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Byggmeister Test Home: Analysis and Initial Results of Cold Climate Wood-Framed Home Retrofit

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Byggmeister Test Home:

Analysis and Initial Results of Cold Climate Wood-Framed Home Retrofit

Prepared for:

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Definitions

ACH	Air changes per hour
ACH 50	Air changes per hour at 50 pascal test pressure
AFUE	Annual fuel utilization efficiency
ASHP	Air source heat pump
ASHRAE	American Society of Heating, Refrigerating, and Air Conditioning Engineers
BEopt	Building Energy Optimization
BSC	Building Science Corporation
Btu	British thermal unit
ccSPF	Closed-cell spray polyurethane foam
cfm	Cubic feet per minute
cfm 50	Cubic feet per minute at 50 pascal test pressure
DEAP	Duclos, Eldrenkamp and Panish Energy Group
DER	Deep energy retrofit
DHW	Domestic hot water
EER	Energy efficiency ratio
ERV	Energy recovery ventilator
ft^2	Square foot
ft^3	Cubic foot
gal	Gallon
HERS	Home Energy Rating System
HRV	Heat recovery ventilator
kBtu	Thousand Btus
kW	Kilowatt
kWh	Kilowatt-hour
MMBtu	Million British thermal units
PV	Photovoltaic
SEER	Seasonal energy efficiency ratio
SHGC	Solar heat gain coefficient
THC	Thousand Home Challenge
yr	Year

Executive Summary

The Building Science Corporation seeks to further the energy efficiency market for retrofit projects in the New England area by supporting projects that are based on solid building science fundamentals and verified implementation. The Building Science Corporation has been working with Byggmeister, a partner on its Building America Program team, on retrofit projects. Byggmeister is a Boston-area design-build firm that specializes in energy efficient retrofits and new construction. The DEAP (Duclos, Eldrenkamp and Panish) Energy Group, which is associated with Byggmeister, conducts energy analysis for projects during design and performs monitoring after completion.

With the high exposure of energy efficiency and retrofit terminology currently being used in the general media, it is important to have evidence that measures being proposed will in fact benefit the homeowner through a combination of energy savings, improved durability, and occupant comfort. Concrete data from specific projects can close the gap between "hype" and reality.

This technical report describes a deep energy retrofit project for a two-family wood framed home located in Belmont, Massachusetts. Built in the 1920s, this home is referred to in this report as the "Belmont Two-Family." The report examines the retrofit measures for the enclosure and mechanical systems and the decision making that took place during project planning. Because the retrofit project is complete, projected and actual energy use data are compared for the 5 months immediately following the retrofit. Occupant reactions and experiences are also described.

The retrofit measures implemented for the Belmont Two-Family resulted in a home with airtightness of 0.93 air changes per hour at 50 pascal test pressure, a Home Energy Rating System index of 44 (excluding photovoltaics), and initial energy use significantly less than the energy models projected. The home is on track to meet the Thousand Home Challenge. In these ways, the project meets or exceeds the energy goals established for the retrofit.

Energy modeling tools were found to be useful during the planning stage for investigating the relative cost effectiveness of retrofit measures. They were less effective, however, in projecting actual energy use. Discrepancies between the results of different tools need to be better understood, and interactions among retrofit measures are not effectively handled by the energy modeling tools at this time.

During the first few months after the retrofit, the homeowner had questions about the effective operation of the mechanical equipment. With the increased airtightness and R-values, the equipment needs to be operated differently to realize the potential energy savings. This information needs to be better understood and disseminated by everyone involved with retrofit projects.

This technical report contributes to several basic areas of research. These include the combination of measures that is feasible, affordable, and acceptable to homeowners as well as expectations versus results.

1 Introduction

The Building Science Corporation (BSC) seeks to further the energy efficiency market for retrofit projects in the New England area by supporting projects that are based on solid building science fundamentals and verified implementation.[1] BSC has been working with Byggmeister, a partner on its Building America Program team,[2] on retrofit projects. Byggmeister is a Boston-area design-build firm that specializes in energy efficient retrofits and new construction. DEAP (Duclos, Eldrenkamp and Panish) Energy Group, which is associated with Byggmeister, conducts energy analysis for projects during design and performs monitoring after completion.

With the high exposure of energy efficiency and retrofit terminology currently being used in the general media, it is important to have evidence that measures being proposed will in fact benefit the homeowner through a combination of energy savings, improved durability, and occupant comfort. Concrete data from specific projects can close the gap between "hype" and reality.

This report explores the retrofit efforts and results for a test home called the "Belmont Two-Family". This typical, wood framed, two-family home was built in 1925 in Belmont, Massachusetts (see Figure 1). This test home contributes to several basic areas of research. These include the combination of measures that is feasible, affordable, and acceptable to homeowners, as well as expectations versus results. In particular, this report examines the package of measures considered, the planning process used, and the construction costs reported. In addition, because the retrofit is complete, initial energy use results are available for analysis.

The Belmont Two-Family was a participant in the National Grid Deep Energy Retrofit Pilot Program (National Grid 2009).[3] The program's goal is to achieve, ideally, at least 50% better energy performance than a code-built or Energy Yardstick home[4]; the program offers financial incentives and technical support to participants. BSC has partnered with National Grid by furnishing technical guidance and program support.

1.1 Context and Relevance to Other Homes

The current owner purchased the Belmont Two-Family in 2009 to renovate and then to serve as an extended family home with the owner's immediate family in the upper unit and his parents in the lower unit. When an older home such as this is purchased at a bargain price, an energy retrofit can be combined with the renovation project. The older home can be brought up to date in terms of energy and HVAC standards as well as modifications needed to meet modern living standards. Given the continuing lower prices in the current home market, this type of situation is likely to continue to generate a strong market for energy retrofits in the near future. For this type of retrofit project, the home is likely to be unoccupied during construction. Although this removes certain constraints, the project schedule can be a driving force to meet an established move-in date for the new owner. These conditions contribute to the decisions made during planning of the energy measures for this type of energy retrofit.

[1] For more information, see www.buildingscience.com.
[2] For more information, see www.buildingamerica.gov.
[3] For more information, see http://www.powerofaction.com/der.
[4] For more information, see https://www.energystar.gov/index.cfm?fuseaction=home_energy_yardstick.showgetstarted.

Figure 1. Pre- and post-retrofit Belmont Two-Family

Pre-retrofit photo provided by National Grid.

2 Retrofit Measures for Belmont Two-Family

Although many of the energy efficiency measures for a retrofit are the same as for new construction, the underlying constraints differ. For new construction, the owner has a clean slate for implementing the most important energy efficient aspects—detailing the air barrier; incorporating ventilation and ductwork for heating and cooling; selecting, installing, and air sealing windows; and using large amounts of insulation. These can be implemented according to standard proven details. For a retrofit, though, the reality of existing conditions results in special case details for nearly all portions of the building. The decision to retrofit a building implies that something about the existing building needs to be preserved—all or parts of the exterior, all or parts of the interior, just the structural framing, or a combination. This complicates everything—from installing an effective air barrier to ventilating the newly air-tightened house.

For the Belmont Two-Family, certain existing elements of the interior, such as window and door moldings, wood floors, and plaster over lath walls were elegant and retained where possible. On the other hand, some interior partitions were to be removed or relocated and bathrooms and kitchens were to be completely gutted, so there were opportunities to introduce retrofit measures that required invasive construction methods.

From the beginning of the project, the owner was committed to creating a home with exceptional energy efficiency that would demonstrate what was possible and serve as an information resource for others interested in energy efficient homes. The energy goals of the project evolved during the planning phase as a result of energy and cost modeling and the availability of rebates and incentives, as well as the constraints of the house itself. The project started out targeting either Passive House certification[5] or net zero energy status, then cut back somewhat to a deep energy retrofit (DER). In the end, designers and the homeowner settled on participating in National Grid's Deep Energy Retrofit Pilot Program (plus photovoltaic [PV] panels). The home also became a participant in the Thousand Home Challenge (THC).[6]

Passive House certification requires meeting stringent performance requirements that include upper limits on air infiltration (≤0.6 air changes per hour at 50 pascal test pressure [ACH 50]), the annual heating requirement (≤4.65 kBtu/ft^2·yr), and total source energy demand (≤38.1 kBtu/ft^2·yr) (Straube 2009). Net zero energy means producing at least as much energy on site as is used over the course of a year. A DER is typically a package of specific energy efficiency measures that addresses all components (e.g., exterior walls, attic/roof, windows, and doors). THC is a performance-oriented program that sets a specific upper limit for total yearly site energy use.

