Evaluation of Early Performance Results for Massachusetts Homes in the National Grid Pilot Deep Energy Retrofit Program

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Ken Neuhauser and Cathy Gates

Abstract:

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

BUILDING TECHNOLOGIES OFFICE

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Building AMERICA
U.S. Department of Energy

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Definitions

AC	Air conditioner
ACH	Air changes per hour
ACH50	Air changes per hour at 50 Pascal test pressure
AHU	Air handling unit
ASHP	Air source heat pump
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BA	Building America Program.
BSC	Building Science Corporation
Btu	British thermal unit
CARB	Consortium for Advanced Residential Buildings
CDD	Cooling degree day
CFM	Cubic feet per minute
CFM50	Cubic feet per minute at 50 Pascal test pressure
DER	Deep energy retrofit
EIA	Energy Information Administration
ERV	Energy recovery ventilator
ft^2	Square foot, square feet
HDD	Heating degree day
HRV	Heat recovery ventilator
HVAC	Heating, ventilation, and air conditioning
OSB	Oriented strand board
PARR	Partnership for Advanced Residential Retrofits
PV	Photovoltaic
RECS	Residential Energy Consumption Survey
RESNET	Residential Energy Services Network
SEER	Seasonal energy efficiency ratio
SPF	Spray polyurethane foam insulation
TMY3	Typical Meteorological Year 3

Executive Summary

With the increasing demand for energy-efficient solutions for the existing housing stock, it is important to have demonstrated evidence that measures being implemented will in fact benefit the homeowner through a combination of energy savings, improved durability, and occupant comfort. Many of the deep energy retrofit (DER) performance data currently available are in terms of individual cases, often of nontypical homes or circumstances, and for many of these there has been insufficient post-retrofit time to adequately assess the actual performance results. The purpose of this research project is to use actual performance results for a diverse community of cold-climate retrofits to assess the effectiveness of a specific package of DER measures. Through the performance analysis of a group of post-retrofit homes, all of which have implemented the same DER measures and all of which have provided post-retrofit performance data for the same time period, a realistic range of post-retrofit performance results is demonstrated. By analyzing the post-retrofit data at the community level, the emphasis is shifted from the post-retrofit performance for the individual case to the post-retrofit performance achievable by using the DER measures package. Trends also begin to emerge about strategies that result in the best performance and how to make reasonable cost projections for a DER.

In 2009, National Grid started a DER pilot program that offered technical support and financial incentives to qualified Massachusetts homeowners who planned and successfully completed a retrofit that incorporated the performance requirements and goals of the National Grid DER measures package. This DER measures package, developed through collaboration with Building Science Corporation (BSC), includes specific thermal and airtightness goals for the enclosure components as well as health, safety, durability, and indoor air quality requirements. By providing measures that can be included with common renovation activities such as roof replacement, window replacement, re-siding, basement remediation, and remodeling, this DER measures package is expected to have widespread application for existing homes in the New England area. The post-retrofit performance and cost ranges provided by this research project can provide concrete input for homeowners who are considering a DER.

In this project, the post-retrofit results for 13 existing homes from the DER Pilot program were analyzed. Ten of these homes are single-family homes; two are two-family homes, and one is a three-family home. The information available for each home that was used in this analysis included pre- and post-retrofit blower door test results, a project description, reason for doing the project, and project cost information; and actual post-retrofit energy use information provided by the utility companies. The post-retrofit energy use for this project was for the 12-month period from August 2011 through July 2012 and for the 6-month period from January 2012 through July 2012.

The pre-retrofit energy use information available for the homes differed because in some cases, the home had been recently purchased but in other cases, the homeowner had been living in the home for many years. Where actual pre-retrofit energy use was not available, energy modeling using BEopt v1.3 was used to estimate the pre-retrofit energy use. The reduction of source energy use from the pre-retrofit homes to the post-retrofit ranged from 27%–75%. Well-maintained homes with the same owner for the pre- and post-retrofit and for which the DER was not combined with other major renovations ranged from 30%–45%.

Total post-retrofit source energy use for the retrofits for the 12-month period ranged from 52–217 MMBtu/yr and from 27–69 kBtu/ft^2-yr. When normalized to account for weather conditions and divided by the number of households, all of these were below the Energy Information Administration Northeast average total source energy use per household of 174 MMBtu/yr of source energy and more than half were below 70% of that average total. Similarly, all but one retrofit were below the Northeast average of 67.5 total source kBtu/ft^2-yr per home and many were below 50% of that average. Heating is the largest energy load in a cold climate and is most impacted by these DER measures. For the post-retrofit 12-month period, the actual source energy use for heating and cooling ranged from 8.5–27 kBtu/ft^2-yr.

The airtightness component in the DER package emphasized the need to identify the air control layer for each component of the enclosure and to plan continuous transitions between components. Using this approach nearly all of the homes were able to reach a post-retrofit airtightness result of 1.5 ACH50. The worst airtightness results occurred for the one home that did not include the basement in the conditioned space.

As a group, the homes that used the “chainsaw” retrofit technique along with the air control layer, roof insulation, and wall insulation applied to the exterior had the best airtightness results and the lowest heating and cooling source energy use results. “Chainsaw” refers to a retrofit technique used at the intersection of the roof and wall whereby the existing rafter tails and rake overhangs are cut off and new overhangs are attached over the insulation at completion.

Projects included in this study implemented enclosure retrofit packages at an average cost of \$18.62/ft^2 of building enclosure. The unit cost for enclosure packages range from \$9.99–\$26.87/ft^2 of building enclosure. For energy-related enclosure measures, the average unit cost is \$13.13ft^2 and the range is from \$8.62–\$22.20/ft^2.

Total HVAC system costs ranged from slightly more than $10,000 to just less than $19,000 for projects that met the pilot program target by installing high efficiency heating and cooling equipment and distributed ventilation with heat or energy recovery. Some projects replaced only certain components of the heating, ventilation, and air conditioning (HVAC) systems as part of the DER project. For other projects, HVAC measures were limited to adding mechanical ventilation. The projects that installed new high efficiency heating equipment, cooling equipment, and distributed ventilation with heat or energy recovery report costs for combined HVAC measures ranging from just more than $10,000 to approximately $39,500.

Analysis of energy-related measure costs and project objectives resulted in a categorization of measures as follows: (1) measures pursued primarily for energy-related objectives; (2) measures pursued for a combination of energy-related and nonenergy-related objectives; and (3) measures pursued primarily in response to nonenergy-related objectives. On average for the projects in this study about half of the energy-related measure costs are assigned solely to energy-related objectives, and 20% of energy-related measure costs are assigned primarily to nonenergy-related objectives.

1 Introduction

Home retrofits have been targeted as an area of great potential for significant energy savings, employment opportunities, and market growth. However, the barriers to widespread adoption of comprehensive retrofit strategies remain high. Two such barriers are the lack of clear evidence that there is a substantial benefit to the average homeowner and perceptions relative to the high cost of a comprehensive energy retrofit. What is missing is evidence from a substantial sample of typical houses and homeowners demonstrating the benefits and indicating costs.

In this project, reported cost and measured performance data have been evaluated to assess the retrofit cost and the post-retrofit airtightness and energy use for a group of houses in Massachusetts which participated in a deep energy retrofit (DER) pilot program sponsored and administered by National Grid (National Grid 2011). By providing financial incentives and technical support to the participating projects, the National Grid DER Pilot program created an opportunity for a broad range of homeowners to undertake a DER project.

As participants in the DER pilot program, these retrofit projects all used the same set of retrofit targets, taken here as a “package of measures” for the measures to be implemented. This report assesses the effectiveness of the overall package of measures as well as the relationship between different implementation strategies used and measures of performance. This is accomplished by analyzing the full set of performance data for the group rather than looking at individual case studies, as has been done in past studies. This approach results in post-retrofit energy use and cost ranges based on the total community data that can be reasonably expected from use of the DER package. This is concrete evidence that can be used by homeowners to assess the potential benefit and cost of a DER.

The post-retrofit analysis of a community of retrofits in this research project is unique in that it incorporates all of the following: the community consists of a diverse group of New England home types as well as differing homeowner lifestyles and values, the DER package is comprehensive and advanced, the analysis is based on actual rather than modeled post-retrofit data and all energy use data are for the same time period, and the analysis is applied to the full community rather than to the individual cases.

The current research project shows that source energy savings from pre-retrofit to post-retrofit conditions ranging from 27%–75% can be achieved. But perhaps more importantly, it demonstrates that the DER retrofits can meet energy performance goals and benchmarks that apply to new home construction.

Using this community of retrofits, the following research questions are addressed:

- Does the DER measures package result in at least 30% actual source energy use reduction from the pre-retrofit conditions? A 30% reduction is the Building America (BA) program 2012 goal for existing homes in cold climates.
- Are there discernible differences in energy use between the variations allowed within the DER measures package?
- What post-retrofit airtightness has been achieved by the DER measures package?

- Are there discernible differences in air leakage results between the variations allowed within the DER measures package?
- What are the costs of the DER measures package?
- Can the net cost of energy performance improvement be separated from the full DER measures package cost?

2 Background

DERs are beginning to be less unusual. It used to be that each time a DER was done, it would show up in a magazine article (for example, Pettit 2008; Joyce 2009). Unfortunately, it is still the case that much of this work is looked upon as experimental. Because of this, it has not been easy to measure the benefits except on a case-by-case basis, or to make the case that the measures needed for an effective retrofit are readily accessible to the average homeowner, since most homeowners are not comfortable experimenting on their houses.

The BA program has been working to overcome these two obstacles. There are several other BA groups doing research to evaluate the performance effectiveness of cold climate home retrofit approaches at the community scale. Among these are the Consortium for Advanced Residential Buildings' (CARB) role in the Retrofit NYC Block by Block project (Eisenberg et al. 2012) and in the recently completed retrofit of the Chamberlain Heights duplex and quad affordable housing complex (Donnelly and Mahle 2012) as well as the Partnership for Advanced Residential Retrofits (PARR) team's work in the Chicagoland project development of energy efficiency retrofit packages for typical houses in the Chicago area (Spanier et al. 2012).

These research projects have the potential to provide a significant set of post-retrofit performance data using utility bills and other testing to evaluate the energy use level achieved and achievable by fairly comprehensive retrofit measures packages. However, the current reports have only limited results available, if any, and thus results are presented in terms of prediction models rather than actual performance data. In this current research project, BSC is making use of a year of post-retrofit utility bills and performance data for retrofit projects and uses this actual performance information to evaluate achievable performance levels for the DER retrofit measure package. The projects evaluated in this current report represent fewer than one third of the total number of National Grid DER Pilot projects for which similar post-retrofit data will soon be available. However, this evaluation of the early projects is deemed important to both establish methodologies of evaluation and to begin to meet the need for measured performance data. In subsequent a research effort already underway, the performance results for the full set of National Grid DER Pilot projects will be evaluated.

The CARB and PARR research projects adopt the approach that the retrofit measures packages be tailored for particular house types—e.g., ranch house, NYC row house, triple-decker. BSC has found that each retrofit project has its own set of unique constraints that are based not so much on house type and age as its history and existing conditions. Therefore, tailoring retrofit measure packages to specific house types may not be necessary. In the results described in the current report, a single DER retrofit measures package has been applied to a variety of housing types, as well as significantly different ages and existing conditions. The evaluation of post-retrofit performance suggests that the post-retrofit performance is impacted more by the specific implementation methods selected for measures package than by the house characteristics.

Other previous work related to high performance retrofit has focused on individual components or measures. For example, in one recent BA project, BSC worked with a weatherization program to evaluate and develop plans for inclusion of roof or attic insulation in the weatherization program (Neuhauser 2012). The current study evaluates the impact of a comprehensive measures package.

BSC has also worked on several projects using individual retrofits from the National Grid DER pilot program. In one project, BSC performed a case by case evaluation of the implementation of the DER measures for five of the DER pilot program participants (Neuhauser 2011). In a second project, BSC looked at the pre- and post-retrofit performance data for seven DER projects, four of which were early participants in the DER pilot program (Osser et al. 2012).

All of these earlier research projects dealt with the individual projects—either in terms of how the DER measures were implemented or the post-retrofit performance that they achieved individually. None of them compared and analyzed the performance data as a group. Now that additional projects have been completed in the National Grid DER pilot program, there are enough data available to warrant the analysis of all of these projects as a community of retrofits rather than as individual cases. The number of completed projects is large enough that the impact of the retrofit measures as a package can be analyzed and trends from the available data about these projects begin to emerge. Using this approach, the emphasis is shifted from the post-retrofit performance for the individual case to the post-retrofit performance achievable by using the DER package. On the other hand, the number of houses involved is not so large that the results of the analysis are limited to statistical assessments. So when a particular project falls out of the performance range for the majority of the community, the details for that project can be further analyzed to explain the discrepancy.

3 The National Grid Deep Energy Retrofit Pilot

3.1 Measures and Targets

The National Grid DER pilot program was established in 2009. The DER homes included in this report are all of those that successfully completed the National Grid DER pilot program and were occupied by January 2012. Participants in the DER pilot program are required to meet health, safety, and indoor air quality guidelines; specific thermal targets for each enclosure component (e.g., roof, above-grade walls); an overall airtightness target; minimum efficiency of mechanical equipment; water management; and durability requirements. While there are not specific instructions for how these targets are to be met, all implementation plans are reviewed for sound building science before the project is accepted into the pilot program and field verification of each completed measure is required in order to receive the financial incentives. In addition, all project teams are to include a qualified contractor or design consultant with previous DER experience and approval by National Grid.

Implementation of a DER will change the overall dynamics of the existing building systems. The overall measures, shown in Table 1, include some essential prerequisites put in place to address possible ramifications of those changes.

Table 1. Overall Measures and Targets or Requirements for National Grid DER Pilot Retrofit

Measure	Target or Requirement for Measure	Comments
Combustion Safety	**Requirement**: No atmospherically vented combustion appliances or fireplaces	Use direct vent, closed combustion, or power-vented mechanical equipment
Indoor Air Quality	**Requirement**: Meet ASHRAE 62.2 ventilation requirements	Provide background ventilation system with easily accessible controls that allow residents to operate the system at a lower rate as well as to temporarily boost to a higher rate.
Durability	**Requirement**: Vapor and water management control of the enclosure	Use appropriate flashings including step and kickout flashings and integrate flashings effectively into the water control layer Ensure that vapor control methods do not trap moisture within building components
Air Infiltration	**Target**: CFM50 ≤ 0.10 * total 6-side enclosure surface area	Identify the air control layer for each enclosure component and how the layer is transitioned between components
Appliances and Lighting	**Target**: ENERGY STAR® appliances; 90% of lighting to be compact fluorescent or better	

The enclosure targets, shown in Table 2, are given for each enclosure component and are in terms of the installed R-value.

Table 2. Enclosure Insulation Measures and Targets for National Grid DER Pilot Retrofit

Measure	Target for Measure	Comments
Roof	R-60+	This is for an unvented attic
Attic	R-60+	This is for a vented attic
Above-Grade Exterior Walls	R-40+	
Insulated Foundation Walls	R-20+	
Insulated Basement Floor	R-10+	
Basement Ceiling	R-30+	This applies only if the basement is not insulated
Floor Over Unheated Garage or Overhang	R-40+	
Windows and Doors	R-5+	

This set of enclosure measures allows the project to choose between a vented or unvented attic and between insulated basement walls or an insulated basement ceiling. In addition, some projects were unable to provide insulation to the basement floor because of head height or structural constraints. This type of flexibility in the measures is necessary when working with retrofits because the existing conditions may preclude certain approaches.

The heating, ventilation, and air conditioning (HVAC) measures are shown in Table 3.

Table 3. HVAC Measures and Targets for National Grid DER Pilot Retrofit

Measure	Target for Measure	Comments
Mechanical Ventilation	Heat recovery, balanced, distributed	HRV[a], ERV[b], exhaust only, or supply only are acceptable provided ASHRAE 62.2 is met and there is a means of distribution; mechanicals and ductwork to be within the thermal enclosure.
Heating Equipment	High efficiency heating	Furnace, condensing boiler, GSHPs[c] or ASHPs[d]; AFUE[e] 95+%, heating season performance factor 8.2+ equipment rating with configuration or operating sequences to allow efficient operation; mechanicals and ductwork to be within the thermal enclosure.
Cooling Equipment	16 SEER[f],13 EER[g] cooling	Cooling is not required; mechanicals and ductwork, if any, to be within the thermal enclosure.

[a] Heat recovery ventilator
[b] Energy recovery ventilator
[c] Ground source heat pump
[d] Air source heat pump
[e] Annual fuel utilization efficiency
[f] Seasonal energy efficiency ratio
[g] Energy efficiency ratio in Btu of cooling per Watt of electricity

3.2 The Community of Retrofits

This report examines the airtightness, energy use, and construction costs of 13 of the homes, all of which were participants in the National Grid DER pilot program. Therefore, all of the retrofits used the same DER measures package and targets in their planning; had plans reviewed for sound building science and for durability, combustion safety, and air quality; and received site verification of the implementation of the DER measures package.

Table 4 provides some basic information about each retrofit, including the three enclosure components for which different implementation approaches were taken—roof and attic, above-grade walls, and basement. Before and after photographs and specific information about each project are provided in the appendices. There is also additional information provided in Section 4.1, Section 4.2, and Section 4.3.

In the "Roof/Attic Measure" column of Table 4, some DER projects are identified as using the "chainsaw" technique. This refers to a retrofit technique used at the intersection of the roof and exterior wall whereby the existing rafter tails and rake overhangs are cut off during the retrofit and new overhangs are built and attached at completion. This approach is often used in a DER when exterior insulation is to be applied to both the roof and the wall, since it allows a continuous layer of insulation to be applied across the intersection, thus reducing thermal bridging. It also simplifies the air control connection between the roof and the wall when the air control layers for both the roof and the wall are on the outside of the existing sheathing, since the intersection becomes a simple edge condition (see Figure 1).

In the "Above-Grade Walls Measure" column of Table 4, there is a note "porch/deck not detached" for some of the projects. When exterior insulating sheathing is used on the above-grade walls for a DER, it is recommended that any porches or decks that are attached to the above-grade wall be temporarily detached during the retrofit so that the air control layer and the insulation can be extended continuously between the porch or deck and the wall. This note indicates that the project did not use this approach.

Table 4. Community of DERs

House Location; Year Built	Post-Retrofit Square Feet of Conditioned Space	Roof/Attic Measure (Installed R-Value)	Above-Grade Walls Measure (Installed R-Value)	Basement Measure	HVAC Measures
Belchertown; Built in 1760	1,907	Insulated below roof deck only (R-56)	Double wall with interior insulation (R-32)	Foundation walls and floor slab insulated	HRV; propane furnace; no air cooling
Belmont (2 Units); Built in 1925	4,768	Exterior and below roof deck insulation (R-63), chainsaw	Exterior and cavity insulation (R-40)	Foundation walls insulated	HRV for each unit; gas furnace; AC[a] coil and outdoor condenser for each unit
Millbury; Built in 1953	1,868	Exterior and below roof deck insulation (R-51), chainsaw	Exterior and cavity insulation (R-37)	Foundation walls and floor slab insulated	ASHP with two AHUs[b] and outdoor supply air; direct vented wood pellet stove as heating backup
Milton; built in 1960	2,368	Insulated below roof deck only (R-56)	Exterior and cavity insulation (R-38)	Foundation walls and floor slab insulated	HRV; hydro air with gas boiler; central air cooling
Quincy; Built in 1905	4,576	Exterior and below roof deck insulation (R-62), chainsaw	Exterior and cavity insulation (R-38)	Foundation walls and floor slab insulated	HRV; hydro air with gas boiler; ASHP for cooling
Arlington (2 Units); Built in 1910	3,627	Insulated below roof deck only (R-58)	Exterior and cavity insulation (R-38); porch/deck not detached	Basement ceiling insulated	HRV for each unit; condensing gas furnace for each unit; AC coil for upper unit
Newton; Built in 1930	2,199	Exterior and Below roof deck insulation (R-56), chainsaw	Exterior and cavity insulation (R-39); porch/deck not detached	Foundation walls and floor slab insulated	ERV; condensing gas boiler; ASHP for cooling

House Location; Year Built	Post-Retrofit Square Feet of Conditioned Space	Roof/Attic Measure (Installed R-Value)	Above-Grade Walls Measure (Installed R-Value)	Basement Measure	HVAC Measures
Jamaica Plain (3 Units); Built in 1907	3,885	Vented attic with attic floor insulation (R-60)	Exterior and cavity insulation (R-40); 3rd floor dormer walls not treated	Foundation walls and floor slab insulated	HRV for each unit; condensing gas boiler; removable window air conditioners
Northampton; Built in 1859	2,747	Exterior and below roof deck insulation (R-60), chainsaw	Exterior and cavity insulation (R-39)	Foundation walls and floor slab insulated	ERV; GSHP, ASHP for upper floor office.
Lancaster; Built in 1900	1,440	Vented attic with attic floor insulation (R-65)	Exterior and cavity insulation (R-44)	Foundation walls and floor slab insulated	ERV; two ASHPs
Brookline; Built in 1899	3,174	Insulated below roof deck only as part of an earlier project (R-48)	Exterior and cavity insulation (R-40)	Foundation walls insulated as part of an earlier project	HRV; condensing gas boiler; no air cooling
Westford; Built in 1993	3,955	Insulated below roof deck only (R-62)	Exterior and cavity insulation (R-39)	Foundation walls insulated	ERV; gas furnace; AC coil and outdoor condenser
Gloucester; Built in 1920	2,424	Exterior and below roof deck insulation (R-67), chainsaw	Exterior and cavity insulation (R-38)	Foundation walls and floor slab insulated	HRV; two ASHPs with backup electric resistance heat

[a] Air conditioner
[b] Air handling unit

Some of the variations in the implementation of the measures that are apparent from information in the table above are as follows:

- Variation in above-grade wall treatment:
    - One project used interior insulation only (a new stud wall was built around the interior perimeter to create a deeper cavity for insulation).
    - Twelve projects applied insulation to the exterior of the existing walls.
- Variation in roof and attic treatment:
    - Two projects used a vented attic with insulation on the attic floor.
    - Five projects created an unvented attic with all of the required insulation below the existing roof sheathing.
    - Six projects created an unvented attic using insulation applied over the existing roof sheathing—all of these projects used the chainsaw technique.
- Variation in basement treatment:
    - One project insulated the basement ceiling rather than the basement walls.
    - Three projects insulated the basement walls but did not insulate the basement floor.
    - Nine projects insulated the basement walls and the basement floor.

As participants in the DER pilot program, all of these DER projects provided data in the application forms, had pre- and post-retrofit blower door testing performed, and are providing energy use information for at least the first two years following completion of the DER. Data from the application form include facts about the house, information about the existing conditions, past energy use, performance concerns, existing R-values, as well as description of plans for implementing the measures and projected costs. This, together with on-site verification of the DER project measures, provided a consistent set of data about each retrofit used for analysis in this research project.

4 Analysis

This analysis section contains five major subsections of analysis: airtightness, energy use, DER costs, relationship between cost and performance, and project objectives relative to energy-related costs.

4.1 Airtightness Results and Analysis

One requirement for the participants in the National Grid DER pilot program was to provide a plan for airtightness with a target of achieving 0.10 CFM/ft^2 of the building enclosure surface area (all six sides) at a 50 Pa air pressure differential. Toward meeting this goal, each participant was asked to identify the air control system for the house and a means for ensuring that it was continuous.

The air control system is a system of materials designed and constructed to control airflow between conditioned space and unconditioned space. It is the primary boundary that separates indoor (conditioned) air and outdoor (unconditioned) air. The air control system can be located anywhere in the building enclosure—at the exterior surface, the interior surface, or anywhere in between—but must be continuous over the entire enclosure, air impermeable, durable, and able to withstand forces acting on the building, both during and after construction (Lstiburek 2006).

The primary purpose of the air control system is to prevent energy loss through direct air exchange between the interior and exterior. Since this air exchange also includes air transported moisture, the air control system is also part of the vapor control system for the building. A typical solution for preventing this air exchange is to "air seal" by locating cracks or leaks and caulking or sealing them. For a DER, this approach is not sufficient. Instead, an air control layer needs to be established for each building component—e.g., house wrap, with seams taped and edges sealed, applied over the exterior wall sheathing can be the air control layer for the exterior walls. In addition, the means of transitioning this to the air control layer of adjacent components needs to be provided. For example, if the wall air control layer is the taped and sealed house wrap and the roof air control layer is fully-adhered roofing membrane over the roof sheathing, a continuous connection between these two materials needs to be established. This can be challenging, especially for a retrofit, and requires preplanning.

Table 5 summarizes information about the retrofit projects used in the analysis of airtightness. The last two columns of Table 5—"Chainsaw?" and "Use of SPF Insulation"—are specific implementation approaches that may impact airtightness. As described in Section 3.2, a chainsaw retrofit can simplify the transition of the roof air control layer to the wall air control layer (see Figure 1). The use of spray polyurethane foam insulation (SPF) is relevant for airtightness because it is an air barrier material and it creates an air seal with the adjacent material provided all of the installation conditions are met (see Figure 2). Either of these characteristics could be expected to improve the robustness of the air control system.

Table 5. Blower Door Test Results and Related Characteristics of Retrofits

House Location	Pre-Retrofit CFM50	Post-Retrofit CFM50	Post-Retrofit 6-Sided Surface Enclosure Area (Square Feet)	Post-Retrofit CFM50/ft^2 Enclosure Area (See Section 4.1.2)	Volume of Cond Space (Cubic Feet)	Post-Retrofit ACH50 (See Section 4.1.2)	Chainsaw?	Use of SPF Insulation (in *Italics* If Part of Air Control Layer)
Belchertown	9,097	468	4,066	0.12	14,972	1.88	No	*Under roof deck, in wall cavities, on foundation wall*
Belmont	5,700	590	9,093	0.06	47,706	0.74	Yes	*On foundation wall*
Millbury	2,860	402	4,278	0.09	17,000	1.42	Yes	Under roof deck
Milton	1,695	584	3,740	0.16	24,458	1.43	No	*Under roof deck, on foundation wall*
Quincy	5,050	762	6,806	0.11	36,346	1.26	Yes	Under roof deck, in wall cavities, *on foundation wall*
Arlington	8,730	3,586	5,925	0.61	29,648	7.26	No	*Under roof deck*, in wall cavities
Newton	3,199	1,299	4,337	0.30	21904	3.56	Yes	Under roof deck, *on foundation wall*
Jamaica Plain	7,729	1,802	7,456	0.24	42,586	2.54	No	*At sloped ceiling, on foundation wall*
Northampton	6,155	473	7,798	0.06	34,624	0.82	Yes	*On foundation wall*
Lancaster	4,254	293	3,222	0.09	12,336	1.43	No	*At attic floor*, in wall cavities, *on foundation wall*
Brookline	1,640	655	5,924	0.11	26,187	1.50	No	*Under roof deck, on foundation wall*
Westford	2,592	930	9,538	0.10	44,475	1.25	No	*Under roof deck*
Gloucester	2,258	235	6,493	0.04	23,285	0.61	Yes	–

Figure 1. Chainsaw retrofit with fully adhered roofing membrane and house wrap as the air control layers

(Photo by Tobias Richon with permission)

Figure 2. Spray foam insulation used for air control in rafter cavities (with cross strapping)

4.1.1 Airtightness Test Results

Blower door testing was performed prior to the beginning of construction and again after construction was completed for each of the retrofits described in this report. Table 5 contains the pre-retrofit and post-retrofit blower door test results for each of the houses.

All blower door testing was done with the house open to the air or thermal enclosure boundary. This means, for example, that if the attic is within the thermal enclosure, the attic hatch or door was left open during blower door testing. This testing setup matches the protocol for blower door testing established by the Residential Energy Services Network (RESNET) (RESNET 2009). In all cases, multipoint depressurization testing was performed and the results were normalized for 50 Pa pressure difference as compared with outside conditions.

While the pre-retrofit blower door test results are interesting, they are totally dependent on the state of the house before the retrofit. Many of the houses in this study were purchased at low prices because the houses were structurally sound but were not well maintained or were seriously out of date with respect to current energy standards and lifestyle requirements. Others were updated at this time because it was a convenient time (e.g., new empty nesters), the upgrade was included as part of larger project (such as building an addition), or for other personal reasons. Therefore, the most important information that analysis of the blower door test results for the full retrofit community provides is to demonstrate the range of air leakage results possible or probable for retrofits in general, and more specifically, achievable using the retrofit measures of the National Grid DER pilot program.

That said, Figure 3 and Figure 4 compare the pre-retrofit and post-retrofit blower door test results.

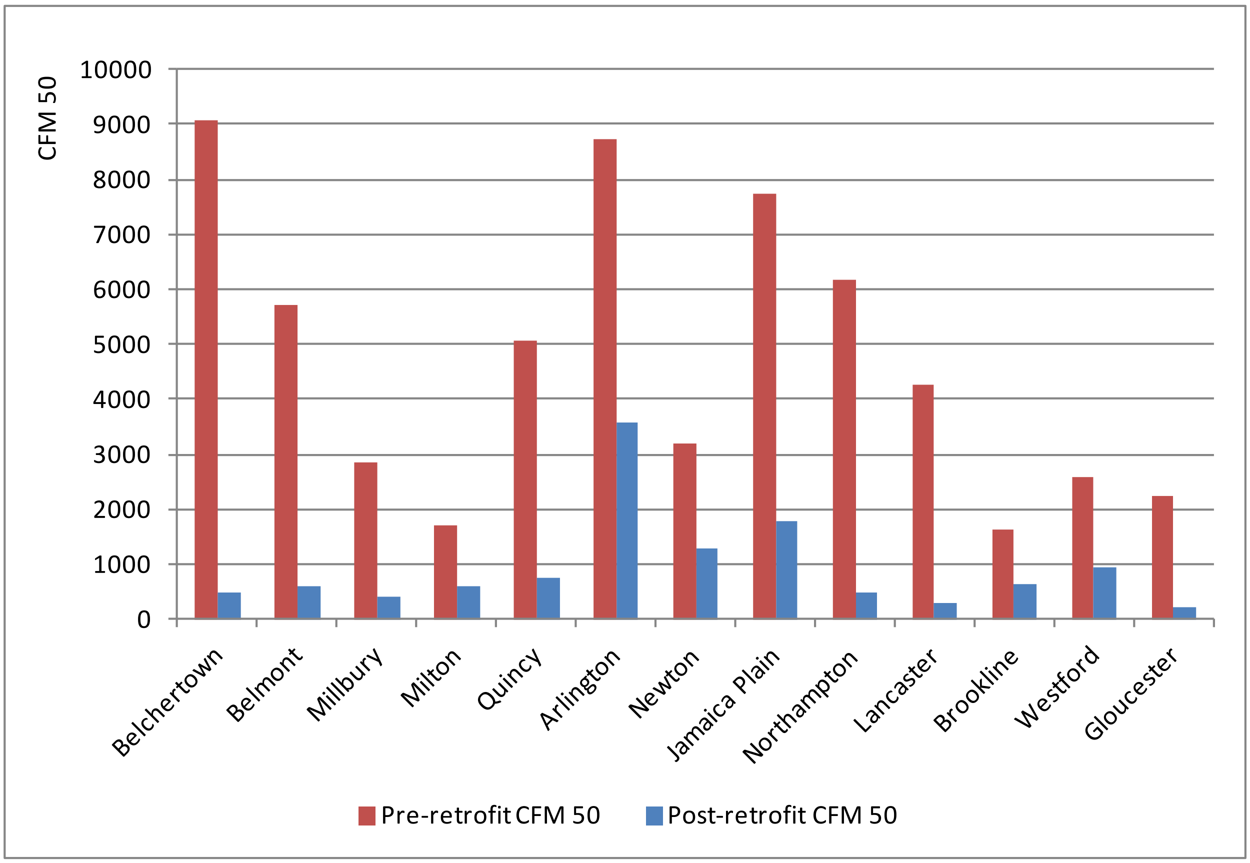


Figure 3. Pre and post-retrofit CFM50 for all projects

Figure 3 shows the pre and post-retrofit CFM50 results that were obtained from the blower door testing for each house. When this information is plotted on a graph with the post-retrofit values on the vertical axis and the pre-retrofit values on the horizontal axis as shown in Figure 4, all points that lie below the dashed line have a post-retrofit CFM50 value that is less than half of the pre-retrofit CFM50 value.

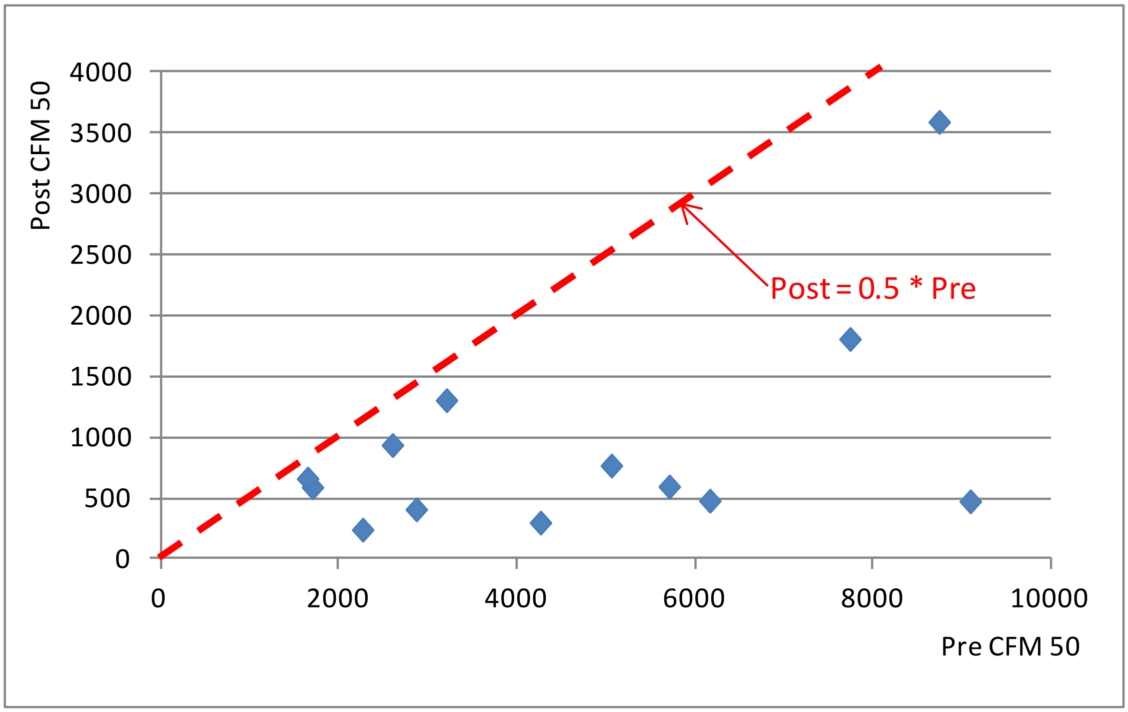


Figure 4. Post-retrofit CFM50 versus pre-retrofit CFM50

This shows that all of the retrofits, regardless of their initial condition, achieved at least a 50% reduction in total CFM50 air leakage.

4.1.2 Normalization of Airtightness Test Results

There are several different ways to report the results of the blower door test. The test itself results in a CFM50 result—cubic feet per minute of air that is required to be exhausted from (or supplied to) the interior of the house in order to maintain a 50 Pa pressure difference between the interior and exterior. This result is calculated using the airflow measured across the calibrated opening at the indicated pressure difference.

Since the sizes of the houses in this community vary significantly, a direct comparison of total CFM50 results between houses is not very meaningful. In this report, two different normalization metrics are used to make the test results more comparable: a metric in terms of surface area air leakage (CFM50/ft^2 enclosure area) and a metric in terms of air changes per hour (ACH50).

While these metrics are assumed to be standard, there are actually three factors that impact these metrics—the setup for the blower door test, the calculation of surface area of the building, and the calculation of volume for the building. Before comparing results using these metrics, it is important to check that these were computed in the same way.

The blower door test setup specifies what parts of the interior space are open during the testing procedure. For the testing in this report, all conditioned space (space within the air control boundary) was opened, regardless of whether it was considered living space or not. As mentioned earlier, this matches the testing protocol for RESNET.

To calculate surface area leakage at 50 Pa pressure difference, the total leakage airflow in CFM50 measured by the testing is divided by the enclosure surface area. In this report, the enclosure surface area calculation includes below grade and above grade surface area. The air leakage that occurs through below-grade surfaces is primarily in the form of soil gas; this leakage can have indoor air quality and health safety impacts so should not be ignored. It should be noted that this metric differs from the Minneapolis Leakage Ratio, which is the ratio between the total leakage at 50 Pa and the *above-grade* surface area.

The CFM50/ft^2 enclosure area metric is used for the National Grid Pilot DER target. This metric is also used in BSC's Building America airtightness testing requirements for high performance homes (BSC 2012). Figure 5 shows the CFM50/ft^2 enclosure area performance results for all of the retrofits. As shown, six of the 13 retrofits met the airtightness target which is 0.10 CFM50/ft^2 enclosure area, while three others came very close to meeting the target. All but two projects met BSC's BA airtightness requirement of 0.25, which is less stringent than the National Grid DER target. The CFM50/ft^2 enclosure area results range from 0.04 for the Gloucester retrofit to 0.61 for the Arlington retrofit, with most retrofits falling between 0.06 and 0.16.

The ACH50 metric is the most commonly used metric for reporting airtightness. The value of this metric depends on what is to be included when computing the volume of a building. In this report, volume is computed as the volume of the enclosure established by the air control layer. This is consistent with RESNET's use of ACH50.

Figure 5 and Figure 6 show the post-retrofit CFM50/ft^2 enclosure area and ACH50 results for all of the projects.

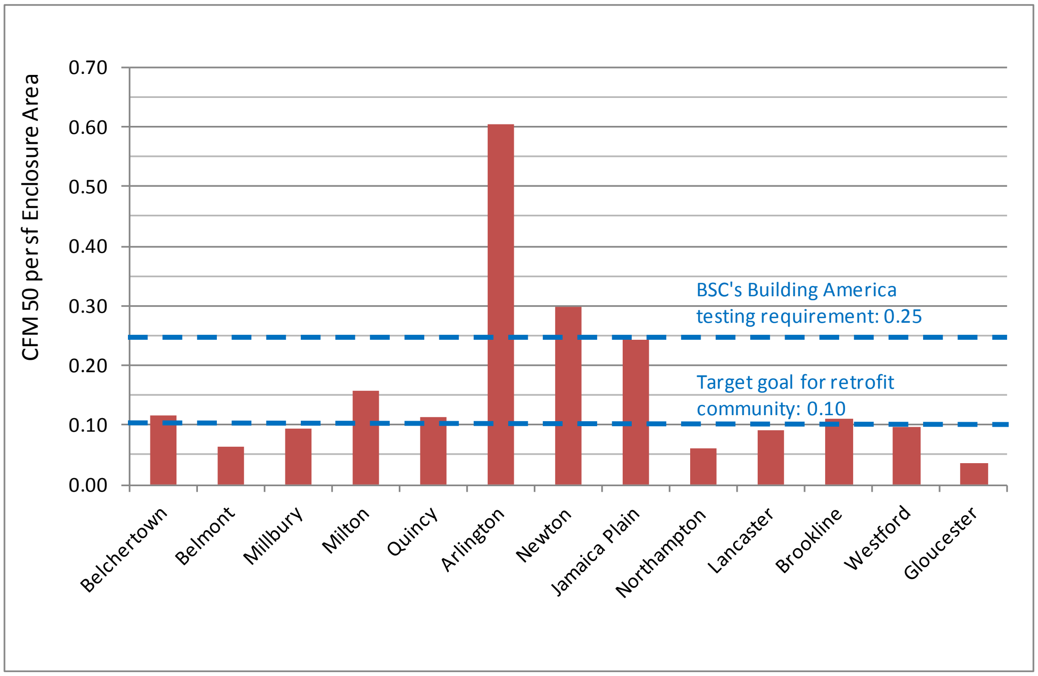


Figure 5. Post-retrofit CFM50/ft^2 enclosure area results

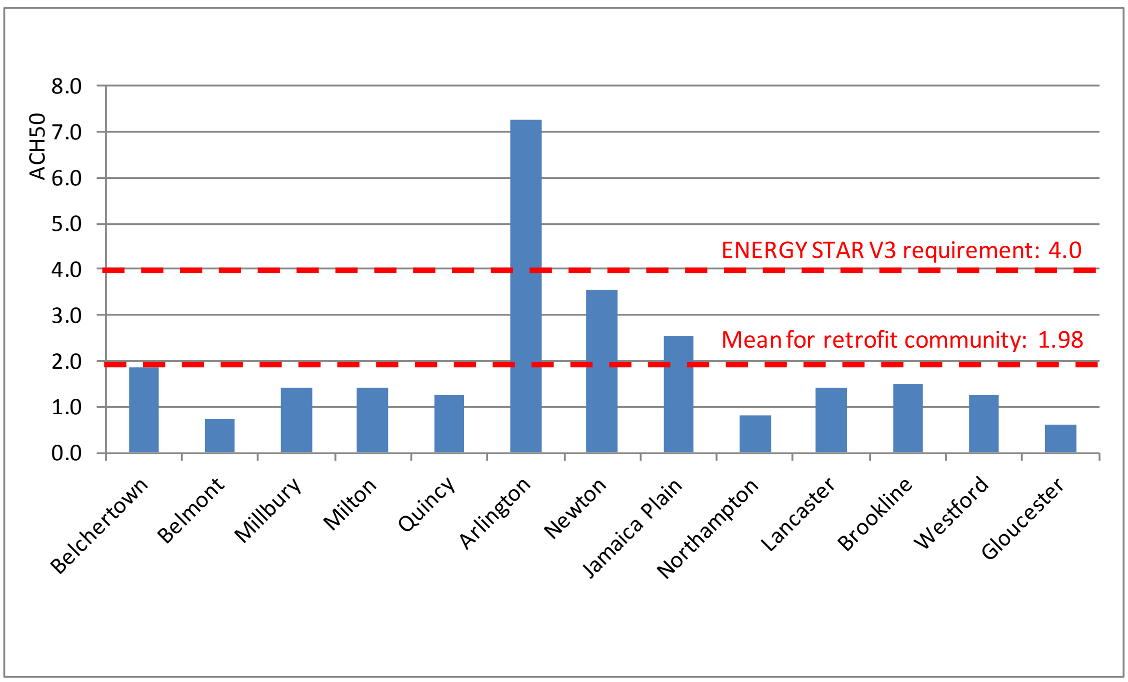


Figure 6. Post-retrofit ACH50 results

The ACH50 results range from .61 ACH50 for the Gloucester retrofit to 7.26 for the Arlington retrofit, with most of the retrofits being below 1.5 ACH50. Since the blower door testing followed the RESNET protocol, these ACH50 results can be compared to the ACH50 ENERGY

STAR V3 requirements. As shown in Figure 6, all but one of the retrofits (Arlington) were well below the ENERGY STAR V3 requirement for airtightness.

Figure 7 shows that there is a strong correlation between the ACH50 and the CFM50/ft^2 enclosure area results. The remaining analysis will use the ACH50 metric, since this is the more commonly used airtightness metric.

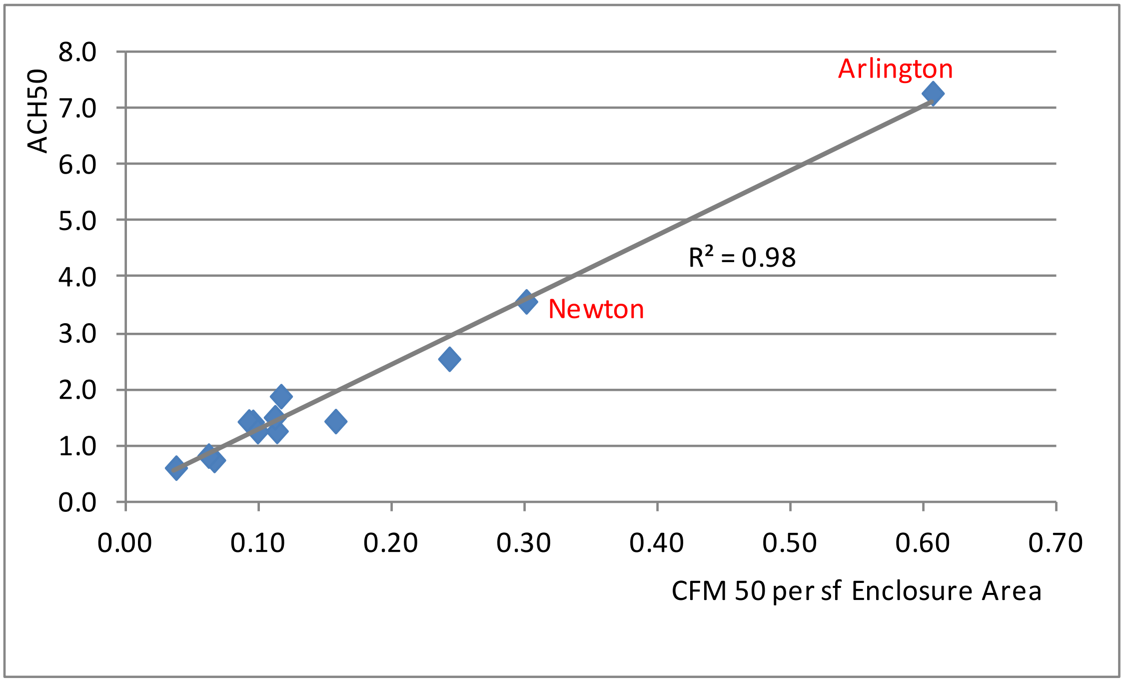


Figure 7. Correlation between ACH50 and CFM50/ft^2 enclosure area results

The airtightness result for the Arlington retrofit deviates significantly from the rest of the community. The Arlington retrofit is the only retrofit in this community that did not include the basement within the conditioned space. Therefore, the lower bound of the air control system was established at the basement ceiling. As has been observed in previous retrofit projects, it is difficult to achieve an effective air separation at the basement ceiling because of the framing and the many penetrations through the ceiling (Ueno 2010a). In the case of the Arlington project, there were also two stairwell connections through the basement ceiling to the first floor, further complicating the geometry of the air control system in the basement. Roughly half of the air leakage found during post-retrofit testing for this project was through the basement ceiling (Ueno and Lstiburek 2012; Neuhauser 2011).

The Arlington retrofit was one of the two retrofits for which existing porches and decks were not temporarily detached from the exterior wall during retrofit, thus making it difficult to provide continuous air control at the connection between the porch or deck and the wall. The other project that did not detach the porch and deck is the Newton retrofit; notably, this project also has one of the highest post-retrofit air leakage results.

4.1.3 Analysis of Airtightness Results

Both the air infiltration measures and the enclosure insulation measures of the DER package contribute to the airtightness results for these projects. The target R-values, especially for the roof and the walls, require a change to the existing wall and roof assemblies in order to accommodate the extra insulation required for the DER. The air control function must be established at an accessible location within the new assembly; in some cases it may be provided by the insulation itself.

Each component of the enclosure—roof or attic, above-grade wall, foundation wall, and basement slab—has an air control layer. For the projects in this community, the locations of the air control layers for the roof and attic and for the above-grade wall are directly related to the DER project's approach to handling the addition insulation. If exterior insulation was used for the component, the air control layer was established between the exterior insulation and the existing structural sheathing and was typically either house wrap with all seams taped and edges sealed or a fully adhered membrane. When the extra insulation was applied only on the interior, the air control layer was established on the interior and typically included spray foam insulation.

For the foundation wall, if it is cast concrete, the wall itself, with cracks patched, serves as the air control layer. Only three of the projects have concrete foundation walls. The other projects have fieldstone or concrete block foundation walls, which are not air barriers. For these projects, the interior insulation layer needs to serve as both the air control and the thermal layers. The only exception to this is the Arlington retrofit for which the basement is not insulated, so the basement ceiling is the air control layer.

The air control layer for a component needs to transition continuously to adjacent components in order to establish the full air control system. These transitions have the potential to introduce air leakage, particularly if the transition requires a connection between an interior air control layer and an exterior air control layer. The major transitions for the air control system occur between the wall and roof, between the wall and doors and windows, and between the above-grade wall and the foundation wall.

In the following sections, the airtightness results for the retrofit community as a whole are analyzed in terms of project characteristics including type and location of thermal and air control layers and pre-retrofit condition of the house. The size of the community is too small to provide definitive results about ways to ensure the best airtightness. However, the trends that are seen can provide guidance for other retrofit projects—both for best approaches and for approaches that will require some extra care for success.

All of the figures in this section are based on the same blower door test results. The results are sorted based on the characteristic in question to look for trends or to refute the existence of such a trend. The Arlington project will be treated as an "outlier" in the airtightness section and will not be considered as contributing toward observed trends.

4.1.3.1 Location of Air Control Layer

There are several factors related to the location of the air control layer (interior or exterior) that could be expected to impact airtightness. Interior side air control of the roof or walls is generally more difficult to implement than exterior side air control, especially for a retrofit. This is primarily because of the restrictions to full access from the interior as well as the presence of framing to framing connections and partition wall obstructions that require special sealing. The transition of the air control layer between the roof and the wall is another factor to be considered. As described in Section 3.2, when both the roof and the wall air control layers are on the exterior, a chainsaw implementation provides a straightforward approach to this transition—overlap the roof air control layer down onto and seal to the wall air control layer. When the transition is from exterior to interior or requires working around rafter tails, it becomes more difficult to make the connection airtight.

Another factor that is relevant if the air and thermal control is on the exterior is the attachment of the porch or deck. If the porch or deck is not detached from the exterior wall during the retrofit, it is difficult to establish sufficient continuity of the air control system to prevent air leakage at these attachments.

All but one of the retrofits in this community have exterior wall insulation and exterior wall air control. All of the retrofits with exterior insulation for both the roof and the wall used the chainsaw retrofit technique for both the insulation and the air control layers. So for this community, grouping the projects for analysis according to the location—interior or exterior—of the roof and wall air control layers is equivalent to first grouping the retrofits according to use or nonuse of the chainsaw technique and then looking at the other factors mentioned above.

In Figure 8, those projects for which porches and decks were not detached during the retrofit have been distinguished by color from the others. In addition, the Jamaica Plain retrofit is distinguished because the walls of the upper floor dormers were not treated during the retrofit creating a discontinuity in the wall air control layer. Both of these situations are likely to contribute to higher ACH50 results.

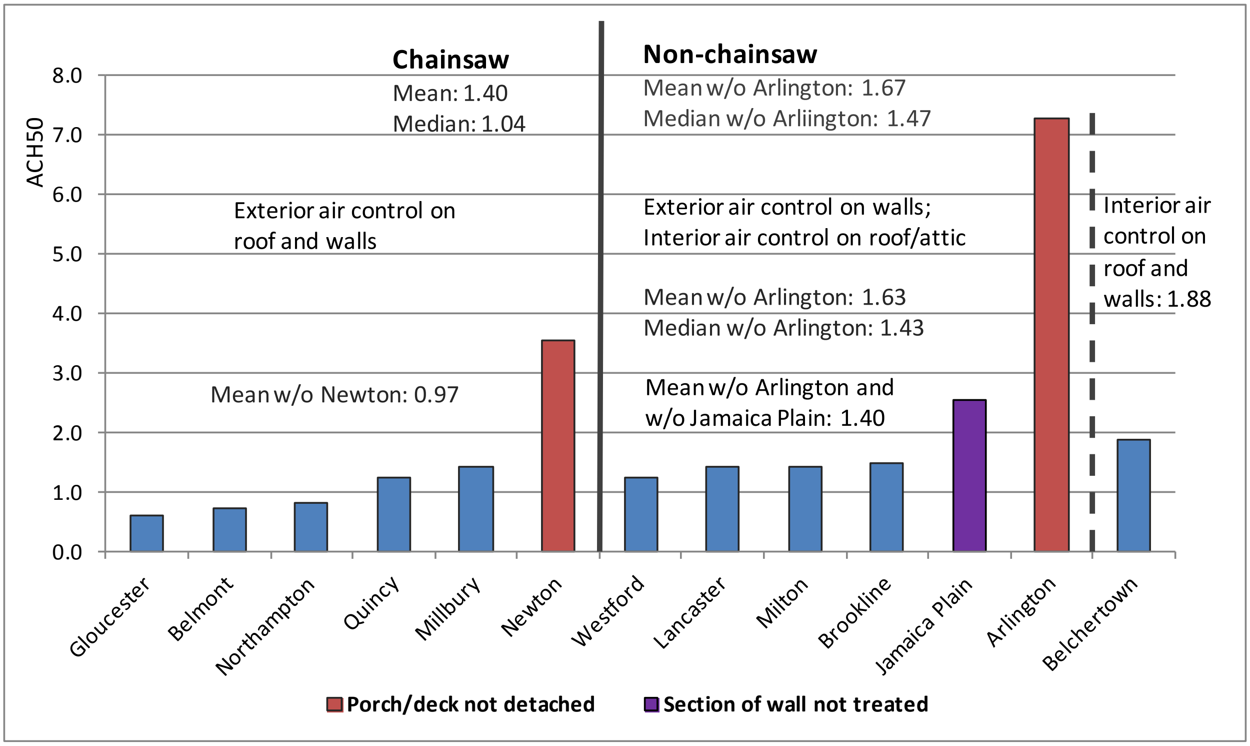


Figure 8. ACH50 results grouped by location of air control layer

As a group, the overall airtightness results are better for the chainsaw retrofits than for the other groups. The group of retrofits for which there is an interior to exterior transition at the wall to roof/attic intersection has somewhat more air leakage than the chainsaw group, but the mean ACH50 value for the group is still quite good.

For both the chainsaw and non-chainsaw groups, those retrofits for which porches and decks were not detached during the retrofit have the worst individual results. With those retrofits (Newton and Arlington) excluded, the overall airtightness results for the chainsaw group are significantly lower than those for the non-chainsaw group. If the Jamaica Plain retrofit is also excluded from the non-chainsaw group, the difference between the two is reduced but is still significant.

The material used for the exterior air control layer could be a contributing factor in the airtightness results. All of the retrofits in this community used taped and sealed house wrap for the exterior wall air control except for Northampton (taped OSB panels), Westford (taped plywood), and Arlington (a combination of taped, sealed house wrap and taped OSB panels). In addition, the Belmont, Brookline, and Jamaica Plain retrofits created a secondary air control layer at the outer layer of insulating sheathing. For those retrofits with an exterior roof air control layer (i.e., the chainsaw group), the roof air control layer was either taped and sealed house wrap (Quincy and Newton) or fully adhered roofing membrane (Gloucester, Belmont, Northampton, and Millbury). Figure 9 adds the material used for primary air control to the previous chart (Figure 8).

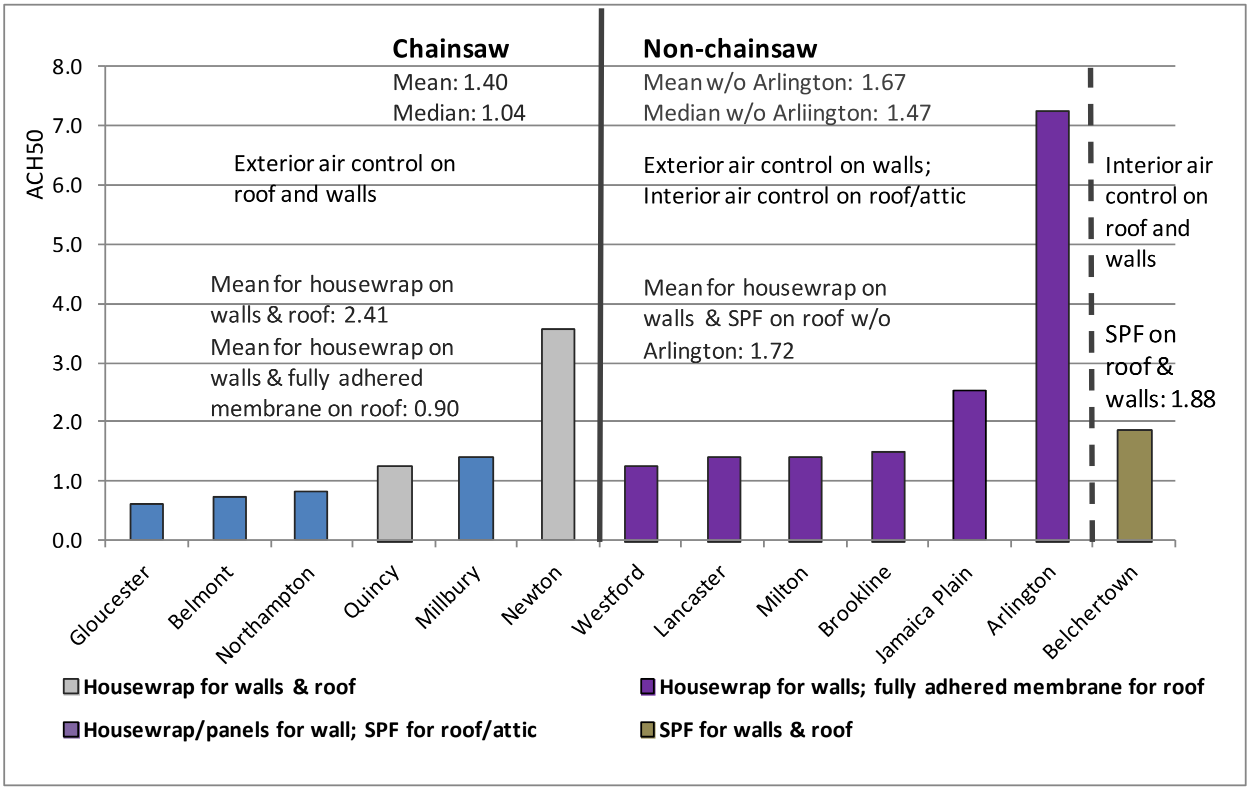


Figure 9. ACH50 results grouped by location of air control layer and air control layer materials

Figure 9 shows that the three retrofits with the best individual results are among the group with fully adhered roof membrane used for roof air control. This may be a contributing factor to their performance, particularly in establishing the seal where the roof air control layer overlaps onto the wall air control layer. Since none of the retrofits in this community used fully adhered roofing membrane as the roof air control layer but did not use the chainsaw technique, no comparison can be made to consider whether the fully adhered roof membrane alone is more significant than the chainsaw technique. However, it does appear that the combination of chainsaw and self-adhered membrane is particularly effective within this retrofit community.

