:* Recreated from Neuhauser 2012.

Arlington, the outlier, was a duplex home where it was challenging to (1) create an optimal air barrier between each unit, and (2) create a satisfactory air barrier between the first floor unit and the unconditioned basement. These factors led to a significantly higher $ACH_{50}$ than for the other homes evaluated. In Newton, the other home with higher than average air leakage, air sealing was hindered by the sequencing of airflow control layer (house wrap) and exterior insulation. The exterior insulation was installed before the existing windows were removed. This made it hard to transition the airflow control layer to provide connection with newly installed windows. Air sealing was also limited by not sealing the airflow control layer to the base of the wall before installing the insulation (Neuhauser 2012).

Drawing from the results of the pilot, National Grid sponsored the development of a detailed, measure-by-measure *Mass Save Deep Energy Retrofit Builder Guide* by Building Science Corporation that has been distributed to builders involved in the current National Grid Deep Energy Retrofit program (NEC 2012). The guide is also publically available. It is used in the full-scale program as a manual of building and installation techniques that are eligible for incentives, and as a basis for developing project scopes. It is designed to provide much of the guidance that was delivered through on-site technical assistance in the pilot. It is part of the effort to reduce spending on technical assistance in the program in comparison to the pilot.

The pilot was designed to scale up to a full scale utility-sponsored efficiency program, and, as intended, National Grid began offering rebates for deep energy retrofit projects to all homes in National Grid electric and/or gas territories in Rhode Island and Massachusetts in 2013 as a part of their suite of energy efficiency utility offerings. Data from homes retrofitted in the pilot homes helped shape the program structure and incentives available in the 2013 program.

### *UTILITY EVALUATION OF DEEP ENERGY RETROFIT PILOTS*

Separate evaluation reports are available from the National Grid affiliates in Rhode Island and Massachusetts, both of which carried out deep energy retrofit pilot programs.

#### Rhode Island

A 2011 energy efficiency evaluation for Rhode Island provides information on the deep energy retrofit pilot spending and activities carried out (table A1).

**Table A1. Rhode Island 2011 natural gas and electric energy efficiency evaluation**

| | Year 1 (2011) | Year 2 (2012) | Overall |
|---|---|---|---|
| Spending | $27,848 | $297,152 | $260,000 |
| Activities | Full day workshop and recruiting of single-family and multifamily owners, builders, developers, and architects. Two projects began in 2011: a two-family residence, and a three-family residence. | Construction was completed in 2012. Two additional projects were under review at end of 2012 for a three-family and single-family building. | |

*Source:* NEC 2013

The evaluation concludes that components of the deep energy retrofit program were cost effective under the state's least-cost procurement benefit-cost tests, which are requirements exclusive to Rhode Island.[19] The utility received Public Utility Commission (PUC) approval to begin offering roof, exterior wall, and basement deep energy retrofit measures in 2013. The program targeted upgrades at the time of other renovations. Even though they were for existing homes, the measures were made part of the Residential New Construction Program, a portfolio designed to address and incentivize building construction and building energy codes (NEC 2013). This program exists within National Grid's electric and gas efficiency program plans and includes residential new construction incentives, renovation/rehabilitation incentives, and energy code technical support.

[19] Rhode Island's least-cost procurement is part of a state law that requires National Grid to invest in all cost-effective energy efficiency that is less expensive than supply (Anthony and Ferguson 2012).

## Massachusetts

The Massachusetts National Grid energy efficiency evaluations for 2011 yielded the results detailed in tables A2 and A3. The deep energy retrofit pilot yielded both electric and natural gas savings. Electric and natural gas savings were evaluated through two separate reports because project funding came from natural gas and electric budgets.[20] Overall, the program yielded fewer participants in 2011 than planned: a total of 10, with program costs per participant being 150% higher than initially expected. The average time to completion for each project proved to be longer than expected in 2011, which was cited as a contributing factor to lower-than-expected participation levels.

**Table A2. 2011 gas energy efficiency report**

| | Planned value | Actual value | Percent change from planned |
|---|---|---|---|
| Program cost | $864,416 | $559,970 | - 35% |
| Number of participants | 27 | 7 | - 74% |
| Program cost/participant | $32,015 | $79,996 | + 150% |

*Source:* National Grid 2012a

**Table A3. 2011 electric energy efficiency annual report**

| | Planned value | Actual value | Percent change from planned |
|---|---|---|---|
| Program costs | $827,107 | $415,042 | - 50% |
| Number of participants | 20 | 5 | - 75% |
| Program cost/participant | $41,355 | $83,008 | + 101% |

*Source:* National Grid 2012b

In 2012, the number of participants was much closer to the planned value of 20, with 17 participants. As a result, program cost per participant was closer to planned than in Year 1 (table A4). The planned program cost per participant was set higher in 2012, and the actual cost was 20% lower than expected. New projects for 2012 stopped being accepted in March 2012 so that all projects could be completed by the end of the pilot in December 2012. This cutoff date was a result of the lengthy timeline of the 2011 projects. With this strategy in place, more than two-thirds of the projects were completed in December 2012 (National Grid 2013d).

[20] Both natural gas and electric budgets feed into the DER program budget. Natural gas and electric program evaluations are separate; for evaluations, National Grid estimates how many participants will have gas heating (and therefore fall under the natural gas budget) or non-gas heating (and therefore will fall under the electric budget). In the 2011 evaluation, there were a total of 10 DER projects. When counting participants, there were two projects that had both gas and electric heating, so the projects were counted twice, once in the electric report, and once in the natural gas report (N. Corsetti, Residential Building Strategy Analyst, National Grid, pers. comm., January 22, 2014).

**Table A4. 2012 Massachusetts electric energy efficiency annual report**

| | Planned value | Actual value | Percent change from planned |
|---|---|---|---|
| Total program costs | $1,316,834 | $899,161 | - 32% |
| Number of participants | 20 | 17 | - 15% |
| Program cost/participant | $65,842 | $52,892 | - 20% |

*Source:* National Grid 2013d

Table A5 breaks down the budget by program element. It is likely that spending on marketing and advertising and on participant incentives was lower than expected because applications were not accepted past March 2013. Conversely, the sales, technical assistance, and training spending was higher than expected, at 33%, a result of the extensive technical assistance provided.

**Table A5. Deep energy retrofit budget for 2012 (electric energy efficiency annual report)**

| | Program planning and administration | Marketing and advertising | Participant incentive | Sales, technical assistance, and training | Evaluation and market research | Total program costs |
|---|---|---|---|---|---|---|
| Planned 2012 budget | $48,563 (4%) | $24,985 (2%) | $1,011,732 (76%) | $228,155 (17%) | $3,398 (<1%) | $1,316,834 |
| Actual 2012 budget | $7,165 (<1%) | $2,997(<1%) | $576,373 (64%) | $304,778 (33%) | $7,848 (<1%) | $899,161 |
| % change | - 85% | - 88% | - 43% | + 34% | + 131% | - 32% |

*Source:* National Grid 2013d