In addition to the specific performance goals incorporated by participating in the DER program and in THC, the contract between the owner and Byggmeister added two specific performance goals: air infiltration of 1,000 cubic feet per minute at 50 pascal test pressure (cfm 50) or less and a Home Energy Rating System (HERS) index of 55 or less.[7]

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[5] For more information about the Passive House methodology and certification in the United States, see http://phaus.org

[6] For more information about this program, developed and directed by the Affordable Comfort Institute (one of BSC's Building America team partners), see http://thousandhomechallenge.org.

[7] HERS was developed by the Residential Energy Services Network. A net zero energy home scores a HERS index of 0.

Regardless of the specific energy efficiency goals being targeted, a set of measures is used to improve performance levels. The measures can be broken into two groups: building enclosure measures and mechanical system measures. Enclosure measures address energy efficiency by reducing heat loss or gain, reducing air infiltration, and improving durability and indoor air quality. Mechanical measures address energy efficiency primarily by upgrading the efficiency of equipment.

The enclosure measures, though, add new requirements to the mechanical systems. Because of increased airtightness, ventilation must be provided and combustion safety must be ensured. Also, because of the reduced load conditions resulting from the improved enclosure, the mechanical systems can and should be downsized.

With the test home located in Massachusetts, the retrofit measures that are described in this document are discussed in the context of cold-climate (U.S. Department of Energy Zone 5A) conditions.

2.1 Enclosure Measures for Belmont Two-Family

Enclosure retrofit measures are described based on the enclosure component or the function as follows: above-grade walls, roof or attic, foundation walls, basement floor, windows and doors, water management system, air barrier system, and other enclosure measures.

The National Grid Deep Energy Retrofit Program has desired project characteristics for qualification, including fenestration, airtightness, and opaque enclosure guidelines. For reference, the program's targets for opaque R-value, fenestration, and airtightness are summarized as follows (National Grid 2009, p. 6–7):

> Insulation - targets for effective R-value: roof-R60, above grade wall-R40, below grade wall - R20, basement floor - R10. Thermal bridging needs to be considered fully in estimation of thermal performance and minimized to the extent possible.
>
> Air Sealing Target – Ideal whole house sealed to achieve 0.1 (zero point 1) cfm 50 /sq. ft. of thermal enclosure surface area (6 sides) with high durability materials.
>
> Windows and Doors - target R5 ($U \leq 0.2$) whole-unit thermal performance, infiltration resistance performance of ≤ 0.15 cfm/sq ft. of air leakage, per AAMA11 standard infiltration test.

When it was accepted into the National Grid DER Pilot program, these became the target R-values for the enclosure measures for the Belmont Two-Family.

2.1.1 Above-Grade Walls

To provide at least nominal R-40 walls, insulating sheathing was applied over the exterior board sheathing and the wall cavities were filled with cellulose insulation.

The specific components of the exterior wall upgrade were as follows:

- Existing cedar shingles and remaining building paper were removed to expose the board sheathing; board sheathing was replaced where damaged.
- Cellulose was blown into the wall cavities from the outside through cores in the board sheathing where the interior plaster walls were to be retained. In areas where there was no existing finished wall (e.g., at the attic gables), netted cellulose was applied from inside.

- Housewrap was applied over the board sheathing.
- Insulating sheathing (4 in.) was applied over the housewrap; the seams of the insulating sheathing were staggered, both vertically and horizontally, and the seams were taped on both layers (see Figure 2).
- Vertical wood strapping was applied over the insulating sheathing and attached to the wall studs using long screws. For this type of installation, the screws need to be hot-dipped galvanized screws sized to extend 1½ in. into the existing wall studs (or as required by code).
- Fiber cement lap siding was attached to the wood strapping.

Figure 2. Insulating sheathing on the Belmont Two-Family

Photo by David Connelly Legg

2.1.2 Roof or Attic

Before the retrofit, the attic space was used for storage. As part of the renovation, living space for the upper unit was created in the attic including a bedroom, a full bathroom, and a sitting area. Also, ductwork and mechanical equipment was located in the space behind the attic kneewalls. The formerly vented attic, then, was changed to an unvented attic.

With a targeted nominal R-value of R-60 for the roof, three layers of 2-in.-thick foil-faced polyisocyanurate insulating sheathing were applied over the existing roof sheathing. Netted dry cellulose was blown into the 7-in.- deep rafter bays. The seams of the insulating sheathing were staggered and taped (see Figure 3).

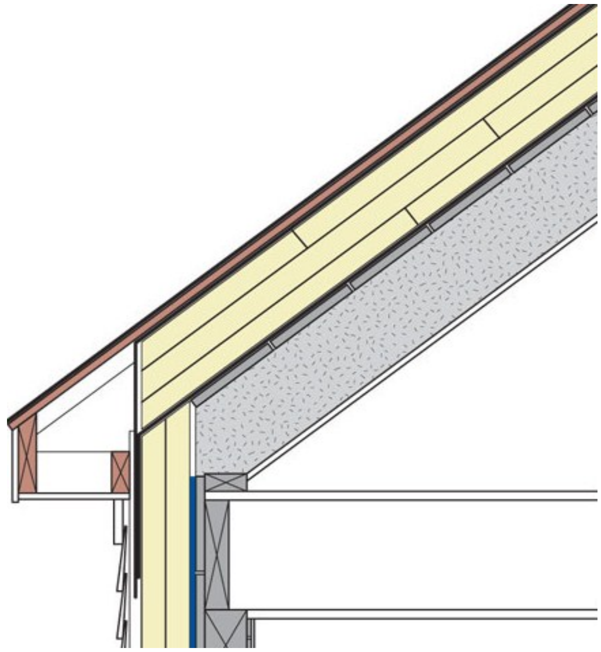

Figure 3. Belmont Two-Family roof and attic insulation

The specific components of the roof upgrade were as follows:

- Existing roofing shingles and old underlayment were removed, exposing the existing roof sheathing; sheathing was replaced where there was damage.
- The overhangs at the eaves and rakes were sawed off (known as a “chainsaw retrofit”) so that the planes of the roof and wall sheathing meet to form a corner. The exterior insulating sheathing on the wall was extended up to the corner.
- Self-adhered roofing membrane was applied over the existing roof sheathing. The membrane was lapped down over the face of the outside layer of insulating sheathing on the wall and sealed to it.
- The insulating sheathing on the roof was installed over the membrane, extending over the top of the wall insulating sheathing; the seams of the insulating sheathing were staggered between layers and were taped to minimize air passage channels.
- A new layer of plywood sheathing was installed, attached through the insulation to the existing rafters using long screws. The plywood was covered with ice and water shield for the entire roof. For this type of installation, the screws need to be hot-dipped galvanized sized to extend 1½ in. into the existing rafters (or as required by code).
- New overhangs for the eaves and rakes were constructed and attached back to the building structure through the insulating sheathing.
- New asphalt shingles were installed.
- On the interior, the 7-in. rafter bays were netted and filled with cellulose.

2.1.3 Foundation Walls

The test home has a full basement that was to be used for storage, mechanical equipment, and laundry. With exposed stone foundation walls, the existing basement before the retrofit was damp and subject to minor flooding. The targeted nominal R-value for basement walls is R-20 and the only feasible option was to insulate from the inside (Lstiburek 2006).

The specific components of the foundation wall upgrade were as follows:

- Two to three inches of closed-cell spray foam (ccSPF) insulation was applied directly onto the stone foundation wall; the spray foam extended up over the mud sill and rim joist and down onto the basement floor.
- A metal stud interior perimeter wall with gypsum wall board was installed inside the ccSPF.
- The space between the wall board and the ccSPF was filled with dense packed mineral wool (see Figure 4).

After the retrofit, the total insulation R-value is approximately R-40.

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Figure 4. Belmont Two-Family basement wall insulation

2.1.4 Basement Floor

It is recommended that basement floors be insulated to at least nominal R-10. For a retrofit, this particular measure can be problematic because adding 2 in. of insulation to the floor raises the floor elevation, often resulting in a ceiling height problem. It can also seem unnecessary to the homeowner because the ground temperature at that level is moderate, which means that the energy loss through the floor is relatively low. An untreated basement floor, though, can be a source of moisture from condensation and possible capillary wicking from below in addition to heat loss (Lstiburek 2006).

This measure was not included for the Belmont Two-Family.