Similarly, since none of the retrofits in this community used exterior roof and wall insulation but did not use the chainsaw technique, no comparison can be made to consider whether the exterior insulation alone is more significant than the use of the chainsaw approach. However, in an earlier report that presented performance results for a group of seven DER projects, six of which used exterior insulation, those which used exterior insulation but were not chainsaw had the highest ACH50 results of the group (Osser et al. 2012). This suggests that the exterior insulation alone does not fully account for the airtightness results of the chainsaw group.

4.1.3.2 Use of Spray Foam Insulation in Assembly

In this section, the airtightness results are examined based on the use of spray foam insulation used in the roof or attic and in the exterior walls.

Spray foam insulation is often used for the air control layer as well as for part of the thermal enclosure because it is air impermeable, it creates a seal with the framing elements when applied properly, and it is relatively easy to apply as a continuous layer even where there is limited access. In this retrofit community, all wall and roof applications of spray foam insulation were applied from the inside to the interstitial or cavity space. Where the spray foam insulation does not actually embed the framing, the spray foam insulation alone is not a continuous air control layer but instead the combination of the spray foam insulation and the framing (studs in walls, rafters in roof) form the air control layer. In this case, the seal of the spray foam insulation to the framing plays a significant role in creating the air control layer. Also, wherever there is insufficient space between framing members to apply spray foam insulation between the members (e.g., at a double stud), a sealant must be applied to transition across this break in the air control layer. For all of the retrofits that used spray foam insulation in the exterior walls, the wall cavity was fully accessible from the interior during construction.

Most of the retrofits used spray foam insulation in the exterior walls and/or in the roof or attic, but this was only relied upon as the air control layer when there was no exterior insulation applied as well. The following chart shows post-retrofit ACH50 values grouped by use of spray foam insulation though not necessarily for air control (Figure 10). Those retrofits that explicitly used spray foam insulation as part of the air control system are distinguished form the others by the color legend.

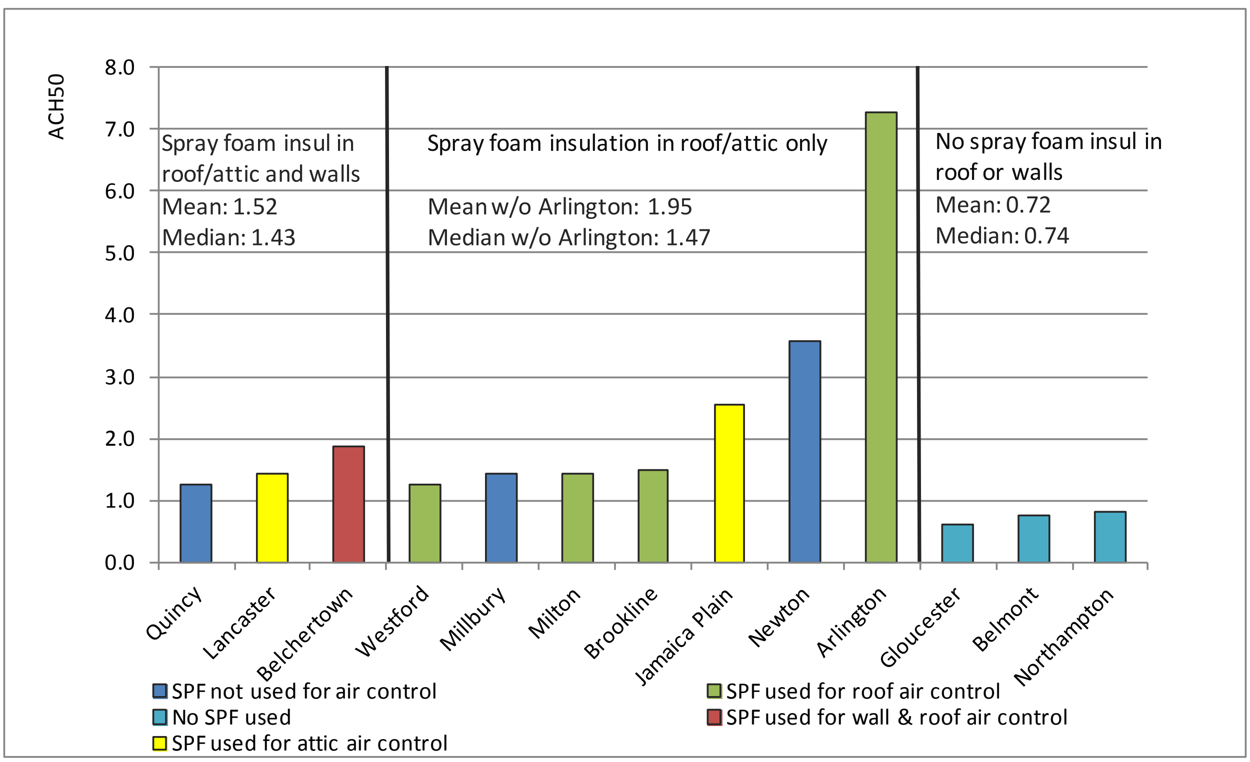


Figure 10. ACH50 results grouped by location of spray foam insulation, if any

The combination of roof and wall spray foam insulation has better overall airtightness results than spray foam insulation at the roof only, but the retrofits that did not use spray foam insulation at all had the best airtightness results. This result is somewhat surprising since, even when not being considered as the primary air control layer, spray foam insulation provides some additional air sealing. The retrofits that did not use spray foam insulation in the roof or walls at all used either densepack or netted cellulose in the wall and rafter cavities with the air control layer on the exterior side of the sheathing.

As shown in Figure 11, the distribution is slightly different when the grouping takes into account whether the spray foam insulation was intended as a primary component of the air control system. In this case, the group that does not use spray foam insulation for air control is precisely the same as the chainsaw group that was discussed earlier. Accepting that spray foam cavity insulation tends to have some benefit to air control, it would appear that the impact of other factors are dominant relative to the use of spray foam insulation.

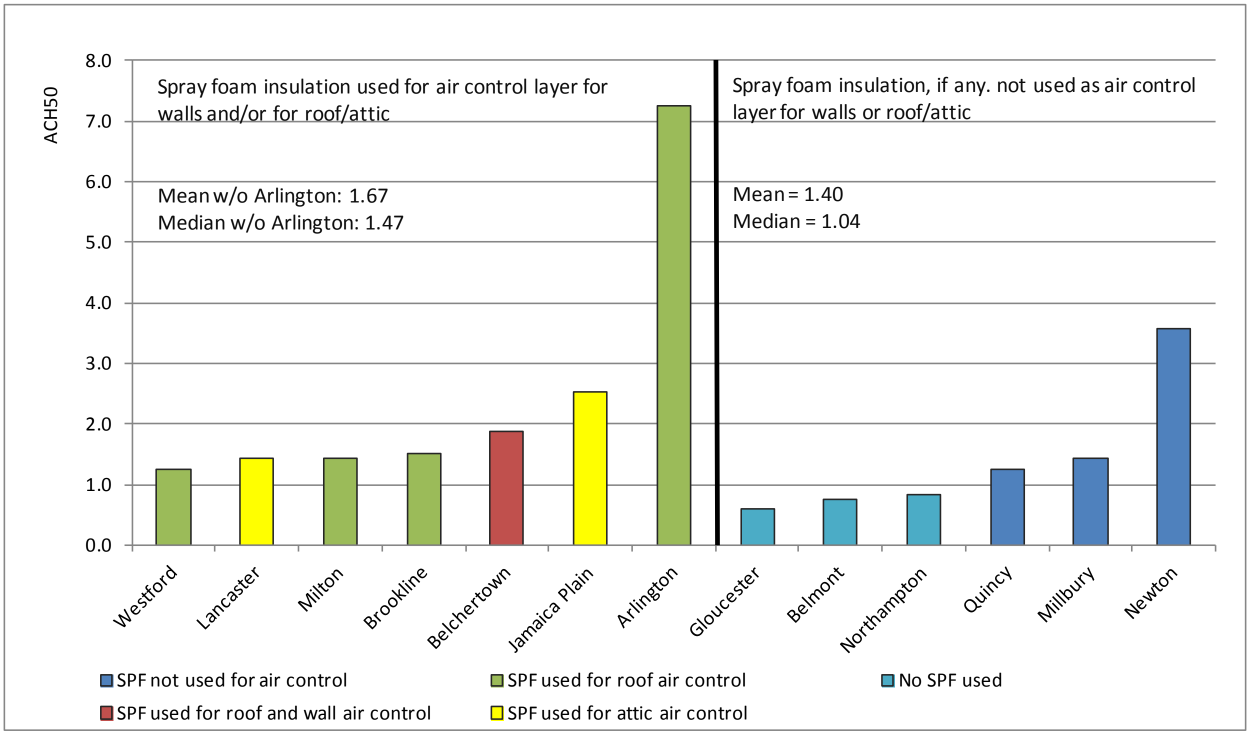


Figure 11. ACH50 results grouped by use of spray foam insulation for air control

4.1.3.3 Unvented Versus Vented Attic

The National Grid DER package specified the target R-value for the roof or attic enclosure but required an unvented attic only if there was to be mechanical equipment or ductwork in the attic. Only two of the retrofits in this community have vented attics. Figure 12 is grouped by unvented versus vented attic.

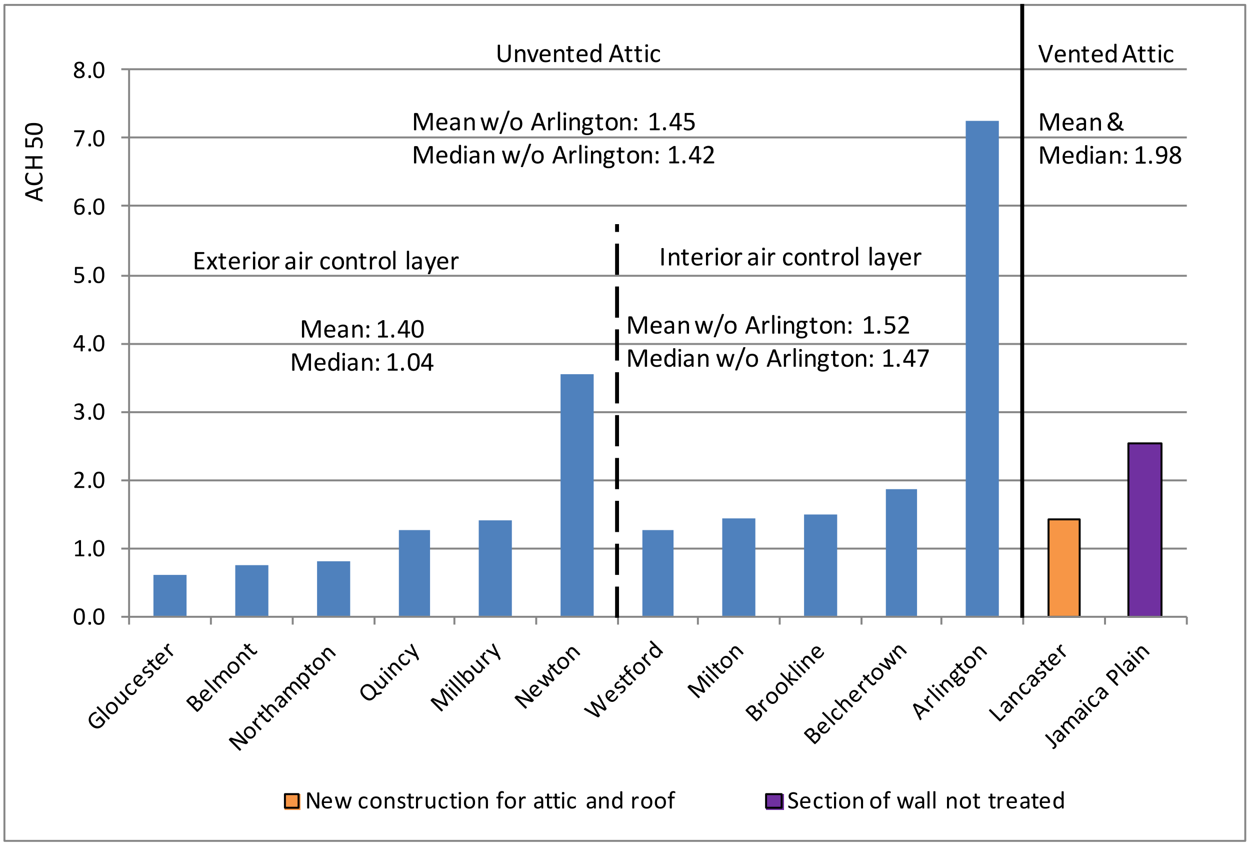


Figure 12. ACH50 results for unvented versus vented attic

The vented attic group has higher ACH50 results than the unvented attic group. However, with only two retrofits in the vented attic group, no definitive conclusion can be drawn from this. Furthermore, neither of the two vented attics in this community is typical for a vented attic DER. For the Jamaica Plain retrofit, a portion of the upper story walls did not have an air control layer provided; this would contribute to higher air leakage. For the Lancaster retrofit, the roof and attic were completely new construction, which allowed a continuous connection to be established between the wall and attic air control layers before the roof trusses were installed.

With the additional breakdown of the unvented attics between those with exterior air control versus those with interior air control, the group with the exterior air control layer has the better results though the difference is not large. This group is precisely the chainsaw group.

4.1.3.4 Impact of Pre-Retrofit Conditions

This section considers the impact of the pre-retrofit conditions of the house on the post-retrofit airtightness results. In particular, can an old, leaky house really be expected to achieve DER level airtightness?

The graph in Figure 13 plots ACH50 (vertical axis) versus the year that the house was built (horizontal axis). There does not appear to be any correlation between age of house and achieved airtightness—both the best and the worst results occurred in houses built between 1850 and 1950.

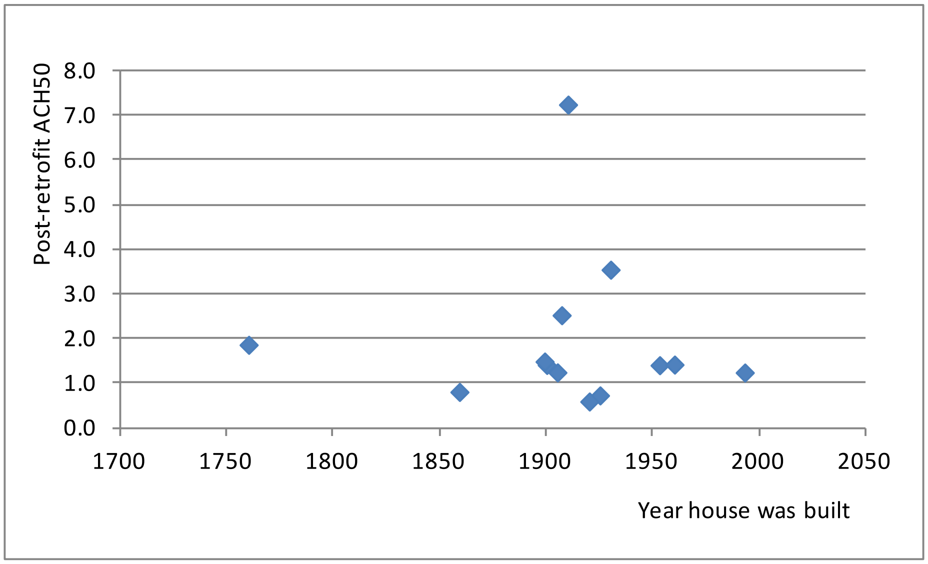


Figure 13. ACH50 results versus year house was built

The graph in Figure 14 plots ACH50 (vertical axis) versus the pre-retrofit total CFM50 results (horizontal axis). As with the previous graph, no relationship is apparent. These two graphs suggest that a very old or very leaky pre-retrofit condition is not necessarily an impediment to very good post-retrofit airtightness results.

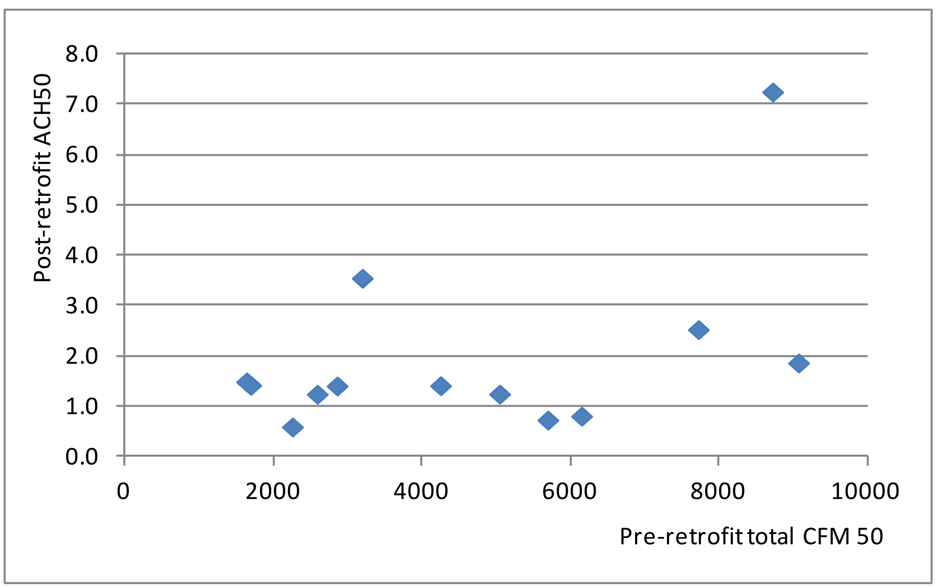


Figure 14. ACH50 results versus pre-retrofit total CFM50

4.1.4 Other Airtightness Analysis

Additional airtightness analysis considered in the project include conditioned versus unconditioned basements and insulation of concrete versus stone foundation walls. With only one unconditioned basement, there were insufficient data to identify any trends using the project data alone. For the insulation of the foundation walls, it was apparent that the above-grade characteristics influenced the results far more than the foundation wall treatment.

4.1.5 Conclusions of Airtightness Analysis

Based on this community of retrofits, the following trends relating DER enclosure and air infiltration measures and resulting airtightness were observed:

- A 50% overall improvement in total air leakage (as measured with 50 Pa pressure differential) can be expected from implementation of the enclosure and airtightness measures of this DER package.
- Post-retrofit ACH50 values of 1.5 and better can be expected from most implementations of the enclosure and airtightness measures of this DER package, provided the basement is included in the conditioned space and porches and decks are temporarily detached where needed to allow continuity of the air control layer. For this retrofit community, nine of the 13 projects were able to achieve this level of airtightness.
- When taken as a group, the best airtightness results in this community are achieved when the chainsaw technique is used at the roof/wall intersection and when exterior insulation is used for both the roof and the above-grade walls. However, it cannot be concluded that these implementation characteristics are the only determining factors.
- The use of spray foam insulation in the roof or walls, whether just for insulation or as a component of the air control system, is not a contributing factor for the best airtightness results.
- Within this retrofit community, the worst results were obtained for the only retrofit that did not condition the basement. However, a larger percentage of unconditioned basements in the community would be required before a definite trend could be asserted for these conditions.

4.2 Energy Use Results and Analysis

A key goal of the National Grid DER pilot project was to demonstrate that significant energy use reduction of 50% or more could be achieved through enclosure upgrades and efficiency upgrades to mechanical equipment. To meet that goal, total installed minimum insulation levels of R-10 (basement slab or ground floor slab), R-20 (foundation walls), R-40 (above-grade exterior walls), and R-60 (roof or attic) were specified and windows were to be at least R-5. These R-values, together with improved airtightness, were expected to reduce heating and cooling loads significantly. In addition, participants were encouraged to replace old equipment—appliances, heating, ventilation, and air conditioning (HVAC) equipment, and lighting—with energy-efficient equipment. In the case of HVAC equipment, this included right-sizing of the equipment to be more in line with the reduced heating and cooling loads.

The percentage of energy use reduction that can actually be achieved is dependent on the pre-retrofit state of the building as well as the relationship between the pre- and post-conditioned floor area, since a retrofit project is often combined with other home improvements. Therefore, this report concentrates primarily on the energy use levels that were achieved rather than on the energy reduction achieved. In this section, the post-retrofit energy use of the projects is analyzed to assess the effectiveness of the National Grid DER package by comparison to benchmarks, by the energy use levels that are achieved, and by energy consumption implications for different implementation strategies.

The analysis is in terms of both source (or primary) energy and site energy use. Looking at site energy allows an analysis in terms of where energy consumption is occurring directly within the house itself; this is the level at which the homeowner can precisely measure energy consumption using meters or monitors. On the other hand, in order to appropriately assess the environmental impact and total energy consumption of the home's energy use (including production and transport of the fuel or electricity), it is the source energy used by the house that is important. In addition, source energy is typically comparable to the energy cost for the end user (Ueno 2010b).

Six of the houses in this retrofit community generate some electricity on site. While this approach reduces the source energy used by that particular house, the analysis of energy use in this report will not take this into consideration. This approach was taken because most homeowners are still unable to generate their own electricity due to budget constraints, site constraints, building orientation, or building configuration. The energy use data without on-site electricity generation better represent what most homeowners will experience with the retrofit measures in the National Grid DER package.

The actual energy use data referenced in this report is for the 6-month period from February 2012 through July 2012 and for the 12-month period from August 2011 through July 2012. Since all of the projects were completed by January 2012, there are full energy use data for all projects for the 6-month period, which includes two months of heating and two months of cooling. Four of the projects were not completed by August 2011, so these are not included in the 12-month period results.

4.2.1 Energy Use Data

Table 6 and Table 7 summarize the pre- and post-retrofit energy use data for the houses included in this report. The pre-retrofit data are from monthly energy use provided by the utility companies or the homeowner, when available, with missing information generated by energy modeling using BEopt v1.3. The post-retrofit energy use for the projects was compiled using the monthly energy use reported by the electricity and gas utility companies, the delivery amounts and dates for propane from the supplier, and on site electricity production reports provided by the user, usually from a monitoring website.

Table 6. Summary of Pre-Retrofit Energy Use—12 Months

House Location	Time Period	Electricity (kWh)	Natural Gas (therm) or Propane (gal)	Fuel Oil (gal)	Other Energy Source	Total Site Energy (MMBtu)	Total Source Energy (MMBtu)
Belchertown	Oct 08–Sep 09	2,139	162 (P)		7 cords of wood	194	211
Belmont	Energy model	8,811	309 (NG)	3,063	–	486	562
Millbury	May 09–Apr 10	7,809	–	375	150 bags of wood pellets	125	188
Milton	Energy model	8,086	903 (NG)	–	–	118	187
Quincy	Jan 09–Dec 09; energy model for oil	12,557	–	1301	_	223	325
Arlington	Energy model	8,866	3,599 (NG)	–	–	390	478
Newton	Oct 09–Sep 10	7,639	1,222 (NG)	–	–	148	215
Jamaica Plain	Aug 09—Jul 10	7,192	1,781 (NG)	_	–	203	268
Northampton	Jan 09–Dec 09	4,443	1,164 (NG)	_	–	132	173
Lancaster	Energy model	5,648	–	738	–	122	168
Brookline	Sep 09–Aug 10	3284	773 (NG)	–	–	89	118
Westford	Jan 10–Dec 10	9,763	1,761 (NG)	–	–	209	296
Gloucester	Mar 09–Feb 10	6,428	–	911	–	148	201

Table 7. Summary of Post-Retrofit Energy Use: February 12–July 12 (6 months) and August 11–July 12 (12 Months)

House Location	Time Period	6 Months Electricity (kWh)	6 Months Natural Gas (therm) or Propane (gal)	6 Months Total Site Energy (MMBtu)	6 Months Total Source Energy (MMBtu)	12 Months Electricity (kWh)	12 Months Natural Gas (therm) or Propane (gal)	12 Months Total Site Energy (MMBtu)	12 Months Total Source Energy (MMBtu)
Belchertown	Aug 11–Jul 12	885	132 (P)	15	22	1,873	335 (P)	37	52
Belmont	Aug 11–Jul 12	6,017 (2,306 excluding on site)	84 (NG)	29	77	11,415 (4,809 excluding on site)	204 (NG)	59	151
Millbury	Aug 11–Jul 12	5,211	28 (P)	21	63	10,597	66 (P)	45 (includes 2.79 for wood pellets)	130 (includes 2.79 for wood pellets)
Milton	Aug 11–Jul 12	2,973 (865 excluding on site)	159 (NG)	26	51	6,648 (2,714 excluding on site)	309 (NG)	54	108
Quincy	Aug 11– Jul 12	4,943 (351 excluding on site)	128 (NG)	30	70	9,894 (1,671 excluding on site)	262 (NG)	60	140
Arlington	Aug 11–Jul 12	5,777	247 (NG)	44	92	14,196	523 (NG)	101	217
Newton	Aug 11–Jul 12	3,291	171 (NG)	28	55	7,167	417 (NG)	66	125
Jamaica Plain	Aug 11–Jul 12	2,915 (1,479	404 (NG)	50	76	6,153 (2,993	798 (NG)	101	154

House Location	Time Period	6 Months Electricity (kWh)	6 Months Natural Gas (therm) or Propane (gal)	6 Months Total Site Energy (MMBtu)	6 Months Total Source Energy (MMBtu)	12 Months Electricity (kWh)	12 Months Natural Gas (therm) or Propane (gal)	12 Months Total Site Energy (MMBtu)	12 Months Total Source Energy (MMBtu)
		excluding on site)				excluding on site)			
Northampton	Aug 11–Jul 12	3,627 (429 excluding on site)	–	12	41	7,697 (1,973 excluding on site)	–	26	88
Lancaster	Feb 12–Jul 12	3,415 (596 excluding on site)	106 (NG)	22	50	–	–	–	–
Brookline	Feb 12–Jul 12	1,798	219 (NG)	28	43	–	–	–	–
Westford	Feb 12–Jul 12	5,613	375 (NG)	57	103	–	–	–	–
Gloucester	Feb 12–Jul 12	5,727	–	20	65	–	–	–	–

For several projects—Belmont, Quincy, and Gloucester—domestic hot water is provided by solar thermal systems with electric domestic hot water backup systems. Since there was no consistent method used to monitor the actual energy use provided by the solar thermal systems, the energy provided by the solar thermal system is not included in the energy consumption data in Table 7.

Six of the projects include on-site generation of electricity: five of those installed photovoltaic (PV) panels on the roof of the house; one project uses a high efficiency gas boiler system with a generator that converts waste heat to electricity. The electricity data given in Table 7 are the total electricity use; the value in parentheses excludes the electricity use that was generated on site.

Source energy use is calculated using the source to site energy conversion factors shown in Figure 15. The total site and source energy use reported in Table 7 presumes that all electricity was from the grid.

Source-Site Ratios for all Portfolio Manager Fuels	
Fuel Type	**Source-Site Ratio**
Electricity (Grid Purchase)	3.34
Electricity (on-Site Solar or Wind Installation)	1.0
Natural Gas	1.047
Fuel Oil (1,2,4,5,6,Diesel, Kerosene)	1.01
Propane & Liquid Propane	1.01
Steam	1.21
Hot Water	1.28
Chilled Water	1.05
Wood	1.0
Coal/Coke	1.0
Other	1.0

Figure 15. Source-site energy ratios from EnergyStar.gov

Using the data in Table 6 and Table 7, Figure 16 compares a year of pre-retrofit source energy use with the actual post-retrofit source energy use for either one year (August 2011–July 2012) or, where a year of data are not yet available, for 6 months (February 2012–July 2012).

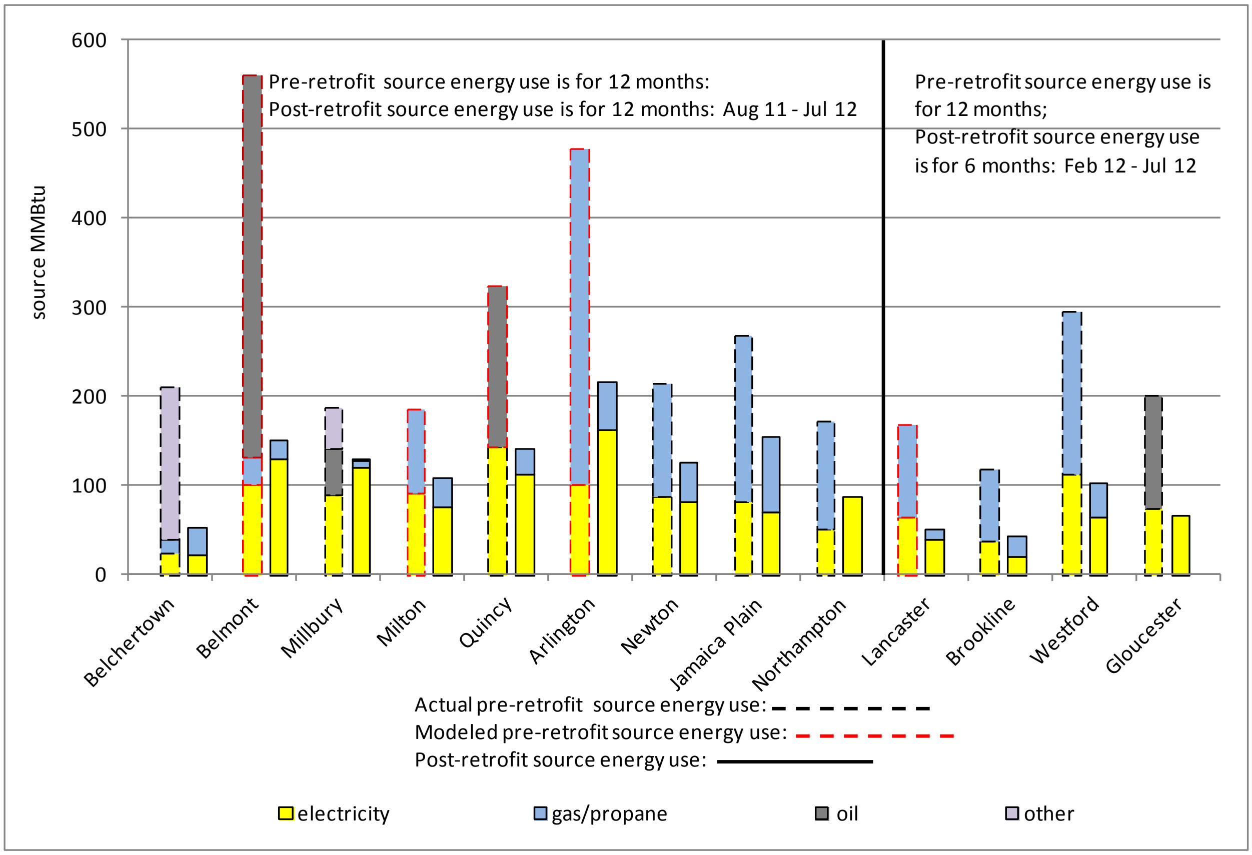


Figure 16. Pre- and post-retrofit source energy use for all retrofits

The total year of source energy for the pre-retrofits ranges from 118–562 MMBtu. For the post-retrofits, the total year of source energy ranges from 52–217 MMBtu. For those with only 6 months of post-retrofit data available, the source energy use for the 6-month period ranges from 43–103 MMBtu.

Figure 17 shows percentage of reduction of the pre-retrofit source energy use that was achieved for each project for the year. For those projects with only 6 months of actual post-retrofit energy use data, the yearly energy use is projected to be two times the 6-month energy use. This approach is plausible since the post-retrofit source data for those four retrofits includes 2 months of heating, 2 months of cooling, and 2 months of "shoulder" season. All but one of the retrofits—Brookline—either have achieved, or are projected to achieve, at least a 30% reduction. Four of the retrofits—Belchertown, Belmont, Quincy, and Arlington—have achieved greater than 50% reduction. These numbers do not include credit for on site electricity generation. With credit for on site generated electricity, the Milton, Jamaica Plain, Northampton and Lancaster projects would also show greater than 50% achieved or projected reduction from the pre-retrofit conditions.

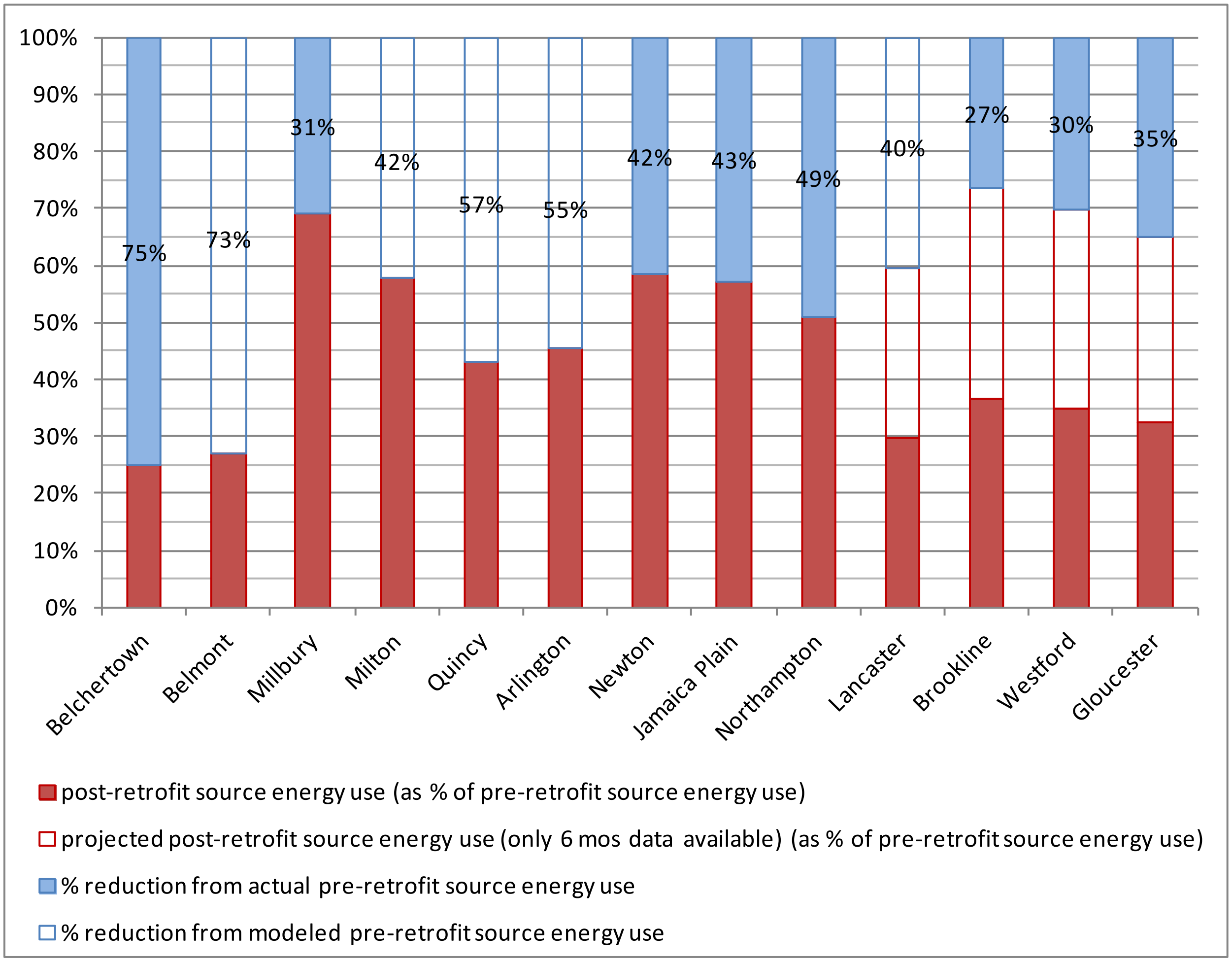


Figure 17. Percent reduction from pre-retrofit to post-retrofit source energy use

The percentage reduction achievable is somewhat dependent on the pre-retrofit state of the house. In the case of the Brookline retrofit, this was the final stage of a two-stage DER project with the roof and basement components having been done several years earlier. Thus, the 27% reduction does not capture the effect of the first stage of the DER.

The Brookline retrofit is one example of a retrofit for which the homeowners had been living in the house prior to the retrofit, the retrofit did not involve a significant addition, and the house had been reasonably well maintained and updated by the homeowners. Other retrofits that fall into that category include the Millbury, Newton, and Jamaica Plain retrofits. The post-retrofit energy reduction for this group ranges from 27%–43%. The other retrofits for which the homeowners did not change between pre-retrofit and post-retroft are Belchertown, Quincy, Northampton, and Westford, but for these retrofits, either the project included a significant upgrade (Belchertown) or a significant addition as well as an upgrade to the existing house (Quincy, Northampton, and Westford). Both the Belchertown and Belmont retrofits, those with the highest reduction in source energy, as well as the Arlington retrofit, were largely uninsulated homes prior to the retrofit project.

It should be noted that the pre- and post-retrofit reductions compare energy use between different years, or in some cases, between actual and modeled energy use, so the reduction results must be viewed as approximate. In Figure 16 and Figure 17, the pre-retrofit data that are from an energy model rather than from actual data are indicated by the legend. The information available about the pre-retrofit houses is generally not complete or detailed enough for weather normalization techniques to provide results that could be considered more accurate (Osser et al. 2012). However, a weather normalization technique is applied to the post-retrofit energy use data when used for benchmarking in the following section.

4.2.2 Normalization and Benchmarking of Energy Use Data

Total energy use for a house is a function of weather conditions during the time period, the size of the house, the number of households, the number of residents, and the life style of the residents. In order to compare and analyze the energy use among different houses, it is necessary to use performance metrics that normalize some of these conditions.

4.2.2.1 Normalization by Weather Conditions

With all of these houses located in the same region of the country and the actual data taken in the same time frame, the prevailing weather conditions for all of these retrofits were similar. However, when compared to typical weather conditions for the area, the actual heating degree days (HDDs) are lower and the actual cooling degree days (CDDs) are higher for the August 2011 to July 2012 time period. Table 8 shows this comparison for the Boston Logan weather station for August 2011 through July 2012 using Typical Meteorological Year 3 (TMY3) weather data. In this case, the actual HDDs were 20% lower and the actual CDDs were 35% higher than for the typical year. Therefore, while the actual post-retrofit energy use data in this report can be used for comparison among the houses of this particular community, they should be normalized for weather conditions when comparisons are to be made to a benchmark for a different or otherwise unspecified year.

Table 8. Monthly Comparison of Actual and TMY3 CDD/HDD for Boston Logan Weather Station for August 2011–July 2012

Month	Actual CDDs	Actual HDDs	TMY3 CDDs	TMY3 HDDs
August 2011	260	2	193	5
September 2011	115	57	53	66
October 2011	29	267	9	348
November 2011	1	449	0	652
December 2011	0	764	0	902
January 2012	0	959	0	1189
February 2012	0	801	0	950
March 2012	18	608	0	813
April 2012	25	398	0	537
May 2012	42	204	11	204
June 2012	142	94	109	87
July 2012	304	2	95	3
Yearly Total	**936**	**4605**	**694**	**5756**

Where weather normalized data are used in this report, they have been normalized with respect to the TMY3 weather data files for the location of the retrofit. TMY3 data files contain weather data meant to represent typical conditions at a particular geographic location over a long period of time (Wilcox and Marion 2008). For use in this report, monthly HDDs and CDDs for the locations were extracted from TMY3 data files using BEopt v1.3.

The weather normalized data for each project was generated using a linear regression analysis method that adjusts the monthly energy use based on the correlation between degree days and energy use. Since this community is located in a heating-dominated climate, only HDDs and consumption of the type of fuel used for heating were used in the regression analysis. The correlation was established using the actual HDDs and then applied using the TMY3 HDDs at the same location to determine the “typical” consumption for that type of fuel for the house. These weather-normalized monthly data were then combined with the actual monthly use for the other fuels to give an estimated total energy use for a typical year for the house.

Specifically,

1. A scatter graph of the actual monthly site kWh energy use versus actual monthly HDDs for August 2011 through July 2012 was generated for each project using Microsoft Excel. Only energy use of the fuel type used for heating was included in the scatter graph. For the four projects with only 6 months of actual data, only 6 months of actual data were plotted.

2. A linear best fit regression equation was generated by the Excel software for the scatter graph of the form

   Site Energy Use in kWh per Month = X1 × Actual HDDs for Month + A

   along with the values of X1, A, and R^2 (coefficient of determination) for the regression line. The value of X1 represents the slope of the line on an energy use/HDD graph. The value of A is the intercept on the energy use axis, roughly representing the base load.

3. By replacing “Actual HDDs for month” with TMY3 HDDs for each month, the equation was used to generate a rough estimate of the typical site energy use for the month for the heating fuel type.

4. These monthly estimates were combined with the actual nonheating site energy use, and totaled to provide 12-month weather normalized site energy use for the project. The 12-month weather-normalized source energy use was computed using the conversion factors in Figure 15.

For those projects with only 6 months of actual data, the additional 6 months of heating energy use was projected using the regression equation determined in Step 1; the additional 6 months of nonheating energy use was projected by multiplying the 6 months actual nonheating energy use by 2.

Due to the low resolution of the energy use data (approximately monthly) and the varying correlation accuracy (R^2) with HDD, the weather-normalized data should be viewed as a rough approximation. In this report, weather-normalized source or site energy use is used within this section only for the purpose of benchmarking the energy use results and is clearly labeled "weather normalized." All other analysis of the results will be performed using the actual post-retrofit energy use data.

4.2.2.2 Normalization by Number of Households

Several of the houses in this community are multifamily, so one performance metric to consider for benchmarking the results is the total energy use per household. This metric is computed by dividing the total building energy use by the number of households in the building.

Figure 18 shows weather-normalized post-retrofit source energy use in MMBtu per household for 12 months. For those households with only 6 months of data, the projected results are shown. The northeast regional household averages for source energy use, derived from data available from the Energy Information Administration (EIA), are shown in the figure for comparison.

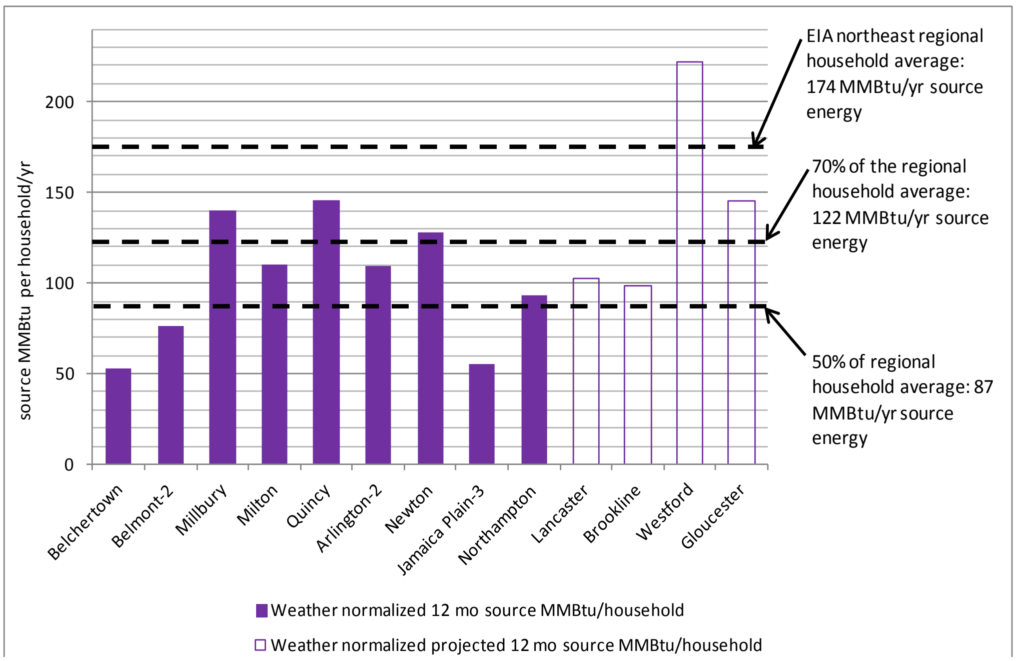


Figure 18. Weather-normalized post-retrofit source MMBtu/yr per household

The U.S. Department of Energy maintains regional energy performance metrics per household that are based on information contained in the EIA Residential Energy Consumption Survey (RECS). The most recent information available is from 2009 (DOE/EIA 2009). For the Northeast region, the EIA average site energy consumption per household is 107.6 MMBtu/yr. The EIA performance information does not include average source energy consumption per household. To convert EIA site energy consumption to source energy use, the average site energy per household was distributed among fuel types according to the distribution of the total fuel consumption for the northeast households in the RECS. The ENERGY STAR source-to-site ratios (Figure 15) were applied based on this distribution yielding an EIA Northeast regional average household source energy use of 174 MMBtu/yr. A 30% reduction in average household source energy use is 122 MMBtu/yr and a 50% reduction is 87 MMBtu/yr.

For the 12-month time period covered in this report, no retrofit exceeded the EIA Northeast regional average household use; however, based on the 6 months of use covered, the Westford retrofit is likely to exceed it. Eight of the retrofits were (or are projected to be) below 70% of the household average and three of those were below 50% of the household average yearly source energy use.

The Quincy and Westford retrofits, which are the two highest "per household" source energy users, are both single-family homes and are the largest in terms of conditioned square feet of the single-family homes in this community. This highlights one of the disadvantages of the "per household" performance metric—while it compensates for duplication of appliance and other miscellaneous use, it does not take into account the square footage of the household.

4.2.2.3 Normalization by Energy Use Intensity

The most common performance metric used for comparing energy consumption is energy use in kBtu per square foot of conditioned floor area per year (kBtu/ft^2-yr). This performance metric, computed by dividing the total energy use in kBtu for the year by the square footage, is called energy use intensity (EUI) and takes the size of the house into consideration. This is the metric used for the energy use targets of the 2030 Challenge and the Passive House program. Since the EUI can refer to either source or to site energy use, any comparisons using EUI must be made between source to source EUI or site to site EUI. Also, the calculation of "square footage of floor area" may vary. In this report, the conditioned space is determined by the interior dimensions of each floor and includes an insulated basement but does not include insulated, unvented but unfinished attic space or crawlspace.

Figure 19 shows weather-normalized post-retrofit source EUI for each of the retrofits in the community. For those retrofits with only 6 months of data available, the projected source EUI is shown. Since these have been weather normalized, they can be compared to the northeast regional EIA average source EUI for single-family or multifamily homes. These regional averages have been computed by Architecture2030 using the regional EIA RECS data (Architecture2030 2006).

For this 12-month period, only two of the retrofits—Millbury and Lancaster—exceeded (or are projected to exceed) the average source EUI for a single-family home. Two projects, Belchertown and Quincy, used less than 50% of the single-family average and the Belmont multifamily used less than 50% of the multifamily average. Although only 6 months of actual data are available, Brookline also appears to be on target to be less than 50% of the single-family average. The range of weather normalized source EUI for the retrofit projects is 28–75 kBtu/ft^2-yr, with most projects falling between 30 and 60 source kBtu/ft^2-yr.

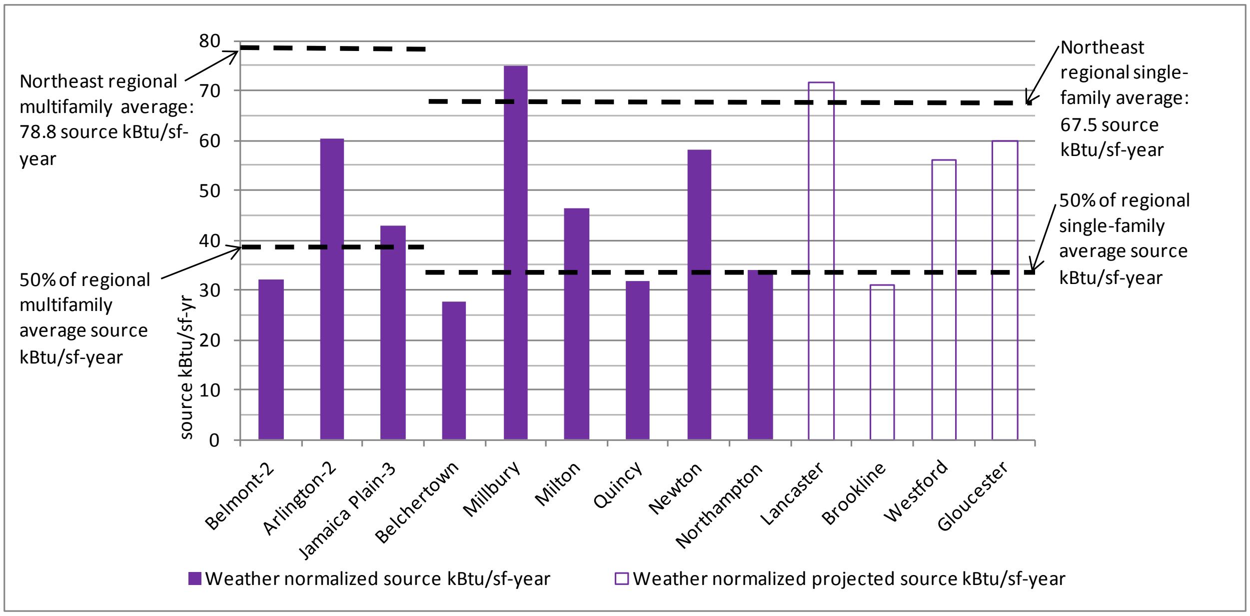


Figure 19. Weather-normalized post-retrofit source kBtu/ft^2-yr

In 2002, Architecture2030 established the 2030 Challenge with the ultimate goal of reducing fossil fuel, greenhouse-gas emitting energy consumption to zero by 2030 and with intermediate goals provided along the way. These goals are stated in terms of fossil fuel-generated site energy. Therefore this energy consumption includes all electricity use from the grid as well as natural gas and propane on site, but does not apply to electricity generated by PV. Goals for the consumption of source energy are not provided. The 2030 Challenge goal for 2012 is a 60% reduction of the average site energy for the particular building type in the region; the goal for 2015 is a 70% reduction.

Figure 20 shows the weather-normalized site energy use in site kBtu/ft^2-yr for the retrofits. The northeast multifamily and single-family 2012 and 2015 goals for the 2030 Challenge are also shown. Even without taking credit for PV-generated electricity, two of the single-family retrofits, Quincy and Northampton, meet the Northeast region 2012 goal for the 2030 Challenge and the Northampton project meets the 2015 goal as well. The Belmont retrofit meets the Northeast region 2012 goal for two- to four-unit multifamily houses as well as the 2015 goal. Based on 6 months of data, the Gloucester retrofit also appears to be meeting the 2030 Challenge for 2012.

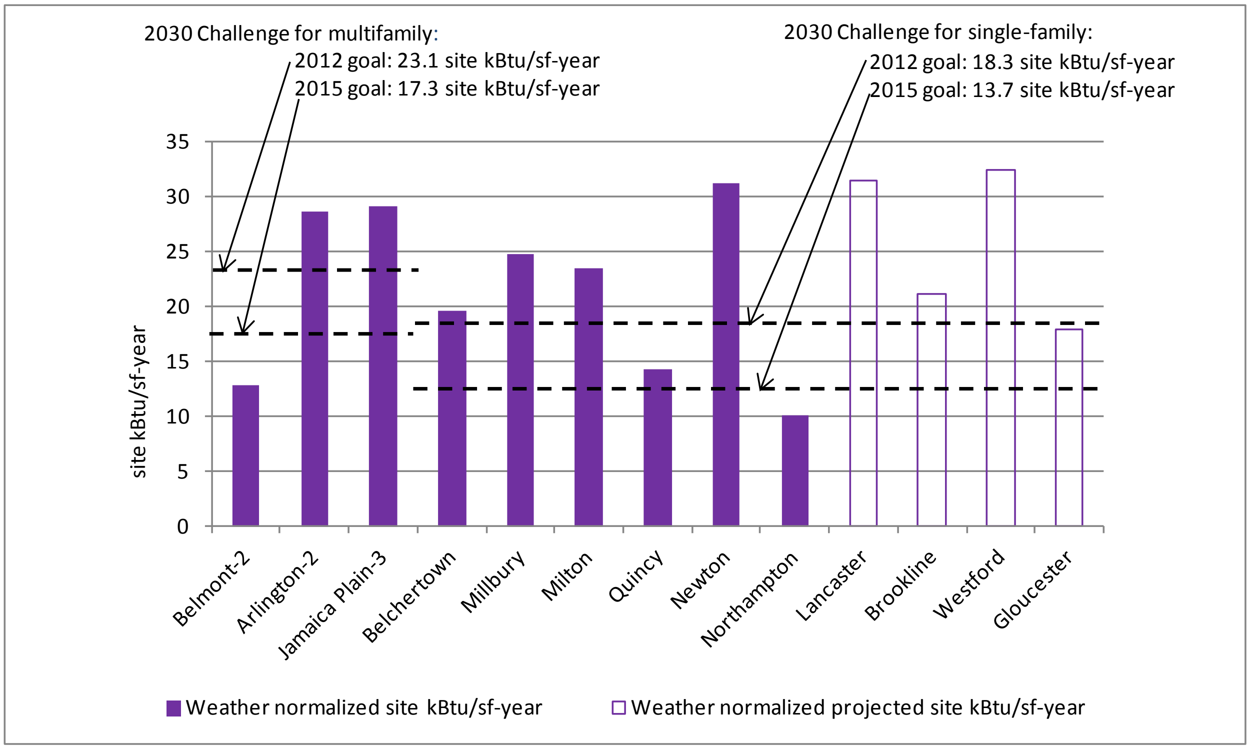


Figure 20. Weather-normalized post-retrofit site kBtu/ft^2-yr

4.2.3 Analysis of Energy Use Data

In the following sections, the post-retrofit energy use is analyzed for the retrofit community as a whole to look for trends of energy use that are associated with the aspects of the National Grid DER package. All energy use is in terms of actual post-retrofit energy use. There is no adjustment made for the weather conditions and there is no use of modeled energy use in this section.

4.2.3.1 Post-Retrofit Source to Site Energy Use Ratio

In the EIA RECS report from 2009, the distribution of total household site energy consumption in the Northeast region was 25% electricity, 51% natural gas or propane, 22% oil, and 2% others. The distribution of site energy use for the nine retrofits with a full year of post-retrofit data is 47% electricity and 53% natural gas or propane. This relative increase in electricity use results in a greater difference between the site energy and source energy use for the projects because the source to site ratio for electricity use is more than three times higher than that for the other fuels. The increase in electricity use may be a reflection of change in lifestyle—e.g., continued increase in use of electronics, more home offices—but more likely is the result of adding air conditioning or of switching from gas or oil to electric heating.

Figure 21 shows the actual total source and site energy use in kBtu/ft^2 for August 2011 through July 2012 for all of those projects for which there are 12 months of data; for the others, this is shown for February 2012 through July 2012. The range for 12 months is 10–30 kBtu/ft^2 of site energy and 27 kBtu/ft^2 –to 69 kBtu/ft^2 of source energy. Most of these retrofits are in the range of 30–60 total source kBtu/ft^2-yr. For the four projects with only 6 months of data, the range is 8–15 kBtu/ft^2 of site energy and 14–35 kBtu/ft^2 of source energy.

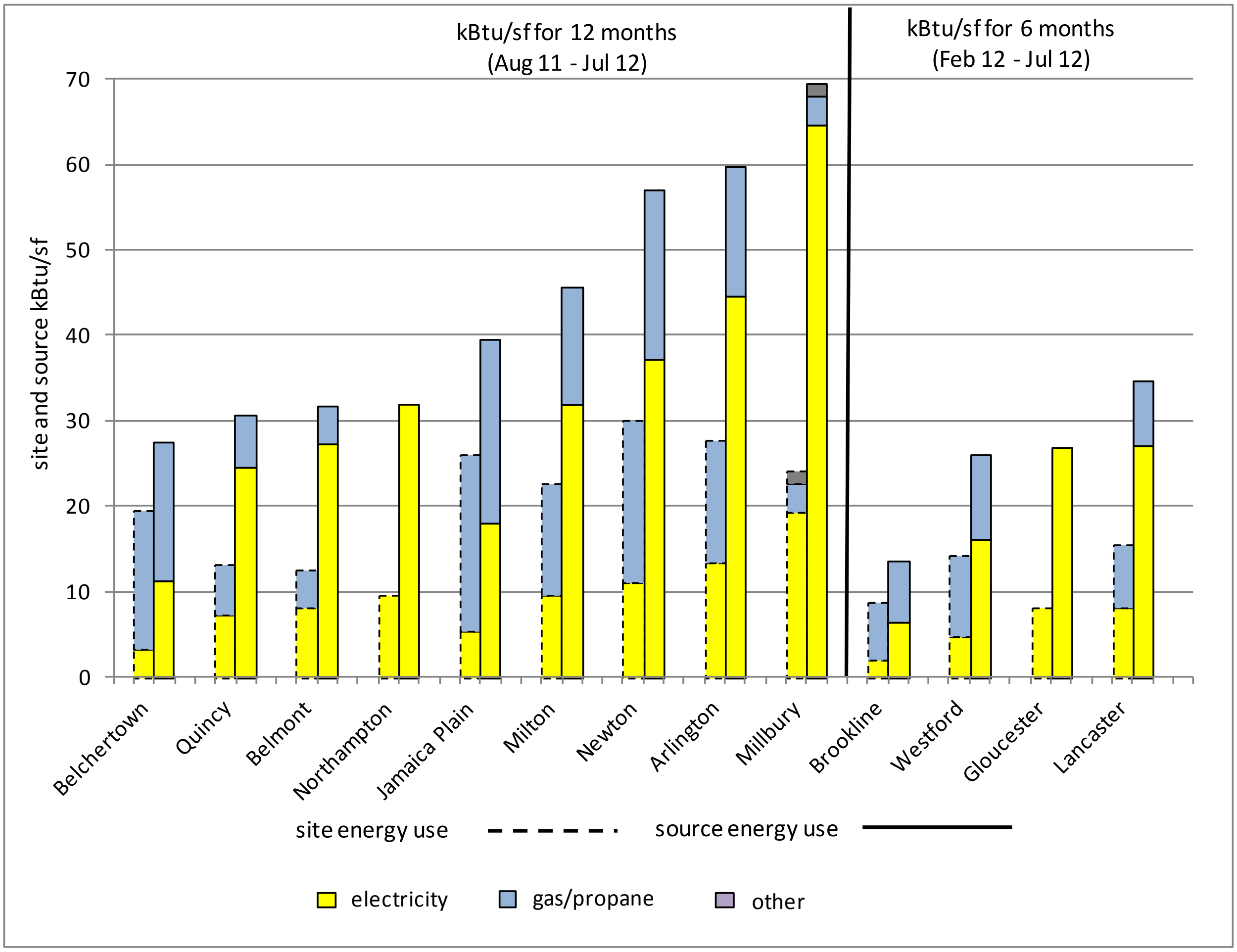


Figure 21. Post-retrofit 12- or 6-month site and source energy use in kBtu/ft^2

With only gas (or propane) and electricity being used for these retrofits, source energy use becomes two times the site energy use as soon as the electricity energy use reaches about 42% of total site energy use using the current source to site conversion factor for electricity (Figure 15). Thus, seemingly low site energy use can quickly result in high source energy use.

