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BUILDING TECHNOLOGIES PROGRAM

National Grid Deep Energy Retrofit Pilot

K. Neuhauser
Building Science Corporation

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National Grid Deep Energy Retrofit Pilot

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Prepared by:

K. Neuhauser

Building Science Corporation

30 Forest Street

Somerville, MA 02143

NREL Technical Monitor: Cheryn Engebrecht

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Contents

List of Figures vii
List of Tables x
Definitions xi
Executive Summary xii
1 Introduction 1
2 National Grid Deep Energy Retrofit Pilot 3
2.1 The Case for Retrofit 3
2.2 National Grid Pilot Background 4
2.3 Future Directions 5
3 Data Sources and Methods 6
3.1 Deep Energy Retrofit Pilot Program Application Materials 6
3.2 On-Site Observation 6
3.3 Performance Testing and Measurement 7
4 Subject Homes 8
4.1 Test Home 1: Garrison Colonial, Comprehensive Deep Energy Retrofit 8
4.1.1 Project Overview 8
4.1.2 Deep Energy Retrofit Project Plan 9
4.1.3 Enclosure System 10
4.1.4 Construction 13
4.1.5 Design Challenge: Retrofit Roof Strategy 13
4.2 Test Home 2: Three-Story Victorian, Partial Deep Energy Retrofit 15
4.2.1 Project Overview 15
4.2.2 Deep Energy Retrofit Project Plan 16
4.2.3 Enclosure System 16
4.2.4 Construction 18
4.2.5 Design Challenge: Connecting the Control Functions 19
4.3 Test Home 3: Two-Family Duplex, Upward Addition and Deep Energy Retrofit 20
4.3.1 Project Overview 20
4.3.2 Deep Energy Retrofit Project Plan 21
4.3.3 Enclosure System 21
4.3.4 Construction 23
4.3.5 Design Challenge: Whether To Include or Exclude the Basement 24
4.4 Test Home 4: Cape, Basement Renovation Turned Comprehensive Deep Energy Retrofit26
4.4.1 Project Overview 26
4.4.2 Deep Energy Retrofit Project Plan 27
4.4.3 Enclosure System 27
4.4.4 Construction 29
4.4.5 Design Challenge: Airtightness of the Enclosure 29
4.5 Test Home 5: Small Colonial, Second Floor Reframing and Deep Energy Retrofit 31
4.5.1 Project Overview 31
4.5.2 Deep Energy Retrofit Project Plan 32
4.5.3 Enclosure System 32
4.5.4 Construction 34
4.5.5 Design Highlight: Hygric Redistribution for Vapor Impermeable Wall Assembly35
5 Performance Assessment of Retrofit Measures 36
5.1 Roof/Attic Strategies 37

5.1.1 Unvented Attic With Closed-Cell Spray Polyurethane Foam 37
5.1.2 Exterior Insulation and Framing Cavity Insulation 41
5.1.3 Vented Attic 44
5.2 Above-Grade Wall Measures 49
5.2.1 Rigid Foam Insulating Sheathing With Air-Permeable Framing Cavity Insulation50
5.2.3 Rigid Foam Insulating Sheathing With Closed-Cell Spray Polyurethane Foam Framing Cavity Insulation 57
5.2.4 Rigid Foam Insulating Sheathing Applied as Successor Retrofit to Roof and Wall Retrofit 60
5.3 Window Measures 61
5.3.1 Window Installed Proud of Drainage Plane....62
5.3.2 Window Aligned With Drainage Plane 65
5.4 Foundation Wall Measures 68
5.4.1 Closed-Cell Spray Polyurethane Foam Applied to Foundation Wall....68
5.5 Floor Over Basement 70
5.6 Basement Floor Measures....72
5.6.1 Insulation Above Existing Slab 72
5.6.2 New Insulated Concrete Slab....74
5.7 Uninsulated Basement Floor Slab....76
6 Enclosure Retrofit Strategy Costs 79
7 Test Home Performance Assessment 81
7.1 Air Leakage Testing....81
7.2 BEopt Energy Modeling 84
7.2.1 Energy Modeling for Test Home 1, the 1960s Garrison Colonial....86
7.2.2 Energy Modeling for Test Home 2, 1890s Three-Story Victorian 89
7.2.3 Energy Modeling for Test Home 3, 1900s Duplex....91
7.1.4 Energy Modeling for Test Home 4, 1930s Cape 94
7.1.5 Energy Modeling Test Home 5, 1900s Small Colonial 96
8 Recommendations for Future Work 98
9 Conclusions 99
10 Appendices 100
10.1 Appendix A: Deep Energy Retrofit Multifamily and Single-family Pilot Guidelines .100
10.2 Appendix B: National Grid Deep Energy Retrofit Application Part (B), Excel component....110
10.3 Appendix C: [Test Home 3] First Application Review 126
10.4 Appendix D: Case Study, National Grid Deep Energy Retrofit Pilot Program, 1960s Garrison Colonial Comprehensive Retrofit (Test Home 1)....131
10.5 Appendix E: Case Study, National Grid Deep Energy Retrofit Pilot Program, Retrofit and Addition to 1900s Duplex (Test Home 3)....137
10.6 Appendix F: Case Study, National Grid Deep Energy Retrofit Pilot Program, Cape Basement Renovation Turned Comprehensive DER (Test Home 4) 143
10.7 Appendix G: Case Study, National Grid Deep Energy Retrofit Pilot Program, Second Floor Reframing Comprehensive Retrofit of 19th Century Small Colonial (Test Home 5) 149
References 155

List of Figures

Figure 1. Vintage of U.S. housing units, subdivided by census region ... 3
Simulated Moisture Performance ... 4
Figure 2. Retrofitted wall with 0.5% of incident rain penetration, north and south exposures, with exterior temperature for reference (seasonal patterns) ... 4
Figure 3. Pre-retrofit Garrison Colonial located in Milton, Massachusetts ... 8
Figure 4. View inside framing cavity forced-air duct return at Test Home 1 ... 9
Figure 5. Schematic wall section for Test Home 1 enclosure retrofit strategy ... 11
Figure 6. Test home 1 retrofit roof assembly ... 12
Figure 7. Left: Window opening at Test Home 1 with existing window still in place. Note exterior insulation and house wrap airflow control layers installed to exterior; Right: Basement slab perimeter insulation at Test Home 1 ... 13
Figure 8. Pre-retrofit Victorian located in Brookline, Massachusetts ... 15
Figure 9. Schematic wall section for Test Home 2 enclosure retrofit strategy ... 17
Figure 10. Left: Initial two-part ccSPF application to connect wall insulation to previous work; Right: subsequent two-part ccSPF providing more robust connection. ... 19
Figure 11. Pre-retrofit duplex located in Arlington, Massachusetts ... 20
Figure 12. Schematic wall section for Test Home 3 enclosure retrofit strategy ... 22
Figure 13. Left: Attached roof cut back to allow application of ccSPF at roof-wall interface; Right: Window flashing problems associated with installation of windows over strapping. ... 24
Figure 14. Left: ccSPF providing transition of airflow control at new roof to new wall transition; Right: Rigid exterior insulation notched around projecting rafters. ... 24
Figure 15. Pre-retrofit Cape located in Newton, Massachusetts ... 26
Figure 16. Schematic wall section for Test Home 4 enclosure retrofit strategy ... 28
Figure 17. Pre-retrofit Colonial in Lancaster, Massachusetts ... 31
Figure 18. Schematic wall section for Test Home 5 enclosure retrofit strategy ... 33
Figure 19. Left: ccSPF insulated roof at Test Home 1; Right: partial ccSPF insulation in a section of roof framing at Test Home 3. Note that Test Home 1 remained unoccupied except for active construction for a period of several months after application of ccSPF. During active construction, doors and windows remained open. During the period after application of ccSPF in Test Home 3, the application floor and floor below were active construction zones with doors and windows typically open during daytime hours. ... 38
Figure 20. Left: Short eave overhang and limited separation between window head and soffit prior to retrofit at Test Home 1; Right: Roof overhang detail at Test Home 1 showing position of soffit and window head relative to pre-retrofit conditions. ... 39
Figure 21. Airflow channels between double roof rafters at Test Home 1 ... 39
Figure 22. Left: Rafter bay continuous to soffit area at Test Home 3; Right: SPF insulation in rafter bay connecting to top of wall at Test Home 3 ... 40
Figure 23. Airflow channels between double roof rafters at Test Home 1 ... 40
Figure 24. Left: SPF insulation being installed in roof framing cavities at Test Home 3. Note how roof framing precludes insulation for an appreciable portion of the roof area and that the strapping depth does not allow much depth for insulation over the framing; Right: roof rafters fully embedded in spray foam insulation at Test Home 1. ... 41
Figure 25. Roof-wall interface in a chain saw retrofit configuration. Note how the airflow control and thermal control layers are uninterrupted over the roof-to-wall transition. Location of the original overhang prior to removal is indicated by the dashed red outline. ... 42
Figure 26. Left and Right: Test Home 4 prior to implementation of the DER project. Note the generous main roof overhangs and the smaller overhangs of the dormer roofs. ... 43
Figure 27: Left and Right: Test Home 4 after implementation of the DER project. Note the generous main roof overhangs and the overhangs of the dormer roofs that are slightly larger than they had been prior to the DER. ... 43
Figure 28. Left: Plywood gable rake support at Test Home 4. Right: fascia and soffit of main roof framed over insulation layers and attached to 2 × 4 purlins. ... 44
Figure 29. ccSPF airflow control layer in vented attic at Test Home 5 ... 45

Figure 30. Ventilation duct initially located above airflow control layer in vented attic at Test Home 5 46
Figure 31. House wrap airflow control transition at top of wall at Test Home 5 47
Figure 32. Example of airflow control transition at gable end of vented attic. The house wrap is taped to the wall sheathing at the level of the attic floor. Note that it is not necessary to tape the house wrap above this level. 48
Figure 33. Loose-blown insulation in vented attic at Test Home 5........ 49
Figure 34: Left: Rigid insulation blocking between roof trusses at Test Home 5 exterior; Right: Rigid insulation blocking between roof trusses at Test Home 5 interior 49
Figure 35. Wall-roof interface at Test Home 4 showing two common flashing errors: 1) step flashing is not located at plane of water control, and 2) drip edge of lower roof creates a condition where water may be directed in behind the drainage plane. Note that both of these conditions were corrected at this test home. 51
Figure 36. Nonterminated flashing membrane presents risk of collecting water 52
Figure 37. Left: Sheathing tape with water accumulated beneath wrinkle. Right: Fastener for insulating sheathing disrupting water control. 52
Figure 38. Left: Exterior insulation installed prior to sealing house wrap to base of wall for airflow control transition; Right: Portions of exterior insulation must be removed to allow air sealing of the house wrap at these pipe penetrations. 53
Figure 39. Left: Porch roof support beam with trim and porch ceiling void airflow control where they connect to the wall and penetrate exterior insulation; Right: A porch roof return that connects to the existing wall challenges continuity of airflow control. 53
Figure 40. Left: ccSPF airflow control around porch roof framing at Test Home 3; Right: Worker applying rigid foam and foam sealant between attached porch roof and porch ceiling, Test Home 4 54
Figure 41. Porch deck, ceiling, and roof cut away from wall to allow continuous air, thermal, and water control, Test Home 2........ 55
Figure 42. Foil-faced cavity insulation representing a second vapor retarder, Test Home 1 56
Figure 43. House wrap airflow control layer sealed to window extension box at Test Home 5 58
Figure 44. Left: Airflow control transition at existing brick foundation wall, Test Home 5; Right: Airflow control transition at new CMU foundation wall section, Test Home 5 58
Figure 45. Brake-formed metal protection for exterior foam insulation at Test Home 5........ 60
Figure 46. Left: Front of building showing overhang during retrofit work, Test Home 2; Right: connection between new work and previous work at wall-overhang interface, Test Home 2 ... 61
Figure 47. Left: Top plate at insulated ceiling showing new rigid insulation to other side of top plate, Test Home 2; Right: Top plate between previously retrofit ceiling and newly retrofit wall, Test Home 2 61
Figure 48. Scoop flashing at head of window installed over strapping at Test Home 3. Arrows indicate where water would be able to pass behind the flashing. 63
Figure 49. Wrinkles in flashing membrane wrapped over strapping and back to drainage plane. Note how this window head flashing requires flashing of its own. 63
Figure 50. Installation of the window over strapping provides a generous drainage gap for the sill pan flashing........ 64
Figure 51. Window installed with flanges aligned with drainage plane at Test Home 2. Note strapping run up to, but not over, bottom flange of window. A single piece of strapping at the side of the window is sufficient to support both trim and cladding attachment. 66
Figure 52. Window sealed to membrane at inside perimeter of window at Test Home 2. Note how the window frame is slightly larger than the finished opening. 67
Figure 53. Thermal break between wood stud wall and concrete underpinning wall at Test Home 468
Figure 54. Thermal break between wood stud wall and existing concrete slab at Test Home 1 70
Figure 55. Left: Structural beam exposed to basement; Right: Framed wall sill exposed to basement 72
Figure 56. Basement floor insulation at Test Home 1 installed near end of project to prevent damage to insulation........ 74
Figure 57. New basement slab and structural support at Test Home 5 75
Figure 58. Equipment platform and shelving in basement of Test Home 2........ 76

Figure 59. Pre- and post-retrofit CFM50 measurements 81
Figure 60. Pre- and post-retrofit ACH50 measurements 82
Figure 61. Post-DER guarded blower door testing at Test Home 3 84
Figure 62. Predicted annual source energy use reduction relative to pre-retrofit condition 85
Figure 63. Incremental project cost for energy performance measures relative to predicted source energy use reduction 86
Figure 64. Test Home 1 BEopt results for as-built condition and alternatives 87
Figure 65. Vinyl siding and deteriorated wood cladding at Test Home 2 89
Figure 66. Test Home 2 BEopt results for as-built condition and alternatives 91
Figure 67. Test Home 3 BEopt results for as-built condition and alternatives 92
Figure 68. Test Home 4 BEopt results for as-built condition and alternatives 94
Figure 69. Test Home 5 BEopt results for as-built condition and alternatives 96

Unless otherwise noted, all figures were created by BSC.

List of Tables

Table 1. Enclosure Strategies Employed in the Pilot Test Homes 37
Table 2. DER Test Home Enclosure Measures and Cost 80
Table 3. Blower Door Testing Summary for DER Test Homes 82
Table 4. Test Home 3 Diagnostic Blower Door Testing Summary 83
Table 5. Project Costs and Predicted Source Energy Savings 85
Table 6. Test Home 1 BEopt Inputs 88
Table 7. Test Home 2 BEopt Inputs 90
Table 8. Test Home 3 BEopt Inputs 93
Table 9. Test Home 4 BEopt Inputs 95
Table 10. Test Home 5 BEopt Inputs 97

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Definitions

ACH	Air Changes per Hour
ACH50	Air Changes per Hour at 50 Pascal Test Pressure
BSC	Building Science Corporation. More information about BSC can be found at www.buildingscience.com
CFM	Cubic Feet per Minute
CFM50	Cubic Feet per Minute at 50 Pascal Test Pressure
ccSPF	Closed-Cell Spray Polyurethane Foam
DER	Deep Energy Retrofit
DHW	Domestic Hot Water
HRV	Heat Recovery Ventilator
HVAC	Heat, Ventilating, and Air Conditioning
o.c.	On Center
ocSPF	Open-Cell Spray Polyurethane Foam
OSB	Oriented Strand Board
PV	Photovoltaic
ft^2	Square Foot, Square Feet
WRT	With Respect To
XPS	Extruded Polystyrene

Executive Summary

Through discussion of five case studies (test homes), this project evaluates strategies to elevate the performance of existing homes to a level commensurate with best-in-class implementation of high performance new construction homes. The test homes featured in this research activity participated in Deep Energy Retrofit (DER) Pilot Program sponsored by the electric and gas utility National Grid in Massachusetts and Rhode Island. Retrofit strategies are evaluated for impact on durability and indoor air quality in addition to energy performance.

The National Grid DER Pilot program was developed as a response to the Massachusetts Governor's Zero Energy Task Force. The National Grid program recognized that pursuit of energy efficiency without regard for impact on durability and indoor air quality is potentially dangerous and risks detrimental impacts to specific customers as well as to the public perception of energy efficiency generally. BSC contributed significantly to the design of the National Grid pilot program, provided review of retrofit plans for individual projects, provided technical support to projects, reviewed implementation of measures, and conducted performance testing of completed projects.

Since the launch of the pilot in 2009, 10 buildings representing 14 housing units have been retrofit through the National Grid DER Pilot program. At the time of writing, retrofit work is ongoing at 17 more projects representing 26 units of housing. Another five prospective DER projects representing 10 housing units of housing are in the application process. The pilot provides lessons about a variety of approaches to high performance retrofit.

The aim of the research project is to develop guidance and identify resources to facilitate successful and cost-effective implementation of advanced retrofit measures. The project will identify risk factors endemic to advanced retrofit in the context of the general building type, configuration and vintage encountered in the National Grid DER Pilot. Information gained in this research project will form the foundation for development of technical guidance and program criteria for an expanded utility-sponsored program aimed at capturing the opportunities represented by common renovation activities such as roof replacement, window replacement, residing, basement remediation, and remodeling.

Results for the test homes are based on observation and performance testing of recently completed or in process projects. Additional observation would be needed to fully gauge long-term energy performance, durability, and occupant comfort. Recommended future work includes development of measure guidelines, information resources to explain recurring technical challenges and monitoring of utility bills. Environmental data monitoring could also be used to evaluate any reported thermal comfort or heating, ventilation, and air conditioning distribution issues that may arise as well as to quantify nonenergy benefits.

1 Introduction

There are a lot of existing homes.

Serious efforts to reduce energy consumption within the residential sector will need to address energy use of existing homes. The most important end use in the residential sector is space conditioning. Significantly reducing the space conditioning load of the building requires radical changes to the energy flows through the building enclosure. Changes to energy flows across the building enclosure change the moisture and airflow dynamics within the structure. And there's where the trouble starts.

Aggressive energy conservation measures risk detrimental impacts to buildings and occupants if these measures are implemented without accounting for the changing dynamics. Conversely, measures to improve building durability and provision of comfort and indoor air quality – when done right – will likely entail benefits to energy performance.

Test homes in this project are participants in a utility-sponsored deep energy retrofit (DER) pilot program. The program is sponsored by the electric and gas utility National Grid and is open to residential electric and or gas customers in National Grid's Massachusetts service territories and to residential electric customers in National Grid's Rhode Island service territories. The pilot program offers financial incentives and significant technical support to National Grid homeowners or building owners who complete a multipart application process and commit to significant energy saving, combustion safety, durability, and indoor air quality measures. The National Grid incentive program is implemented as a research pilot intended to develop and refine guidance for DER measures so that a subsequent incentive program could be established to capture opportunities represented by common renovation activities such as roof replacement, window replacement, residing, basement remediation, and remodeling. The program is described in detail in the document "Deep Energy Retrofit Multifamily and Single-family Pilot Guidelines" (see Appendix A).

When National Grid set out to launch a DER pilot program, it engaged Building Science Corporation (BSC) as a partner to help ensure that radical energy performance improvements also represented technically sound practices. Resources brought by the utility-sponsored program allowed a number of customers to pursue extensive retrofit of homes toward the goal of achieving advanced levels of performance. BSC provided the technical guidance to ensure that energy performance measures in these projects are robust and that project teams understand and adequately manage combustion safety, moisture, and air quality risks (see Appendix C for an example of BSC review comments to a prospective project first-round application to the program).

Most of the projects participating in the DER pilot involve comprehensive retrofits that treat the entire thermal enclosure and mechanical systems. Some projects participating in the DER pilot are "partial" retrofits that elevate the performance of a limited number of enclosure components (e.g., above-grade walls and windows or roof only) to DER levels. The structures are all wood framed with full basements, as is typical for older homes in the region.

The projects participating in the National Grid DER Pilot Program represent a healthy variety of major strategies and an even richer variety of challenges faced. This report highlights the lessons learned from five of these DER projects.

2 National Grid Deep Energy Retrofit Pilot

2.1 The Case for Retrofit

A significant number of existing houses were constructed prior to the enactment of building energy efficiency codes and without the benefit of energy efficiency measures employed in more recent construction. Data from the U.S. Census show that older existing homes (built more than 50 years ago) are concentrated in the Northeast and Midwest (see Figure 1). The regions also represent heating-dominated climates. Heating end use represents a significant portion of primary energy used in the residential sector.

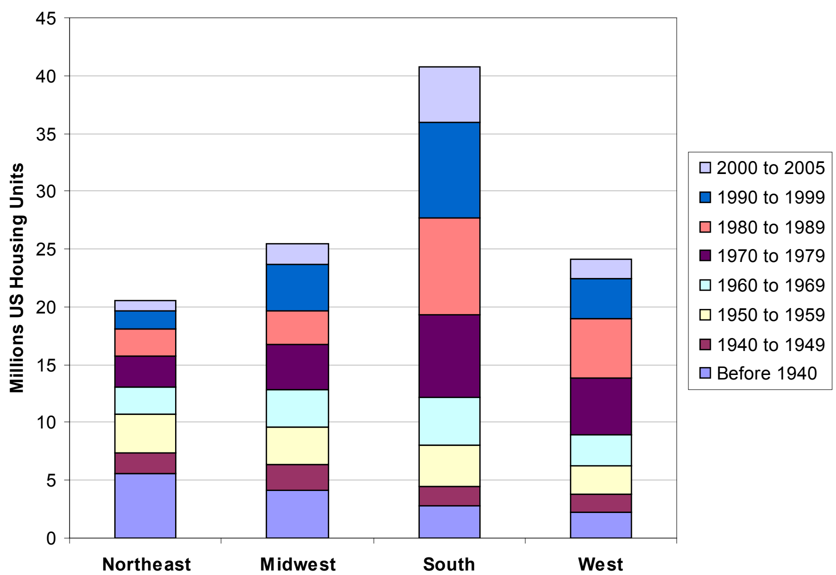

Figure 1. Vintage of U.S. housing units, subdivided by census region

(EIA 2005)

Numerous programs plying public and utility resources have targeted typically modest performance improvements through measures generally grouped into the category of weatherization. Although the energy savings benefits of weatherization applied on a large scale are substantial, what typical weatherization measures can achieve for an individual home is fundamentally limited. For example, weatherization measures are unlikely to elevate the performance of an older home to that of a home built to current code levels of performance. It is also not reasonable to expect that weatherization measures can improve the level of performance of a home to that of advanced performance new homes. Also, new homes built to merely code levels of performance a decade or more into the future from now will likely compare favorably to what would today be considered advanced performance homes.

BSC has conducted previous research projects which demonstrated the application of DER techniques to existing wood-frame homes (BSC February and April 2010, Pettit 2009). Each of these retrofit projects employed thick exterior insulation over existing walls and roofs to provide a super-insulated above-grade enclosure.

Ueno (2010) pointed out inherent advantages of the exterior insulation approach to super-insulation retrofit for energy performance and building durability. However, he also noted that exterior insulation can reduce the ability of existing wall systems to dry (see Figure 2). Therefore, he concludes, "if an exterior foam retrofit is done, it is vital to ensure that windows and mechanical penetrations are flashed properly."

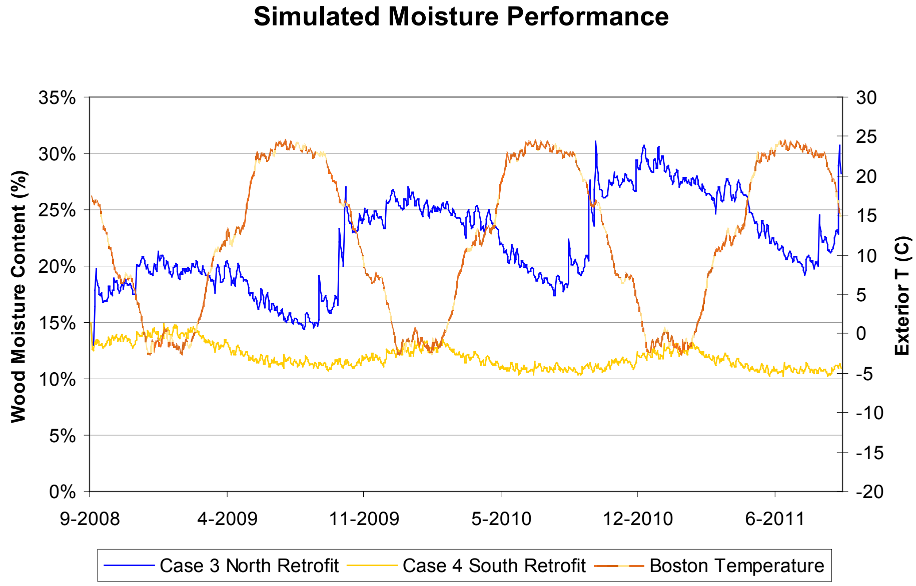

Figure 2. Retrofitted wall with 0.5% of incident rain penetration, north and south exposures, with exterior temperature for reference (seasonal patterns)

(Ueno 2010)

BSC has found that proper implementation of water management details has not gained a ubiquitous presence in the construction industry – commercial or residential, new construction or retrofit. In retrofit situations, the implementation of effective water management details is often more complicated than it is in new construction.

Whether out of patriotic zeal, concern for the global environment, quest for comfort, or fiscal frugality, homeowners across the country can be expected to look for ways to significantly improve the energy performance of their homes in the coming years. In retrofit situations, where the subject building is, presumably, a functioning and serviceable structure, it is especially imperative that the well-intentioned measures to reduce energy use do not have unfortunate unintended consequences. This research project identifies important risk management measures pertinent to advanced retrofit strategies in the context of a building type that is significant to national energy use.

2.2 National Grid Pilot Background

The National Grid DER Pilot Program was established to promote robust performance and ensure, as far as possible, that energy efficiency measures would also support durability and air quality. This is deemed necessary to avoid detrimental impacts to participating customers and to protect positive public perception of advance retrofit activity.

The program requirements for the National Grid pilot address combustion safety, ventilation and hazardous material mitigation. The program requirements also state that "The project plan and implementation must demonstrate sound building physics as it relates to moisture management of the enclosure and effectiveness of the mechanical system configuration." This provides the program with leverage to require, for example, proper flashing and effective routing of ventilation distribution.

National Grid's *Deep Energy Retrofit Multifamily and Single-family Pilot Guidelines* indicate that program's overall energy performance goal for participating houses is a 50% reduction in total energy use relative to a home built to standard code levels of performance. The DER Pilot Guidelines outline specific performance criteria deemed necessary to support the overall performance goal. The performance targets for opaque R value, fenestration, and airtightness are summarized as follows (National Grid 2011):

> 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.[1]
>
> 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.

The program offers significant financial incentives. Incentives are intended to offset a portion of net incremental costs specifically related to energy performance measures. Base incentive limits for one- and two-family dwellings are indexed to conditioned floor area of the building and range from $35,000 to $42,000 for detached single-family residences and $50,000 to $60,000 for duplexes. The incentive offered to multifamily buildings of three units or more varies according to the number of units in the building. The base incentive for the three-family building is $72,000 and for a building with 10 or more units, the base program incentive is $106,000.

2.3 Future Directions

As the pilot designation would imply, the pilot program is intended to lay the groundwork for a full scale utility-sponsored efficiency program. The likely focus of a full scale program would be specific components retrofit rather than comprehensive DER. A desired outcome of the pilot is measures guidance and guidance for packages of high performance retrofit measures. An efficiency program supporting high performance retrofit of specific building components has the potential to reach a large population through integration with current distribution channels of products and services for items such as roofing, windows, siding, and basement remodeling.

---

[1] The correlation of this air leakage target to figures of air changes per hour at 50 Pascals (ACH50), or CFM/ft^2 of conditioned floor area depends on the geometry of a particular building or enclosure. For the test homes in this study, 0.1 CFM50/ ft^2 of thermal enclosure corresponds to 1.2–1.7 ACH50 and 0.16–0.24 CFM50/ft^2 conditioned floor area.

3 Data Sources and Methods

The research project employs three principal means of collecting information about the test home retrofit projects:

- Program application materials
- On-site observation
- On-site performance testing and measurement.

Ancillary to these is communication and exchange of information with participants in the project.

3.1 Deep Energy Retrofit Pilot Program Application Materials

The program application forms are designed to collect relevant information about the proposed retrofit project (see Appendix B). This information includes identification of roles and contact information for the project team; reasons for the planned work; information about the existing structure and its use; past energy use; existing performance concerns; areas, existing R-value and proposed R-value for enclosure components; description of proposed measures; and estimated costs for proposed measures.

In addition to the application forms, prospective projects are also required to submit project drawings, product cut sheets, and heating, ventilation, and air conditioning (HVAC) sizing calculations.

3.2 On-Site Observation

Field visits arranged for projects participating in the National Grid DER Pilot are generally targeted to provide technical guidance to the project and to verify implementation of measures eligible for incentives through the program.

- *Pre-work inspection:* Prior to work commencing at the project but after the prospective DER Pilot participant has formally entered the application process, National Grid arranges for BSC to visit the project site. This purpose of this visit is to gather data to supplement data contained in Pilot program applications that describe the pre-retrofit conditions. The visit is also used to identify and report pertinent issues not addressed in the application or project plan, and conditions that render aspects of the proposed project plan inappropriate. BSC typically provides technical guidance about the retrofit plan at these site visits.
- *Verification of completed measures in the DER project plan:* During the course of construction, site visits are scheduled to coincide with completion of groups of measures identified in the DER project plan as incentive payment groups.[2] BSC may conduct inspections at intermediate stages if critical aspects of the project plan such as

[2] National Grid provides base incentives in up to three separate payments. Payment is triggered by verification of implemented measures and proof of payment to the implementing contractor by the customer. During the application process, the customer/applicant designates the eligible measures that will be grouped together in an incentive payment group. All the measures in an incentive payment group must be implemented before the incentive for the group of measures can be dispersed.

implementation of air barrier and drainage measures do not coincide with stages indicated by program incentive grouping. BSC typically provides technical guidance toward implementation of DER measures at these site visits.

- *Final inspection, testing:* Upon completion of the DER project plan, BSC returns to the project site to verify implementation of measures in the DER Project plan. It is at this visit that BSC conducts blower door air leakage testing and, where appropriate, duct leakage testing.

Site visits arranged for various stages of each project allow verification of specific measures and assessment of challenges the project faces relative to continuity of air and thermal control, correct arrangement of flashings and water management features.

3.3 Performance Testing and Measurement

Blower door testing is employed to assess the airtightness performance of the building both before and after the retrofit work. In some cases, pressure diagnostics or guarded blower door testing may be employed to assess leakage across different parts of the enclosure.

4 Subject Homes

4.1 Test Home 1: Garrison Colonial, Comprehensive Deep Energy Retrofit

Figure 3. Pre-retrofit Garrison Colonial located in Milton, Massachusetts

(Credit: Andrew Koh, used with permission)

4.1.1 Project Overview

Building Type, Style: Single-family detached, Garrison Colonial

Era Built: 1960s

Pre-DER Floor Area: 1,600 ft^2, 2,368 ft^2 including basement

The current owner purchased this bank-owned, unoccupied home in 2010 with the intention of conducting significant energy performance improvements prior to occupancy. The National Grid DER Pilot Program provided technical and financial assistance to extend these renovations to the level of a DER.

The retrofit project for this home included a comprehensive enclosure retrofit and new heating, cooling, and ventilation systems. Prior to the retrofit project, the home had fiberglass cavity insulation in the attic floor, exterior framed walls and between wood framing to the interior of the basement foundation walls. The home had a forced-air duct system that employed framing cavities for some of the returns (see Figure 4).

Figure 4. View inside framing cavity forced-air duct return at Test Home 1

Through grants and product donations, the owner was able to supplement the enclosure measures with advanced combination space/water heating, high-efficiency heat recovery ventilation (HRV), a photovoltaic (PV) system, and energy monitoring equipment. The owner is pursuing Thousand Homes Challenge designation.

This test home provides an example of a thoroughly comprehensive retrofit that did not involve major additions or changes to the configuration of the building enclosure.

4.1.2 Deep Energy Retrofit Project Plan

The design for this extensive renovation included super-insulation of the thermal enclosure and reconfiguration of the spaces within the thermal enclosure.

The home already had insulation between wood framing against the concrete foundation walls. However, the insulation was a fibrous insulation with an interior-side vapor barrier. This system did not provide adequate insulation or management of moisture risks. The builder specified closed-cell spray polyurethane foam (ccSPF) insulation for the retrofit of the foundation wall. The existing wood framing was incorporated in the plan and reused, after some height adjustment, as the frame wall to support a gypsum board thermal barrier for the insulation.

The design called for rigid extruded polystyrene (XPS) insulation installed directly over the concrete basement floor. The seams of the rigid insulation are taped and the perimeter is embedded in the spray foam of the wall to create a continuous airflow control for the foundation system.

The project team determined that liquid water was not an adequate risk to merit a drainage system at the basement floor; hence, there is no drainage mat between the rigid insulation placed on top of the slab. Still, a sump pit was cut into the existing slab to provide a location where the homeowner will be able to install a sump pump to remediate liquid water problems should such be experienced at some time in the future.

The design thickens the above-grade walls with a layer of exterior insulation. The existing roof plane was retained in the design as the builder opted to provide insulation to the inside of the roof sheathing.