2.1.5 Windows and Doors

The targeted R-value for doors and windows was R-5 or more (a U-value of 0.2 or less). New triple glazed, flanged vinyl windows were installed with a U-value of 0.2, a solar heat gain coefficient (SHGC) of 0.25, and visual transmittance of 0.42. These windows were installed as "outie" windows (see Ueno 2010), meaning that the outside plane of the windows is at the outside of the exterior wall. The installation for this project nailed the flanges to strapping surrounding the windows that was applied over the insulating sheathing; the strapping was attached through the insulating sheathing to the wall framing by long screws. With windows in an outie installation, it is necessary to extend the existing interior jamb, head, and sill window trim to reach the position of the new windows (see Figure 5).

Figure 5. Belmont Two-Family outie windows

New insulated exterior doors were installed as well.

2.1.6 Water Management System

The water management system needs to be coordinated among all the components of the enclosure (BSC May 2009a). For the roof, the ice and water shield underlayment over the plywood sheathing is the drainage plane. The eave overhangs extend the water management system beyond the roof/wall intersection.

The drainage plane for the exterior walls is the outer layer of insulating sheathing. To serve this function, all seams of the insulating sheathing were taped to prevent water from passing through the seams. The window flashing and sill pan were integrated with the outer surface of the insulating sheathing. The gap between the insulating sheathing and the lap siding that is created by the vertical strapping furnishes space for drainage as well as ventilation to assist drying.

In the basement, the primary water management concern was to handle bulk and capillary water that penetrates through the foundation walls. Because water does not pass through ccSPF, the basement wall treatment prevents water from entering the basement interior until it reaches the floor. To handle water at the bottom of the foundation wall, a subslab interior perimeter drainage system connected to a new sump pump was installed (see Figure 6). In addition, a short segment of drainage mat was installed along the base of the foundation wall when the trench was created for the subslab drainage system. The drainage mat forms a channel that directs the water from behind the ccSPF down to the subslab drainage system.

Figure 6. Belmont Two-Family sump pump installed (before basement wall was insulated)

Photo by David Connelly Legg

Because the basement slab insulation was not used in this project, there was a risk of condensation on the basement floor slab and capillary action or diffusion of water through the basement slab. An application of an epoxy coating was applied to the slab to prevent diffusion. If this does not control moisture sufficiently, a dehumidifier will need to be installed in the basement.

2.1.7 Air Barrier System

The air barrier system separates indoor (conditioned) air from outdoor (unconditioned) air. To be effective, it must be continuous over all six sides of the building. The retrofit plan needs to identify the air barrier for each component of the enclosure and how it is to be continuously transitioned to the air barrier of adjacent components (Lstiburek 2005).

For the Belmont Two-Family, the air barrier system consists of the following components:

- Self-adhered roofing membrane over the existing roof sheathing (roof)
- The taped outer layer of exterior insulating sheathing on the exterior walls (wall)
- The ccSPF on the inside of the stone foundation walls (foundation wall)
- The existing concrete basement slab (basement floor).

Transitions between these components were as follows:

- **Roof to exterior wall.** The roofing membrane was extended down and sealed onto the outer layer of the insulating sheathing at the top of the walls (see Figure 7). This simple transition was possible because there were no overhangs or eaves (i.e., the chainsaw retrofit).

- **Exterior wall air barrier (the outer layer of insulating sheathing) to foundation wall (ccSPF on the interior side).** This was complex and labor intensive because there were so many layers between the outer layer of insulating sheathing and the interior ccSPF on the foundation wall. Sealant was required between the layers of insulating sheathing at all edges and between the insulating sheathing and the board sheathing and mud sill. In addition, the ccSPF was extended up over the interior side of the mud sill. To be effective, each of these transitions needed to be continuous.
- **Foundation wall to concrete basement slab.** The transition was created by extending the ccSPF down onto the concrete slab.

Figure 7. Belmont Two-Family, showing the roof membrane that was sealed to exterior insulating sheathing

The blower door test results (590 cfm 50 or 0.93 ACH 50) indicate that even though the air barrier system was complicated and difficult to implement, the implementation was thorough and yielded excellent results.

2.1.8 Other Enclosure Measures

The chimney and the fireplaces were removed. The porch roofs and porch decks were removed and rebuilt and attached after the insulating sheathing had been applied over the house (see Figure 8). This approach prevents thermal bridging where these attach to the house.

Figure 8. Belmont Two-Family porch deck attachment (from below)

2.1.9 Enclosure Retrofit Costs

The costs of renovating and those of including a DER with the renovation differ significantly. At one point during project planning, it seemed that the performance improvement part of the project might need to be deferred because of cost. This would have severely limited the type of energy upgrades that could be made in the future. Fortunately, the availability of rebates, grants and other financial incentives allowed the project to go forward with the original plans, even enabling the addition of a PV component.

Table 1 summarizes the pre-retrofit condition, retrofit enclosure measures implemented, and the construction cost for the enclosure measures for the Belmont Two-Family.

The costs given in Table 1 are the actual construction costs to the owner for the enclosure measures before rebates or other incentives were applied. In some cases, the actual cost to the owner will, of necessity, include more than just the cost of the enclosure measure. For example, because the roofing and siding must be removed so that the insulating sheathing can be applied to the exterior, new roofing shingles and usually new siding will be needed as well. The additional costs for shingles and siding are not included in the table.

Table 1. Belmont Two-Family Enclosure Measures and Cost

Parameter	Existing Condition	Enclosure Measures	Construction Cost (number of units)
Roof or Attic	Vented attic; fiberglass batts on attic floor	R-63: 6-in. polyisocyanurate exterior insulating sheathing with 7-in. netted cellulose filling rafter cavities; asphalt shingles; unvented attic	\$28,055; excludes new roof shingles (approximately 1,708 ft^2 roof deck area at \$16.50/ft^2)
Above-Grade Walls	No insulation in 2 × 4 wall cavity	R-40: 4-in. polyisocyanurate exterior insulating sheathing with 4-in. dry cellulose insulation in wall cavities; fiber cement lap siding over vertical strapping	\$45,138; excludes new siding and trim (approximately 3,262 ft^2 at \$14.00/ft^2)
Foundation Wall	Stone wall, uninsulated	R-20: 3-in. ccSPF covered with mineral wool insulation within a metal stud perimeter wall	\$9,051 (approximately 1,112 ft^2 at \$8.14/ft^2)
Basement Floor	Concrete floor, uninsulated	No insulation; subslab drainage system, sump, and sump pump added for water management	No separate construction cost available (approximately 1,200 ft^2)
Windows and Doors	Wood, single glazed	U-value = 0.25, SHGC = 0.25 vinyl, krypton/argon blend, triple glazed, low-E windows; new insulated doors	\$40,305 (55 windows, 5 doors at \$596.45/window and \$1,500/door)
Water Management System`	Roofing felt under asphalt shingles; building paper under wood shingles on walls; overhangs at eave and rake	Ice and water shield under shingles; taped insulating sheathing behind lap siding; subslab drainage, sump, and sump pump	No separate construction cost available
Air Barrier System/ Airtightness	None/ 5,700 cfm 50 or 15.2 ACH 50 (attic and basement closed)	Self-adhered membrane over existing sheathing (roof), exterior insulating sheathing taped (walls), ccSPF (foundation walls and mud sill), with taped, sealed, or spray foam transitions; 590 cfm 50 or 0.93 ACH 50	\$3,000 for testing and sealing; air barrier materials combined with other costs
Other Enclosure Measures		Removed chimney roof penetration; porch roofs, stairs, landing at back rebuilt to allow continuous exterior wall insulation behind	No separate construction cost available

2.2 Mechanical System Measures for the Belmont Two-Family

Replacing outdated, inefficient mechanical equipment is a major source of energy savings for a retrofit. With improved R-values and airtightness of the house after the retrofit, smaller and more energy efficient systems can be installed (Ueno 2008). Because of the improved airtightness, it is important for occupant safety and indoor air quality that the installed mechanical systems have controlled, outside-supplied combustion air and exhaust venting. In addition, the improved airtightness introduces the need for mechanical ventilation.

The mechanical systems retrofit measures include upgrades to heating, cooling, ventilation, and domestic hot water (DHW). These generally work together as an interdependent system.

The existing systems for the Belmont Two-Family consisted of old and outdated equipment, all of which needed to be replaced. Heat was produced by two oil boilers, one for each unit, with steam radiators. There was no cooling. Atmospheric natural gas water heaters generated hot water, and only spot exhaust was provided.