Within this community, two of the retrofits—Northampton and Gloucester—converted to all electric energy use. Two other retrofits—Millbury and Lancaster—converted from fossil fuel heating to all-electric for heating/cooling (ASHPs) but not for hot water. In these four cases, the decision to convert to an all-electric house or to electric heating and cooling was done in anticipation of adding on-site generation of electricity, either at the time of the retrofit or as a future project. However, on-site electricity generation is not an option for most DER projects so that continued increase in percentage of electricity use, particularly if used for heating, could undermine the anticipated source energy savings. It should be noted, however, that the increased use of renewables for the generation of grid electricity will lower the source to site ratio in the future, thus reducing the relative impact of grid electricity on total source energy use.

Figure 22 compares the source to site ratio with the actual source energy kBtu/ft^2 for February 2012 through July 2012 for all of the projects. The Lancaster, Millbury, and Gloucester projects account for the highest 6-month source kBtu/ft^2 results and are also among the highest source to site ratios for the period. Notably, the other three projects with high source to site ratios are among the lowest 6-month source kBtu/ft^2 results. These retrofits—Quincy, Belmont, and Northampton—are all participants in the Thousand Home Challenge program (ACI 2010). This is a program that emphasizes behavior, lifestyle, and community solutions for additional reduction of energy use so these households carefully monitored their energy use, which could explain why their energy use is low. A contributing factor to the high source to site ratio for the Quincy and Belmont retrofits, both of which use gas for heating, is the low post-retrofit heating load.

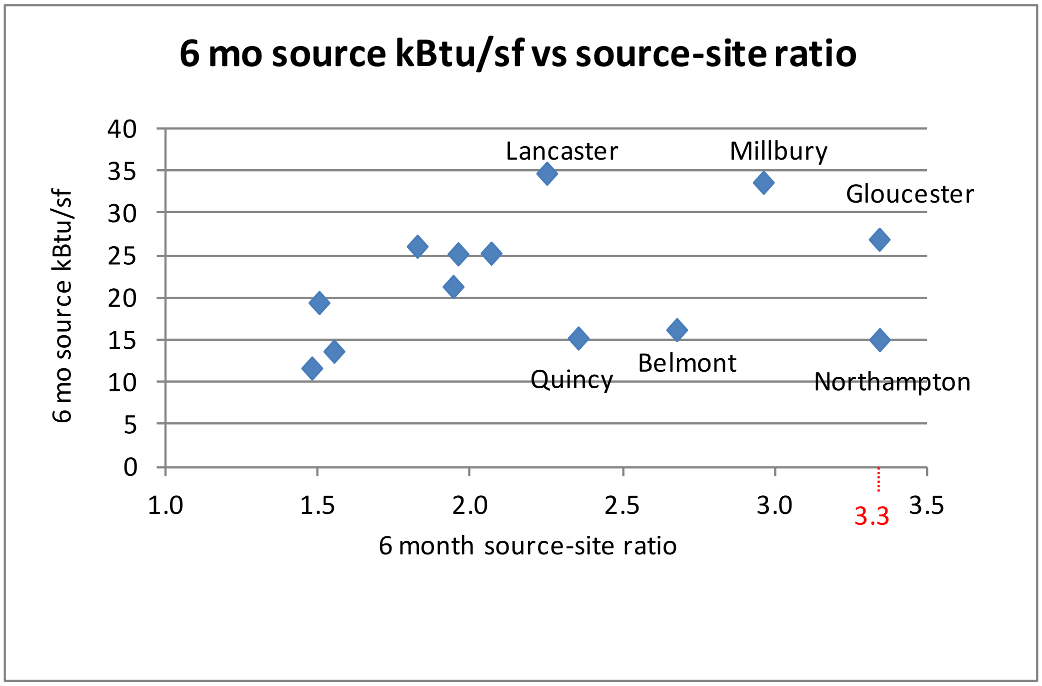


Figure 22. Correlation between post-retrofit 6-month source to site ratio and 6-month source kBtu/ft^2

Several of the projects compensated for the shift toward electricity use by providing PV panels or other on-site generation techniques to offset the increase in source energy. For the six retrofits that use on site generation of electricity, Figure 23 shows a breakdown of the energy use between that which was generated by fossil fuels (which includes electricity from the grid) and that which was generated on site for the 6-month period from February 2012 through July 2012.

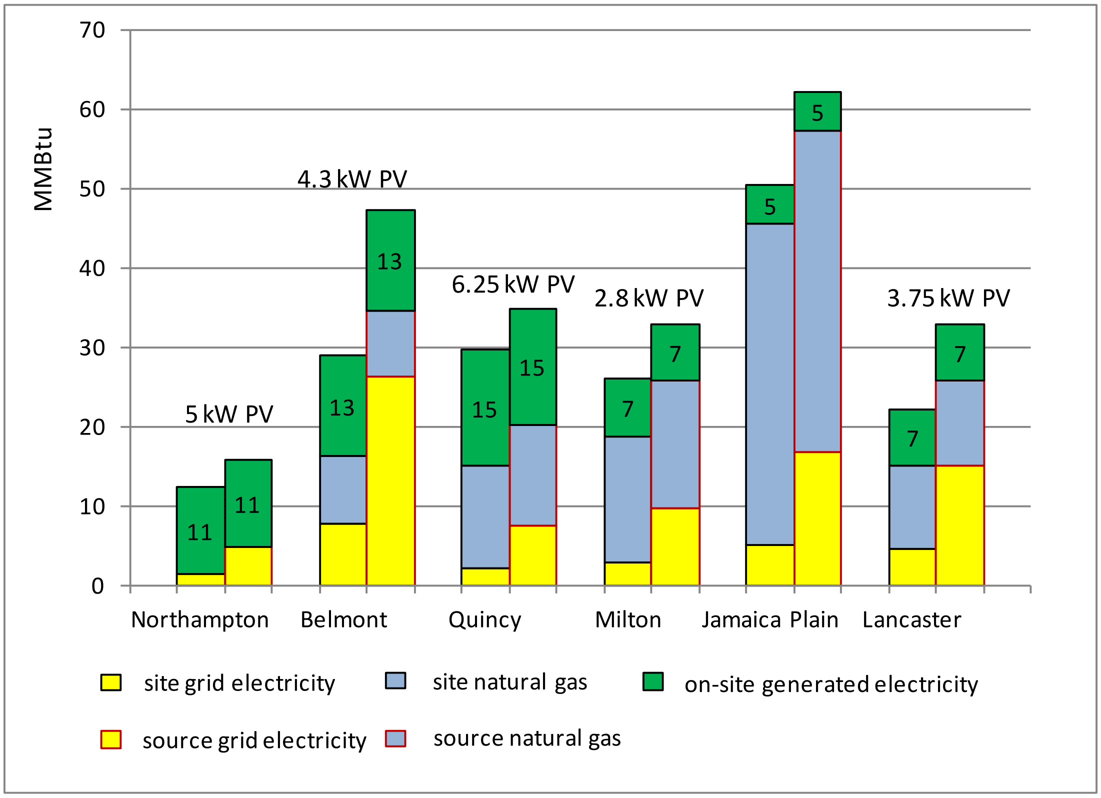


Figure 23. Post-retrofit February 12–July 12 site and source energy use with credit for on-site generated electricity

4.2.3.2 Heating and Cooling Energy Use

Most of the measures in the National Grid DER package address reduction of energy use by minimizing heat loss (or gain) through the building enclosure. The effectiveness of these enclosure measures is best demonstrated by the post-retrofit heating and cooling energy use.

The energy use information available for these retrofits does not support a clear disaggregation of heating and cooling energy use versus other energy uses. However, an approximate disaggregation can be made by asserting that the lowest monthly use for each fuel type represents the nonheating/cooling load. Subtracting this amount from each month of post-retrofit energy use data results in energy use that can be attributed primarily to heating or cooling.

Figure 24 shows the total site and source estimated heating and cooling energy use per household for August 2011 through July 2012 for those retrofits with a year of data and for February 2012 through July 2012 for those with only 6 months of data. It should be noted that this is a time period that included an exceptionally mild winter and an exceptionally hot summer. The range for the 12-month period was 7–35 site and 19–51 source heating and cooling MMBtu per household; the range for the 6-month period was 2.5–31 site and 8–45 source heating and cooling MMBtu per household.

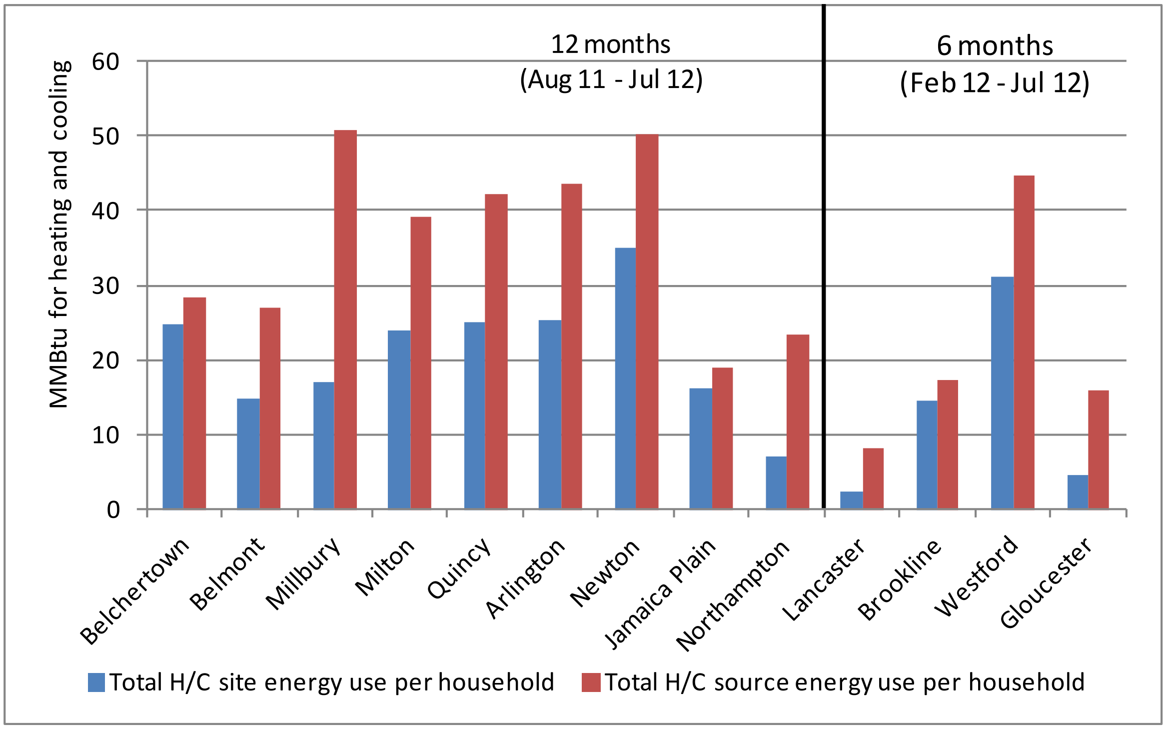


Figure 24. Post-retrofit 12- or 6-month total site and source MMBtu for heating and cooling per household

Figure 25 shows the post-retrofit heating and cooling source energy use in $kBtu/ft^2$ for February 2012 through July 2012 for all of the projects and for August 2011 through July 2012 for those projects with a full year of data.

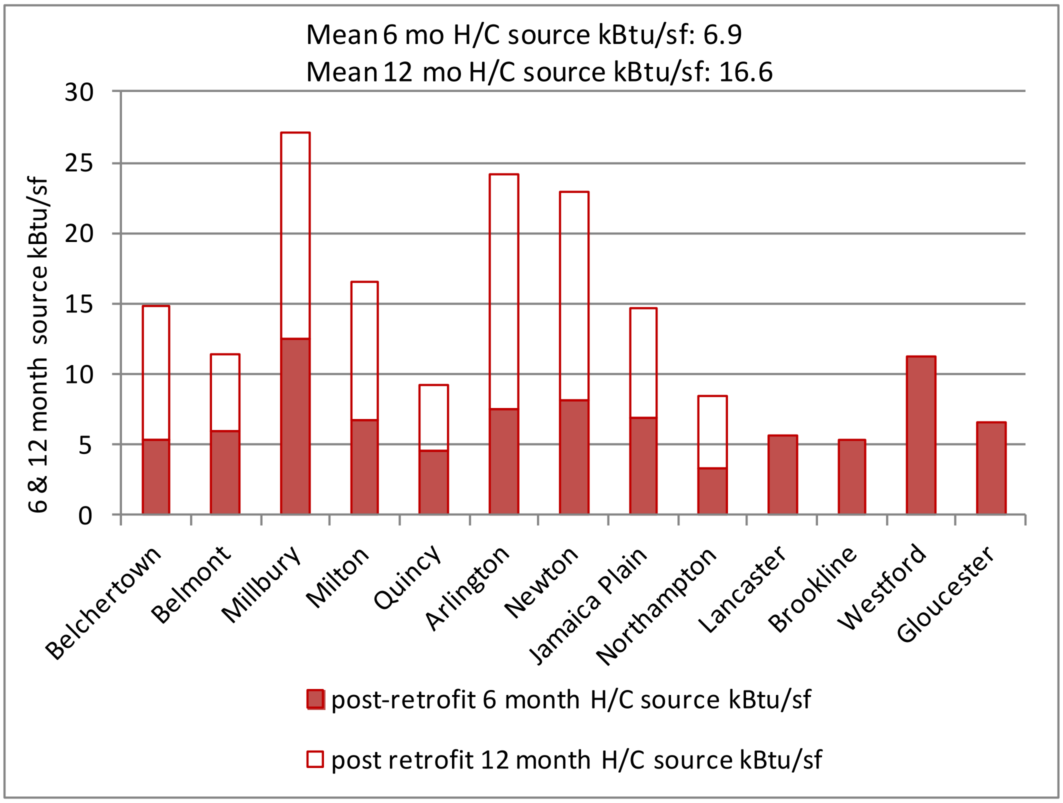


Figure 25. Post-retrofit 6- and 12-month source kBtu/ft^2 for heating and cooling

For the 6-month period, the range of energy use is 3.3–12.5 source kBtu/ft^2 for heating and cooling; for the 12-month period, the range is 8.5–27 source kBtu/ft^2 for heating and cooling. Most of the retrofits with 12 months of data are in the range of 10–25 source kBtu/ft^2-yr for heating and cooling.

As can be seen in Figure 25, the post-retrofit 12-month heating and cooling source energy use in kBtu/ft^2 for the Millbury retrofit is significantly higher than the other 12-month retrofits, and the post-retrofit 6 month heating and cooling source energy use for both the Westford and the Millbury retrofits is significantly higher than for the other retrofits. These two retrofits were also among the highest in overall source energy use in kBtu/ft^2 (and the highest in total heating and cooling source energy use per household [Figure 24]). Therefore, these two retrofits are further analyzed as “outliers” in Section 4.2.3.

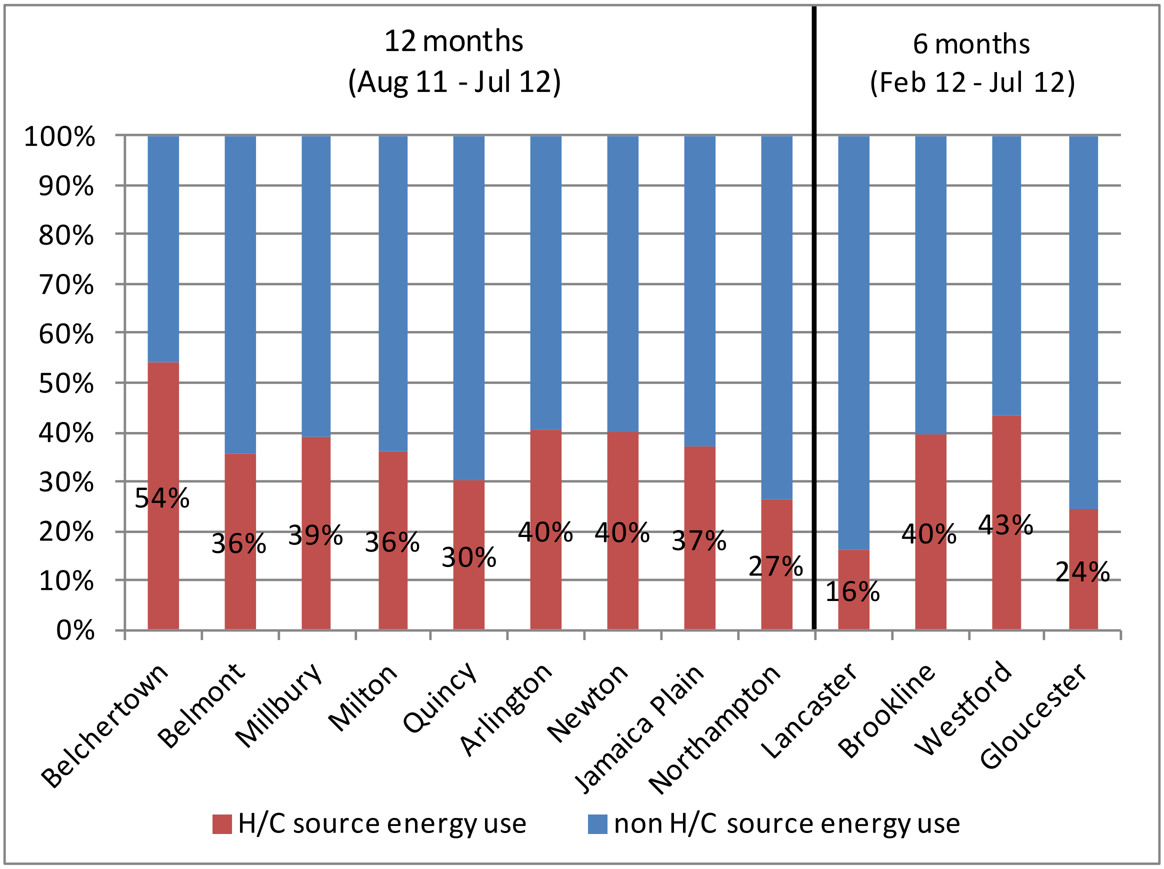


Figure 26. Heating and cooling source energy as percent of total source energy use

Figure 26 shows the source energy use for heating and cooling as a percentage of the total source energy use. The range is 27%–54% of the total source energy for those projects with a full year of data. For those with only 6 months of data, the range is 16%–43%.

While all of the projects initially used gas, propane, or oil heating, several of the projects switched to electric heating as part of the energy retrofit. As noted earlier, electricity usage incurs a higher source to site ratio so the increased efficiency of the electric heating solution needs to compensate for this to be an effective energy use reduction strategy. "Efficient" in this sense includes not only the efficiency of the equipment, but also that of the design and installation, the operation of the equipment, and the building enclosure. In Figure 27 the projects on the left use natural gas or propane for heating; the projects on the right use ASHPs or GSHPs. With the exception of the Millbury retrofit, the source energy used for the electric heating solutions for the retrofits are in the same range as that for efficient natural gas or propane boilers or furnaces.

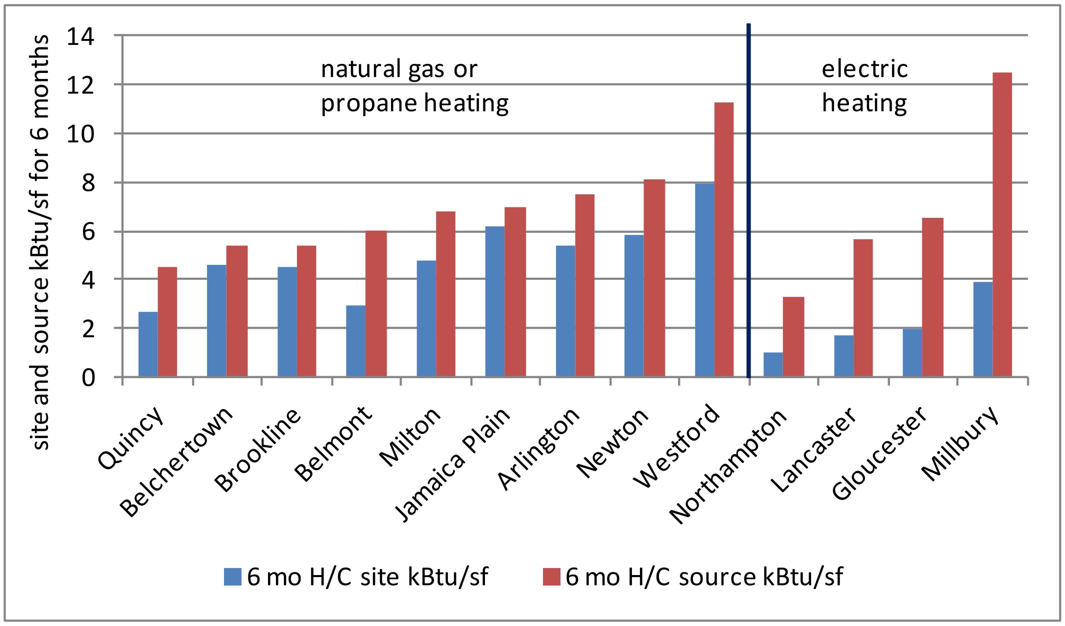


Figure 27. Electric versus nonelectric 6-month site and source heating and cooling kBtu/ft^2 for February 12–July 12

For the remainder of this section, the heating and cooling energy use is analyzed in terms of specific DER enclosure characteristics and variants to see if these demonstrate any differences in heating and cooling energy consumption.

4.2.3.2.1 Chainsaw Versus Non-Chainsaw

The installed R-value for the enclosure components is approximately the same for all of the retrofits, since these were specified in the DER package. However, the performance of the enclosure depends on other factors, including the approach chosen for implementing the DER measures.

Two enclosure characteristics that impact the performance of the enclosure are the extent of thermal bridging and the amount of air leakage through the enclosure. In the analysis of airtightness, the projects that used the chainsaw technique were seen to have the best airtightness results. The chainsaw technique also reduces thermal bridging through the enclosure, since the thermal control layer is wrapped completely around the exterior of the above-grade portion of the house.

Figure 28 shows the energy use in kBtu/ft^2 for the 6-month and 12-month time periods grouped according to whether the retrofits used the chainsaw technique or not. This shows only a minimal difference in overall heating and cooling energy use in the 6-month source kBtu/ft^2 between the chainsaw and the non-chainsaw groups, but the difference becomes more pronounced in favor of lower energy consumption by the chainsaw group for the 12-month period.

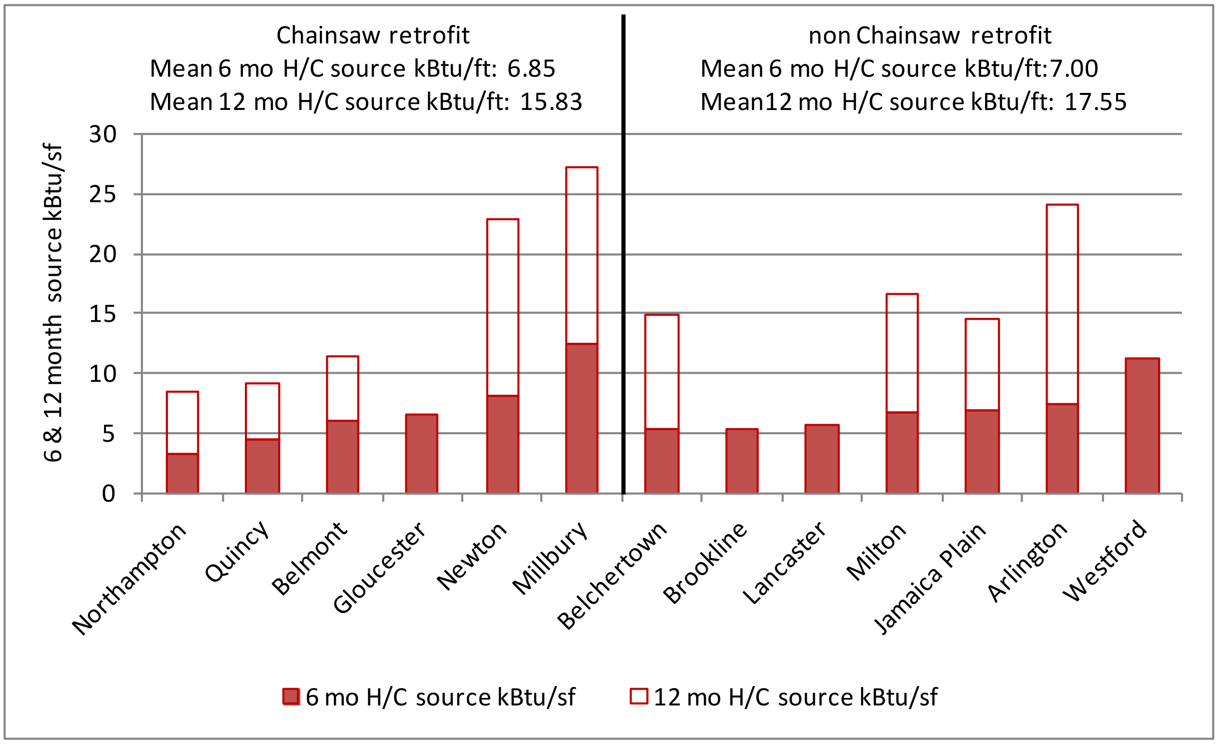


Figure 28. Chainsaw versus non-chainsaw 6- and 12-month heating and cooling source kBtu/ft^2

It should be noted that the two retrofits in the chainsaw group with the highest heating and cooling source energy use for both the 6- and 12-month periods—Millbury and Newton—were also the retrofits with the highest ACH50 measurements among the chainsaw retrofits. Another factor that may increase heating and cooling energy use for the Newton retrofit is that the porch roof and deck were not detached during the retrofit which allows some thermal bridging through the above-grade wall at the attachment.

None of the retrofits in this community used exterior insulation on both the roof and wall without also using the chainsaw technique. Use of exterior insulation without the chainsaw introduces some thermal bridging at the roof/wall intersection in spite of the exterior insulation, and as noted in Section 4.1.3 has been observed in other projects to result in more air leakage. Therefore, it is unlikely that exterior insulation alone accounts for these energy use results achieved by the chainsaw group.

4.2.3.2.2 Uninsulated Versus Insulated Basement

One of the enclosure variants among the retrofits was the treatment of the basement. Three different approaches were used:

- Unconditioned basement with insulation in the ceiling
- Conditioned basement with insulated walls but uninsulated slab
- Conditioned basement with insulated walls and insulated slab.

As noted in Section 4.1.2, the only retrofit that has an unconditioned basement—Arlington—had a significantly higher ACH50 measurement than the other retrofits. This would be expected to result in higher heating energy use. This expectation is supported in the overall 6-month and 12-month group results shown in Figure 29, but no definitive conclusion can be drawn with data from just one retrofit.

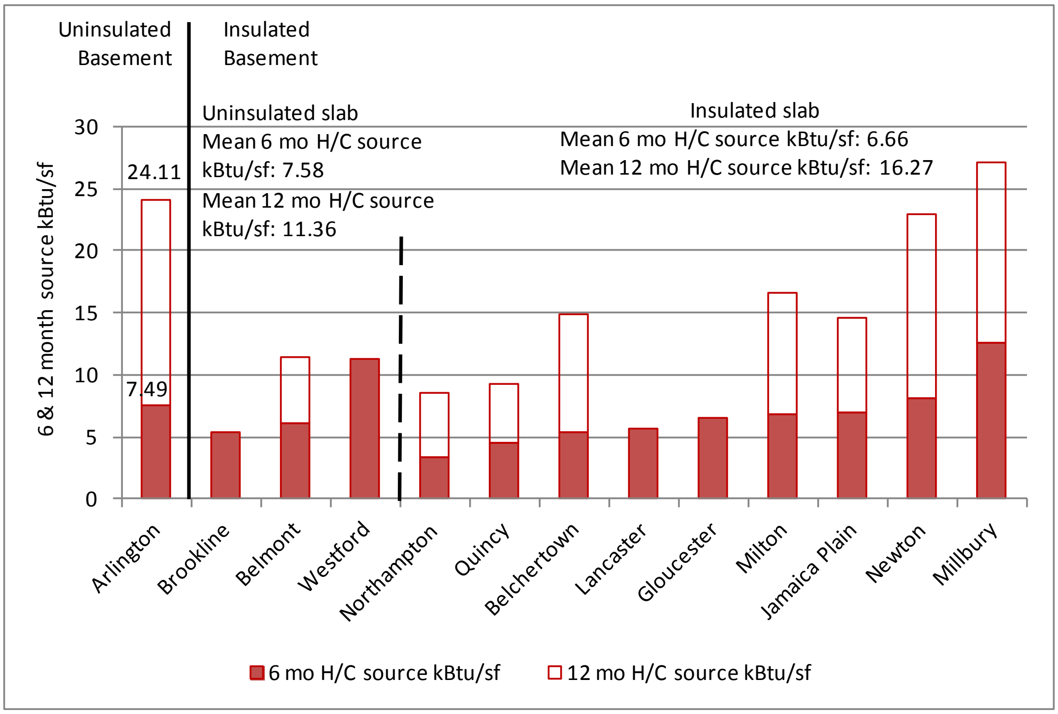


Figure 29. 6- and 12-month heating and cooling source kBtu/ft^2 grouped by basement treatment

There is no significant difference in heating and cooling kBtu/ft^2 between the conditioned basement groups with and without insulated basement slab. This is as expected since the moderate ground temperature reduces the potential for heat loss through the basement slab. The main reason that insulation on the basement slab is included in the DER package is to prevent condensation and control moisture transfer through the slab for improved indoor air quality and durability.

4.2.3.2.3 Unvented Versus Vented Attic

Another variant among the retrofit projects was treatment of the attic. The different approaches used were as follows:

- Vented attic with insulation at the attic floor
- Unvented attic with insulation under the roof deck
- Unvented attic with exterior insulation over (as well as under) the roof deck.

Vented attics and unvented attics with all insulation below the roof tend to have some heat loss at the wall/roof intersection due to the thermal bridging through the framing there and the limitation on the amount of insulation that can be installed between the top of the wall and the roof sheathing. Figure 30 shows the heating and cooling source kBtu/ft^2 for the 6- and 12-month periods grouped according to the attic and roof treatment.

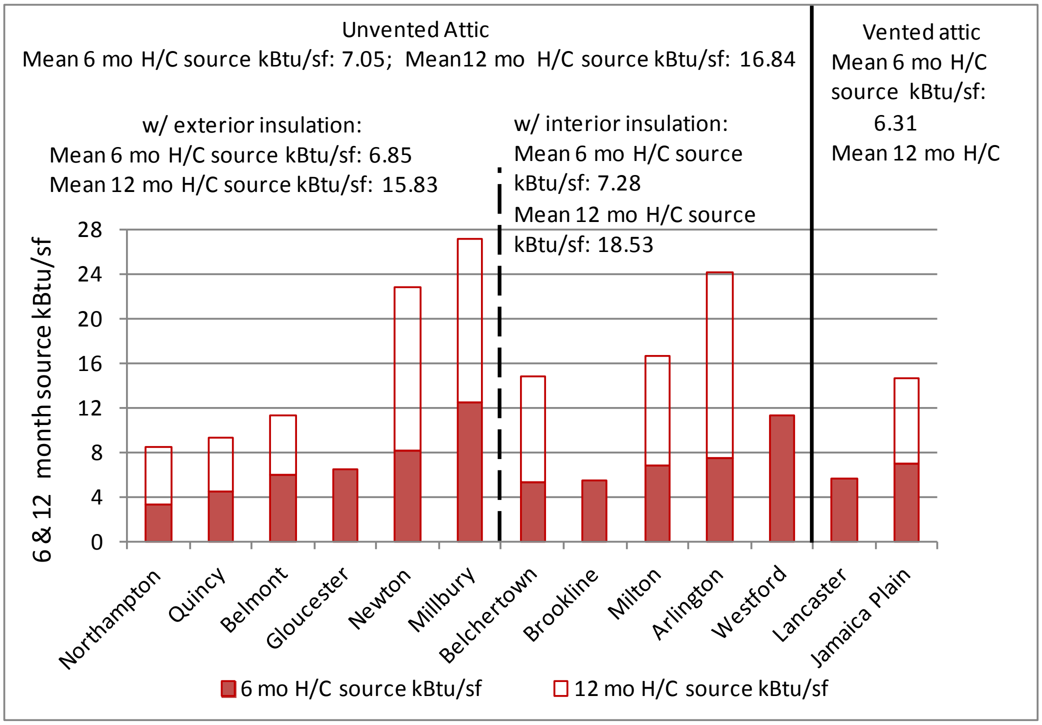


Figure 30. 6- and 12-month heating and cooling source kBtu/ft^2 grouped by roof and attic treatment

With this grouping, the vented attics have the best heating and cooling kBtu/ft^2 as a group. However, only two projects in this community have vented attics and neither of these projects is typical for a vented attic DER. For the Lancaster project, the roof and attic are new construction; for the Jamaica Plain project, some of the walls in the upper floor are not treated.

For the unvented attic groups, the overall heating and cooling kBtu/ft^2 as a group for the exterior roof insulation was better than for the group with interior roof insulation. In this community, the group with exterior roof insulation corresponds to the chainsaw group.

4.2.3.2.4 Airtightness Versus Heating and Cooling

Air leakage is a major source of heat loss for existing homes in the Northeast region. Figure 31 and Figure 32 check for a correlation between the post-retrofit heating and cooling source kBtu/ft^2 and the post-retrofit ACH50 for the 6- and 12-month time periods.

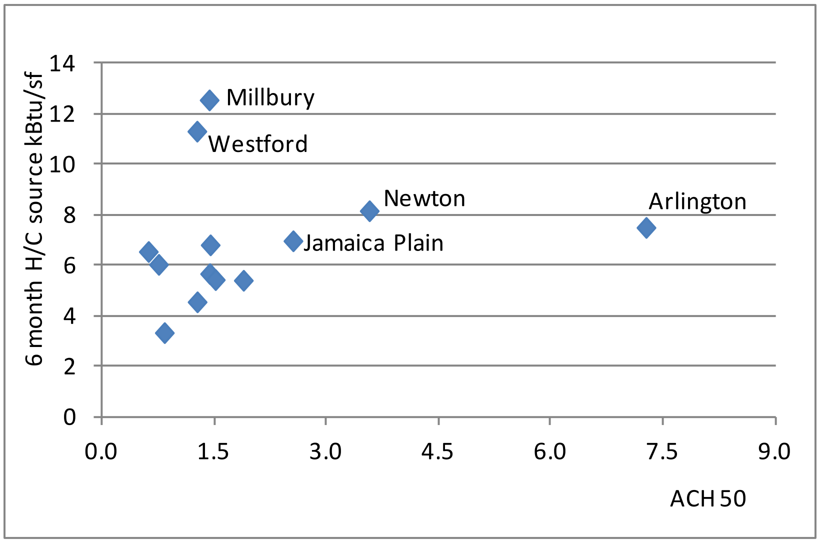


Figure 31. Relationship between 6-month heating and cooling source kBtu/ft² and ACH50

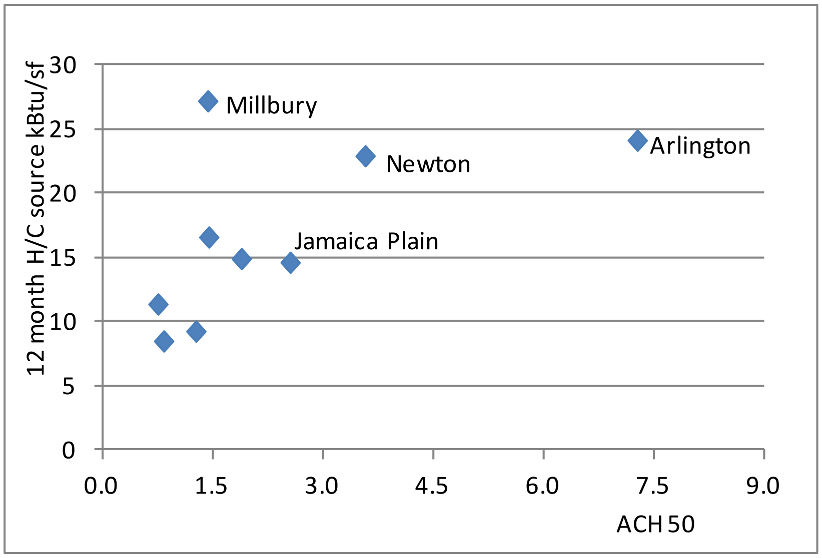


Figure 32. Relationship between 12-month heating and cooling source kBtu/ft² and ACH50

There is not a strong correlation shown for either of the time periods. It can be noted, however, that the Arlington, Newton, and Jamaica Plain retrofits had the least successful airtightness results and these are among the higher heating and cooling energy consumers in kBtu/ft² for the two time periods. Most of the projects with ACH50 of 1.5 or less are in the lower energy use range with the notable exceptions of Millbury and Westford. While ACH50 results lower than 1.5 may improve comfort and indoor air quality, the results from this group of retrofits do not show a clear advantage for those with even lower ACH50 results.

4.2.4 Analysis of Energy Use "Outliers"

In the preceding analysis, the Westford and Millbury retrofits are among the highest projects in total source energy use and are the two "outliers" in the analysis of heating and cooling energy use. Both of these homes have airtightness below 1.5 ACH50 and have efficient heating and cooling equipment, so these results are unexpected. As a result, site investigations and a closer look at the energy data for these two homes were undertaken during October 2012 to look for explanations.

4.2.4.1 Further Investigation of Westford Retrofit

The Westford retrofit was completed in December 2011, so only 6 months of post-retrofit energy use data are available for this report. The Westford house was built in 1993, the most recently built of all of retrofits in this retrofit community. The retrofit project included the addition of 1,049 ft^2 of conditioned space, which was a combination of a two-story addition (with basement) and a new roof structure to support the development of finished space in the attic. Following the retrofit, this house has 2,955 ft^2 of conditioned space distributed through three stories and the basement.

Since airtightness had already been tested, the purpose of the site investigation in October 2012 was to check the operation of the HVAC equipment. Heating is provided by a natural gas furnace that was reconfigured from one to three zones (main house, master bedroom suite above garage, and basement) as part of the retrofit. The AHU fan has an electronically commutated motor but is set to deliver a constant airflow regardless of the zone configuration thus failing to take advantage of electronically commutated motor capabilities.

Cooling is provided by a new indoor air coil attached to the AHU with a 16 SEER outdoor unit. There is an ERV in the basement with exhaust air taken from a partially above-grade space in the basement (which is to be finished by the owner) and outside air delivered to a single floor register on the first floor. The ERV is operated on a 10% run time setting. This outside air is further distributed through the main part of the house by operating the furnace AHU in fan-cycling mode.

Measurements and observations of the operation of these systems did not indicate any malfunction or abnormally high wattage draw. However, during the site investigation, it was observed that some of the registers were covered or closed, with approximately half of those in the master bedroom suite covered in an attempt by the homeowners to cut back on the conditioning or airflow, or both, in certain areas. Given the components and configuration of the system, this would result in a somewhat higher wattage draw by the AHU fan than would be the case if the system were operated with all registers open.

There is a dehumidifier located in the basement. The homeowners report that this had run essentially 100% of the time in the summer. Since there was probably still moisture in the basement from the construction (both from the new concrete in the basement and water that accumulated on the basement floor during construction), some operation of the dehumidifier would have occurred during the first several months as well. However, the continuous operation during the summer would contribute to the reported electricity use for the heating and cooling loads. During the site visit, the dehumidifier did not appear to be removing moisture effectively. This was determined by operating the dehumidifier for a period of time and then measuring the level of humidity at the air intake and output of the dehumidifier. Measurements taken on site also found the dehumidifier to draw 450–480 W when operating. If the dehumidifier operates a significant portion of time, presumably in response to a humidistat, but does not effectively remove moisture, it would use significantly more energy than if the dehumidifier were working correctly. Given the draw of this equipment, the energy use associated with this dehumidifier would also factor significantly in the total energy use for the home.

While the Westford retrofit met most of the target DER goals for the enclosure, the window component for the Westford retrofit deviates slightly from the DER target U-value of 0.20. Due to aesthetic and cost considerations, the owners decided to use a high quality double-glazed window with U-value of 0.29 rather than use any of the available windows with U-value of 0.20 or lower. The glazing to above-grade wall ratio for this house is around 10%. This substitution increases the total heat loss coefficient by about 10% for the building enclosure.

The combination of the observations from the site visit and the less efficient windows would contribute to a somewhat elevated energy use for heating and cooling. However, these issues would not be expected to be as significant as indicated by the analysis in the previous sections. Since the project was not completed until December 2011, it may be that some of the additional energy use experienced during the 6 months is due to initial operation and learning how to effectively use the installed systems. The energy use on this project will continue to be monitored to see if the trend for exceptionally high energy use for heating and cooling continues.

4.2.4.2 Further Investigation of Millbury Retrofit

The Millbury retrofit was completed in December of 2010. In an analysis of post-retrofit energy use through August 2011 (Osser et al. 2012), it was noted that the energy use was higher than expected. Since this continues to be the case, this cannot be attributed to initial operation issues.

The Millbury retrofit was among the first participants in the National Grid DER pilot project. The house is a compact Cape Cod style with a full basement. An existing shed dormer was extended across the rear of the second floor as part of the retrofit. Even with added space, this is one of the smallest houses in the retrofit community. The homeowners are recent “empty nesters” who have lived in the house for more than 25 years. The retrofit was undertaken in keeping with their long-standing goal of being energy efficient and reducing their impact on the environment.

In addition to thermal and airtightness enclosure improvements, the retrofit included installation of an ASHP system for heating and cooling to replace an oil boiler system supplemented with a pellet stove and four window air conditioners. The pellet stove was converted to a closed combustion system and retained as a backup heating system, but the homeowners report that it was rarely used during the 12-month period that this report covers. Other energy use improvements included switching from desktop to laptop computers, replacement of incandescent lighting with compact fluorescent lamps and light-emitting diodes, and installation of a propane instantaneous hot water system.

The primary purpose of the site investigation in October 2012 was to check the operation of the HVAC system, but also to look for an explanation for why the baseline energy use was not appreciably lower than it had been before the retrofit. The ASHP system is a ducted mini-split with one outdoor unit supplying two indoor compact AHUs. Both AHUs are located within the thermal enclosure—one in the basement and one in the attic. The ventilation system is supply-only with outside air delivered to the return at each of the AHUs and controlled by a motorized damper. The homeowners have been very satisfied with the heating and cooling comfort levels since the retrofit, though they noted occasional "stuffiness" (Osser et al. 2012) and somewhat slow response time from the AHUs.

During the site visit in October 2012, the following observations were made:

- The ductwork for the AHUs is very restricted with 4-in. ducts, long runs, and multiple elbows that would result in more static pressure than the systems were designed to handle.
- The AHUs are operating significantly below the rated airflow capacity.
- There was a draw of 150–180 W on the heat pump circuits when the system was not operating—no fans or compressors were operating.
- The outdoor air supply controller had no connection to the AHU controls; this type of supply-only system is expected to be distributed by fan-cycling.
- There was an error code displayed at the thermostat—the homeowner's service manual indicated that the resolution of this error is to replace the indoor or outdoor control board, or both.

The first two observations would contribute to higher energy consumption for heating and cooling than expected. The third adds to the base load even when the heat pump is not in use. The fourth means that the background ventilation air is not being distributed through the living space unless there is also a call for heating or cooling. The final observation indicates that there is malfunction in the system.

Subsequent to the site visit, the homeowner has contacted a manufacturer-approved contractor for assistance. The error code has been resolved—a wire had come loose—but the other performance issues have not yet been resolved.

4.2.5 Conclusions of Energy Use Analysis

The nine retrofits in this retrofit community for which 12 months of post-retrofit data were available each achieved the 2012 BA goal of 30% reduction in total source energy use for 12 months of pre- versus post-retrofit energy use. Of those, four of the retrofits were able to achieve the National Grid DER goal of 50% reduction. For the retrofits for which only 6 months of post-retrofit energy data were available, most of these appear to be on track for at least a 30% reduction in yearly source energy use. For retrofits that were primarily an enclosure upgrade and involved a reasonably well-maintained and continuously occupied home, the precentage energy use reduction was within 30%–45%.

The following comparisons to benchmarks are based on weather normalized post-retrofit energy use for the nine retrofits with a full year of post-retrofit data:

- All of these retrofits are below the EIA Northeast regional household average of total source energy use; three of the retrofits are less than 50% of that household average.
- All but one of the retrofits are below the EIA Northeast regional multifamily and single family average for source EUI averages with three retrofits below 50% of those averages.
- Three of the retrofits meet the 2012 site EUI goal for the 2030 Challenge without taking any credit for on-site electricity generation.

Based on this community, this DER package may be expected to result in yearly source energy use of 30–60 source kBtu/ft^2-yr during a year with HDDs and CDDs comparable to August 2011 through July 2012. Similarly heating and cooling source energy use may be expected to be in the range of 10–25 kBtu/ft^2-yr. Post-retrofit thermostat setpoints were not tracked for this community, so these ranges do not incorporate specific operating condition assumptions.

The following trends relating enclosure characteristics to heating and cooling source EUI were observed within this community:

- When taken as groups, heating and cooling source EUI is lower for chainsaw retrofits than for non-chainsaw retrofits and lower for unvented attics with exterior insulation than for unvented attics with interior insulation only; however, with the available data, it cannot be concluded that these are the only determining factors for these results.
- In a conditioned basement, insulation of the basement slab does not appear to impact heating and cooling energy use.
- While the lower heating and cooling source EUI results were obtained by retrofits with ACH50 of 1.5, there is no clear advantage demonstrated for even lower ACH50 results.

The follow-up analysis of the two outlier cases suggest that the DER process needs to be more specific with the HVAC measures to ensure the following:

- The homeowner’s expectations are factored into the design of the HVAC system.
- The HVAC designer and contractor has knowledge of, and experience with, the systems being installed.
- The HVAC contractor verifies the operation of, and the performance of, the system after installation.
- The homeowners receive simple and clear instructions about the operation of the systems that include how to operate these for maximum efficiency.

4.3 Construction Cost Analysis

4.3.1 Deep Energy Retrofit Measure Costs Data

Prior to participating in the National Grid DER Pilot, prospective participants completed a series of application forms that provided information about the project team, project financing, existing building conditions, energy use history for the building, project plans, project costs, and homeowner objectives. (See Appendix B for a blank application form.) The application requires projected cost information for specific DER measures. These measures correspond to major enclosure components, air sealing (if implemented as a separate retrofit measure), as well as ventilation, heating, and cooling systems. The contractor for the prospective project team provided the measure cost information included in the application. The cost information in the application typically reflects the contractual cost for implementation of these measures. Therefore, the cost reported is the cost to the homeowner and not the contractor's cost to implement the measure.

The application also distinguished between total DER project costs and those costs that are "allowable" or eligible for incentives. The types of costs that are not allowable or are excluded from the allowable costs include costs for related repair or renovation, third-party contributions, and certain deductibles. For example, the materials and labor for installation of new roofing or siding over exterior insulation would not be an allowable cost, whereas the labor and materials needed to install exterior insulation would be an allowable cost. Rebates or incentives from other programs are excluded from DER costs eligible for incentives. Also, the value of donated labor and materials (applicable to a Habitat for Humanity project included in this study) would be excluded from incentive eligible costs. The DER pilot program provides incentives toward the full cost of installing qualified windows less a deductible of $15/ft^2 of window area.

The project application forms also solicit input from project teams as to the details of the reported costs. This cost detail information might indicate, for example, the cost for installation of exterior insulation as distinct from the cost for cavity insulation for a DER roof measure. The level of cost detail is not consistent among the participants in the DER program. However, the information does provide some basis for distinguishing, for each measure and for each project, the DER measure costs related to energy performance and those not related to energy performance. The homeowner and contractor for one of the projects collaborated on a post-completion analysis of project that included an analysis of the project costs. Through study of the cost detail data provided in the application forms or in separate analysis produced by project teams, costs related to measures affecting energy savings were identified. These include some necessitated by measures affecting energy performance. In most cases there are modest differences between allowable DER measure costs and energy-related cost for each project. The energy-related costs include the full window replacement measure cost as the window measure affects the energy savings for the building.

Table 9 below shows the total DER project cost and the allowable DER measures costs reported on the applications for the 13 projects in this study. It also shows the energy-related DER measure cost as determined through this study.

Table 9. National Grid DER Project Costs, Allowable Project Costs and Energy-Related DER Measures Costs as Derived From Program Application Forms

DER Project	Total DER Project Cost	Allowable DER Measures Cost	Energy-Related DER Measures Cost	Energy-Related Enclosure Measures Cost	Energy-Related HVAC Measures Cost*
Belchertown	$64,629	$60,129	$51,642	$35,045	$16,597
Belmont (Two-Unit Building)	$178,938	$146,453	$174,762**	$142,094	$32,668
Millbury	$82,719	$66,234	$71,569	$49,894	$18,875
Milton	$77,762	$59,477	$66,236	$51,236	$15,000
Quincy	$125,547	$99,483	$108,515	$68,915	$39,600
Arlington (Two-Unit Building)	$124,853	$88,628	$95,163	$69,537	$26,856
Newton	$148,252	$92,552	$96,039	$65,539	$31,500
Jamaica Plain (Three-Unit Building)	$214,650	$170,060	$180,678	$165,528	$15,150
Northampton	$241,991	$125,931	$119,701	$85,061	$34,640
Lancaster	$75,998	$41,402	$57,446	$47,408	$10,038
Brookline (Partial DER: Walls and Windows Only)	$134,409	$80,929	$73,055	$58,850	$14,205
Westford	$117,710	$106,123	$107,464	$94,080	$13,384
Gloucester	$142,316	$95,436	$89,165	$70,665	$18,500

* HVAC measures costs to not include water heating measure costs that are included in the DER measures costs for some projects.
** Energy-related DER measure costs for Belmont are taken from a post-project analysis produced by the homeowner with input from the contractor.

There is considerable variation between projects in the DER measure costs. While many factors will affect variation in project costs, the size and scope of the project will have a very significant impact. Figure 33 and Figure 34 show the DER measure costs relative to post-retrofit conditioned floor area and treated enclosure area, respectively.

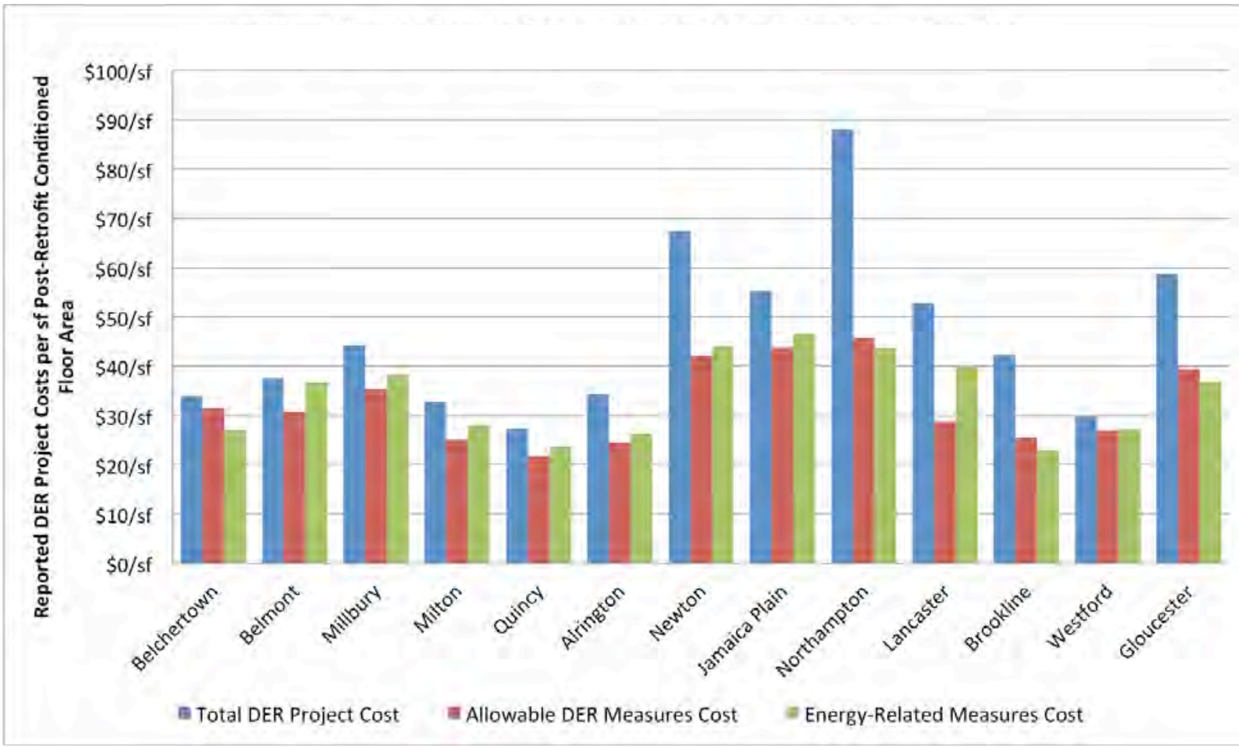


Figure 33. Total, allowable, and energy-related DER measure costs normalized to post-retrofit conditioned floor area

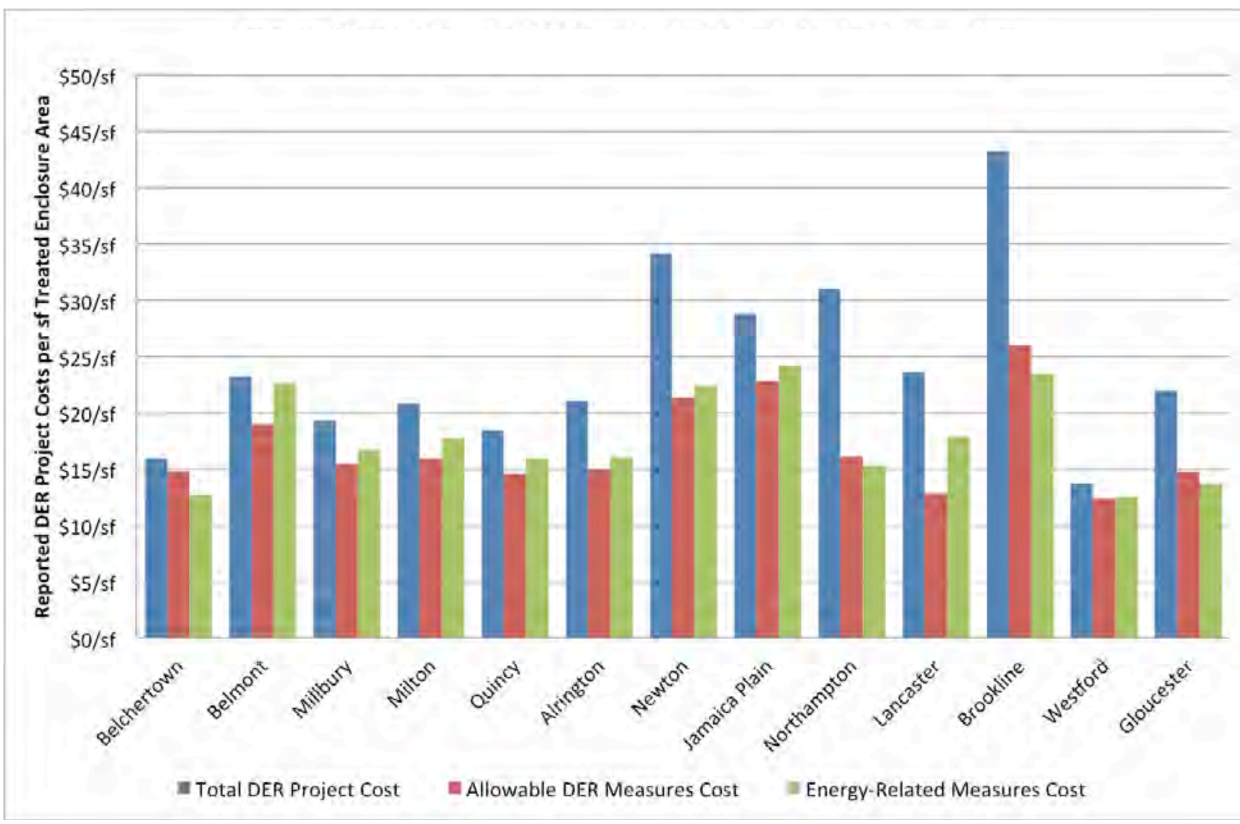


Figure 34. Total, allowable, and energy-related DER measure costs normalized to treated enclosure area

When normalized to conditioned floor area, the allowable DER measure costs range from \$21.74–\$45.84/ft^2 of post-retrofit conditioned floor area. The average for the group of projects is \$32.40/ft^2 of post-retrofit conditioned floor area. Normalized to treated enclosure surface area, the allowable DER measure costs range from \$12.39–\$26.03 and average \$17.00/ft^2 of treated enclosure surface area. While not exhibiting as much of a range as the nonnormalized DER project costs, the normalized project costs still vary by a factor of more than 2.