The builder selected casement windows to replace existing double-hung windows. The intention behind the selection of casement windows was to minimize air leakage through window units.

The mechanical system plan included forced-air heating and cooling distribution and balanced ventilation. The equipment selection for this system as well as the water heating system and the configuration of the attic/roof insulation were dictated by the availability of donated products.

4.1.3 Enclosure System

Figure 5 shows a schematic representation of the retrofit enclosure strategy. It is followed by an outline of the retrofit strategies for major building enclosure elements. Additional images and information about this project are presented in a case study created for this project (see Appendix D).

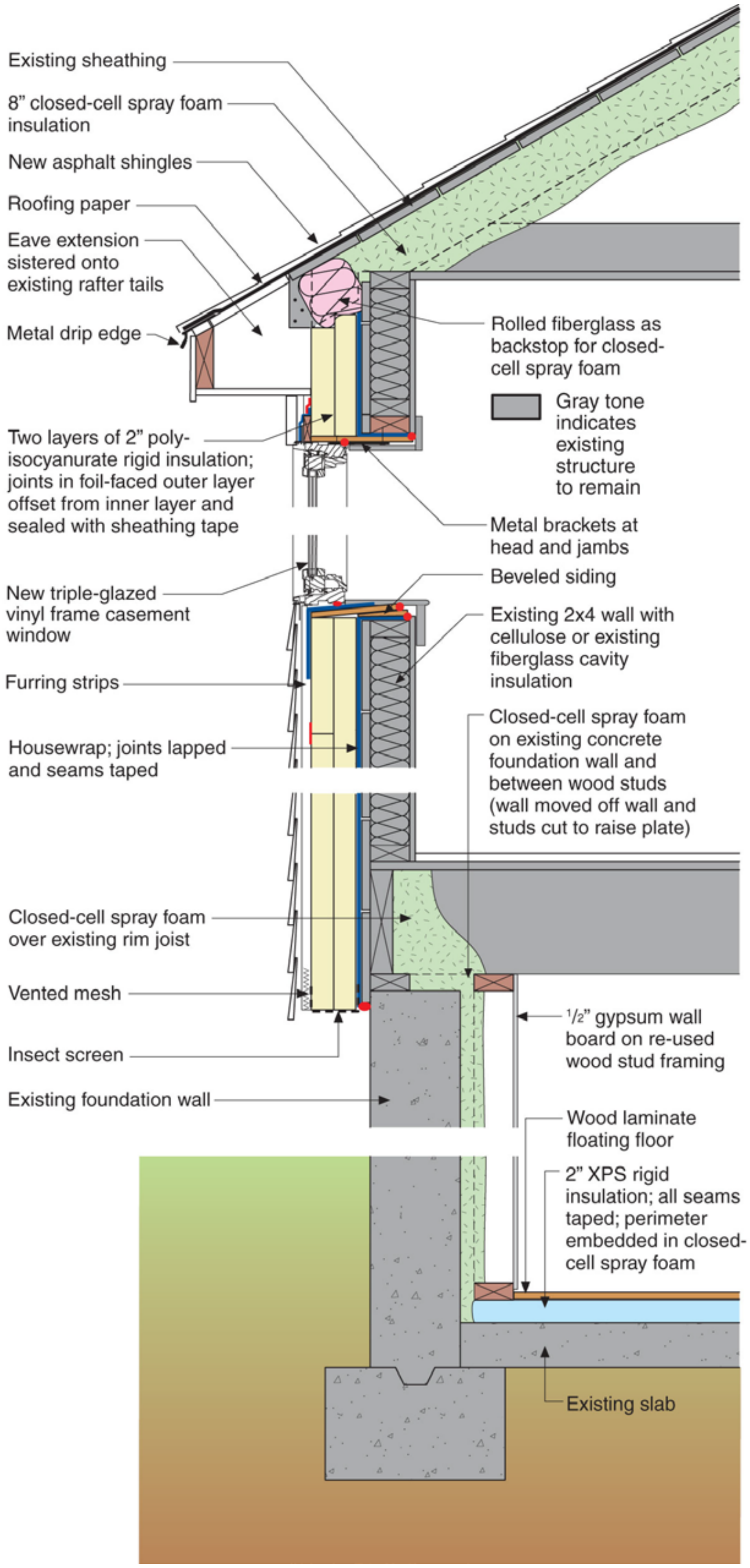

Figure 5. Schematic wall section for Test Home 1 enclosure retrofit strategy

Roof Assembly: R-56 (nominal) unvented roof: New asphalt shingle roof and underlayment over existing roof sheathing; rolled fiberglass batt as eave backstop for 8 in. of ccSPF between and over the existing 2 × 6 rafters (see Figure 6).

Figure 6. Test home 1 retrofit roof assembly

Wall Assembly: R-38 (nominal): Fiber cement cladding installed over 1 × 3 wood furring strips; two layers of 2-in. polyisocyanurate exterior insulating sheathing; joints of foil-faced outer layer offset and taped; house wrap with joints lapped and seams taped applied over existing wall sheathing; existing 2 × 4 wall cavities with cellulose or existing fiberglass insulation.

Window Specifications: New EcoShield triple-pane, low-E, argon-filled, vinyl-framed casement windows; U = 0.21, SHGC = 0.18.

Airflow Control: House wrap with joints lapped and seams taped over existing sheathing and the taped outer layer of insulating sheathing on the wall provide the airflow control layers for the field of the walls; ccSPF provides the air control layer for the roof and for the foundation wall; the transition from the air control for the foundation wall to the exterior wall air control is through the top of the foundation wall and mudsill relying on a tight joint between the exterior sheathing and the mudsill and then the ccSPF over the foundation wall extending up over the mudsill; the transition between the air control layers for the exterior wall and for the roof is through sealed connections of each with the board sheathing at the top of the wall.

Foundation Assembly: Conditioned basement with the following major enclosure components:

Foundation Wall: Existing cast concrete with ccSPF applied to existing foundation walls and partially embedding repositioned wood frame wall.

Basement slab: Existing cast concrete slab insulated to topside with 2-in. XPS rigid insulation. Joints of rigid insulation taped and perimeter embedded in wall ccSPF. New sump pit added through existing slab. Floating wood laminate floor installed over rigid insulation.

4.1.4 Construction

During construction, the availability of donations changed a few specific aspects of the plan. The project team was able to adapt to these changes, although the initial design of the project may have been slightly different had the availability of the products and equipment been known prior to construction.

The builder installed the house wrap and exterior wall insulation before installing the new windows in the existing openings. This sequence complicates the transition of the house wrap airflow control at the window. In this project, the exterior face of insulating sheathing was also detailed as an airflow control layer and may have had a more dominant airflow control role.

To protect the basement slab insulation from construction abuse, the builder installed just a 1 ft-wide strip of insulation around the perimeter before reinstallation of the wood stud wall and application of ccSPF at the foundation wall (see Figure 7). This allowed for a continuous thermal and capillary break beneath the wood framing. The sequence also allowed the ccSPF contractor to embed the floor insulation perimeter in ccSPF for transition of airflow control. When the rest of the basement slab insulation was installed, it was a simple matter to seal it to the perimeter starter strip.

Figure 7. Left: Window opening at Test Home 1 with existing window still in place. Note exterior insulation and house wrap airflow control layers installed to exterior; Right: Basement slab perimeter insulation at Test Home 1.

4.1.5 Design Challenge: Retrofit Roof Strategy

For various reasons, the builder included a vented roof with air sealing and insulation at the attic floor in the DER design. To accommodate the additional wall thickness of 4-in. exterior foam and furring strips, the roof eaves were extended. Then the roof was reshingled.

As is shown in the photograph of pre-retrofit conditions, the second floor window heads were already very close to the eave soffit and the gable end overhangs were weak. Extending the eave overhang along the slope of the existing roof meant that the window heads actually had to be lowered to allow for some window trim above the second floor windows.

Later in the project, when the homeowner decided to pursue an unvented roof with the attic inside the conditioned space, the only practical option was ccSPF installed to the underside of the roof deck.

In retrospect, the design decision not to insulate over the roof represents a missed opportunity: exterior insulation and overclad in combination with a chain saw approach (see discussion of the chain saw approach in Section 5.1) would have allowed the soffit to stay at same height as existing or even be reconstructed at a higher position. An exterior insulation and overclad approach would also have allowed more insulation over the top plate of the wall and a more robust airflow control transition than is possible with the configuration implemented.

4.2 Test Home 2: Three-Story Victorian, Partial Deep Energy Retrofit

Figure 8. Pre-retrofit Victorian located in Brookline, Massachusetts

(Credit: Carin Aquiline, used with permission)

4.2.1 Project Overview

Building Type, Style: Single-family detached, Victorian

Era Built: 1890s

Pre-DER Floor Area: 2,284 ft^2 not including insulated basement

The owners of this single-family Victorian had previously gone through a retrofit in the spring of 2009. The upgrades included adding ccSPF insulation to the underside of the replacement roof as well as to the existing fieldstone foundation walls. Work had also been done to modernize the radiant hydronic heating distribution system which was originally steam. With the financial and technical support offered through National Grid's DER Pilot Program, the owners decided to continue making the improvements to the house and incorporate a DER to the remaining parts of the house.

The current retrofit project for this home includes addition of exterior wall insulation and cladding, replacement of windows with high performance R-5 triple-pane windows, air sealing to connect the new and previous retrofit measures, replacement of heating and water heating equipment, provision of mechanical ventilation and, addition of a mechanical cooling (pending decision from the owners).

This test home provides an example of a staged approach turned comprehensive retrofit. New retrofit measures are carefully thought out and integrated with the measures implemented previously. This staged approach may be a more realistically accessible path to broad adoption of DER. The nature of the retrofit work in this current phase of the larger project imposed minimal disruption to the interior.

4.2.2 Deep Energy Retrofit Project Plan

To build upon the direction set by previous work, the current enclosure retrofit project for this test home focuses on the above-grade walls and windows. The existing composite of vinyl siding and original wood siding were showing signs of deterioration. The DER plan for this test home involved stripping the above-grade walls to the sheathing, repairing sheathing as needed, then establishing control layers to the exterior of the sheathing.

To provide generous protection for the walls and to maintain the refined period aesthetics of the home, the plan also involved extending the roof eaves. The roof eaves had not been extended as part of the previous project in which the roof was retrofit.

The project team and owners deliberated for some time about whether to replace the windows. The existing windows had been installed relatively recently (within the past five years) and offered reasonable thermal performance. Ultimately the owners decided to replace the windows to provide for better integration with water management and to capture the incremental performance benefits.

4.2.3 Enclosure System

Figure 9 shows a schematic representation of the retrofit enclosure strategy. It is followed by an outline of the retrofit strategies for major building enclosure elements.

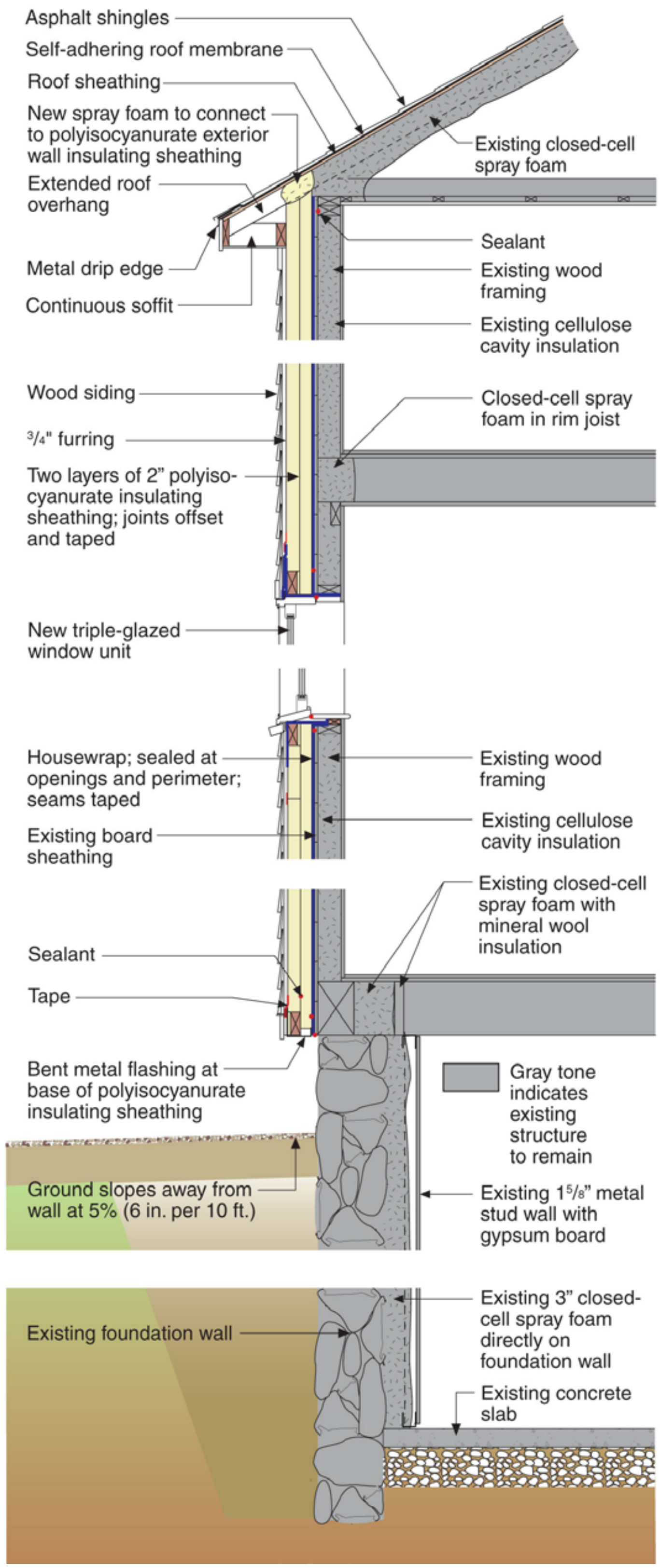

Figure 9. Schematic wall section for Test Home 2 enclosure retrofit strategy

Roof Assembly: [Retrofit measures completed in a previous enclosure retrofit] R-48 (nominal) unvented roof; 8 in. of ccSPF between the rafters; ½-in. plywood; fully adhered membrane; asphalt shingles.

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

Window Specifications: New Paradigm triple-glazed, krypton/argon blend gas, low-E vinyl windows, U = 0.22, SHGC = 0.20; windows installed in alignment with drainage plane.

Air Sealing: Sealant applied between house wrap 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; two-part foam applied at the top of insulating sheathing to connect to ccSPF of previous work.

Foundation Assembly: Conditioned basement, not fully insulated:

Foundation Wall: [Retrofit measures completed in a previous enclosure retrofit] 3 in. ccSPF applied directly onto the existing field stone foundation walls, gypsum wallboard thermal barrier on 1⅝-in. metal stud partially embedded in ccSPF; 7 in. ccSPF at sill beam with a layer of rigid mineral wool insulation.

Basement Floor Slab: Slab remained uninsulated.

4.2.4 Construction

The contractor demonstrated an innovative approach to installing the windows in the drainage plane. Wood blocking let in to exterior layer of insulation is covered by self-adhered flashing that wraps into the opening over the wood blocking and inner layer of insulating sheathing. Because the insulated sheathing used is 2 in. thick, the blocking is padded to the inside with ½ in. of rigid foam insulation. The blocking is fastened to the wall framing through the inner layer of exterior insulating sheathing. Positive drainage of the window sill pan flashing is established by cutting the foam at the bottom of the window to provide a slope. With the opening prepared, the window is installed and flashed as per typical practice with fasteners into the 2x blocking through the nailing flanges.

This project demonstrated robust means of maintaining continuity of the water, air and thermal control at attached porch roof and porch deck connections by temporarily supporting the structures, cutting them back from the wall, installing the air, water and thermal control layers, then re-attaching the structures over these layers.

The contractor for this project had completed several previous DER projects and demonstrated acumen in implementing control function transitions at the bases of wall and window openings, for example.

4.2.5 Design Challenge: Connecting the Control Functions

This project presented interesting challenges of connecting the control functions of an exterior wall retrofit system to previous retrofit work. At the front of the building is an overhanging floor where the previous retrofit had applied ccSPF. The exterior insulating sheathing added as part of the current retrofit was applied to the face of the wall and continuous through the location where the porch roof had been cut away. As seen in Figure 10, the two-part kit foam does not appear to have successfully connected the new work to the previous work on the first attempt. The builder reports that a second application of two-part foam was needed to provide robust connections.

Figure 10. Left: Initial two-part ccSPF application to connect wall insulation to previous work; Right: subsequent two-part ccSPF providing more robust connection.

4.3 Test Home 3: Two-Family Duplex, Upward Addition and Deep Energy Retrofit

Figure 11. Pre-retrofit duplex located in Arlington, Massachusetts

4.3.1 Project Overview

Building Type, Style:	Two-family over-under duplex
Era Built:	Early 1900s
Pre-DER Floor Area:	2112 ft^2 excluding basement and attic

The project for this owner-occupied two-family residence started with the idea of enlarging the upper unit to accommodate a growing family and renovating the lower floor unit for the mother of one of the owners. With support of the National Grid DER Pilot program, the owners were able to realize these objectives while dramatically reducing energy consumption.

The project involved removing the roof and adding a full third floor. Exterior insulation was added to the existing walls as well as the newly constructed walls. Windows were replaced throughout. The renovated apartments received new heating systems with new distribution, new water heating systems, and HRV systems. The interior of the building was gutted during the course of the renovation. The project was staged such that the first floor apartment interior work and exterior insulation was completed first; then the family moved into the lower unit while work progressed on the upper floors.

This project provides an example of a major addition and renovation that incorporated super insulation and other higher performance enclosure and mechanical system measures. It also provides an example of the difficulties in achieving robust air and thermal control at an existing basement ceiling.

4.3.2 Deep Energy Retrofit Project Plan

To accommodate the desired increase in space, the design called for demolition of the roof and half-story to make way for a new third floor and roof to be framed on top of the second floor. The design for the retrofit of the existing enclosure as well as the new structure is intended to provide a high level of thermal performance.

Initially the design called for a vented roof with deep layers of cellulose insulation on a flat top-floor ceiling and vented cathedralized ceilings. The builder then determined that an unvented roof assembly, with insulation to the interior of the roof deck, would be more feasible.

For the exterior walls, the design provided a thick layer of exterior insulation over house wrap on the retrofit walls and over a Zip System wall at the third floor addition. Open-cell spray polyurethane foam (ocSPF) was specified for insulation and airflow control in the wall cavities of the first floor apartment unit. Wall cavities of the upper apartment unit were insulated with fiberglass batt insulation.

Where acceptable to the client, the builder selected casement windows with the intention of reducing air leakage through window units.

Against the recommendation of BSC, this project decided to exclude the partially finished basement from the thermal enclosure. With the basement excluded from the thermal enclosure, robust airflow control would be needed at the floor over the basement as well as at the stair access from each apartment to the basement. This configuration also placed the air handler for the first floor apartment and some of the ductwork in an ostensibly unconditioned space. The initial design for the floor over the basement was to apply a flash coat of ccSPF to the underside of the subfloor, a continuous layer of taped foil-faced rigid insulation to the underside of the floor framing, and a dense-packed cellulose cavity fill. For cost reasons, the ccSPF was limited to application of canned foam as a sealant at penetrations through the subfloor and at the perimeter of and penetrations through the rigid insulation layer. The builder used ocSPF in the walls of the basement access stairs to isolate these from the apartments

4.3.3 Enclosure System

Figure 12 shows a schematic representation of the retrofit enclosure strategy. It is followed by an outline of the retrofit strategies for major building enclosure elements. Additional images and information about this project are presented in a case study created for this project (see Appendix E).

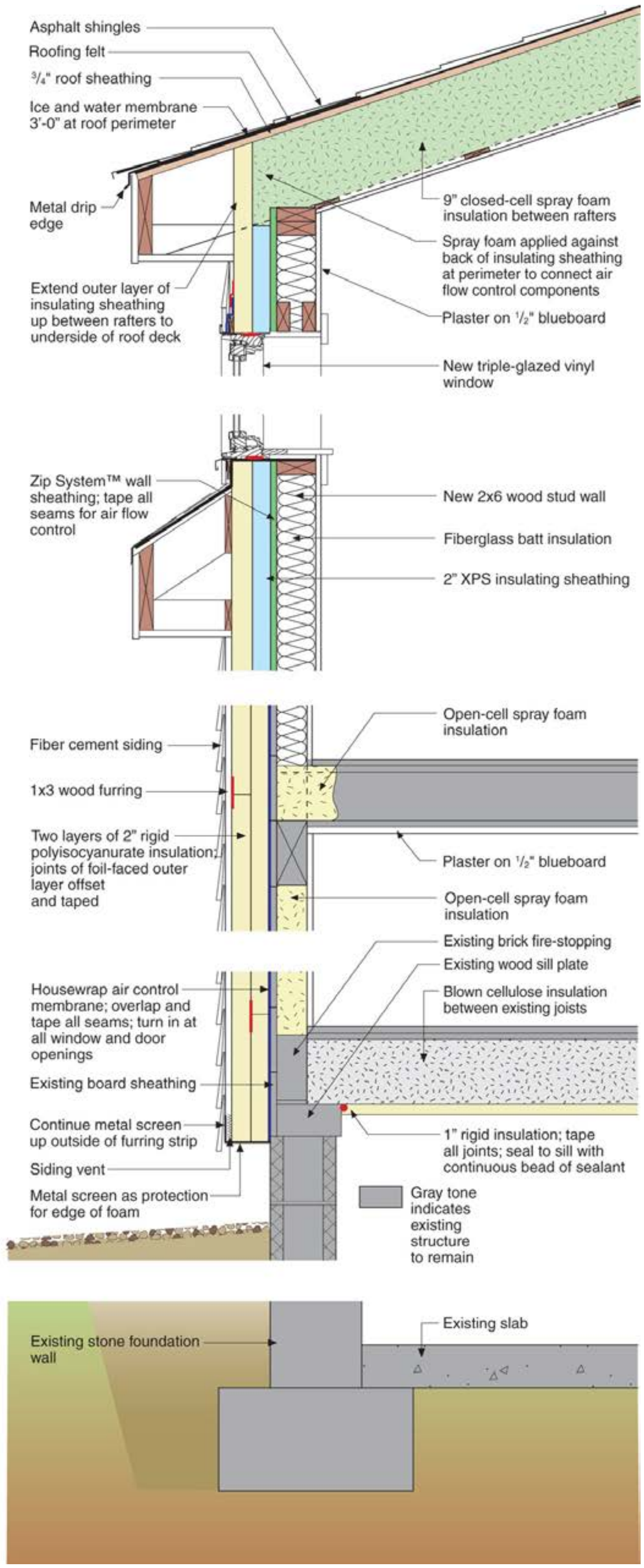

Figure 12. Schematic wall section for Test Home 3 enclosure retrofit strategy

Roof Assembly: R-58 (nominal) unvented roof assembly: 9-in. ccSPF; ¾-in. roof sheathing, roofing felt; asphalt shingles.

Wall Assembly: R-38 retrofit assembly first and second floors: ocSPF or fiberglass batt in 2 × 4 wall on first floor; board sheathing with house wrap; two layers of 2-in. polyisocyanurate insulating sheathing, joints offset and taped. R-41 new construction assembly. Third floor: fiberglass batt in 2 × 6 wall; taped Zip System wall sheathing; one layer 2-in. XPS; one layer 2-in. foil-faced polyisocyanurate with seams taped.

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

Airflow Control: House wrap with lapped and taped seams; taped exterior insulation layer; ocSPF at first floor framing cavities and basement access stair walls; ccSPF in roof rafter cavities extended onto back side of wall insulating sheathing; taped foil-faced rigid insulation at basement ceiling; ccSPF to underside of enclosed porch floor.

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

4.3.4 Construction

The staging of the project required that exterior wall retrofit measures and interior work for the first floor apartment be essentially complete before work could commence on the renovation and addition of the second and third floors.

The project budget did not allow for detaching the open porches at the rear of the building to allow the air and thermal control to be applied in a continuous layer behind the porch connection. To address the concern about airflow control and insulation, the builder cut back a strip of porch roof adjacent to the exterior wall of the building so that spray foam could be applied against the wall and around the porch roof framing (see Figure 13).

The installation of windows over strapping rather than in plane with the face of exterior insulation created challenges for proper flashing of the windows. A sequencing problem emerged where vertical strapping adjacent to windows prevented window head flashing from being connected back to the drainage plane. To provide head flashing across the top of the window, the adjacent vertical strapping would have to be cut and the upper piece temporarily removed.

Figure 13. Left: Attached roof cut back to allow application of ccSPF at roof-wall interface; Right: Window flashing problems associated with installation of windows over strapping.

(Credit [right]: Robert Isbel/Boston Green Building, used with permission)

At both the newly constructed roof at the third floor and existing lower roofs over conditioned space, projecting rafters created a condition of thermal bridging and difficult airflow control transitions. At the newly constructed roof, exterior insulating sheathing was notched around rafters and extended up to the underside of the roof sheathing. This allowed the ccSPF of the roof system to seal between roof sheathing and wall insulating sheathing and the framing top plate (see Figure 14). At the overhang of existing roof sections where there was no access from the interior, the transition of airflow control was more challenging. At these locations, exterior insulating sheathing was notched around projecting rafters to allow one-part foam sealant to seal between the projecting framing and the exterior insulation (see Figure 14).

Figure 14. Left: ccSPF providing transition of airflow control at new roof to new wall transition; Right: Rigid exterior insulation notched around projecting rafters.

4.3.5 Design Challenge: Whether To Include or Exclude the Basement

Basements present a host of challenges to high performance retrofit. Basements tend to be cool, damp, and musty spaces. Often low framing heights render the spaces unsuitable for habitable space. Basements can also be a source of soil gas or other airborne contaminants. What is often not adequately appreciated is that basements tend to have fairly strong airflow connections to living spaces above.

Insulation and air sealing at the ceiling over the basement may initially seem a more cost-effective thermal enclosure retrofit than properly insulating the entire basement. However, many factors make it difficult to provide effective airflow control between a basement and adjacent spaces.

The difficulties in achieving a robust separation, despite strong efforts, were evident in this project. Although the overall leakage of the basement space was significantly reduced as a result of the retrofit measures, the basement remained nearly three times leakier to the apartment spaces than to the outside directly.

4.4 Test Home 4: Cape, Basement Renovation Turned Comprehensive Deep Energy Retrofit

Figure 15. Pre-retrofit Cape located in Newton, Massachusetts
(Credit: Vahe Ohanesian/V.O. Design-Build, Inc., used with permission)

4.4.1 Project Overview

Building Type, Style:	Single-family detached, Cape
Era Built:	1930s
Pre-DER Floor Area:	1,724 ft^2, 2,044 ft^2 including basement

The owners of this single-family home initially set out to remodel the basement into conditioned space and upgrade the heating and water heating systems. Working with a builder oriented toward high performance construction, the owners decided to expand the project and turn it into a DER after the builder introduced them to the National Grid DER pilot program.

The original project scope already included thick interior insulation for the foundation walls, a new insulated basement slab, and a new boiler and water heater. The expanded comprehensive DER scope included exterior and interior insulation and recladding of the walls and roof, new triple- and double-glazed windows, replacement of the central air-conditioning system with a high-efficiency air source heat pump, and an HRV for mechanical ventilation.

This test home provides an example of a thoroughly comprehensive retrofit that did not involve major additions or changes to the building footprint, but nonetheless expanded living space by including the basement within the thermal enclosure.

The retrofit was implemented while the home was occupied. The renovation took 10 months to complete.

4.4.2 Deep Energy Retrofit Project Plan

Retrofit of exterior walls by applying thick layers of insulating sheathing can be pursued without much disruption to the interior. The homeowners, who occupied the home throughout the project, decided to take this approach. Cavity insulation was installed or supplemented where missing or inadequate.

A significant design direction pursued by this project is the chain saw retrofit approach to the roof-wall transition of the main roof. In this approach, the existing eave and rake overhangs of the roof are cut off so that the exterior wall and roof planes meet to form a straight edge. This allows the air and thermal control layers of the roof to connect directly to the corresponding control layers of the wall system. The approach also eliminates thermal bridging of roof framing at eaves and rake transitions. The reconstruction of overhangs that is required for this approach provides an opportunity to address aesthetic goals and to increase protection of walls.

To provide sufficient head height in the renovated basement, the design involved excavation of the existing basement floor to lower the floor elevation. This necessitated installation of a concrete underpinning wall beneath the existing rubble stone foundation wall. The design also provides for installation of a subslab drainage system beneath the new concrete floor slab. To connect this drainage system to the water control system of the foundation wall, a polyethylene sheet vapor retarder was placed between rigid insulation and the new concrete slab continues up the face of the underpinning wall to the base of the rubble stone wall. The polyethylene is embedded in the ccSPF applied to the foundation wall. Should liquid water pass through the rubble stone foundation wall, it would be directed by the ccSPF insulation and then by the polyethylene sheet to the subslab drainage. Irregularities in the surface of the concrete at the underpinning wall provide drainage pathways for liquid water to reach the subslab drainage system.

The wall assembly for this project establishes the exterior face of the insulating sheathing as the drainage plane; the house wrap applied over the board sheathing serves as the primary air control layer. The multiple layers of materials in this system provide additional control. The thickness of exterior insulation also places the rain shedding layer further from the water-sensitive structure.

4.4.3 Enclosure System

Figure 16 shows a schematic representation of the retrofit enclosure strategy. It is followed by an outline of the retrofit strategies for major building enclosure elements. Additional images and information about this project are presented in a case study created for this project (see Appendix F).

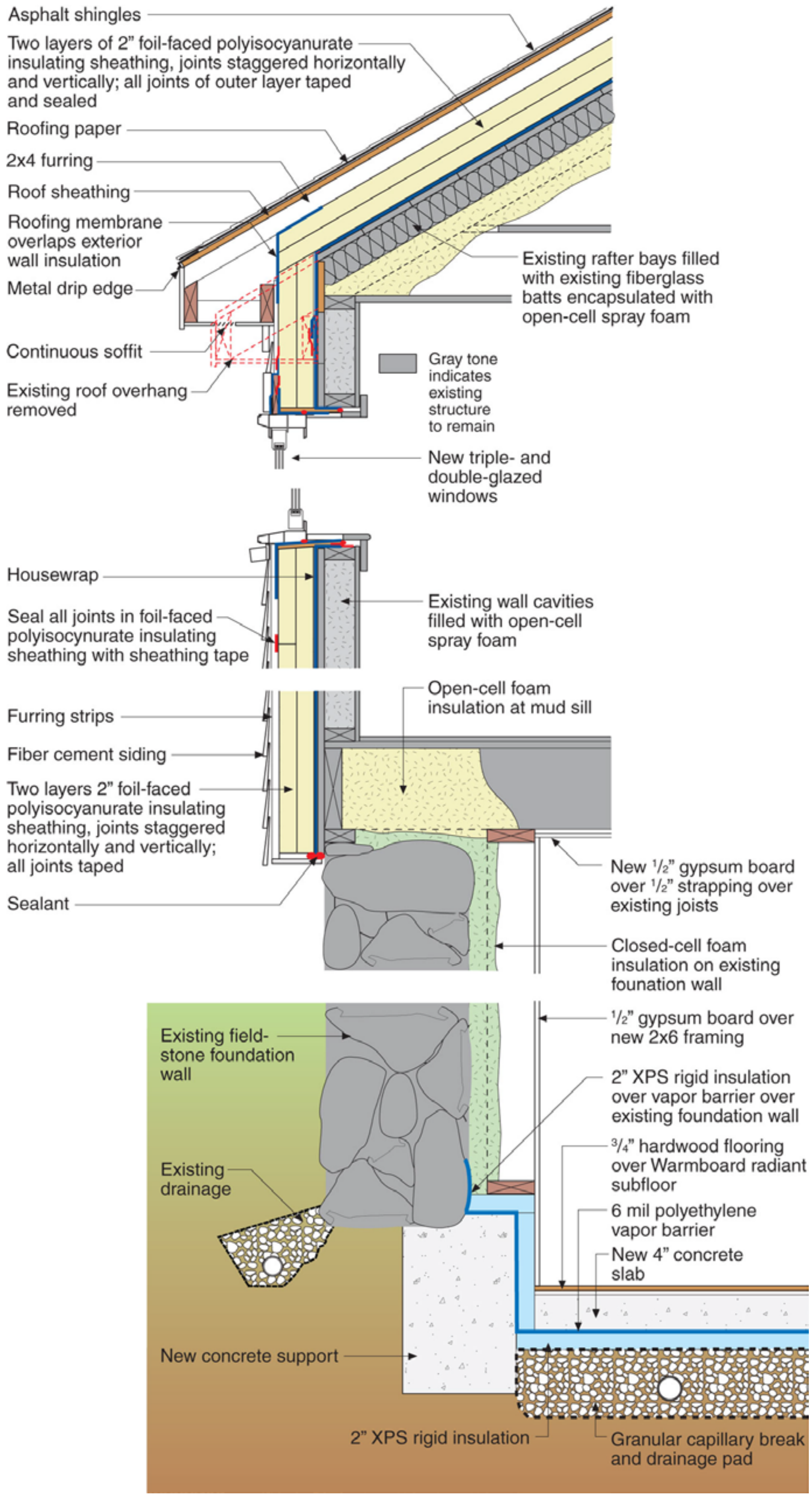

Figure 16. Schematic wall section for Test Home 4 enclosure retrofit strategy

Roof Assembly: R-56 (nominal) Unvented attic with vented over-roof: rafter cavities at kneewall space filled with existing fiberglass batts encapsulated with ocSPF, cellulose insulation sprayed into bays at cathedral ceilings, ocSPF in rafter bays at attic space above flat ceiling; house wrap over existing sheathing; two layers of 2-in. foil-faced polyisocyanurate insulating sheathing; 2 × 4 purlins; ½-in. plywood; underlayment and asphalt shingles.