As part of the retrofit planning, the team decided to switch to forced air heating and cooling. Because so much of the interior was opened up for the renovation, installing ductwork was not a major obstacle. With all interior space including the attic, the kneewall space and the basement being within the thermal enclosure layer, all ductwork is located in conditioned space.

Figure 9. Belmont Two-Family natural gas furnace in basement with air-conditioner coil attached

For each unit, a new heating/cooling system was installed. The lower unit's systems are in the basement; the upper unit's systems are in the kneewall attic space. Each system consists of a 96.7 annual fuel utilization efficiency (AFUE) direct vent, closed combustion natural gas variable speed furnace with an Air-Conditioning, Heating, and Refrigeration Institute-rated

14 seasonal energy efficiency ratio (SEER)/12 energy efficiency ratio (EER) coil attached to the air handler and an outdoor unit at the back of the house (see Figure 9).

Ventilation is supplied by one energy recovery ventilator (ERV) for each unit. The ductwork for the ERVs is independent of the air handler's ductwork. The supply air is ducted to common space and the exhaust is taken from the bathrooms. The ERV for the lower unit is located in the basement; the ERV for the upper unit is located in the kneewall attic space (see Figure 10).

Figure 10. Belmont Two-Family ERV for upper unit in attic kneewall space

DHW combines a 77-ft^2 solar thermal collector system with a 100-gal common tank and a separate 40-gal electric heat backup tank for each unit (see Figure 11).

Figure 11. Belmont Two-Family DHW storage tank for solar thermal with backup electric tanks

2.2.1 *Mechanical System Construction Costs*

Table 2 summarizes the existing and retrofit mechanical system measures, and gives the approximate cost to the owner for the new equipment.

Table 2. Belmont Two-Family Mechanical System Measures and Cost

Parameter	Existing Conditions	Mechanical System Measure	Approximate Construction Cost
Heating System	Two oil boilers in basement with steam radiators	For each unit, 96.7 AFUE direct vent, closed combustion natural gas furnace	$15,995 (2 units for heating, including ductwork)
Cooling System	None	For each unit, 14 SEER/12 EER coil installed at air-handling unit and connected to outdoor unit	$3,000 (2 outdoor units)
Ventilation	Spot exhaust only	ERV installed for each unit	$7,084 (2 units, including dedicated ductwork)
DHW	Atmospheric natural gas water heater	Solar thermal with single storage tank and, for each unit, electric backup tank	$14,070
Site-Generated Electricity	None	4.3 kW (21 panels)	$37,810

2.3 Deciding Which Measures To Include in the Retrofit

As in most construction projects, the final decision about the measures to include is primarily driven by cost—initial cost, operational cost, or some combination. It can also be observed that the measures eliminated because of cost are probably an indicator of their value as perceived by the homeowner.

For this project, specific performance goals—air infiltration level and HERS index—were also significant factors in the decision process.

2.3.1 *The Planning Process*

For this test home, the owner was committed to ultra-high energy efficiency from the start, even considering Passive House certification. As a result, all of the measures of a DER that showed progress toward the project's performance goals were considered. To evaluate the performance, the project's energy consultant, DEAP Energy Group, developed a REM/Rate energy model for use during the planning process. The model was developed to show projected energy use changes for incremental application of measures.

The planning process went through several iterations. The initial concept was to target either the passive house standard or net zero energy status. Energy modeling created the more realistic goal of a DER. Acceptance into the National Grid DER Pilot Project set specific goals for the retrofit measures and—with the associated financial incentive—designers were able to include PV. At each step along the way, the energy model was used to inform the process (Duclos and Eldrenkamp 2011). Table 3 presents the measures that were included in or eliminated from the final plan.

Table 3. Retrofit Measures Included

Retrofit Measure	Belmont Two-Family
Roof or Attic	Included
Above-Grade Walls	Included
Foundation Wall	Included
Basement Floor	Not included
Windows and Doors	Included
Airtightness	Included
Water Management	Included
Heating	Included
Cooling	Included
Mechanical Ventilation	Included
DHW	Included
On-Site Power Generation	Included

2.3.2 Basement Decisions

Except for the basement measures, all enclosure measures were included. Insulating the basement is the retrofit measure most often left out of a retrofit project. In this case, the basement floor was not insulated. Logistically, this would have been a difficult measure to implement because there was insufficient head height in the basement to allow insulation over the existing slab and still include a laundry room on that level. In addition, replacing the existing slab and excavating down far enough to allow application of 2 in. of insulation would have required underpinning of the existing stone foundation walls.

The energy modeling done during planning projected only 2.3 MMBtu/yr (or about 2%) reduction of total energy use by insulating the basement floor once the basement wall insulation was included. Given the difficulty of implementing this measure for this project, it was eliminated.

Although the reduction in energy use might not be significant in this case, the impact on indoor air quality could be important. Without the underslab insulation, there is potential for condensation on the basement floor or capillary action or diffusion through the slab. To reduce this risk, BSC suggested installing a dehumidifier in the basement and painting the existing slab with an epoxy coating to resist hydrostatic pressure and capillary moisture transport through the slab. The epoxy coating was included. The conditions of the basement floor will be monitored to determine if a dehumidifier is necessary.

2.3.3 Mechanical System Decisions

To meet the airtightness goals of the project, including a mechanical ventilation system was a given. Decisions about the rest of the mechanical system, however, underwent the same energy modeling process that was applied to the enclosure decisions.

The overall plan was to replace the two existing oil burners and steam radiator systems with forced air heating and cooling systems. Determining the system type required further analysis with the help of energy modeling and cost comparisons. For heating, the options were an air source heat pump (ASHP) or a gas unit (with air conditioning). For the air conditioning, the choice was between a coil integrated unit with an air handler and a ducted/ductless mini-split unit.

Alternative DHW systems were also considered during planning and evaluated by energy modeling. Options included indirect water heater, ASHP with electric backup, standard gas DHW, and solar thermal with electric backup using tanks of varying sizes.

In each case, the options were modeled and the final HERS score for the selected packages were compared to identify systems that met the goals of the project.

2.4 Cost Effectiveness of the Retrofit Measures Package

As described earlier in this section, planning for the retrofit was a combination of energy modeling, cost analysis, and desired goals and targets of the homeowner. These considerations were balanced by analyzing the modeling results.

At approximately the time that this retrofit was completed, a new version of Building Energy Optimization (BEopt, an hourly energy simulation program used as a primary Building America performance analysis tool), was released. Support for energy retrofits is a new feature in BEopt. The tool includes an optimization capability that uses user-supplied cost data and energy use information for a specified set of energy saving measures to determine combinations of measures that are optimal or near optimal in terms of cost effectiveness. On a graph that plots the average source energy savings per year against the annualized energy related costs, the optimal packages are those that form the lower bound of the plotted data points. BEopt uses a sequential searching technique so that not every possible combination of options is simulated.

Even though the project was already completed, a BEopt optimization simulation was performed. This simulation included the measures implemented as well as some of those that were considered during planning. BEopt does not currently support comparisons between different types of mechanical systems (e.g., between a heat pump system and a gas furnace), so this type of decision cannot be evaluated using BEopt's optimization feature. The optimization feature can, however, help with decisions such as the amount of insulation to apply or the AFUE needed for a gas furnace.

For the BEopt optimization prepared for this report, the default cost values for the Chicago Retrofit were used with user option costs adjusted relative to the similar default options.[8] Although the costs do not represent the Boston-area costs, the BSC team believes that the optimal and near optimal selections would be the same. The utility rates used were the state average values for Massachusetts supplied by BEopt.

Options selected for the optimization of the enclosure included different amounts of exterior insulation on the above-grade walls and on the roof and different amounts of interior insulation on the basement walls. The targeted R-values for the walls and roof could not be achieved without exterior insulation so no options without exterior insulation were included. Because mechanical equipment was located in the basement and in the attic kneewall area, all options selected included the basement and all of the attic space within the thermal layer of the enclosure.

For the mechanical equipment, options included different AFUE and SEER values for heating/cooling, energy factor values for the water heater, and amount (including "NONE") of solar collectors and PV panels. For the mechanical ventilation, the operating modes of 50% and 100% of ASHRAE 62.2 were included (ASHRAE 2010).

[8] The BEopt v1.1 simulation program includes default costs for a Chicago-area retrofit as a sample cost selection set.