The variation in normalized project costs exhibited between projects highlights the varying circumstances of each project, experience of the implementing contractors, and variations in approach. The remainder of this section presents the total measure cost and energy-related measure cost for a number of significant DER project components. This allows for an exploration of how different approaches to the DER measure package affect the measure costs. To facilitate the comparison between projects of varying size and circumstance, the cost data are presented as unit cost; i.e., normalized to area (either conditioned floor area, total enclosure area, or treated enclosure area) or number of dwelling units served (for HVAC measures).

4.3.1.1 Building Enclosure Measures

Figure 35 shows the reported unit (per square foot) total measure and energy-related measure cost for attic and roof retrofit measures implemented by projects in this study. For the projects that implemented insulating sheathing and cavity insulation, the major difference between total measure cost and energy-related measure cost is the cost of reroofing. One of the projects that implemented cavity insulation only also included the cost of reroofing in the total measure cost. The high total measure cost indicated for one of the projects implementing a vented attic approach represents the cost of framing and installing a new roof.

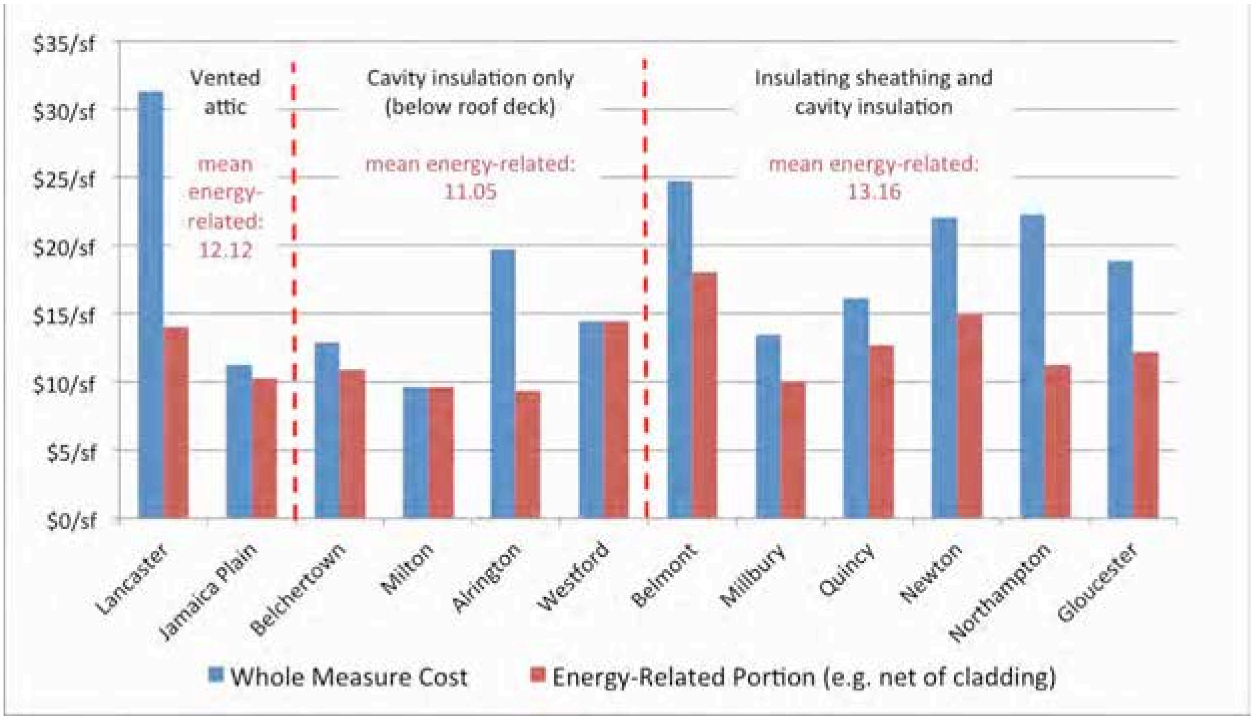


Figure 35. Unit costs for attic and roof measures

Among the different attic and roof approaches implemented by projects included in this study, the mean energy-related unit costs are lowest for those projects that implemented an unvented attic approach using spray foam insulation applied entirely below the existing roof deck. The mean energy-related unit cost is somewhat higher for the vented attic approach. Insulating sheathing plus cavity insulation is the attic and roof approach that exhibits the highest mean energy-related unit cost. The mean energy-related unit cost for this approach is 16% higher than the mean energy-related unit cost for the cavity insulation only approach.

For all the projects in this study, the energy-related unit cost for the attic/roof measure ranges from \$9.36–\$18.05/ft^2. The project with highest energy-related unit cost implemented an approach of insulating sheathing and roof framing cavity insulation. There was no insulation in the roof framing cavities prior to the DER project and the project also used three layers of insulating sheathing on the roof. One project (Millbury) that implemented a roof retrofit strategy involving insulating sheathing and cavity insulation has a reported energy-related unit cost that is lower than the mean for the cavity insulation only approach. For this project, existing insulation in the framing cavities was sufficient to allow the project to substantially meet the performance targets with two layers of insulating sheathing installed above the roof sheathing. This house is a 1½-story cape that presents a relatively low height and simple geometry roof that required minimal staging.

The above analysis of unit costs for attic and roof measures compares measure cost to surface area of the enclosure. Once could argue that it would be more appropriate to compare the measure cost to the area of the building footprint that is covered by the attic and roof assembly, as is shown for the energy-related attic and roof measure costs in Figure 36.

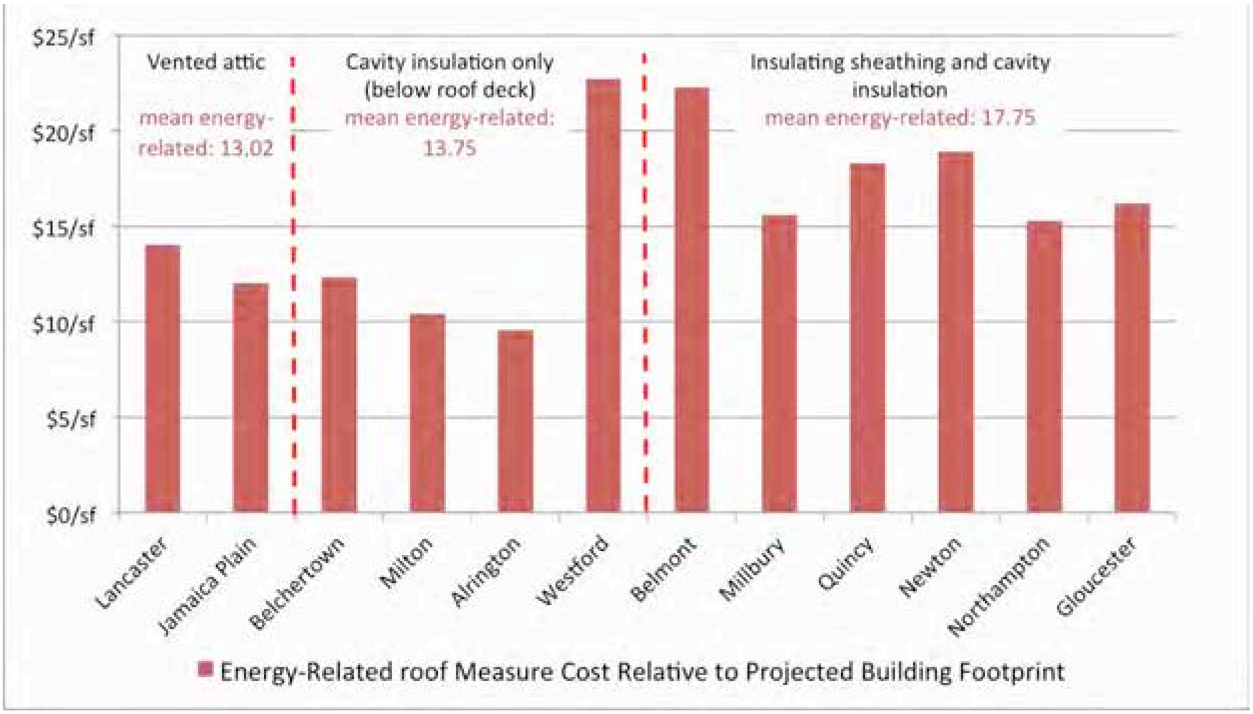


Figure 36. Costs for energy-related attic and roof measures per square foot of building footprint covered

It has been asserted by Straube and Grin (2010) that insulation of the attic floor in a vented attic is the least costly strategy for achieving a high R-value attic and roof assembly. This is not immediately apparent in the data from this group of projects. In fact, excluding one apparent unvented attic outlier, it appears that the cost of providing thermal control at the top of the building may, in fact, be noticeably less with an unvented attic strategy using cavity insulation directly below the roof deck.[1] Regardless of whether the unvented attic approaches are somewhat more or somewhat less costly than the vented attic strategy, it must be acknowledged that the unvented attic approach has the potential to enclose more usable space than a strategy employing insulation at the attic floor. Three of the projects in this study involve Cape Cod style homes that included living space within the roof enclosure prior to the retrofit. For four of the projects in this study, establishing the thermal enclosure at the plane of the roof allowed an increase in conditioned floor area.

Figure 37 shows the reported unit (per square foot) total measure and energy-related measure cost for wall retrofit measures implemented by projects in this study. One project, Belchertown, implemented a wall retrofit measure involving interior insulation only. The other 12 projects in this study implemented a wall retrofit strategy of exterior insulation in addition to existing or new wall cavity insulation.

[1] The increase in area to be insulated as well as the generally more expensive insulation material typically used in the unvented attic approach make this seem implausible. Mitigating factors that would add to the cost of the vented attic approach include efforts needed to make penetrations through the top floor ceiling airtight and to provide a well gasketed and insulated access (where needed).

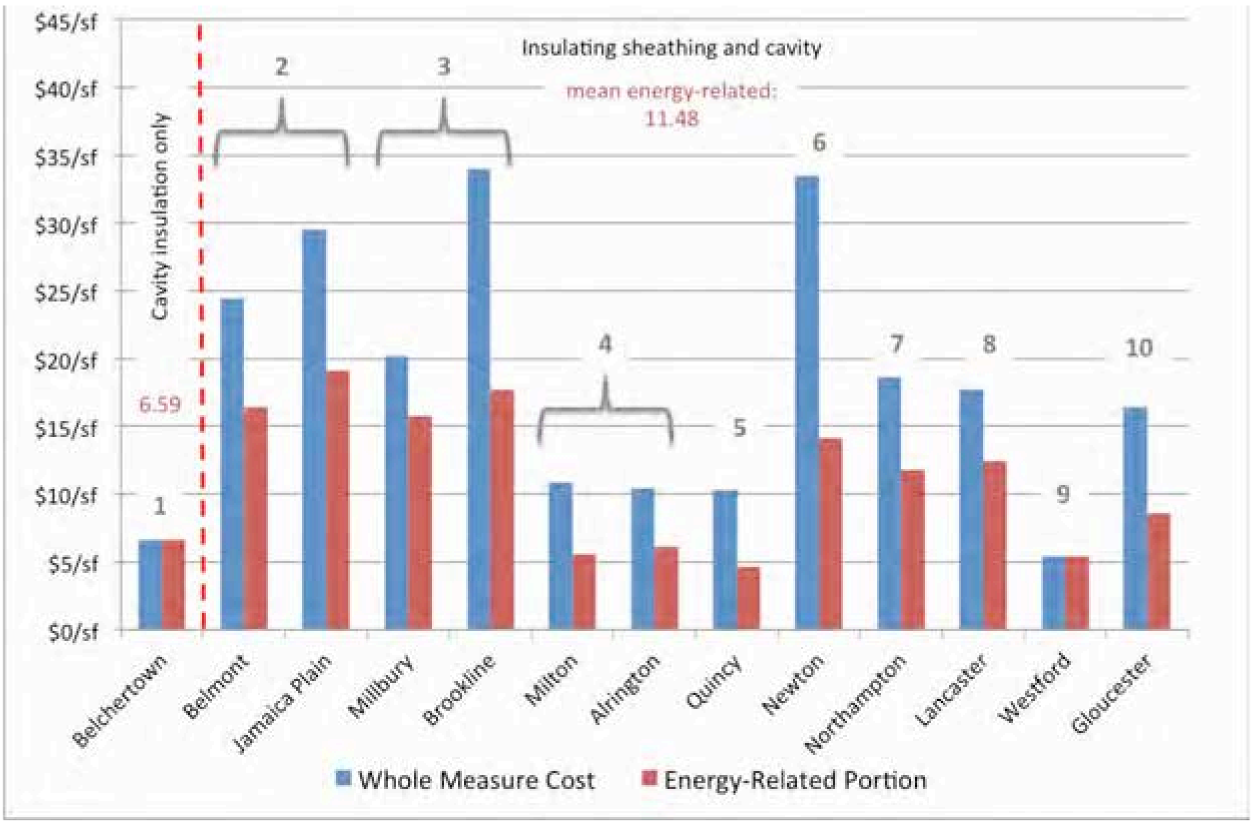


Figure 37. Unit costs for wall measures

The mean energy-related unit cost for the insulating sheathing and cavity insulation approach is clearly higher than the energy-related wall retrofit cost for the one project that implemented a cavity insulation only approach. Interestingly, four of the projects that implemented the insulating sheathing and cavity insulation approach exhibit a lower energy-related unit cost for this measure than the project implementing the cavity insulation only approach.

Numbers above the bars in this chart designate the contractor implementing the project. It is worth noting that the contractor designated by the number “3” was a subcontractor to contractor “2” for the exterior wall insulation at the Belmont and Jamaica Plain projects. The data presented in this chart suggest that the variability of unit costs between contractors is more significant than the variability of cost between the different approaches.

Figure 38 shows the reported unit (per square foot) total measure and energy-related measure cost for foundation wall retrofit measures implemented by projects in this study. All of the foundation wall retrofit approaches implemented by projects in this study involve foam plastic insulation (rigid board or spray-applied) that requires an ignition barrier. This typically takes the form of an intumescent coating (for spray foam) or a frame wall with gypsum sheathing (for rigid insulation or spray foam). Two projects installed rigid board foam insulation without a frame wall. One of these used a proprietary insulation board with a thick aluminum facer, the other used OSB and plywood fastened directly over the foam boards. Only one of the projects in this study provided a cost break-out with sufficient detail to distinguish energy-related measure costs from total foundation wall measure costs.

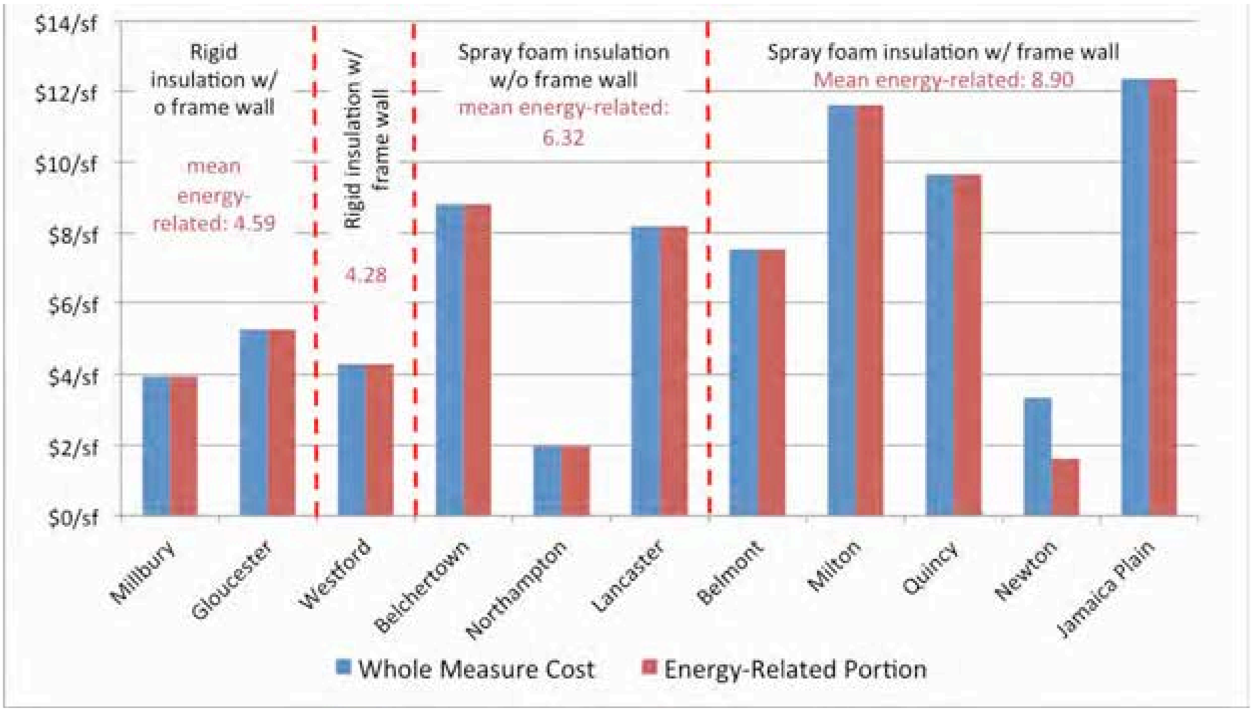


Figure 38. Unit costs for foundation wall measures

There appear to be some unit cost anomalies for the two spray foam insulation approaches. Excluding these anomalies, the unit costs for foundation retrofit approaches using rigid insulation are clearly lower than for either approach involving spray foam insulation. Among the spray foam insulation approaches, the approach that uses a frame wall and gypsum board to establish the fire protection exhibits a higher mean unit cost. It should be noted that the rigid insulation approach is appropriate only for foundation walls with a flat interior surface. Also, the frame wall with gypsum board clearly provides a different level of finish to the basement space than does the spray foam with an intumescent coating.

Figure 39 shows the reported unit (per square foot) total measure and energy-related measure cost for the floor or slab insulation retrofit measures implemented by projects in this study. For the projects that implemented a strategy of insulating over an existing slab, the cost information appears quite consistent. Among the projects that installed a new concrete slab over a new insulation layer, the variation in unit cost reflects differences in cost reporting. Only one of these projects reported costs in a way that allowed for the distinction of energy-related costs. The measure cost appeared to include the cost of a concrete slab in some cases. In one case, the basement slab measure is associated with comprehensive work to remediate bulk water problems. In another case, the slab retrofit measure cost appears to reflect the cost of the insulation only.

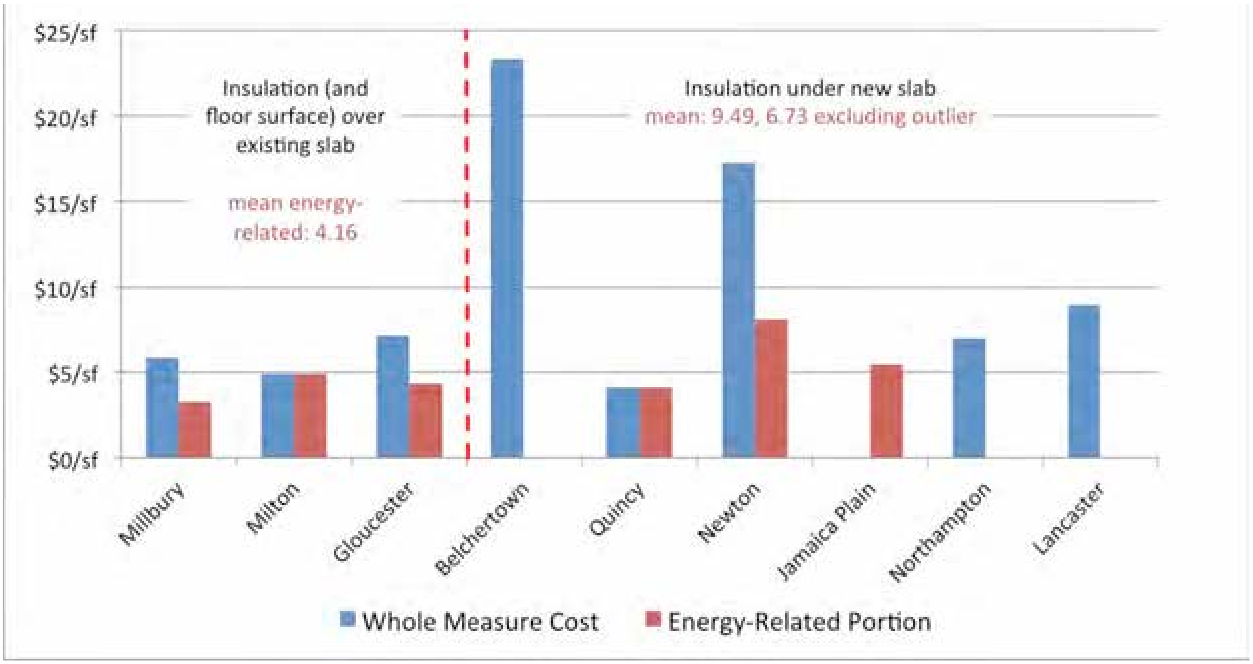


Figure 39. Unit costs for conditioned basement floor and slab measures

Because of the inconsistencies in the cost information for the measures involving insulation under a new slab, it is not possible to make comparison between the energy-related unit cost for different approaches based on the data used in this study. However, one would expect that inclusion of a new concrete slab (plus associated excavation if needed) would render the total cost much higher for the approach involving casting a new concrete slab.

Only one project in this study pursued a strategy of insulating the basement ceiling to exclude the basement from the thermal enclosure. The total reported cost (all energy-related) for this measure is $5,870 with a unit cost of $5.56/ft^2 basement ceiling area. This reported measure cost is lower than the reported cost for combined foundation wall and slab retrofit measures for the projects that included the basement within the thermal enclosure. For projects in this study that insulated foundation walls the average reported total measure cost, including reported costs for insulating the framing sill area (sometimes reported separately) is $6,793. For projects that insulated over an existing slab the average reported total measure cost is $5,005. Therefore, the average cost for combined foundation wall plus basement slab measures would be considerably more than the reported cost for insulating at the basement ceiling only.

Although we do not have direct cost comparison between an approach of insulating the basement ceiling versus an approach of insulating the foundation walls at a particular house, the cost information suggests that establishing the thermal boundary at the basement ceiling costs significantly less. As with the unvented versus vented attic strategies, the measure cost comparison for basement strategies must also consider the value of usable space that could be added through some of the strategies.

Figure 40 shows the reported unit (per square foot) total measure cost for window measures implemented by projects in this study. There is no distinction between total measure cost and energy-related cost for this measure.

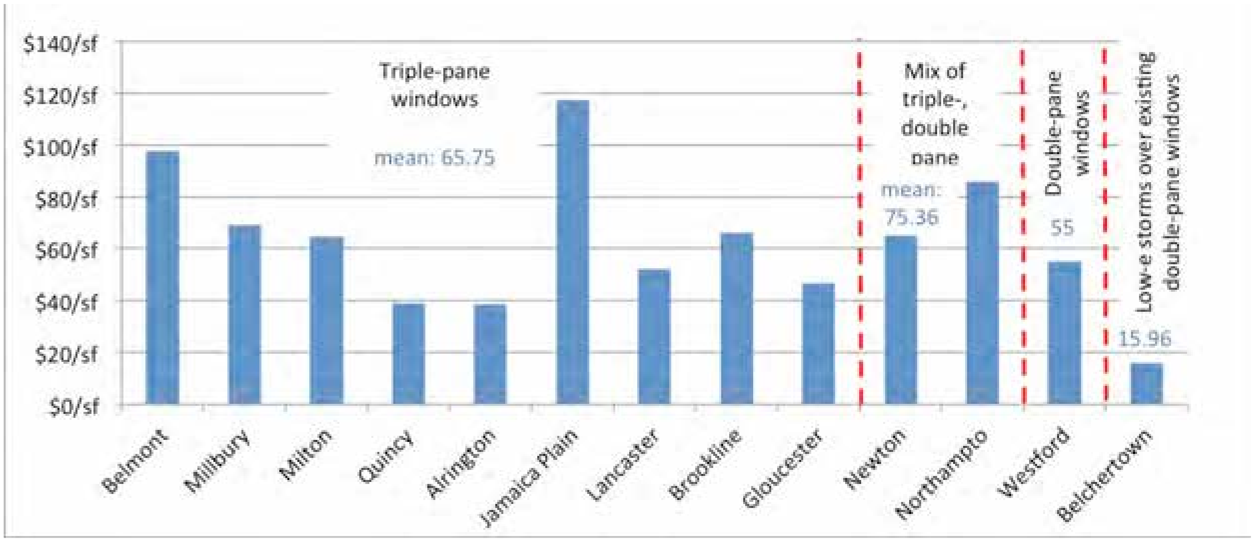


Figure 40. Unit costs for window measures

All but one of the projects included in this study involved installation of new windows. The cost for the window measure varies significantly among the projects that installed new windows. Four of the projects that installed triple-pane windows reported a lower unit cost for the window measure than the project that installed double-pane windows.

Figure 41 shows the unit (per square foot) total measure cost for air sealing measures as reported by projects in this study. There is no distinction between total measure cost and energy-related cost for this measure.

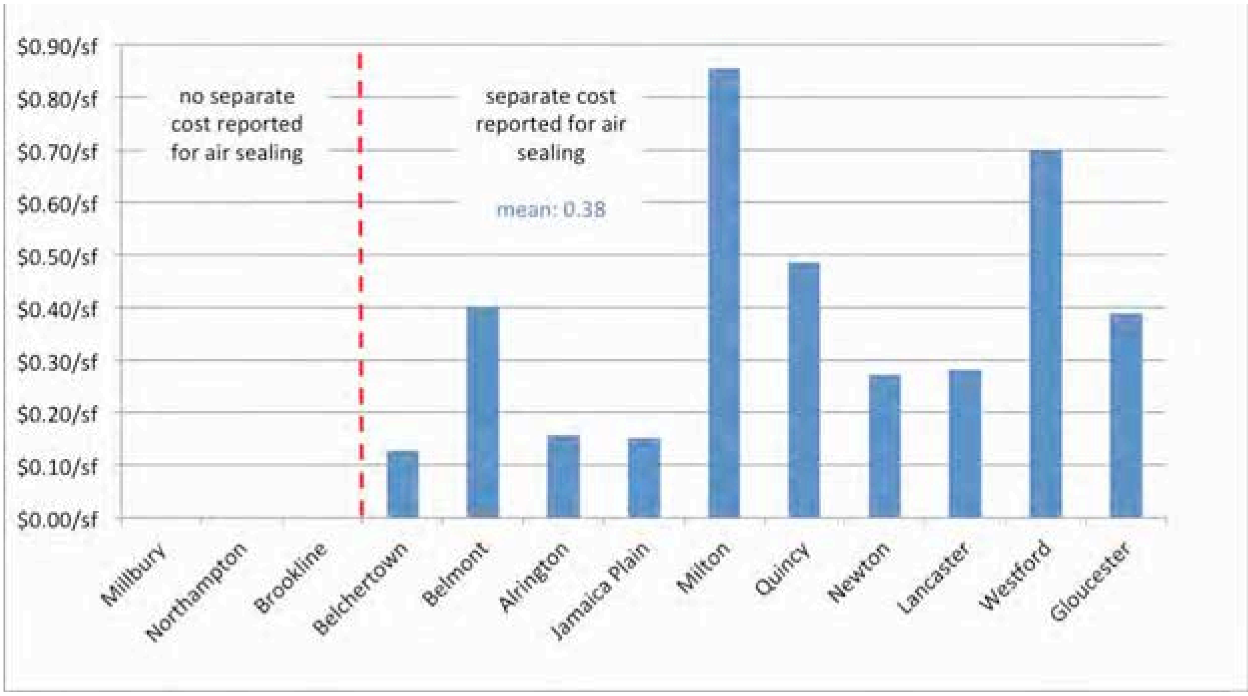


Figure 41. Unit costs relative to enclosure area for air sealing measures

Three of the projects reported no separate costs for air sealing. For the projects that did report a separate cost for air sealing measures, the description of air sealing measures varied widely. While some applications provided a description of techniques and materials, others appear to provide a general allowance under the heading of air sealing measures. It is interesting that three of the projects that reported the highest unit costs for air sealing measures also reported among the lowest unit costs for wall retrofit measures. Three of the projects reported no separate costs for air sealing.

Figure 42 shows the reported unit (per square foot) total measure cost and energy-related measure cost for all enclosure measures combined for each of the projects in this study. The combined enclosure measure costs are shown relative to the treated enclosure area for each project.

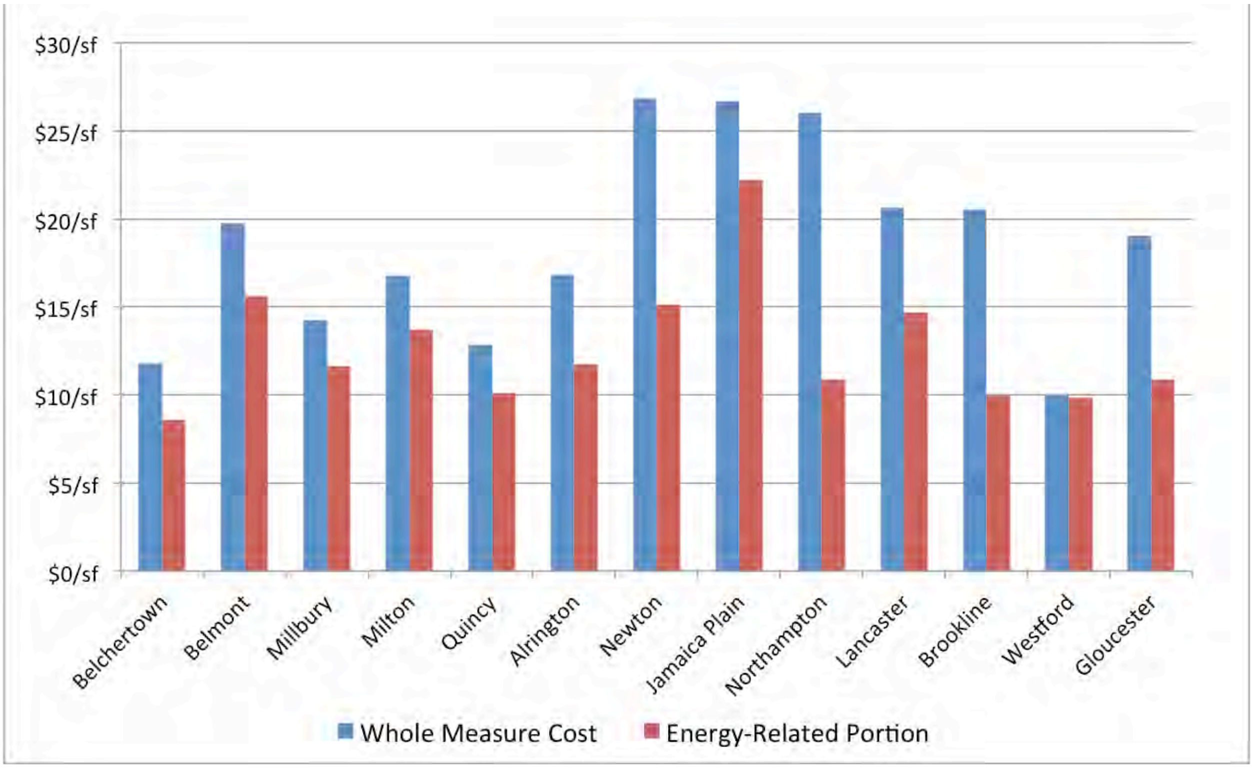


Figure 42. Unit costs relative to enclosure area for all enclosure measures

The enclosure measure costs relative to enclosure surface appears more tightly clustered than the unit costs for individual components. For the total measure costs, the average enclosure measure cost relative to enclosure surface area is $18.62/ft^2 and the range is $9.99–$26.87/ft^2. When considering only the energy-related enclosure measures, the average unit cost is $13.13/ft^2 and the range is $8.62–$22.20/ft^2.

To assess whether data show the relative cost of enclosure measures to be impacted by pre-retrofit conditions, the enclosure measure costs normalized to enclosure area are compared to the pre-retrofit air leakage measurement also normalized to enclosure area. The pre-retrofit air leakage measurement is taken as an indicator of the condition of the building enclosure prior to retrofit. As seen in Figure 43, there appears to be a slight relationship between relative enclosure measure costs and relative pre-retrofit air leakage measurement.

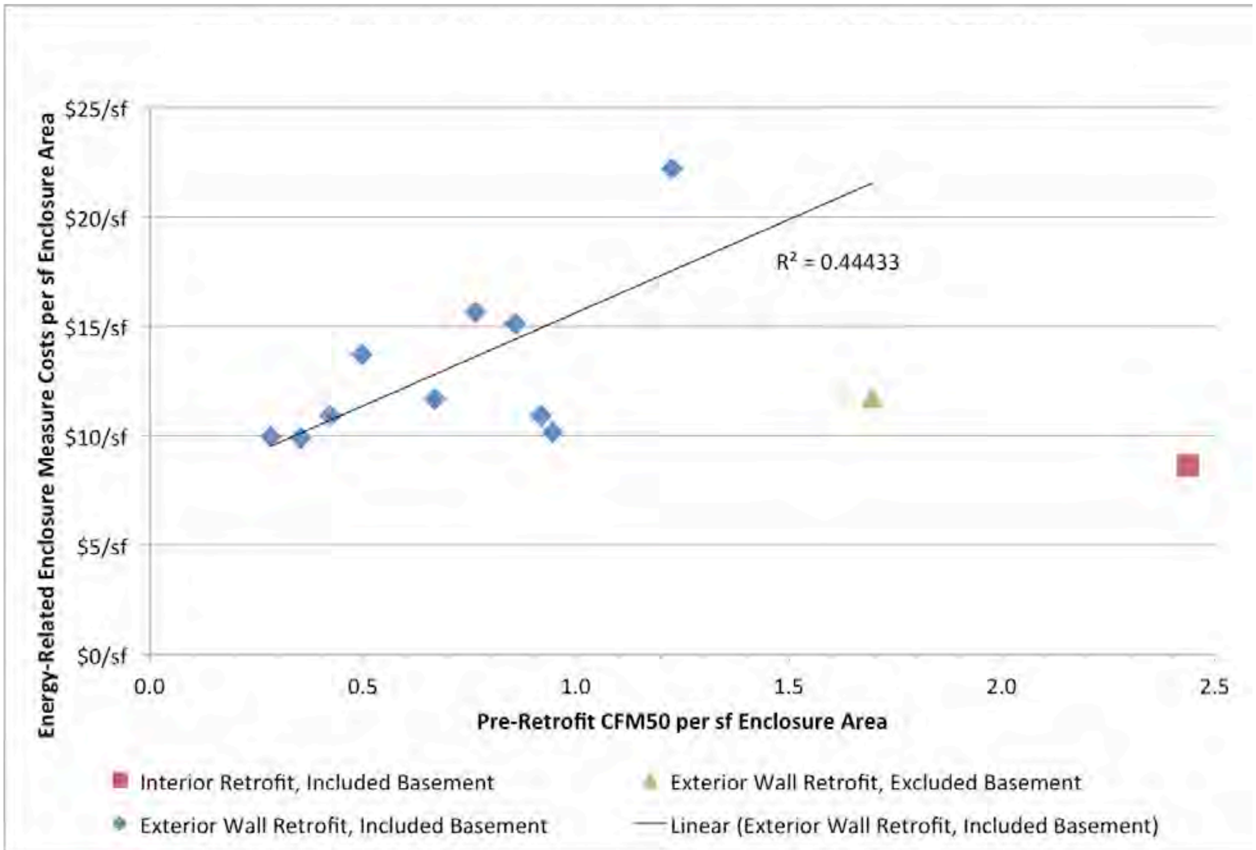
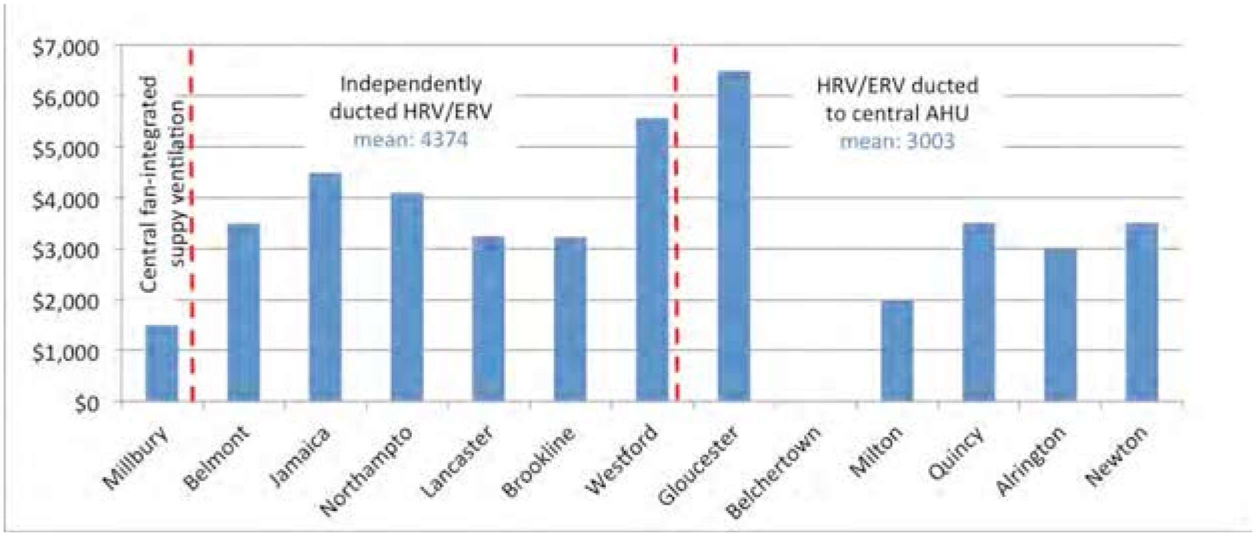


Figure 43. Energy-related enclosure measure costs compared to pre-retrofit air leakage measurement

4.3.1.2 Heating, Ventilation, and Air Conditioning Measures

For mechanical system measures, the unit cost reflects the cost per system. This is important given that some of the projects in this study involve two- or three-family buildings with separate mechanical systems for each dwelling unit. There is no distinction between total measure cost and energy-related cost for these measures.

Figure 44 shows the unit total measure cost for mechanical ventilation measures reported by projects in this study.



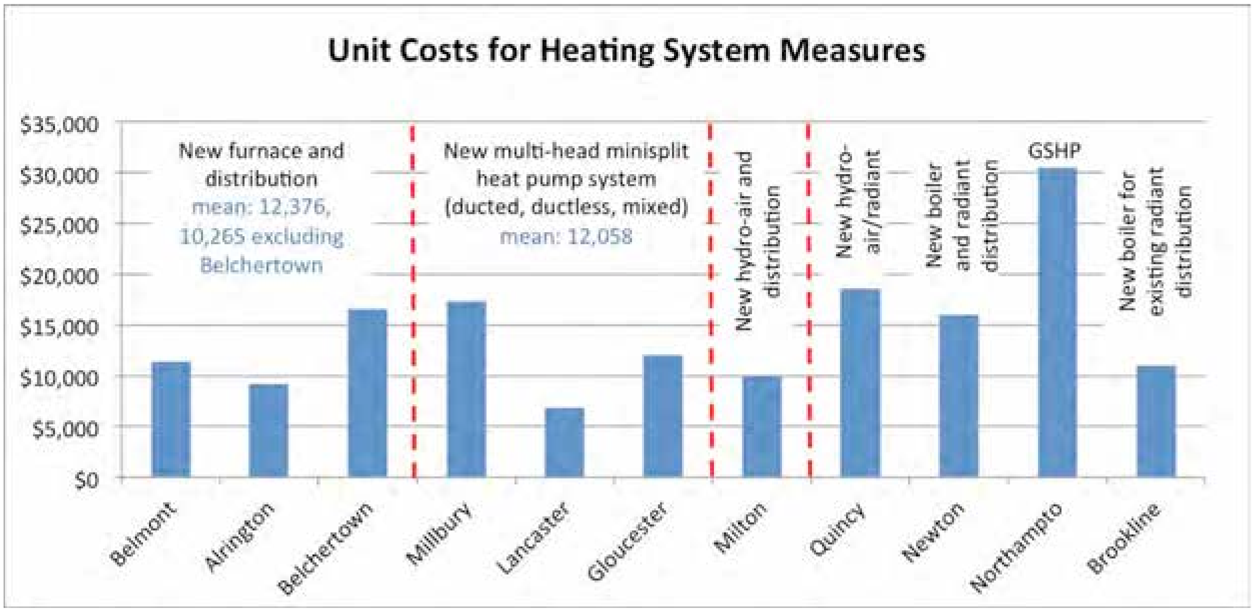
* For the Belchertown project, the mechanical system cost is included in the reported cost for the HVAC measures reported in aggregate.

Figure 44. Unit (per system) costs for mechanical ventilation

The central fan-integrated supply ventilation system implemented by the Millbury project has the lowest reported system cost at $1,500. The average of the reported system costs for HRV/ERV systems ducted directly to central heating and cooling system ductwork is approximately twice the reported cost for the central fan-integrated supply system. The average of the reported system costs for independently ducted HRV/ERV systems is approximately 40% more than the average of the reported system costs for HRV/ERV systems ducted directly to central heating and cooling system ductwork. Two of the projects implementing an independently ducted HRV/ERV system installed equipment that is significantly more expensive than the equipment installed in other implementations of the independently ducted HRV/ERV.

The cost for the HRV/ERV ducted to a central AHU did not include the cost for dampers needed to isolate the HRV/ERV from the heating and cooling system ductwork when the ventilation system is idle. Therefore, the costs for a properly functioning ventilation system with HRV/ERV ducted to the central AHU are expected to be slightly higher than those reported. The central fan-integrated supply ventilation system implemented is not compatible with the heating and cooling system installed at this project and does not provide the desired control of ventilation. However, there is no reason that the cost of the ventilation system would be different if connected to a compatible heating and cooling system.

Figure 45 shows the unit total measure cost for heating system measures reported by projects in this study. There is no distinction between total measure cost and energy-related cost for this measure.



* For the Belchertown project, the heating system cost includes cost for the ventilation and cooling system measures implemented at this project.

Figure 45. Unit (per system) costs for heating system measures

Eleven of the projects included in this study implemented new heating systems as part of the DER project. As can be seen in Figure 45, there is considerable variation in the heating system approach as well as system cost. For all projects implementing a new heating system the average reported system cost is $14,282. This average excludes the reported system cost for the Belchertown project, as the reported system cost for this project also includes the cost for the ventilation system and cooling measures.

The cost for the multi-head mini-split ASHP systems appear to be significantly impacted by the extent to which these are provided with ducted distribution. The reported cost for both the ducted and partially ducted mini-split systems are comparable to reported costs for projects that implemented ducted furnace-base heating and ducted air conditioning.

Costs for cooling system measures are difficult to isolate for many of the projects, because the cost of the cooling system measure as well as the cooling system function is represented in the heating system measure. Therefore, it is more useful to compare composite HVAC measure costs for the projects in this study as shown in Figure 46.

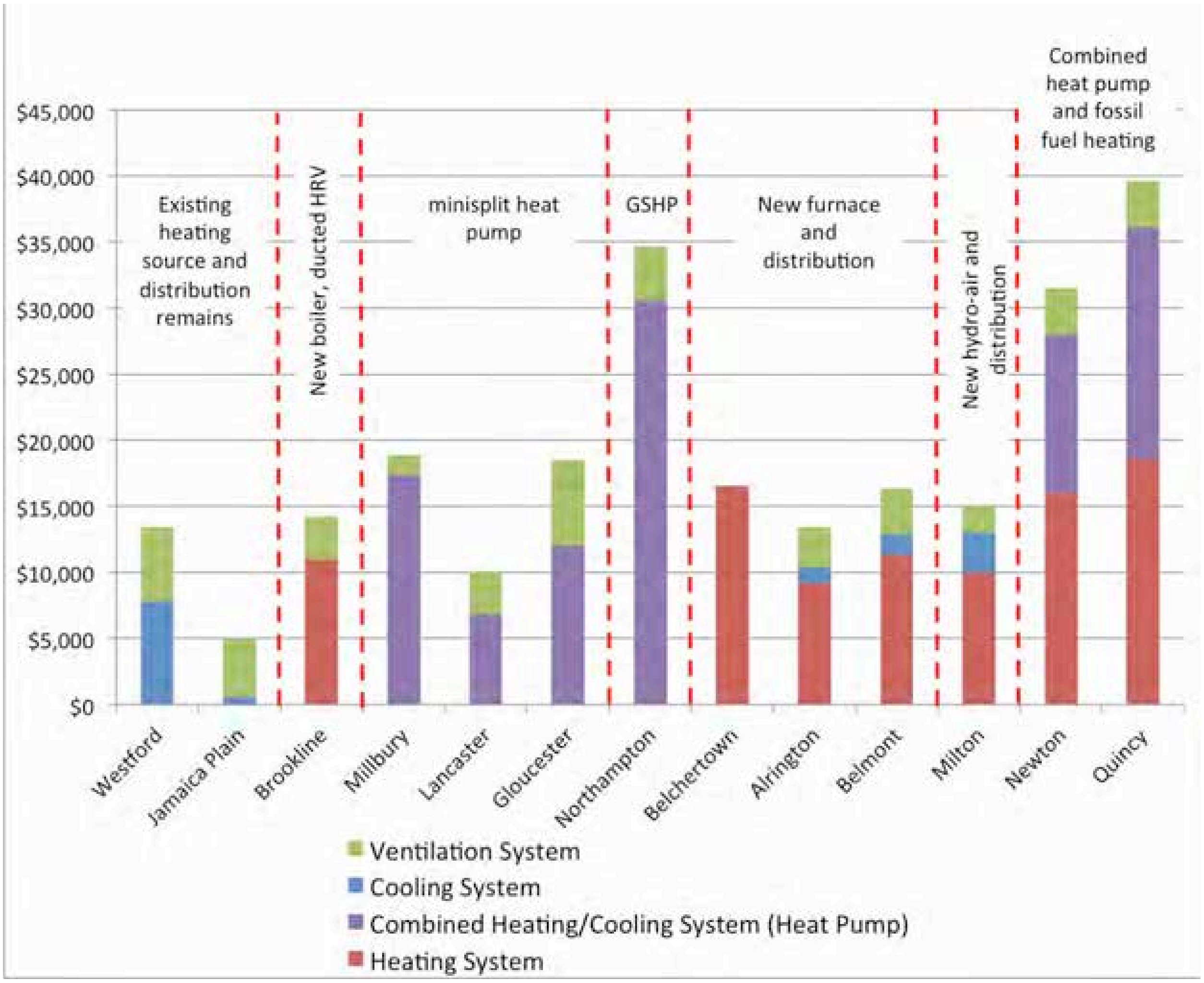


Figure 46. Unit (per system) costs for HVAC measures

In Figure 46 the HVAC costs for the GSHP system as well as for the HVAC systems that combine ASHP with fossil fuel combustion heating are noticeably higher than for other HVAC systems. Two projects, Westford and Jamaica Plain, retained pre-retrofit heating systems. One project (Brookline) replaced a boiler but retained the pre-retrofit hydronic heating distribution.

Table 10 below provides a summary of the HVAC measures implemented by each project with the total cost of HVAC measures implemented by each project. Total system costs ranged from just more than $10,000 to just more than $39,000 for projects that included installation of new high efficiency heating and cooling equipment and distributed ventilation with heat or energy recovery.

Table 10. HVAC Measures and Composite System Cost

Project	Heat Source	Cooling Source	Heating/Cooling Distribution	Ventilation	Composite System Cost
Quincy	New heat pump, and New boiler/water heater	From heat pump	Heat pump: new duct system, Boiler/water heater: hydro-air and new radiant	HRV/ERV ducted to AHU	$39,600
Northampton	Ground-source heat pump	From heat pump	New duct system	Independently ducted HRV/ERV	$32,590
Newton	New heat pump and New boiler/water heater	From heat pump	Heat pump: modified existing duct system Boiler/water heater: new and existing radiant	HRV/ERV ducted to AHU	$31,500
Millbury	New Heat pump	From heat pump	Ducted mini-split (2 heads)	Central fan-integrated supply	$18,875
Gloucester	New Heat pump	from heat pump	Ducted (2 heads) and ductless (2 heads) mini-split	Independently ducted HRV/ERV	$18,500
Westford	Existing furnace	New AC (outdoor unit and indoor coil)	Modified existing duct system	Independently ducted HRV/ERV	$16,868
Belchertown	New furnace	New Indoor coil only	New duct system	HRV/ERV ducted to AHU	$16,597
Belmont	New furnace	New AC	New duct system	Independently ducted HRV/ERV	$16,334
Milton	New boiler/water heater	New AC	New duct system (hydro-air heating)	HRV/ERV ducted to AHU	$15,000
Brookline	New boiler/water heater	none	Existing hydronic	Independently ducted HRV/ERV	$14,205
Arlington	New furnace	New indoor coil only	New duct system	HRV/ERV ducted to AHU	$13,428
Lancaster	New heat pump	From heat pump	Ductless mini-split (2 heads)	Independently ducted HRV/ERV	$10,038
Jamaica Plain	Existing boiler/water heater	Existing hydronic	New gasketed panels for existing window A/C	Independently ducted HRV/ERV	$5,050

4.3.2 DER Cost Conclusions

Analysis of the cost information provided for the projects included in this study yield the following information regarding DER project costs:

- Total DER project costs for the group of projects included in this analysis averaged $133,060 and ranged from $64,629–$241,991. Energy-related measure costs for the group of projects included in this analysis averaged $99,418 and ranged from $51,642–$180,678.
- For projects that included comprehensive implementation of the DER enclosure package including retrofit of the attic and roof, walls, windows, and either basement ceiling or foundation walls:
  - Total enclosure measure costs averaged $112,663 and ranged from $48,032–$203,151.
  - Energy-related enclosure measure costs averaged $77,219 and ranged from $35,045–$165,528
- Relative to the area of building enclosure treated, energy-related enclosure measure costs averaged $13.69/ft^2 and ranged from $8.62–$22.20/ft^2.
- The enclosure measure costs relative to enclosure surface appears more tightly clustered than the unit costs for individual components.
- For projects included in this study that met the HVAC performance targets for heating and ventilation and installed new equipment including, at least, ventilation equipment and heating equipment, the average combined HVAC measure cost was $22,156 and ranged from just more than $10,000 to approximately $39,500.
- The project that implemented a GSHP system as well as the projects that combined heat pump heating with fossil fuel heating exhibited significantly higher HVAC measure costs. Excluding these projects, the average HVAC measures cost for projects that installed, at least, new heating and ventilation equipment was $15,151.

The variation in total project costs as well as energy-related measure costs results from many factors, including the physical size of the project. The unit costs for building enclosure measures reflect varying levels of experience among DER contractors, various conditions of existing buildings, as well as various approaches to the DER package of measures. In some cases, the contractors less experienced with DER techniques appear to have higher units cost, in some cases lower. This variability may decrease as the local market for DER services matures.

4.3.3 Cost and Effect

Despite a relatively uniform package of measures implemented by the projects, the reported costs for the DER projects vary greatly. This section explores whether the data collected from the early projects in the National Grid DER Pilot show relationships between cost and performance.

4.3.4 Cost and Effect Analysis

4.3.4.1 Enclosure Measure Costs and Post-Retrofit Airtightness

To assess the relationship between enclosure measure costs and airtightness, both enclosure measure costs and post-retrofit air leakage measurements are normalized to enclosure area.

Figure 47 shows post-retrofit CFM50 per square foot of enclosure area plotted against energy-related enclosure measure costs relative to enclosure area. There does not appear to be a strong relationship. The trendline suggests it is possible that the enclosure tends to be slightly leakier with increasing relative enclosure measure costs.

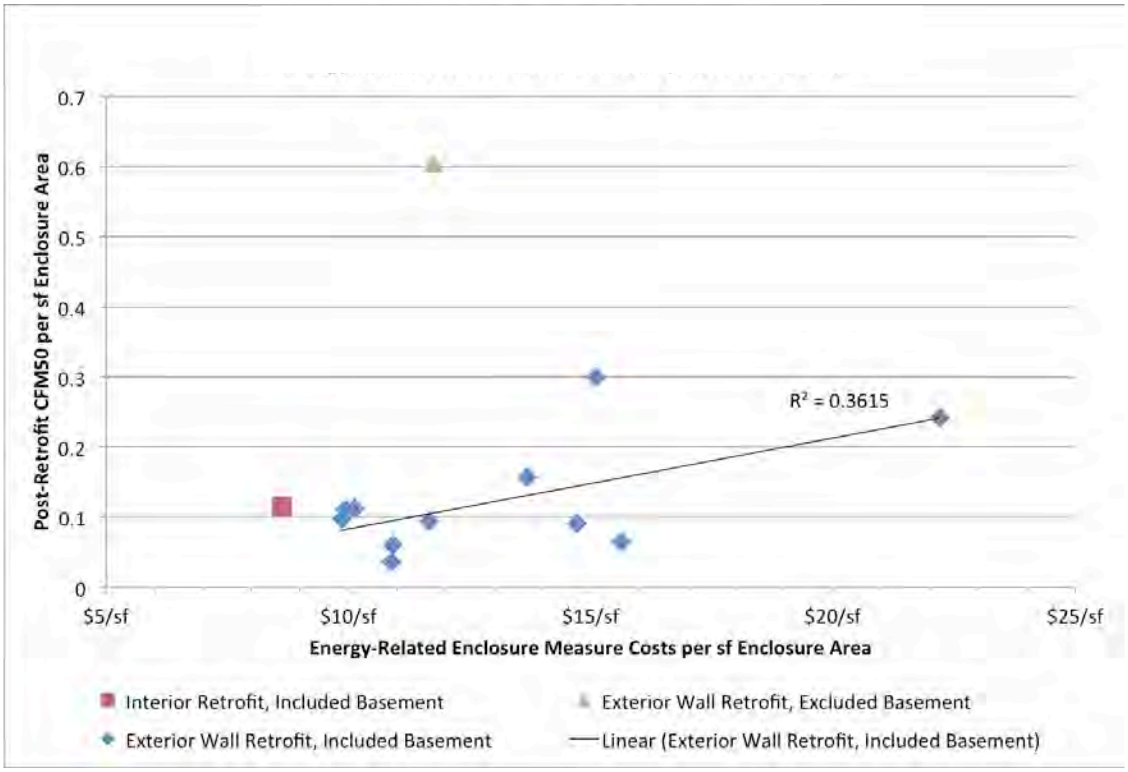


Figure 47. Post-retrofit CFM50/ft^2 enclosure area versus energy-related enclosure measure costs/ft^2 enclosure area

Data presented in the previous section hinted at a relationship between pre-retrofit air leakage and enclosure measure costs. Therefore, the increase in relative enclosure measure costs seen with increasing post-retrofit relative air leakage may be a phenomenon of pre-retrofit air leakage affecting both relative enclosure measure costs and post-retrofit air leakage.

Figure 48 presents, for projects that did not significantly alter the exterior enclosure (e.g., through an addition), the reduction in relative air leakage compared to energy-related enclosure measure cost relative to unit area of the enclosure.

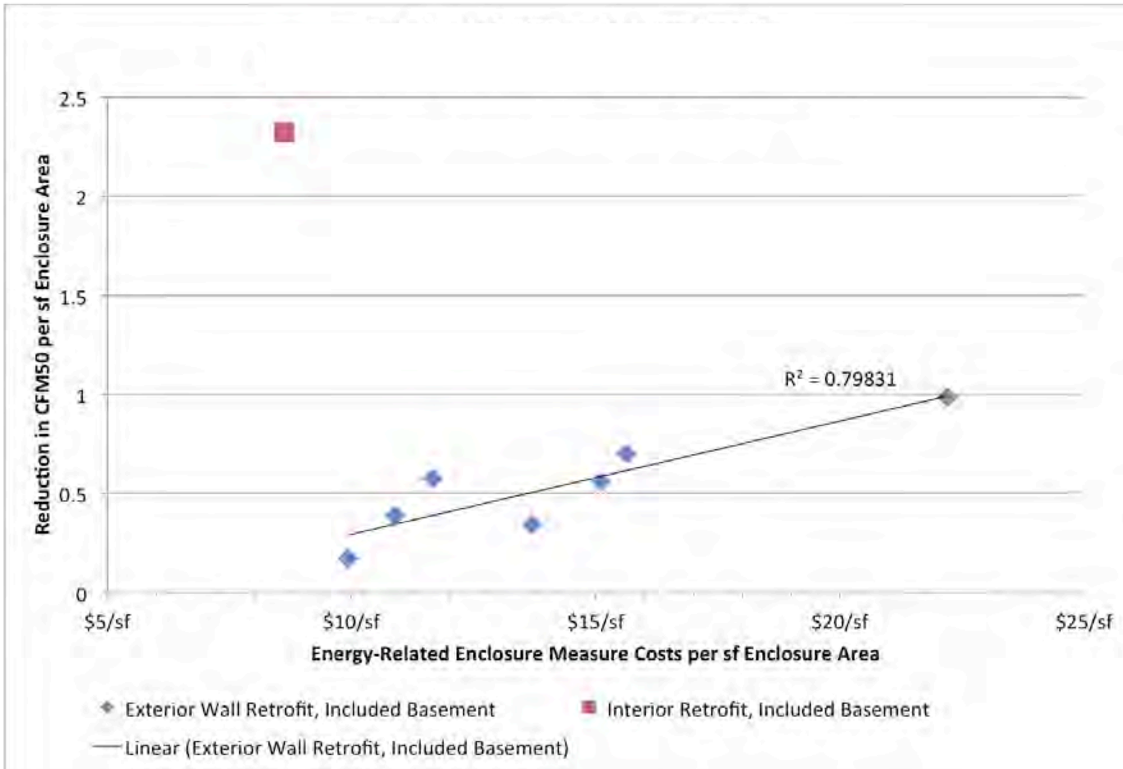


Figure 48. Reduction in post-retrofit CFM50/ft^2 enclosure area versus energy-related enclosure measure costs/ft^2 enclosure area

There does appear to be a relationship between the reduction in relative enclosure leakage and the energy-related enclosure measure cost per square foot of enclosure area. This is unlikely to be a causal relationship, since both enclosure measure cost and available air leakage reduction are likely to be impacted by pre-retrofit air leakage.