Wall Assembly: R-39 (nominal): Existing 2 × 4 wall framing cavities with fiberglass insulation supplemented with dense-packed cellulose where needed; house wrap; two layers of 2-in. foil-faced polyisocyanurate insulating sheathing; ¾-in. furring strips; fiber-cement siding.

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.

Airflow Control: House wrap applied over existing wall and roof sheathing, with joints lapped, seams taped, and continuous over transition between wall and roof; ocSPF at framing sill, ccSPF over rubble stone foundation wall, taped rigid insulation at concrete underpinning wall; new concrete slab.

Foundation Assembly: Conditioned basement with the following major enclosure components:

Foundation Wall: 3 in. ccSPF applied to rubble stone foundation wall in new 2 × 6 stud walls finished with drywall, 12 in. of ocSPF extending up the mud sill, 2 in. XPS at interior of concrete underpinning wall.

Basement Slab: Gravel drainage pad, 2 in. of XPS insulation and polyethylene vapor retarder beneath new concrete slab; radiant subfloor finished with hardwood flooring.

4.4.4 Construction

During the course of construction, the builder devised solutions for conditions of continuous exterior insulation. A strip of plywood was used at the top of the gables to support a rake overhang that was otherwise aligned with exterior insulation of the roof. The added thickness of the roof would have brought the roof surface too close to the sill of dormer windows. The insulation was thickened at the face of the dormer to align the face with the wall below and to allow the eave overhang to break at the dormer.

In other areas the application of exterior insulation presented challenges. Installation of exterior insulation over the house wrap, before making critical airflow control connections, complicated many of the air sealing details (see Section 4.4.5, Design Challenge). The builder purchased windows with an integral trim channel designed to receive lapped siding. Windows were installed to blocking on top of the exterior insulation to align the window’s receiving channel with the siding (which is installed over furring strips to create a ventilation/drainage space as well as for attachment). Installing the windows this way created significant challenges to the implementation of proper flashing and airflow control.

4.4.5 Design Challenge: Airtightness of the Enclosure

Implementation sequence was a critical factor in airflow control. The house wrap – intended to be the primary airflow control – and exterior insulation had been installed prior to removing the existing windows. This made it difficult to transition the airflow control layer into the window opening and to provide connection to the new window. To make the connections, sections of insulating sheathing around the windows had to be removed to allow pieces of air control membrane (house wrap or adhered membrane) to attach to in-place house wrap. Also, the house wrap had not been sealed to the base of the wall prior to installation of exterior insulation, leaving limited options for a robust connection there.

While the builder pursued a chain saw approach at the roof-wall interface, porches were left attached, thus precluding continuous air control and insulation layers at these locations. Sealing around the intervening framing and roof decks proved challenging.

4.5 Test Home 5: Small Colonial, Second Floor Reframing and Deep Energy Retrofit

Figure 17. Pre-retrofit Colonial in Lancaster, Massachusetts

(Credit: Michael Nobrega/Habitat for Humanity North Central Massachusetts, used with permission)

4.5.1 Project Overview

Building Type, Style:	Single-family detached, small Colonial
Era Built:	Early 1900s
Pre-DER Floor Area:	908 ft^2, 1,470 ft^2 including basement

Habitat for Humanity North Central Massachusetts received this circa 1900 property as a donation from the Town of Lancaster. The building had been in a state of significant deterioration, yet preserving the footprint and first floor framing was essential to preserving the ability of Habitat to provide a home on the otherwise nonconforming lot. Due to programmatic requirements, the roof was removed and a new second floor and roof were framed on top of the existing balloon-framed structure. Significant parts of the rubble-stone-and-brick foundation wall also required replacement. The interior of the remaining first floor was completely gutted.

Being a Habitat project, the project plan needed to be formed around donated materials and volunteer labor. The result is a project that serves as an impressive example of what is attainable under such circumstances. The project also developed interesting strategies to pursue ambitious performance targets with the available materials and resources.

In addition to the super-insulated enclosure, triple-glazed windows, energy-efficient mechanical systems, and exceptional airtightness, the house design also includes a 3.75-kW PV array. The completed house was turned over to the new homeowners in August 2011.

4.5.2 Deep Energy Retrofit Project Plan

To achieve the thermal performance targets set by the National Grid DER pilot program, the project decided to use ccSPF in the wall cavities in addition to donated 4-in. XPS rigid foam insulation on the exterior. However, because both types of insulation are vapor impermeable, BSC expressed concern about the durability of the wall assembly and offered solutions to provide better moisture management. The Habitat construction manager elected to install a breather mesh over the wood sheathing between the house wrap and the first layer of exterior insulation. This allows for the assembly to redistribute and dissipate moisture if small amounts of water get behind the primary drainage plane, which is the rigid foam.

Water control at the roof is provided by standard roofing practices. Purpose-built roof trusses enable adequate overhangs and the new rakes are extended to provide ample protection for the walls below. The wall system uses the exterior face of the insulating sheathing as the primary drainage plane with the house wrap layer behind the vapor diffusion mesh as a secondary drainage plane. A new exterior footing drain at the rear (uphill side) and a layer of gravel beneath the new basement slab provide water control for the foundation.

Because the plan called for a vented attic, airflow control at the top of the building is achieved by sealing the perimeter and the penetrations at the top floor ceiling. Careful detailing is needed to transition the ceiling airflow control to that of the wall system. A raised heel truss allows the full depth of insulation to continue to the perimeter of the attic. Rigid foam installed up the height of the raised heel protects the ceiling insulation from wind washing or displacement. This approach accommodates very high levels of insulation at a low marginal cost. Mechanical systems and ventilation distribution are located entirely within the conditioned space and not in the vented attic.

4.5.3 Enclosure System

Figure 18 shows a schematic representation of the retrofit enclosure strategy. It is followed by an outline of the retrofit strategies for major building enclosure elements. Additional images and information about this project are presented in a case study created for this project (see Appendix G).

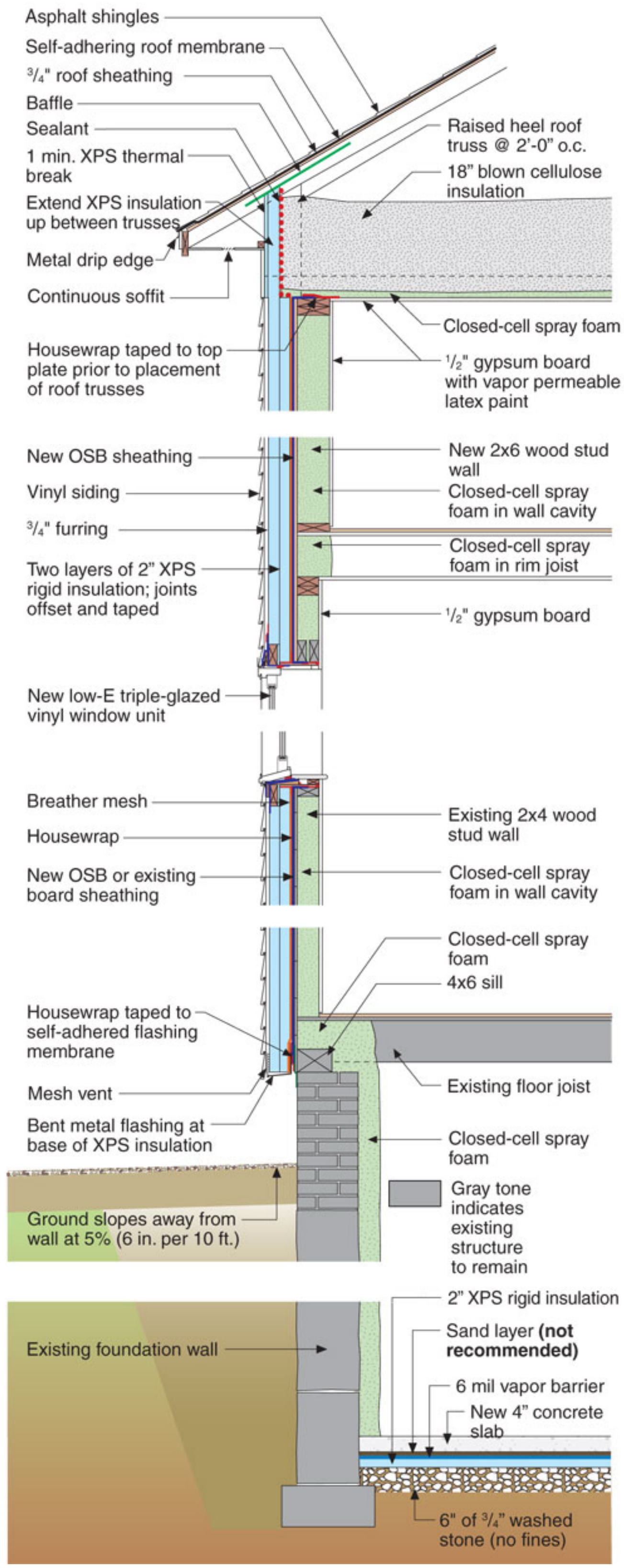

Figure 18. Schematic wall section for Test Home 5 enclosure retrofit strategy

Roof Assembly: R-65 vented attic: 1 in. ccSPF on attic floor covered with 18 in. loose-blown cellulose.

Wall Assembly: R-44 (nominal): existing 2 × 4 and new 2 × 6 wall cavities filled with ccSPF; house wrap over wall sheathing; breather mesh; two layers of 2-in. XPS insulating sheathing; ¾-in. furring strips; vinyl siding.

Window Specifications: Paradigm triple-glazed, krypton/argon blend, low-E vinyl windows; U = 0.2, SHGC = 0.23; windows installed over strapping at exterior face of insulating sheathing.

Airflow Control: Taped house wrap over existing board and new oriented strand board (OSB) sheathing; ccSPF in wall framing cavities and caulking at framing joints; 1 in. ccSPF flash coat at attic floor; house wrap wraps over the top plate of second floor wall where ccSPF on attic floor extends over the top plate and connects to house wrap; the bottom of the house wrap is sealed to the existing board sheathing and to top of foundation wall; ccSPF at foundation wall extends and seals to the new concrete slab.

Foundation Assembly: Conditioned basement with the following major enclosure components:

Foundation Wall: Minimum 3 in. ccSPF insulation applied directly to existing fieldstone and brick foundation walls and to new concrete wall in rear of building; dampproofing with 2-in. XPS insulating sheathing below grade on exterior of new concrete foundation wall.

Basement Slab: New concrete slab cast over sand layer (not recommended), polyethylene vapor barrier, 2 in. XPS insulation, and gravel.[3]

4.5.4 Construction

To address the challenge of connecting the airflow control layer of the wall system to that of the top floor ceiling, BSC advised the project team to wrap the wall house wrap onto the top plate and tape it to the top plate of the top floor wall prior to placement of the roof trusses. There was some concern that the placement of the roof trusses would damage the house wrap. Observation after installation of the roof trusses confirmed that the house wrap has held up just fine.

The new basement slab was cast directly against the foundation wall, which creates a thermal bridge and precluded establishing a direct connection between the water control function of the foundation wall with the subslab drainage system. What allows this system to still provide adequate control of liquid water is 1) the exterior perimeter drain controlling ground water and 2) the surface regrading, which will improve draining of surface water away from the foundation.

The project team used a brake-formed metal guard to protect the base of the foam insulation from animals. Attachment of the guard to furring strips provides a reliable slope to the outside and the simple building footprint avoids inside corners where such a flashing element along the bottom of the wall might concentrate water.

[3] BSC does not recommend allowing a sand layer between a vapor retarder and a concrete slab.

4.5.5 Design Highlight: Hygric Redistribution for Vapor Impermeable Wall Assembly

This particular project employed an approach of combining 4 in. of exterior insulation and ccSPF framing cavity insulation. The exterior foam insulation in this case is XPS. The insulation in this assembly offers very low vapor permeability (low drying potential) to either side of the structure. This is a particular concern for a project where critical details may be implemented by unskilled volunteer labor. As mitigation for the moisture risk, a breather mesh was installed over the structural sheathing between the house wrap and the exterior rigid insulation boards. The breather mesh serves as a hygric redistribution layer to allow minor moisture concentrations to dissipate. Liquid water is able to drain over the house wrap and through the mesh layer, and the mesh layer suppresses convection airflow sufficiently to avoid degradation of the thermal insulation to the exterior.

5 Performance Assessment of Retrofit Measures

Although many of the energy efficiency measures for a retrofit are the same as for new construction, the underlying constraints are different. For new construction, the owner has a clean slate for implementing the most important energy-efficient aspects – detailing the air barrier; providing ventilation and ductwork for heating and cooling; selecting, installing, and air sealing windows; and providing large amounts of insulation. As such, these can be implemented following standard, proven details. On the other hand, for a retrofit, the reality of existing conditions results in "special case" details for nearly all portions of the building. Also, the decision to pursue a retrofit of an existing building implies that there is something about the existing building that needs to be preserved – it may be all or parts of the exterior, it may be all or parts of the interior, it may be just the structural framing, or it may be a combination of the above. This complicates everything – from installing an effective air barrier to providing ventilation in the newly airtightened house.

How an existing building is currently functioning may not be understood. By virtue of being an existing building, it might be presumed to be functioning. Notwithstanding the apparent functioning, an existing building may have latent problems that are either tolerated or not readily apparent. A DER will significantly change the moisture, airflow, and thermal dynamics of the structure. These changes may create problematic dynamics or might make previously masked problems apparent. This is why any approach to an *energy performance* retrofit must be very sensitive to the moisture, airflow, and thermal implications to minimize risk of damaging the function of people's homes.

During BSC's review of DER project plans, enclosure retrofit strategies are evaluated according to four fundamental control functions:

- Water control
- Airflow control
- Vapor control
- Thermal control.

Observation of the projects during and after construction allows for assessment of the strategies in practice. Evaluation of planned retrofit strategies together with field observations and measurements (where applicable) form the basis of assessments presented in this section.

The variety of projects participating in the National Grid Pilot program yields a variety of approaches. Table 1 presents a summary of the enclosure retrofit strategies employed in each test home as described in the previous section. Following this table is an assessment of each major enclosure strategy employed.

Table 1. Enclosure Strategies Employed in the Pilot Test Homes

Test Home	Roof or Attic	Above-Grade Wall	Window	Foundation Wall	Basement Floor/Floor Over Basement
1	Unvented roof/attic; ccSPF to underside of roof sheathing	4 in. polyisocyanurate exterior insulating sheathing, 2 × 4 wall cavities with existing fiberglass or cellulose	Triple-pane vinyl frame windows	3 in. ccSPF, gypsum wall board thermal barrier	2 in. XPS over existing slab and under OSB floating floor
2	(not in project, previous work)	4 in. polyisocyanurate exterior insulating sheathing, 2 × 4 wall cavities with existing fiberglass or cellulose	Triple-pane vinyl-frame windows	(not in project, previous work)	Painted concrete, no treatment planned
3	New stick-framed roof, unvented, ccSPF to underside of roof sheathing	4 in. polyisocyanurate exterior insulating sheathing, 2 × 4 wall cavities with existing fiberglass or cellulose	Triple-pane vinyl-frame windows	N/A, insulation at floor over basement	1 in. ccSPF, dense pack cellulose, 1 in. foil-faced polyisocyanurate
4	4 in. polyisocyanurate exterior insulating sheathing, ocSPF in framing cavities, with existing fiberglass or cellulose at cathedral sections	4 in. polyisocyanurate exterior insulating sheathing, 2 × 4 wall cavities with existing fiberglass or cellulose	Combination: Triple-pane vinyl-frame windows, double-pane wood-frame windows	3 in. ccSPF, gypsum wall board thermal barrier	2 in. XPS under new concrete slab
5	New truss-framed roof, vented, loose-blown cellulose at attic floor	4 in. XPS exterior insulating sheathing, 2 × 4 wall cavities with ccSPF	Triple-pane vinyl-frame windows	3–6.5 in. ccSPF, intumescent paint thermal barrier	2 in. XPS under new concrete slab

5.1 Roof/Attic Strategies

5.1.1 Unvented Attic With Closed-Cell Spray Polyurethane Foam

Two of the five projects reviewed in this report (Test Homes 1 and 3) employed this approach (see Figure 19). ccSPF was applied between and over roof framing to a depth of 8–10 in. The ccSPF forms the primary airflow control layer for the assembly. The insulation is applied to a roof with a newly installed roof cladding (asphalt shingles) and water control layer (ice and water membrane and roofing felt). In Test Home 3 the roof framing and sheathing were also entirely new.

Figure 19. Left: ccSPF insulated roof at Test Home 1; Right: partial ccSPF insulation in a section of roof framing at Test Home 3. Note that Test Home 1 remained unoccupied except for active construction for a period of several months after application of ccSPF. During active construction, doors and windows remained open. During the period after application of ccSPF in Test Home 3, the application floor and floor below were active construction zones with doors and windows typically open during daytime hours.

This system uses a single component to achieve thermal performance. The contractor for these two test homes prefers this approach as it does not rely on specially skilled roofing trades, nor do carpenters need to work on a steep roof and attempt to locate sometimes irregular roof framing with long screws.

Adequate space for insulation beneath the roof sheathing and roofing provides effective control of rain and melt water. This approach can provide super-insulation retrofit without necessitating a change to the existing roof.

Water control – Primary water control is provided by conventional roofing. This approach should not be implemented without a new roof or, at minimum, a roof for which there is a high degree of confidence in the performance. This is because the ccSPF does not allow significant drying to the inside and conventional asphalt roofing does not allow drying to the outside. Any insulation appropriate for this application will reduce the ability of moisture sensitive materials to the exterior of the insulation to recover from a wetting event.

This approach can pose a challenge in providing adequate overhangs to protect the walls of the building when the walls are to be thickened with exterior insulation. In Test Home 3, the roof was newly framed as part of the project; thus, the contractor had the opportunity to accommodate added thickness of the walls with deeper overhangs. In Test Home 1, the project had initially decided to establish the thermal barrier at the attic floor. Then, after a new roof was installed, the homeowner decided to move the thermal barrier to the roof plane. At this point the only practical solution was to apply ccSPF to the underside of the roof deck and over the roof rafters (see Figure 20). This resulted in a missed opportunity to address the roof overhang depth as well as the relationship between the eave soffit and windows. The builder opted to lower the window heights and window head heights slightly on the second floor to allow the overhang to provide as much protection for the wall as prior to the retrofit.

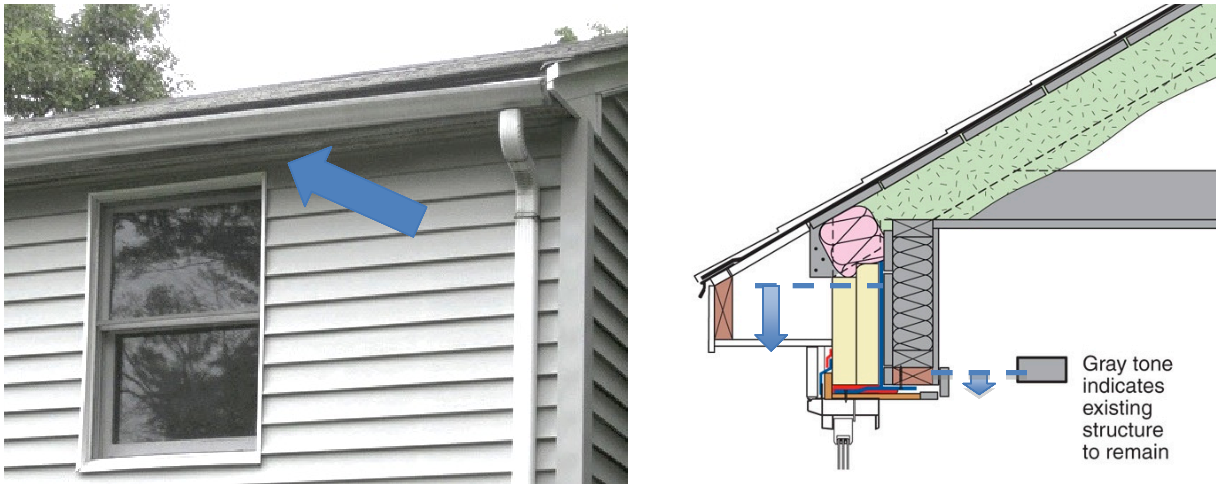

Figure 20. Left: Short eave overhang and limited separation between window head and soffit prior to retrofit at Test Home 1; Right: Roof overhang detail at Test Home 1 showing position of soffit and window head relative to pre-retrofit conditions.

Airflow control – A framing cavity approach to airflow control usually requires supplemental sealing at framing joints. Although the approach in both of these subject homes was to completely embed the roof framing rafters, some framing joints were left exposed (see Figure 21). Joints between roof framing members that project to the exterior through the airflow control layer can represent an airflow control bypass in this approach.

Figure 21. Airflow channels between double roof rafters at Test Home 1

Although airflow control in the field of the roof is typically straightforward, lapses often occur in the transition of airflow control from roof to wall assembly. In the case of a rigid airflow control material at the wall, the airflow control function of the roof can transition to the wall airflow control directly if the airflow control material of the wall is extended above wall top plate toward roof deck. The ccSPF can then be applied against the back side of the rigid airflow control material as depicted in Figure 22.

Figure 22. Left: Rafter bay continuous to soffit area at Test Home 3; Right: SPF insulation in rafter bay connecting to top of wall at Test Home 3

If a flexible membrane serves as the airflow control material of the wall, it is possible to directly connect the roof airflow control to that of the wall if the flexible membrane is wrapped over the top plate prior to placement of roof framing. However, this is not typically an available measure in retrofit.

Figure 23 represents the roof-to-wall interface of Test Home 1. In this representation, vulnerabilities in the airflow control transition are apparent. Given that the spray foam is installed from the interior of the attic, it is unlikely that it will fully capture the edge of the top sheathing board or seams between sheathing boards. Similarly, if the wall airflow control layer is the house wrap, the spray foam applied from the attic interior may not adequately capture the top edge of the house wrap. If the top edge of the house wrap is also not taped to the sheathing, there is no airtight transition between the roof and the wall.

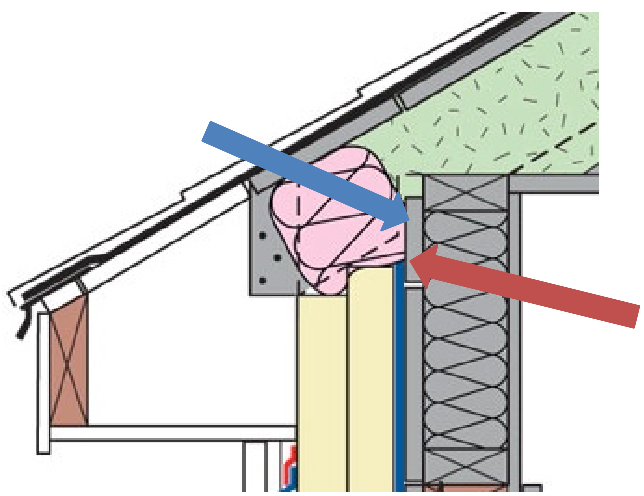

Figure 23. Airflow channels between double roof rafters at Test Home 1

Water vapor control – ccSPF was used for this roof/attic strategy in the test homes featured in this report. At the thickness needed for adequate thermal control, the ccSPF provides enough water vapor control to protect moisture sensitive roof framing and sheathing from interior water vapor sources. ocSPF would not provide adequate water vapor control, and therefore should not be used without supplemental vapor control. Although ccSPF does provide adequate operational vapor control performance, its low vapor permeability could prove problematic if roof sheathing is exposed to weather and not permitted to fully dry before the application of the insulation.

Thermal control – Thermal control is achieved with a single component, provided it is applied to adequate thickness. If the insulation is applied between framing but does not cover the framing, it is likely that the assembly will still have significant thermal bridging (see Figure 24). Test Home 3 employed strapping to allow for insulation to be installed (in a thin layer) over the bottom of joists. At Test Home 1, where the attic remained unfinished, the installer was able to more thoroughly embed the roof framing.

Figure 24. Left: SPF insulation being installed in roof framing cavities at Test Home 3. Note how roof framing precludes insulation for an appreciable portion of the roof area and that the strapping depth does not allow much depth for insulation over the framing; Right: roof rafters fully embedded in spray foam insulation at Test Home 1.

In the examples reviewed in this report, as well as in other projects in the National Grid DER Pilot, the unvented roof with ccSPF strategy is employed in configurations where roof framing projects through the insulation at the eaves. This configuration of roof framing introduces thermal bridges at the roof-wall transition.

5.1.2 Exterior Insulation and Framing Cavity Insulation

In this unvented roof approach, a thick layer of exterior insulation is added above the roof sheathing. The exterior insulation has sufficient thermal resistance to allow for an unvented roof with air- or vapor-permeable interior insulation in the framing cavity below the roof sheathing.

An airflow control layer must be applied to the underside of exterior insulation to prevent warm, moisture-laden air from passing to the colder elements of the assembly. Also, rigid board insulation is typically applied in two layers with seams offset. A nailing base material (e.g. ½-in. plywood) is fastened to the roof framing through the rigid board insulation. Shingles and underlayment are then installed on the nail base as per conventional steep roof practice. Additional insulation as needed to reach the target assembly performance value is placed between the rafter framing. Any type of insulation may be used to the inside of the roof sheathing, provided the roof is properly detailed to provide robust control of water and that sufficient insulation is provided to the exterior of the structural roof deck.

This approach is compatible with roofs that have existing cathedralized ceilings that restrict access to framing cavities, or in situations where available space for insulation between and below rafter framing is otherwise limited. This approach is also compatible with reroofing and reconstruction of roof overhangs, as is often recommended with wall retrofit, to provide adequate overhang and meet aesthetic requirements.

A significant advantage of this approach is that, pending the condition of roof rafter support, it lends itself well to the chain saw retrofit approach (see Figure 25).[4] In the chain saw approach, the existing eave and rake overhangs are removed to allow for a more direct transition of control functions between the roof and the wall (Orr and Dumont 1987). In this approach, roof sheathing and rafters are cut back to flush with the face of the wall below so that air control and thermal control layers can directly wrap from roof to wall. Roof overhangs are then constructed outboard of the continuous airflow control and thermal control layers.

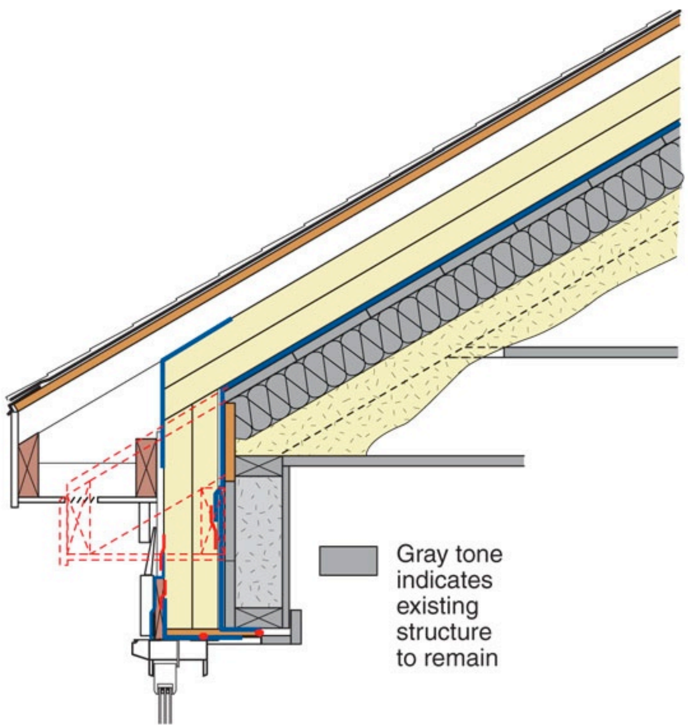

Figure 25. Roof-wall interface in a chain saw retrofit configuration. Note how the airflow control and thermal control layers are uninterrupted over the roof-to-wall transition. Location of the original overhang prior to removal is indicated by the dashed red outline.

Despite the exterior insulation strategy being relatively popular among the projects in the wider National Grid DER Pilot, Test Home 4 is the only test home in this study that employed this strategy for roof insulation.

Water control – This approach provides additional water control layers between cladding and roof structure in the insulation and air control layers placed outboard of the structural sheathing.

[4] In framing configurations where the roof rafter bears upon a framing member that is cantilevered over the top of the wall, a chain saw approach may not be feasible.

The test home in this study that employed this strategy used 2 × 4 purlins between the rigid insulation layer and the roof cladding nail base. This provides a generous drainage gap beneath the primary water control of the asphalt shingle roofing system.

The need to reestablish rake and eave details with this approach provides an opportunity to increase overhangs to better protect the walls. Test home 4 already had generous overhangs prior to the retrofit. In the retrofit project, proportions of the main roof overhang were replicated and the overhangs of the dormer roofs were increased slightly (see Figures 26 and 27).

Figure 26. Left and Right: Test Home 4 prior to implementation of the DER project. Note the generous main roof overhangs and the smaller overhangs of the dormer roofs.

(Credit: Vahe Ohanesian/V.O. Design-Build, Inc., used with permission)

Figure 27: Left and Right: Test Home 4 after implementation of the DER project. Note the generous main roof overhangs and the overhangs of the dormer roofs that are slightly larger than they had been prior to the DER.

Airflow control – Airflow control is provided by a taped house wrap membrane applied over the existing roof sheathing. The chain saw approach to the roof-wall transition allows for a robust connection between the roof and wall airflow control layers. Additional airflow resistance at the roof is provided by rigid insulation boards with staggered joints.

Vapor control – This strategy protects the moisture-sensitive roof structure by providing sufficient insulation to the exterior to maintain the roof structure above normal dew points and to lower operational relative humidity. The use of vapor permeable insulation to the interior of the existing roof sheathing permits drying to the inside.

Thermal control – Continuous insulation to the exterior of the roof structure significantly reduces thermal bridging of roof framing in field of the roof. The chain saw approach also minimizes thermal bridging of roof framing at eaves and rake transitions. The eave fascia and soffit are framed over the top of exterior insulation, which is continuous from the roof to the wall.

The contractor for Test Home 4 employed a novel technique to allow attachment of the rake overhang without compromising the continuity of insulation in this area. Plywood of thickness equivalent to that of the strapping was installed along the rake. The piece of plywood is also wide enough that it can be fastened through the wall exterior insulation into framing while also extending up to the level of the roof insulation. The strip of plywood provides fastening to support a rake overhang that was otherwise aligned with exterior insulation of the roof. It also provides for continuous attachment substrate for lapped siding along the slope of the gable (Figure 28).

Figure 28. Left: Plywood gable rake support at Test Home 4. Right: fascia and soffit of main roof framed over insulation layers and attached to 2 × 4 purlins.

5.1.3 Vented Attic

Test Home 5 employed this strategy.

This strategy provides airflow control by air sealing the top floor ceiling. Careful detailing is needed to transition this airflow control to that of the wall system. It is also necessary to protect the ceiling insulation from wind washing or displacement at the roof perimeter. This approach can accommodate very high levels of insulation at a low marginal cost. A raised heel truss or other framing accommodation is often needed to allow the full depth of insulation to continue to the perimeter of the attic.

Although this is unquestionably the least cost approach to high levels of insulation at the top of the building, it precludes use of the attic as conditioned habitable space and as a reasonable location for mechanical equipment. In terms of the providing conditioned living space, it is worth evaluating whether providing conditioned space directly beneath an insulated roof assembly is more cost effective than constructing a full story and vented attic.

In Test Home 5, where the vented attic approach was used, new second floor wall framing and a new roof were built to accommodate a full second floor. In this particular case, it was determined that the roof needed to be rebuilt for other reasons. However, for the general case, one would have to ask whether the material and labor cost savings in loose-blown insulation relative to rigid foam board or SPF are enough to offset the additional framing needed to create living space beneath a vented attic. Space may be accommodated more cost effectively within unvented roof/attic space than by constructing walls and a roof above.

Water control – Water control for this approach is provided by standard roofing practices. For Test Home 5, purpose-built roof trusses enabled adequate overhangs. In cases where a vented attic approach is used with an existing roof, the eaves and rakes may need to be extended to provide adequate protection for the walls below.

Airflow control – Airflow control is achieved by sealing the top floor ceiling, sealing the perimeter, and sealing penetrations. At Test Home 5 a wall-to-wall flash coat (approximately 1 in. thick) of ccSPF applied to the gypsum ceiling board substrate after all services had been installed to provide robust airflow control at the plane of the attic ceiling (Figure 29).