The BEopt optimization, which simulated 58 of a possible 4,096 total combinations of options, calculated a set of options for maximum savings (energy use) that differed from the implemented measures only in selecting 50% instead of 100% of ASHRAE 62.2 for the ERV. This is an operating mode change instead of any change in the measures implemented. The BEopt optimization for minimum cost reduced the amount of insulation on the roof and on the basement walls, reduced the AFUE and SEER for the heating and cooling, and eliminated the PV panels. The difference in source energy use between the “maximum savings” and “minimum cost” projected by BEopt was 73.5 MMBtu/yr after the PV-generated electricity was subtracted (see Figures 12 and 13).

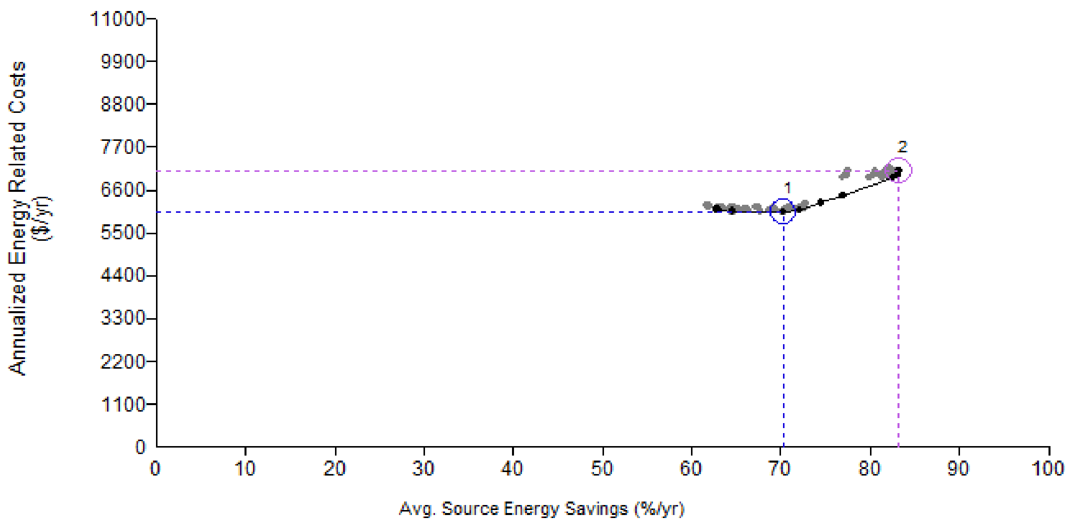

Figure 12. Belmont Two-Family BEopt optimization results, cost versus energy use

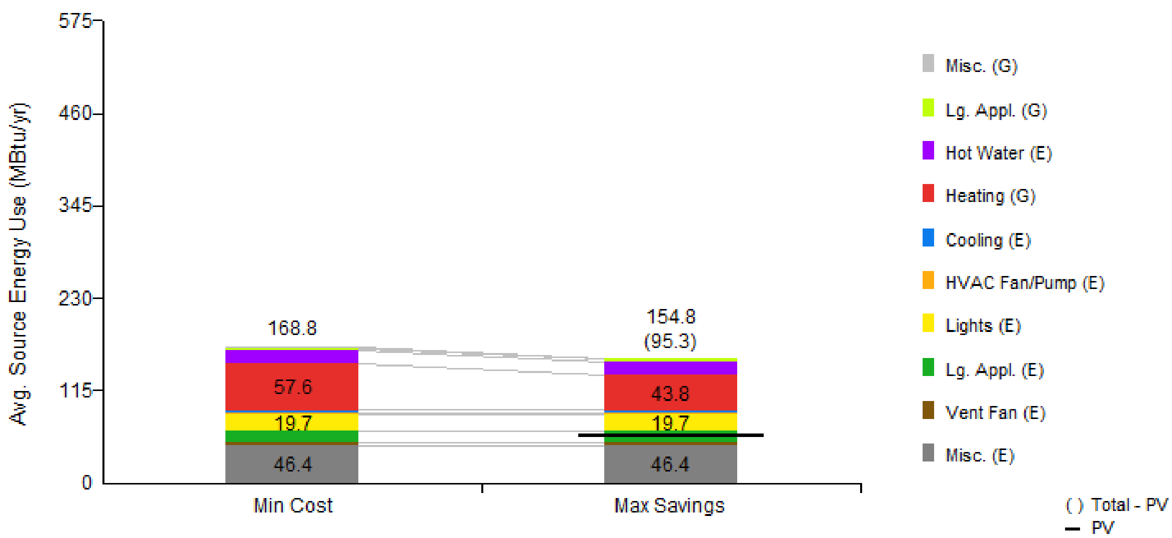

Figure 13. Belmont Two-Family BEopt optimization results, source energy use

3 Testing and Analysis for Belmont Two-Family

Various types of testing and analysis were performed during the planning phase of the retrofit project and immediately after the retrofit was complete. Monitoring of actual conditions and energy use is ongoing.

3.1 Measurements

Blower door testing was performed before and after the retrofit project (see Figure 14). The two units of the house have separate front and rear entrances. The first-floor unit has an interior connection to the basement; the upper unit has an interior connection to the third floor. There is also an exterior entrance (bulkhead) to the basement. The initial blower door testing was done by DEAP Energy Group using two blower doors with several different setups (e.g., interior basement door open and closed, and attic door open and closed). Testing of the two units with the attic and basement closed resulted in 5,700 cfm 50. With the original living space volume of 22,507 ft^3 (which excludes the basement and attic), this represents existing air infiltration conditions of 15.2 ACH 50. It should be noted that the pre-retrofit testing was performed on a windy day so that the results are approximate.

Once the retrofit was complete, the BSC team performed blower door testing using two blower doors and both guarded and unguarded testing setups. For unguarded testing, the blower door was run in one unit with the windows and doors open to the exterior for the other unit. For the guarded testing, all doors, windows, and other openings to the exterior were closed and the second blower door was used to keep the pressure the same in both units.

For the unguarded case, the infiltration for the lower unit was 971 cfm 50 and the upper unit was 928 cfm 50. Because there was no attempt to air seal between the units as part of the renovation project, much of this infiltration occurs between units. In most multifamily housing, air sealing between units would be important for indoor air quality and for controlling energy use, but for this extended family configuration, this was not a concern. This situation would need to be corrected for future use of the building as multifamily housing by air sealing the common interior walls and the common floor/ceiling.

For the guarded case, which eliminates the infiltration between units by keeping both units at the same pressure, the infiltration for the lower unit was 312 cfm 50 and the upper unit was 278 cfm 50, so total building shell infiltration was 590 cfm 50. The guarded testing included the basement in the lower unit and the attic in the upper unit. The total volume for this test, then, was 38,035 ft^3, resulting in 0.93 ACH 50 (see Appendix A).

Because the blower door test results are indicative of the effective integration of all of the retrofit measures, they yield one quantifiable metric of the success of the retrofit package. This value was also used as input for the energy modeling at the end of the project.

Figure 14. Belmont Two-Family: Setting up blower door testing

Table 4 summarizes the blower door testing results for the Belmont Two-Family.

Table 4. Blower Door Testing for the Belmont Two-Family

Pre-Retrofit Results (cfm 50)			
Lower Unit	**Upper Unit**	**Combined**	**Conditions**
2,900	0	2,900	Basement and attic doors closed
0	4,000	4,000	Basement and attic doors closed
3,400	2,300	5,700 (15.20 ACH 50)	Basement and attic doors closed
Post-Retrofit Results (cfm 50)			
971	0	971	Basement door closed, unguarded
0	928	928	Basement door closed, unguarded
312	278	590 (0.93 ACH 50)	Basement and attic doors open, guarded

3.2 Energy Modeling

Energy modeling was used extensively during the planning phase of the retrofit project. DEAP Energy Group developed a REM/Rate energy model for the house at the beginning of the project. Using this model, the HERS rating, annual energy consumption (in million British thermal units per year) and peak heating loads were generated for alternative scenarios to help with the decision process.

In an unusual move, the homeowner and Byggmeister agreed to include HERS and airtightness goals in the construction contract. The HERS goal was 55 and the air tightness goal was 1,000 cfm 50. The energy modeling was used to develop different approaches that could be used to reach these goals. In the initial model, the variables included levels of insulation in the walls and roof, wall and slab treatment in the basement, airtightness metrics, SHGC and U values for windows and doors, and mechanical configurations to create different scenarios.

The REM/Rate model was updated throughout the project with the final model including final infiltration values, actual appliance ratings, and PV panels (Duclos and Eldrenkamp 2011). Appendix B contains a presentation of the results for the final energy model. Table 5 summarizes the projected yearly energy use generated by the final REM/Rate model.