4.3.4.2 Deep Energy Retrofit Measure Costs and Post-Retrofit Energy Performance

Among energy uses, heating and cooling energy use are most directly targeted by the package of DER measures. Figure 49, Figure 50, and Figure 51 show estimated heating and cooling EUI compared to energy-related measure costs for enclosure measures, HVAC measures, and aggregate DER project measures, respectively. The energy-related measure costs are normalized to post-retrofit conditioned floor area in these charts. The heating and cooling EUI is presented only for those projects for which 12 months of post-retrofit energy use data were available. The heating and cooling EUI is expressed in terms of site energy to avoid impacts of heating fuel choices.

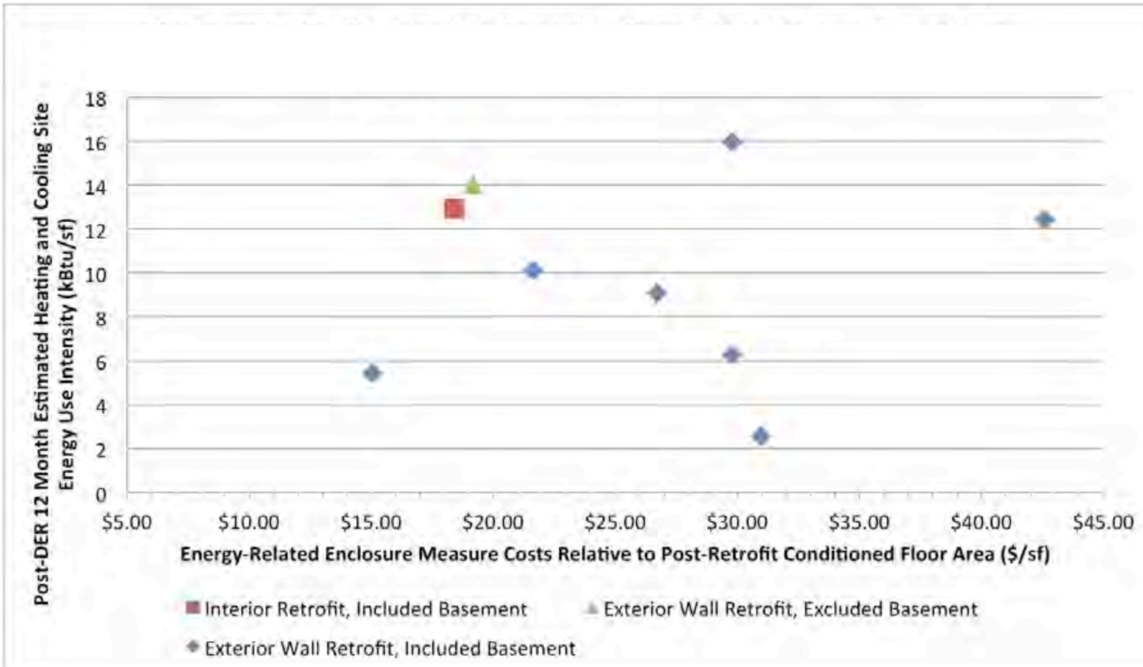


Figure 49. Heating and cooling site EUI versus energy-related enclosure measure costs/ft^2 conditioned floor area

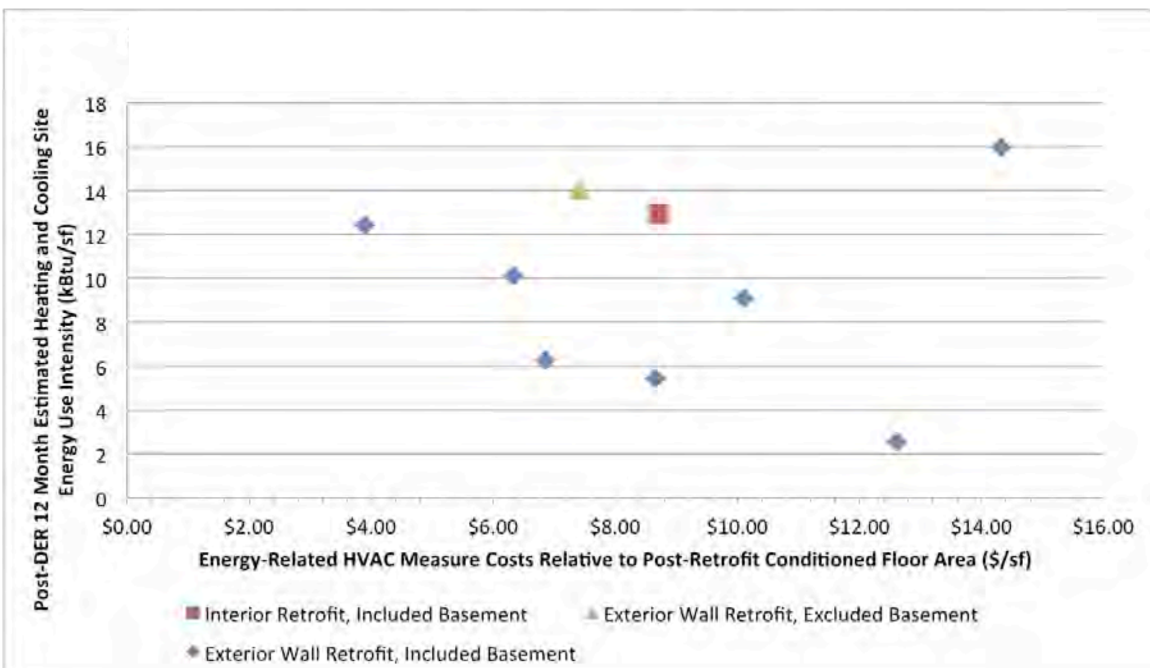


Figure 50. Heating and cooling site EUI versus energy-related HVAC measure costs/ft^2 conditioned floor area

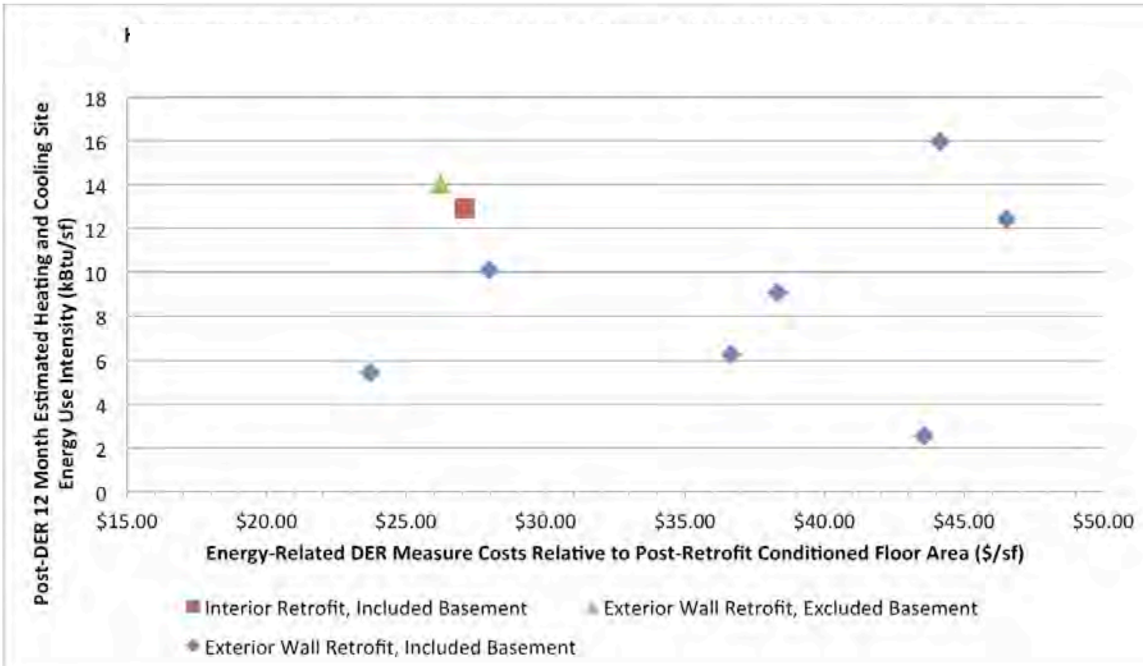


Figure 51. Heating and cooling site EUI versus combined energy-related DER measure costs/ft^2 conditioned floor area

There does not appear to be any relationship between variations in area-normalized energy-related costs and the level of heating and cooling energy performance achieved. It follows that total post-retrofit EUI also appears unrelated to area-normalized energy-related measure costs (Figure 52 and Figure 53)

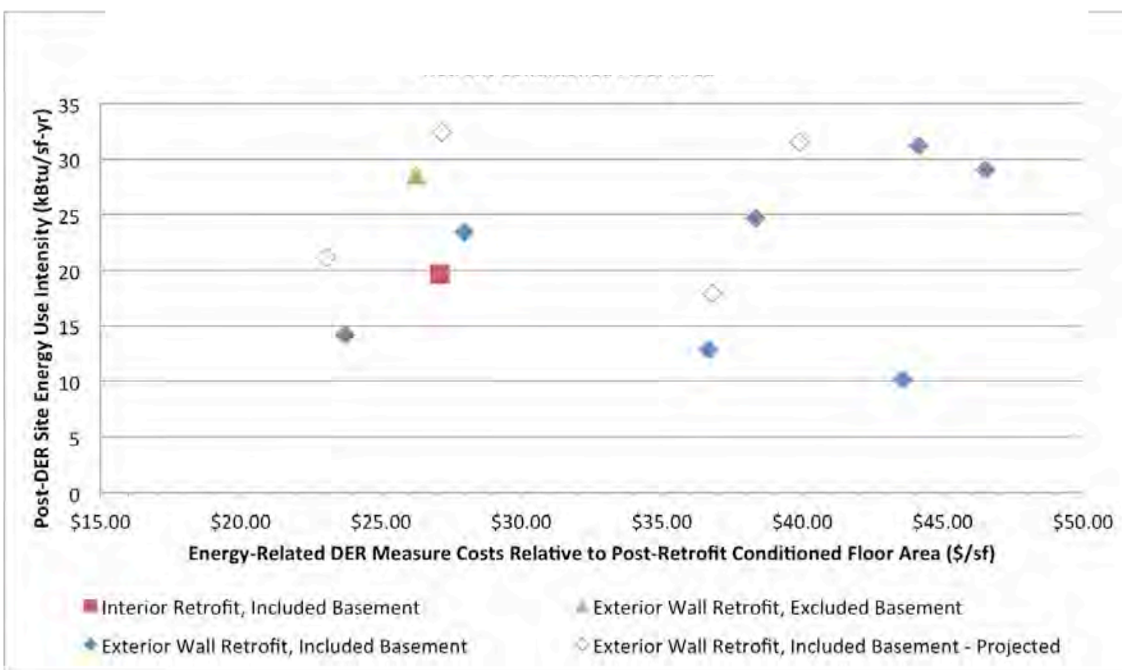


Figure 52. Site EUI versus combined energy-related DER measure costs/ft^2 conditioned floor area

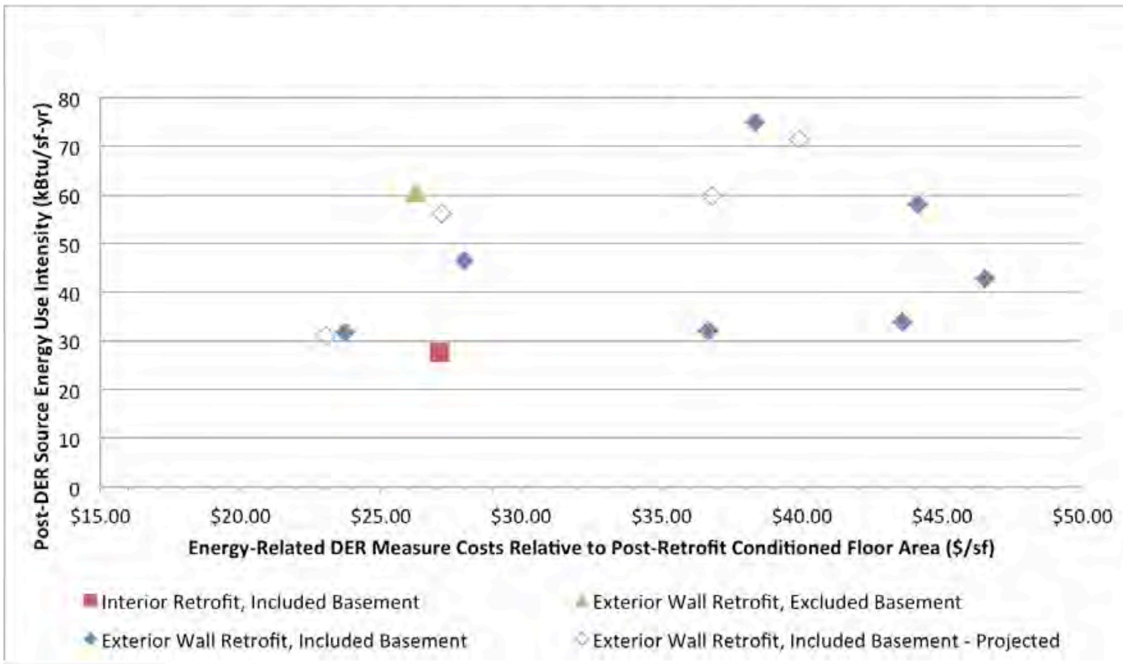


Figure 53. Source EUI versus combined energy-related DER measure costs/ft^2 conditioned floor area

Figure 54 and Figure 55 present a comparison of total energy use reduction to energy-related DER costs. There does not appear to be a relationship except for the few cases where pre-retrofit energy use is derived from an energy model rather than actual energy use data.

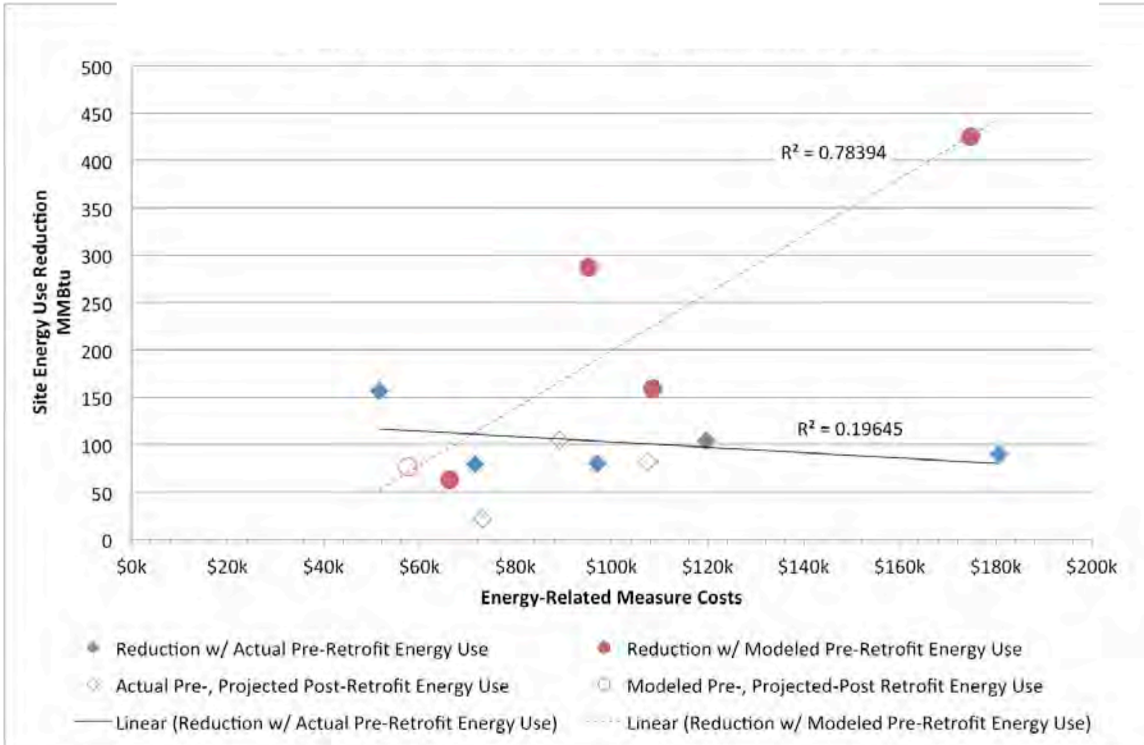


Figure 54. Site energy use reduction versus combined energy-related DER measure costs

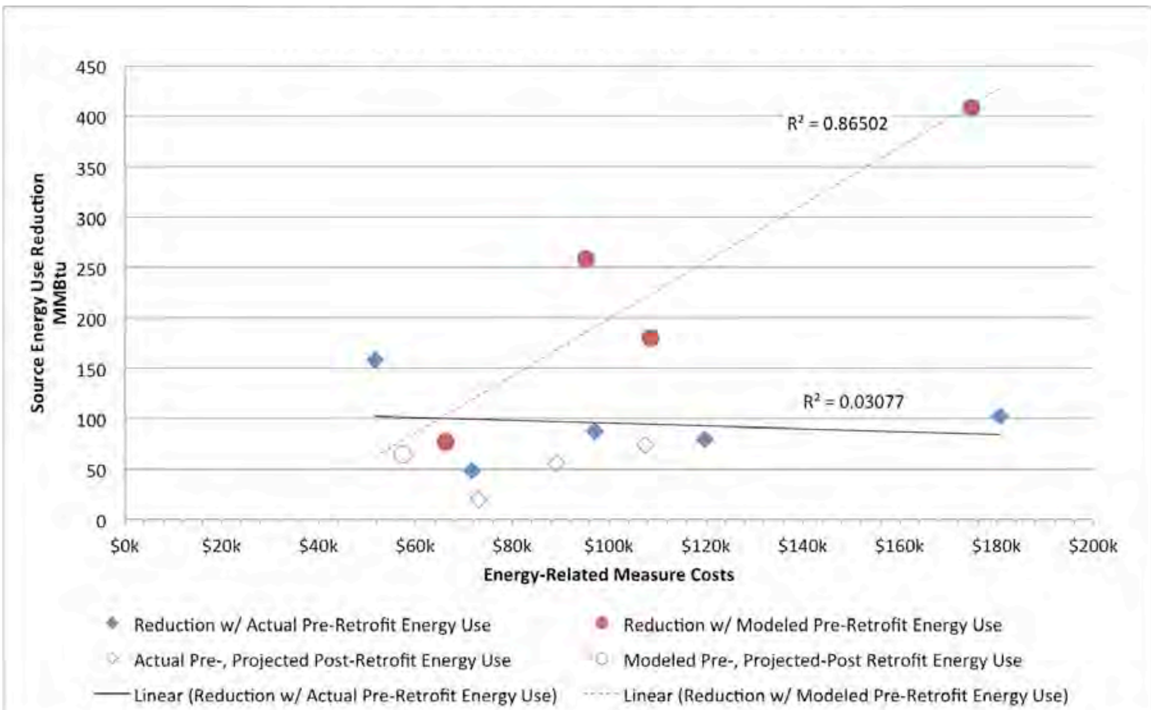


Figure 55. Source energy use reduction versus combined energy-related DER measure costs

As appeared to be the case with air leakage, the amount of reduction available for energy use is likely to be significantly determined by the pre-retrofit conditions and use of the building. The pre-retrofit conditions and use are highly variable. It is possible that deriving a projection of pre-retrofit energy use from a model removes particular idiosyncrasies that tend to render actual energy use highly variable. If the model creates a more stable and more general baseline then it may be that greater levels of expenditure in DER tend to be generally correlated with greater energy use reductions.

Figure 56 presents the total energy-related measure costs per unit of energy use reduction. This metric might be referred to as an "energy-use-reduction-cost-effectiveness" measure as the *cost* of energy-related measures are expressed relative to the *effect* of energy use reduction.

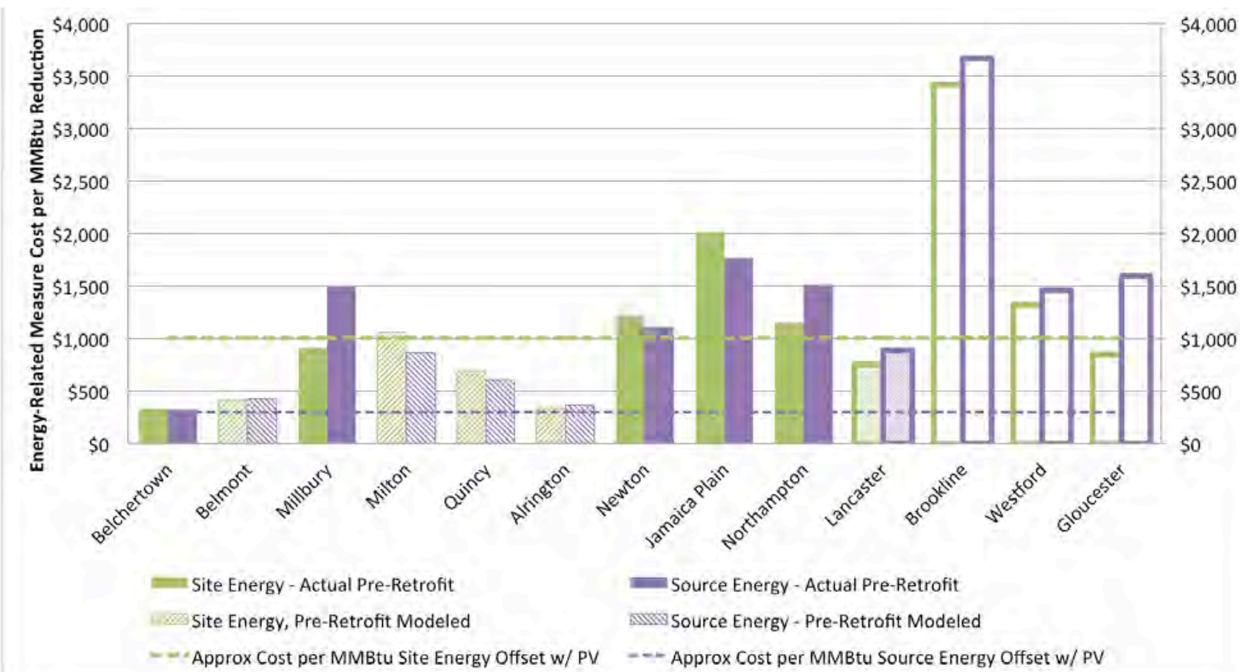


Figure 56. Energy-related measure costs relative to energy use reduction

The significant outlier in this group, Brookline, represents a DER project consisting of the continuation and final stage of a comprehensive DER implemented over the course of several years and in discrete stages. Prior to the DER project stage evaluated in this study, the owners had undertaken significant measures to reduce energy use. It is likely that this earlier work resulted in relatively low energy use prior to the project that is evaluated in the current study. An already efficient (relatively speaking) home would yield less opportunity for energy use reduction. With smaller energy use reduction available, the general costs for the project are borne by lesser energy use savings in the energy-use-reduction-cost-effectiveness measure.

The horizontal lines in Figure 56 represent the approximate cost of achieving a 1 MMBtu energy use reduction or offset through the installation of a residential-scale, roof-mounted PV system with reasonably favorable exposure. Among the five projects with actual pre-retrofit energy use data and 12 months of post-retrofit data, three show site energy-use-reduction-cost-effectiveness very near that of the hypothetical PV system, one project shows site energy use reduction cost that is significantly above that of the PV system, another project shows site energy use reduction cost that is significantly below. Obviously there are too few qualifying observations to be able to draw hard conclusions relative to site energy-use-reduction-cost-effectiveness. However, the preliminary DER pilot results examined in this study hint at the possibility that the DER package can achieve site energy use reductions for approximately the same cost as a PV system could offset site energy use.

With respect to source energy use reductions and offsets, the preliminary results appear to indicate that source energy use is offset by a reasonably sited residential-scale PV system at a cost that is considerably lower than that of source energy use reductions achieved with the DER measures package.

4.3.5 Cost and Effect Conclusions

Analysis of preliminary performance results and cost data for the DER pilot supports the following conclusions:

- Both in terms of post-retrofit airtightness and EUI, there does not appear to be a relationship between performance achieved and variations in energy-related measure costs.
- The reduction in air leakage measurement does appear to be mildly correlated with variations in energy-related enclosure measure costs. A causal relationship between these cannot be suggested, as both air leakage reduction and energy-related enclosure measure costs are likely to be impacted by pre-retrofit conditions of the building.
- When energy use reduction is calculated from actual pre- and post-retrofit energy use data, there does not appear to be a relationship between energy use reduction and variations in energy-related measure costs.
- It appears at least possible that energy use reductions are correlated with variations in energy-related DER measure costs when and if it is possible to remove idiosyncrasies of actual pre-retrofit conditions from the pre-retrofit energy use baseline.
- Considering the energy use reduction effect in isolation, it appears possible that the package of DER measures can achieve site energy use reductions and offsets for a cost per MMBtu comparable to that of a reasonably well-sited residential PV system. However, in terms of source energy use, the preliminary results of the pilot suggest that reductions and offsets can generally be achieved at lower cost through installation of a reasonably well-sited residential PV system.

4.3.6 Measure Costs and Benefits Relative to Homeowner Objectives

Homeowners perform upgrades and modifications to homes for a variety of different motivations. Sometimes, achieving energy savings might be an objective in performing upgrades, perhaps even the only objective of a particular expenditure. In other cases, energy savings might be a welcome by-product of an upgrade or modification pursued primarily for nonenergy motivations. For most measures involving energy savings, objectives relating to energy performance share a place among other motivations.

Window replacement is one common upgrade or modification where achieving energy savings is blended with other objectives. The National Grid DER pilot program imposes a $15/ft^2 deductible in determining the portion of window replacement cost that is eligible for incentives. The deductible amount is intended to represent the base cost for windows offering performance typical of vinyl-framed double-pane windows. But the increment of cost beyond $15/ft^2 cannot be associated with purely energy-related objectives. Certainly, one would expect high quality wood or fiberglass-framed double-pane windows to cost considerably more than $15/ft^2. The reported window measure costs shown in Section 4.3 demonstrate that one could pay more for a double-glazed window than for windows that offer a higher level of energy performance. Thus, the window measure provides an example of a measure for which it would be difficult to associate energy performance increment with a measure cost increment.

Mechanical systems are often replaced because the existing equipment has exceeded its useful service life (whether or not this is manifest in the equipment). Mechanical systems might also be replaced to provide better comfort or to address concerns for combustion safety.

Many of the projects participating in the DER pilot program implemented a conversion of basement or attic space to living space. Other projects involved a significant addition to the building. Because of building code requirements, these modifications and additions would require the installation of insulation *whether or not* the homeowner was interested in saving energy.

Where measures are implemented in response to multiple objectives, how might the measure costs be associated with and apportioned among the various intended benefits? Where energy savings result from a DER measure, a portion of the costs might be associated with the energy savings benefits. But what portion of the measure costs might be attributed solely to energy benefits? What portion of measure costs might be assigned to other benefits? Answering these questions would first require an understanding of the motivations for a particular project. The National Grid DER pilot provides a unique opportunity to explore these questions as many project provided specific and general information about project objectives.

4.3.7 Analysis of Project Objectives Relative to Energy-Related Measure Costs

The application for participation in the DER pilot includes a “Homeowner Objectives Check List” where the applicant can indicate the relative importance to the project for each of a list of objectives.[2] The importance is rated on a scale of 1 to 5 with 5 being the most important. Figure 57 shows, for illustration purposes only, an image of a completed checklist for one of the projects in this study. This is an optional input on the application. It was provided for nine of the projects included in this study. From this checklist is it possible to identify the priority objectives for the project.

[2] As indicated in Figure 43, this checklist is adapted from the application form for the Thousand Homes Challenge initiative of the Affordable Comfort Institute (ACI).

Enter 1-5 in each row in column D to indicate the importance of your objectives for this project. **Ratings 5 = Extremely, 4 = Very, 3 = Somewhat, 2 = Slightly, 1 = Not a Factor**	Project Name: ______ this work sheet is optional		
HOMEOWNER OBJECTIVES CHECK LIST	**Explore or Accomplish**	**Planned to do apart from DER?**	**Rate Importance 1 to 5**
			5 is highest
Reduce energy use	Accomplish	Yes	5
Reduce household carbon footprint	Explore	No	3
Reduce energy cost	Accomplish	Yes	5
Reduce use of finite resources	Explore	Yes	3
Reduce water / waste water use	Explore	No	3
Reduce peak electrical use	Explore	No	2
Increase physical comfort	Accomplish	Yes	5
Improve indoor air quality	Explore	Yes	5
Upgrade building systems / façade: replace roof	Accomplish	Yes	5
Upgrade building systems / façade: replace siding	Accomplish	Yes	5
Upgrade building systems / façade: replace windows	Explore	No	3
Upgrade building systems / façade: retrofit windows	Explore	No	3
Remodel bathroom or kitchen	Accomplish	Yes	5
Upgrade building systems: basement conversion	Explore	Yes	5
Improve property market value & salability	Accomplish	Yes	5
Address problem; durability	Accomplish	Yes	5
Address structural problem	Accomplish	Yes	5
Address maintenance issue	Accomplish	Yes	5
Address problem: critters, insects, pests		No	1
Address moisture problem		No	
Address lead paint risk		No	
Address problem: allergens	Explore	Yes	5
Address problem: soil gas, radon		No	
Address problem: combustion safety	Explore	Yes	5
Change living space - (i.e addition, comfort zone)	Accomplish	Yes	5
Increase resilience - drought		No	
Increase resilience - extended power outage		No	
Increase resilience - earth quake		No	
Increase resilience - severe rain, flooding	Accomplish	Yes	2
Increase resilience - wild fire		No	
Increased adaptability - energy price increases	Explore	Yes	2
Increased adaptability - economic uncertainty	Explore	Yes	2
Support local economy & economic development	Explore	Yes	2
Contribute to community carbon reduction demonstration	Explore	No	2
Invest my resources in long-term solution	Accomplish	Yes	4
Enhance neighborhood preservation	Accomplish	Yes	2
Serve as an example for others	Explore	No	1
Contribute to knowledge re energy carbon reductions		No	
Demonstrate emerging technology and systems		No	
Demonstrate impact of lifestyle and behavior		No	
Demonstrate potential for increased community resilience		No	
Develop skills to enhance professional career		No	
Go further than most think possible		No	
Other:			
Total			

Adapted from Thousand Home Challenge with permission by Linda Wigington and Dave Legg for National Grid

Figure 57. Optional homeowner objectives checklist from DER program application

For another project in the study, a Web-posted report of the project assembled by the homeowner indicates objectives pursued in the DER project.

For the nine projects that provided input on the "Homeowner Objectives Check List" the importance rankings for each objective were aggregated across the checklist forms for individual projects to obtain a representation of the relative importance of various objectives for the group of projects. Figure 58 shows the results of this aggregation with objectives grouped into categories similar to how they are presented on the checklist. Figure 59 shows the top 20 objectives for this group of projects as determined by this aggregation of importance rankings. As might be expected for a sample of projects where the homeowners are pursuing DER projects, objectives related to energy savings figure prominently for the group. Nonenergy-related objectives also appear as significant for the group. Top nonenergy objectives for projects in this group include:

- Changing living space (i.e., addition, comfort zone)
- Increasing physical comfort
- Upgrading building systems/façade: replace siding
- Investing resources in a long-term solution
- Improving indoor air quality
- Improving property market value and salability
- Addressing problems related to durability.

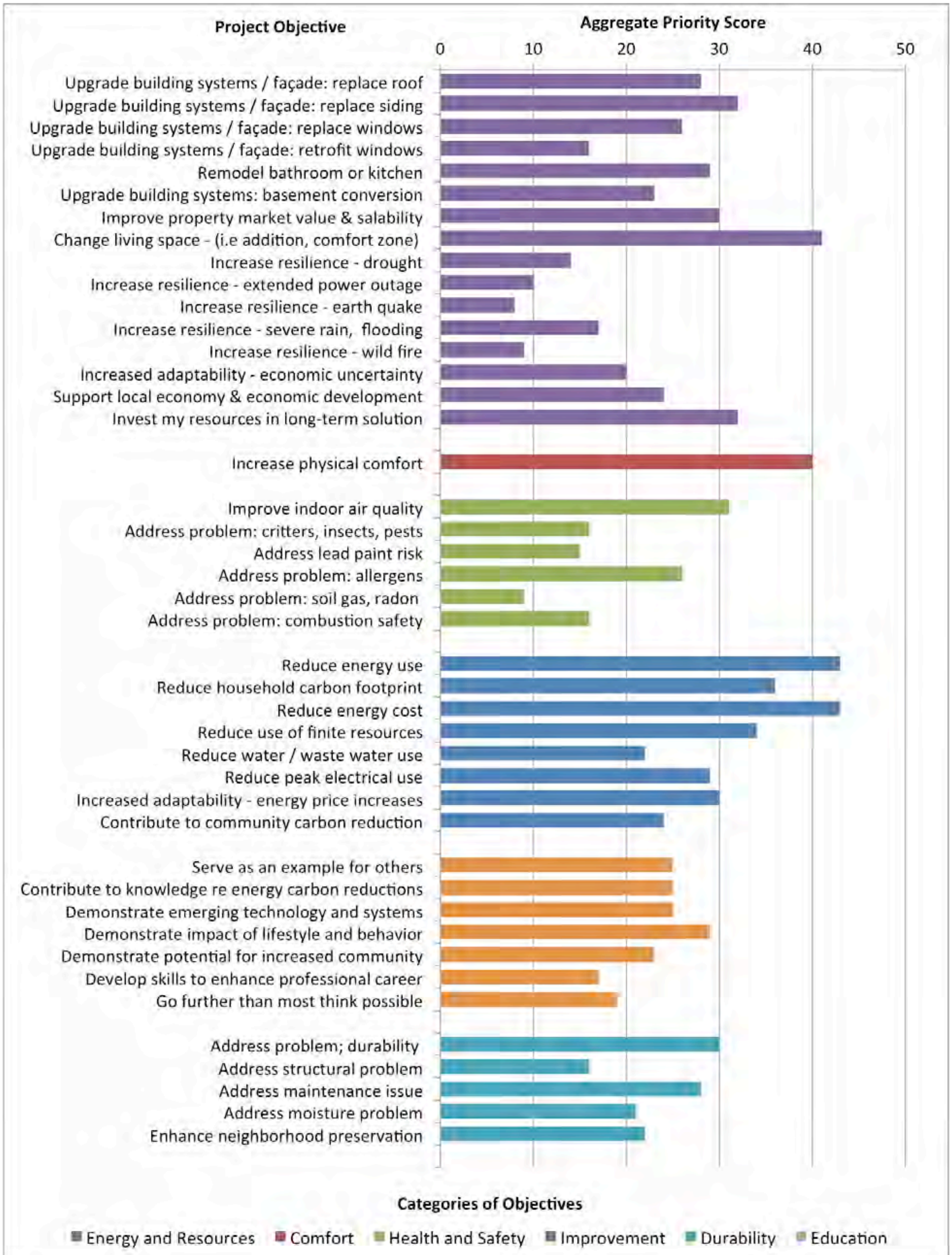


Figure 58. Numerical aggregation of objective priority score

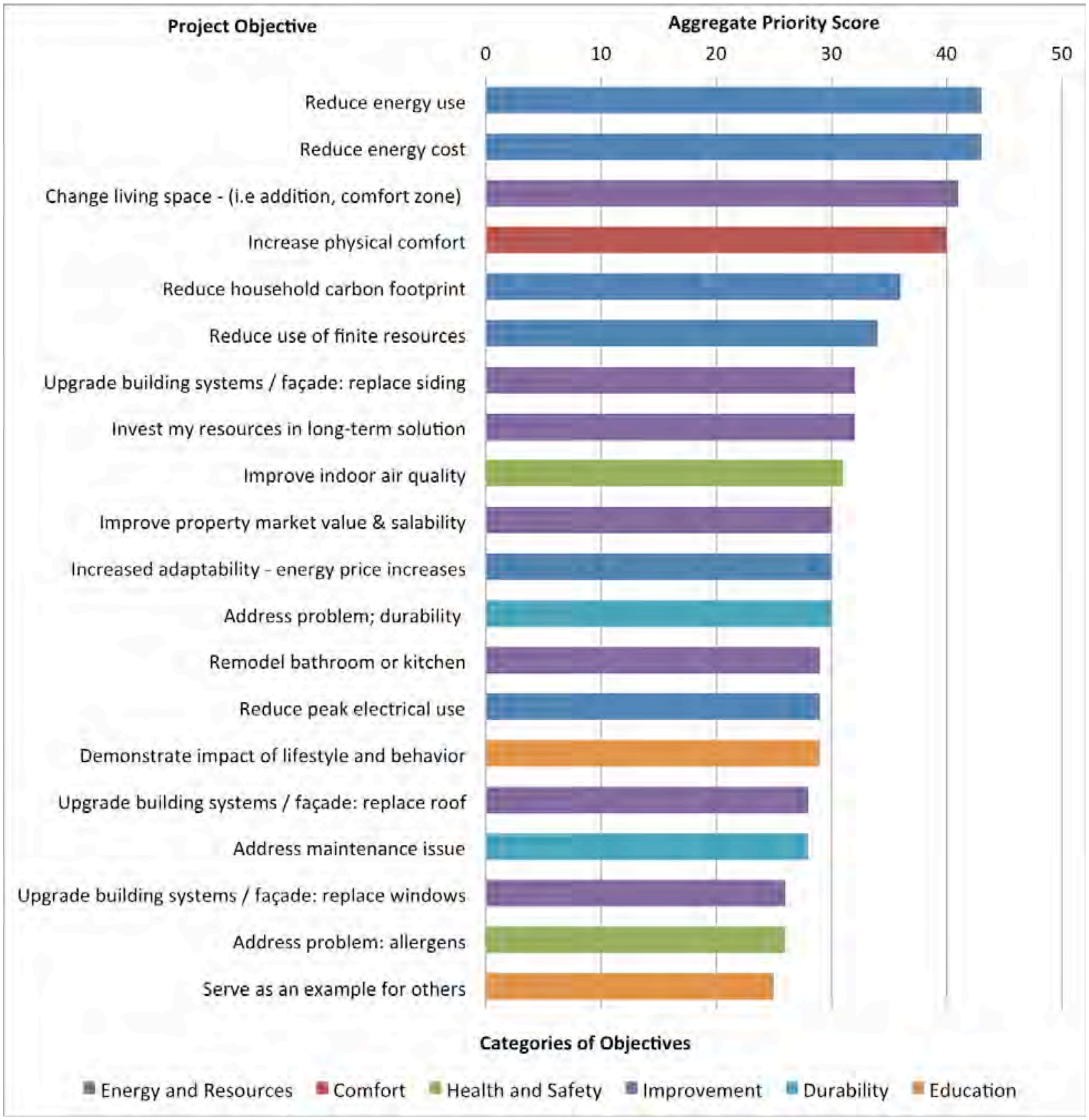


Figure 59. Project objectives ranked by aggregate priority score

Other parts of the program application also provide useful information about the project objectives. The applicants are asked to indicate other significant work related to the DER that the homeowner plans to undertake with or without the DER. For example, the applicants indicate whether reroofing, re-siding, basement conversion, major remodeling, or an addition is planned.

For individual DER projects, information about project objectives, project scope, as well as measure cost detail provides a basis for categorizing DER measures or portions of measures according to the relation of these measures to energy performance objectives and nonenergy objectives. For the 10 projects that provided information about project objectives, the energy-related measures or portions of measures were evaluated to determine whether a project objective other than energy savings is primary, significant, or ancillary.

Identifying the nonenergy objective as primary for a given measure indicates that this measure is likely to have been implemented in the absence of energy savings objectives. For example, where a project includes an addition or renovation that exposes wall cavities, building code requires that the wall framing cavities be insulated to the depth of the cavity or up to a nominal R-value of R-19 (whichever is less). The cavity insulation portion of a wall measure would have a nonenergy objective (i.e., code compliance) that is primary. Similarly, where a rough basement is converted to finished space and where the homeowner has indicated that addressing moisture issues and improving indoor air quality are important objectives of the project, nonenergy objectives would be primary for the depth of spray foam foundation insulation needed to control moisture, control airflow, and meet code insulation requirements. Also, for a home that had no working automatic heating system and where the homeowners wished to be relieved of the need to split several cords of wood each year, installation of a furnace is primarily a measure providing comfort and facilitating a change in lifestyle.

The window allowance (or window deductible) relative to a window replacement measure represents a portion of the measure cost allocated to primarily nonenergy objectives where the project indicated an intention to replace windows with or without the DER project. The cost for replacing a door between a basement and bulkhead access would reflect a portion of project costs where nonenergy objectives are primary in the case where the existing door had deteriorated and proved ineffective at excluding pests.

For measures where nonenergy objectives are determined to be significant, the measure may not have been pursued without the promise of energy savings; however, other indicated objectives for the project support implementation of the measure. In a sense, the nonenergy objectives for the project "subsidize" the energy savings benefit of the measure. Examples of measures for which a nonenergy project objective is significant include:

- Cooling system measures
- Installation of mechanical HRV or ERV systems
- Basement slab insulation where moisture-sensitive materials are to be installed or stored on the basement floor
- New heating systems where the homeowners indicated an intention to discontinue heating with oil and eliminate on-site heating oil storage
- Adding blown-in insulation to undisturbed wall cavities where the project application indicates improving comfort as an important project objective.[3]

[3] One could argue that all wall insulation could be responding to an objective of increasing comfort. In this analysis we apply the judgment that proper cavity insulation is sufficient to alleviate that majority of comfort concerns and

Cooling system measures are significantly associated with comfort and amenity-related objectives. Cooling system measures, particularly adding a cooling system to a home that did not have mechanical cooling, may not result in energy savings. Similarly, installing a ventilation system will not provide energy savings relative to having no mechanical ventilation. Where the ventilation system provides some recovery of energy from the ventilation system exhaust, there is assumed to be an intention to reduce the energy impact of ventilation; therefore, the nonenergy objectives cannot be primary for this measure. However, because of the net negative impact on energy savings, nonenergy objectives would need to be regarded as at least significant.

The nonenergy-related project objectives are determined to be ancillary for a measure or portion of a measure if no other significant or primary project objectives can be associated with the measure. In this analysis, nonenergy objectives are determined to be ancillary for layers or depth of insulation beyond what is required by code. Insulating sheathing added above a roof as well as the cavity insulation added between roof framing are both considered to respond primarily to energy-related objectives if insulation at the attic floor is serviceable and no change in use is planned for the attic space. A layer of roof sheathing installed as a roofing nail base above insulating sheathing is considered primarily an energy-related measure because it is made necessary by the layers of insulating sheathing added as part of the roof retrofit measure. Utility program rebates (excluding the incentives provided through the DER pilot program) for heating, cooling or ventilation systems are considered to be portions of the measure cost reflecting energy-related objectives.

The portion of the window measure cost beyond the window allowance or deductible is considered in this analysis to reflect energy-related objectives. This may under-represent the project cost allocation to nonenergy benefits because, as is seen in the examples presented in this study, homeowners do expend beyond the allowance amount for windows for nonenergy objectives.

The contractor for one project in the study provided code-baseline cost alternates for DER measures related to expansion and conversion of space. For another project in the study, a post-project analysis produced by the homeowner in collaboration with the contractor indicated code-baseline costs for some of the DER measures implemented. This provided a clear basis for distinguishing between portions of measure cost reflecting primarily nonenergy objectives and portions of measure costs reflecting energy-related objectives. In many other instances, another method was needed to allocate costs for DER measure between code requirements (i.e., nonenergy objectives as primary) and energy-related objectives. Where the energy-related component of a particular DER measure involves a single insulation type and the reported measure cost detail does not otherwise divide the cost of this measure, the analysis allocated the cost of the measure component proportionally according to the R-value for the insulation layer that would be required by code and the R-value provided beyond code requirements. For example, where a foundation wall measure for a converted basement provides nominal thermal resistance of approximately R-20, one half of the reported cost for the insulation measure is assigned to primarily nonenergy objectives and one half of the reported cost is assigned to energy-related objectives. Admittedly, this is a crude division of cost; however, it provides an

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that the motivating comfort objective is typically derived from a desire to improve poor comfort conditions rather than to further improve already good comfort conditions.

allocation of costs that is more nearly representative than regarding all of measure cost as either only related to nonenergy objectives or only related to energy savings goals.

Through this measure-by-measure analysis and cost allocation, the total energy-related measure costs for each project can be represented in three categories:

1. Costs for energy-related measures for which a nonenergy project objective is primary.
2. Costs for energy-related measures for which a nonenergy project objective is significant.
3. Costs for energy-related measures pursued for no other apparent significant objective than achieving energy savings.

The chart in Figure 60 shows the result of the measure cost categorization for each of the 10 projects that provided information regarding project objectives. Table 11 summarizes the results for this group of projects.

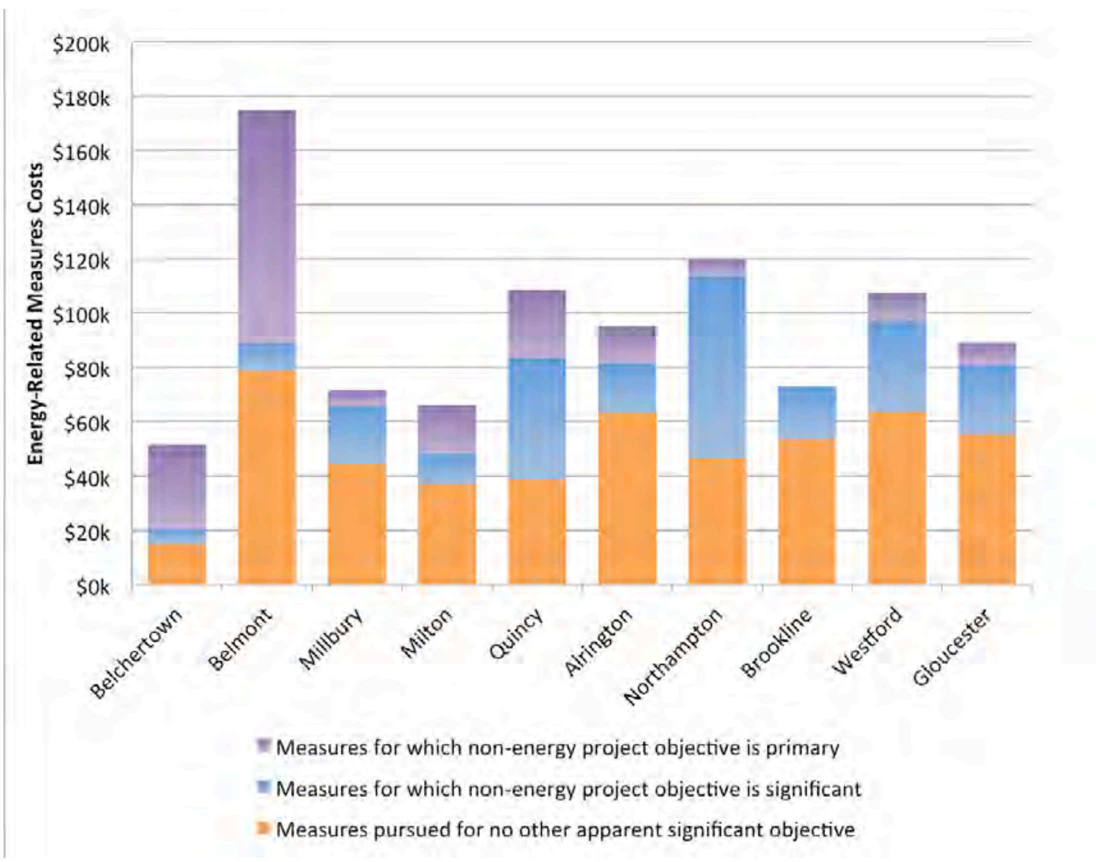

Figure 60. Cost of energy-related DER measures relative to project objectives

Table 11. Allocation of Energy-Related DER Measure Costs According to Project Objectives

	Average of Sample	Minimum	Maximum
Portion of energy-related measure costs for which nonenergy project objective is primary	20%	0%	49%
Portion of energy-related measure costs for which nonenergy project objective is significant	27%	6%	56%
Portion of energy-related measure costs for which nonenergy project objective is primary or significant	47%	27%	64%
Costs of energy-related measures pursued for no other apparent significant objective relative to total energy-related measure costs	53%	36%	73%

It is important to note that measure costs associated with no apparent significant project objective other than energy savings does not provide the basis for a comparison of measure costs to benefits defined in terms of energy cost savings. The projects providing information regarding project objectives indicated that energy objectives beyond those reflected in energy cost are significant for these projects. Figure 58 showed the project objective importance rankings aggregated for nine projects. Among the listed objectives presented in the "Homeowner Objectives Check List," seven relate to energy performance. These are:

- Reduce energy use.
- Reduce household carbon footprint.
- Reduce energy cost.
- Reduce use of finite resources.
- Reduce water/waste water use.
- Reduce peak electrical use. Increase adaptability - energy price increases.
- Contribute to community carbon reduction demonstration.

Some of these objectives—"Reduce energy cost" and "Increase adaptability [with respect to] energy price increases—are clearly related to energy cost. Others—"Reduce energy use" and "Reduce peak electrical use"—may reflect energy cost objectives but might also reflect objectives related to certain externalities associated with energy use. Three of the energy-related objectives—"Reduce household carbon footprint," "Reduce use of finite resources," and "Contribute to community carbon reduction demonstration"—appear to reflect objectives related to externalities of energy use. Objectives related to energy costs can be monetized, that is, they can be measured in units that are directly comparable to units used to measure implementation costs. Objectives reflecting externalities of energy use are not easily monetized.

Figure 61 represents an aggregation across the same nine projects for only those objectives related to energy performance.

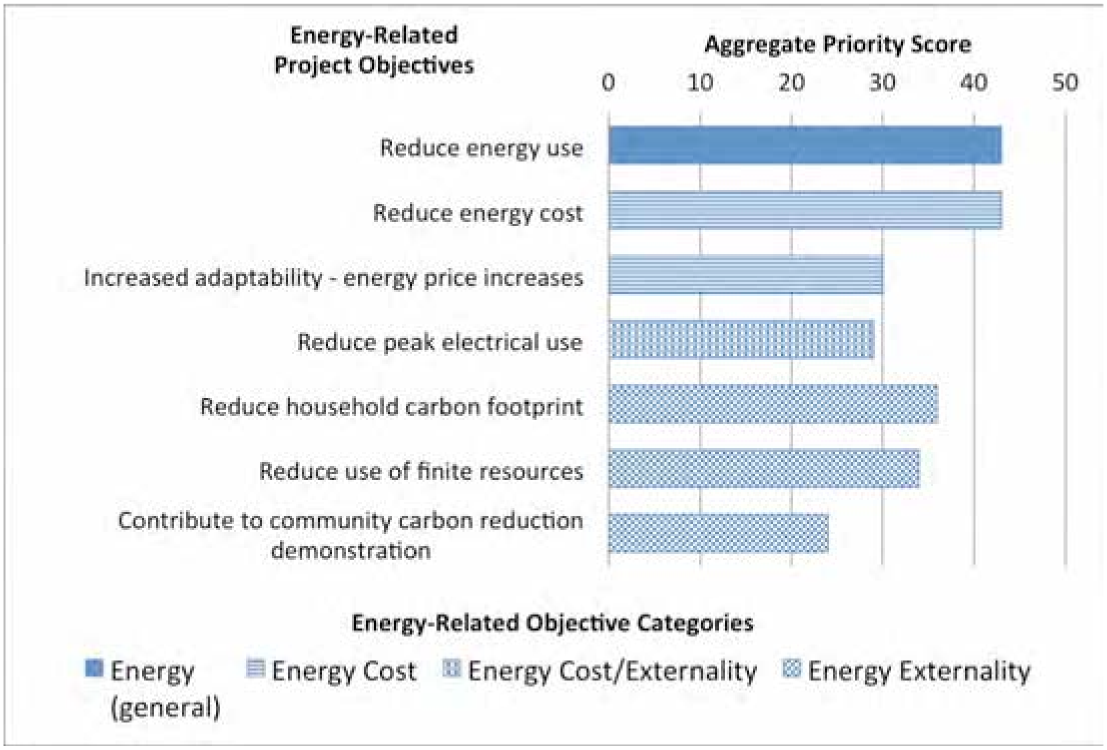

Figure 61. Numerical aggregation of energy-related objective scores

The aggregation of objective ranking represented in Figure 61 indicates that among the two most important energy-related objectives for the group of projects, one objective relates to energy cost and another may relate to energy cost but might also reflect an objective relating to certain externalities associated with energy use. The third and fourth most important energy-related objectives for this group reflect concerns for externalities of energy use. The fifth most important energy-related objective represents an energy cost objective.

4.3.8 Energy-Related Measures Costs and Objectives Conclusions

The analysis of measure costs relative to project objectives was able to assert allocation of energy-related measure costs to energy objectives alone, energy and other project objectives and primarily nonenergy project objectives. As can be seen in Figure 60 and Table 11, the analysis suggests that nonenergy project objectives that are either of primary importance or significant for a sizeable portion of energy-related measure costs. Figure 61 reminds us that important energy-related objectives are not necessarily related to energy costs. This suggests that a cost-effectiveness measure that compares the cost of a measure to an energy cost benefit is a significantly inadequate representation of the effectiveness of the measure relative to project objectives.

5 Conclusions

5.1 Summary of Results and Conclusions

General conclusions from this research project are as follows:

- For a homeowner who has kept the home reasonably well maintained and up to date, a DER can be expected to result in a 30%–45% energy use reduction, assuming that the post-retrofit conditions do not include a major addition or major change in lifestyle.
- The emphasis in this DER package on establishing the air control system can result in an ACH50 of 1.5 or lower, provided the basement is included within the thermal enclosure.
- As a group within this community, the chainsaw retrofits had the lowest heating and cooling energy use (in kBtu/ft^2) as well as the best airtightness results. However, given the data available, it cannot be concluded that use of the chainsaw technique is the only determining factor.
- Improvements are needed in the design, installation, and homeowner education of HVAC systems for DERs.
- The costs for building enclosure measures reflect varying levels of experience among DER contractors, various conditions of existing buildings as well as various approaches to the DER package of measures.
- Contractor experience and a number of other factors impact costs to the extent that trends are difficult to identify at this stage and with this size sample of DER projects. This could be ameliorated by analysis of a larger sample of DER projects after the local market for DER services has had additional time to mature and stabilize.
- When comparing costs for HVAC measures between DER projects it is important to consider the composite HVAC measure costs. The projects exhibit a great variety of approaches relative to separate HVAC function (i.e., heating, cooling, ventilation).
- Analysis of measure costs relative to project objectives demonstrate that objectives beyond energy cost are often the primary motivation for measures related to energy savings. Therefore a cost-effectiveness metric that compares the cost of a measure to an energy cost benefit alone is a significantly inadequate representation of the effectiveness of the measure relative to project objectives.

Additional specific conclusions for the airtightness, energy use, construction cost, and project objective relative to cost analyses are provided at the end of each of the analysis sections.

5.2 Progress on Research Questions

The following summarizes responses to the research questions based on the analysis of the 13 retrofits in this community.

- **Does the DER measures package result in 30% source energy reduction use?**
    - The range of post-retrofit source energy reduction when compared to a year of pre-retrofit source energy use was 27%–75%. However, this is dependent on the pre-retrofit conditions as well as the lifestyle of the occupants.

- **Are there discernible differences in source energy use reduction between the variations allowed within the DER measures package?**
  - The lowest levels of source energy use for heating and cooling in kBtu/ft^2-yr were achieved by the chainsaw retrofits with the air control layer outside of the existing sheathing and with exterior insulating sheathing for the walls and roof. However, given the data available, it cannot be concluded that these characteristics are the only determining factors.
  - The lowest levels of source energy use for heating and cooling in kBtu/ft^2-yr were achieved by retrofits for which the airtightness was measured at 1.5 ACH50 or less.
  - Failure to include the basement in the thermal enclosure appears to result in higher heating and cooling EUI. However, with only one example in this community, this is only an anecdotal conclusion at this time.
- **What post-retrofit airtightness has been achieved by the DER measures package?**
  - For this community, the post-retrofit airtightness results ranged from 0.61–7.26 ACH50 with all but four of the retrofits falling below 1.5 ACH50.
- **Are there discernible differences in air leakage reduction between the variations allowed within the DER measures package?**
  - When taken as a group, the lowest air leakage results in this community were achieved by the chainsaw retrofits with the air control layer outside of the existing sheathing and with exterior insulating sheathing for the walls and roof. However, given the data available, it cannot be concluded that these characteristics are the only determining factors.
  - The highest air leakage result, which was significantly higher than all others, occurred for the one retrofit that did not include the basement in the conditioned space, for which the air control layer transitioned from the inside for the roof to the outside for the exterior walls, and for which porches and decks were not temporarily detached during the retrofit—all of these conditions can contribute to higher air leakage results.
- **What are the costs of the DER measures package?**
  - For projects included in this study, the average enclosure measure cost relative to enclosure surface area is \$18.62/ft^2 and the range is \$9.99–\$26.87/ft^2. When considering the costs for energy-related enclosure measures only, the average unit cost is \$13.13/ft^2 and the range is \$8.62–\$22.20/ft2.
  - Total HVAC system costs ranged from slightly more than \$10,000 to just less than \$19,000 for projects that met the pilot program target by installing high efficiency heating and cooling equipment and distributed ventilation with heat or energy recovery.