Figure 29. ccSPF airflow control layer in vented attic at Test Home 5

For Test Home 5, the ceiling and roof were newly framed as part of the project. This vastly improves conditions to create airflow control at the ceiling. In an existing attic, old insulation, flooring, stored belongings, etc. often complicate access to surfaces needing to be sealed. The materials of the ceiling in older buildings may be inherently leaky (e.g., crumbly plaster on wood lathe) and the surfaces of elements needing to be sealed are unlikely to be clean. The ccSPF that was employed in Test Home 5 would likely be more critical to success of this strategy in attics with older construction.

It is important to avoid locating conditioning ductwork in a vented attic. Exhaust ductwork passing through the attic must be well sealed. At Test Home 5, an in-process site visit revealed a ventilation system duct passing through the attic (see Figure 30). A different routing for the duct was identified with the contractor and the duct routing was subsequently changed to avoid having the duct above the airflow control layer in the vented attic space.

Figure 30. Ventilation duct initially located above airflow control layer in vented attic at Test Home 5

The appropriate method for transitioning the airflow control of the ceiling to the wall depends on what and where the airflow control material of the wall is. For Test Home 5, the primary airflow control material of the wall is the house wrap applied over the wall sheathing. To address the challenge of connecting the airflow control layer of the wall system to that of the top floor ceiling, BSC advised the project team to wrap the wall house wrap onto the top plate and tape it to the top plate of the top floor wall prior to placement of the roof trusses (see Figure 31). There was some concern that the placement of the roof trusses would damage the house wrap, but this did not occur.

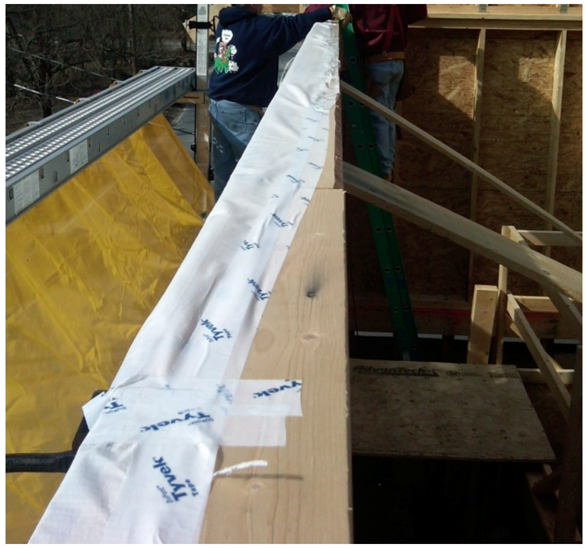

Figure 31. House wrap airflow control transition at top of wall at Test Home 5

(Credit: Michael Nobrega/Habitat for Humanity North Central Massachusetts, used with permission)

Of course, this elegant and direct airflow control transition strategy is available only when a roof is being framed over the top floor wall. In more typical retrofit situations involving a vented attic retrofit, the airflow control would need to be transitioned across the wall top plate to a rigid material that is then connected to the airflow control of the wall system.

At gable end walls an airflow control transition is needed at the height of the top floor ceiling. The house wrap or rigid foam (depending on which is the primary airflow control layer) should be sealed to the wall sheathing at the location of the top floor ceiling/top floor top plate. At the interior it is necessary to seal the sheathing to the top plate of the wall framing and subsequently to the ceiling. At Test Home 5, the house wrap, which was installed up the entire gable, was cut at the level of the attic floor and taped to the wall sheathing (Figure 32).

Figure 32. Example of airflow control transition at gable end of vented attic. The house wrap is taped to the wall sheathing at the level of the attic floor. Note that it is not necessary to tape the house wrap above this level.

Water vapor control – In this approach, water vapor control is provided by (1) air sealing at attic floor/top floor ceiling; and (2) by ventilation. The ccSPF used to provide air sealing at the attic floor also performs as a vapor diffusion retarder.

Thermal control – In an attic relatively free of obstructions, loose-blown insulation can provide continuous insulation coverage (see Figure 33). What is sometimes challenging with this approach is maintaining full insulation depth to the perimeter of the attic floor. Typically, in existing structures with sloped roofs, there is insufficient height between the top plate of the wall and the underside of the roof to allow both full depth of insulation and adequate roof ventilation. This is a concern for thermal performance; it may also be a factor contributing to the risk of ice damming.

Loose-blown fibrous insulations need to be protected from wind washing and displacement at the perimeter. Also, when the top floor ceiling is installed over strapping, there is a risk that intended roof ventilation may actually ventilate the ceiling below the insulation.

Figure 33. Loose-blown insulation in vented attic at Test Home 5

The Test Home 5 project capitalized upon the relative luxury of having purpose-built trusses that provide ample room for insulation at the perimeter. The project also provided robust wind washing protection of the attic insulation with rigid insulation blocking installed between each roof truss (Figure 34).

Figure 34: Left: Rigid insulation blocking between roof trusses at Test Home 5 exterior; Right: Rigid insulation blocking between roof trusses at Test Home 5 interior

5.2 Above-Grade Wall Measures

All of the projects featured in this report employed a wall retrofit strategy involving a thick layer of exterior insulation with the exterior face of the insulation serving as the primary water control layer for the wall system. The exterior insulation is installed over a house wrap that is installed over the wall sheathing and provides an airflow control function. Cladding is installed over strapping that is attached to the structure through the exterior foam. The test homes featured in this report illustrate three variations to this basic approach.

5.2.1 Rigid Foam Insulating Sheathing With Air-Permeable Framing Cavity Insulation

The most common variation of the exterior insulation retrofit strategy represented in three of the test homes (Test Homes 1, 3, and 4) is associated with a fibrous framing cavity insulation in the context of a comprehensive enclosure retrofit. This retrofit wall assembly consists of the following:

- Existing 2 × 4 frame wall with fibrous insulation
- House wrap applied over the existing sheathing
- 4 in. of polyisocyanurate insulating sheathing in two 2-in. thick layers, seams of the insulating sheathing staggered, both vertically and horizontally, and the outer layer seams taped.
- Vertical wood strapping applied over the insulating sheathing and attached to the wall framing using long screws
- Fiber-cement cladding attached to the wood strapping.

Retrofit of exterior walls using this approach can be pursued without disruption to the interior. Cavity insulation, if present, can remain.

Water control – The test homes featured in this research report all established the drainage plane of the wall at the exterior face of the insulating sheathing. The multiple layers of materials in this system provide additional layers of control. The thickness of exterior insulation means that the rain shedding layer is further from the water-sensitive structure.

The application of exterior insulation layers to the exterior of an existing structure seems to pose persistent challenges to proper flashing. This is particularly prevalent with the roof-wall interface. A common mistake with exterior insulating sheathing used as the drainage plane is to place step flashing for lower roofs at the plane of the existing sheathing and not at the face of the insulating sheathing where the drainage plane is. In Figure 35, the roof-wall flashing is not at the face of the drainage plane and the drip edge creates a condition where water may be directed behind the drainage plane. This situation was corrected for this test home.

Figure 35. Wall-roof interface at Test Home 4 showing two common flashing errors: 1) step flashing is not located at plane of water control, and 2) drip edge of lower roof creates a condition where water may be directed in behind the drainage plane. Note that both of these conditions were corrected at this test home.

Other problems with flashing seen in these test homes are not necessarily unique to the application of thick exterior insulation, but relate to using the face of a rigid sheathing material as a water control layer. The top edge of bituminous flashing membranes must be terminated with mastic or tape to resist the tendency of these membranes to curl away from the substrate at the edges (Figure 36). When sheathing tape is relied on to provide continuity for the water control layer, it must be applied carefully to avoid "fish mouths" or wrinkles that could collect water (Figure 37). The sequence of tape application is also important relative to installation of furring strips that would complicate drainage plane continuity if installed prior to taping the sheathing. The improper positioning of sheathing fasteners could also disrupt the continuity of the water control. With the observation of these test homes as well as of other projects in the National Grid DER Pilot, it appears that strong guidance on proper flashing will be needed for retrofit strategies that employ the face of rigid insulation for water control.

Figure 36. Nonterminated flashing membrane presents risk of collecting water

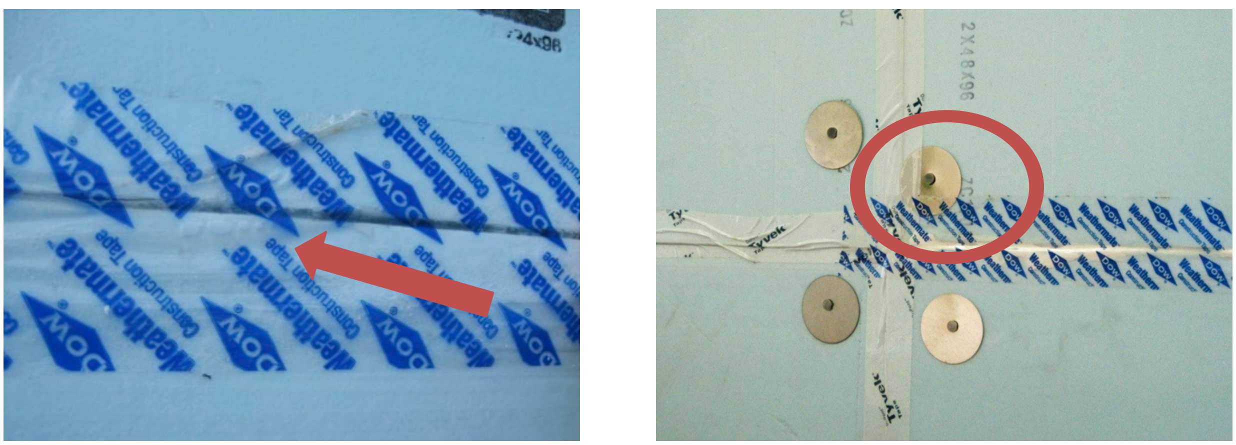

Figure 37. Left: Sheathing tape with water accumulated beneath wrinkle. Right: Fastener for insulating sheathing disrupting water control.

Airflow control – The airflow control is pursued through detailing both a house wrap and the exterior face of the rigid insulation as an airflow control layer with one or the other intended to provide the primary airflow control function.

In the test homes where the house wrap layer is installed behind the exterior insulation to provide airflow control, installation sequence appears to frequently pose a challenge (Figure 38). Airflow control connections to the house wrap layer need to be made prior to installation of exterior insulation. Test homes that installed exterior insulation prior to completing airflow control detailing at the house wrap layer (Test Homes 3 and 4) encountered significant difficulties in implementing airflow control transitions, notably at windows. For these two test homes, difficulties resulting from sequence also may have contributed to disappointing air leakage measurements.

Figure 38. Left: Exterior insulation installed prior to sealing house wrap to base of wall for airflow control transition; Right: Portions of exterior insulation must be removed to allow air sealing of the house wrap at these pipe penetrations.

Sequence of installation could also be leveraged to the benefit of performance where completing the airflow control details for the house wrap layer at a section of the building provides a milestone for inspection. Most airflow control transitions to the house wrap layer also allow the house wrap to provide temporary weather protection.

Whether the airflow control is at the house wrap layer or at the face of the exterior insulation, structural connections through the airflow control layers pose significant challenges (see Figure 39). In many situations, the structural element or connection is clad in finish material that provides a cavity capable of conducting airflow through the assembly.

Figure 39. Left: Porch roof support beam with trim and porch ceiling void airflow control where they connect to the wall and penetrate exterior insulation; Right: A porch roof return that connects to the existing wall challenges continuity of airflow control.

The roof-wall interface presents challenges to airflow control and to water control. Test Homes 3 and 4 both addressed the air leakage vulnerability of a connected porch roof by cutting the roof to allow application of ccSPF or rigid board insulation and foam sealant against the wall and around the roof framing (Figure 40).

Figure 40. Left: ccSPF airflow control around porch roof framing at Test Home 3; Right: Worker applying rigid foam and foam sealant between attached porch roof and porch ceiling, Test Home 4

Credit (left): Robert Isbel/Boston Green Building, used with permission) (Credit (right): Vahe Ohanesian/V.O. Design-Build, Inc., used with permission)

Despite these impressive measures, both Test Homes 3 and 4 achieved disappointing air leakage testing results relative to efforts expended.

Test Home 2 provided examples of cutting porch roof, ceiling and deck away from the wall of the house to allow the control functions to be more continuous at the face of the wall. This project demonstrated some success in obtaining a more robust means of maintaining continuity of the water, air and thermal control at attached roof connections by temporarily supporting the structure, cutting it back from the wall, installing the air, water, and thermal control layers, then reattaching the structure over these layers (Figure 41).

Figure 41. Porch deck, ceiling, and roof cut away from wall to allow continuous air, thermal, and water control, Test Home 2

Thermal control – Exterior insulation provides a continuous layer of thermal control in the field of the wall. With a significant portion of the assembly thermal resistance outside of the structure, thermal bridging is significantly reduced. Challenges to continuity of the thermal control remain – as they do for continuity of airflow control – at wall-roof interfaces and the penetration of attached elements and at penetrations of structural members.

Water vapor control – Generally speaking, the exterior insulation provides water vapor control by controlling the temperature of the sheathing and moisture sensitive structure. All other factors being equal, raising the temperature of the structure lowers the relative humidity of air in contact with it and consequently lowers the equilibrium moisture content of wood materials.

Test Home 1 exhibited a potential concern that is not uncommon in retrofit. Existing cavity insulation at this home included a robust vapor retarder. With the addition of foil-faced exterior insulation, the assembly would have a double vapor retarder (see Figure 42). Although the interior vapor retarder is not a factor in cold weather condensation within the wall cavity (as this is controlled by the exterior insulation), the interior-side vapor retarder would inhibit the ability of the assembly to recover from a wetting event. Paradoxically, the more robust the vapor retarder and the more continuous its installation, the greater risk it presents of trapping moisture within the wall cavity.

Figure 42. Foil-faced cavity insulation representing a second vapor retarder, Test Home 1

At Test Home 1 it was decided to remove most of the existing foil-faced cavity insulation, particularly near wall openings (windows and doors) and in walls containing plumbing. The risk must be evaluated for each case where an interior vapor barrier is either present or suspected. Risk factors to be evaluated include:

- Confidence in water control and flashing of wall assembly
- Confidence in plumbing distribution within the wall assembly
- Permeability of the interior vapor retarder
- Continuity of the interior vapor retarder
- Humidity control within the building.

Of course, water vapor control is of secondary concern if liquid water is not controlled by effective water management and good plumbing. An interior-side vapor retarder is only a significant risk factor in water vapor control if it has very low vapor permeance such as with metal foil or polyethylene. Even a very low vapor permeance vapor retarder to the interior side of the wall presents little concern if it is largely discontinuous and therefore permits drying around it. Humidity control within the interior space would affect the rate at which water vapor is able to move around a vapor retarder through more vapor-permeable elements.

The safest path in terms of performance is to either remove the interior vapor retarder or provide a means for drying or hygric-redistribution to the exterior. But these need only be considered with a relatively continuous and low-permeance interior-side vapor retarder.

5.2.3 Rigid Foam Insulating Sheathing With Closed-Cell Spray Polyurethane Foam Framing Cavity Insulation

Test Home 5 represents a case where an interior-side vapor retarder significantly influenced the wall retrofit strategy.

Due to use of donated materials and services combined with determination to meet the DER Pilot performance targets, Test Home 5 employed an approach combining 4 in. of exterior insulation and ccSPF framing cavity insulation. The exterior foam insulation in this case is XPS. The insulation in this assembly offers very low vapor permeability (low drying potential) to either side of the structure. This is a particular concern for a project where critical details may be implemented by unskilled volunteer labor. As mitigation for the elevated moisture risk of a vapor impermeable assembly, the Habitat construction manager elected to install a breather mesh between the house wrap and the exterior rigid insulation boards.

Unique circumstances associated with this approach are evaluated below.

Water control – The exterior face of foam is detailed as the primary water control layer (drainage plane), but the house wrap behind the breather mesh is also drained and flashed away from the building at the base of the framed wall assembly. The house wrap is able to function as a secondary drainage plane because the breather mesh over it provides a drainage gap through which liquid water can move by force of gravity. Ultimately, the function of enabling a secondary drainage plane may be as important to overall moisture control as the function of allowing water vapor redistribution.

Airflow control – Airflow control in this assembly is provided by the cavity insulation and the carefully detailed house wrap layer. Because there is an air-permeable material over the house wrap and beneath the exterior insulation, the exterior insulation cannot function as an airflow control layer.

Prior to installation of the rigid insulation, airflow control details were carefully implemented at the house wrap layer. The house wrap layer was sealed to window extension boxes with sheathing tape (see Figure 43). This allowed for subsequent transition of the airflow control to the window units. At the base of the framed wall, the house wrap was taped to a self-adhered membrane that lapped from the sheathing to the foundation wall to provide a transition of airflow control to the foundation assembly (see Figure 44).

Figure 43. House wrap airflow control layer sealed to window extension box at Test Home 5

Figure 44. Left: Airflow control transition at existing brick foundation wall, Test Home 5; Right: Airflow control transition at new CMU foundation wall section, Test Home 5

(Credit: Michael Nobrega/Habitat for Humanity North Central Massachusetts, used with permission)

Water vapor control – Given the possibilities for minor imperfections in the drainage plan, the water vapor redistribution provided by the spacer mesh appeared to be a prudent addition to the assembly at the design phase. Most flashing details observed at this site were well implemented, and the water vapor redistribution or hygric redistribution layer does provide a buffer to make the assembly more tolerant of imperfections. As such, the strategy should be considered for other retrofit projects facing similar conditions and constraints.

- The strategy may also help to mitigate risks where the framing sill is subject to capillary moisture from the foundation. For foundation wall materials that are porous (e.g., brick, concrete, certain types of stone, concrete masonry units) and have a limited exposure above grade, there may be concern about capillary transport of water to the framing sill at the top of the foundation wall. Risk of damage to the sill resulting from the capillary transport of water can be elevated when there is significant potential for the porous foundation wall material to be in contact with liquid water and where the wood framing at the top of the foundation wall has limited ability to dry. A breather mesh providing vapor redistribution may help to dissipate moisture accumulating at the foundation sill.
- The vapor diffusion drying for the sill provided by the spacer mesh in the wall assembly of Test Home 5 is somewhat limited by the transition membrane depicted in Figure 41. This vapor-impermeable, self-adhered membrane extends up the sheathing for most of the height of the wood sill. Optimally, this airflow control transition membrane would extend up the sheathing only as far as needed to reliably adhere to the sheathing, thus leaving significant surface area of sheathing adjacent to the sill with the ability to dry toward the exterior. Alternatively, the transition membrane could be a vapor-permeable membrane.

Thermal control – The thermal resistance of the continuous exterior insulation layer is expected to be marginally affected by the breather mesh. The breather mesh air gap is open to the exterior at the base of the wall assembly only. Therefore, it is unlikely that there would be significant airflow through the gap as a result of wind or stack effect pressures. Convection currents within the gap are unlikely to develop because of the size of the gap and the convection suppression effect of the random mesh.

The ccSPF insulation to the interior provides robust thermal control in the wall framing cavities. With solid adhesion to surrounding framing, the ccSPF insulation would be less affected by bypasses than are some other types of cavity insulation. Although the material does provide robust cavity insulation performance, it is not reasonable to expect that it would be affordable to every project. Where robust airflow and thermal control are provided at or outside of the wall sheathing, the relative benefits of the ccSPF cavity insulation are diminished.

The vented, unconditioned attic raises the question of whether the exterior wall insulation should continue at the gable wall. It is not necessary for thermal reasons because the attic is insulated at the attic floor. Reducing the thickness or omitting the exterior insulation at the gable will usually require careful detailing to ensure the drainage plane function is carried continuously down the wall. In general this question seeks the balance between material costs, labor costs, risks of changing details, desire to avoid waste, etc.

Critter control – The project team for Test Home 5 was particularly concerned about protecting the exterior insulation from pests and insisted on using a brake-formed metal guard to protect the base of the foam wall (see Figure 45). Having such an element at the base of the wall entails the possibility that it will, if not properly sloped, risk concentrating water and depositing it onto the building. At Test Home 5, the metal guard for the exterior insulation has a reliable slope to the outside, and the simple building footprint avoids inside corners where such a flashing element along the bottom of the wall might concentrate water.

Figure 45. Brake-formed metal protection for exterior foam insulation at Test Home 5

(Credit: Michael Nobrega/Habitat for Humanity North Central Massachusetts, used with permission)

5.2.4 Rigid Foam Insulating Sheathing Applied as Successor Retrofit to Roof and Wall Retrofit

Test Home 2 involved an exterior wall insulation retrofit at a home where the roof and foundation had already been retrofit in a previous project. This situation created some particular challenges to transitioning of airflow control, as discussed below. The DER plan for this test home involved stripping the above-grade walls to the sheathing, repairing sheathing as needed, then adding house wrap over existing board sheathing; two layers of 2-in. foil-faced polyisocyanurate insulating sheathing; ¾-in. furring strips; and wood siding. Because the resulting retrofit assembly is similar to that implemented in other test homes featured in this report, the discussion below highlights the control function implications of integrating this strategy with previous retrofit measures.

Airflow control – The retrofit strategy employed both a house wrap layer and the face of the exterior insulation as airflow control layers. The previous retrofit to the roof and foundation assembly presented a well-installed ccSPF application. The contractor used sealant to transition the airflow control of the house wrap to the sheathing at the top and bottom of the wall assembly. At the base of the wall above the foundation, the airflow control of the exterior insulation is transitioned back to the house wrap layer through sealant applied between successive layers. The use of sealant between layers in this way provides an air seal that is not visually inspectable once it is implemented; however, the methods and materials are familiar.

Connecting the airflow control function of the exterior insulation to previous retrofit work proved challenging in some areas (see Figures 46 and 47). At the front of the building is an overhanging floor where the previous retrofit had applied ccSPF. The exterior insulating sheathing added as part of the current retrofit was applied to the face of the wall and continuous through the location where the roof had been cut away. As seen in the photos on the right, the use of two-part kit foam does not appear to have successfully connected the new work to the previous work.

Figure 46. Left: Front of building showing overhang during retrofit work, Test Home 2; Right: connection between new work and previous work at wall-overhang interface, Test Home 2

Figure 47. Left: Top plate at insulated ceiling showing new rigid insulation to other side of top plate, Test Home 2; Right: Top plate between previously retrofit ceiling and newly retrofit wall, Test Home 2

5.3 Window Measures

All of the projects featured in this report replaced existing windows with vinyl-framed triple-glazed new construction windows. The projects exhibited two different strategies for the location of the new window within the wall assembly.

5.3.1 Window Installed Proud of Drainage Plane

Four of the test home projects (Test Homes 1, 3, 4, and 5) installed windows proud of the drainage plane on either strapping or plywood blocking. The primary motivation for this approach appears to be to make use of a siding channel of the integral window casing trim that is a feature of many vinyl windows.

Windows installed following this method are fastened to wood strapping or plywood blocking that is itself installed over the exterior insulation and fastened back to the wall framing. This installation has the flange of the window installed in the same plane as the back of the siding, as would be the case for the typical practice of installing siding directly over sheathing/drainage plane without a ventilation/drainage gap behind the siding.

Window rough openings are lined with plywood or OSB to provide a nailing base for interior trim extensions. The bottom of the opening needs to provide a sloped base for the window sill drainage plan. This can created by plywood shimmed to slope to the outside (Test Home 1), plywood lining the opening positioned to have a positive slope (Test Home 4), or by a piece of beveled siding placed over the plywood/OSB lining the bottom of the opening (Test Homes 3 and 5). After the lining is installed in the opening, the opening is flashed with self-adhered membrane to the outer face of insulating sheathing or, in some cases, over the strapping installed over the exterior insulating sheathing around the window opening. Contractors for three of these projects installed metal attachment brackets at the sides of windows to fasten the window to the rough framing; these were used in addition to the fasteners in the nailing flanges.

Many contractors of both retrofit and new construction projects apparently struggle with structural attachment of windows (e.g., use of metal attachment brackets) and with integration of window trim and siding. This leads some contractors to install windows over strapping so that the nailing flanges can be used for attachment or so that the window flanges are aligned with the back of the siding.

Water control – It is possible to provide effective water control and flashing of windows installed proud of the drainage plane over strapping or blocking. Often, however, the transition of the drainage plane at the strapping or blocking proves a major vulnerability, as shown in Figure 48.

For retrofit projects where the window is installed over strapping, a sequencing problem is often observed where vertical strapping adjacent to windows prevented window head flashing from being connected back to the drainage plane. To provide head flashing across the top of the window, the adjacent vertical strapping would have to be cut and the upper piece temporarily removed.

Also, the installation of windows over strapping appears to increase the risk of flashing membrane fish mouths or wrinkles that present a bypass to water control (see Figure 49). These result from the complex folds to which the flashing membrane is subject as it wraps from the opening, over the strapping and then back to the drainage plane. These lapses in water control of the flashing membrane usually are mitigated by termination of the top edge of the flashing, which is necessary anyway. In these cases, the tape used to terminate the top edge of the flashing membrane amounts to flashing for the flashing.

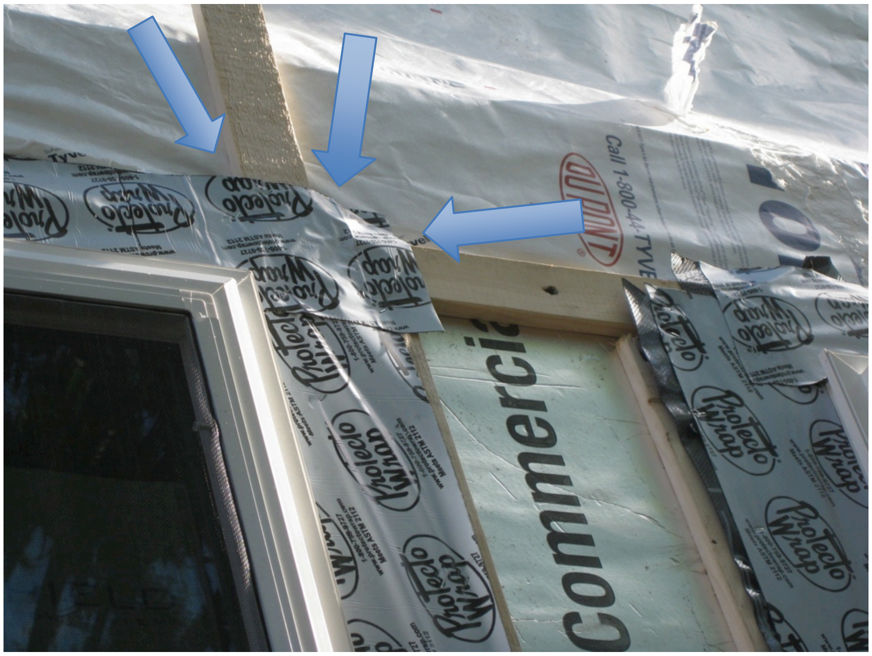

Figure 48. Scoop flashing at head of window installed over strapping at Test Home 3. Arrows indicate where water would be able to pass behind the flashing.

Figure 49. Wrinkles in flashing membrane wrapped over strapping and back to drainage plane. Note how this window head flashing requires flashing of its own.

It has been observed in the test homes as well as in other high performance and retrofit projects that misconceptions about the function of windows in regard to water control lead installers to seal the bottom flange of the window to the drainage plane. This blocks drainage of the sill pan flashing beneath the window. When windows are installed over strapping and only vertical strapping is installed beneath the sill flange, the strapping gap can provide an emphatic drainage gap that is difficult to subvert (Figure 50).

Figure 50. Installation of the window over strapping provides a generous drainage gap for the sill pan flashing.

Airflow control – In the test homes that used the house wrap against the sheathing as the primary airflow control layer, implementation sequence was a critical factor in the ability to achieve airflow control at the window. In two of the test homes, the house wrap and exterior insulation had been installed *prior* to removing the existing windows. This made it difficult to transition the airflow control membrane into the window opening in a continuous manner. Where the house wrap is turned into the window opening, adhered membrane that also serves to flash the opening can provide airflow control transition to the window.

Where the outer face of insulating sheathing is intended to provide airflow control, installation of the window over strapping generally requires that the opening through the exterior insulation be wrapped with an airflow control transition membrane prior to installation of strapping or blocking around the window. In practice it is very difficult to achieve continuous airflow control at the windows if the airflow control transition membrane is wrapped over strapping that is installed around the opening and over the face of the exterior insulation.

Vapor control – Because the plywood or OSB lining of the window opening extends through the thermal control layer, there is a question of whether this material is vulnerable to condensation moisture risk. Through thousands of implementations, BSC has not seen evidence that it is.

Thermal control – The window is relied on to provide thermal control for the opening. For this window installation approach, the plywood or OSB lining and strapping may create thermal bridging from outside of the exterior insulation to inside of the window opening, but if so, it is relatively minor. In one of the projects, the plywood lining around the window opening extended only through the innermost 2-in. layer of insulating sheathing. In this case, the assembly provided a thermal break for the plywood extension box.

5.3.2 Window Aligned With Drainage Plane

The one project that exhibited windows installed in alignment with the drainage plane of the wall, employed 2x blocking let in to the outermost layer of exterior insulating sheathing. Because the insulated sheathing used is 2 in. thick, the blocking is padded to the inside with ½ in. of rigid foam insulation. The blocking is fastened to the wall framing through the inner layer of exterior insulating sheathing. The window opening is fully flashed to the exterior face of insulation with self-adhered membrane extending over the 2x blocking. Positive drainage of the window sill pan flashing is established by cutting the foam at the bottom of the window opening to provide a slope. With the opening prepared, the window is installed and flashed as per typical practice with fasteners into the 2x blocking through the nailing flanges.

Installing the window aligned with the drainage plane follows acceptance of exterior window trim separate from any integral trim of the window unit. The contractor for Test Home 2 was the only contractor who managed to install the window aligned with the drainage plane. This contractor developed elegant solutions for doing so.

The windows used in Test Home 2 did have an integral siding channel as did windows for the other test homes. Because the siding is installed over furring strips to create a drainage and ventilation space behind it, the siding channel was co-opted for functions other than concealing the butt ends of siding (see Figure 51). Rather than attempt to run siding into the integral siding channel as support for window trim, the Test Home 2 contractor used this flange to provide support for window casing trim and to provide closure for the cladding vent space. The edge of the exterior window casing trim was rabbeted on the side toward the window to allow the casing trim to lie flat across both the strapping and the flange of the window's siding channel. Because the casing meets the flange of this siding channel, there is no need to close or screen an opening to the ventilation gap around at the jamb and head of the window. With the window casing trim supported at the edge toward the window, the furring strip, which is needed for trim and siding attachment at the side of the window, can be installed further from the window. This strapping is able to be installed flat against the insulating sheathing and not partially over the window flange. Thus the contractor for Test Home 2 was able to make use of a feature of the windows that had been an obstacle for other contractors.

Figure 51. Window installed with flanges aligned with drainage plane at Test Home 2. Note strapping run up to, but not over, bottom flange of window. A single piece of strapping at the side of the window is sufficient to support both trim and cladding attachment.

Another innovative benefit realized by the installation method used in Test Home 2 is that reduction in view area of the new window relative to the window it replaces is minimized. The new window installed at the exterior can be the full size of existing window opening or even slightly larger. Newer windows typically have a frame and sash frame that occupies a thicker profile than the frame and sash frame of older wood windows. Therefore, installation of new windows in existing window openings will typically reduce the view and daylight area of windows. The window installation method exhibited in Test Home 2 allows for installation that does not reduce the view and daylight area of the windows. In this test home the inside edge of the wood blocking was set approximately ½ in. to the outside of the existing window opening (see Figure 52).

Figure 52. Window sealed to membrane at inside perimeter of window at Test Home 2. Note how the window frame is slightly larger than the finished opening.

Water control – Water control at the window is more robust and more reliably implemented because flashing of the opening and the window can be done per standard manufacturer installation details. Also, the window flashing negotiates fewer corners than in the case where flashing is wrapped from the opening, over strapping, and back to the face of the insulating sheathing. Therefore, the window flashing is much less prone to wrinkles and fish mouths.

Airflow control – The exterior face of insulating sheathing provides the primary airflow control of the wall. A self-adhered membrane transitions the airflow control into the window opening. The interior perimeter of the window is sealed to the membrane with backer rod and sealant at the jamb and sill and with appropriate caulk at the window head.

Water vapor control – Wood blocking that is let in to exterior layer of insulation is shielded from interior vapor by a vapor impermeable self-adhered flashing that wraps into the opening over the wood blocking and inner layer of insulating sheathing. If the window itself is constructed of moisture-insensitive materials (as it is in this case), all moisture-sensitive materials are protected from condensation risk at the window opening.[5]

Thermal control – This window approach is unique in that it allows a layer of exterior insulation to be uninterrupted up to the window opening. The exterior insulation is bridged only by fasteners for the blocking. There is no plywood or OSB thermally bridging through the exterior insulation into the window opening.

[5] This approach to window installation would also provide robust protection from inward vapor drive such as might be experienced with an air-conditioned building in a hot humid climate.

5.4 Foundation Wall Measures

It is typical in this region for homes to have full basements, which are often regarded as important usable spaces. Also, for durability of structure and energy performance reasons, it is important to include the basement in the thermal enclosure when feasible (Lstiburek 2006).