When the project was nearing completion, BSC created an energy model for the project using BEopt. BEopt support for the retrofit type became available during the last quarter of 2010. Using BEopt 1.0 (subsequently updated to version 1.1), the expected energy use for the Belmont Two-Family was generated based on the measures that were implemented. For those options that were not related to a retrofit measure, the default values were used. These results were compared to the REM/Rate results, to the THC goals, and to the actual energy use. This information can provide further evidence of the relevance, accuracy, and appropriate use of energy use modeling tools during retrofit planning and assessment. Because energy use or energy savings are important components in calculating cost effectiveness, it is particularly important that this be validated for the energy modeling programs being used.

To compare the BEopt results with the final REM/Rate energy model information, the projected yearly site energy use was divided into the categories of DHW, natural gas for heating, and all electricity use, along with total site energy use. The output was derived from the average site energy use data generated by BEopt (see Table 5 and Appendix C).

Table 5. Final Energy Model Site Energy Use for Belmont Two-Family (MMBtu/yr)

	Annual Heating (gas)	Annual Cooling	DHW	Other	Total Site Energy Consumed	Total On-Site Generated Energy	Total Site Energy Use
REM/Rate	41.7	4.0	3.1	54.7	106.2	–19.2	87.0
BEopt v1.1	44.8	0.8	4.8	31.1	81.5	–17.8	63.7

The heating, DHW, and on-site generated energy projections are similar for the BEopt and REM/Rate models. The other BEopt energy use projections are significantly lower than the REM/Rate projections. Because BEopt does not support multifamily houses, the BEopt model assumes a 5-bedroom, 3.5-bath single-family house. The distinction between single-family and multifamily energy use assumptions would account for some of this discrepancy. For example, having two kitchens and two distinct families using two sets of other appliances would be expected to increase the total energy use.

On the other hand, the overall relative reductions in energy use of the REM/Rate and BEopt energy models are in agreement, even if the actual numbers generated are not the same (see Table 6). REM/Rate predicts an 83% reduction in energy use; BEopt predicts an 88% reduction.

Table 6. Energy Use Reduction by Component for Belmont Two-Family (MMBtu/yr)

Site Energy (MMBtu)	Pre-Retrofit (Existing)	DER Insulation, Ventilation, Windows (4)	Airtightness, Air-Handling Unit, Solar Thermal (9)	Appliances and Compact Fluorescent Lamps (11)	PV Panels (12)
REM/Rate Model	508	168	114	106	87
BEopt v1.1 Model	524	172	85	81	64

The REM/Rate projection for annual consumption of non-site-generated site energy is 87.0 MMBtu/yr or 25,588 kWh/yr. The BEopt projection for annual consumption of non-site-generated site energy is 64 MMBtu/yr or 18,823 kWh/yr. Both of these projections are generated using standard benchmark energy use factors (e.g., set points, miscellaneous loads, and appliance use assumptions).

Using the projection of the REM/Rate energy model, the project applied to and was accepted as a candidate for the THC program. Within the program, the candidate is given a specific energy use threshold for yearly site energy use. This threshold is computed based on location, number of people and number of households, area of conditioned space, and heating fuel type. The THC threshold for the Belmont Two-Family is 17,006 kWh/yr. This is lower than the projections of BEopt and REM/Rate. Although an energy efficient enclosure and mechanical system and on-site energy generation are expected to be required to stay below the threshold, it is also expected that behavior, lifestyle, and community-based solutions will be necessary. These behavior-based criteria were not incorporated into the energy models.

3.3 Actual Energy Use for January 2011 Through May 2011

Since January 2011, the owner of the Belmont Two-Family has been reporting monthly energy use information. Table 7 summarizes the use from January through May 2011. The homeowner maintains a THC tracking spreadsheet.

Table 7. January 2011–May 2011 Actual Site Energy Use

	January	February	March	April	May
DHW (kWh)	251	251	114	110	96
Gas (kWh)	2,316	1,706	1,067	366	91
Electricity used except DHW (kWh)	782	692	783	783	739
Total kWh of energy used	3,349	2,649	1,964	1,259	926
Electricity from PV (kWh)	–303	–376	–590	–534	–585
Total site energy kWh	3,046	2,273	1,374	725	341

Monthly projections from REM/Rate are not available for comparison to the actual energy use. BEopt monthly projections can be extracted from the hourly output of BEopt, however. These projections were used to generate the information in Table 8 (see Appendix D).

Table 8. January 2011–May 2011 BEopt Projected Site Energy Use

	January	February	March	April	May
DHW (kWh)	259	183	164	124	62
Gas (kWh)	3,198	2,590	2,108	1,320	435
Electricity Used Except DHW (kWh)	831	747	708	643	629
Total kWh of Energy Used	4,288	3,520	2,980	2,086	1,126
Electricity from PV (kWh)	–346	–415	–461	–462	–519
Total Site Energy (kWh)	3,942	3,105	2,519	1,624	606

Such a small sample of comparative data is not statistically significant, but continued monitoring of monthly results could help improve understanding of the applicability of the lower level information that BEopt provides. Of particular note for this test case is that the owner is very interested in the behavior aspect of reducing energy use, as encouraged by the tenets of the THC. If the projected energy use represents “average behavior” for a house of the specified geometry and options, the actual energy use might be expected to show a general lower energy use pattern than that projected by BEopt. Deviations such as specific weather conditions, though, can affect the actual use for any given month.

3.4 Occupant Feedback

The owner of the Belmont Two-Family maintains a website where he includes information about his retrofit experiences along with other local energy issues. In addition, there were some email exchanges with Byggmeister while adjustments were being made after the homeowner first occupied the house. Here is a summary of some of the issues discussed:

- Upgrading of insulation and inclusion of solar thermal both appear to be cost effective for this particular project. PV cells, though, are probably not cost effective without substantial incentives.
- If planning a retrofit that goes beyond current code requirements, blower door testing (to assess current status) and energy modeling in the planning are important first steps.
- There have been some questions about the interaction between the mechanical ventilation and the operation of the air handler.
- There has been some discussion that suggests a need to consider how to effectively use natural ventilation during the “shoulder seasons.”

This summary illustrates two issues that should be addressed with each retrofit project and are areas for further study:

- To an owner, cost effectiveness can involve more than a straight calculation of initial costs and dollars saved in energy use. Indoor air quality, durability, and combustion safety should apply to every job but might not show up in the cost-effectiveness calculations. An individual’s weighting of goals also do not compute; for example, meeting the THC objectives is an important goal for this project, but this could not be achieved without the PV panels, which otherwise appear not to be cost effective. If an energy model is used during planning, it needs to provide sufficient transparency or flexibility to allow optimizing cost effectiveness with a broader definition of cost.
- A better way to describe the interactions among the various components of the mechanical systems, as well as with the high performance enclosure, needs to be developed. Example questions to be considered include (1) what are the constraints of a DER and (2) when is natural ventilation undermining the energy use reduction? This type of information needs to be better understood by everyone on the project. There should also be a period of follow-up with the owner.

4 Conclusions

This report examined the planning, construction, and initial energy use results of a package of retrofit measures for a case study involving the renovation of a wood framed, two-family, suburban New England home built in the 1920s.

With a blower door test result of 0.93 ACH 50 and a REM/Rate generated HERS index of 44, the retrofit package that was applied to the Belmont Two-Family is successful from an energy use point of view. The house is on track to meet the THC, which usually results in 15%–30% of the Home Energy Yardstick estimation for the same household.

The question of whether there will be condensation in the basement, resulting from not including the basement floor insulation portion of the retrofit measures package, cannot be addressed until at least a year's worth of monitoring data is available. If it becomes necessary to run a dehumidifier in the future, it will raise the energy use somewhat.

An energy model used in combination with a proposed package of retrofit measures proved to be an effective planning tool for this project. Cost effectiveness of proposed energy reduction measures was estimated during planning using the projected energy use and initial costs, particularly of mechanical equipment. In this case, the homeowner wanted to include certain additional measures and was able to take advantage of incentive programs so that the final package went somewhat beyond the most cost-effective solution.

The energy modeling tools used during the project yielded good relative information about energy use, but should not be expected to predict actual use. Furthermore, they do not model interactions and durability issues. For example, failure to include sufficient exterior insulation might result in condensation in the wall or roof, shortening their lives. This type of interaction is not effectively supported in the energy modeling tools that were used.

During the first few months after the retrofit, questions about effective operation of the mechanical equipment requires follow-up with the owner. The increased airtightness and R-values will slow temperature swings, which will affect system operation and require a different pattern of operation from the past.