- **Can the net cost of energy performance improvement be separated from full DER measures package cost?**
    - The net cost of energy performance improvement cannot be fully separated from measure package costs. However, given sufficient measure cost detail and information pertaining to project scope and objectives, it is possible to assert the portion of costs representing (1) measures pursued solely for energy-related objectives; (2) measures pursued for a combination of energy-related and nonenergy-related objectives; and (3) measures pursued primarily in response to nonenergy-related objectives.

5.3 Recommendations for Future Work

Satisfying the long-term goal of significantly reducing residential energy use will require that existing homes be retrofit to levels of performance commensurate with current *high-performance* practice. DER represents a path toward high performance for existing homes. There are significant barriers to widespread adoption of DER among these are the following:

- Savings potential of DER is not adequately understood or accepted
- Costs for DER are not adequately understood
- DER methods are not adequately understood
- Perceptions that DER will compromise the aesthetics of existing homes.

Below is an outline of research efforts that would address these barriers.

5.3.1 Analyze Measured Performance and Costs of Expanded Deep Energy Retrofit Project Population

The current research advances the understanding of DER savings potential and costs. However, with the National Grid DER pilot having completed another year of implementation, there will soon be an opportunity to expand the analysis both in terms of number of projects examined and time period of examination. In 2012, the final year of the National Grid DER pilot, more projects completed a DER project through the program than in the previous years of the program combined. Expanding the number of projects included in the analysis is important to evaluating trends that are merely suggested or not even apparent in the population analyzed for the current research. Expanding the time period of examination for projects that have completed in past years will provide an opportunity to assess the durability of energy savings and other performance measures.

5.3.2 Builder Costs

The current research has analyzed costs of DER measures in terms of costs to the homeowner. Wider adoption of DER measures by contractors is likely to require greater understanding of the contractor's cost of implementation. Revealing actual implementation costs may place contractors in an awkward position vis-à-vis current and potential clients. A larger population of completed DER projects and deeper experience of contractors having completed multiple DER projects may create a situation conducive to sharing implementation cost information.

5.3.3 Deep Energy Retrofit Measure Guidance

With 44 DER projects completed, the National Grid DER program provides an opportunity to review challenges encountered and solutions achieved with the goal of disseminating these lessons learned. Information resources could be developed to explain common challenges and illustrate successful solutions. Such information resources would support contractors interested in implementing high performance retrofit of existing homes.

5.3.4 Case Studies Focused on Comprehensive Performance

The DER projects supported by National Grid and BSC have pursued comprehensive high performance. This includes high performance in terms of health and safety, durability, comfort, energy use and, quite arguably, aesthetics. Many of the projects encountered have demonstrated significant aesthetic improvement relative to the pre-retrofit conditions. Case studies of particularly attractive or visually interesting DER projects could highlight the potential aesthetic benefits of DER projects. Placing these case studies in publications oriented toward aesthetic performance of homes would strengthen the impact relative to addressing perceptions that DER might negatively impact the appearance of a home.

5.3.5 Collaboration With Historic Preservation Stakeholders

Some resistance to DER of buildings is expected from those interested in preserving the character of existing buildings. Collaboration with experts in historic preservation might yield guidance for specialized high performance retrofit techniques needed in particularly sensitive or significant structures.

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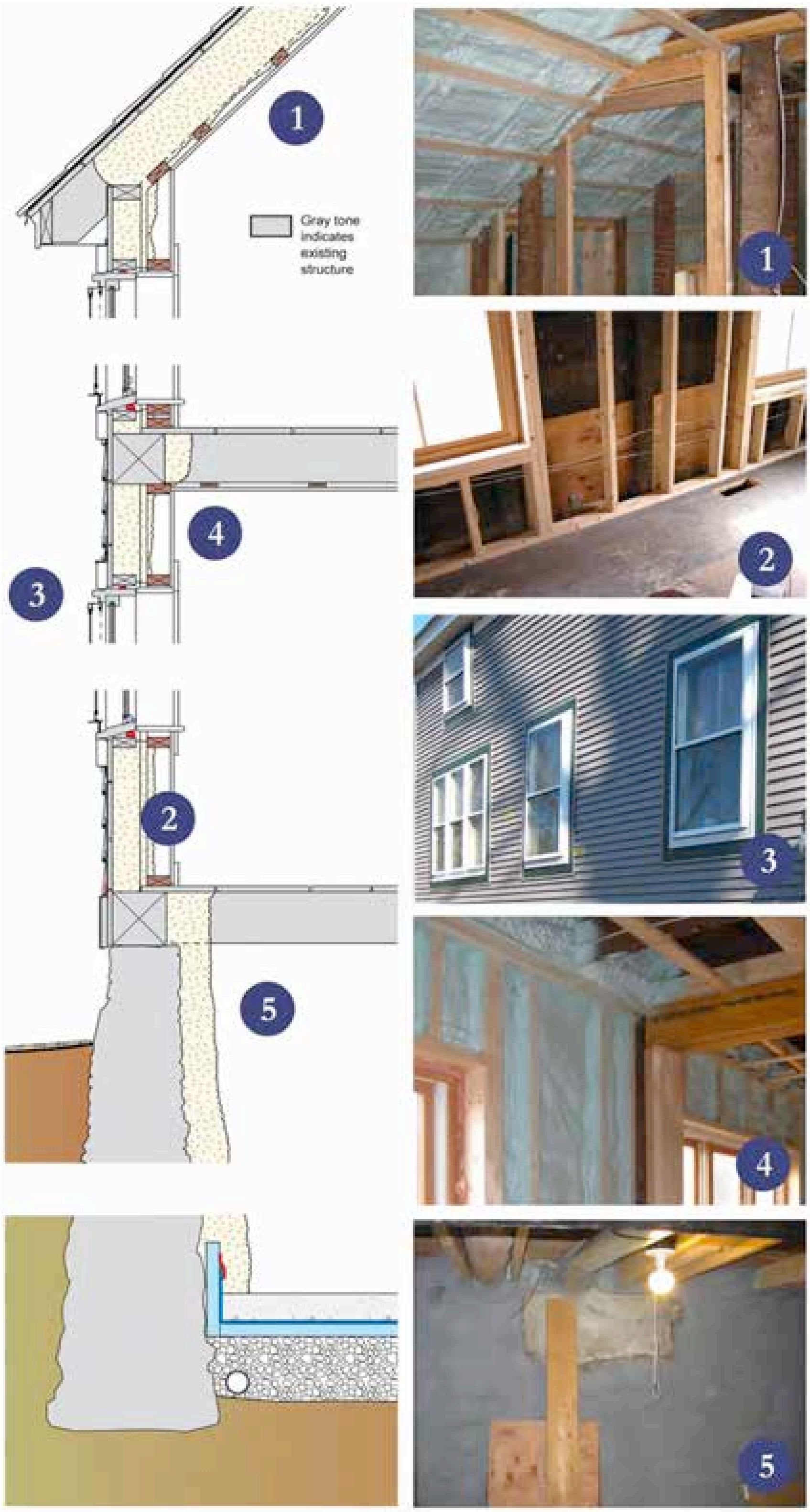
Appendix A:

Appendix A.1: Belchertown MA Retrofit

Figure A.1.1. Belchertown Pre-retrofit (left) and Post-retrofit (right, photo by David Connelly Legg)

The long-time residents of this home have an extremely frugal life style. Prior to the retrofit, the house was largely uninsulated and was heated using a wood stove. There was often standing water in the basement. The DER project was part of a comprehensive renovation project that included structural repairs, extensive water management improvements and a full interior rehabilitation as well as a full implementation of the DER package except for the windows.

- House Type: Single-family 1.5 story house with full basement
- Date Built: around 1760
- DER Completion: January 2010
- Pre-Retrofit Conditioned Space: 1,435 sf
- Post-Retrofit Conditioned Space: 1,907 sf
- Pre-Retrofit Heating Fuel: Wood
- Post-Retrofit Heating Fuel: Propane



Enclosure Design

❶ Roof Assembly: Compact (unvented) roof assembly with existing 2x8 rafter framing and 2x3 cross furring, framing cavity and portion of furring cavity filled with R-56 Demilec Heatlok Soy™ medium density spray foam insulation.

❷ Wall Assembly: 2x4 stud wall constructed to inside of original post and beam frame with 1" gap between existing and new framing. R-32 (~5") medium density spray foam insulation sprayed into wall cavities and over rim beam.

❸ Window Specifications: New Harvey Tru Channel storm windows over existing wood-framed, double-glazed, low-E windows; approx. composite performance: U=0.25, SHGC=0.52.

❹ Air Sealing: Continuous layer of medium density, closed-cell spray foam insulation provides air flow control in the field of the wall and roof assemblies. Spray foam insulation also applied at rim beams and in a floor assembly over a crawl space. Low-expansion foam sealant applied around windows and doors, and at any mechanical or electrical penetrations through the enclosure.

❺ Foundation Assembly: Conditioned basement with 3-5" medium density spray foam insulation applied directly to field stone and concrete foundation walls. Spray foam insulation painted with Blaze Lok 1B™ ignition barrier paint. A 12" high strip of 2" XPS as the slab perimeter thermal break also allows foundation walls to drain to the sub-slab drainage system. Several trenches with drainage pipe connected to drain and filled with gravel manage bulk water. New cast concrete basement floor slab over 6 mil poly, 2" XPS and continuous bed of gravel.

Figure A.1.2. Belchertown DER Enclosure Profile

Mechanical Design

1 Heating: 96.7% AFUE sealed combustion propane furnace in conditioned space. High SEER coil installed for future connection to air-source heat pump.

2 Ventilation: High efficiency heat recovery ventilator (HRV) with dual ECM motors and 74% recovery efficiency. Outside air supply ducted to heating system distribution, exhaust air taken from bathroom.

3 Space Conditioning Distribution: Insulated sheet metal trunks with insulated flex run-outs. Ducted return in each bedroom plus two additional returns in first floor areas. Entire distribution system within thermal enclosure.

4 DHW: 0.86 EF on-demand propane-fired water heater.

5 Lighting: Hard wired ENERGY STAR®CFL lighting plus high efficacy (60 lumen/Watt) LED lighting.

6 Appliances: ENERGY STAR® dishwasher, refrigerator and clothes washer.

Figure A.1.3. Belchertown DER Mechanical Design

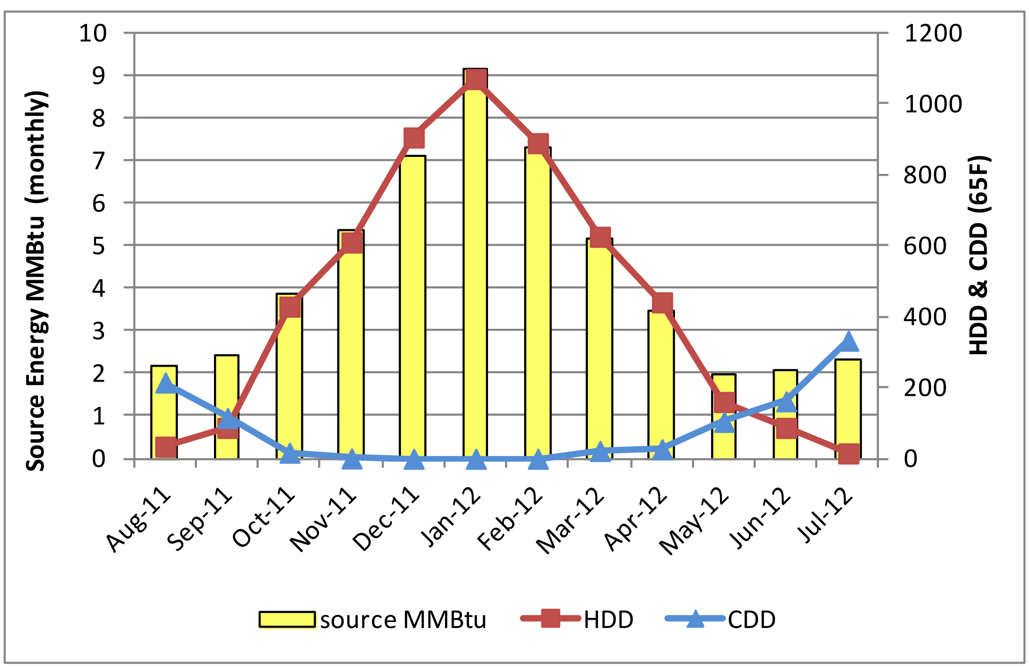


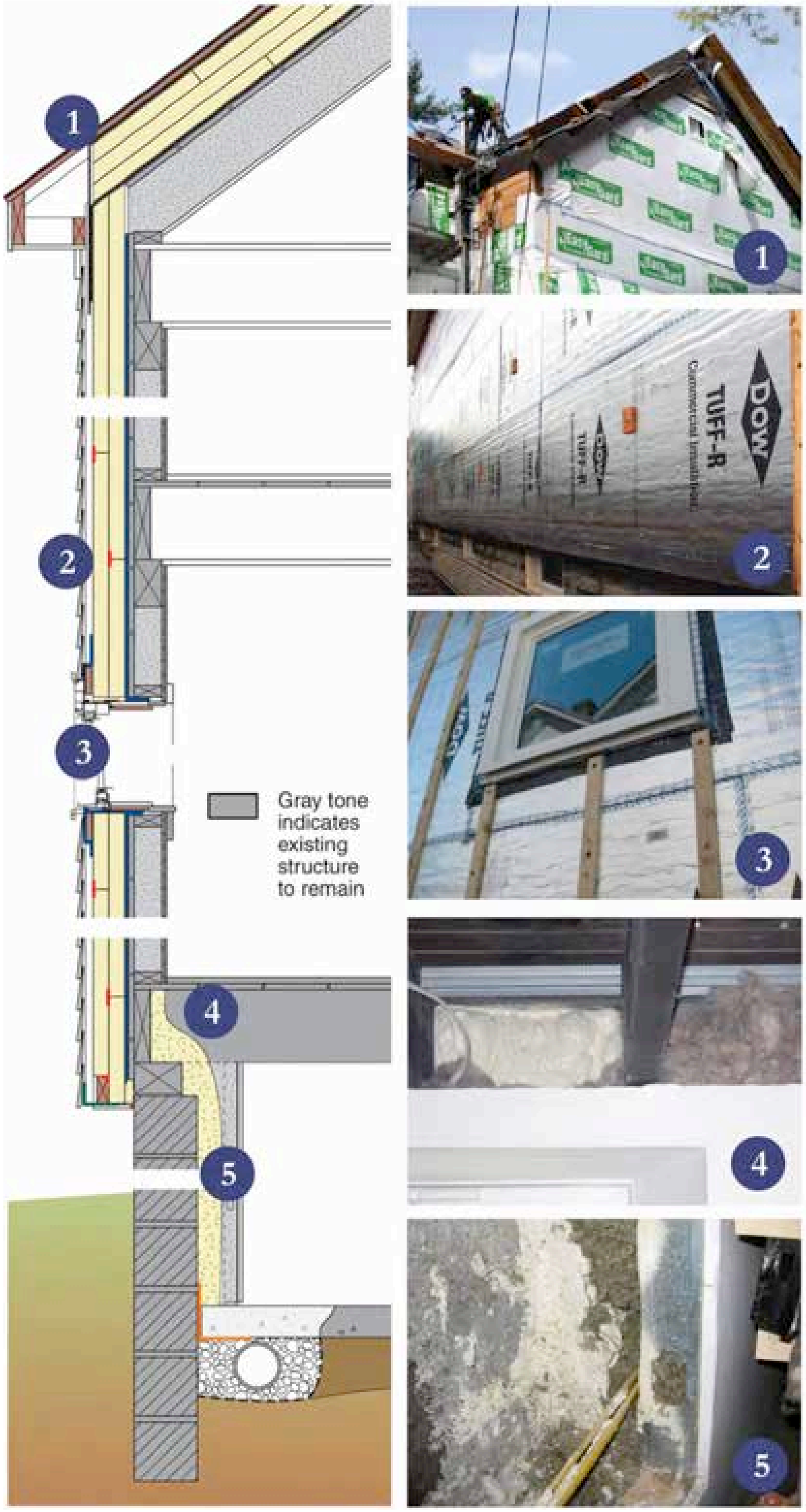
Figure A.1.4. Belchertown Monthly Total Source Energy Use August 2011 – July 2012

Appendix A.2: Belmont MA Retrofit

Figure A.2.1. Belmont Pre-retrofit (left, with permission of National Grid) and Post-retrofit (right)

This two-family house with attic and full basement was largely uninsulated and in need of major renovations and updating when purchased by the current owner. The renovations were combined with a DER after which the owner and his family moved into the upper unit and his parents moved into the first floor unit. The renovations included extensive interior improvements and modifications along with a full implementation of the DER package except that the basement slab was not insulated.

- House Type: Two-family colonial with full basement
- Date Built: 1925
- DER Completion: September 2010
- Pre-Retrofit Conditioned Space: 3,417 sf
- Post-Retrofit Conditioned Space: 4,768 sf
- Pre-Retrofit Heating Fuel: Oil
- Post-Retrofit Heating Fuel: Natural Gas



Enclosure Design

❶ **Roof Assembly:** Compact (unvented) roof assembly with existing 7" deep rafter bays filled with netted cellulose insulation and with three 2" layers of foil-faced polyisocyanurate exterior insulating sheathing.

❷ **Wall Assembly:** Existing wall framing cavities filled with dry cellulose and two 2" layers of foil-faced polyisocyanurate exterior insulating sheathing.

❸ **Window Specifications:** New Paradigm triple-glazed, krypton/argon blend, low-E vinyl windows; U=0.2, SHGC=0.25.

❹ **Infiltration:** Self-adhering membrane over existing roof sheathing provides air control in field of roof. The taped outer layer of insulating sheathing on the wall is the air control layer for the field of the walls. The roofing membrane overlaps the exterior wall insulation to provide a continuous transition. Closed-cell spray foam provides the air control layer for the foundation wall. The transition from the exterior wall air control to the foundation wall air control is through the mudsill with sealant applied between the exterior insulating sheathing and the mudsill and the spray foam over the foundation wall extending up over the mudsill.

❺ **Foundation Assembly:** Conditioned basement with 3" closed-cell, high-density SPF insulation applied directly to stone foundation walls covered by metal stud walls with rock wool insulation. Sub-slab perimeter drainage system was installed and connected to a new sump pump. A drainage mat was installed along the base of the foundation wall and down under the new section of slab to allow foundation walls to drain to the sub-slab system.

Figure A.2.2. Belmont DER Enclosure Profile

MECHANICAL DESIGN

❶ **Heating and Cooling:** For each unit, 96.7 AFUE sealed combustion natural gas furnace in conditioned space with AHRI-rated 14 SEER/12 EER coil installed and connected to outdoor AC unit.

❷ **Ventilation:** For each unit, Energy Recovery Ventilator installed with dedicated ductwork; outside supply ducted to common space; inside exhaust taken from bathrooms.

❸ **Space Conditioning Distribution:** Entire distribution system within thermal enclosure: ductwork in basement for lower unit; ductwork in attic kneewall space and floors for upper unit.

❹ **DHW:** Solar thermal with common 100 gal. tank and, for each unit, a 40 gal. electric backup tank.

❺ **Lighting:** ENERGY STAR® CFL lighting.

❻ **Appliances:** ENERGY STAR® dishwasher, refrigerator and clothes washer.

Figure A.2.3. Belmont DER Mechanical Design

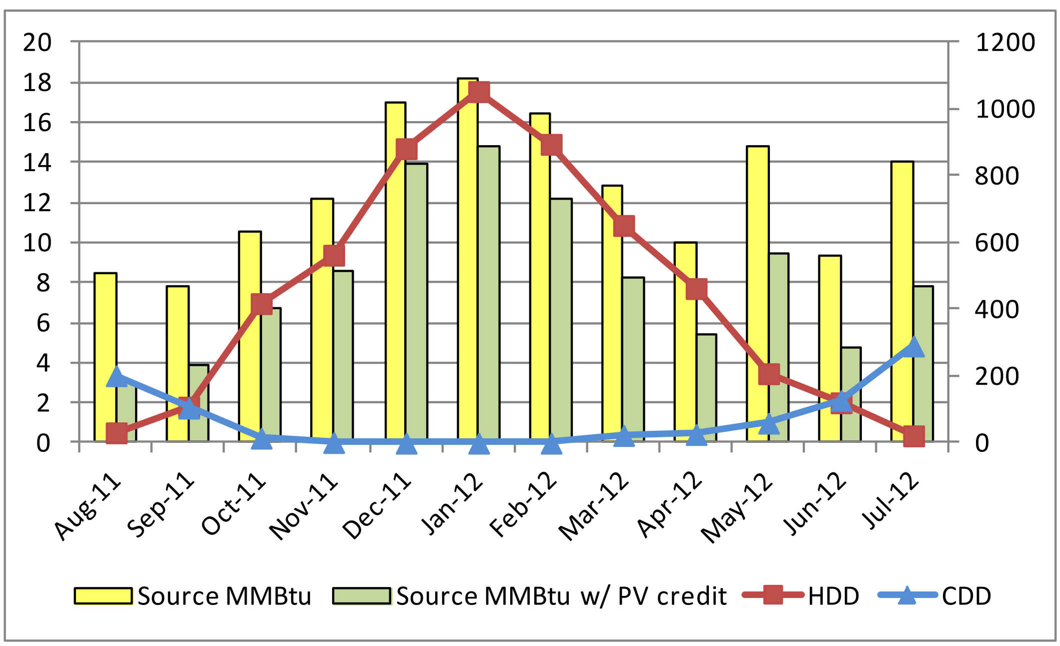


Figure A.2.4. Belmont Monthly Total Source Energy Use August 2011 – July 2012

Appendix A.3: Millbury MA Retrofit

Figure A.3.1. Millbury Pre-retrofit (left, with permission of National Grid) and Post-retrofit (right)

The owners have lived in this Cape Cod style house for more than 25 years making interior improvements and repairs during that time as needed. Upon becoming "empty nesters", they undertook an exterior-only upgrade that included a full implementation of the DER package. As part of the project, a partial shed dormer in the rear of the upper floor was extended to the full length of the house.

- House Type: Single-family 1.5 story Cape Cod style house with full basement
- Date Built: 1953
- DER Completion: December 2010
- Pre-Retrofit Conditioned Space: 1,868 sf
- Post-Retrofit Conditioned Space: 1,868 sf
- Pre-Retrofit Heating Fuel: Oil and wood pellets
- Post-Retrofit Heating Fuel: Electricity

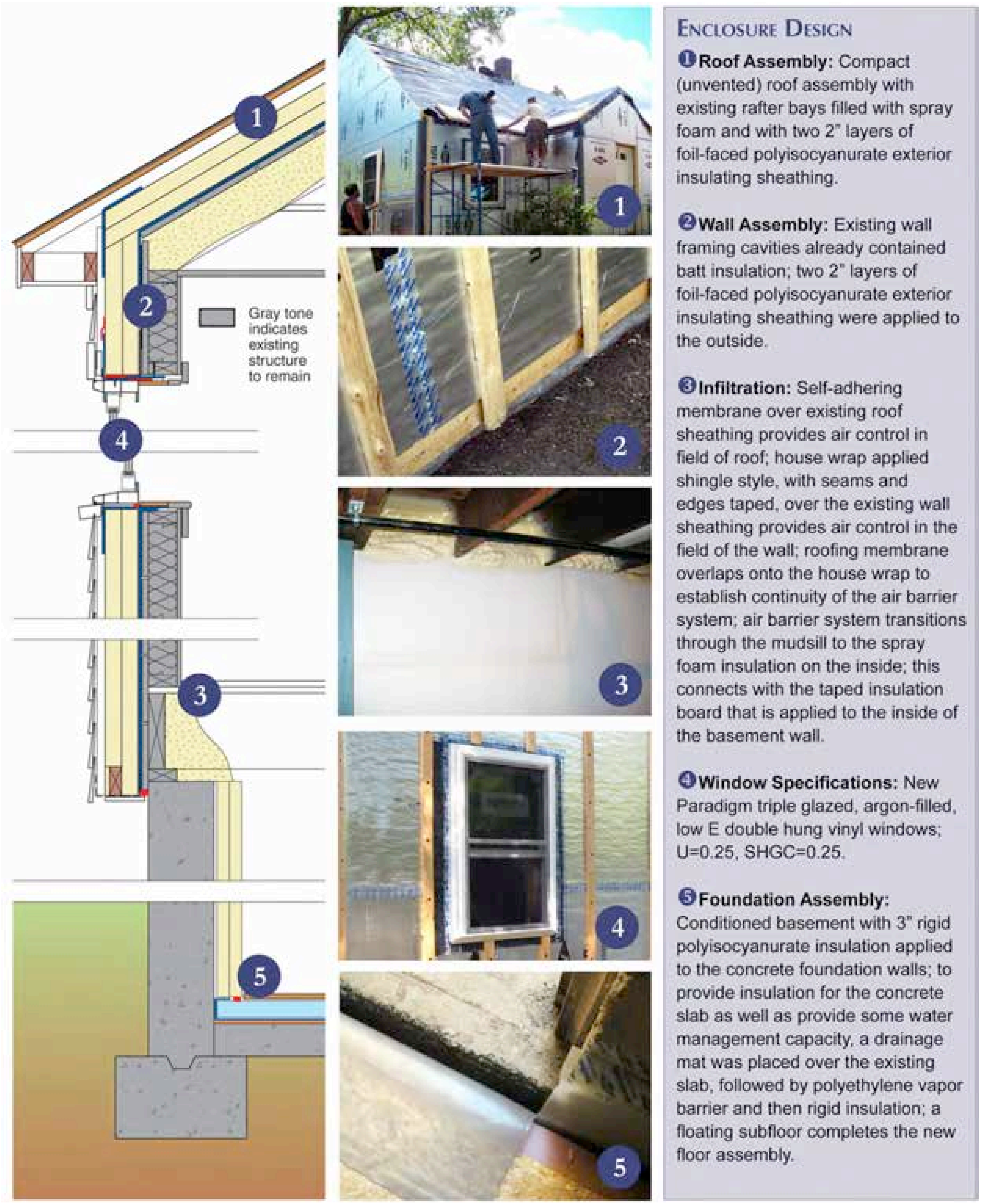


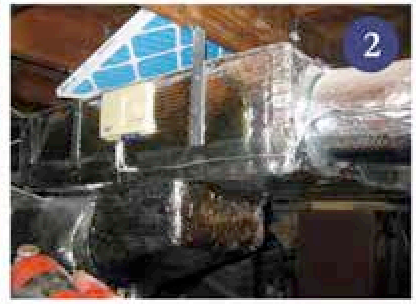
Figure A.3.2. Millbury DER Enclosure Profile

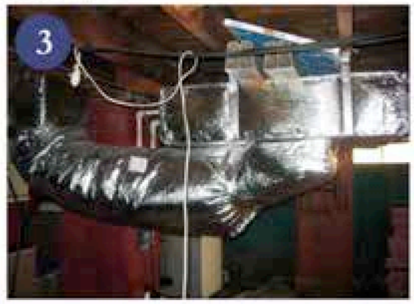
Mechanical Design

❶ **Heating and Cooling:** Mini-split heating and cooling heat pump system with two ducted air handlers and one outdoor unit; one air handler is located in the basement and one is in kneewall space; direct vented pellet stove is available as backup for heat.

❷ **Ventilation:** An outdoor air supply is integrated with each air handler; outdoor air intake ducts are provided with ventilation controllers and mechanical dampers; spot exhaust fans are provided in the bathrooms.

❸ **Space Conditioning Distribution:** Insulated sheet metal trunks with insulated flex run-outs; entire distribution system within thermal enclosure; ductwork in basement ceiling for basement air handler; ductwork in attic and kneewall space for the second floor air handler.





❹ **DHW:** Instantaneous propane water heater.

Lighting: ENERGY STAR® CFL lighting.

Appliances: No change at this time.

Figure A.3.3. Millbury DER Mechanical Design

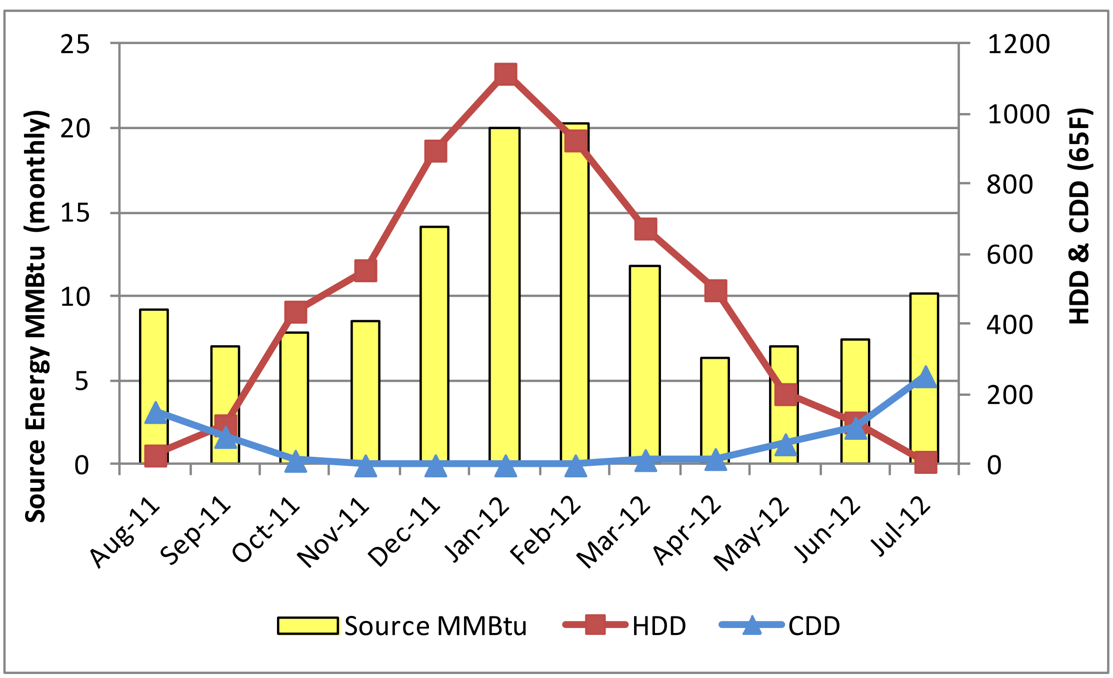


Figure A.3.4. Millbury Monthly Total Source Energy Use August 2011 – July 2012

Appendix A.4: Milton MA Retrofit

Figure A.4.1. Milton Pre-retrofit (left) and Post-retrofit (right)

The Milton home was unoccupied and bank-owned when purchased by the current owner in 2010. The existing home had fiberglass cavity insulation in the exterior walls and in the attic floor. A comprehensive interior renovation, including reconfiguration of interior spaces, and a full implementation of the DER package was completed prior to when the current owner moved in. The owner uses the home for his family as well as for a home office.

- House Type: Single-family garrison colonial with full basement
- Date Built: around 1960
- DER Completion: February 2011 (Move in August 2011)
- Pre-Retrofit Conditioned Space: 2,368 sf
- Post-Retrofit Conditioned Space: 2,368 sf
- Pre-Retrofit Heating Fuel: Natural Gas
- Post-Retrofit Heating Fuel: Natural Gas

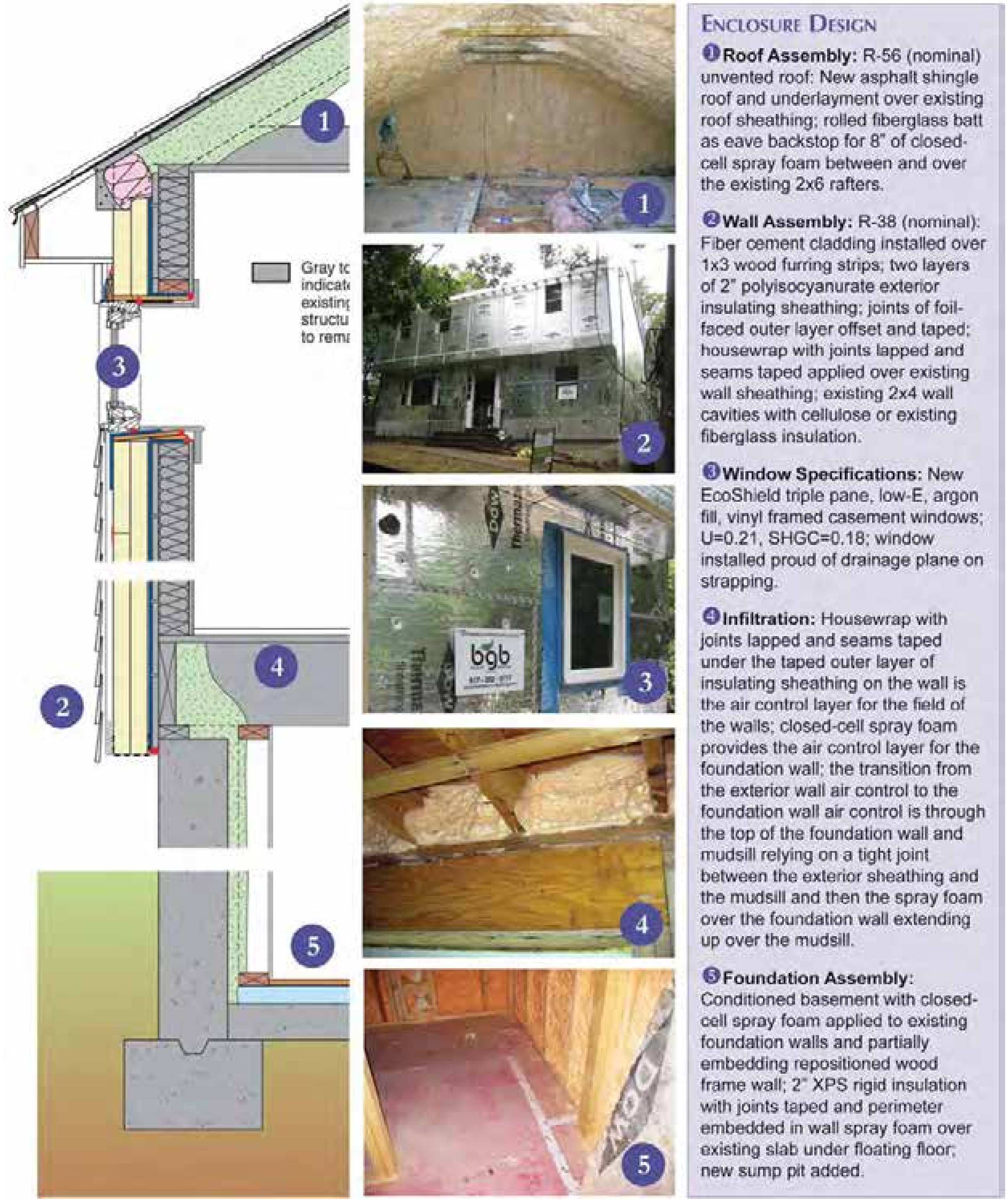


Figure A.4.2. Milton DER Enclosure Profile

Mechanical Design

❶**Heating and Cooling:** Hydro-air heating with heating supplied by A.O. Smith Vertex™ high efficiency direct-fired storage water heater; central cooling with with 16 SEER/13.1 EER 2.5 ton AC

❷**Ventilation:** Venmar EKO 1.5 HRV system ducted to heating/cooling distribution system.

❸**Space Conditioning Distribution:** Entire distribution system within thermal enclosure.

❹**DHW:** A.O. Smith Vertex™ high efficiency direct-fired storage water heater.

Lighting: ENERGY STAR® CFL lighting.

❺**Appliances:** ENERGY STAR® dishwasher, refrigerator and clothes washer.

❻**Site Generated Power:** 2.8 kW PV array

Figure A.4.3. Milton DER Mechanical Design

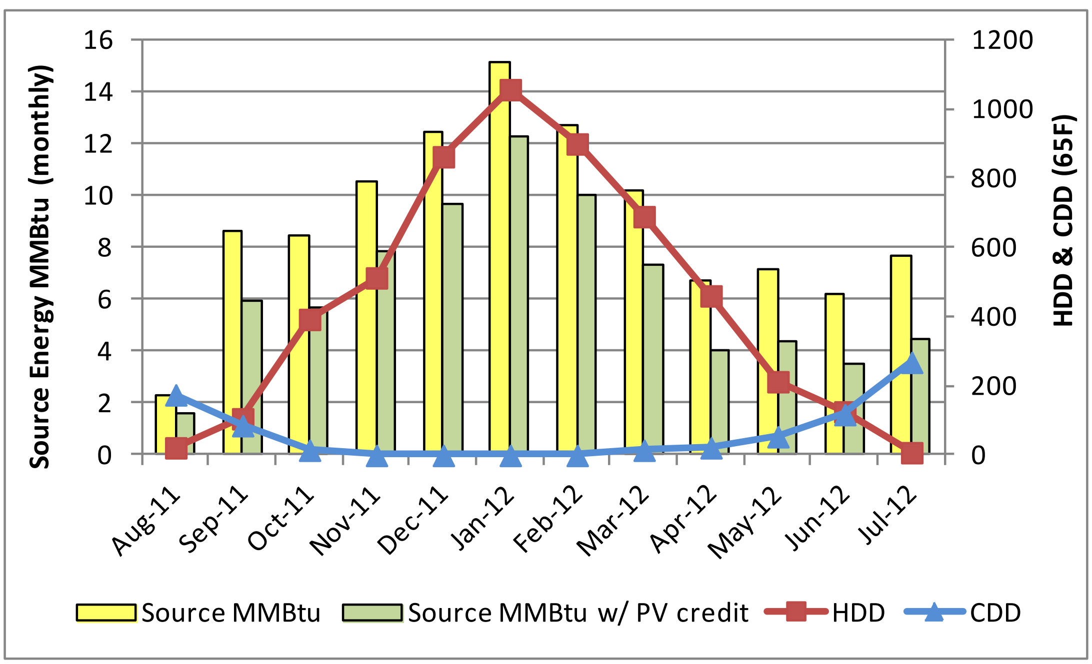


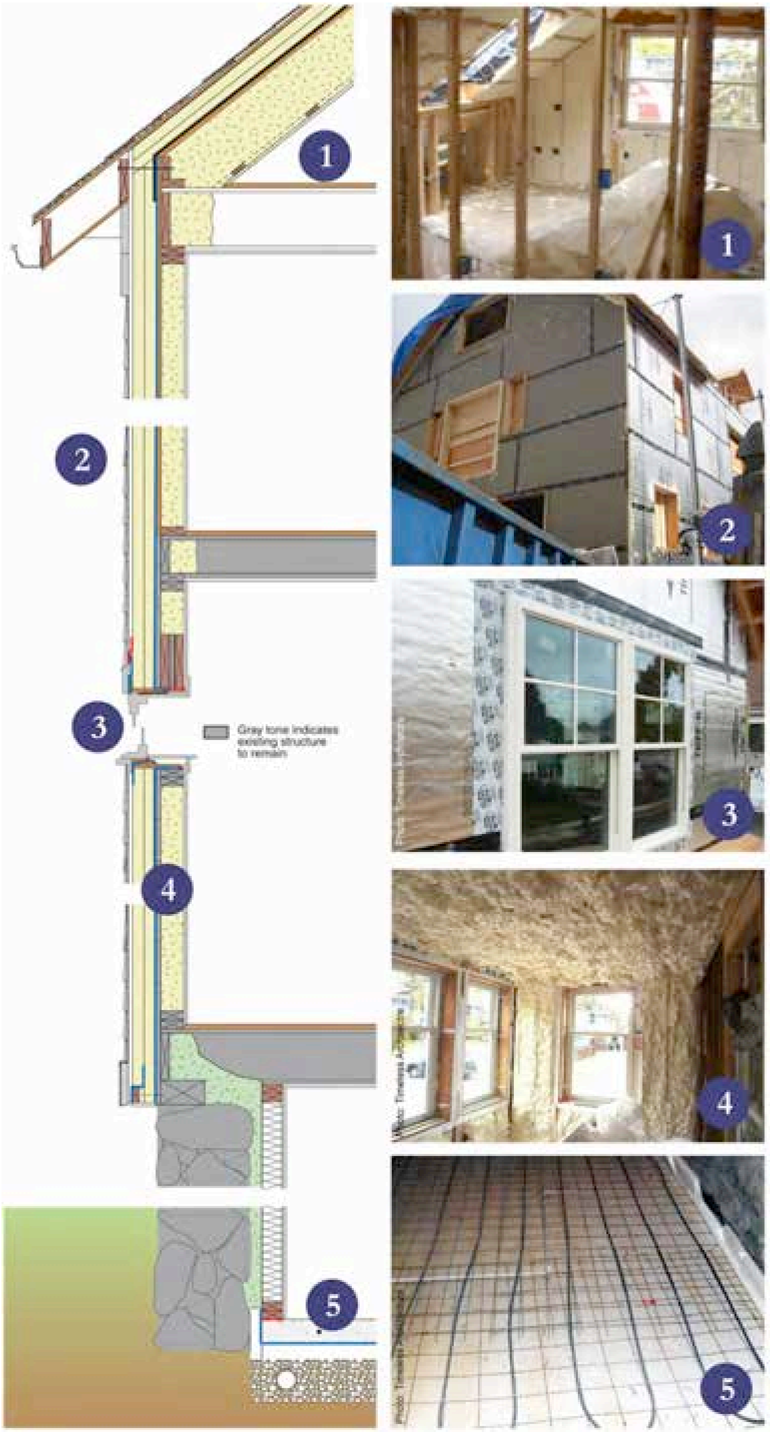
Figure A.4.4. Milton Monthly Total Source Energy Use August 2011 – July 2012

Appendix A.5: Quincy MA Retrofit

Figure A.5.1. Quincy Pre-retrofit (left) and Post-retrofit (right)

This 1.5 story bungalow home with full basement was purchased and occupied by the current owners in 1985. In 2011, a major expansion of the original house was combined with implementation of the full DER package. The newly expanded home also serves as a home office.

- House Type: Single-family 2.5 story expanded bungalow with full basement
- Date Built: around 1905
- DER Completion: December 2010
- Pre-Retrofit Conditioned Space: 3,484 sf
- Post-Retrofit Conditioned Space: 4,576 sf
- Pre-Retrofit Heating Fuel: Oil
- Post-Retrofit Heating Fuel: Natural Gas



ENCLOSURE DESIGN

1 Roof Assembly: R-62 unvented roof: 10" Icynene® open-cell spray foam insulation in rafter cavities; roof sheathing; housewrap; two layers of 2" polyisocyanurate insulating sheathing, joints offset and taped; plywood nail base; roof underlayment; asphalt shingles.

2 Wall Assembly: R-38 (nominal): Icynene® open-cell spray foam insulation in 2x4 wall framing cavities; existing board sheathing or new plywood sheathing; housewrap; two layers of 2" polyisocyanurate insulating sheathing joints offset and taped; 1x3 wood furring; fiber cement siding.

3 Window Specifications: New Paradigm triple-pane, vinyl framed, low-e, krypton blend or argon gas filled; U=0.20 – 0.26, SHGC=0.23 – 0.21; windows installed in plane with primary water control layer.

4 Infiltration: Taped housewrap over roof and wall sheathing; adhered membrane wrapping from roof to wall; two layers of 2" polyisocyanurate insulating sheathing joints offset and taped; open-cell spray foam insulation in wall and roof framing cavities; closed-cell spray foam applied over framing sill and granite block foundation wall; spray foam extends to new concrete slab.

5 Foundation Assembly: Conditioned basement: 2" closed-cell spray foam applied over framing sill and foundation wall; 3½" fiberglass batt in new wall framing cavity; 6-10" gravel, 2½" EPS insulation; polyethylene vapor retarder under new concrete slab with radiant tubing.

Figure A.5.2. Quincy DER Enclosure Profile

Mechanical Design

❶❷ **Heating and Cooling:** Carrier Infinity® two stage heat pump; SEER 16.5; HSPF 9.5; Phoenix Evolution Versa-Hydro™ direct-fired storage water heater with heat exchanger for heating and for input from solar thermal system.

❸ **Ventilation:** LifeBreath HRV, ducted to central AHU distribution.

❹ **Space Conditioning Distribution:** Ductwork for forced-air system entirely within conditioned space; hydronic radiant in new concrete basement slab; hydronic panel radiator at entry and front/porch room.

❺ **DHW:** Phoenix Evolution Versa-Hydro™ direct-fired storage water heater with heat exchanger for input from 6 Velux integrated solar thermal collector panels.

Lighting: ENERGY STAR® CFL lighting.

Appliances: ENERGY STAR® dishwasher, refrigerator and clothes washer.

❻ **Site Generated Power:** 6.25 kW solar PV array.

Figure A.5.3. Quincy DER Mechanical Design

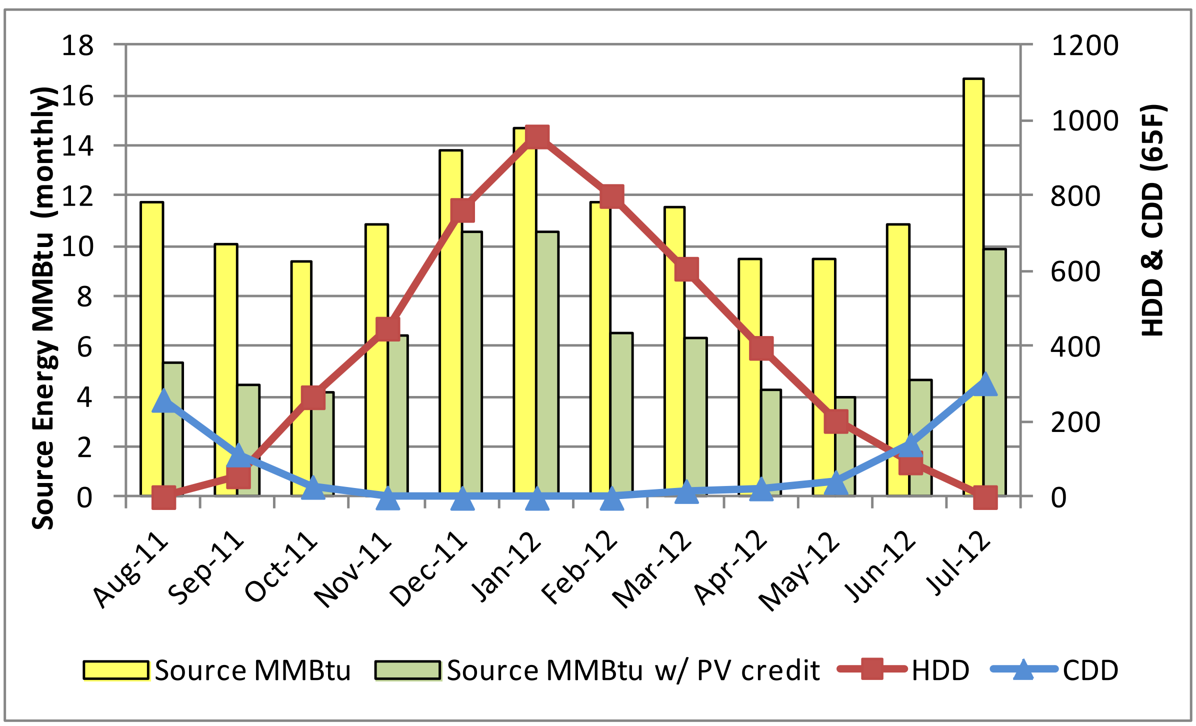


Figure A.5.4. Quincy Monthly Total Source Energy Use August 2011 – July 2012

Appendix A.6: Arlington MA Retrofit

Figure A.6.1. Arlington Pre-retrofit (left) and Post-retrofit (right)

This two-family home was purchased in 2009 with the intent of renovation and then to serve as homes for the owners and the parents of one of the owners. The renovation included the addition of space on the upper floor and was combined with a full implementation of the DER package. The project team decided to leave the basement unconditioned and to insulate and air seal at the basement ceiling.

- House Type: Over-under two-family with full basement
- Date Built: around 1910
- DER Completion: March 2011
- Pre-Retrofit Conditioned Space: 2,502 sf
- Post-Retrofit Conditioned Space: 3,627 sf
- Pre-Retrofit Heating Fuel: Natural Gas
- Post-Retrofit Heating Fuel: Natural Gas

Enclosure Design

❶ Roof Assembly: R-58 (nominal) unvented roof assembly: 9" closed-cell spray foam; ¾" roof sheathing, roofing felt; asphalt shingles.

❷ Wall Assembly: R-38 retrofit assembly 1st and 2nd floor: open-cell spray foam or fiberglass batt in 2x4 wall on first floor; board sheathing with housewrap; two layers of 2" polyisocyanurate insulating sheathing, joints offset and taped. R-41 new construction assembly 3rd floor: fiberglass batt in 2x6 wall; taped Zip System™ wall sheathing; one layer 2" XPS; one layer 2" foil-faced polyisocyanurate with seams taped.

❸ Window Specifications: New EcoShield triple pane, low-E, argon fill, vinyl framed, double-hung and casement windows; U=0.22-0.21, SHGC=0.21-0.18; window installed proud of drainage plane on strapping.

❹ Infiltration: Housewrap with lapped and taped seams; taped exterior insulation layer; open-cell spray foam at 1st floor framing cavities and basement access stair walls; closed-cell spray foam in roof rafter cavities extended onto back side of wall insulating sheathing; taped foil-faced rigid insulation at basement ceiling; closed-cell spray foam to underside of enclosed porch floor.

❺ Floor Over Unconditioned Basement: R-30 (nominal): dense-packed cellulose in floor framing cavities; 1" foil-faced polyisocyanurate to underside of floor framing with seams taped; one-part foam sealant at perimeter of and penetrations through rigid insulation layer.

Figure A.6.2. Arlington DER Enclosure Profile

Figure A.6.3. Arlington DER Mechanical Design

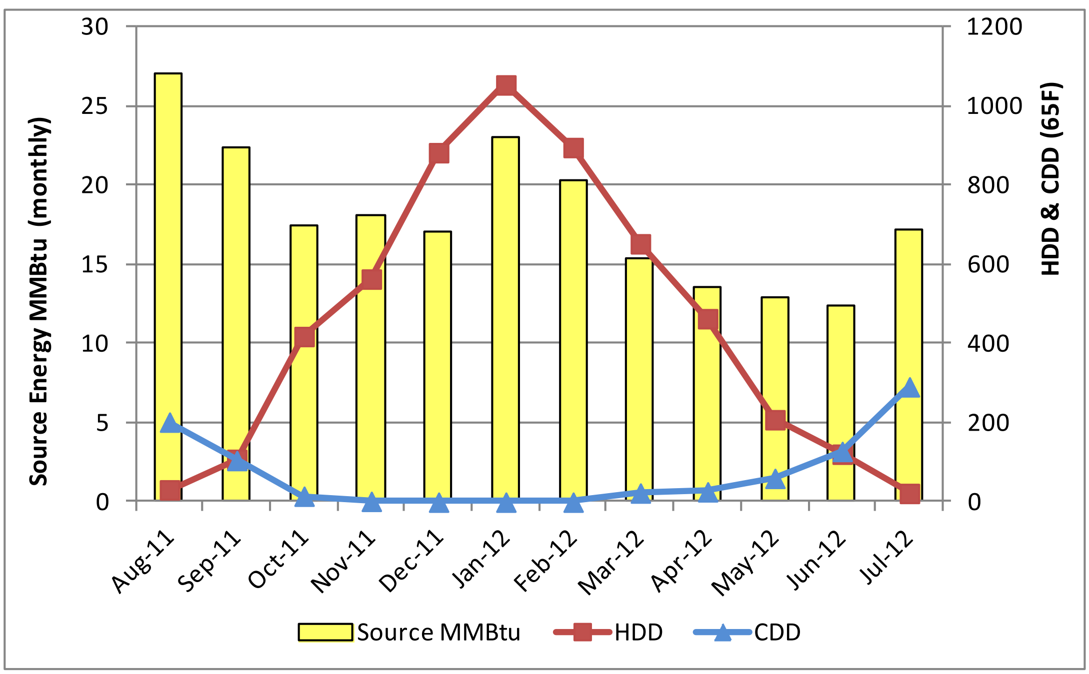


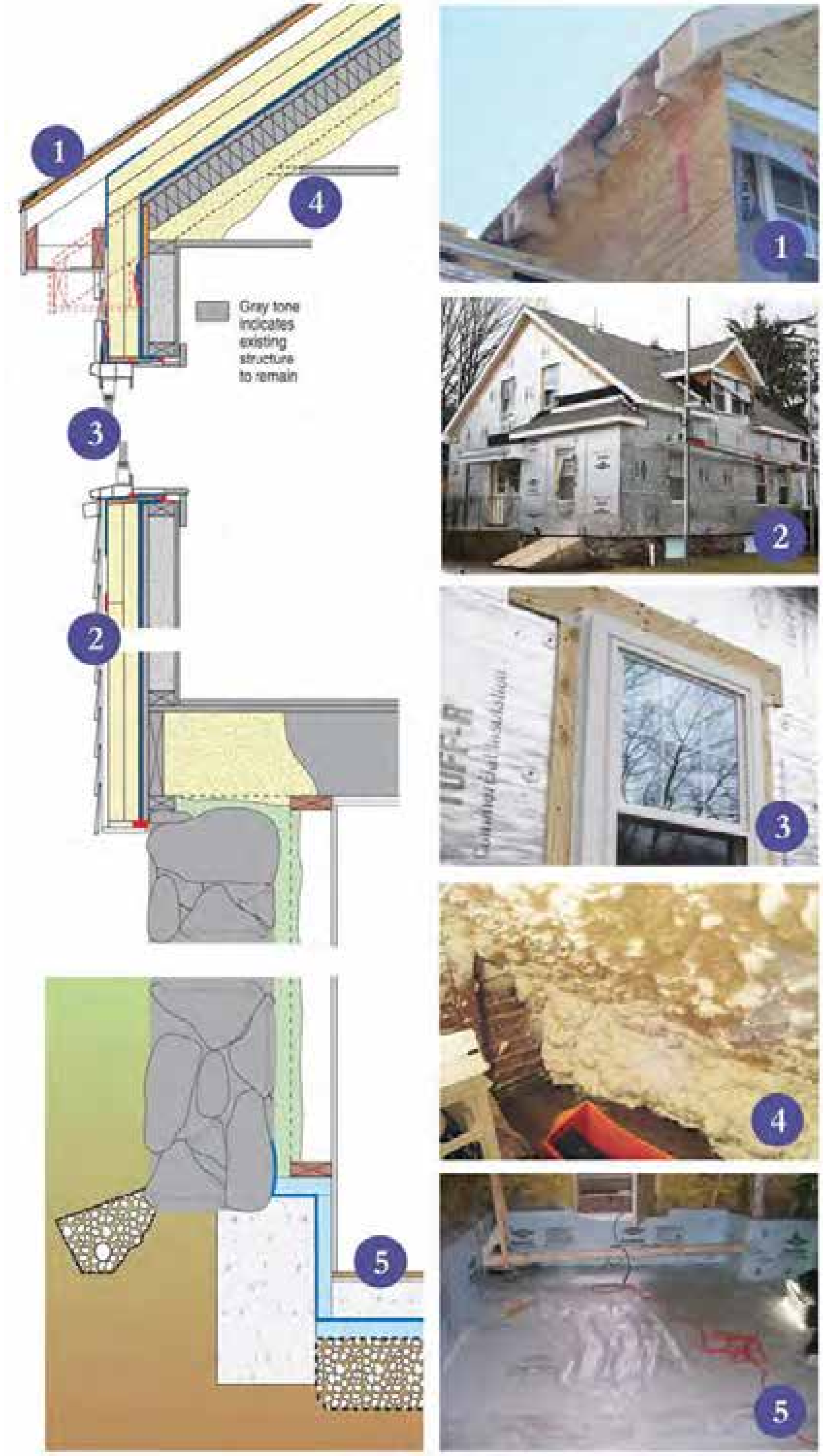
Figure A.6.4. Arlington Monthly Total Source Energy Use August 2011 – July 2012

Appendix A.7: Newton MA Retrofit

Figure A.7.1. Newton Pre-retrofit (left, with permission of National Grid) and Post-retrofit (right)

This 1.5 story Cape Cod style house was purchased and occupied by the current owner in 2006. The retrofit project started in 2010 as a conversion of the basement to conditioned living space along with an upgrade of the existing heating and hot water systems but was expanded to include a full implementation of the DER package.

- House Type: Single-family Cape Cod style with full basement
- Date Built: 1930
- DER Completion: June 2011
- Pre-Retrofit Conditioned Space: 1,815 sf
- Post-Retrofit Conditioned Space: 2,199 sf
- Pre-Retrofit Heating Fuel: Natural Gas
- Post-Retrofit Heating Fuel: Natural Gas



Enclosure Design

1 Roof Assembly: R-56 (nominal) Unvented roof assembly with vented over-roof: rafter cavities at eave space filled with existing fiberglass batts encapsulated with open-cell spray foam, cellulose insulation at cathedral ceilings, open-cell spray foam above flat ceiling; housewrap over existing sheathing, two layers of 2" foil-faced polyisocyanurate insulating sheathing, 2x4 purlins, ½" plywood, underlayment and asphalt shingles.