5.4.1 Closed-Cell Spray Polyurethane Foam Applied to Foundation Wall

Three of the test home projects (Test Homes 1, 4, and 5) included foundation insulation strategies.[6] Each of these employed ccSPF at 2–4 in. thickness to provide insulation, air sealing, and water management at the foundation wall. Two of these projects involved an existing rubble stone foundation wall and one involved a cast concrete foundation wall. One of the projects with a rubble stone wall also had a new concrete underpinning wall that was insulated to the interior with 2 in. XPS.

To provide a thermal barrier for the ccSPF foundation wall insulation, two of the projects installed gypsum wall board on a wood stud wall (see Figure 53). The wood stud walls were set 1–2 in. away from the foundation wall to allow the ccSPF to provide continuous insulation, air and water control between the wood framing and the foundation wall. One of the rubble stone foundation wall projects elected to apply an intumescent paint coating over the ccSPF as a means to provide the required thermal barrier.

Figure 53. Thermal break between wood stud wall and concrete underpinning wall at Test Home 4

Water control – The ccSPF is an adequate control layer. It is capable of managing liquid water that may pass through the foundation wall. In situations where the wall is known to pass water or has potential to pass water, the water control of the foundation wall should be connected to a drainage system at the floor.

[6] One other project, Test Home 2, has a conditioned basement that was brought into the thermal enclosure through application of ccSPF to the foundation wall as part of a prior project. The prior project is not evaluated in this report.

This drainage system at the floor typically follows one of three methods:

- Subslab drainage system. This is applicable to projects that have the opportunity to install a new concrete slab over gravel layer. The drainage field must be connected to a sump or piped to daylight.
- Interior foundation perimeter drain. For projects where complete excavation of the existing slab is not feasible, a perimeter drain may be installed at the inside perimeter of the basement and below the level of the slab; it must be connected to a sump or piped to daylight.
- Drainage layer over existing slab. A drainage layer consisting of a drainage mesh or dimple mat is applied over the existing floor. The sump is located at the lowest point of the floor. This is a least-cost approach for projects where it is not feasible to excavate or cut through the existing slab. There is some sacrifice on headroom with this method.

The project team for Test Home 1 determined that liquid water was not an adequate risk to merit a drainage system at the basement floor.

Test Home 5 installed basement foundation insulation after casting the slab, which was cast directly to the rubble stone foundation wall. This missed an opportunity to connect the water control of the foundation wall to the subslab drainage system (gravel with pipe to daylight). Also, this configuration results in a significant thermal bridge. For this project, the exterior perimeter drain on three sides of the foundation is likely to provide adequate control of groundwater. The owner also reports that the foundation had not exhibited signs of liquid water intrusion in three years of observation prior to installation of the exterior drain.

Test Home 4, which involved excavation to allow a lower slab and a concrete underpinning wall, demonstrated a connection of the foundation water control to the subslab system. Polyethylene sheet vapor retarder placed on top of rigid insulation beneath the concrete slab continues up the face of the underpinning wall to the base of the rubble stone wall. The polyethylene is embedded in the ccSPF applied to the foundation wall. Figure 53 shows the polyethylene sheet turned up to the rubble stone wall. Should liquid water pass through the foundation wall, it would be controlled by the ccSPF insulation and then by the polyethylene sheet. Irregularities in the surface of the concrete provide drainage pathways for liquid water to reach the subslab drainage system.

Airflow control – Observation of the implementation of ccSPF foundation wall insulation in the test homes confirmed that ccSPF provides robust airflow control in the field of the wall. Connections are critical. Particular attention is needed to ensure continuous connection to the slab or perimeter insulation at the base of the wall, and to the top of foundation wall.

Water vapor control – ccSPF provides adequate control of ground source water vapor in the field of the wall. There is a potential concern with strategies exhibited in the test homes where wood stud framing is partially embedded in the ccSPF insulation layer. If the ccSPF is not continuous or of adequate thickness between the wood framing and the foundation wall, the wood framing could be exposed to high levels of relative humidity. More robust water vapor resistance would be provided by:

- Greater separation between the foundation wall and wood studs if wood framing is used

- Use of moisture-insensitive framing support such as metal studs for the thermal barrier.

Greater separation between the foundation and wood framing does infringe on the usable space in the basement. Metal framing should not be deeply embedded into the ccSPF, as the thermal bridging it introduces would negate much of the thermal benefit of the insulation. Metal framing is available in smaller dimensions that, with a slight embedment in the ccSPF for stiffness, can reduce the infringement into usable space.

Thermal control – Observation of the implementation of ccSPF foundation wall insulation in the test homes confirmed that this approach provides a reliable and consistent thermal control in the field of the wall. Where the ccSPF is applied to the foundation wall between wood framing members, there is concern that the application may not be entirely continuous behind the framing.

Both projects that employed a wood stud wall in conjunction with the ccSPF foundation wall insulation demonstrated an effective thermal break underneath the bottom plate of the stud wall. As shown in Figure 54, the contractor for this test home (Test Home 4) placed the bottom plate of the stud wall over a 2-in. layer of XPS rigid insulation. Test Home 1 employed ccSPF foundation wall insulation in conjunction with a wood stud wall over an existing cast concrete foundation wall. The stud wall is actually reused from the wood stud wall that had existed in the basement prior to retrofit. When the wall framing was rebuilt, the studs were cut to allow the bottom plate to be placed over a strip of 2-in. XPS rigid insulation. This provided a thermal break between the basement slab and the wall framing, which allowed the airflow control of the wall system to be positively connected to the airflow control of the floor system, and resolved a sequencing challenge so that construction activity could continue in the basement without damaging the basement floor insulation.

Figure 54. Thermal break between wood stud wall and existing concrete slab at Test Home 1

5.5 Floor Over Basement

One of the projects featured in this report, Test Home 3, elected to exclude the semifinished basement from the thermal enclosure. The contractor was determined to achieve an airtight separation between the conditioned space above the basement and the basement. The project plan for the floor over the basement included removal of the existing basement ceiling, application of a 1-in. flash coat of ccSPF to the underside of the subfloor above, installation of 1 in. foil-faced polyisocyanurate insulation to the underside of the floor joists, taped seams of the rigid insulation and application of foam sealant at penetrations, then dense-packed cellulose insulation in the floor framing cavity.

In addition to the floor/ceiling treatment, the walls to basement access stairs were insulated with either ocSPF or cellulose cavity insulation where the stair is adjacent to either the first floor or upper floor apartment. During the course of the project, the ccSPF flash coat was eliminated for cost reasons. Still, the builder did use canned foam as a sealant at penetrations through the subfloor and at the perimeter of and penetrations through the rigid insulation layer.

Water control – This assembly is presumed to not need to provide liquid water control.

Airflow control – It appears that the basement isolation approach employed in the test home failed to provide robust air separation between the basement and the living space. The primary airflow control materials used in the assembly are similar to those used successfully in the retrofit wall strategies. However, one major difference between a typical basement ceiling and an exterior wall is that there are many more penetrations made through the basement ceiling (e.g., penetrations for plumbing and electrical services). Also, access stairs to the basement from conditioned space typically involves partitions and “ceilings” with complex geometries and poorly defined airflow control planes. This particular project also had an air handler; ventilation equipment located in the basement with the ductwork connecting to the conditioned space above; a brick chimney that extended from the basement into conditioned parts of the building; and framed wall assemblies in the basement that may have presented airflow bypasses around the intended airflow control layer.

The floor over basement strategy also differs from wall strategies in that a single layer of rigid material – 1 in. polyiosocyanurate rigid foam with taped joints and foam sealant at the perimeter and penetrations – is expected to provide airflow control. Most of the wall assemblies employed two layers of rigid material with joints offset to perform this function. The dense-packed cellulose would provide some resistance to airflow, but would not provide sufficient resistance to be considered an air barrier material. Loose brick fireblocking that was observed at portions of the perimeter of the basement create airflow channels that could bypass the floor assembly and connect the basement and framed wall cavities to air leakage gaps at the base of the framed wall.

Water vapor control – The configuration of the assembly with a foil-faced rigid insulation board to the basement side provides robust diffusion control of water vapor that might otherwise diffuse into the living space. The general moisture loading of the conditioned space is generally not as great a concern as would be the specific moisture loading of moisture-sensitive elements. The assembly exhibited in this test home does not provide water vapor control for structural elements exposed to the basement environment.

What is of particular concern with this approach is that it has the potential to leave all of the existing moisture-sensitive materials and finishes in the partially finished basement exposed to a generally higher relative humidity.

Thermal control – As with the airflow control, the assembly would appear to offer robust performance in the basic arrangement of layers. However, this is partially undermined by thermal bridging of structural elements (carrying beams and framing in side walls of the access stairs) and of masonry chimney (see Figure 55). Also, the location of forced air heating and ventilation equipment in the basement means that these systems are subject to additional conduction and likely convection losses.

Figure 55. Left: Structural beam exposed to basement; Right: Framed wall sill exposed to basement

5.6 Basement Floor Measures

Test home projects that included the basement in the thermal enclosure exhibited two approaches to basement floor insulation. One project, Test Home 2, elected not to insulate the existing basement floor.

5.6.1 Insulation Above Existing Slab

This approach, which was used in Test Home 1, involves 2 in. XPS rigid insulation installed directly over the existing concrete slab and a walking surface of plywood, OSB, or engineered laminate flooring installed as a floating floor on top of the rigid insulation.

Water control –Test Home 1 employed insulation over the existing slab. The team had determined that liquid water did not present an adequate risk to merit a drainage system; hence, there is no drainage mat between the rigid insulation placed on top of the slab. A sump pit was cut into the existing slab. This measure provides a location where the homeowner will be able to install a sump pump to remediate liquid water problems should such be experienced at some time in the future. In the meantime, the owner minimized the expense toward a contingency for a problem that, according to all available indications, does not exist at this site.

If there were indications of liquid water penetration through the foundation assembly, it would have been necessary to provide for control and collection of liquid water at the basement slab. One means of doing so is to remove a portion of the basement slab to install an interior perimeter drain. Provided the perimeter drain is below the slab and that there is provision for the water control of the foundation wall to drain into the perimeter drain (see discussion of water control at foundation wall), the perimeter drain can be assumed to intercept liquid water and prevent it from reaching the top of the slab through the hygric head.[7] Another means of collecting and controlling liquid water is to drain across the top of the slab. This requires a slope to a sump (with a pump or drain outlet) and a drainage gap between the slab and insulation placed above it.

Airflow control – Taped seams of the rigid insulation provide airflow control at the field of the floor. The design achieves positive airflow control connection to the foundation wall system with floor insulation placed prior to the perimeter wood stud wall so that the ccSPF of the wall system is joined to the floor system.

Interestingly, the decision not to install a drainage layer to the basement slab ("cold") side of the insulation may benefit the control of airborne moisture in the basement floor assembly. Drainage mats and dimple mats installed over a basement slab and beneath a layer of insulation have been observed to provide a slight give to the floor assembly. This compression of the floor assembly results in a pumping action that could move air from one side of the insulation and airflow control layer to the other. With the insulation layer installed directly over the concrete, it provides sufficient resistance to compression that, once the traffic surface is installed, deflection underfoot is not noticeable.

On the other hand, the decision not to install a drainage layer above the existing slab or a subslab perimeter drain precluded the opportunity to collect and evacuate soil gases passing through incidental cracks in the foundation.

Water vapor control – The concrete slab and 2-in. layer of XPS were deemed to provide sufficient diffusion control of water vapor. Convective transfer of water vapor is effectively managed by a thorough taping of seems in the rigid insulation layer.

Thermal control – The approach provides for a continuous and robust thermal control across the basement floor. There are thermal bridges through the insulation layer represented by the structural columns (see Figure 56), but these would be expected to be of minor consequence to building energy use and, with proper control of indoor humidity, should not represent a significant risk for summertime condensation.

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[7] That is, liquid water from the ground will not flow onto the slab under the force of gravity. However, unless there is a capillary break beneath the slab, it would still be subject to capillary transfer.

Figure 56. Basement floor insulation at Test Home 1 installed near end of project to prevent damage to insulation

5.6.2 New Insulated Concrete Slab

Test Homes 4 and 5 excavated the existing basement slabs. This provided the opportunity to provide new insulated and water managed basement floor slabs. In outline, the assembly is as follows:

- Free draining gravel
- 2-in. XPS rigid insulation
- Polyethylene vapor retarder
- 4-in. concrete slab.

Water control – Effective water control for this system relies on effective perimeter or subslab drainage to manage groundwater, as well as a connection between the foundation wall water control system and the perimeter or subslab drainage system.

At Test Home 5 it was observed that the new basement slab was cast directly against the foundation wall. This precluded establishing a direct connection between the water control function of the foundation wall with the excellent subslab drainage system. This system will likely still be able to provide adequate control of liquid water because of the exterior perimeter drain controlling groundwater and the surface regrading, which improve draining of surface water away from the foundation.

More problematic for liquid water management at Test Home 5 is the layer of sand placed between the polyethylene vapor retarder layer and the newly cast concrete slab (see Figure 57). This sand layer will serve as a reservoir for excess water in the basement slab concrete mix. This reservoir can store large amounts of water and would only be able to dry very slowly, as it is between polyethylene and concrete.

Figure 57. New basement slab and structural support at Test Home 5

(Credit: Michael Nobrega/Habitat for Humanity North Central Massachusetts, used with permission)

Also, the sand reservoir is easily recharged by groundwater if groundwater should rise to the layer of the polyethylene beneath the slab. The sand reservoir beneath the concrete slab could detrimentally affect finishes placed over the slab (Lstiburek 2008). With a low head height of just over 6 ft, this space is not intended to be used as finished space. It will house mechanical equipment and laundry facilities.

Airflow control – The concrete slab can be expected to provide adequate control of soil gases and infiltration from below the slab – until it cracks. BSC always recommends that homes with new basement slabs in this region include a passive radon pre-mitigation system as described in the U.S. Environmental Protection Agency builder resource, "Building Radon Out."(EPA 2001) Test Home 5 was already underway when it joined the National Grid DER Pilot. As such, the basement slab was cast before BSC had the opportunity to recommend the soil gas control measure. Because the subslab drainage system opens to daylight, it provides a means to relieve soil pressure to the atmosphere. Because the warmer air in the house is buoyant, the drainage system does not necessarily provide pressure mitigation of soil gas pathways if the basement is at a lower pressure than the ground and the ground level atmosphere.

At Test Home 4, the contractor placed a soil gas collection pipe in the gravel beneath the slab with a vertical connection stub extending through the newly cast slab. This measure provides accommodation for a soil gas vent at some point in the future but minimizes cost to the current project. Where a soil gas collection pipe is cast through a slab, it is very important that the pipe connection be clearly labeled so that it is not mistaken for a soil pipe/sewer access.

Water vapor control – For reasons that are not clearly understood by this research team, the contractor for Test Home 5 installed a layer of graded sand above the polyethylene vapor retarder before placing the concrete slab. In most building situations, this configuration has the potential to subvert the vapor and capillary control function of the polyethylene in several ways as explained by Lstiburek (2006; 2008). For Test Home 5, the granular layer is unlikely to represent a significant water vapor risk because both the subslab gravel layer and the foundation perimeter drain are connected to a pipe that is sloped to drain to daylight.

Thermal control – The continuous rigid insulation placed beneath the slab provides adequate thermal resistance to provide comfort and control of condensing surface temperatures in the middle of the basement. At Test Home 5, casting the slab directly against the foundation wall precluded a thermal break at the perimeter to thermally isolate the slab.

5.7 Uninsulated Basement Floor Slab

The project team for Test Home 2 opted not to install insulation to the existing concrete basement floor slab. The current owners had occupied the home for several years, and two years had passed since the foundation walls had been insulated as part of a prior retrofit. The owners reported that they had not observed any bulk water in the basement and that it had not smelled musty since the walls had been insulated with ccSPF. Observation during site visits on two different occasions confirmed that the basement did not smell musty and that exposed portions of foundation wall and the slab did not show evidence of liquid water.

The approach of leaving the basement slab untreated does not provide robust moisture risk management, soil gas control, or thermal control. Fortunately, it is also a zero-cost approach that does not impede implementation of a more robust approach at some point in the future.

Water control – The system does not provide a means to control or collect liquid water. Instead, the strategy employed is one of minimizing damage should water enter the basement (e.g., groundwater, surface water, or plumbing leak). The concrete itself is not susceptible to damage from being wet. Paper-faced gypsum wallboard providing a thermal barrier for the ccSPF on the foundation walls would be susceptible to damage from water. As shown in Figure 58, appliances are lifted off the basement slab on a platform and other stored items are raised off the floor on moisture-insensitive shelving. Sections of carpet shown in this image are easily removable.

Figure 58. Equipment platform and shelving in basement of Test Home 2

The decision to manage liquid water risk in this way rather than to install liquid water management systems involves value judgments best left to informed building users and owners.

In this case, the owners had a reasonable period of observation to inform their decision about the magnitude of the risk. The users and owners of the space also assume responsibility for managing the impact of potential liquid water events by the way in which the space is used. In any case, it would not be recommended to install or store moisture sensitive materials on top of the slab in this situation.

Even without liquid water flowing onto the top of the slab, liquid water could be transferred to the slab surface through capillarity. The water would then evaporate or be wicked into hydrophilic materials contacting the slab. There did not appear to be indications (e.g., musty smells, darkened areas of concrete around cracks, or abrasions in the concrete) that capillary transport of moisture through the slab is a significant moisture transport mechanism at this test home. Had such indications been present, coating the concrete slab with epoxy paint would be recommended.

Airflow control – The concrete slab provides reasonable control of soil gases where it is intact. Cracks in the slab or penetrations through the slab would need to be sealed with urethane caulk to maintain the airflow control function of the slab.

The decision not to install a drainage layer above the existing slab or a subslab perimeter drain precluded the opportunity to collect and evacuate soil gases passing through incidental cracks in the slab. The retrofit measures already applied to the home as well as those applied as part of the current project all serve to make to make the home more airtight. Therefore, it would be particularly important to control soil gas infiltration by the following measures:

- Seal any cracks or gaps in the concrete.
- Provide robust dilution ventilation to manage contaminants that do enter into the home.

Water vapor control – Where the slab is not coated and where it is of an age where it would not have a vapor diffusion retarder beneath it, concrete would provide the only vapor diffusion control between the basement space and the ground beneath the slab. Although vapor diffusion through the slab may not represent a significant load on the general conditions inside the home, it would be locally significant for moisture-sensitive materials on top of the slab. For example, the bottom of a cardboard box containing materials or items that restrict vapor diffusion would be vulnerable if placed on top of the slab. For this reason, it would be recommended to either:

- Avoid storing or installing moisture sensitive materials in close proximity to the slab, or
- Coat the slab with an epoxy paint.

The concrete slab would be expected to be cooler than interior conditions throughout the year. Therefore, it presents a risk of condensation on – or elevated humidity surrounding – materials in contact with or in close proximity to the slab. Materials stored on top of the slab could also act to insulate the slab from interior conditions, meaning that the top of the slab beneath a pile of stuff would tend to be cooler than exposed slab surfaces. For this reason, it would be recommended to either:

- Avoid storing or installing moisture-sensitive materials in close proximity to the slab, or

- Actively control humidity within the space to maintain a dew point cooler than area ground temperatures.

Given the risks inherent in vapor diffusion through the slab, as well as condensation risks associated with the ground-coupled slab, moisture-sensitive materials should not be installed or stored in close proximity to the slab.

Thermal control – The approach does not provide appreciable resistance to heat loss into the soil. For the climate in which these test homes are located – a predominantly heating climate, the potential benefit that this ground coupling would have in the cooling season would be more than offset by the liability it presents in terms of heating load.

6 Enclosure Retrofit Strategy Costs

For most of the enclosure measures discussed in this report, there is a significant difference between the cost of typical exterior maintenance (e.g., replacing the siding or replacing the roof) and the cost for the high performance energy retrofit. However, the siding or roofing project provides the perfect opportunity to execute energy efficiency improvements. Failure to include performance improvements at the time of enclosure component replacement or upgrade effectively precludes such improvement for the service life of the component.

The comprehensive retrofits or combinations of high performance measures that these test homes represent are in fact unlikely to have been feasible without the significant financial incentives made available through the National Grid DER Pilot. The goal of the pilot program has never been to promote comprehensive DER as a fiscally compelling proposition. Rather, it is positioned as a research platform whereby a relatively small number of projects, each including multiple component measures or comprehensive retrofit, provide experience and lessons relative to multiple building system components. These lessons and experiences can then be applied to advanced retrofit measures aligned with renovation activity already taking place in the residential home improvement market. Although a homeowner is unlikely to have resources and motivation to fund the incremental cost of a comprehensive retrofit, the incremental cost associated with a planned siding replacement, basement remodeling, or roof replacement, for example, is more likely to be something that a homeowner would willingly support.

The measure cost information provided in Table 2 is as reported on the pilot program application forms. The costs reflect builder proposals and estimates prior to construction. The costs will reflect varying and unique circumstances of each project and site. The costs shown do not reflect offsets from utility program rebates or other incentives. Where more than one test home employed the same enclosure component strategy, the range of unit costs is provided.

The total measure costs represent the cost to implement the measure to a level of DER performance as well as the cost inherent to the retrofit measure without DER levels of insulation and air sealing. An example of total measure cost would be a wall retrofit measure cost that includes the cost of exterior insulation as well as the cost of new siding. The incremental performance improvement cost is meant to reflect the incremental cost above code or standard practice for the measure. This figure is somewhat dependent on the builder’s interpretation of DER specific components of the measure. For example, the robust water management required by the DER Pilot Program may or may not be included as incremental performance costs.

Some costs reported reflect binding fixed-price quotes from contractors or subcontractors. It is expected that binding fixed-price quotes given after several iterations of the measure by a contractor would provide more accurate cost data.

Table 2. DER Test Home Enclosure Measures and Cost

Enclosure Component/Strategy	Additional Parameters	Total Measure Cost	Incremental Performance Improvement Cost
Roof or Attic Unvented Attic With ccSPF	8 in. target depth, 2 × 6 rafter framing 10" target depth, 2 × 10 rafter framing with strapping	N/A $17.76/ft^2$	$3.15/ft^2$ $5.09/ft^2$
Exterior Insulation and Framing Cavity Insulation (includes rebuilding of rakes, eaves, trim)	Mix of cavity insulation including ocSPF and dense-packed cellulose	$22.22/ft^2$	$7.44/ft^2$
Vented Attic (total cost includes re-framing roof, new eave and rake trim and re-roofing)		$31.35/ft^2$ (relative to attic area)	$7.00/ft^2$
Above-Grade Wall Rigid Foam Insulating Sheathing With Air Permeable Framing Cavity Insulation	Fiber-cement siding Vinyl siding	$10.88–$32.40/ft^2$ $10.41/ft^2$	$3.92–17.37[8]/ft^2$ $4.46/ft^2$
Rigid Foam Insulating Sheathing With ccSPF Framing Cavity Insulation, Breather Mesh	Vinyl siding	$17.73/ft^2$	$11.59/ft^2$
Windows Triple-glazed, vinyl frame	Double-hung casement	$56.12–$65/ft^2$ $38.64–$64.60/ft^2$	– –
Foundation Wall Insulation With ccSPF	Wood stud wall supporting gypsum wall board thermal barrier Intumescent paint thermal/ignition barrier	$3.77–$5.80/ft^2$ $8.87/ft^2$	$2.15–$4/ft^2$ $7.71/ft^2$
Floor Over Basement ccSPF, dense packed cellulose, foil-faced polyisocyanurate		$5.18/ft^2$	$4.33/ft^2$
Basement Floor Slab Insulation above existing slab	No drainage layer, OSB floating floor	$4.88/ft^2$	$1.68/ft^2$
Insulation under new slab	Excavation of existing slab	$9–$16.91/ft^2$	$1.68/ft^2$

[8] The higher cost figure for this measure includes reconstruction of roof overhang necessitated by increased wall thickness

7 Test Home Performance Assessment

The test home project comprehensive performance, which reflects the interaction of measures implemented through the project, was assessed through air leakage testing and energy modeling. Air leakage testing results are employed in the energy modeling. Energy modeling produced estimates of source energy reduction achieved relative to pre-retrofit conditions. Despite the fact that this report targets the assessment of thermal enclosure retrofit strategies, it should be noted that assessment of comprehensive performance necessarily includes effects of nonenclosure measures.

7.1 Air Leakage Testing

For each of the test homes, blower door testing was conducted prior to starting retrofit work and after completion of the project. Figures 59 and 60 represent the CFM50 and ACH50 measurements for each test home before and after retrofit.

Table 3 summarizes the air leakage results and provides the air leakage measure in metrics normalized to area of thermal enclosure, conditioned floor area, and enclosed volume.

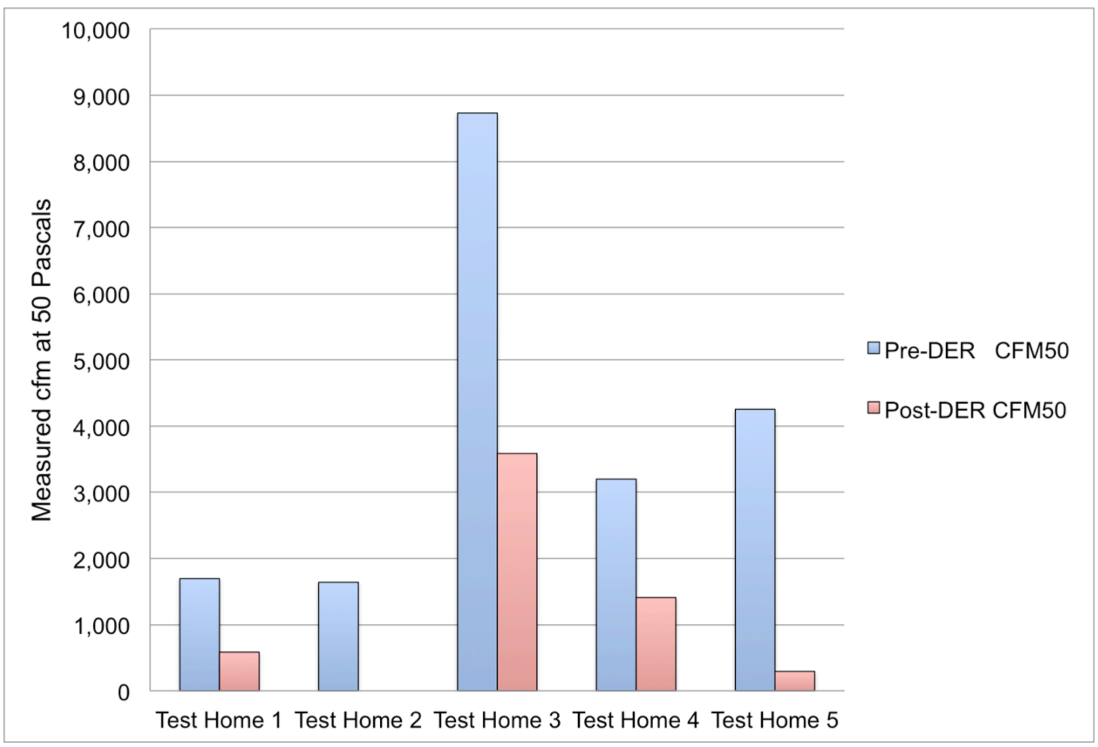

Figure 59. Pre- and post-retrofit CFM50 measurements

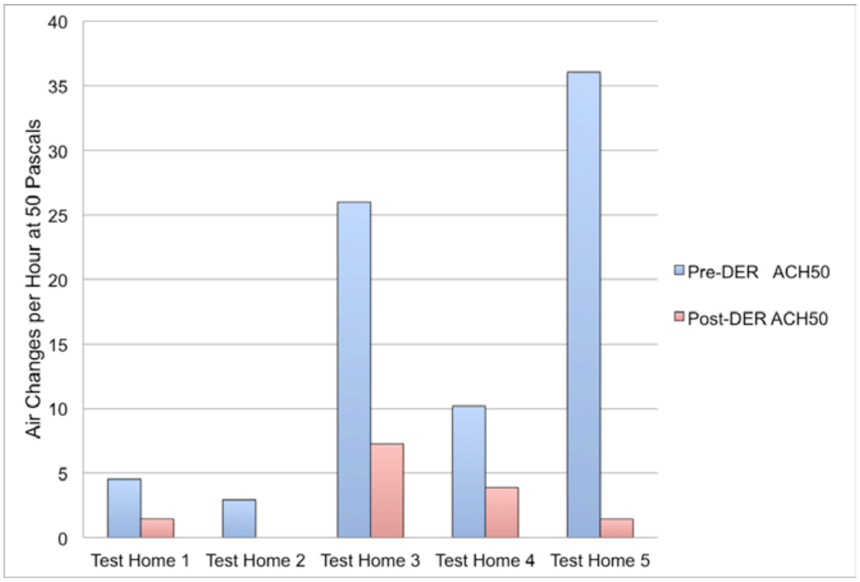

Figure 60. Pre- and post-retrofit ACH50 measurements

Table 3. Blower Door Testing Summary for DER Test Homes

Test Home Pre-/Post-	Pre- and Post- DER Test Results				Testing Configuration
	CFM50	CFM50/ft² Enclosure	CFM50/ft² Conditioned Floor Area	ACH50	
Test Home 1 Pre DER	1695	0.50	1.06	4.5	Basement included
Post-DER	584	0.16	0.25	1.4	Basement included, increased enclosure area and volume for conditioned attic
Test Home 2 Pre-DER	1640	0.22	0.52	2.9	Existing insulated basement included
Post-DER	Pending	Pending	Pending	Pendin g	
Test Home 3 Pre-DER – unguarded WRT basement	8730	1.69	3.49	26	Basement open to outside
Post-DER – unguarded WRT basement	3586	0.61	0.99	7.3	Basement open to outside, increased enclosure area for full 2nd floor, cathedralized roof and gable walls
Test Home 4 Pre-DER	3199	0.86	1.76	10.2	
Post-DER	1410	0.33	0.64	3.9	Increased enclosure area for conditioned basement, roof and gable walls
Test Home 5 Pre-DER	4254	1.65	4.34	36	Data for neighboring house of similar construction
Post-DER	293	0.09	0.20	1.43	Insulated basement included, increased enclosure area for full 2nd floor

Although the pre- and post-retrofit air leakage results vary significantly among the test homes, it can be observed that most of the homes achieved post-DER normalized air leakage rates at one third or less of the pre-DER values.

Test Home 5 achieved the lowest post-DER air leakage measurement normalized to thermal enclosure area and conditioned floor area. Test Home 5 also achieved the greatest reduction percentage. It must be noted, however, that the upper floor of this home is entirely new construction. This was also the only home to have spray foam insulation in the wall framing cavities. Another factor that benefited the air leakage performance for this home is the well-detailed house wrap airflow control at the exterior wall. This project used robust means to seal the house wrap at both the top and bottom of the wall.

Test homes 2 and 4 are notable for the fact that these projects retained interior finishes and therefore would not have had access for sealing the exterior wall from the interior side.

What clearly stands out among the air leakage testing results is the poor performance achieved by Test Home 3, which is the two-family test home that designated the ceiling over the basement as part of the thermal enclosure. It appears that, despite earnest efforts on the part of the contractor, there is still significant leakage between the basement and the apartments above. Through guarded blower door testing, it was determined that leakage at 50 Pa between the apartments and the basement is approximately the same as the leakage at 50 Pa through the rest of the apartments' enclosure. The rest of the apartments' enclosure, excluding the separation to the basement, was measured to have a normalized air leakage rate of 0.33 CFM50/ft^2 of enclosure. This air leakage measurement is similar to what was measured for the basement alone in the guarded test (see Table 4 and Figure 61). This suggests that measures to isolate the basement from the conditioned space only marginally reduced the overall leakage of the building. If the untreated basement enclosure provides equal or better airflow control than the extensively air sealed basement ceiling and access stair walls, it is reasonable to expect that a much smaller air sealing effort applied to the basement enclosure would have yielded better airflow control results.

Table 4. Test Home 3 Diagnostic Blower Door Testing Summary

	Fully Unguarded WRT Basement	Guarded WRT Basement	Estimated CFM50 Leakage Across Basement Separation
		CFM50	
Pre-DER Testing	8730	4888	4250–4298
Post-DER Testing	3586	1847	1800–1942
Difference (reduction)	5144	3041	~2300–2500
% Reduction	59%	62%	~54%–58%

Figure 61. Post-DER guarded blower door testing at Test Home 3

7.2 BEopt Energy Modeling

The retrofit project plans for these test homes were a combination of measures that have been successfully used in earlier retrofits and in new construction (Pettit 2009, BSC 2010a, 2010b) as well as approaches developed by the project teams. Whole-house energy consumption simulations were not used in the planning phase for these test homes. Typically, the project had already determined basic directions for the retrofit measures prior to BSC's involvement.

Using BEopt software, each test home was modeled in its as-built or as-designed condition as well as with selected alternatives for various components. Two of these test homes involved significant additions of space or complete reconstruction of portions of the building. In such cases, the baseline pre-retrofit model actually includes this additional space and models it as if it were constructed using the same assemblies as in the existing pre-retrofit structure.

The energy modeling presented in this report is aimed at informing two distinct lines of inquiry. The first line of inquiry seeks to estimate the overall energy use reduction of the project. This prediction of overall annual energy use reduction can then be compared to reported project costs for a measure of the overall energy savings cost-effectiveness of the project. This analysis uses cost information provided by contractors during the application phase of the DER Pilot participation.