This project met the goals of the retrofit and identified areas for further study. In addition, it will yield measurable longer term information about the retrofit measures through ongoing monitoring.

References

ASHRAE (2010). ASHRAE Standard 62.2-2010: Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings. Atlanta, GA: ASHRAE.

BSC (May 2009a). *Info-301: Drainage Plane/Water Resistive Barrier.* Accessed January 7, 2011: http://www.buildingscience.com/documents/information-sheets/drainage-plane-water-resistive-barrier.

Duclos, M.; Eldrenkamp, P. (2011). "Modeling and Marketing the Deep Energy Retrofit." Presented at the Better Buildings by Design 2011 Conference, Burlington, Vermont, February 8–9, 2012. Accessed June 14, 2011: www.efficiencyvermont.com/for_our_partners/bbd/archive.aspx.

Lstiburek, J. (July 2005). "Understanding Air Barriers" *ASHRAE Journal* (47); pp. 24–30.

Lstiburek, J. (October 2006). *BSD-103: Understanding Basements*. Accessed January 7, 2011: http://www.buildingscience.com/documents/digests/bsd-103-understanding-basements/.

National Grid (2009). "Deep Energy Retrofit Multifamily and Single-Family Pilot Guidelines." Accessed May 16, 2011: www.powerofaction.com/media/pdf/der_desc.pdf.

Straube, J. (2009). *BSI-025: The Passive House (Passivhaus) Standard: A Comparison to Other Cold Climate Low-Energy Houses.* Accessed June 15, 2011: www.buildingscience.com/documents/insights/bsi-025-the-passivhaus-passive-house-standard/.

Ueno, K. (2010). "Residential Exterior Wall Superinsulation Retrofit Details and Analysis." *Performance of the Exterior Envelopes of Whole Buildings XI*. Atlanta, GA: ASHRAE.

Ueno, K. (June 2008). *RR-0110: HVAC Equipment Sizing Strategies: Taking Advantage of High-Performance Buildings.* Accessed January 7, 2011: www.buildingscience.com/documents/reports/rr-0110-hvac-equipment-sizing-strategies-taking-advantage-of-high-performance-buildings/view.

Appendix A: Belmont Two-Family: Final Blower Door Test

BUILDING LEAKAGE TEST

Date of Test: 2010.09.23 Test File: 2010-09-23 Gilbert Rd Apt 1 guarded	Technician: CG, KN
Customer: Brownsberger 118-120 Gilbert Belmont, MA Phone	Building Address: 118-120 Gilbert Belmont, MA

Test Results

1. Airflow at 50 Pascals: (50 Pa = 0.2 w.c.)	312 CFM (+/- 3.6 %) 0.08 CFM per ft2 floor area
2. Leakage Areas:	28.3 in2 (+/- 18.1 %) Canadian EqLA @ 10 Pa 14.0 in2 (+/- 26.5 %) LBL ELA @ 4 Pa
3. Minneapolis Leakage Ratio:	0.04 CFM50 per ft2 surface area
4. Building Leakage Curve:	Flow Coefficient (C) = 18.0 (+/- 39.2 %) Exponent (n) = 0.730 (+/- 0.092) Correlation Coefficient = 0.96984
5. Test Settings:	Test Standard: = CGSB Test Mode: = Depressurization Equipment = Model 3 Minneapolis Blower Door, S/N 4

Infiltration Estimates

1. Estimated Average Annual Infiltration Rate:

2. Estimated Design Infiltration Rate:	Winter:	34.7 CFM
	Summer:	14.7 CFM
3. Recommended Whole Building Mechanical Ventilation Rate: (based on ASHRAE 62.2)		93.4 CFM

Cost Estimates

1. Estimated Cost of Air Leakage for Heating:
2. Estimated Cost of Air Leakage for Cooling:

Date of Test: 2010.09.23 Test File: 2010-09-23 Gilbert Rd Apt 1 guarded

Building Conditions

Inside Temperature:	75 deg F	Heating Fuel:	Gas
Outside Temperature:	77 deg F	Heating Fuel Cost:	
# of Stories	3.0	Heating Efficiency:	
		Heating Degree Days:	5641
Wind Shield:	M	Cooling Fuel Cost:	
# of Occupants	7.0	Cooling SEER:	
		Cooling Degree Days:	275
# of Bedrooms:	5.0		
Volume:		Ventilation Weather Factor:	1.07
Surface Area:	7468 ft2	Energy Climate Factor:	18.0
Floor Area:	4092 ft2		
Design Winter Wind Speed:	18.0 mph	Design Winter Temp Diff:	61 deg F
Design Summer Wind Speed:	7.0 mph	Design Summer Temp Diff:	13 deg F

Comments

apartment 1 guarded

Date of Test: 2010.09.23 Test File: 2010-09-23 Gilbert Rd Apt 1 guarded

Data Points: Data Entered Manually

Nominal Building Pressure (Pa)	Fan Pressure (Pa)	Nominal Flow	Temperature Adjusted Flow	% Error	Fan Configuration	Baseline Std Dev (Pa)
0.6	n/a					+/- 0.00
-86.5	60.4	463	464	-0.6	Ring B	
-79.1	54.5	440	441	0.8	Ring B	
-71.8	47.3	410	411	0.8	Ring B	
-64.4	42.1	387	388	3.0	Ring B	
-63.3	34.0	348	349	-6.2	Ring B	
-55.7	33.0	343	344	1.4	Ring B	
-0.1	n/a					+/- 0.00

BUILDING LEAKAGE TEST

Date of Test: 2010.09.23	Technician: CG, KN
Test File: 2010-09-23 Gilbert Rd Apt 2 guarded	

Customer:	Brownsberger 118-120 Gilbert Belmont, MA Phone	Building Address:	118-120 Gilbert Belmont, MA

Test Results

1. Airflow at 50 Pascals: (50 Pa = 0.2 w.c.)	278 CFM (+/- 4.4 %) 0.07 CFM per ft2 floor area
2. Leakage Areas:	28.7 in2 (+/- 21.2 %) Canadian EqLA @ 10 Pa 15.3 in2 (+/- 30.9 %) LBL ELA @ 4 Pa
3. Minneapolis Leakage Ratio:	0.04 CFM50 per ft2 surface area
4. Building Leakage Curve:	Flow Coefficient (C) = 21.9 (+/- 45.6 %) Exponent (n) = 0.650 (+/- 0.106) Correlation Coefficient = 0.96224
5. Test Settings:	Test Standard: = CGSB Test Mode: = Depressurization Equipment = Model 3 Minneapolis Blower Door, S/N 4

Infiltration Estimates

1. Estimated Average Annual Infiltration Rate:

2. Estimated Design Infiltration Rate:	Winter:	37.9 CFM
	Summer:	16.1 CFM
3. Recommended Whole Building Mechanical Ventilation Rate: (based on ASHRAE 62.2)		93.4 CFM

Cost Estimates

1. Estimated Cost of Air Leakage for Heating:
2. Estimated Cost of Air Leakage for Cooling:

Date of Test: 2010.09.23 Test File: 2010-09-23 Gilbert Rd Apt 2 guarded

Building Conditions

Inside Temperature:	75 deg F	Heating Fuel:	Gas
Outside Temperature:	77 deg F	Heating Fuel Cost:	
# of Stories	3.0	Heating Efficiency:	
		Heating Degree Days:	5641
Wind Shield:	M	Cooling Fuel Cost:	
# of Occupants	7.0	Cooling SEER:	
		Cooling Degree Days:	275
# of Bedrooms:	5.0		
Volume:		Ventilation Weather Factor:	1.07
Surface Area:	7468 ft2	Energy Climate Factor:	18.0
Floor Area:	4092 ft2		
Design Winter Wind Speed:	18.0 mph	Design Winter Temp Diff:	61 deg F
Design Summer Wind Speed:	7.0 mph	Design Summer Temp Diff:	13 deg F

Comments

apartment 1 guarded

Date of Test: 2010.09.23 Test File: 2010-09-23 Gilbert Rd Apt 2 guarded

Data Points: Data Entered Manually

Nominal Building Pressure (Pa)	Fan Pressure (Pa)	Nominal Flow	Temperature Adjusted Flow	% Error	Fan Configuration	Baseline Std Dev (Pa)
0.3	n/a					+/- 0.00
-88.2	46.1	405	406	0.8	Ring B	
-82.3	40.3	379	380	-1.4	Ring B	
-65.9	28.5	319	320	-4.1	Ring B	
-64.5	33.6	346	347	5.5	Ring B	
-55.8	165.4	294	295	-1.5	Ring C	
-0.2	n/a					+/- 0.00