2 Wall Assembly: R-39 (nominal): Existing 2x4 wall framing cavities with fiberglass insulation supplemented with dense-packed cellulose where needed, housewrap, two layers of 2" foil-faced polyisocyanurate insulating sheathing, ¾" furring strips, fiber cement siding.

3 Window Specifications: New Harvey Tribute triple-glazed, argon gas, low-E vinyl windows, U=0.2, SHGC=0.21; six Harvey Majesty, double-glazed, argon, low-E wood windows, U=0.3, SHGC=0.24; windows installed proud of drainage plane on blocking.

4 Infiltration: "Chain saw" retrofit approach; housewrap, air control layer wraps directly from roof to wall; open-cell spray foam at framing sill, closed-cell over rubble stone foundation wall, taped rigid insulation at concrete underpinning wall; new concrete slab.

5 Foundation Assembly: Conditioned basement with 3" closed-cell spray foam applied to rubble stone foundation wall in new 2x6 stud walls finished with drywall, 12" of open-cell spray foam extending up the mud sill, 2" XPS at interior of concrete underpinning wall; gravel drainage pad, 2" of XPS insulation and polyethylene vapor retarder beneath new concrete slab; radiant subfloor finished with hardwood flooring.

Figure A.7.2. Newton DER Enclosure Profile

Mechanical Design

1 Heating and Cooling: Condensing boiler located in the basement mechanical room for existing hot water baseboards and new Warmboard radiant heating in the basement; high efficiency air-source heat pump using expanded central A/C ductwork.

2 3 Ventilation: Bryant Energy Recovery Ventilator (ERV) ducted to central air handler located in the attic.

4 Space Conditioning Distribution: Ductwork entirely inside the conditioned space.

5 6 DHW: SuperStor® Ultra storage hot water heater supplied by boiler located in the basement mechanical room.

Lighting: All CFLs in light fixtures.

Appliances: ENERGY STAR® appliances.

Figure A.7.3. Newton DER Mechanical Design

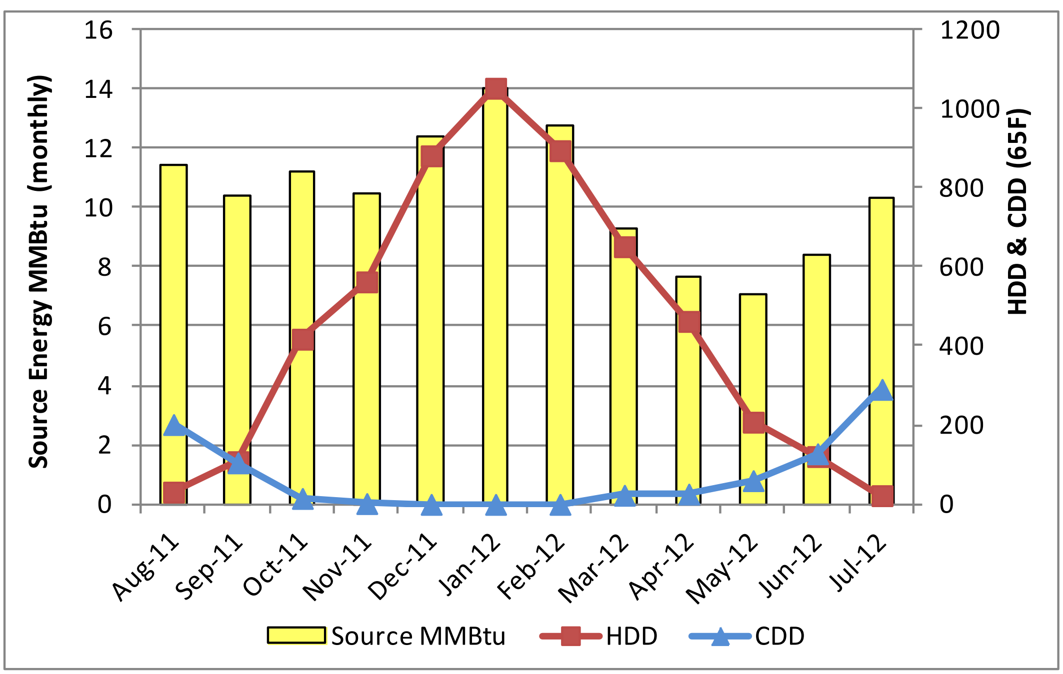


Figure A.7.4. Newton Monthly Total Source Energy Use August 2011 – July 2012

Appendix A.8: Jamaica Plain MA Retrofit

Figure A.8.1. Jamaica Plain Pre-retrofit (left) and Post-retrofit (right)

The current owner of this triple-decker purchased the house in 2006, occupying the 2nd floor unit. As a first step towards improved energy efficiency, a high performance gas boiler system with a generator was installed in 2008 to provide heating for all units. Two years later, efficiency improvements were continued with a full implementation of the DER package.

- House Type: Triple-decker with full basement
- Date Built: 1907
- DER Completion: July 2011
- Pre-Retrofit Conditioned Space: 3,885 sf
- Post-Retrofit Conditioned Space: 3,885 sf
- Pre-Retrofit Heating Fuel: Natural Gas
- Post-Retrofit Heating Fuel: Natural Gas

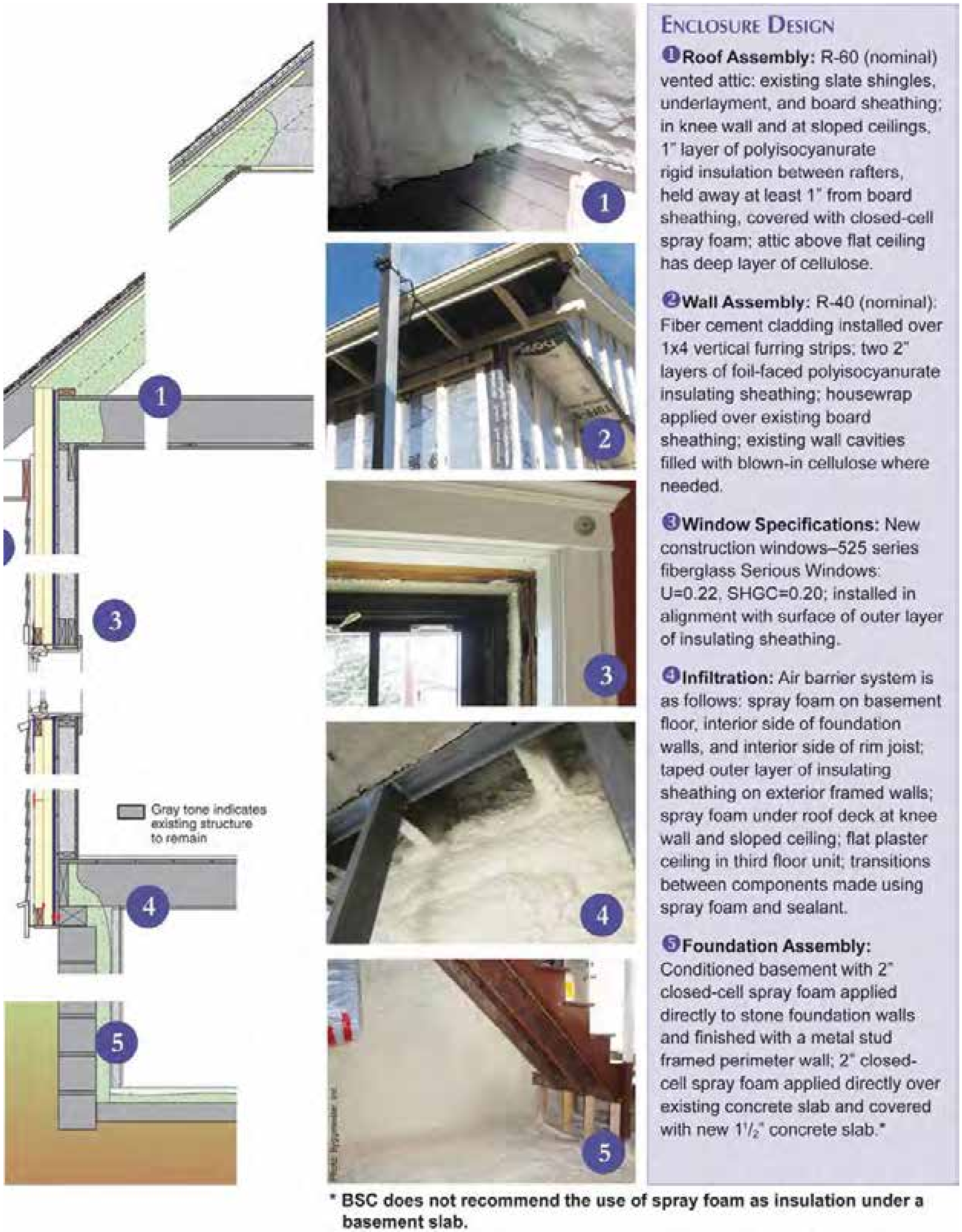


Figure A.8.2. Jamaica Plain DER Enclosure Profile

Figure A.8.3. Jamaica Plain DER Mechanical Design

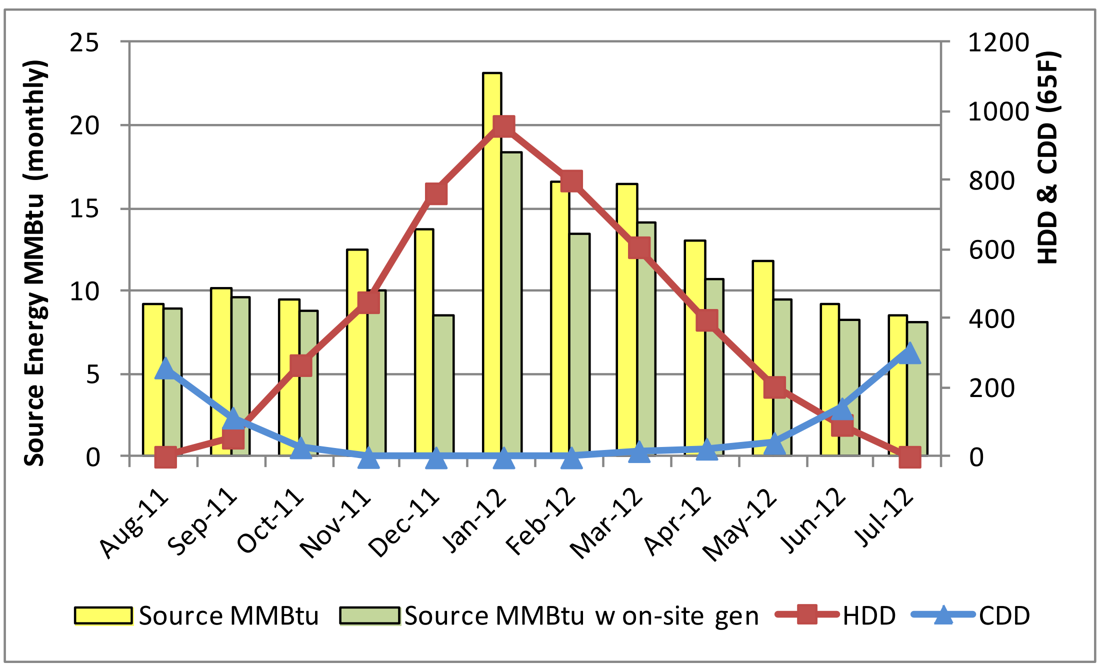


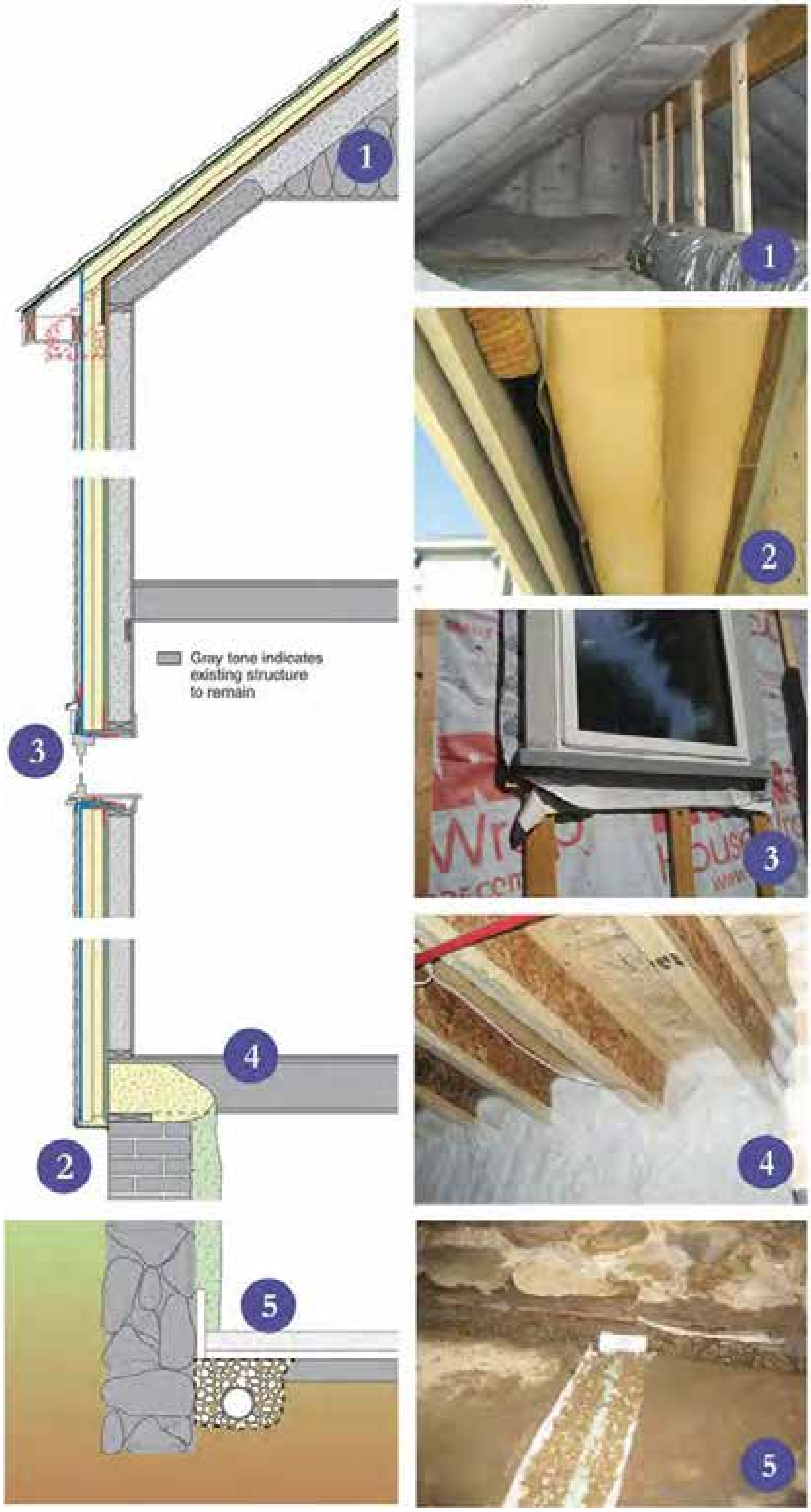
Figure A.8.4. Jamaica Plain Monthly Total Source Energy Use August 2011 – July 2012

Appendix A.9: Northampton MA Retrofit

Figure A.9.1. Northampton Pre-retrofit (left, with permission of National Grid) and Post-retrofit (right)

The owners of this house have lived there with a low energy life-style since 1988 and have made renovations and additions over the years. In anticipation of needing additional first floor space to accommodate an older extended family member, they decided to rebuild an earlier addition and to add some new space including a home office. This project was combined with a full implementation of the DER package.

- House Type: Single-family Victorian with full basement
- Date Built: 1859
- DER Completion: August 2011
- Pre-Retrofit Conditioned Space: 2,032 sf
- Post-Retrofit Conditioned Space: 2,747 sf
- Pre-Retrofit Heating Fuel: Natural Gas
- Post-Retrofit Heating Fuel: Electricity



Enclosure Design

❶Roof Assembly: R-60 (nominal) Unvented roof assembly: Rafter bays netted and dense-packed with cellulose insulation, ½" plywood over existing board sheathing; fully adhered membrane; 4" polyisocyanurate insulating sheathing in 2 layers; taped OSB sheathing system (Zip System® Roof); 2nd layer of fully adhered membrane; asphalt shingles.

❷Wall Assembly: R-39 (nominal): Dense-packed cellulose insulation in existing wall framing cavities; taped OSB sheathing system (Zip System® Wall) over existing board sheathing; two layers of 2" foil-faced polyisocyanurate insulating sheathing; housewrap; ¾" furring strips; fiber cement siding.

❸Window Specifications: Serious Windows triple-glazed, krypton gas, low-E fiberglass windows; U=0.14-0.17, SHGC=0.33-0.42; windows installed over strapping at exterior face of insulating sheathing; rigid insulation inserts at basement windows.

❹Infiltration: Taped OSB sheathing system, walls and window extension boxes; adhered membrane over ½" plywood at roof; "Chain saw" retrofit approach at roof-wall transition; open-cell spray foam at sill beam with closed-cell spray foam extending down and over the newly cast concrete slab.

❺Foundation Assembly: Conditioned basement with 5" of closed-cell spray foam at existing fieldstone and brick foundation walls; open-cell spray foam at sill beam; intumescent coating on spray foam; new concrete slab cast in "bathtub" of 2" high-density EPS over existing slab, interior drain and gravel.

Figure A 9.2. Northampton DER Enclosure Profile

Mechanical Design

❶ **Heating and Cooling:** ClimateMaster ground-source heat pump system*; Carrier air handler unit located in the conditioned basement.

❷ **Ventilation:** Venmar EKO 1.5 Energy Recovery Ventilator (ERV) located in the conditioned basement and ducted to central distribution system.

❸ **Space Conditioning Distribution:** Heating, cooling and ventilation ductwork located entirely within the conditioned space.

❹ **DHW:** GE GeoSpring Hybrid Water Heater* located in the conditioned basement.

❺ **Lighting:** Combination of CFL and LED lighting.

❻ **Appliances:** ENERGY STAR® appliances.

Site Generated Power: 5 kW PV system on roof of new addition.

* The client elected to pursue all-electric heating and water heating system. This was not the recommendation of the architect or BSC.

Figure A.9.3. Northampton DER Mechanical Design

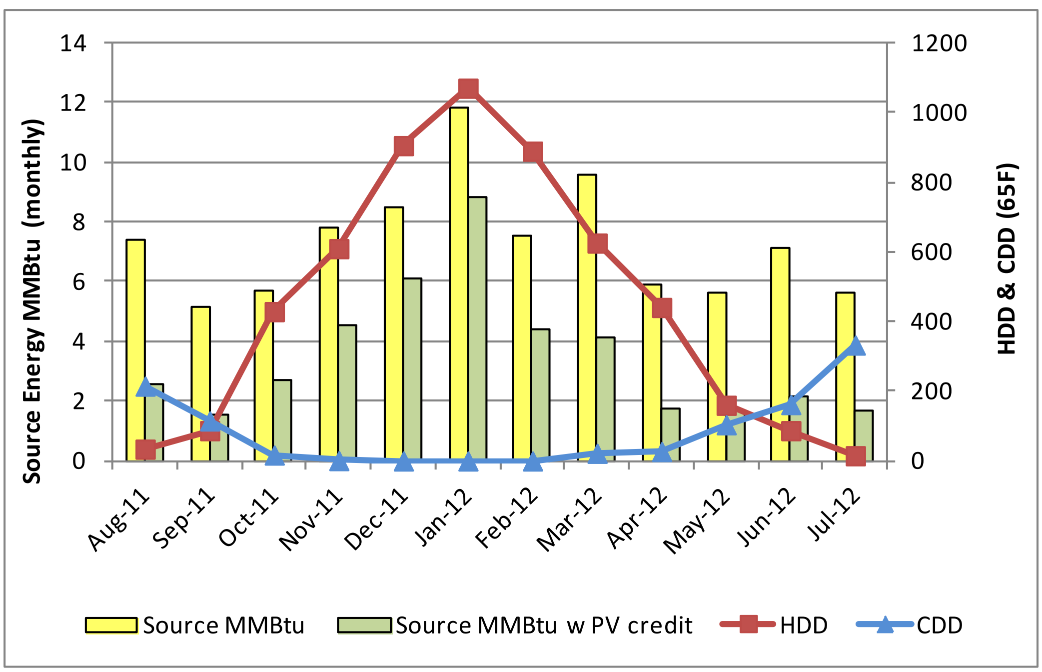


Figure A.9.4. Northampton Monthly Total Source Energy Use August 2011 – July 2012

Appendix A.10: Lancaster MA Retrofit

Figure A.10.1. Lancaster Pre-retrofit (left, with permission of National Grid) and Post-retrofit (right)

This building on property donated to Habitat for Humanity was in a significant state of deterioration. The basement and first floor framing of the building were retained though repairs of the foundation wall were required. In order to provide the living space required by the program, the roof was removed and a new second floor and roof were built. A full implementation of the DER package was included as part of the project. The new owners moved in after completion of the project.

- House Type: Single-family 2-story colonial with full basement
- Date Built: 1900
- DER Completion: August 2011 (Move in September 2011)
- Pre-Retrofit Conditioned Space: 980 sf
- Post-Retrofit Conditioned Space: 1,440 sf
- Pre-Retrofit Heating Fuel: Oil
- Post-Retrofit Heating Fuel: Electricity

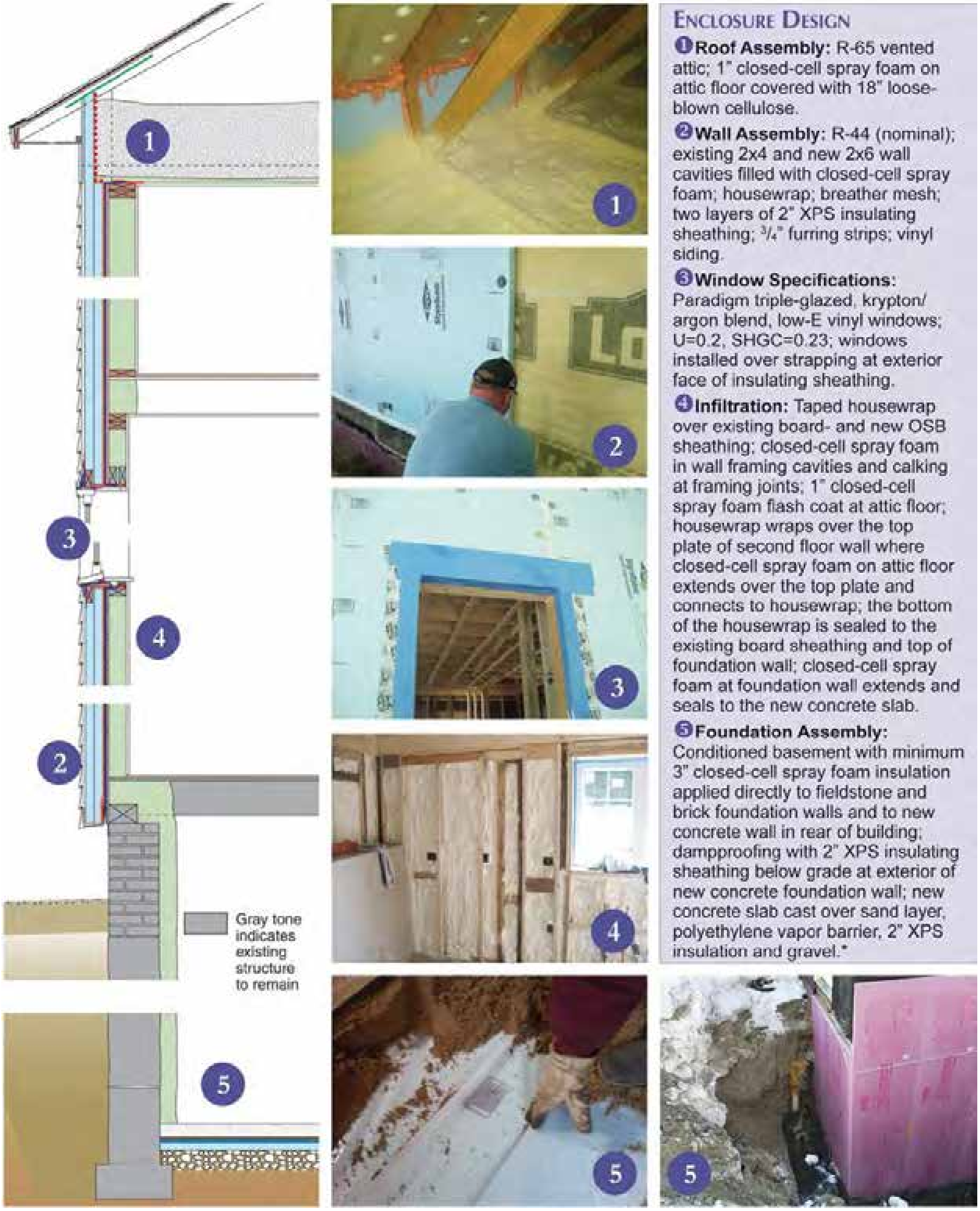


Figure A.10.2. Lancaster DER Enclosure Profile

Figure A.10.3. Lancaster DER Mechanical Design

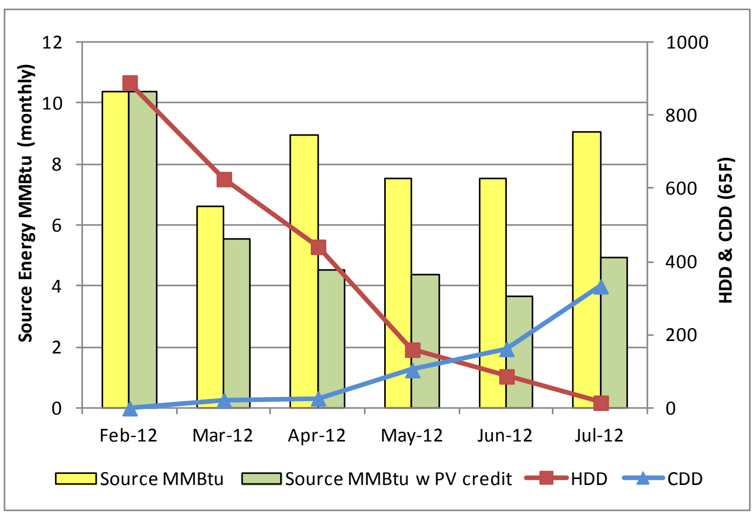


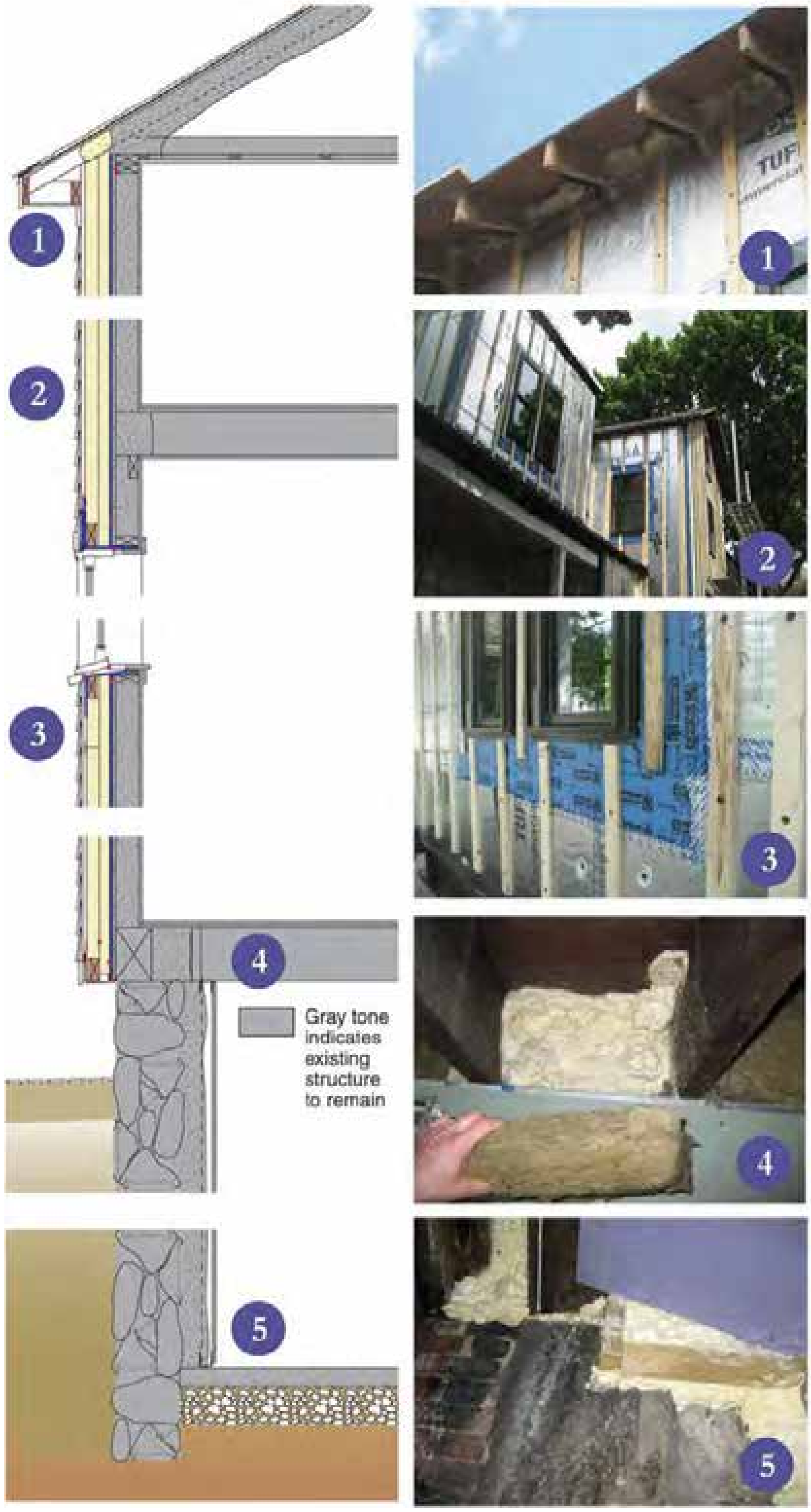
Figure A.10.4. Lancaster Monthly Total Source Energy Use February 2012 – July 2012

Appendix A.11: Brookline MA Retrofit

Figure A.11.1. Brookline Pre-retrofit (left) and Post-retrofit (right)

The current owners purchased and moved into this house in 2006. In 2009, some upgrades for modernization and for better energy efficiency were made, including installing insulation under the roof deck and on the inside of the existing foundation walls. Therefore, the 2011 DER retrofit was actually the 2nd stage of a 2 stage DER after which all of the measures of the DER package had been carried out with the exception of insulating the basement floor.

- House Type: Single-family 3-story Victorian with full basement
- Date Built: 1899
- DER Completion: November 2011
- Pre-Retrofit Conditioned Space: 3,078 sf
- Post-Retrofit Conditioned Space: 3,174 sf
- Pre-Retrofit Heating Fuel: Natural Gas
- Post-Retrofit Heating Fuel: Natural Gas



Enclosure Design

❶ **Roof Assembly:** Retrofit measures completed in the previous enclosure retrofit; R-48 (nominal): Unvented roof assembly with 8" of closed-cell spray foam between the rafters; ½" plywood; fully-adhered membrane; asphalt shingles.

❷ **Wall Assembly:** R-40 (nominal): Existing dense-packed cellulose insulation in wall framing cavities; housewrap over existing board sheathing, sealed at perimeter and all penetrations with seams taped; two layers of 2" foil-faced polyisocyanurate insulating sheathing; ¾" furring strips; wood siding.

❸ **Window Specifications:** New Paradigm triple-glazed, krypton/argon blend gas, low-E vinyl windows, U=0.20, SHGC=0.25; windows installed in alignment with drainage plane.

❹ **Infiltration:** Sealant applied between housewrap and existing board sheathing at top and bottom of wall; sealant between successive layers at bottom of wall transitions airflow control to foundation airflow control of previous work; taped insulating sheathing with joints offset; two-part foam applied at the top of insulating sheathing to connect to closed-cell spray foam of previous work.

❺ **Foundation Assembly:** Retrofit measures completed in the previous enclosure retrofit; 3" closed-cell spray foam applied directly onto the existing field stone foundation walls; gypsum wall board thermal barrier on 1⅝" metal studs partially embedded in closed-cell spray foam; 7" closed-cell spray foam at sill beam with a layer of rigid mineral wool insulation; slab remained uninsulated.

Figure A.11.2. Brookline DER Enclosure Profile

Mechanical Design

❶ **Heating:** Buderus condensing boiler located in the basement for hot water radiators. The owners chose not to install cooling.

❷ **Ventilation:** Imperial Heat Recovery Ventilator (HRV) located in the basement. Ventilation supply ducted to living and dining room and hallways, stale air exhausted from bedrooms. Point source ventilation from kitchen and bathrooms.

❸ **Space Conditioning Distribution:** Ventilation ductwork and hydronic distribution located entirely within the conditioned space.

❹ **DHW:** SuperStor® Ultra hot water storage tank connected to the boiler located in the basement.

❺ **Lighting:** Combination of CFL and incandescent light bulbs in light fixtures.

Appliances: ENERGY STAR® appliances.

Figure A.11.3. Brookline DER Mechanical Design

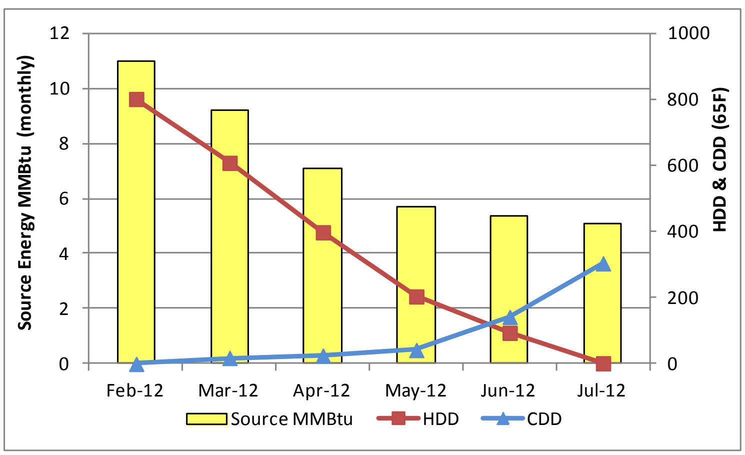


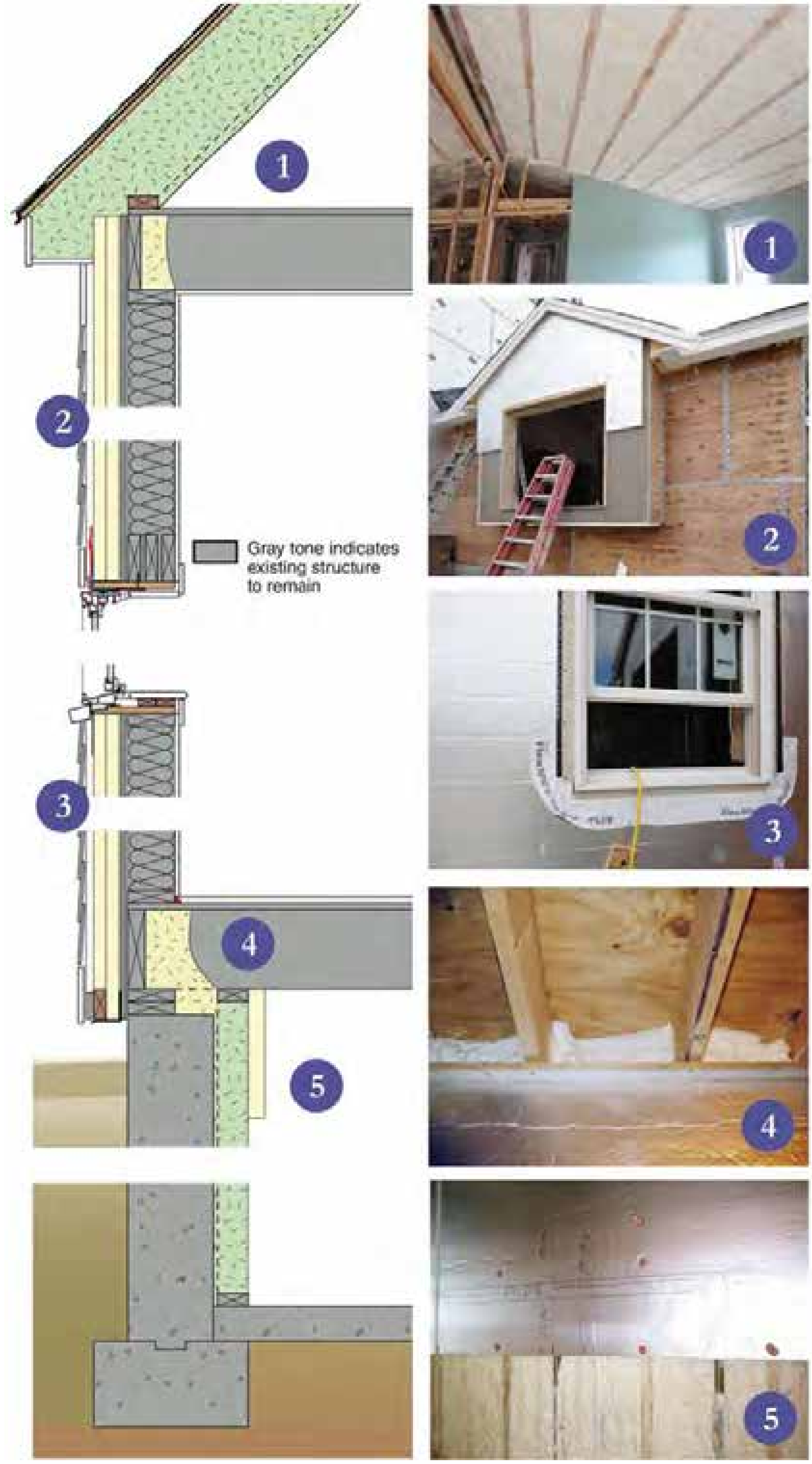
Figure A.11.4. Brookline Monthly Total Source Energy Use February 2012 – July 2012

Appendix A.12: Westford MA Retrofit

Figure A.12.1. Westford Pre-retrofit (left) and Post-retrofit (right)

Having been built in 1993, this is the newest house among this retrofit community. The current owners purchased and moved into the house in 2003. After living there for several years, they started planning for improvements that would better meet their needs including an addition on the back and reframing the roof so that living space could be accommodated in the attic. These modifications were combined with implementation of the full DER package with the exception of the insulation of the basement floor. For aesthetic reasons, they also chose to install windows that were somewhat below the target R-value.

- House Type: Single-family modern Colonial with full basement
- Date Built: 1993
- DER Completion: December 2011
- Pre-Retrofit Conditioned Space: 2,906 sf
- Post-Retrofit Conditioned Space: 3,955 sf
- Pre-Retrofit Heating Fuel: Natural Gas
- Post-Retrofit Heating Fuel: Natural Gas



Enclosure Design

1 Roof Assembly: R-62 (nominal) unvented roof assembly: asphalt shingles over underlayment and plywood; closed-cell spray foam (ccSPF) insulation in 2x10 rafter cavities; the bottom of the rafters are covered with 1" rigid insulation and drywall in finished cathedral space and with 1" of ccSPF in attic space.

2 Wall Assembly: R-39 (nominal): Fiber cement cladding installed over 1x4 vertical furring strips; two 1 1/2" layers of polyisocyanurate insulating sheathing (outer layer foil-faced, inner layer fiber reinforced facing) with seams staggered and taped on the outer layer; plywood sheathing with seams taped; 2x6 walls filled with fiberglass batts (existing) or open-cell spray foam (ocSPF) insulation (new).

3 Window Specifications: Marvin Integrity double hung, new construction flanged windows, U-Value 0.29, SHGC 0.28, installed in the plane of the insulating sheathing.

4 Infiltration: Air barrier system is as follows: concrete walls in basement; spray foam in cavity of new above grade framed walls, taped sheathing and interior sealing on existing above grade framed walls; spray foam under roof sheathing; transitions made using sealant, spray foam, and caulking.

5 Foundation Assembly: Unfinished basement walls insulated with 3" of taped polyisocyanurate insulation below grade and additional 3" polysiocyanurate above grade; finished or to-be-finished basement walls insulated with 4" of ccSPF below grade and additional 2" polyiso above grade. Existing basement slab was not insulated. New basement slab has 2" XPS insulation below.

Figure A.12.2. Westford DER Enclosure Profile

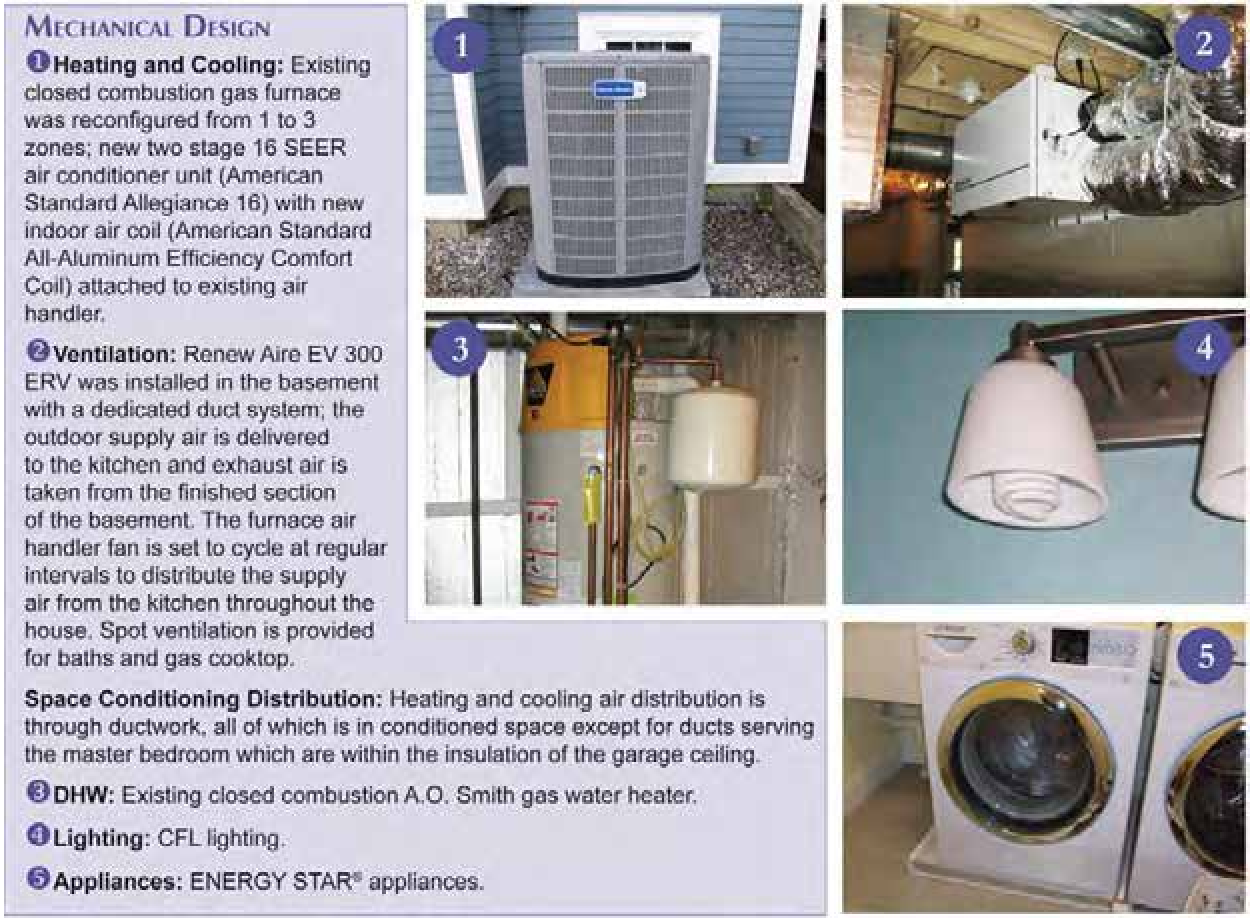


Figure A.12.3. Westford DER Mechanical Design

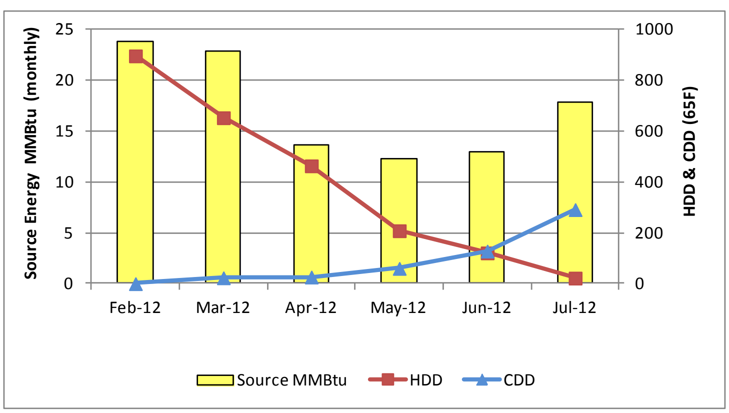


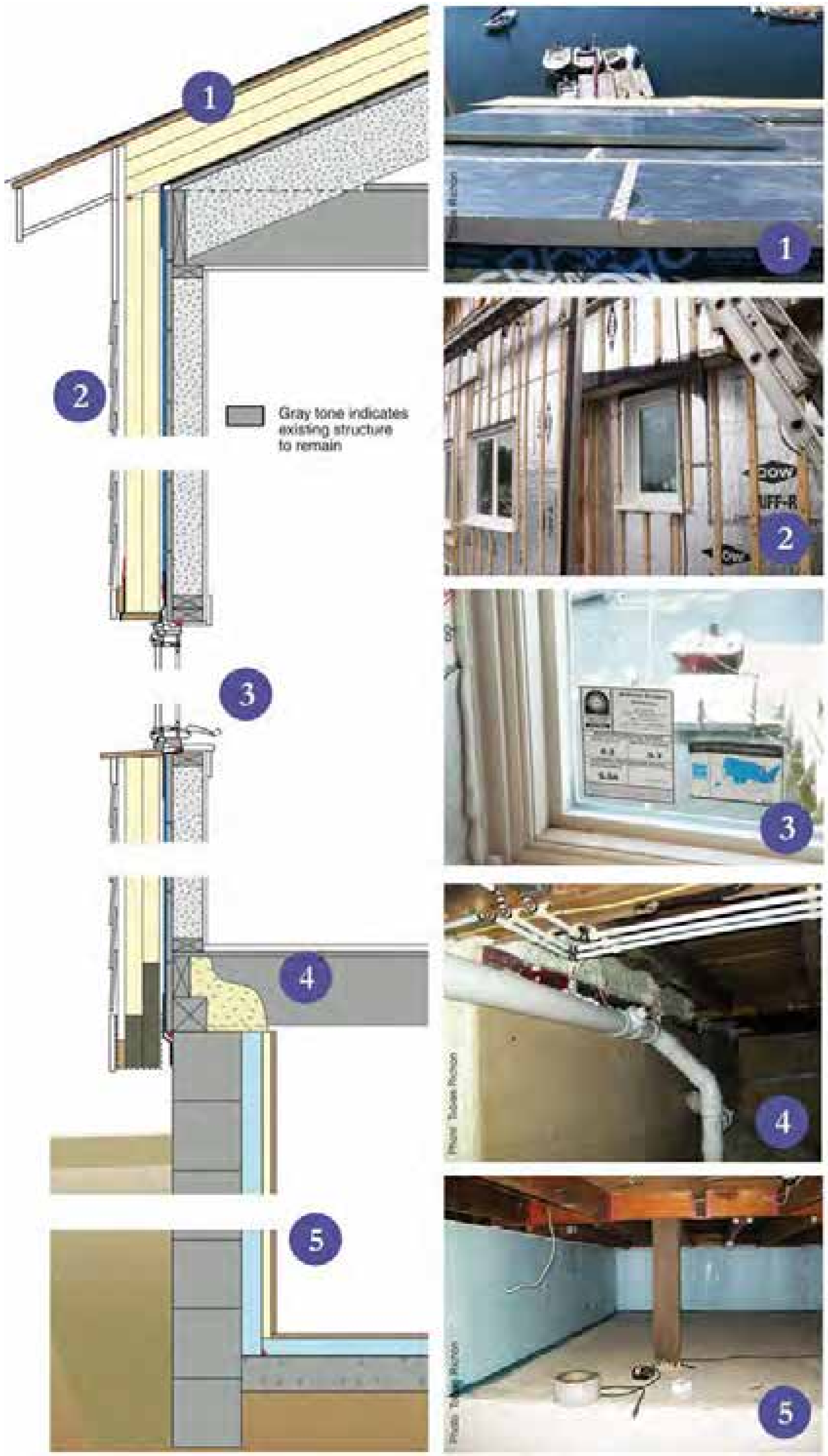
Figure A.12.4. Westford Monthly Total Source Energy Use February 2012 – July 2012

Appendix A.13: Gloucester MA Retrofit

Figure A.13.1. Gloucester Pre-retrofit (left) and Post-retrofit (right)

This cottage on a coastal cove had been in a family for many years but had been unoccupied since the death of the owner in 2009. Another family member purchased the house in 2010. Prior to moving in, the new owners had the interior updated and, since an upgrade of the enclosure was needed as well, incorporated a full implementation of the DER package into the renovation project.

- House Type: Single-family coastal cottage with full basement and crawlspace
- Date Built: 1920
- DER Completion: January 2012
- Pre-Retrofit Conditioned Space: 2,171 sf
- Post-Retrofit Conditioned Space: 2,424 sf
- Pre-Retrofit Heating Fuel: Oil
- Post-Retrofit Heating Fuel: Electricity



Enclosure Design

1 Roof Assembly: R-67 (nominal) unvented roof assembly: new asphalt shingles over underlayment and new plywood; three 2" layers of foil-faced polyisocyanurate insulating sheathing with seams offset and taped; continuous layer of fully adhered membrane over existing roof sheathing; 8" of netted cellulose in rafter cavities.

2 Wall Assembly: R-38 (nominal): Fiber cement cladding installed over 1x4 vertical furring strips; two 2" layers of foil-faced polyisocyanurate insulating sheathing with seams offset and taped; taped housewrap applied over existing board sheathing; existing wall cavities filled with cellulose.

3 Window Specifications: Mathews Brothers triple-glazed, argon, low-E vinyl, flanged, new construction casement and awning windows, U=0.2, SHGC=0.3; windows installed in alignment with the existing board sheathing.

4 Infiltration: Air barrier system is as follows: existing basement slab with two coats of epoxy paint; taped rigid insulation on inside of foundation walls; spray foam at the rim joist; taped housewrap on above grade walls; fully adhered membrane on existing roof sheathing; transitions between roof and above grade walls made by lapping membrane over the housewrap; other transitions made using sealant.

5 Foundation Assembly: Conditioned basement with 2.5" of taped XPS insulation and 1" of rigid polyisocyanurate applied to inside of concrete block foundation walls and covered with plywood. Existing basement slab covered with two coats of epoxy paint (for air sealing and vapor control) and then with 2" of XPS rigid insulation except at the workshop area which has no insulation and the living area which has only 1" of XPS.

Figure A.13.2. Gloucester DER Enclosure Profile

Figure A.13.3. Gloucester DER Mechanical Design

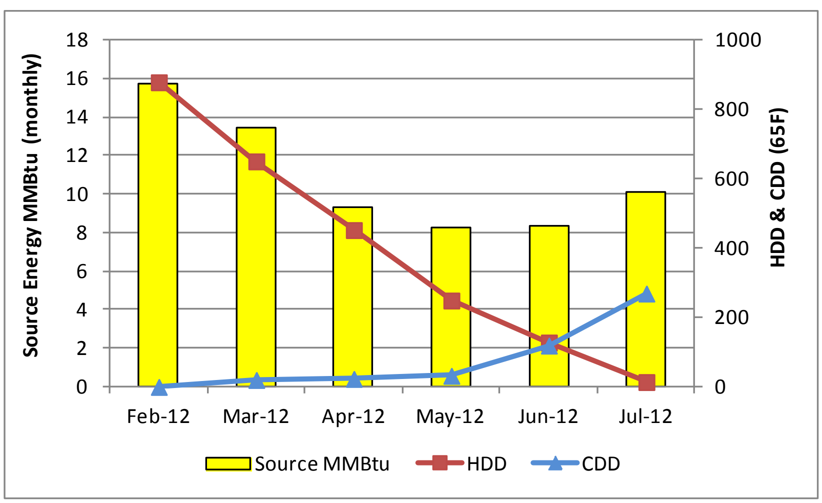


Figure A.13.4. Gloucester Monthly Total Source Energy Use February 2012 – July 2012

Appendix B:

Appendix B: BEopt V1.3 Generated Pre-retrofit Data for Belmont, Milton, Quincy, Arlington, and Lancaster Retrofits

For several of the projects in this community, pre-retrofit energy use data was not provided in the National Grid DER Pilot Program application because it was unavailable or it was incomplete. For this research project and report, when the pre-retrofit data was not provided, a BEopt V1.3 model for the pre-retrofit conditions was created and the yearly site energy use generated by BEopt was used for the pre-retrofit data in Table XXX.

In the following subsections, the graphs of yearly site electricity, natural gas, fuel oil, and/or propane site energy use that were generated by BEopt are provided. Since the reference building is not relevant for this purpose, the "Existing" and the "Pre-Retrofit" buildings are identical.

Belmont Retrofit

The Belmont pre-retrofit energy use includes electricity, natural gas (for domestic hot water and for clothes dryer) and fuel oil (for heating).

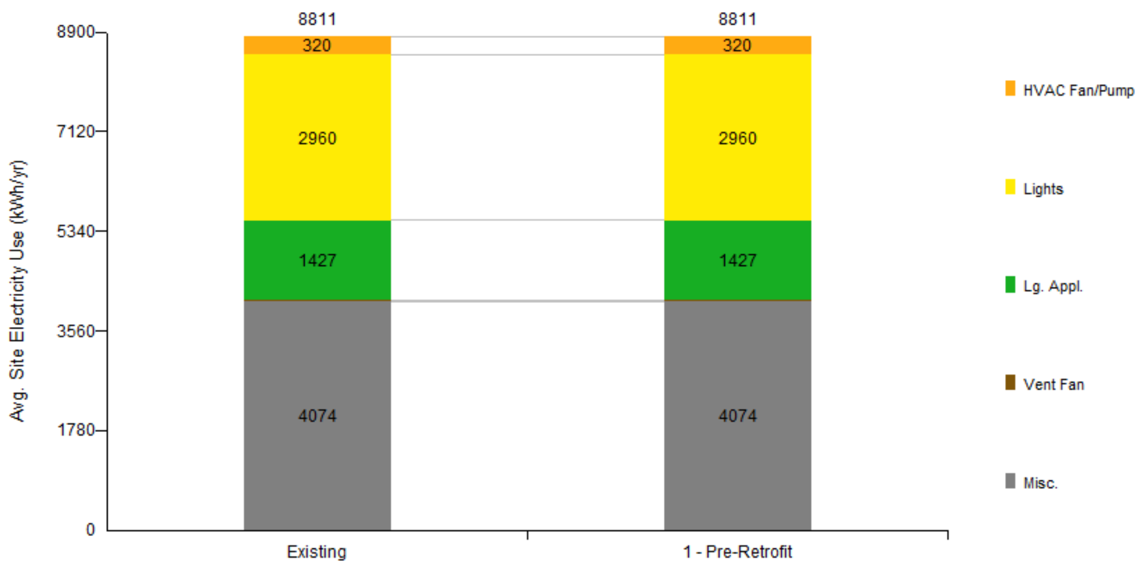


Figure B.1. Belmont Pre-Retrofit Yearly Site Electricity Use Generated by BEopt V1.3

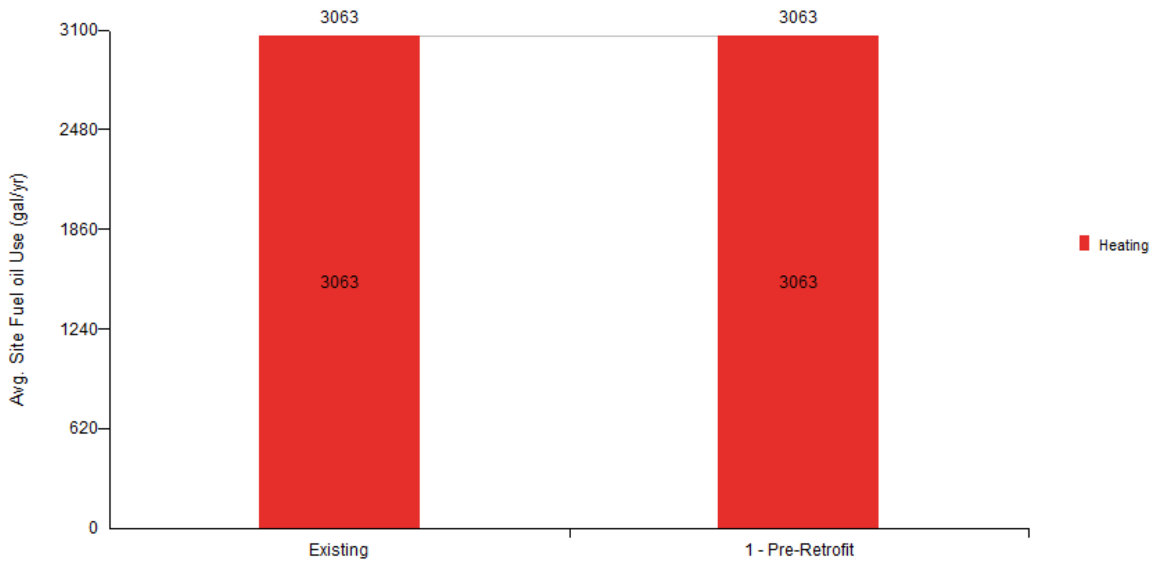


Figure B.2. Belmont Pre-Retrofit Yearly Site Fuel Oil Use Generated by BEopt V1.3

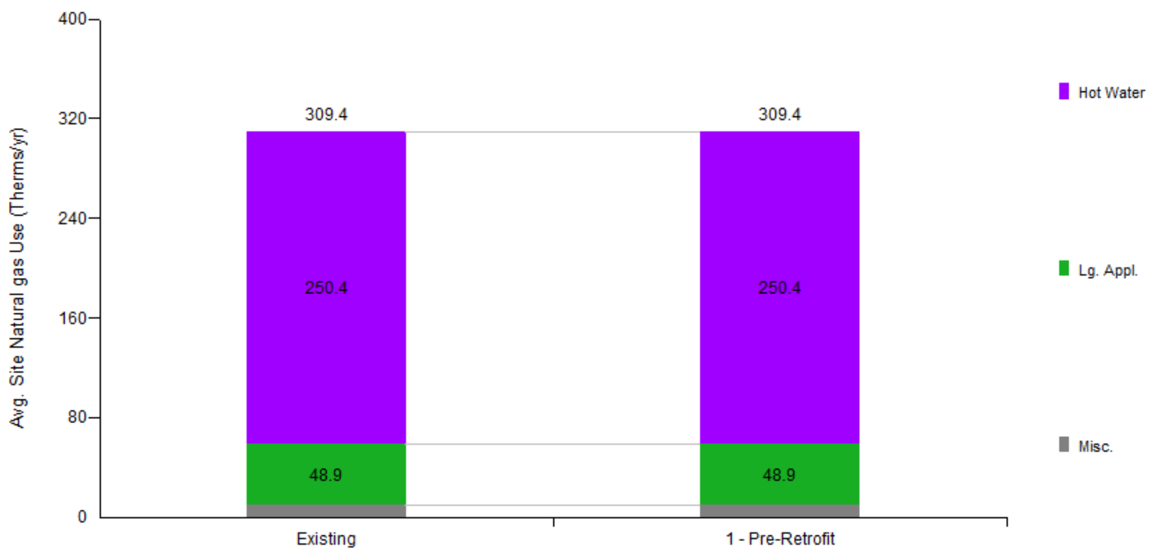


Figure B.3. Belmont Pre-Retrofit Yearly Site Natural Gas Use Generated by BEopt V1.3

Milton Retrofit

The Milton pre-retrofit energy use includes electricity and natural gas (for domestic hot water and for heating).