A separate line of inquiry involves evaluation of the individual DER measures implemented. These measures are evaluated for energy savings cost effectiveness relative to conceivable alternatives. This type of analysis is very sensitive to the accurate representation of individual measures and alternatives. This is often difficult within the capabilities of the modeling tool and of the user of the tool. Many DER measures implemented in test homes must be significantly abstracted to be represented to the energy modeling tool. Also, assessment of the impact of individual measures must either ignore interactive effects or use unverifiable assumptions about interactions between measures. For example, the window replacements provide an opportunity to reduce infiltration both through the window unit and through the window-to-wall interface. The improved connection between the window and wall is, in turn, dependent on the wall system being retrofit with an airflow control layer typically implemented as part of a wall insulation strategy.

Cost information used in assessment of individual measures is derived from RS Means databases and the BEopt default libraries and supplemented with information in DER Pilot Program application forms only where needed. It is important to derive cost information for an individual measure and alternatives to which it is compared from a common source. The DER application forms contain cost information only for measures contained in the DER project plan.

One overarching qualifier for both approaches to energy savings cost effectiveness is that the analysis does not apportion measure costs between energy savings and other nonenergy motivations for the measures. Discussion of modeling for individual test homes includes examples of where nonenergy motivations were particularly significant.

Figure 62 provides a graphic representation of the predicted source energy use reductions for the test homes. Table 5 presents an overview of overall project costs and energy savings predictions.

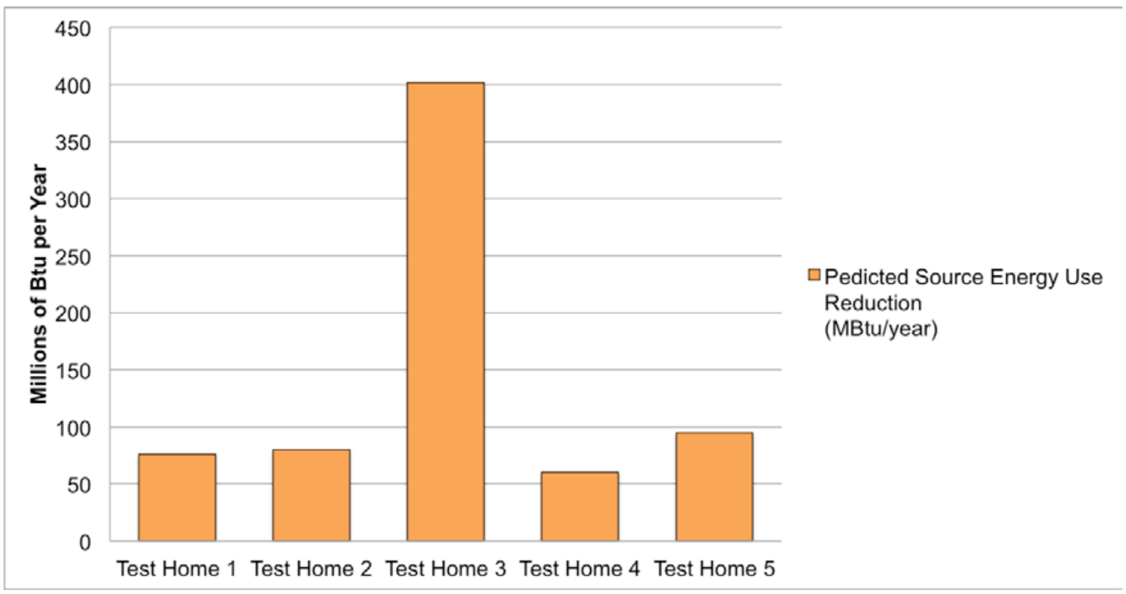

Figure 62. Predicted annual source energy use reduction relative to pre-retrofit condition

Table 5. Project Costs and Predicted Source Energy Savings

Project	Total Project Cost Including Non-DER Work	Incremental Energy Performance Measures Costs	Predicted Source Energy Use Reduction (MBtu/year)	Incremental Cost per MBtu Source Energy Use Reduction ($/MBtu-year)
Test Home 1	$156,762	$43,885	75.7	$580
Test Home 2	$150,329	$76,613	79.8	$960
Test Home 3	$233,055	$69,580	401.6	$173
Test Home 4	$191,343	$59,540	59.8	$996
Test Home 5	$155,339	$47,950	94.7	$506

The incremental energy performance costs for DER measures were arrived at through examination of information provided in the DER Pilot Program application forms. The examination of measure costs sought to filter out reported measure costs, those portions of the measure costs that reflect what the builder would have been required to do in a major renovation of the assembly and the cost to reimplement an performance measure that may have already been in place (e.g., reinstall fibrous insulation in a wall assembly that was gutted) and then filter out costs reflecting, in some cases, costs not directly related to the insulation and airflow control measures needed to be extracted from reported incremental measure costs.

Figure 63 represents each project's total incremental energy performance costs relative to the source energy use reduction predicted by the energy modeling. To provide a gauge for this energy savings cost effectiveness measure, the figure also represents the approximate cost relative to source energy reduction of a residential-scale PV system. PV Watts calculator (NREL 2009) was used to estimate the annual production of a 1-kW DC PV system in the climate of the test homes. Data for costs of residential systems were derived from Barbose et al. (2010). Assuming that 100% of PV generation offsets grid-produced electricity, the source energy cost effectiveness measure is approximately $500/MBtu of source energy offset. This measure is represented by the horizontal purple line.

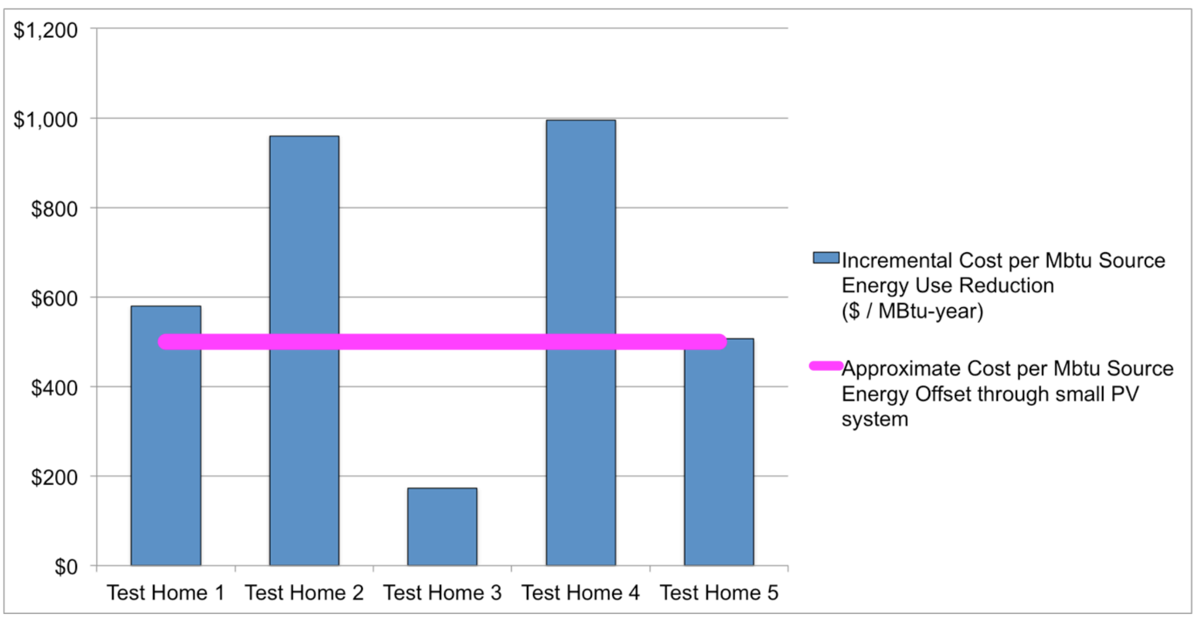

Figure 63. Incremental project cost for energy performance measures relative to predicted source energy use reduction

Energy modeling results for each of the test homes featured in this report are presented in the sections below.

7.2.1 Energy Modeling for Test Home 1, the 1960s Garrison Colonial

Using the available cost information for the measures incorporated in this project and for the alternatives selected, the as built case falls on the least cost curve (Figure 64). The predicted annualized energy related costs for the completed project are well above those of the pre-DER case. For this particular case, the homeowner had an intention to replace the roof, windows, and siding and to gut and refinish the basement space. The homeowner is also investing resources in the home in an attempt to meet the Thousand Homes Challenge.

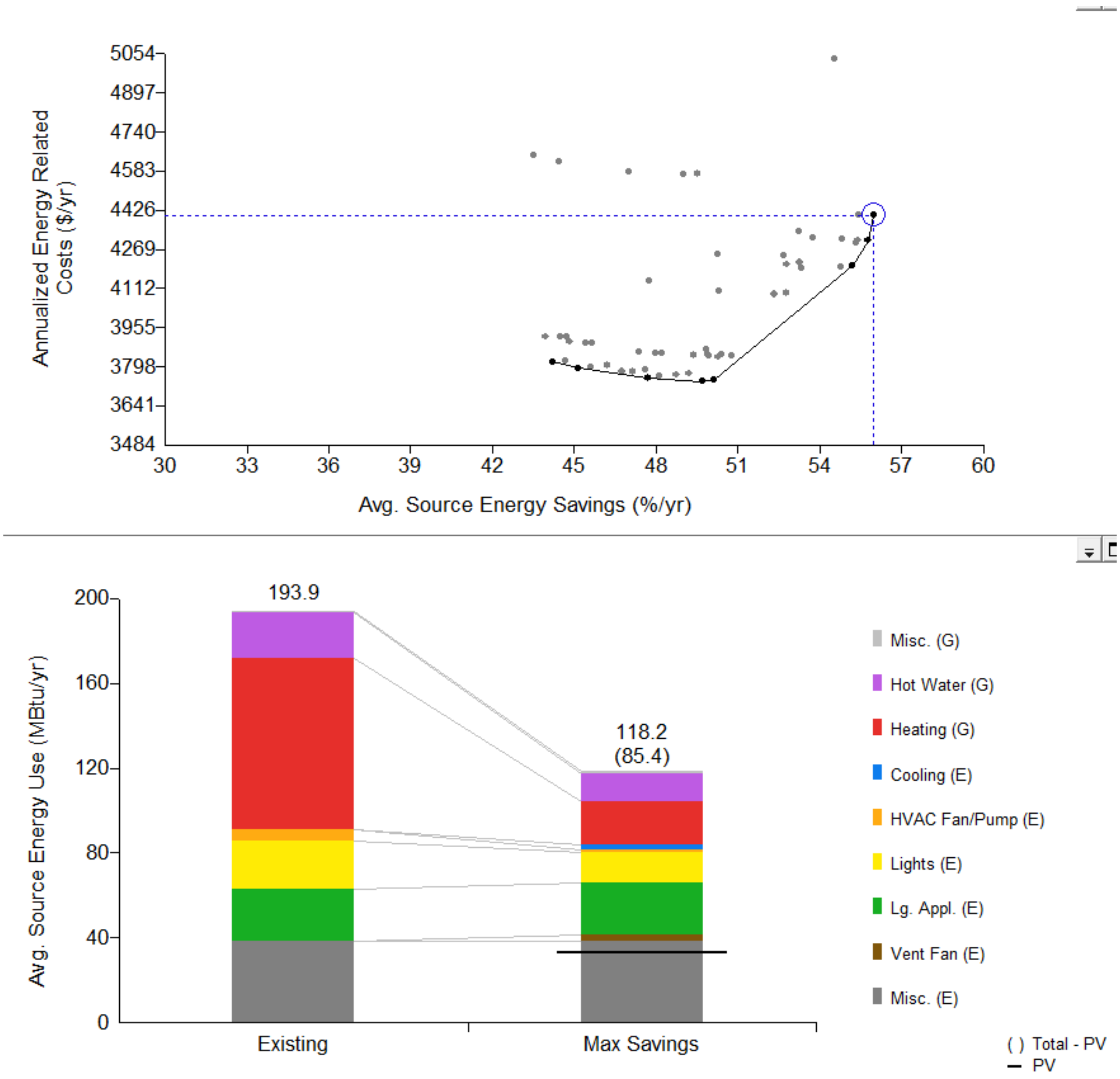

Figure 64. Test Home 1 BEopt results for as-built condition and alternatives

Inputs used to describe the building components for the pre-retrofit case, post-retrofit case, and selected alternatives are presented in Table 6 with the cost information used in the modeling. The table represents some simplifications in the inputs such as representing the hydro-air heating system as a gas-fired furnace and representing the high-efficiency condensing storage water heater as a condensing tankless water heater.

Table 6. Test Home 1 BEopt Inputs

Building Component	Pre-Retrofit Parameter	Post-Retrofit Parameter and Alternatives	Cost of Upgrade	Cost Source
Walls	Estimate R-12	Add 4 in. PIR to existing 2 × 4 studs, 16 in. o.c.	$7.58/ft^2$ of wall	RSMeans
		Alternative: Add 2 in. PIR to existing 2 × 4 studs, 16 in. o.c.	$5.73/ft^2$ of wall	RSMeans
		Alternative: Add 1 in. XPS to existing 2 × 4 studs, 16 in. o.c.	$1.34/ft^2$ of wall	RSMeans
		Alternative: Add 1 in. PIR to existing 2 × 4 studs, 16 in. o.c.	$1.35/ft^2$ of wall	RSMeans
Roof	R-11 at attic floor	Add 8 in. ccSPF between rafters	$6.15/ft^2$ of roof	RSMeans
		Alternative: Add 3.5 in. ccSPF and R-19 batts between rafters	$3.84/ft^2$ of roof	RSMeans
Foundation Walls	Uninsulated	Add R-20 ccSPF	$1.93/ft^2$ of wall	RSMeans
		Alternative: Add R-10 ccSPF	$1.01/ft^2$ of wall	RSMeans
Windows	U = 0.33, SHGC = 0.56	Triple Eco casement, U = 0.2, SHGC = 0.19	$41/ft^2$ of window	From National Grid application
		Alternative: Marvin clad triple pane (U = 0.24, SHGC = 0.19)	$111/ft^2$ of window	From another local project
Infiltration	4.5 ACH 50	1.7 ACH 50	$2.73/ft^2$ enclosure	From BEopt library
Heating System	Gas-fired furnace, 60% AFUE	Gas-fired furnace, 96% AFUE	$1,806	From BEopt library
Cooling System	None	SEER 16	$2,641	From BEopt library for 1.5 ton systems.
		Alternative: SEER 14	$2,391	From BEopt library for 1.5 ton systems.
Ventilation	None	50% of 62.2, 80% effective Venmar model	$2,000	From National Grid application.
		Alternative: 50% of 62.2, 72% effective	$1,838	From BEopt library
		Alternative: 50% of 62.2, no HRV	$463	From BEopt library
Lighting	BA Benchmark	100% Fluorescent, hardwired, and plugin	$0.07/ft^2$ living space	From BEopt library
DHW Heater	Gas Standard, EF 0.59	Gas tankless, condensing, EF 0.96	$1,800	From BEopt library
		Alternative: Gas premium, EF 0.67	$970	From BEopt library
PV System	None	2.4-kW PV	$18,750	From National Grid application

7.2.2 Energy Modeling for Test Home 2, 1890s Three-Story Victorian

Using the available cost information for the measures incorporated in this project and for the alternatives selected, the as-built case falls on the least cost curve. The predicted annualized energy related costs for the completed project are well above those of the pre-DER case. For this particular case, the homeowner had desired to replace existing vinyl siding. It appears that some of the wood cladding and sheathing beneath existing vinyl had deteriorated (see Figure 65). Replacement of siding would have required removal of cladding, repairs to sheathing, and if following good practice, significant remediation of the flashing and water management system. Many of these needs are addressed in the overcladding strategy employed. Partly because the owners were intent on meeting particularly ambitious energy performance goals, relatively recent windows were replaced. The style of the windows may have also been a factor in the window replacement.

Figure 65. Vinyl siding and deteriorated wood cladding at Test Home 2

The measures implemented in this project are intended to complement the high performance retrofit measures implemented previously. Greater than 20% of the incremental project cost is attributable to extension of the roof eaves to better accommodate the increased wall thickness and preserve the aesthetics represented by the overhang proportions. Arguably, the roof may have been more economically extended at the time of the major roof retrofit implemented through a previous project at this test home.

Inputs used to describe the building components for the pre-retrofit case, post-retrofit case, and selected alternatives are presented in Table 7 and Figure 66 with the cost information used in the modeling. Note that, because the project is not yet complete, a projection of post-retrofit air leakage is used in the modeling.

Table 7. Test Home 2 BEopt Inputs

Building Component	Pre-Retrofit Parameter	Post-Retrofit Parameter and Alternatives	Cost of Upgrade	Cost Source
Walls	Uninsulated	Add cellulose to cavity and 4 in. PIR	\$8.12/ft^2 of wall	RSMeans
		Alternative: Add cellulose to cavity and 2 in. PIR	\$6.27/ft^2 of wall	RSMeans
		Alternative: Add cellulose to cavity and 1 in. XPS	\$1.88/ft^2 of wall	RSMeans
		Alternative: Add cellulose to cavity and 1 in. PIR	\$1.89/ft^2 of wall	
Roof	R-48	R-48; no upgrade	N/A	N/A
Foundation Walls	R-18	R-18; no upgrade	N/A	N/A
Windows	U = 0.3, SHGC = 0.43	U = 0.2, SHGC = 0.25	\$59/ft^2 of window	From National Grid application
		Alternative: Marvin clad triple pane	\$111/ft^2 of window	From another local project
Infiltration	4.1 ACH 50	1.5 ACH 50	\$2.73/ft^2 enclosure	from BEopt library
Heating System	Gas hydronic, 84% AFUE	Gas hydronic, 95% AFUE	\$3,300	From BEopt library for 60 kBtu/h
Cooling System	None	SEER 18	\$2,891	From BEopt library for 1.5 ton systems. Note: Cooling system selection not final.
		Alternative: SEER 16	\$2,641	From BEopt library for 1.5 ton systems
		Alternative: SEER 14	\$2,391	From BEopt library for 1.5 ton systems
Ventilation	None	50% of 62.2, 63% effective Fantech model	\$3,220	From National Grid application. Note: Ventilation system selection not final.
		Alternative: 50% of 62.2, no HRV	\$463	From BEopt library
Lighting	BA Benchmark	100% fluorescent, hardwired and plugin	\$0.07/ft^2 living space	From BEopt library
DHW Heater	Gas EF 0.80	Gas tankless, condensing, EF 0.95	\$1,800	From BEopt library

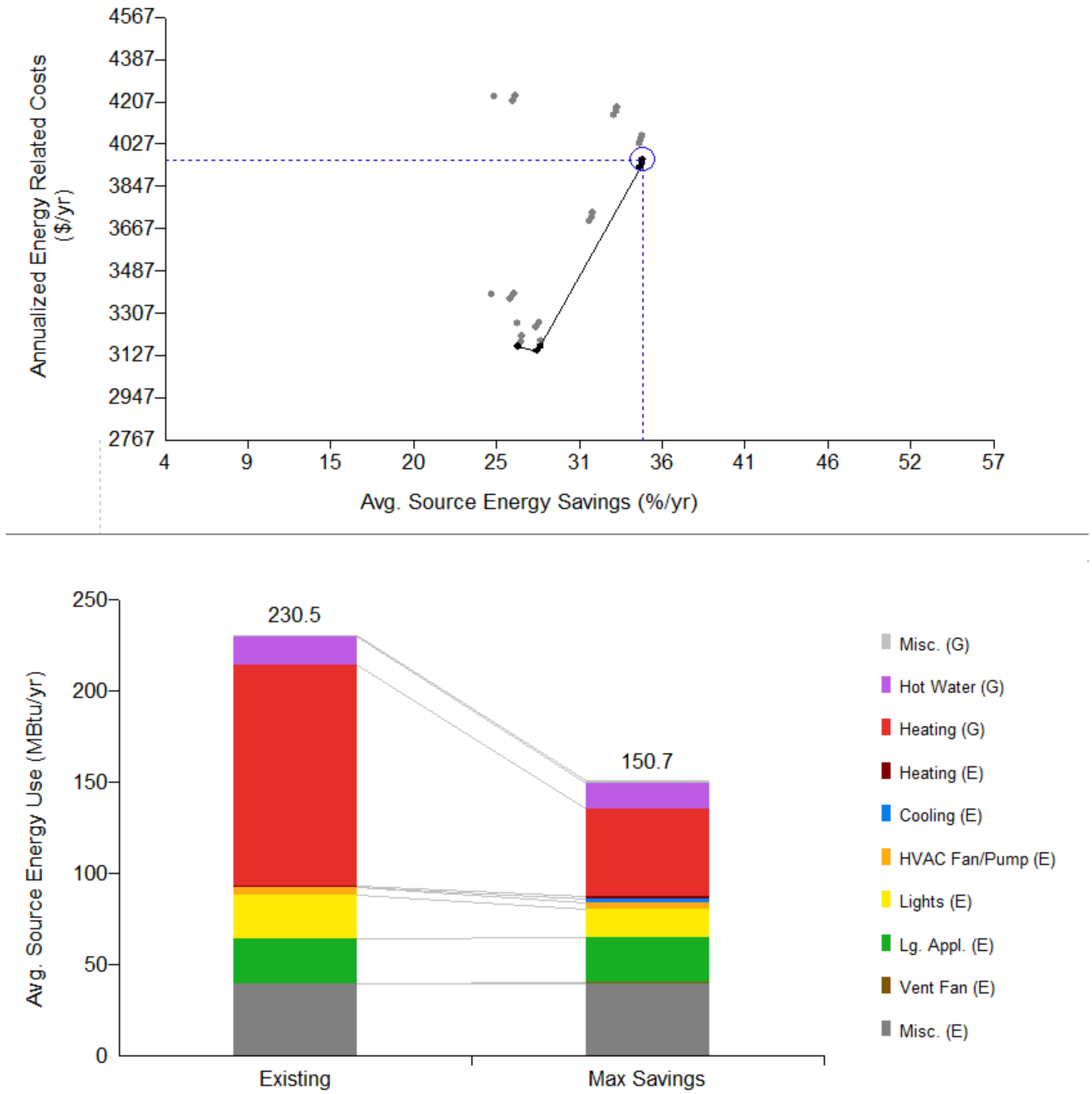

Figure 66. Test Home 2 BEopt results for as-built condition and alternatives

7.2.3 Energy Modeling for Test Home 3, 1900s Duplex

This home was modeled as a single-family home, as modeling of multiunit buildings is not readily feasible in BEopt.

Using the available cost information for the measures incorporated in this project and for the alternatives selected, the as-built case falls on the least cost curve. The predicted annualized energy related costs for the completed project are also below those of the pre-DER case. For this particular case, the building owners had incorporated a DER into a planned expansion and reconfiguration of the duplex. This work was to include construction of a new roof and replacement of siding and new mechanical systems.

The estimated savings achieved through this project are remarkable. The starting conditions will, of course, have significant bearing on available energy use reductions. The particular test home was remarkably air leaky prior to the retrofit. Even though the air leakage measurement achieved at the completion of this project is not especially airtight, it represents a very significant reduction from pre-retrofit air leakage.

The shape of the least cost curve shown in Figure 67 is curious. It is the result of including some alternatives in the modeling that were more expensive and less energy efficient than the chosen design (e.g., aluminum-clad triple-pane windows). This window option represents the reality that some homeowners will select features (such as clad double-hung windows, granite countertops, and big screen televisions) for nonenergy reasons. The relative cost effectiveness of the vinyl-framed triple-glazed windows should be appreciated in the context of this reality.

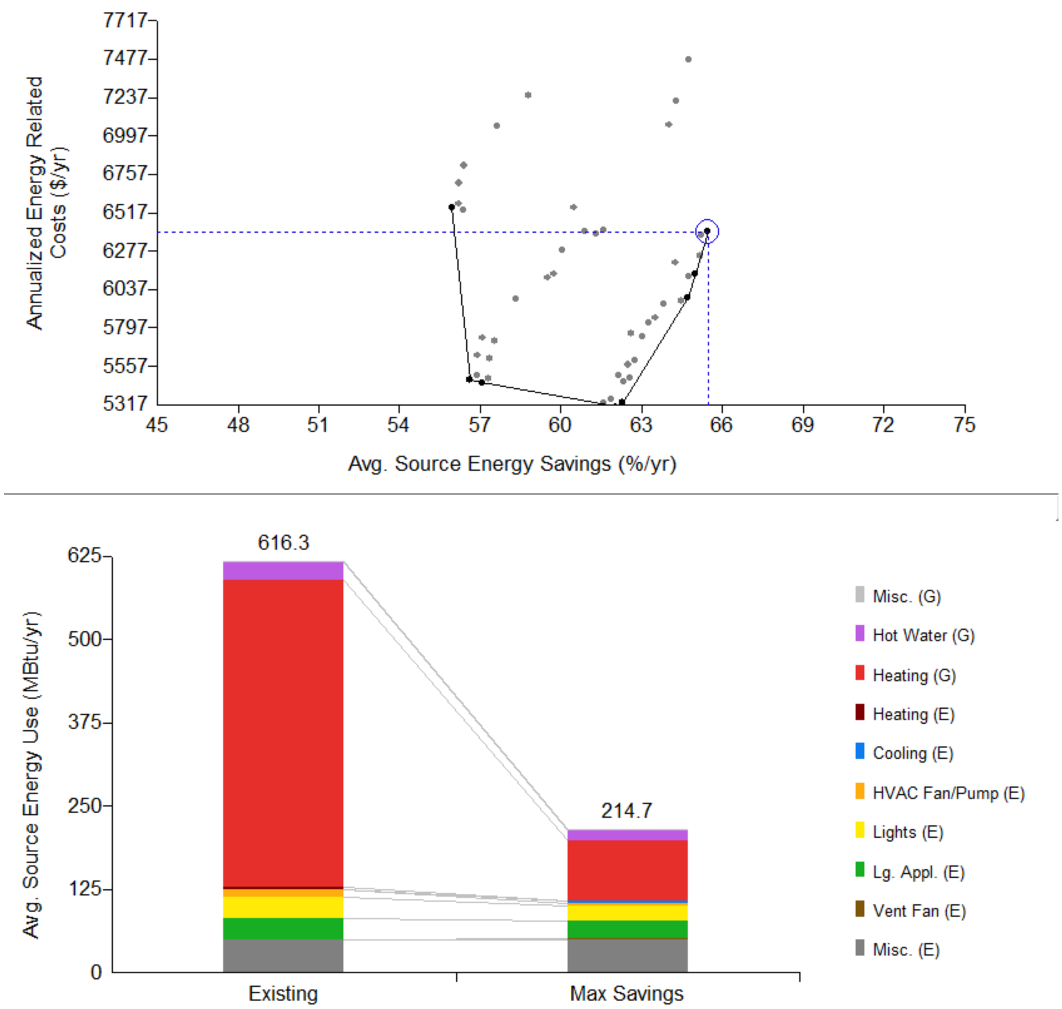

Figure 67. Test Home 3 BEopt results for as-built condition and alternatives

Inputs used to describe the building components for the pre-retrofit case, post-retrofit case, and selected alternatives are presented in Table 8 with the cost information used in the modeling.

Table 8. Test Home 3 BEopt Inputs

Building Component	Pre-Retrofit Parameter	Post-Retrofit Parameter and Alternatives	Cost of Upgrade	Cost Source
Walls	Uninsulated	Add cellulose to cavity and 4 in. PIR	$8.12/ft^2$ of wall	RSMeans
		Alternative: Add cellulose to cavity and 2 in. PIR	$6.27/ft^2$ of wall	RSMeans
		Alternative: Add cellulose to cavity and 1 in. XPS	$1.88/ft^2$ of wall	RSMeans
		Alternative: Add cellulose to cavity and 1 in. PIR	$1.89/ft^2$ of wall	RSMeans
Roof	R-11 at attic floor	Add 10 in. ccSPF under the roof	$7.98	RSMeans
		Alternative: Add 3.5 in. ccSPF and R-19 batts between rafters	$3.84	RSMeans
Foundation Walls	Uninsulated	Add 2 in. ccSPF, 3.5 in. cellulose, 1 in. ff polyiso to basement ceiling	$3.48/ft^2$ of ceiling	RSMeans
		Alternative: Add R-19 fiberglass to basement ceiling	$0.95/ft^2$ of ceiling	RSMeans
Windows	BEopt default "double clear"	Eco-shield casement, U = 0.2, SHGC = 0.19	$75/ft^2$ of window	From National Grid application
		Alternative: Marvin clad triple pane (U = 0.24, SHGC = 0.19)	$111/ft^2$ of window	From another local project
Infiltration	20.6 ACH 50	6.6 ACH 50	$2.73/ft^2$ enclosure	From BEopt library
Heating System	Steam hydronic, 65% AFUE	Gas furnace forced air, 95% AFUE	$2,167	From BEopt library for 60 kBtu/h
Cooling System	None	SEER 16	$2,641	From BEopt library for 1.5 ton systems.
		Alternative: SEER 18	$2,891	From BEopt library for 1.5 ton systems
		Alternative: SEER 14	$2,391	From BEopt library for 1.5 ton systems
Ventilation	None	50% of 62.2, 77% effective Fantech model	$3,220	From National Grid application.
Lighting	BA Benchmark	90% fluorescent, hardwired and plugin	$0.07/ft^2$ living space	From BEopt library
DHW Heater	Gas Standard, EF 0.59	Gas tankless, condensing, EF 0.96	$1,800	From BEopt library
		Alternative: Electric premium, EF 0.95	$700	From BEopt library

7.1.4 Energy Modeling for Test Home 4, 1930s Cape

Using the available cost information for the measures incorporated in this project and for the alternatives selected, the as-built case falls on the least cost curve (see Figure 68). The predicted annualized energy related costs for the completed project are well above those of the pre-DER case. For this particular case, the homeowners had initially set out to contract an expansion (by excavation) and remodeling of the basement. During the project, the homeowners decided to pursue a full overclad retrofit of the building, replace windows, and change the air-conditioning system to a heat pump system supplemented by the upgraded hydronic heating and water heating.

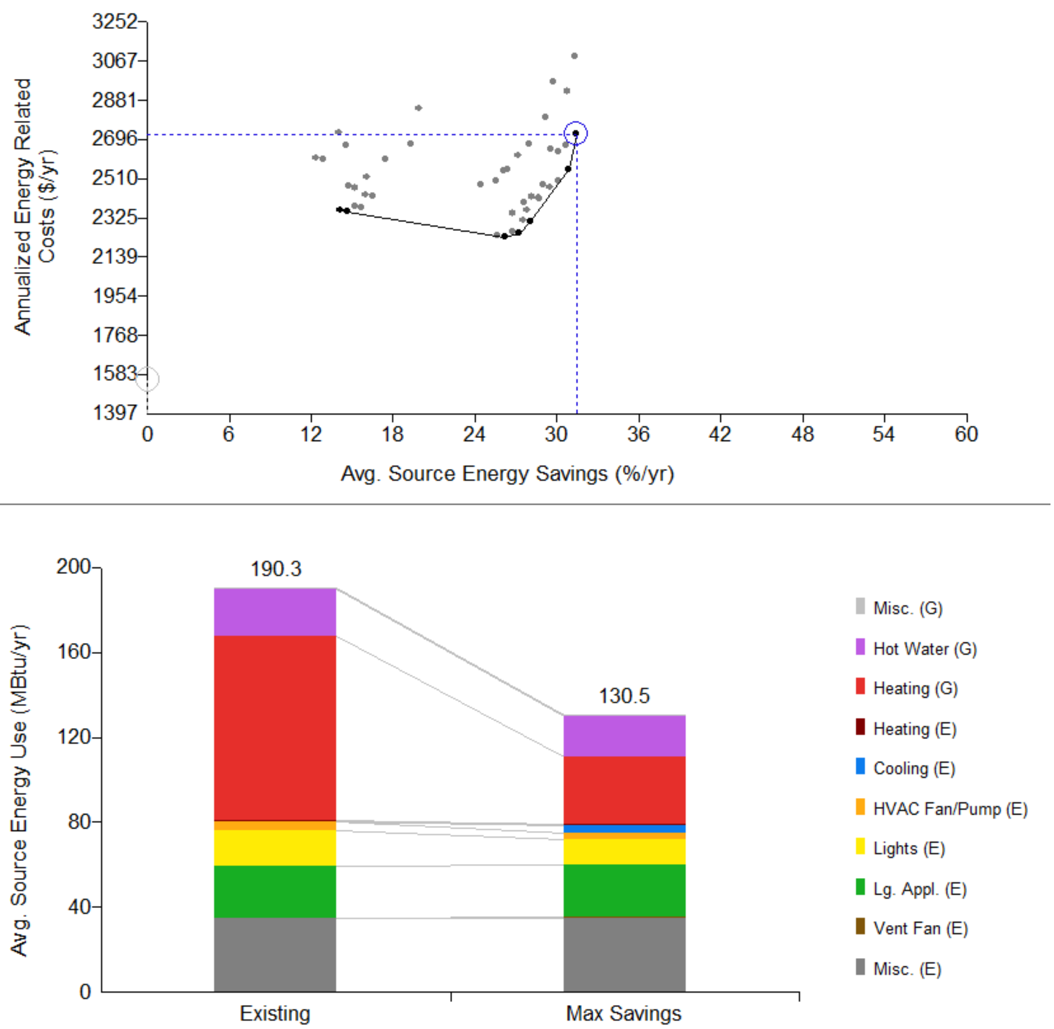

Figure 68. Test Home 4 BEopt results for as-built condition and alternatives

The homeowners also decided to pursue Thousand Homes Challenge designation. Hence the energy savings cost-effectiveness question is one of a least cost path to a performance goal.