Appendix B: Belmont Case Study: HERS as Planning, Goal-Setting Tool for a Deep Energy Retrofit

Belmont case study:

HERS as planning, goal-setting tool for a DER

Provided by Mike Duclos of The DEAP Energy Group

118 & 120 Gilbert Scenarios - 11/20/2010 DesLd = Design Load, Peak energy demand in KBTU/Hr AnnLd = Annual Load, Annual useful energy demand, MMBTU/Yr (millions of BTUs) AnnCs - Annual Consumption, Annual Site Energy use in MMBTU/Yr DHW = Domestic Hot Water Annual site energy in MMBTU/Yr	HERS	Heat DesLd	Cool DesLd	Heat AnnCs	Cool AnnCs	DHW AnnCs	Total AnnCs	Total Cond. Space sf
S0 - Baseline - Blower Door = 5700 CFM @ 50 Pa	197	99.8	0.0	276.6	0.0	27.9	339.5	2728
S1 - Thermal boundary includes attic, no insulation, change to 5 bedrooms	181	128.5	0.0	353.9	0.0	31.9	433.5	4092
S2 - No basement insulation but include basement in thermal boundary	166	153.6	0.0	415.3	0.0	31.9	507.8	5478
S3 - Two Renewaire EV130 Energy Recovery Ventilators at 100 CFM	170	155.3	0.0	420.9	0.0	31.9	520.6	5478
S4 - DP CE Above Grade Walls	148	129.8	0.0	343.8	0.0	31.9	443.6	5478
S5 - Add 4" Polyisocyanruate rigid foam on AGWalls	140	121.3	0.0	318.4	0.0	31.9	418.1	5478
S6 - Blower Door to 4500 CFM at 50 Pa	135	115.0	0.0	298.0	0.0	31.9	397.8	5478
S7 - Insulated Rafters with R26 Dense Pack Cellulose	107	84.7	0.0	209.8	0.0	31.9	309.6	5478
S8 - Add 6" Polyisocyanruate rigid foam on top of roof sheating	105	82.1	0.0	202.3	0.0	31.9	302.1	5478
S9 - Blower Door to 3000 CFM at 50 Pa	98	74.2	0.0	177.0	0.0	31.9	276.8	5478
S10 - Insulate Foundation Walls to R12 with closed cell spray foam	83	55.0	0.0	119.7	0.0	31.9	219.5	5478
S11 - Insulate Foundation Walls to R40 average with mineral wool	81	52.4	0.0	111.9	0.0	31.9	211.7	5478
S12 - Blower Door to 1700 CFM at 50 Pa	76	45.6	0.0	91.0	0.0	31.9	190.8	5478
S13 - Window upgrade to triple glazed & Door Upgrade	65	35.4	0.0	67.8	0.0	31.9	167.5	5478
S14 - Blower Door to **590 CFM at 50 Pa**	61	29.6	0.0	50.1	0.0	31.9	149.8	5478
S15 - Changed oil boiler to natural gas	52	29.6	0.0	38.1	0.0	0.0	106.0	5478
S15a - Added two 40 gal 0.90 EF electric DHW heaters	52	29.6	0.0	38.1	0.0	18.1	124.0	5478
S16 - Added air conditioning	52	29.6	20.6	38.1	4.6	18.1	128.7	5478
S17 - Solar Thermal	46	29.6	20.6	38.1	4.6	3.4	114.0	5478
S19 - Fridge estimate was 1500 KWHR/Yr, actual was 1541 KWHR/Yr	46	29.6	20.6	38.1	4.6	3.4	114.1	5478
S20 - Dishwasher estimated EF = 0.46 changed to average of both = 0.82	46	29.6	20.6	38.2	4.6	3.1	113.5	5478
S21 - CFLs were 0%, changed to 95.0%	42	29.6	19.6	41.7	4.0	3.1	106.2	5478
S22 - 21 Sanyo HIT-A 220 @ 204.4 CEC PTC each, Solectra PVI 5000 @ 96%	32	29.6	19.6	41.7	4.0	3.1	87.0	5478

Slide 1

Appendix C: Belmont Two-Family: Yearly Site Energy Use Data Generated by BEopt

Exported Data for Belmont Two-Family generated by BEopt v1.1 for Belmont Two-Family

Avg. Site Electricity Use (kWh/yr)

	Existing	1- Basic Insulation	2 - DER Insulation	3 - High Perf Windows	4 - ERV 2	5 - Air Tightness	6 - High Perf Furnace	7 - DHW- electric	8 - Air conditioning	9 - Solar HW	10 - 100% CFL	11 - ES Appliances	12 - PV Panels
Misc. (E)	4074	4074	4074	4074	4074	4074	4074	4074	4074	4074	4074	4074	4074
Vent Fan (E)	30	30	115	30	593	724	724	724	724	724	724	724	724
Lg. Appl. (E)	1426.81	1426.81	1426.81	1426.81	1426.81	1426.81	1426.81	1426.81	1426.81	1426.81	1426.81	1222.59	1222.59
Lights (E)	2960	2960	2960	2960	2960	2960	2960	2960	2960	2960	1732	1732	1732
HVAC Fan/Pump (	770	632	431	349	354	285	339	339	293	290	301	305	305
Cooling (E)	0	0	0	0	0	0	0	0	249	247	222	217	217
Hot Water (E)	0	0	0	0	0	0	0	4713.22	4713.22	1688.09	1688.09	1403.79	1403.79
Total	9260.81	9122.81	9006.81	8839.81	9407.81	9469.81	9523.81	14237.03	14440.03	11409.89	10167.89	9678.38	9678.38
PV	0	0	0	0	0	0	0	0	0	0	0	0	5222.71
Net (Total - PV)	9260.81	9122.81	9006.81	8839.81	9407.81	9469.81	9523.81	14237.03	14440.03	11409.89	10167.89	9678.38	4455.68

Avg. Site Natural gas Use (Therms/yr)

	Existing	1- Basic Insulation	2 - DER Insulation	3 - High Perf Windows	4 - ERV 2	5 - Air Tightness	6 - High Perf Furnace	7 - DHW- electric	8 - Air conditioning	9 - Solar HW	10 - 100% CFL	11 - ES Appliances	12 - PV Panels
Heating (G)	0	0	0	0	0	0	396	396	404	400	429	438	438
Hot Water (G)	250.54	250.54	250.54	250.54	250.54	250.54	250.54	0	0	0	0	0	0
Lg. Appl. (G)	48.92	48.92	48.92	48.92	48.92	48.92	48.92	48.92	48.92	48.92	48.92	37.59	37.59
Misc. (G)	10	10	10	10	10	10	10	10	10	10	10	10	10
Total	309.46	309.46	309.46	309.46	309.46	309.46	705.46	454.92	462.92	458.92	487.92	485.59	485.59

Avg. Site Fuel oil Use (gal/yr)

	Existing	1- Basic Insulation	2 - DER Insulation	3 - High Perf Windows	4 - ERV 2	5 - Air Tightness	6 - High Perf Furnace	7 - DHW- electric	8 - Air conditioning	9 - Solar HW	10 - 100% CFL	11 - ES Appliances	12 - PV Panels
Heating (O)	3078	1788	1076	682	728	542	0	0	0	0	0	0	0
Total	3078	1788	1076	682	728	542	0	0	0	0	0	0	0

Appendix D: Belmont Two-Family: Monthly Average Site Energy Use Data Generated by BEopt

Exported Monthly Data for Belmont Two-Family generated by BEopt 1.1 using Hourly Output Tool

This represents the average site energy use per hour for the month. To get monthly use, multiply by days/month X 24 hrs/day

	Hot Water (E)	PV (E)	Total (E)	Total (G)
	kWh	kWh	kWh	Btu
Jan	0.34826	0.46456	1.4647	14616
Feb	0.26272	0.59696	1.3362	12654
Mar	0.22107	0.6195	1.1721	9634
Apr	0.17166	0.64207	1.0646	6233
May	0.08316	0.6982	0.9281	1998
June	0.08419	0.67066	0.9001	1007
July	0.04199	0.7027	1.01	499
Aug	0.02031	0.68726	0.8906	404
Sept	0.05291	0.64289	0.8741	527
Oct	0.14512	0.56144	1.0557	2126
Nov	0.24599	0.45257	1.2221	6780
Dec	0.25303	0.41643	1.3503	10505

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