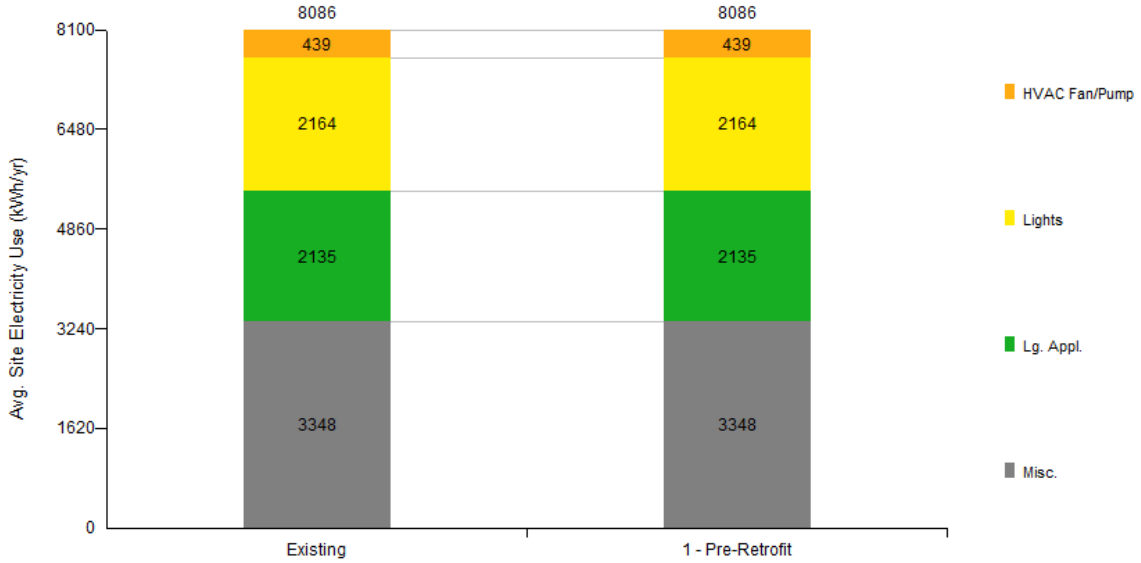


Figure B.4. Milton Pre-Retrofit Yearly Site Electricity Use Generated by BEopt V1.3

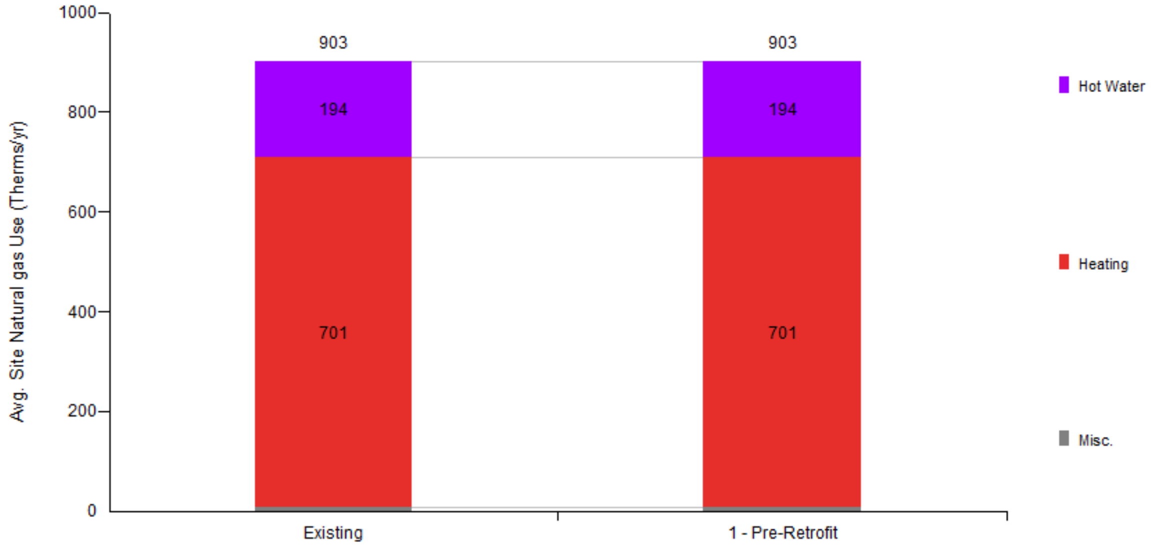


Figure B.5. Milton Pre-Retrofit Yearly Site Natural Gas Use Generated by BEopt V1.3

Quincy Retrofit

The Quincy homeowners provided a year of pre-retrofit electricity use but were unable to provide a full year of fuel oil use which was used for heating and domestic hot water. Therefore the use of fuel oil (in gallons) for the year of pre-retrofit data was provided by the BEopt model.

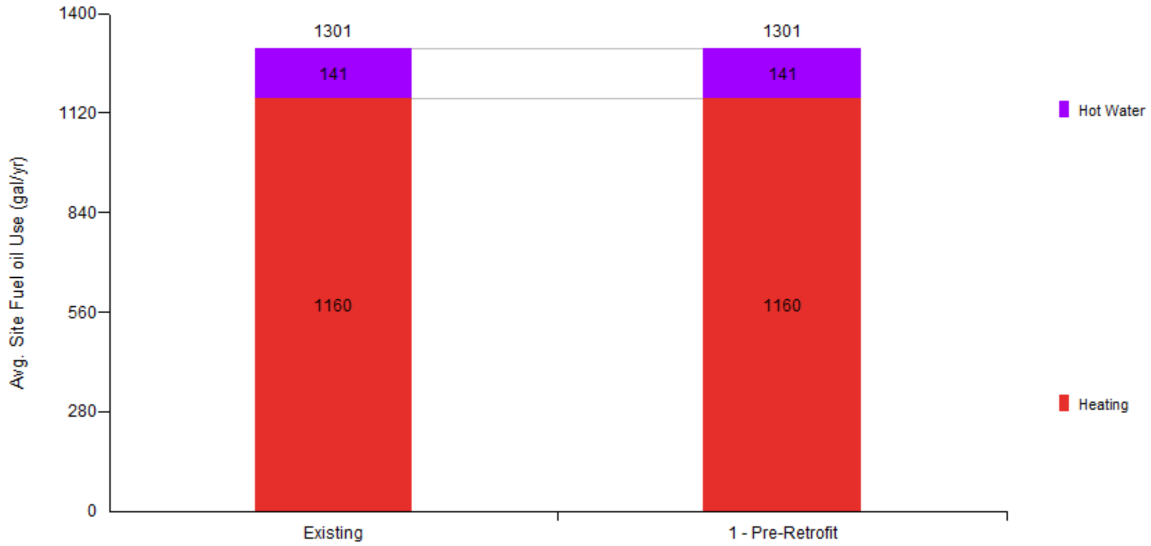


Figure B.6. Quincy Pre-Retrofit Yearly Site Fuel Oil Use Generated by BEopt V3

Arlington Retrofit

The Arlington pre-retrofit energy use includes electricity and natural gas (for domestic hot water and for heating).

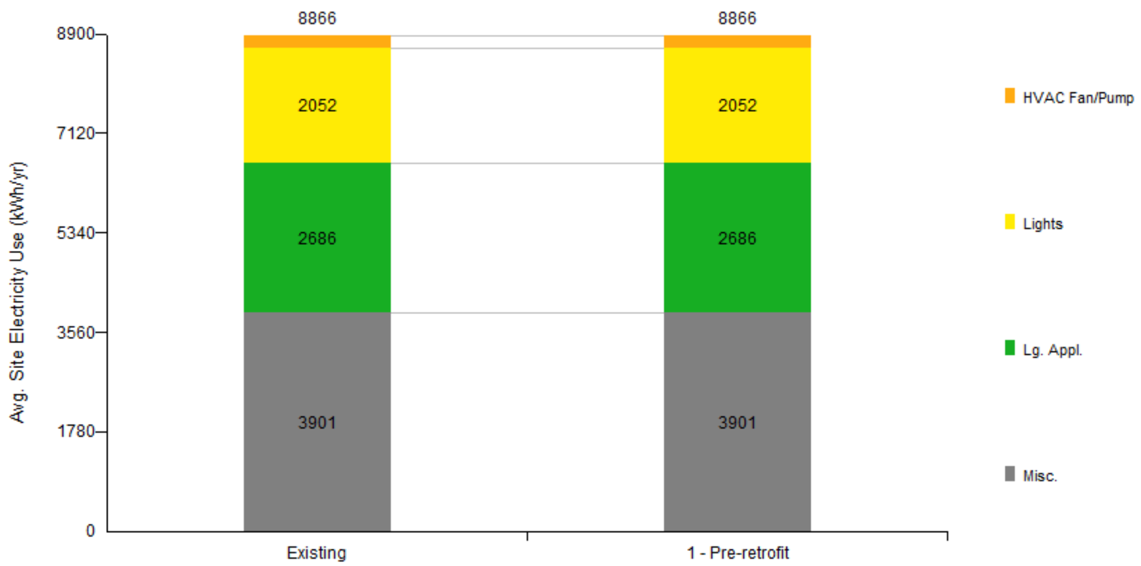


Figure B.7. Arlington Pre-Retrofit Yearly Site Electricity Use Generated by BEopt V1.3

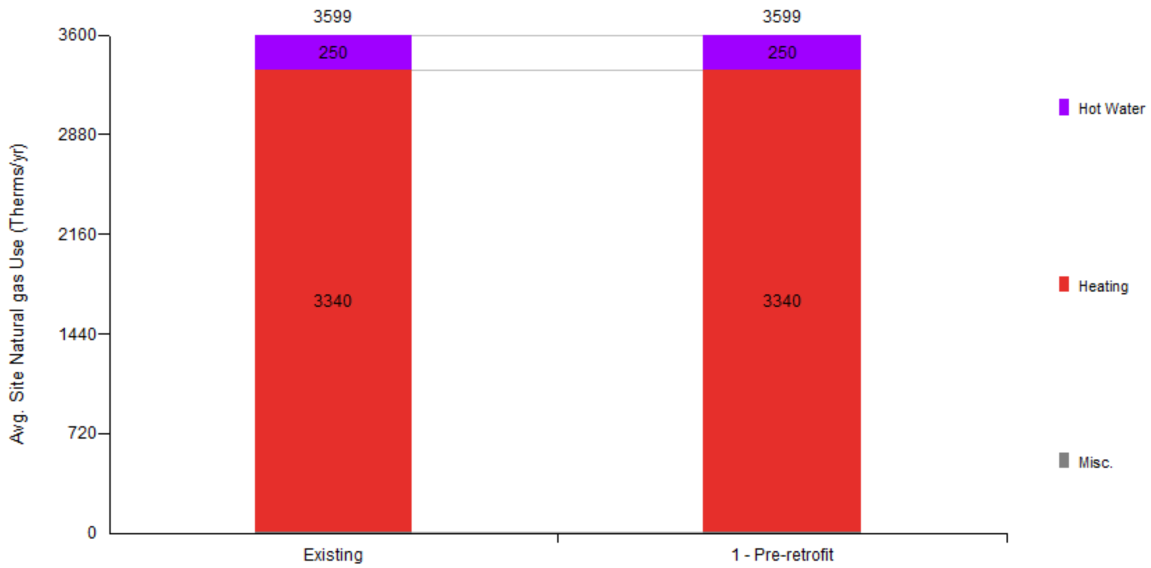


Figure B.8. Arlington Pre-Retrofit Yearly Site Natural Gas Use Generated by BEopt V1.3

Lancaster Retrofit

The Lancaster pre-retrofit energy use includes electricity and fuel oil (for heating and domestic hot water).

Figure B.9. Lancaster Pre-Retrofit Yearly Site Electricity Use Generated by BEopt V1.3

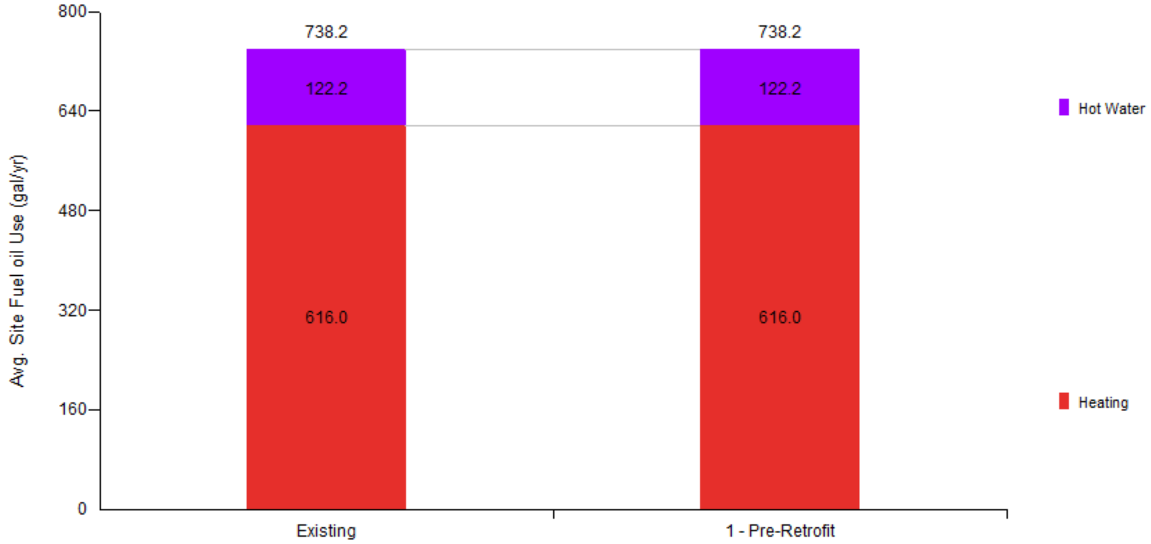


Figure B.10. Lancaster Pre-Retrofit Yearly Site Fuel Oil Use Generated by BEopt V1.3

Appendix C

Appendix C: National Grid Deep Energy Retrofit Application Part (B), Excel Component

Contents

Part A is Word Document which contains general instructions as well as sections noted here
Part B is this Excel File

Application Sections	Application Inputs In Part
1) Application Documentation and Signatures	A
2) Project Team Information	B
3) General Project Information	B
4) Building and Energy Use Profile	B
5) Energy and Baseline Data	B
6) Health, Safety and Durability	B
7) Building Enclosure and HVAC Measures and Incentives	B
8) Summary and Finances	B
9) Level 2 Measures (optional)	A
10) Resources	Guidance and calculators, no "Inputs"

Please Note:File names for submitted documents, photos and materials should be provided in Part A Section 1 for all sections except #9.

Note: Typical Color coding for inputs;

	(light yellow)	= First application input cells (also update with second application)
	(deep yellow)	= Second application input cells
	(medium blue)	= Cell references data from another section or that is shared across multiple sections
	(light blue)	= Cell contains calculation on input data in the current section

IMPORTANT: Due to formatting and password problems, Google Docs are not an acceptable way of handling or sharing these files for the program

2) Project Team

First Application Date: ____ Second Application Date ____ Final Revision for Agreement Date ____ How owner heard of pilot? ____

A. Contact information – Customer and Tenants

(i) Customer contact information and account

Customer Name:		Other Occupant of Primary Unit Name:	
(As name appears on electric bill)		Other Contact Relationship:	
	The applicants certify this building is occupied and heated through the winter:		
NGRID Elect Acct#	= 10 Digits	Electric Rate: (e.g. R1)	
NGRID Gas Acct#	=11 Digits	Gas Rate Type Code:(eg R3)	
Home Phone Number:		Other Contact Phone:	
Work 1 Phone Number and ext:		Other Occ. Work Phone	
Cell Number:		Cell Number Other:	
Project Site Street Address:		City/Town:	
State:		Zip:	
Mail Address if Different			
Customer E-Mail Address: 1		Other E-Mail Address:	

(ii) Tenant contact information for 1-4 family projects

Tenant Name:			
Apt# or Indicator:			
Home Phone Number:		Ok as alternate contact ?	

Tenant Name:			
Apt# or Indicator:			
Home Phone Number:		Ok as alternate contact ?	

Tenant Name:			
Apt# or Indicator:			
Home Phone Number:		Ok as alternate contact ?	

Note: Permission to obtain tenant fuel use required prior to time of agreement

C. Further Verification of Project Team Roles and Experience

IMPROTANT NOTE:The General Contractor is required to fullfill all obligations for that role per DER Guidelines
Exceptions may be made for cases where another party will take on some aspects of that function, but NEVER insurance requirements.

	The HVAC contractor will be under contract to the General Contractor
	Project team member with primary responsibility to provide application data

If the party in either row above isn't the general contractor or designer with DER prerequisite expereince please describe credentials and expereince of the primary person completing the application and the lead for HVAC.
This could include prior expereince of HVAC contractor on DER projects specifically related to the equipment mentioned above.

B. Contact information and role – Project Team Professionals

(iii) General Contractor Role:		(iv) 2nd Team Member Role:		(v) HVAC Contractor:	
Name:		Name:		Name:	
Indicate planned contractual role on team		Indicate planned contractual role on team		Indicate planned contractual role on team	
Confirm if under contract to customer		Confirm if on team		Confirm if on team	
Title:		Title:		Title:	
Company Name:		Company Name:		Company Name:	
HIC License #		HIC License #		HIC or Other License #	
Const Supervisor Lic:	Qty on staff;	Const Supervisor Lic:	Qty on staff;		
Office Phone Number:		Office Phone Number:		Office Phone Number:	
Fax Number:		Fax Number:		Fax Number:	
Principal's Cell Number:		Principal's Cell Number:		Principal's Cell Number:	
Street Address:		Street Address:		Street Address:	
City/Town:		City/Town:		City/Town:	
State:	Zip:	State:	Zip:	State and Zip:	MA Zip:
E-Mail Address:		E-Mail Address:		E-Mail Address:	
Website:		Website:		Website:	
Other Co. Contact Name:		Other Co. Contact Name:		Other Co. Contact Name:	
Other Contact Title:		Other Contact Title:		Other Contact Title:	
Other Contact Phone:		Other Contact Phone:		Other Contact Phone:	
Other E-Mail Address:		Other E-Mail Address:		Other E-Mail Address:	
Note or Comment:		Note or Comment:		Note or Comment:	

HVAC plays a critical role in effective DER projects. If the General Contractor with DER experience is not overseeing the HVAC contractor the project team must thoroughly document the experience of the party doing or overseeing that work with respect to i

Notes regarding team

✓ For the second application, we will need the same information reflecting any updates from the first application. At that point all members of your Project Team should be confirmed.

3) General Project Information

Customer Name: First Application Date: Second Application Date: #REF!

Provide the information below. Be sure that each section is complete, checked off below and all attachments are included as required for that application version.

A. Desired Project Level and Desired Timeline

This application is for:

Select Level

Select Group and Year

Select Level	Level 1 incentives (75% cost share of eligible measures)
	Level 2 incentives 25% above level 1 to a maximum of $10,000.
Select Group and Year	Group 1 timeframe; seeking to be selected as a project to be fully completed in DESIGNATED calendar year.
	Group 2 timeframe; seeking to be selected as a project to be at least 50% complete the DESIGNATED year and by April 1 of the next

B. Facility Size and Desired Incentives

Total number of eligible dwelling units		Avg Sq Ft\Unit	
Total EXISTING Conditioned Usable Floor Space for Building			Sq Ft % Change
Total PLANNED Conditioned Usable Floor Space for Building			0%
			Incentive per unit
Proposed Incentive From Table Below			
Proposed Incentive if competitive mode is deployed for facilities over 4 Apt units.			

MF project selection may be competitive in terms of alternate incentives depending upon the number of applications received that meet desired criteria.

Maximum Level One Incentives per Facility

[1] Conditioned area sq ft incentive ranges apply to interior dimensions of usable living space per to 780 Cmr 5303 Light, Ventilation And Heating And 780 Cmr 5305 Ceiling Height	Dwelling Units in Facility	Conditioned [1] Sq Ft Floor Area per Unit	Maximum Project Incentive	Dwelling Units in Facility	Maximum Project Incentive
	1	<2000	$35,000	4	$80,000
	1	2000 - 2500	$38,000	5	$85,000
	1	>2500	$42,000	6	$90,000
	2	<1000	$50,000	7	$94,000
	2	1000 to 1500	$55,000	8	$98,000
	2	>1500	$60,000	9	$102,000
	3	n/a	$72,000	=>10	$106,000

C. Incentive Acknowledgement

I have read the DER Guidelines and understand that incentives are subject to funding availability, project requirements, desired criteria and the selection process.

D. Non- Energy Renovations Planned

(i) What work were you already planning?

Enter "yes", "no", "High Priority", or "TBD" = To Be Determined.

other describe in timing section below.

Applicable?		Applicable?	
	New Roof		Major remodeling including gut remodel
	New Windows and or Doors		Remodel bathroom or kitchen
	Replace Siding\Cladding		Adding space
	Basement Remediation	Addition square feet TOTAL	
	Conversion to finished space	Addition sq ft that's not converted space	
	Type(s) of Conversion Space(s)	% new space relative to final	

(New floor space must be no more than 50% of final total sq.ft. of floor space)

#DIV/0!

(ii) Indicators related to renovation timing

Briefly describe condition and age of siding, roof, foundation, water heater, central AC, and boiler or furnace

E. Summary of Deep Energy Retrofit Plans

Briefly describe the conceptual plan for deep energy retrofit and remodeling\rehab\addition plan in context with each other. Describe specific approach planned for insulation of walls, foundation, attic and other aspects such as HVAC. (500 words max)

F. Comprehensive, Partial or Advanced Deep Energy Retrofit Statements

Indicate If plan is for **Full Building Comprehensive DER** or if project team is proposing **staged or partial DER** and has rec'd pre-approval for basic concept in terms of mix of measures and requirements for partial DERs. (Describe "staged" approach in narrative in 3E.)

If proposing Level 2 Incentives - indicate approach planned

4) Building and Energy Use Profile

Customer Name: First Application Date: Second Application Date:

Complete sections A thru D below. Blue cells linked here from other tabs, in sections with deep yellow cells , those inputs are needed for 2nd application only

A. Building Characteristics

# units in building:	0	# stories: (excluding basement)		Finished Area Existing (sq.ft.)		Initial six sided surface area:	0
Age - time period:		Year built, if known		Total PLANNED Conditioned Sq. Ft.	0	Total six sided surface area after project completion	0
Style 1-4 family:		Year previously remodeled		Basement heated?		Garage Configuration:	

Style 5+ Units and Other (specify)

Year building purchased

Pre DER Air Tightness: CFM@50pa

Foundation Type:

Type 1:

Type 2:

Foundation material

Roofing Material

B. Temperature Settings

	Zone Description	Set back \ Source of Temp Info	Avg Heating F^0
Zone 1			
Zone 2			
Zone 3			
Zone 4			

Give best estimate of average temperature and settings at left for evaluation process. This need not correspond to single heating zones but temperature zones. For multifamily rough best guess is acceptable. Required for Second Application only.

Note or Comment

C. Occupancy

Owner Resides in Apt:# (not required for incentives)

Total number occupants in building in Winter:

Briefly Describe demographics for occupants of multifamily building. e.g. elderly, mixed income, section 8

Master or Separate Metering

Apt or Unit #		Floor # Loc.	Occupants:	Bedrooms	Floor Area	Electric Account	Gas Account
Apt 1:							
Apt 2:							
Apt 3:							
Apt 4:							
Apt 5:							
Apt 6:							
Apt 7:							
Apt 8:							
Apt 9:							
Apt 10:							

For Multifamily - enter common area meter account in Section/Tab 2A, and tenant account#s above.

D. End-use profile for major end uses

(i) Energy Sources Used

Electricity and Heating Fuel Data:
Please provide usage and billing history data in Section/Tab 5A

Total Use (per year) | Total Cost (per year)

Electricity: 0 kWh | $0

Primary Heating System:

Existing Count: System Age

Will energy/fuel type or system type for this end use change in DER? | List any planned changes for these enduses

^ provide data on 5A

Proposed Count:

Fuel/Energy Type:

enter # of systems in building

Heating System Type:

Primary Heating: 0 #N/A $0

^ provide data on 5A

Secondary Heating System or Other Non-Electric Fuel Used (if any):

Fuel/Energy Type:

Heating System Type:

Secondary Heating/other fuel: 0 #N/A $0

Tertiary Heating System or Other Non-Electric Fuel Used (if any):

Fuel/Energy Type:

Heating System Type:

Tertiary Heating/other fuel: 0 #N/A $0

If "other" entered above, please explain:

Note: If some aspects of choices for cost conscious HVAC to address guidelines are under consideration but undecided at the time of first application. Explain what options are under consideration in section 6B or a cover email.

(ii) Water Heating, Cooking and Laundry

Will energy/fuel type or system type for this end use change in DER? | List any planned changes for these enduses

Domestic Hot Water:
Fuel Source:
Type:

If "other" entered above, please explain:

Cook top - Fuel Source:
Oven - Fuel Source:
Dryer - Fuel Source:

If "other" entered above, please explain:

(iv) Electric Appliances (indicate number, enter 0 if none)

Refrigerator	
Well pump	
Central air conditioning	
Freezer	
Dehumidifier	
Room air conditioners	

(v) Heating or cooling system and/or ducts located in attic spaces?

5 A) Energy Use and Billing History

Customer Name:

Project Address: ,

First Application Date:

Second Application Date:

National Grid typically has access to either gas or electric use. Records for all fuels are needed for evaluation. The project team may find monthly usage data very helpful to assess end-use savings opportunities. For **Final submittal after Second Application please scan and submit a summary bill with 12 months usage for electric or heating use if not by National Grid.**

Please provide twelve months usage and a few scattered months of cost data for your primary heating fuel, water heating fuel if different and electric consumption using the table below. Do not include arrearage or budget amounts in costs

Electric					
Electric Company		**National Grid**			
Account number					
Account name					
Month	Reading Date	Usage	Year-to-Date Usage	Monthly Cost	Year-to-Date Cost
(Month 1 intended as most recent month)		kWh		$	
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
(default calculation is most recent 12 months)					
12 Month Total		0		0	

Primary Heating Fuel				Type:	0
#N/A					
Account number					
Account name					
Billing/Delivery Frequency		monthly			
Month	Reading Date	Usage	Year-to-Date Usage	Monthly Cost	Year-to-Date Cost
(Month 1 intended as most recent month)		#N/A		$	
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
Enter 12 month total (or accept default calculation)					
12 Month Total		0		0	

Secondary Heating or Other Fuel			Type:	0	
#N/A					
Account number					
Account name					
Billing/Delivery Frequency		periodic / other			
Read / Delivery Period	Reading or Purchase Date	Usage or Purchase Qty	Year-to-Date Usage	Cost for Period	Year-to-Date Cost

Tertiary Heating or Other Fuel				Type:	0
#N/A					
Account number					
Account name					
Billing/Delivery Frequency		periodic / other			
Read / Delivery Period	Reading or Purchase Date	Usage or Purchase Qty	Year-to-Date Usage	Cost for Period	Year-to-Date Cost

(Period 1 intended as most recent)		#N/A		$	
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
Enter 1 year total		0	<Enter total	0	<Enter total
1 Year Total		0		0	

(Period 1 intended as most recent)		#N/A		$	
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
Enter 1 year total			<Enter total		<Enter total
1 Year Total		0		0	

5B) Energy Use and Baseline Data

Customer Name: Project Address: ,

First Application Date: Second Application Date:

Blue cells linked here from other tabs, in sections with deep yellow cells , those inputs are needed for 2nd application only

In the second application all participants must provide simple input and output from the Thousand Homes Challenge Calculator to bench mark the building.

B. Summary - Total annual energy used

(i) Total annual energy used

		Units		Energy Cost	Site Energy MBtu	Site Energy kWh	Source (Primary) Energy MBtu	Source (Primary) Energy kWh
Electricity		0	kWh	$ -	0.0	0	0	0
Oil / Kerosene		0	Gallons	$ -				
Natural Gas		0	Therms	$ -				
Propane		0	Gallons	$ -				
Wood - cordwood		0	Cords	$ -				
Wood - pellet		0	Tons	$ -				
other		0		$ -				
(Indicate other fuel if applicable and apply conversion factors)								
			Total	**$ -**	**0.0**	**0**	**0**	**0**

(ii) Annual energy use intensity

			Energy Cost/ Sq Ft	Site Energy kBtu/ Sq Ft	Site Energy kWh/ Sq Ft	Source (Primary) Energy kBtu/ Sq Ft	Source (Primary) Energy kWh/ Sq Ft
Building Area:							
Exisitng Building Conditioned Area:	0	sq ft	**#DIV/0!**	**#DIV/0!**	**#DIV/0!**	**#DIV/0!**	**#DIV/0!**

		Energy Cost/ Occupant	MBtu/ Occupant	kWh/ Occupant	MBtu/ Occupant	kWh/ Occupant
Building Occupancy:						
Total Occupants in Building:	0	**#DIV/0!**	**#DIV/0!**	**#DIV/0!**	**#DIV/0!**	**#DIV/0!**

C. Annual energy use benchmarking

Baseline data doesn't determine eligibility for incentives except for level 2 projects (see section 9 instructions). However it is required for the Second Application for evaluation. It is vital data, especially if occupancy or space size changes.

For the second application, all participants must provide the simple Threshold Calculator benchmark from Thousand Homes Challenge. The Threshold Calculator EXCEL file is available at:

http://thousandhomechallenge.com/join-us

The benchmark there is based on the EPA Home Energy Yardstick but provides more detail than the yardstick score. In the THC calculator*, you will need to enter:

Your zip code:	0	< in THC Calculator Tab 1, cell C:7
Number of people living in the building:	0	
PROPOSED conditioned floor area	0	'< conditioned and useable area of the building post-retrofit
Number of households in the building:	0	

As well as the enclosure area abutting other conditioned space (e.g. another buildings) as a % of total building enclosure area.

Output from THC Calculator

Enter the resulting baseline value from tab 2 "Threshold Calculator", cell C36 "EPA Home Energy Yardstick, Avg kWh/yr" below

Home Energy Yardstick, Avg kWh/yr:

This above Home Energy Yardstick, Avg kWh/yr value represents approximate performance of a code built home based on statistical averages. One goal of the DER pilot is for projects to achieve performance 50% better than that level. You can check how this compares with how your building performs now by comparing the values in section (ii) to the values below.

	Site Energy MBtu	Site Energy kWh	Site Energy Intensity kBtu/ Sq Ft	Site Energy Intensity kWh/ Sq Ft
EPA Home Energy Yardstick, Avg	0.0	0	#DIV/0!	#DIV/0!
50% of EPA Home Energy Yardstick, Avg	0.0	0	#DIV/0!	#DIV/0!
Your Buildng (existing usage reflecting existing conditions)	0.0	0	#DIV/0!	#DIV/0!

6) Health, Safety, and Durability Issues

Project Name: ______________________ First Application Date: ______________________ Second Application Date: #REF!

Complete sections A, B and C below

Section (6A) Identification of Health, Safety, and Durability Issues

Category	DIRECTIONS: In the Stage 1 Application, please complete Column B with "yes","no", "high priority" or "TBD" (to be determined).	Applicable to project?	Second Application:Brief description of proposed resolution. (More detail will be needed for final work plan)
Combustion Safety	Combustion products from vented furnace or water heater spilling due to inadequate draft or house depressurization (NOTE: Natural draft gas & oil combustion appliances are not acceptable see DER Guidelines)		
Combustion Safety	Combustion products (NOX / CO / water vapor) from gas range / cook stove in living space		
Combustion Safety	Combustion products from fireplace or woodstove due to house depressurization		
Indoor Env Quality	Inadequate source control (exhaust) of moisture & odors		
Indoor Env Quality	Inadequate indoor-outdoor air exchange, dilution of contaminants		
Indoor Env Quality	Inadequate distribution of indoor and fresh air		
Indoor Env Quality	VOCs from building materials, interior finishes		
Indoor Env Quality	VOCs and/or SVOCs from consumer products		
Indoor Env Quality	Unit-to-unit cross contamination of indoor air pollutants (tobacco smoke, cooking odors, etc.) (Attached dwelling)		
Indoor Env Quality	Contaminants from attached garage entering living spaces		
Indoor Env Quality	Radon and other soil gases entering living spaces		
Indoor Env Quality	Lead health risk from paint		
Indoor Env Quality	Lead health risk from outdoor contamination (indoor dust)		
Indoor Env Quality	Exposure to asbestos (from zonolite loose-fill insulation, HVAC system, popcorn ceilings, etc.)		
Code Issue	Hazard due to unsafe or inadequate electrical system		
Code Issue	Structural problem due to rot, subsidence, or substandard construction		
Durability	Interior moisture from faulty plumbing		
Durability	Bulk water entry from inadequate roof and flashing		
Durability	Deterioration of insulation & air sealing due to pests		
Durability	Wintertime condensation on cold surfaces		
Durability	Summertime condensation on cold surfaces		
Durability	Condensation that could support mold growth (or growth of other biologicals/allergens)		
Durability	Hidden condensation in building cavities that could support mold growth or deterioration		
Durability	Trapped water / moisture / loss of durability due to bulk water event (interior such as plumbing leak or spill)		
Durability	Trapped water / moisture due to bulk water event (exterior i.e. rain, flood, sprinkler)		
Durability	Excessive moisture in basement or crawl space		
Durability	Basement or crawl space flooding (from storm or inadequate drainage)		

Thanks to PG&E for permission to adapt this above part of this worksheet from NorCal Thousand Home Challenge Submittal Form

B. Combustion Safety

Describe briefly how your project will meet the requirements in section 4D of the DER Guidelines which starts with this sentence: *"With the exception of oven\ranges and condensing dryers* ***all combustion appliances including, but not limited to fireplaces, woodstoves, heating and hot water systems must be direct-vent, sealed combustion or power vented."***

C. Health Safety and Durability

If some of the aspects identified in the checklist in Section 6A of the application (other than combustion safety) were significant and are a key part of the remediation or renovations planned describe those planned actions in either: (1) Section 6A or (2) in a brief narrative below**.** Note: This relates to sections 4E and 4F of the DER Guidelines.

7a) Building Enclosure, HVAC and Incentives

Customer Name: Project Address: ,

For First Application provide estimated costs and proposed incentives, see notes about costs below. For Second Application Update Section (7A) and Complete (7B) You may provide (7B) w/1st Application. For FUTURE STAGE enclosure measures, which must be specified for a DER partial, indicate just existing and proposed area\units in (7A), but costs and proposed RValues in (7B.)

Component	Applicable to Building	Component treated in DER Project?	Note	a Enter areas below! Existing Conditions (Units)	b Proposed	c Performance Specifications Existing Condiitons *	d Proposed	e DER Pilot Targets	f Equipment or Material
Enclosure Measures				Area of Enclosure Component (Sq Ft)		Effective R-value (R-value = 1 / U-value)			Indicate thickness and type of insulation added
Attic or Roof			area likely to change if thermal boundary moved					R 60+	
Above Grade Walls			gross area including windows and doors					R 40+	
Insulated Foundation Wall - Above Grade			include if basement walls insulated or basement is intentionally heated, can shift from one way existing to another in DER					R 40+	
Insulated Foundation Wall - Below Grade								R 20+	
Floor of Insulated/Conditioned Basement								R 10+	
Basement Ceiling			**do not include if** basement walls insulated or basement is **intentionally heated**					R 30+	
Slab on Grade								R 10+ under and perimeter	
Floor over Unheated Garage or Overhang								R 40+	
Windows	Yes							R 5 (U.2) **	
Doors	Yes							R 5 (U.2)	
Tight Storm or Modify Windows and Doors			area of affected windows or doors					R 5 (U.2)	
				Enclosure surface area		enter air leakage test measurement in cfm at 50 Pascal pressure difference			indicate basic strategy for airflow control
Air sealing		Yes		0	0			0	
HVAC	exists ?			# units	# units	enter appropriate performance specification			indicate equipment type, MBTUh, manufacturer and model number
Mechanical Ventilation			include (CFM) and, if applicable, recovery efficiency (%)					Heat Recovery, Balanced, Distributed	
Heating equipment	Yes		enter AFUE of existing and proposed						
Cooling equipment			SEER and EER proposed (existing if applicable)					16 / 13	
Other (w/ prior approval)									

Applicant Notes or Comment: First Application Date: Second Application Date:

** use UValue calculator in tab 9 to calculate average R-value if window R-values will vary. Window Notes>	number of basement windows: __
* See Input and more R-Value Entry Tips for Tab 7A in Application Part A Appendix.	

7a) Building Enclosure, HV

Customer Name: ____________ Project Address: , ____________

Comprehensive or Staged DER: **Comp** Incentive Level: **1**

Estimated Measure Costs and Incentives

Component		g Total Measure Cost	h Non-allowable Costs Renova-tion	i Third Party	j Deduct-ible	k Allowable Cost	l Incentive % (calculates)	m Estimated Incentive (e x f)	n Applicant explanation of non-allowable cost
Enclosure Measures				**Enclosure Measures**					
Attic or Roof						$0	75%	$0	
Above Grade Walls						$0	75%	$0	
Insulated Foundation Wall - Above Grade						$0	75%	$0	
Insulated Foundation Wall - Below Grade						$0	75%	$0	
Floor of Insulated/Conditioned Basement						$0	75%	$0	
Basement Ceiling						$0	75%	$0	
Slab on Grade						$0	75%	$0	
Floor over Unheated Garage or Overhang						$0	75%	$0	
Windows					$0	$0	100%	$0	
Doors	Fenstr %					$0	75%	$0	
Tight Storm or Modify Windows and Doors	#DIV/0!					$0	75%	$0	
Air sealing						$0	75%	$0	
HVAC				**HVAC**					
Mechanical Ventilation						$0	75%	$0	
Heating equipment						$0	50% w/ $4k cap, 2.5K after 1st unit	$0	
Cooling equipment						$0	50% w/ $1k cap	$0	
Other (w/ prior approval)						$0	75%	$0	
	Total	$0	$0	$0	$0	$0		$0	

Maximum Incentive:

Applicant Notes or Comment:

* Note - Most incentives will not calculate w/o Sq Ft areas

** use UValue calculator in tab 9 to calculate average R-value if window R-values will vary. Window Notes>

* See Input and more R-Value Entry Tips for Tab 7A in Application Part A Appendix.

Section (7B) Building Enclosure and HVAC Measures Customer Name: Project Address: ,

For First Application basic measure details will link in from Section 7a into darker blue rows here. NOTES here will help inform those entries. For Second Application update to more precise costs in Section 7a and finalize detail explaining materials, and non allowable costs in Section 7b. Section 7 B provides space to describe future measures for a staged DER. Select "Future" if DER will be partial but describe in this line what would be done for component that's excluded from current proposal but planned for potential future deployment. For FUTURE after DER partial measures indicate proposed area only in tab 7A, costs and proposed RVaules in tab 7B.

DER Measure Detail

				a	b	c	d	e	f
Component	Applicable to Building	Addressed in DER Project (Y, N or Future)	**Note:** regarding entries for specific enclosure and equipment measures	Existing Conditions	Proposed / Potential	Performance Specifications Existing Conditions	Proposed / Potential	DER Pilot Targets	Equipment or Material
Enclosure Measures				Area of Enclosure Component **(Sq Ft)**		Effective R-value of Enclosure Component (**R-value** = 1 / U-value)			Provide additional detail for measure components. Indicate thickness and type of insulation added.
Attic or Roof	0	0	area likely to change if thermal boundary moved from attic flat to roof. FOR ANY MEASURE: Edit detailed component label in Column at LEFT to Specify Location or other measure attribute.			0 <- Sum from appropriate entries below	0	R 60+	0
Insulated sloped roof (cavity)									
Insulated sloped roof (exterior)									
Insulated Attic flat (ceiling)									
Roof Other									
Attic Other									
Attic Other									
Above Grade Walls	0	0	enter gross area excluding foundation including windows and doors			0 <- Sum from appropriate entries below	0	R 40+	0
Above grade wall 1 (cavity)									
Above grade wall 1 (exterior)									
Above grade wall 2 (cavity)									
Above grade wall 2 (exterior)									
Above grade wall 3 (other)									
Above grade wall 3 (other)									
Insulated Foundation Wall - Above Grade	0	0	include if basement walls insulated or basement is intentionally heated			0 <- Sum from appropriate entries below	0	R 40+	0
Rim/Band Joist									
Above Grade Foundation Wall (interior)									
Above Grade Foundation Wall (exterior)									
Insulated Foundation Wall - Below Grade	0	0				0 <- Sum from appropriate entries below	0	R 20+	0
Below grade walls (interior)									
Below grade walls (exterior)									
Floor of Insulated/Conditioned Basement	0	0	Slab Floor of Basement pertains to Insulated/Conditioned basements.			0 <- Sum from appropriate entries below	0	R 10+	0
Floor of conditioned basement									
Floor of conditioned basement									
Slab on Grade	0	0	for Slab on Grade enter R value of perimeter insulation. Indicate depth of perimeter insul and insul. under			0 <- Sum from appropriate entries below	0	R 10+ under and perimeter	0
Slab area 1									
Slab area 2									
Basement Ceiling	0	0	do not include if bsmt walls insulated or if bsmt heated. WHEN bsmt is semi- conditioned effective R value of floor ins derated min 50%			0 <- Sum from appropriate entries below	0	R 30+	0
Basement ceiling (1)						6.0			
Alternate basement ceiling									
Floor over Unheated Garage or Overhang	0	0	Slab Floor of Basement pertains to Insulated/Conditioned basements.			0 <- Sum from appropriate entries below	0	R 40+	0
Floor over unheated garage									
Overhang									
other floor over uncond.									

Customer Name:

Project Address: ,

Comprehensive or Staged DER: **Comp**

Incentive Level: **1**

DER Measure Cost and Incentive Detail

	g	h	i	j	k	l	m	n	o	q	r	s	t	u
	Unit Cost and Quantity of Proposed Measure						Non-allowable Costs							
Component	Cost / Measure Unit e.g. Sq. Ft.	Number or Units for Measure	# of Apt Units Involved	Total Potential Measure Cost	Total Future Measure Cost	Total DER Measure Cost	Total Renova-tion Cost	Explanation Detail non-allowable cost	Third Party	Deduct-ible	Allowable Cost	Incentive % (calculates)	Estimated Incentive (e x f)	Applicant explanation of provisions for measure if that component is in the "future" category
Enclosure Measures	**Enclosure Measures**													
Attic or Roof				$0		$0	$0		$0	$0	$0		$0	
		Sums From Below >		$0	$0	$0	$0	0	$0	$0	$0		$0	
Insulated sloped roof (cavity)				$0	$0							75%		
Insulated sloped roof (exterior)				$0	$0									
Insulated Attic flat (ceiling)				$0	$0									
Roof Other				$0	$0									
Attic Other				$0	$0									
Attic Other				$0	$0									
Above Grade Walls				$0		$0	$0		$0	$0	$0		$0	
		Sums From Below >		$0	$0	$0	$0	0	$0	$0	$0		$0	
Above grade wall 1 (cavity)				$0	$0							75%		
Above grade wall 1 (exterior)				$0	$0									
Above grade wall 2 (cavity)				$0	$0									
Above grade wall 2 (exterior)				$0	$0									
Above grade wall 3 (other)				$0	$0									
Above grade wall 3 (other)				$0	$0									
Insulated Foundation Wall - Above Grade				$0		$0	$0		$0	$0	$0		$0	
		Sums From Below >		$0	$0	$0	$0	0	$0	$0	$0		$0	
Rim/Band Joist				$0	$0							75%		
Above Grade Foundation Wall (interior)				$0	$0									
Above Grade Foundation Wall (exterior)				$0	$0									
				$0	$0									
Insulated Foundation Wall - Below Grade				$0		$0	$0		$0	$0	$0		$0	
		Sums From Below >		$0	$0	$0	$0	0	$0	$0	$0	75%	$0	
Below grade walls (interior)				$0	$0									
Below grade walls (exterior)				$0	$0									
Floor of Insulated/Conditioned Basement				$0		$0	$0		$0	$0	$0		$0	
		Sums From Below >		$0	$0	$0	$0	0	$0	$0	$0	75%	$0	
Floor of conditioned basement				$0	$0									
Floor of conditioned basement				$0	$0									
Slab on Grade				$0		$0	$0		$0	$0	$0		$0	
		Sums From Below >		$0	$0	$0	$0	0	$0	$0	$0	75%	$0	
Slab area 1				$0	$0									
Slab area 2				$0	$0									
Basement Ceiling				$0		$0	$0		$0	$0	$0		$0	
		Sums From Below >		$0	$0	$0	$0	0	$0	$0	$0	75%	$0	
Basement ceiling (1)				$0	$0									
Alternate basement ceiling				$0	$0									
				$0	$0									
Floor over Unheated Garage or Overhang				$0		$0	$0		$0	$0	$0		$0	
		Sums From Below >		$0	$0	$0	$0	0	$0	$0	$0	75%	$0	
Floor over unheated garage				$0	$0									
Overhang				$0	$0									
other floor over uncond.				$0	$0									

Section (7B) Building Enclosure and HVAC Measures

Customer Name:

Project Address: ,

For First Application basic measure details will link in from Section 7a into darker blue rows here. NOTES here will help inform those entries. For Second Application update to more precise costs in Section 7a and finalize detail explaining materials, and non allowable costs in Section 7b. Section 7 B provides space to describe future measures for a staged DER. Select "Future" if DER will be partial but describe in this line what would be done for component that's excluded from current proposal but planned for potential future deployment. For FUTURE after DER partial measures indicate proposed area only in tab 7A, costs and proposed RVaules in tab 7B.

DER Measure Detail

Component	Applicable to Building	Addressed in DER Project (Y, N or Future)	**Note:** regarding entries for specific enclosure and equipment measures	a Existing Conditions	b Proposed / Potential	c Performance Specifications Existing Conditions	d Performance Specifications Proposed / Potential	e DER Pilot Targets	f Equipment or Material
Windows	Yes	0	Enter sq. ft for exisiting and proposed conditions, note number of **windows** in column F			0.00 <- Sum from appropriate entries below	0	R 5 (U.2)	0
Windows (Replacement)									
Windows (Replacement)									
Doors	Yes	0	Enter sq. ft for exisiting and proposed conditions, note number of **doors** in column F			0.00 <- Sum from appropriate entries below	0	R 5 (U.2)	0
Door replacement									
Bulkhead door replacement									
Tight Storm or Modify Windows and Doors	0	0	Enter sq. ft of modified doors and windows, note number of windows or doors in col F, Equipt.			0 <- Sum from appropriate entries below	0	R 5 (U.2)	0
Windows (storms)									
Doors storms									
Windows (block over, basement)			for doors or windows eliminated or blocked indicate proposed R Value = to wall					Yes R 20 +	
Windows (reduce or eliminate)								Yes R 40	
Doors (block or eliminate)									
				Enclosure surface area		enter air leakage test measurement in cfm at 50 Pascal pressure difference			indicate basic strategy for airflow control
Air sealing		Yes	Enter test results w/ and w/o basement			0	0	0	0
HVAC			**Provide detail as appropriate for components**						indicate equipment type, manufacturer and model number
Mechanical Ventilation	0	0	include 24 hour average airflow (CFM) and, if applicable, recovery efficiency (%)		0	0 <- Sum from appropriate entries below	0	Heat Recovery, Balanced, Distributed	0
Heating equipment	Yes	Yes	enter AFUE of existing and proposed equipment		0	0 <- Sum from appropriate entries below	0		0
Cooling equipment	0	0	enter SEER and EER of existing and proposed equipment			0 <- Sum from appropriate entries below	0	16 / 13	0
Other (w/ prior approval)	0	0				0	0		0

Applicant Notes or Comment:

Section (7B) Building Encl

Customer Name:

Project Address: ,

Comprehensive or Staged DER: **Comp** Incentive Level: **1**

DER Measure Cost and Incentive Detail

	g	h	i	j	k	l	m	n	o	q	r	s	t	u
	Unit Cost and Quantity of Proposed Measure						Non-allowable Costs							
Component	**Cost / Measure Unit e.g. Sq. Ft.**	**Number or Units for Measure**	**# of Apt Units Involved**	**Total Potential Measure Cost**	**Total Future Measure Cost**	**Total DER Measure Cost**	**Total Renova-tion Cost**	**Explanation Detail non-allowable cost**	**Third Party**	**Deduct-ible**	**Allowable Cost**	**Incentive %** (calculates)	**Estimated Incentive (e x f)**	**Applicant explanation of provisions for measure if that component is in the "future" category**
Windows				$0		$0	$0		$0	$0	$0	100%	$0	
		Sums From Below >		$0	$0	$0	$0	0	$0	$0	$0		$0	
Windows (Replacement)				$0	$0									
Windows (Replacement)				$0	$0									
Doors				$0		$0	$0		$0	$0	$0	75%	$0	
		Sums From Below >		$0	$0	$0	$0	0	$0	$0	$0		$0	
Door replacement				$0	$0									
Bulkhead door replacement				$0	$0									
Tight Storm or Modify Windows and Doors				$0		$0	$0		$0	$0	$0	75%	$0	
		Sums From Below >		$0	$0	$0	$0	0	$0	$0	$0		$0	
Windows (storms)				$0	$0									
Doors storms				$0	$0									
Windows (block over, basement)				$0	$0									
Windows (reduce or eliminate)				$0	$0									
Doors (block or eliminate)				$0	$0									
Air sealing				$0		$0	$0	$0	$0	$0	$0	75%	$0	
				$0	$0	$0				$0	$0		$0	
HVAC	**Mechanical Systems**													
Mechanical Ventilation				$0		$0	$0		$0	$0	$0	75%	$0	
		Sums From Below >		$0	$0	$0	$0	0	$0	$0	$0		$0	
				$0	$0									
				$0	$0									
Heating equipment				$0		$0	$0		$0	$0	$0	50% w/ $4k cap	$0	
		Sums From Below >		$0	$0	$0	$0	0	$0	$0	$0		$0	
				$0	$0									
				$0	$0									
				$0	$0									
Cooling equipment				$0		$0	$0		$0	$0	$0	50% w/ $1k cap	$0	
		Sums From Below >		$0	$0	$0	$0	0	$0	$0	$0		$0	
				$0	$0									
				$0	$0									
				$0	$0									
Other (w/ prior approval)				$0		$0	$0	$0	$0	$0	$0	75%	$0	
	Total From 7a			$0			$0		$0	$0	$0		$0	
	Total From 7b above			$0	$0	$0	$0		$0	$0	$0		$0	

National Grid Deep Energy Retrofit Application Part (B), Excel component

First Application Date: ##

Second Application Date:

Enter 1, 2 or 3 to indicate which measures to be Installed and Inspected in each TIME FRAME group for incentive payment purposes

8) Summary of Project and Finances

Customer Name: -

A) Summary of Measures and Incentives

Comprehensive DER   Incentive Level: 1

Component	Indicator	Existing Condiitons *	Proposed Value	Description or Type and Model	Units Proposed	Total Measure Cost	Allowable Cost	Incentive %	Estimated Incentive
Attic or Roof	R Value	0	0		0	$0	$0	75%	$0
Above Grade Walls	R Value	0	0		0	$0	$0	75%	$0
Foundation A.G.	R Value	0	0		0	$0	$0	75%	$0
Foundation B.G.	R Value	0	0		0	$0	$0	75%	$0
Slab Floor	R Value	0	0		0	$0	$0	75%	$0
Basement Ceiling	R Value	0	0		0	$0	$0	75%	$0
Floor over Garage or Overhang	R Value	0	0		0	$0	$0	75%	$0
Repl Windows\ Doors	R Value	0	0	-	0	$0	$0	100%	$0
Other Window & Door	R Value	0	0		0	$0	$0	75%	$0
Air sealing	CFM50	0	0	0	0	$0	$0	0%	$0
Mechanical Ventilation	Eff %	0	0		0	$0	$0	75%	$0
Heating equipment	AFUE	0			0	$0	$0	50% w/ $4k cap, 2.5K after 1st unit	$0
Cooling equipment	SEER / EER	0	0		0	$0	$0	50% w/ $1k cap	$0
Other w/ Prior Approval		0	0		0	$0	$0	1	$0
TOTALS Enclosure and Heating Ventilation and HVAC						$0	$0		$0
Solar hot water system	Qty. panel(s)							case by case for Level 2 projects only	
Water Heating	En.Factor (EF)			-					
Wind turbine system	kW						N/A	N/A	N/A
Other Incl. Appliances							N/A	N/A	N/A
Lighting							CFL or better, NGrid to provide $200 worth LED or CFLs		
Grand Totals Deep Energy Retrofit						$0	$0	N/A	$0

D) Worksheet for Proposed Payment Plan

Group 1, 2, or 3	Total Group 1	Total Group 2	Total Group 3
	$0	$0	$0
	$0	$0	$0
	$0	$0	$0
	$0	$0	$0
	$0	$0	$0
	$0	$0	$0
	$0	$0	$0
	$0	$0	$0
	$0	$0	$0
	$0	$0	$0
	$0	$0	$0
	$0	$0	$0
	$0	$0	$0
	$0	$0	$0
	$0	$0	$0
Group Split $	$0	$0	$0
Payment #	1	2	3
Adjusted for Max	**$0**	**$0**	**$0**
Total of Payment Groups	**$0**	^ May become included in Exhibit A of Agreement	

B. Summary of Project Costs

Project Category	Pre Application Estimated Costs	Current Application Costs	
Renovation Associated with DER	**$0**	**$0**	For first application provide ballpark estimates of the project cost components described below. Use second column for second application providing revised more accurate figures. Show full costs before value of incentives, in-kind services or materials are accounted for.
Addition, Remodeling, other Renovation\Remediation			
Total non-Energy Related	**$0**	**$0**	
DER Enclosure and HVAC w/o Renovation	**$0**	**$0**	
DER Retrofit excluding Enclosure and HVAC	**$0**	**$0**	
Total Energy Related	**$0**	**$0**	
Total Project Costs	**$0**	**$0**	

C. Financing Confirmation

This Section of the worksheet is intended to verify that all the funding and incentives are sufficient to cover the entire project. This is a vital component of project viability. Sufficient Funds is a MUST.

(i) Costs, Incentives and Finances	Current Application	Incentive Level	Max Incentives for Project
(a) Total Project Costs	**$0**	Level 1 >	**$0**
(b) Total Incentives minus Level 2 set aside	**$0**	Level 2 25% additional	**$0**
(c) Costs Less Incentives = a minus b	**$0**	Combined >	**$0**
(d) Total Customer and Other Funding and Financing (from Word Part A Sect 1Biia)	**$0**	Level **2** Incentive set aside >	**$0**
Balance of Funds or (Shortfall) = D minus C	**$0**		

Heat Fuel:	0	**Building Type:**	
Construction Period:			**Total Incnt$\Encl SF**
DER Enclosure $	**$0**		$0.0

Conditioned Sq. Ft.

Planned Conditioned Sq. Ft.	**Existing**	**Encl $ \ S.Q F.T.**
0	**0**	**$0.0**
DER Surface Area \ $SF	**0**	**$0.0**
Occupants: 0	# Apts	0
NOTICE: This application and proposed payment plan is not a commitment to provide incentives. Incentives are NOT part of an "official" offer until project agreement is signed	**Site Mbtu Pre Plan** 0	**Source kBtu/ Sq Ft** 0

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About this Report

This report was prepared with the cooperation of the U.S. Department of Energy's Building America Program.

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