Inputs used to describe the building components for the pre-retrofit case, post-retrofit case, and selected alternatives are presented in Table 9 with the cost information used in the modeling. The table represents some simplifications in the inputs such as representing the indirect-fired storage hot water heater as a condensing tankless water heater.

Table 9. Test Home 4 BEopt Inputs

Building Component	Pre-Retrofit Parameter	Post-Retrofit Parameter and Alternatives	Cost of Upgrade	Cost Source
Walls	Estimate R-12	Add 4 in. PIR to existing 2 × 4 studs, 16 in. o.c.	$7.58/ft^2 of wall	RSMeans
		Alternative: Add 2 in. PIR to existing 2 × 4 studs, 16 in. o.c.	$5.73/ft^2 of wall	RSMeans
		Alternative: Add 1 in. XPS to existing 2 × 4 studs, 16 in. o.c.	$1.34/ft^2 of wall	RSMeans
		Alternative: Add 1 in. PIR to existing 2 × 4 studs, 16 in. o.c.	$1.35/ft^2 of wall	RSMeans
Roof	R-11 at attic floor	Add 4 in. PIR and 6" cellulose	$8.12/ft^2	RSMeans
		Alternative: Add 3.5 in. ccSPF and R-19 batts between rafters	$3.84/ft^2 of roof	RSMeans
Foundation Walls	Uninsulated	Add R-20 ccSPF	$1.93/ft^2 of wall	RSMeans
		Alternative: Add R-10 ccSPF	$1.01/ft^2 of wall	RSMeans
		Alternative: Add R-40 ccSPF	$3.83/ft^2 of wall	RSMeans
Windows	BEopt default "double clear"	Triple Ecosheild and some Harvey casement, U = 0.24, SHGC = 0.25	$60/ft^2 of window	From National Grid application
		Alternative: Marvin clad triple pane (U = 0.24, SHGC = 0.19)	$111/sf of window	From another local project
Infiltration	11.2 ACH 50	4.9 ACH 50	$2.73/ft^2 enclosure	From BEopt library
Heating System	Gas hydronic, 80% AFUE	Gas hydronic, 96% AFUE	$3,300	From BEopt library
Cooling System	None	SEER 13	$2,260	From BEopt library for 1.5 ton systems.
Ventilation	None	50% of 62.2, 80% effective Venmar model	$2,000	From National Grid application.
		Alternative: 50% of 62.2, no HRV	$463	From BEopt library
Lighting	BA Benchmark	90% Fluorescent, hardwired and plugin	$0.07/ft^2 living space	From BEopt library
DHW Heater	Gas Standard, EF 0.59	Gas tankless, condensing, EF 0.96	$1,800	From BEopt library
		Alternative: Electric premium, EF 0.95	$700	From BEopt library

7.1.5 Energy Modeling Test Home 5, 1900s Small Colonial

Using the available cost information for the measures incorporated in this project and for the alternatives selected, the as-built case is decidedly off the least cost curve (see Figure 69). The predicted annualized energy related costs for the completed project are still below those of the pre-DER case.

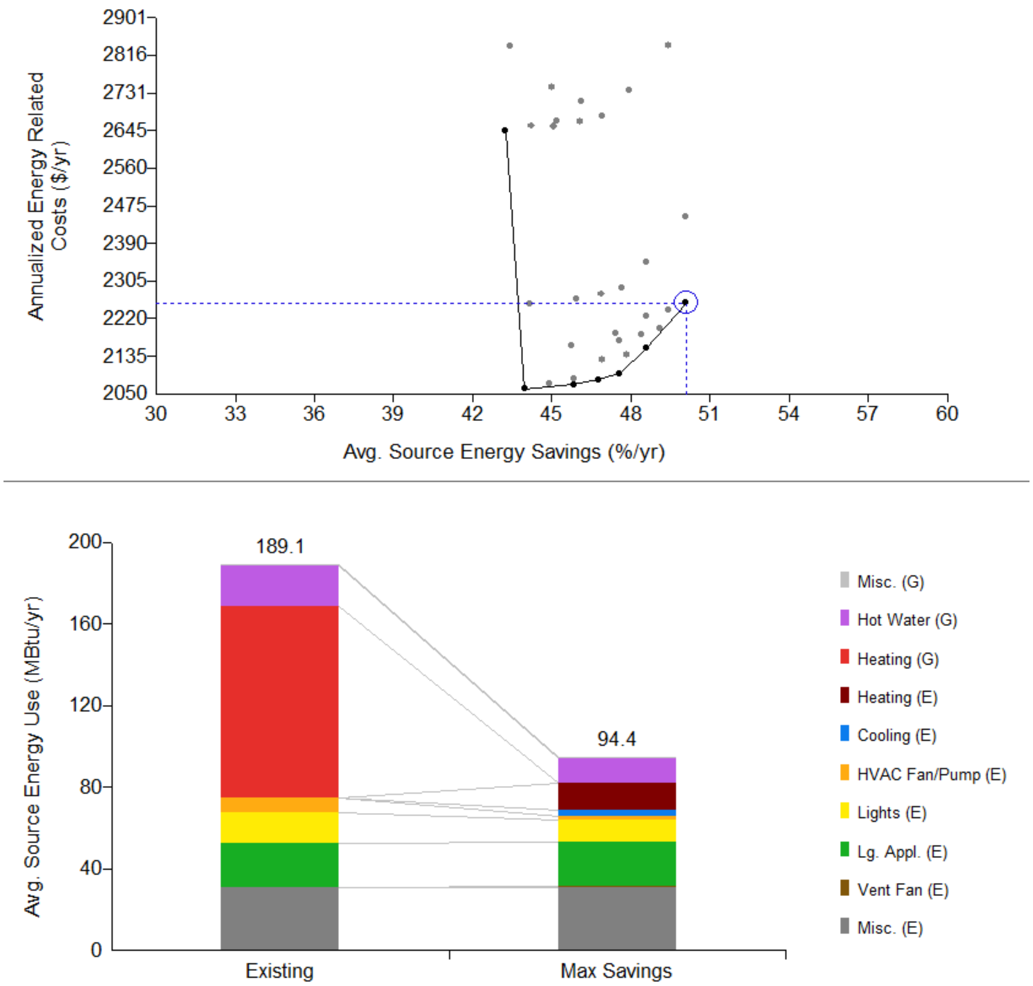

Figure 69. Test Home 5 BEopt results for as-built condition and alternatives

As with Test Home 3, this project exhibited significant energy use reduction opportunities relative to air leakage in the pre-retrofit conditions. An important factor in the individual measure cost savings analysis for this particular project derives from the nature of a Habitat for Humanity project. The project must use donated materials and services. For example, the donation of material and services was a deciding factor in designing a wall system using XPS insulating sheathing material – a material of approximately the same cost as polyisocyanurate but of lower R-value – and ccSPF—an insulation offering higher R-value that cellulose or fiberglass but at greater cost/ft^2-R.

Inputs used to describe the building components for the pre-retrofit case, post-retrofit case, and selected alternatives are presented in Table 10 with the cost information used in the modeling.

Note that, because the project is not yet complete, a projection of post-retrofit air leakage is used in the modeling. Also, because the project was in significant disrepair prior to the retrofit, default values for air leakage were used based on measurements obtained for a neighboring building of similar configuration to the pre-retrofit Test Home 5.

Table 10. Test Home 5 BEopt Inputs

Building Component	Pre-Retrofit Parameter	Post-Retrofit Parameter and Alternatives	Cost of Upgrade	Cost Source
Walls	Estimated R-13	3.5 in. ccSPF, 4 in. XPS rigid foam	$5.81/ft^2$ of wall	RSMeans
		3.5 in. ccSPF, 2 in. XPS rigid foam	$3.87/ft^2$ of wall	RSMeans
Roof	Estimated R-30 at attic floor	Add 18 in. cellulose at attic floor	$2.41/ft^2$ of floor	RSMeans
Foundation Walls	Uninsulated	Add R-40 ccSPF	$3.83/ft^2$ of wall	RSMeans
		Alternative: R-20 ccSPF	$1.93/ft^2$ of wall	RSMeans
		Alternative: R-10 ccSPF	$1.01/ft^2$ of wall	RSMeans
Windows	Old, single pane	Paradigm triple pane	$54/ft^2$ of window	From National Grid application
		Alternative: Marvin clad triple pane (U = 0.24, SHGC = 0.19)	$111/ft^2$ of window	From another local project
Infiltration	BEopt library "Leaky" (14.5 ACH50)	2.9 ACH 50	$2.73/ft^2$ enclosure	From BEopt library
Heating and Cooling System	Estimate gas furnace, AFUE 78%	Mitsubishi heat pump. Use SEER 18, HSPF 9.2 from BEopt library	$2,993	From BEopt library for 1.5 ton systems
		Alternative: SEER 16, HPSF 8.4	$2,698	From BEopt library for 1.5 ton systems
		Alternative: SEER 14, HSPF 8.6	$2,403	From BEopt library for 1.5 ton systems
Ventilation	None	50% of 62.2, 75% effective Lifebreath model	$3,238	From National Grid application
		Alternative: 50% of 62.2, no HRV	$463	From BEopt library
Lighting	BA Benchmark	100% Fluorescent, hardwired and plugin	$0.07/ft^2$ living space	From BEopt library
DHW Heater	Gas Standard, EF 0.59	Gas tankless, condensing, EF 0.96	$1,800	From BEopt library

8 Recommendations for Future Work

The comprehensive nature of most of the projects featured in this report would render the activity unaffordable to most homeowners. What is needed for widespread adoption of DER measures – and the consequent evolution toward reduced enclosure load of existing housing stock – is guidance for implementation of high performance retrofit measures to single building components or systems. Technical guidance for high performance retrofit measures should focus on details that support integration with previous or future high performance retrofit measures. This would support a phased approach to high performance retrofit that could be implemented in conjunction with regular home maintenance and replacement activity for which delivery channels are well established.

The experience gained through this research project has also identified recurring challenges in retrofitting buildings of the types represented. Information documents in the form of measure guidelines might address these challenges and explain principles involved such that contractors would have the necessary information to develop appropriate solutions.

Also encountered in this research were innovative techniques that solved problems of implementation, cost, and performance. Best practice highlights documents could help to disseminate these innovations for wider adoption.

Results for the test homes are based on observation and performance testing of recently completed or in process projects. Additional observation would be needed to fully gauge long-term energy performance, durability, and occupant comfort. Recommended future work includes development of measure guidelines, information resources to explain recurring technical challenges, and monitoring of utility bills. Environmental data monitoring could also be used to evaluate any reported thermal comfort or HVAC distribution issues that may arise as well as to quantify nonenergy benefits. Continued monitoring of utility bills to verify long-term energy savings may help to identify ways in which usage could be reduced further. Environmental data monitoring could also be used to evaluate any reported thermal comfort or HVAC distribution issues that may arise and also help to quantify nonenergy benefits.

9 Conclusions

Energy cost savings are not the dominant motivation for pursuing high performance retrofit. More likely reasons for pursuing high performance retrofit are comfort, increased amenity, attaining a performance target, and new lease on life for a building. Efforts to promote significant enclosure load reductions in existing housing stock should leverage these motivations.

Despite the fact that energy savings are seldom the benefit that carries the entire cost burden of high performance measures, significant energy savings are possible.

There are many challenges in the field of retrofit strategy and cost benefit research. Although best practice strategies for new construction in different climates are relatively straightforward, every retrofit is a unique case. Even with a specific locality and among buildings of a similar building period, each may exhibit a wide variety of building construction techniques and details. Older buildings or poorly constructed new buildings can have any number of failures or deficiencies that must be addressed. These can include structural issues, moisture problems, occupant discomfort, or even dated aesthetics. Addressing deficiencies in existing housing stock can detract from investment in energy performance. Or this effort can be harnessed as motivation to pursue improvements to the building that entail a comprehensive list of benefits including durability, indoor air quality, comfort, and energy performance.

10 Appendices

10.1 Appendix A: Deep Energy Retrofit Multifamily and Single-family Pilot Guidelines

See attached.

Deep Energy Retrofit Multifamily and Single-family Pilot Guidelines

National Grid is expanding a pilot program to demonstrate Deep Energy Retrofits ("DER") in existing single and multi-family homes in Massachusetts (and in 2011 only for 1 to 4 family buildings in Rhode Island). The goal is ideally to achieve at least 50% better energy performance than a code built or Federal Energy Yardstick home. Financial incentives and targeted technical support are being offered for selected projects in a significant number of dwellings to be completed each year in 2010 through 2012. This pilot is for customers with gas heat in our gas service area. It's for customers who own 1-4 family buildings with any other form of heat in our electric service area, and larger multi-family buildings with electric heat. It may also include gas heat in a town in our electric service area if the gas company there is out of funds for a DER Pilot.

This document describes the following: (1) Incentives for Selected Project, (2) Process Steps, (3) Pilot Project time line, (4) Requirements of Selected Projects, (5) Desired Project Characteristics, (6) Project Team Requirements and (7) Project Selection Process and Selection Criteria.

There are additional program documents, including but not limited to, (1) a two-part project application and (2) the Application for Deep Energy Retrofit ("DER") Contractor and Design Consultant List available at www.powerofaction.com/der/. The prospective project team must include at least one contractor or design consultant from this list

This is not an offer to fund work or constitute a guarantee of savings. Incentive payments will only be made for selected projects which meet pilot requirements, criteria and budget.

A DER is a complex undertaking. Through the DER process an existing home is transformed to a high performance home in which the dynamics of energy, moisture and air flows are changed in both subtle and significant ways. The contractor or consultant who develops the DER design and takes responsibility for its implementation must have a thorough understanding of how the various measures of the DER change energy, moisture and airflow dynamics. This understanding is essential to managing the risks necessarily entailed in changing how a building works.

The name "Deep Energy Retrofit" implies that improving energy performance is the primary objective. In fact, a successfully designed and implemented DER should also result in improved comfort, durability and indoor air quality. Other benefits that might motivate the pursuit of DER include enhanced functionality, increased amenity, and/or opportunities to improve the aesthetic appearance of the building. It is important to keep in mind that the performance benefits of a DER are comprehensive and not limited to energy savings.

1. Incentives for Selected Projects

A. Incentives for Whole Building Deep Energy Retrofits:

1. Level one incentives are for selected projects involving a comprehensive whole building (six sided) enclosure package which meets or approaches the Desired Project Characteristics including for mechanical ventilation, and other high efficiency technology. Reimbursement will be up to 75% of owner's otherwise net cost of the Deep Energy Retrofit up to the maximum in the incentive table below. Please see section 5aii related to incentive adjustments related to air sealing targets. This will apply for projects that did not yet have the second application approved as of 1/1/11.
2. Level two incentives provide additional incentives (only in Massachusetts) for project achieving more advanced levels of performance. Level two incentives are in the amount of 25% of eligible level one incentives up to a maximum of $10,000 per unit. Eligible advanced performance initiatives include the Passive House Institute[1] ("PHI") EnerPhit

[1] In the US, the Passive House Institute US (PHIUS)

program, the Affordable Comfort Institute (ACI) Thousand Home Challenge[2] (THC) Option B, or a Net Zero Energy ("NZE") retrofit project.

B. Incentives for Staged Deep Energy Retrofits

Staged or partial DERs are intended to seize opportunities arising represented by home remodeling and maintenance schedules to place a building firmly on a path toward high performance. Incentives for partials to date for building enclosure improvements were prorated based on thermal impact per sq ft and % surface area treated relative to whole building DER. Staged DERs will be considered on a case by case basis provided that the **measures eligible for incentives are consistent with DER Desired Project Characteristics (see section 5)** and:

1. the project will also save at least 50% of what the full DER would or result in a HERS 70
2. the proposal represents sound building science
3. the application includes a plan and cost projections for a complete DER and includes details that expressly facilitate completion of a full DER at a later date.

We are now considering a limited number of projects (in MA only) that will treat less than 50% of the building enclosure surface - provided the plan also includes complete exterior wall or roof deck insulation build-outs at the time of re-siding or re-roofing. ["Special Component(s) DER"]

Maximum Level One Incentives per Facility

Dwelling Units in Facility	Conditioned Sq Ft Floor Area[3] 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

Multi-unit and Income Eligibility

- To count as a unit for purposes of incentives apartments must have separate legal egress, bath and kitchen and electric meters. In a building with 3 or less units, apartments must have at least 500 sg.ft.floor space to be eligible.
- **For buildings with 5 or more units only National Grid gas or National Grid electric heat customers are eligible.**
- One master metered gas heated facility may be considered each year based on available funds.
- Public housing is ineligible for DERs
- Other income eligible[4] properties will be under consideration for 2011 put project must declare status AND CAN NOT also accept low income funding such as coordinated through LEAN, the Low Income Energy Affordability Network.

C. Cost Basis and by Measure Maximums for Incentives

Allowable project costs eligible for incentives are limited to net incremental costs, of implementing the DER measures. For example; for super insulation on wall exterior, the

[2] The Thousand Home Challenge goal is to demonstrate energy reduction in homes by 75-90% through; energy efficiency, renewables, community-based solutions, and behavioral choices. http://www.thousandhomechallenge.org/

[3] 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. Only applies to 1-2 family buildings.

[4] Where 50% or more of tenants are regularly at or below 60% of median income.

customers' costs of the insulation material, its installation, special attachments and trim modifications required to accommodate the super insulation would be eligible for incentives, whereas costs for the new siding (or cladding such as stucco) and its installation would not.

For mechanical systems, pilot incentives are limited 50% of costs up to a maximum of $4000 for high efficiency heating and $1000 for cooling. Reimbursement for replacement windows is intended to cover 100% of incremental **cost** above typical replacement cost of $15/sq ft. **National Grid reserves the right to verify the reasonableness of submitted costs which must not exceed reasonable market values.**

D. Exclusions

Projects already underway at time of application process maybe excluded, or accommodated as a staged retrofit. Projects involving demolition and rebuild or new additions must retain a minimum 50% original sq ft of floor. If planned addition or demolition is over 50% of final floor space the project would be excluded but may be eligible for the Major Renovation Pilot or the Energy Star Homes program. Other program incentives may be leveraged or split, but not double paid for same measures. National Grid contest incentives such as "smack downs" or "zero energy challenge" and MASS-SAVE shell measure incentives for the same treated components cannot be combined with Pilot incentives.

E. Technical Support

Through a mutual agreement with the Building America program (http://www1.eere.energy.gov/buildings/building_america/index.html) and Building Science Corporation the pilot will provide thorough, but not unlimited, advanced technical support for the project team. Building Science Corporation and certain of its subcontractors in the Building America program will perform the role of the Technical Team in DER Pilot implementation. Technical support relative to design and implementation of DER measures will be provided to projects by the Technical Team.

NOTE: the Technical Team will provide support to the project primary through the entity on the DER project team designated as having primary responsibility for the design and implementation of the DER project. The party having primary responsibility, or "DER project lead" must be contracted to the building owner unless the owner is also a listed contractor or designer. Technical support provided is predicated on the DER project lead having a solid foundation of understanding in building science, building construction and mechanical systems.

F. Other Funding Resources

Participants are encouraged to explore **additional funding and incentive resources:**

- For information on Tax credits for energy efficiency: www.energy.gov/taxbreaks.htm
- National Grid offers rebate programs for lighting, appliances, heating and water heating equipment, HRVs, central air and mini-split heat pumps. https://www.powerofaction.com/
- The 0% HEAT loan is available up-to $25,000 with terms up-to seven years through Mass-Save in coordination with the DER pilot. www.masssave.com/
- Project teams are encouraged to leverage other resources. Some manufacturers offer products to participants in programs such as THC at very favorable terms

2. Process Steps

A. *Pre-Application intake screening*

National Grid will conduct intake screening and give feedback on possible eligibility and remaining slots for this funding cycle.

- Screening will verify basic eligibility (per the criteria in these DER Guidelines), customer interest, willingness and ability to invest in such a project, as well as planned and compatible non energy improvements. Sincerely interested customers are requested to submit a web form indicating heating fuel type and town and stating intentions relative to the basic scope at https://www.powerofaction.com/der_forms/ .
- Contractors and designers meeting experience and qualification criteria may apply for listing on National Grid's "Deep Energy Retrofit (DER) Participating Contractor and Design Consultant List." www.powerofaction.com/der/
- Customers who do not qualify may be able to participate in other programs[5].

B. ***Review of program description materials*** by customer and contractor including these Guidelines as well as the Deep Energy Retrofit Contractor and Design Consultant List to help customers find contractors.

C. Project team formation by contractor or designer or housing organization with customer is required. Team formation may be initiated by any party. During the application period National Grid will host a Q&A conference call and may arrange for DER open houses.

D. ***First application*** requires mid-level detailed application that;

1. shows basic project concept and how it will meet pilot requirements and desired characteristics for energy and health safety and durability
2. includes dwelling characteristics and fuel use information, photos, basic description of remodeling or rehab plans, proof of financing,
3. initial estimate of costs of measures, related costs and other funding

E. ***Selection of project pool for stage two*** by technical specialist team[6] and National Grid of best candidates that meet the selection criteria. These candidates will be invited to proceed to the second application stage. Depending upon the mix and volume of viable multi and single family projects proposed some multi-family incentives may move to a negotiated or competitive bid approach.

F. ***Application feedback*** through written reviews, email, phone calls, or other suitable format, the Tech Team and DER program staff will identify opportunities for project refinement and provide feedback on documentation needed as project teams prepare the stage two application.

G. ***Second (more detailed) application*** requires physical representation drawings, floor plan with dimensions, detailed inventory of current and proposed equipment and fenestration suitable for comprehensive review and in some cases building energy modeling. The second application shall fully detail all proposed energy improvements including health and safety including detailed costs, expected incentives, and additional required documentation such as may be required for Level 2 incentive paths, i.e. Passive House EnerPhit, THC, NZE.

H. ***Analysis and review to screen final candidates*** Tech Team and DER program staff will conduct comprehensive in-depth review of proposed projects relative to all desired project characteristics and technical soundness. This review may include in-field inspection.

I. ***Develop final project plans and agreements*** including development of inspection and payment schedules and verification of insurance and that all program requirements are addressed in the plan. (Submitted materials will be cataloged into Exhibit A in the contract.)

J. ***Participation in required workshop*** will be scheduled at intervals each year and required prior to final payment for owner occupied projects.

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[5] Visit www.masssave.com/ for details on any MA utility or program administrator program.

[6] Project teams are expected to keep their own technical support resources throughout planning and implementation which may often add up to 5% to project costs.

K. ***Work commences*** [7] Tech Team conducts onsite technical support and inspections. Any changes to the project plan must be agreed to and accepted by the Program Administrator prior to being implemented in order for the measures involved to maintain eligibility for incentives.

L. ***Program visits*** including for inspections, press coverage, and monitoring for evaluation and mentoring of other contractors will be scheduled with reasonable advance notice.

M. ***Incentive payments*** will be made in up to four stages as work progresses and results are verified of customer fulfillment of agreement and project plan. Payments will be made upon inspection and receipt of proof that measures are installed as specified and paid to the contractor by the customer. Final 50% of level two incentives will be held until full verification which in some cases will require 12 months after completion to verify usage data.

N. ***Open houses and press*-related** communications and visits will continue for subsequent two years for owner occupied1-3 family buildings.

O. Project team to share all utility data and key lessons learned from operating the home with National Grid and Tech Team[8] for up to two (2) year period post completion

P. Deep energy savings and big carbon reductions for your building for generations to come.

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3. Pilot Project Time Table

DER Pilot applications considered on rolling basis according to the schedule outlined in the time table below for 2010 through 2012. In 2012 there will be no Group 2.

Application\Project Time Table	Group 1 - complete current year by November 30	Group 2 - complete next year by April 1 (Not In Rhode Island)
First Application Due	Any time Feb 15 to May 1	Any time before August 15
Review by NGRID team	10 days after receipt	10 days after receipt
Second Application Due	2 weeks after review	2 weeks after review
Project contracts finalization	4 weeks after review	Late-September

- Group 2 projects are to be 50% done in the application year and complete by April 1 of the next calendar year. If quota and budget are filled by Group 1 applicants, Group 2 projects will shift to Group 1 of the following year.
- Depending upon mix of single and multi-family the goal is for 40 to 50 units to be completed each year, this includes approximately five (5) units in RI in 2011.

4. Requirements of Selected Projects

A. Building owner and dwelling must be an eligible National Grid customer on the appropriate rate with the correct heating fuel type

B. Projects involving demolition and rebuild or new additions must; a) retain a minimum 50% original structure, b) also improve the rest of building, and c) treat standard levels of insulation in the addition as non-allowable costs.

C. Design, technical review and approval according to timeline above. Complete installation of energy and related measures per the project application as amended for the final agreement by the time specified in the timetable and agreement. **For a project to be eligible we require a**

[7] See requirements on page 5 regarding timing of blower door test

[8]. Much of the value for the DER Pilot and Building America program and knowledge to support the broader adoption of DER is derived post-completion.

blower door test from the Tech team or with prior permission from an approved 3rd party before work that may disrupt or improve building tightness can begin.

D. Combustion Safety:

i) 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. National Grid may consider exceptions on a case-by-case basis for outstanding projects in which the project team would need to propose an appropriate solution and get written code official approval on a plan that includes maintaining desired building tightness. This may involve chimney relining, chimney caps, controls, monitoring and feedback devices such as spill switches and CO alarms. Switching fuels is discouraged but acceptable if essential to control project costs while addressing combustion safety or other technical challenges. However this may affect incentives for that equipment and eligibility for National Grid[9] incentives. (See gas heating reference on page 1)

ii) For a home or building with an attached garage the wall between the house and garage as well as any horizontal separation (e.g. floor/ceiling) between the garage and living space must be air-sealed and insulated. The door between the house and garage must be weather-stripped. Air sealing between the garage and living space may be subject to verification by zone-pressure diagnostics to determine adequacy of air separation. No ductwork or air handler devices are permitted to be located in the garage Exception: if other approaches prove a cost prohibitive challenge, the Pilot may consider it acceptable to locate supply ducts within garage ceiling framing provided that there is air impermeable insulation and well seal gypsum wall board between the ducts and the garage space. In addition to applicable code and state law requirements for CO alarms, a CO alarm must be installed in each separate space of the home/building that is adjacent to or above the garage.

E. **Sound Building Science Related to Mechanical Systems and Water Management:** The project plan and implementation must demonstrate sound building physics as it relates to moisture management of the enclosure and effectiveness of the mechanical system configuration. For example, the project must include appropriate flashings, integration of water control materials, and measures to control temperatures of condensing surfaces within assemblies. Also, projects that involve integration of ventilation systems with heating and cooling systems must provide easily operated means to control the amount of ventilation delivered by the ventilation system.

F. If wet basements, asbestos, lead, radon, wood rot and other health\safety and durability issues are present, these must be adequately addressed to meet applicable government standards and as agreed upon per technical review process to be remedied either prior to or during the project. Prior to final payment, the customer must provide documentation and applicable certificates to document remediation of identified hazards. Customers may need to have a home inspection at a cost of about $500 to check potential wood rot and other conditions identified by the team and have those addressed in the plan.

G. Mechanical ventilation which is ASHRAE62.2 compliant and easy to control.

H. Access to the home with reasonable notice for learning and monitoring must be provided

i. Access is required for Indoor Air Quality (IAQ) and energy monitoring and verifiable pre- and post-usage data for a period as soon as application is approved through a minimum of two full heating seasons after the project is completed

ii. Press coverage, photos and a minimum of two open houses are required in the two years after completion for single family and owner occupied projects

[9] However another program administrator\utility may provide similar incentives.

iii. Access for reasonable number of other contractor personnel authorized by the program for on-site training is required.

I. Appliance audits and participation in two workshops including a workshop focusing on lighting and appliance use will be required to reinforce efforts to achieve energy use reductions. Efficient lighting upgrade is required such that at least 90% of sockets have fixture appropriate compact fluorescent lamps ("CFL"), or better, with support by National Grid.

J. For Level two incentives, design must meet the performance threshold of the selected Level 2 incentive program (i.e. EnerPhit, NZE, THC), obtain full certification through the selected program, and validate attainment of the performance threshold with one year of operating data.

K. Participant must demonstrate sufficient financing or other leveraged resources and sign an agreement with additional detail regarding the project plan and implementation.

5. Desired Project Characteristics

A. *Building Enclosure and Mechanical Ventilation Package*

National Grid is seeking projects with building enclosure and mechanical systems modifications including super-insulation wall build-outs, window upgrades and mechanical ventilation systems that dramatically transform a home's performance. Staged retrofits will be addressed as described in section 1B. The list below indicates targets or in some cases ideals for each major building component. In some cases, these targets cannot be readily met as stated. Creative solutions for meeting the intent, such as reducing north/west facing and basement window area are acceptable and encouraged.

i. **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

ii. **Air Sealing Target** – **Ideal** whole house sealed to achieve 0.1 (zero point 1) CFM50 /sq ft of thermal enclosure surface area (6 sides) with high durability materials.

a. Air Sealing incentive adjustments – projects that reach or fail to reach the targets below will have the following adjustments to the overall total incentive:

CFM50 /sq ft of thermal enclosure LEVEL	**% change**
0.1 (zero point 1) or less	+ 5% e.g.$2100 added to $42,000
>.01 and < 0.2 (between zero points 1 and 2)	No change (80% thru 1/1/11 were in this range)
0.2 (zero point 2) or more	- 5% e.g.$2100 subtracted from $42,000
0.25 (zero point 25) or more	-10%
Partial DER <60%[10] *Encl. or Special Component(s) DER*	
Exterior wall included: 0.35 or more	-10%
Exterior wall not included: 0.5 or more	-10%

b. Tightness levels should be maintained by provisions in the plan sufficient to avoid need for or use of window air conditioners. Alternatively, as a last resort in some cases, plans may be accepted where use of window AC is coupled with shading, reusable effective sealing for window unit and cross ventilation, provided units are deployed so as to make for easy removal.

[10] For Partial DER projects treating 60% or more of the building enclosure area, the CFM50/sq ft incentive reduction thresholds in the air sealing table above will be increased by the percentage of building enclosure area not included in the DER project plan. E.G. 80% DER would increase first row level by 20% to 0.12. Exception, if just slab is left out of DER project plan there will be no change in the thresholds.

iii. **Windows and Doors** - target R5 (U ≤ 0.2) whole-unit thermal performance, infiltration resistance performance of ≤ 0.15 CFM/sq ft. of air leakage, per AAMA[11] standard infiltration test. Orientation appropriate glazing; windows and doors will be NFRC (National Fenestration Rating Council www.nfrc.org) certified and bear the NFRC performance label; Movable shutters, high performance storm windows or two separate window units within a window opening may be considered as an alternative. Treatment for all windows and doors within in the thermal envelope (which usually includes the basement) must be addressed in the plan.

iv. **Mechanical Ventilation** - Ideal whole building ventilation system that is efficient both of fan energy and heat recovery; balanced, distributed, and automatic; All kitchen stoves/ovens should have an exhaust fan vented to the outside fitted with a damper and a capture hood equal to the size of the stove top. Required: easy to control and complies with ASHRAE 62.2

B. ***Project windows of opportunity*** - at time of residing, new windows or roof, major remodeling including gut remodel, or basement conversion or remediation.

C. ***Completion likely for desired timeframe***

D. ***Project will successfully leverage***:

- customer creativity and dedication to total household energy reductions
- design to achieve and not miss or block opportunities along the path to achieve THC, NZE or PHI thresholds
- measures including; advanced lighting, high efficiency and innovative HVAC and hot water systems, and renewables (note: priority must be given to solar hot water over PV)
- learning opportunities for other contractors and others to learn from project

E. ***Variety*** in projects based on different windows of opportunity and other desired learning **including** different housing types, project types and identification of OPTIMAL approaches.

F. **Cost effectiveness** in total energy related project costs relative to lifetime energy savings.

6. Project Team Requirements

Successful project design, implementation and completion will ideally involve a diverse team to leverage resources and increase the impact of the project. The party to pull a project together could be a customer, general contractor, green remodeler, design professional, energy consultant, nonprofit organization, local government or an educational institution.

Project Team Basic Required Qualifications

- Owner and building must be eligible as described above
- Contracting party must have Massachusetts Home Improvement Contractor (HIC) license
- A qualified general contractor must be on board for duration of the project.
- In most cases an HVAC contractor with experience installing mechanical ventilation integrated with duct work and completing room by room heat loads will be needed.
- Project team must include at least one general contractor or design professional listed on Deep Energy Retrofit ("DER") Contractor and Design Consultant List.
- Eligibility for this list requires prior DER related experience which may include:

[11] AAMA American Architectural Manufacturers Association http://www.aamanet.org/

- ENERGY STAR® Certified homes with Home Energy Rating Score ("HER") scores approaching or below 60, and or remodeling with HERs below 70
- Net Zero Energy or Passive House built or under contract. PHI certification
- Remodeling involving super insulation and extensive blower door verified air sealing.

General Contractor Responsibilities [12]

1. Contractor must be the general contractor and work with the customer and others on project proposal and appropriate sections of the application for pilot.
2. Provide cost detail sufficient to determine incentives and net incremental cost, relative to standard practice, of implementing the DER measures
3. Negotiate costs with customer and agree on final plan with incentives and work schedule
4. Complete project on schedule according to requirements and agreed upon specifications
5. Install measures and, in most cases, the "finish" materials
6. Contribute to maximum learning from project, cooperate with the Pilot implementation team including evaluators
7. General contractor must meet insurance, licensing and experience requirements

7. Project Selection Criteria

The two-stage application process provides many benefits including a phased opportunity for project development\improvement and a process to identify candidates that best meet requirements. Key objectives include a concrete plan that; defines deliverables and timelines, provides cost and other data that's needed for study of DERs, as well as solid building science to best promote efficiency, indoor air quality, durability and occupant health and safety

FIRM CRITERIA: Project and team viability, meets all requirements including funding, timing and comprehensive approach.

PRIORITIES:

- Level 2 incentive (THC, NZE or PHI) preferred provided good value and lifetime savings
- Matches desired project characteristics especially that project will be completed on time[9].
- **No more than three projects involving the same general contractor selected to be in process in a project group (see time table in section (3)).**
- Diversity of project type and variety of house type and super-insulation approaches
- Geographic diversity with some preference for combined gas and electric customers
- Mix of single family and multifamily to fulfill project goals and budget for the year

[12] Contractors may be removed from the list and consideration for a group of projects for failure to complete a project on time

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

See attached.

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.

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

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 Performance Specifications **DER Pilot Targets**	f **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.									

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**
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									
Insulated sloped roof (exterior)				$0	$0							75%		
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									
Above grade wall 1 (exterior)				$0	$0							75%		
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									
Above Grade Foundation Wall (interior)				$0	$0							75%		
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	$0	100%	$0	
		Sums From Below >		$0	$0	$0	$0		$0	$0	$0		$0	
Windows (Replacement)				$0	$0									
Windows (Replacement)				$0	$0									
Doors				$0		$0	$0	0	$0	$0	$0	75%	$0	
		Sums From Below >		$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	$0	75%	$0	
		Sums From Below >		$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	$0	75%	$0	
		Sums From Below >		$0	$0	$0	$0		$0	$0	$0		$0	
				$0	$0									
				$0	$0									
Heating equipment				$0		$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									
Cooling equipment				$0		$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									
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**	

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.)

				a	b	c	d	e	f
Component	Applicable to Building	Component treated in DER Project?	Note	Enter areas below! **Existing Conditions (Units)**	**Proposed**	**Performance Specifications** **Existing Condiitons ***	**Proposed**	**DER Pilot Targets**	**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

		g	h	i	j	k	l	m	n
Component		**Total Measure Cost**	**Non-allowable Costs**			**Allowable Cost**	**Incentive %** (calculates)	**Estimated Incentive (e x f)**	**Applicant explanation of non-allowable cost**
			Renova-tion	**Third Party**	**Deduct-ible**				
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.

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.

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

Building Area:			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
Exisitng Building Conditioned Area:	0	sq ft	**#DIV/0!**	**#DIV/0!**	**#DIV/0!**	**#DIV/0!**	**#DIV/0!**

Building Occupancy:		Energy Cost/ Occupant	MBtu/ Occupant	kWh/ Occupant	MBtu/ Occupant	kWh/ Occupant
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!

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	

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		Foundation Type: Type 1:		Foundation material	
		Pre DER Air Tightness: CFM@50pa		Type 2:		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)	**Proposed Count:**
Electricity	0	kWh	$0	
^ provide data on 5A				
Primary Heating	0	#N/A	$0	
^ provide data on 5A				
Secondary Heating/other fuel	0	#N/A	$0	
Tertiary Heating/other fuel	0	#N/A	$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

Fuel/Energy Type:

enter # of systems in building

Heating System Type:

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

Fuel/Energy Type:

Heating System Type:

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

Fuel/Energy Type:

Heating System Type:

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?

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	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

	Dwelling Units in Facility	Conditioned [1] Sq Ft Floor Area per Unit	Maximum Project Incentive	Dwelling Units in Facility	Maximum Project Incentive
[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	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

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.

10.3 Appendix C: [Test Home 3] First Application Review

See attached.

bsc Building Science Corporation

2010.07.06

David Connelly Legg

Principal Analyst, Residential Tech Services
Energy Products
National Grid
40 Sylvan Road

Waltham, MA 02451
ph: 978.907 1612

Re: **National Grid Deep Energy Retrofit Pilot, [Test Home 3]**
First Application Review

CC: Betsy Pettit, Building Science Corporation

Dear Mr. Legg:

I have reviewed the first application for the proposed [Test Home 3] deep energy retrofit in Arlington. I find the proposed plan to be substantially consistent with the targets established in the DER Pilot Description and Guidelines. The application is refreshingly complete with useful data provided on tabs 4, 5A, and 6 where other applications have been lacking.

I noted two minor inconsistencies in the application and another input that invites further explanation:

- Window specification – confirm whether the proposed specification is R 3.5 or R 5,
- Ventilation – clarify whether the intent is to install one HRV or two, and
- Heating system – confirm that the proposed distribution system is forced air.

Communication with the applicant should suffice to resolve these questions before the second application.

As the project moves forward, I hope to have the opportunity to better understand the rationale for the roof/attic insulation approach as well as the decision to pursue isolation of the basement. I would like to explore whether there might be more cost effective options to insulate the roof. It would also be interesting to investigate whether alternative approaches to the basement might respond to the project concerns for performance and value.

On the following pages are comments on specific elements of the project plan. If, after reviewing this information, you have further questions, please contact me as per the contact information below.

Thank you,

Ken Neuhauser

ken@buildingscience.com

978 589 5100 x5279

The following comments are offered to the project plan as described in the first application submitted to National Grid for consideration in the Deep Energy Retrofit Pilot program.

1. General

The retrofit involves a two story, two family residence. The plan will expand the second floor apartment by bringing the existing attic space into conditioned usable space. Although the conditioned area of the building is projected to increase by 50% there is no projected increase in the building footprint and the building enclosure is not expanded beyond the current enclosure structure. The application did not expand upon the rationale for excluding the basement from conditioned space. It is possible that issues of ownership and use for the basement space influence the plan direction.

Overall, the application is quite thorough. The applicant provided information on the utility accounts for each of two apartments in Tab 4. Tab 5A includes utility consumption data. This appears to be data for only one apartment. It is possible that the vacant unit had no consumption but this is not confirmed. The information provided in Tab 6 is useful in that it gives an indication of drivers for this project.

A useful input that was not included with the application is a narrative of the project plan such as might be provided in Tab 3.

2. Attic/Roof

The plan indicates that the roof will be replaced for non-energy reasons and that the roof structure will be insulated from the interior with 10" SPF along the slope and 18" of cellulose over the flat ceiling portion. From the images of the building provided with the application, I infer that the span of the flat ceiling would be quite short (ref. Figure 1 below).

Figure 1: Front elevation existing conditions

I find it curious that the project would insulate to the interior with closed cell spray foam when the application indicates that the roof is to be replaced. The depth of foam that would be required to meet the target R-value would represent a significant material cost per unit area, probably somewhere in the range of $3.75-7/s.f. To reach a comparable R-value with polyisocyanurate above the roof and fiberglass batt insulation within the roof framing cavities would entail a material cost in the neighborhood of $3.60/s.f. (including ½ plywood for nailbase and 6" screws). It will be interesting to learn from the builder about the labor costs and how these affect the relative costs of different roof insulation strategies.

It is also curious that the proposed plan would include a vented attic space where it seems that there is a very small area in which to realize the benefit of a lower unit area insulation cost. Cellulose insulation certainly represents a lower cost/s.f. than SPF for the target R-value, but venting the attic space introduces complications especially with the depth of insulation required. If the project continues with the combination of compact roof assembly and ventilated attic, it will need to explain how ventilation of the attic will be achieved and whether or not the sloped portion of the roof will be vented as well.

3. Walls

The project plan for superinsulated wall assembly includes cellulose cavity fill and 4" of exterior insulating sheathing.

4. Basement Isolation

The project plan proposes to isolate the basement from conditioned space. The planned retrofit to the basement ceiling includes a flash coat of closed cell spray foam, full cavity cellulose insulation, and rigid foam insulation installed to the bottom of the floor framing. The plan also proposes to construct a thermal enclosure around mechanical equipment.

BSC would like to better understand the rationale for the isolation of the basement so that we can better appreciate advantages that builders and homeowners perceive in this approach relative to challenges perceived in the approach of including a basement within the thermal enclosure.

As you are aware, we have yet to encounter a basement separation assembly that is effective at providing adequate airflow control between the unconditioned basement and the living space. This is of concern to performance and air quality because the unconditioned basement will tend to have greater likelihood of developing mold and moisture problems. The proposed system appears to vigorously address air flow control and also provides a measure of protection for the floor framing. While BSC would be interested in having more observations wherein we could measure the performance of unconditioned basement approaches, we would not recommend projects pursue this approach if insulating and conditioning the basement is a viable approach.

5. Windows

The application indicates that the post retrofit R-value of the windows will be R-3.5 but the window measure description indicated R 5 Eco-Shield windows. Because Eco-Shield is a participant in the DOE R-5 window program, I assume that the R 3.5 input is a mistake. The project should confirm this before proceeding to the second application.

It is worth noting that the application inputs for quantity of windows and cost of the window measure represents a cost of $390/window. It would be a significant boon to high performance building objectives if R-5 windows were available at prices below $400.

6. Mechanical Systems

Ventilation

The application indicates that one Fantech HRV will be installed in the building. The cost indicated for this measure appears to be more representative of the installation of two HRV units. The applicant should confirm whether the project plan includes one or two HRV units. If the plan includes just one HRV unit, then the applicant must describe how ventilation is provided to both apartments and should also explain the measure cost in greater detail. The project should also indicate the proposed ventilation distribution in later application phases.

Heating

The project plan proposes to install two new condensing furnace units. The application indicates on Tab 4 that the current heating system is steam and that the existing system will be changed to hot water baseboard. The applicant should resolve this discrepancy before the second application. Assuming that the proposed heating systems are intended to be forced-air systems there are a few comments I would offer on the proposed heating systems:

- The indicated size of one of the units is 100 kBtu/h, this would seem large relative to expected post-retrofit loads
- The efficiency of one of the systems is not indicative of a premium efficiency model
- One of the proposed furnace units does not appear to include a variable speed air handler fan.

The indicated size of one of the furnaces would appear to be very large relative to the post-retrofit heating load. Efficiencies in the range of 95-97 AFUE represent a relatively small price increment in many common furnace lines. With properly designed duct work, significant electrical savings can be attained through the use of a variable speed motor.

Air Conditioning

The project plan does not currently include provision of central air conditioning. However, the application does indicate a planned installation of a cased coil for future installation of air conditioning. I applaud the decision to install a cased refrigerant coil at the time of installing a new forced-air system. I would offer to the project that the indoor coil can be a limiting factor on system efficiency and, therefore, would encourage selection of a coil that offers the maximum of heat exchange area and the minimum of static pressure drop.

In order to facilitate the future provision of air conditioning in the other forced-air system, this ductwork should be sized for cooling. While such would tend to result in duct work of larger cross-sectional area than heating-only systems, the likely reduced static pressure of the distribution system can benefit a heating system that uses a variable speed blower motor.

Water Heating

The application does not directly collect information on proposed domestic water heating for the DER projects. Since water heating can be a major energy use it would be useful for applicant projects to provide an indication of proposed water heating strategies. This would provide and opportunity for BSC to evaluate the proposed system and offer guidance on implementation of efficient approaches to water heating.

10.4 Appendix D: Case Study, National Grid Deep Energy Retrofit Pilot Program, 1960s Garrison Colonial Comprehensive Retrofit (Test Home 1)

See attached.

Case Study

National Grid Deep Energy Retrofit Pilot Program

1960s Garrison Colonial Comprehensive Retrofit

Milton, Massachusetts

Overview

The current owner purchased this bank-owned and unoccupied home in 2010 with the intention of conducting significant energy performance improvements prior to occupancy. The National Grid Deep Energy Retrofit Pilot Program provided technical and financial assistance to extend these renovations to the level of a deep energy retrofit (DER).

The retrofit project for this home included a comprehensive enclosure retrofit and new heating, cooling and ventilation systems. Prior to the retrofit project, the home had fiberglass cavity insulation in the attic floor, exterior framed walls and between wood framing to the interior of the basement foundation walls. The home had a forced-air duct system that employed framing cavities for some of the returns.

Through grants and product donations, the owner was able to supplement the enclosure measures with advanced combination space/water heating, high efficiency heat recovery ventilation, a photovoltaic system, and energy monitoring equipment. The owner is pursuing Thousand Homes Challenge designation.

This test home provides an example of a thoroughly comprehensive retrofit that did not involve major additions or changes to the configuration of the building enclosure.

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Project Profile

Project Team:
Boston Green Building, Builder and DER Lead; Building Science Corporation, DER Consultants and Technical Support; National Grid, Massachusetts, DER Pilot Program Administrator/Sponsor

Location:
Milton, Massachusetts

Description:
2,368 ft^2 (including conditioned basement) comprehensive renovation of circa 1960's Garrison Colonial

Completion Date:
February 2011

Estimated Annual Energy Savings:
39% energy use reduction before PV; 57% reduction indcluding PV contribution

Project Website:
http://www.miltongreenhome.com/

Building Science Corporation
30 Forest Street
Somerville, MA 02143
www.buildingscience.com

Builder Profile

Established in 2007, Boston Green Building (BGB) has quickly become one of Boston's premier full-service, green builders. The Boston Green Building team builds beautiful and healthy spaces that increase the well-being and comfort of individuals and families, while decreasing the operational costs and carbon footprints of their homes.

Participating Programs & Certifications

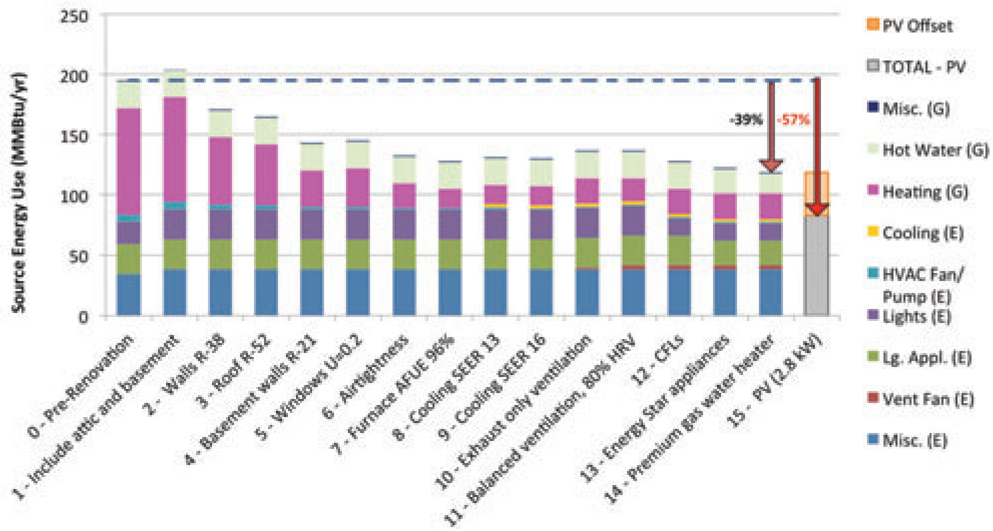
U.S. Department of Energy's Building America Program

U.S. Environmental Protection Agency ENERGY STAR® Program

Deep Energy Retrofit Pilot Program
For more information, go to
www.powerofaction.com/der

Design

Parametric Study



The design for this extensive renovation included super-insulation of the thermal enclosure and reconfiguration of the spaces within the thermal enclosure.

The home already had insulation between wood framing against the concrete foundation walls. However, the insulation was a fibrous insulation with an interior-side vapor barrier. This system did not provide adequate insulation or management of moisture risks. The builder specified closed-cell spray foam insulation for the retrofit of the foundation wall. The existing wood framing was incorporated in the plan and re-used, after some height adjustment, as the frame wall to support a gypsum board thermal barrier for the insulation.

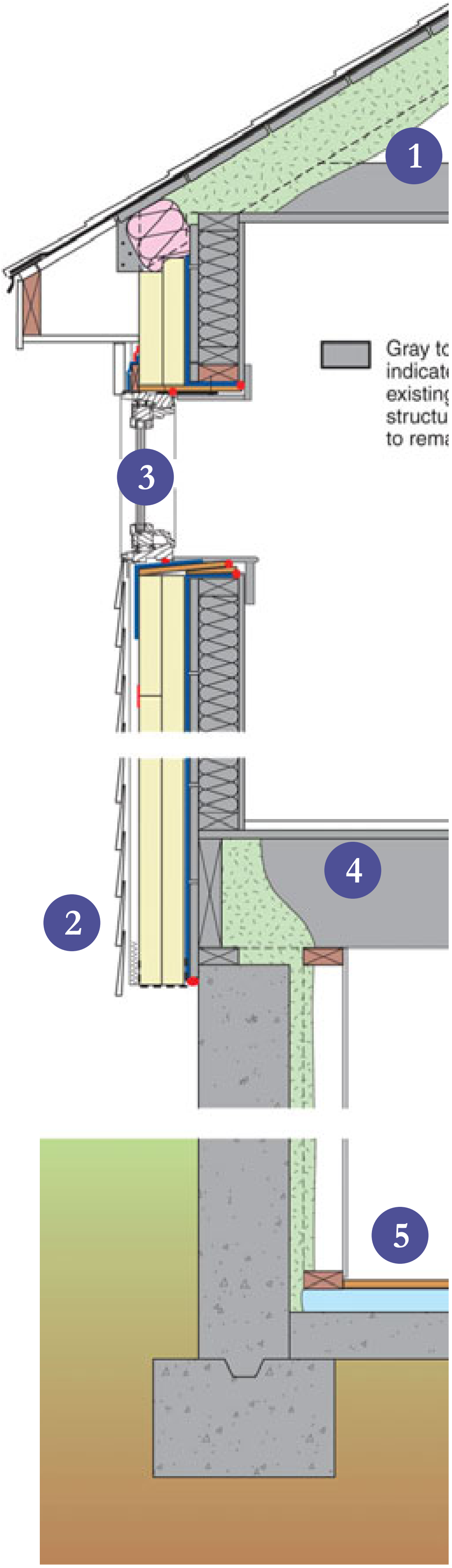
The design called for rigid XPS insulation installed directly over the concrete basement floor. The seams of the rigid insulation are taped and the perimeter is embedded in the spray foam of the wall to create a continuous airflow control for the foundation system.

The project team determined that liquid water was not an adequate risk to merit a drainage system at the basement floor. Hence, there is no drainage mat between the rigid insulation placed on top of the slab. Still, a sump pit was cut into the existing slab to provide a location where the homeowner will be able to install a sump pump to remediate liquid water problems should such be experienced at some time in the future.

The design thickens walls with a layer of exterior insulation. The existing roof plane was retained in the design as the builder opted to provide insulation to the inside of the roof sheathing.

The builder selected casement windows to replace existing double hung windows. The intention behind the selection of casement windows was to minimize air leakage through window units.

The mechanical system plan included forced-air heating and cooling distribution and balanced ventilation. The equipment selection for this system as well as the water heating system and configuration of the attic/roof insulation were dictated by the availability of donated products.



Enclosure Design

❶ **Roof Assembly:** R-56 (nominal) unvented roof: New asphalt shingle roof and underlayment over existing roof sheathing; rolled fiberglass batt as eave backstop for 8” of closed-cell spray foam between and over the existing 2x6 rafters.

❷ **Wall Assembly:** R-38 (nominal): Fiber cement cladding installed over 1x3 wood furring strips; two layers of 2” polyisocyanurate exterior insulating sheathing; joints of foil-faced outer layer offset and taped; housewrap with joints lapped and seams taped applied over existing wall sheathing; existing 2x4 wall cavities with cellulose or existing fiberglass insulation.

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

❹ **Infiltration:** Housewrap with joints lapped and seams taped under the taped outer layer of insulating sheathing on the wall is the air control layer for the field of the walls; 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 top of the foundation wall and mudsill relying on a tight joint between the exterior sheathing and the mudsill and then the spray foam over the foundation wall extending up over the mudsill.

❺ **Foundation Assembly:** Conditioned basement with closed-cell spray foam applied to existing foundation walls and partially embedding repositioned wood frame wall; 2” XPS rigid insulation with joints taped and perimeter embedded in wall spray foam over existing slab under floating floor; new sump pit added.

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.

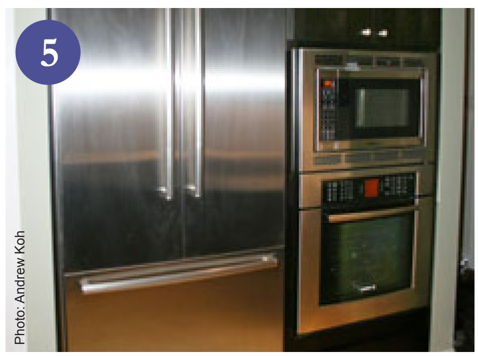
❸ **Space Conditioning Distribution:** Entire distribution system within thermal enclosure.

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

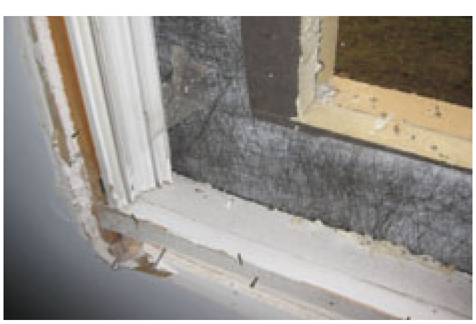


Construction

During construction, the availability of donations changed a few specific aspects of the plan. The project team was able to adapt to these changes although the initial design of the project may have been slightly different had the availability of the products and equipment been known prior to construction.

The builder installed the house wrap and exterior wall insulation before installing the new windows in the existing openings. This sequence complicates the transition of the house wrap airflow control at the window. In this project, the exterior face of insulating sheathing was also detailed as an airflow control layer and may have had a more dominant airflow control role.

To protect the basement slab insulation from construction abuse, the builder installed just a 1' wide strip of insulation around the perimeter before re-installation of the wood stud wall and application of spray foam at the foundation wall. This allowed for a continuous thermal and capillary break beneath the wood framing. The sequence also allowed the spray foam contractor to embed the floor insulation perimeter in spray foam for transition of airflow control. When the rest of the basement slab insulation was installed, it was a simple matter to seal it to the perimeter starter strip.



Testing and On-Site Technical Support

Observations of framing cavity returns that BSC made during a preconstruction site visit provided the motivation to entirely replace the existing duct system.

During the course of construction BSC conducted multiple site visits to review construction details with the general contractor. BSC advised of the need to tape the top edge of membrane flashings and also pointed out the complication to airflow and water control caused by installing windows over strapping instead of in plane with the drainage plane.

BSC performed both pre- and post-retrofit air leakage testing to assess the air leakage reduction. The pre-retrofit air leakage measurement was actually quite good for an existing home of this

age at 1695 cfm at 50 Pascals or near 4 ACH50. BSC measured the post-retrofit air leakage to be 584 cfm50 or 1.6 ACH50.

Moving Forward

The homeowner commissioned extensive energy monitoring systems in order to guide the family toward meeting the ambitious Thousand Home

Challenge goals for the home. The energy monitoring provides a unique opportunity to gauge the performance of the enclosure retrofit, mechanical system and site generation strategies. The homeowner's commitment to share data with BSC and the DER Pilot Program sponsor provides further opportunity to learn from this project.

Design Challenge: Retrofit Roof Strategy

For various reasons, the builder included a vented roof with air sealing and insulation at the attic floor in the DER design. To accommodate the additional wall thickness of 4" exterior foam and furring strips, the roof eaves were extended. Then, the roof was re-shingled.

As is shown in the photograph of pre-retrofit conditions, the second floor window heads were already very close to the eave soffit (and the gable end overhangs were weak). Extending the eave overhang along the slope of the existing roof meant that the window heads actually had to be lowered to allow for some window trim above the second floor windows.

Later in the project, when the homeowner decided to pursue an unvented roof with the attic inside the conditioned space, the only practical option was closed-cell spray foam installed to the underside of the roof deck.

In retrospect, the design decision not to insulate over the roof represents a missed opportunity: exterior insulation and overclad in combination with a "chainsaw" approach would allow the soffit to stay at same height as existing or even go higher. An exterior insulation and overclad approach would also have allowed more insulation over the top plate of the wall and a more robust air flow control transition than is possible with the approach implemented.

10.5 Appendix E: Case Study, National Grid Deep Energy Retrofit Pilot Program, Retrofit and Addition to 1900s Duplex (Test Home 3)

See attached.

Case Study

National Grid Deep Energy Retrofit Pilot Program

Retrofit and Addition to 1900s Duplex

Arlington, Massachusetts

Overview

The project for this owner-occupied two-family residence started with the idea of enlarging the upper unit to accommodate a growing family and renovating the lower floor unit for the mother of one of the owners. With support of the National Grid DER Pilot program, the owners were able to realize these objectives while dramatically reducing energy consumption.

The project involved removing the roof and adding a full third floor. Exterior insulation was added to the existing walls as well as the newly constructed walls. Windows were replaced throughout. The renovated apartments received new heating systems with new distribution, new water heating systems and heat recovery ventilation systems. The interior of the building was gutted during the course of the renovation. The project was staged such that the first floor apartment interior work and exterior insulation was completed first, then the family moved into this lower unit while work progressed on the upper floors.

This project provides an example of a major addition and renovation that incorporated super insulation and other higher performance enclosure and mechanical system measures. It also provides an example of the difficulties in achieving robust air and thermal control at an existing basement ceiling.

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Project Profile

Project Team:
Boston Green Building, Builder and DER Lead; Building Science Corporation, DER Consultants and Technical Support; National Grid, Massachusetts, DER Pilot Program Administrator/Sponsor

Location:
Arlington, Massachusetts

Description:
Comprehensive retrofit and upward addition of over-under duplex; 2,340 ft^2 pre-retrofit; 3,430 ft^2 post-retofit; 6 bedrooms, 4 baths total; 3 stories plus unconditioned basement

Completion Date:
March 2011

Estimated Annual Energy Savings:
Predicted source energy reduction is 57% from pre-retrofit conditions.

Building Science Corporation
30 Forest Street
Somerville, MA 02143
www.buildingscience.com

Builder Profile

Established in 2007, Boston Green Building (BGB) has quickly become one of Boston's premier full-service, green builders. The Boston Green Building team builds beautiful and healthy spaces that increase the well-being and comfort of individuals and families, while decreasing the operational costs and carbon footprints of their homes.

Participating Programs & Certifications

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U.S. Department of Energy's Building America Program

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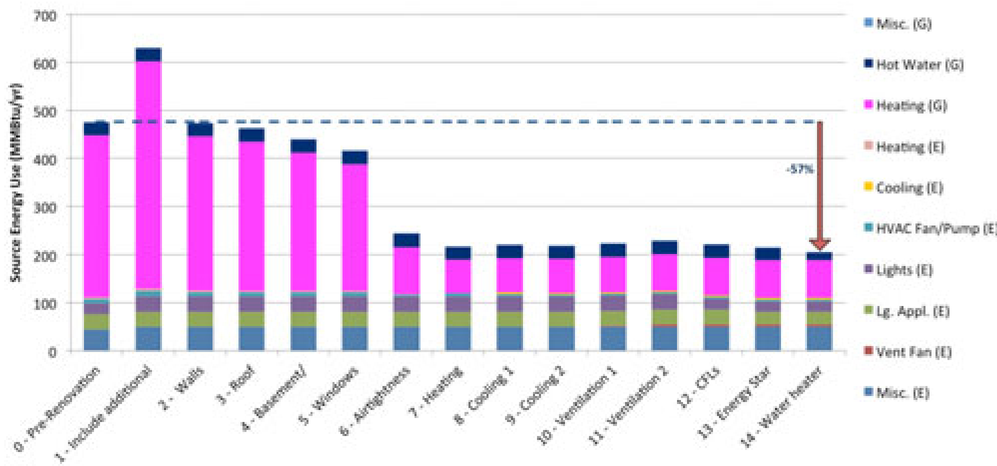
The power of action.

Deep Energy Retrofit Pilot Program
For more information, go to www.powerofaction.com/der

Design

Parametric Study



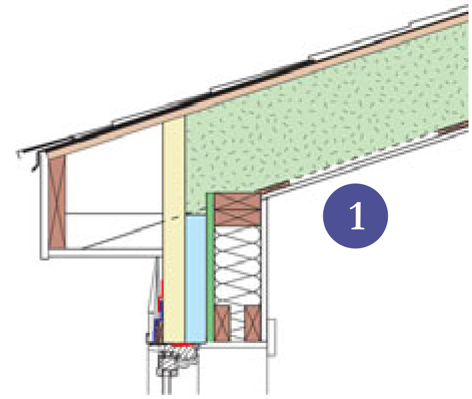
To accommodate the desired increase in space, the design called for demolition of the roof and half-story to make way for a new 3rd floor and roof to be framed on top of the 2nd floor. The design for the retrofit of the existing enclosure as well as the new structure is intended to provide a high level of thermal performance.

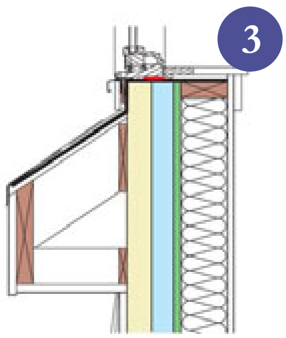
Initially the design called for a vented roof with deep layers of cellulose insulation on a flat top-floor ceiling and vented cathedralized ceilings. The builder then determined that an unvented roof assembly, with insulation to the interior of the roof deck, would be more feasible.

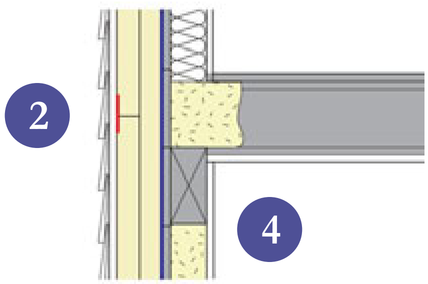
For the exterior walls, the design provided a thick layer of exterior insulation over a housewrap on the retrofit walls and over a Zip System™ wall at the 3rd floor addition. Open-cell spray foam was specified for insulation and air flow control in the wall cavities of the first floor apartment unit. Wall cavities of the upper apartment unit were insulated with a fiberglass batt insulation.

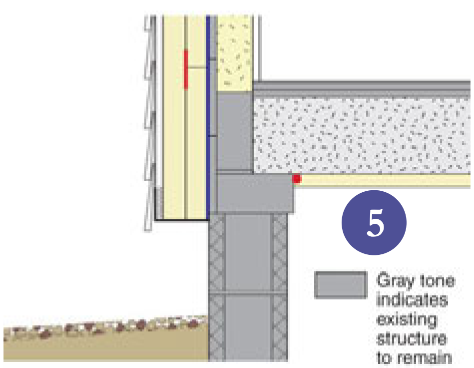
Where acceptable to the client, the builder selected casement windows with the intention of reducing air leakage through window units.

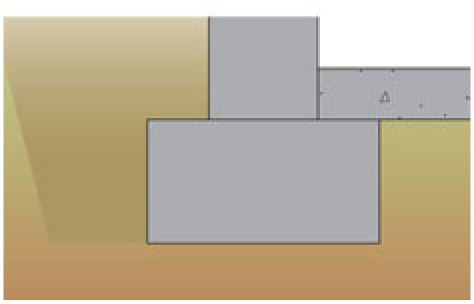
Against the recommendation of BSC, this project decided to exclude the partially-finished basement from the thermal enclosure. With the basement excluded from the thermal enclosure, robust airflow control would be needed at the floor over the basement as well as at the stair access from each apartment to the basement. This configuration also placed the air handler for the first floor apartment and some of the ductwork in an ostensibly unconditioned space. The initial design for the floor over the basement was to apply a flash coat of closed-cell spray foam to the underside of the subfloor, a continuous layer of taped foil-faced rigid insulation to the underside of the floor framing, and a dense-packed cellulose cavity fill. For cost reasons, the closed-cell spray foam was limited to application of canned foam as a sealant at penetrations through the subfloor and at the perimeter of and penetrations through the rigid insulation layer. The builder used open-cell spray foam in the walls of the basement access stairs to isolate these from the apartments.











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.

Mechanical Design

❶ **Heating and Cooling:** 96.6% AFUE variable speed condensing furnaces located in 1) insulated mechanical space in unconditioned basement, and 2) conditioned mechanical closet inside apartment; refrigerant coil in air handlers prepped for future A/C.

❷ **Ventilation:** 3 speed HRV, 65-200 cfm nominal capacity, ducted to heating distribution system; one for each apartment.

❸ **Space Conditioning Distribution:** 1st floor apartment with air handler and ductwork in unconditioned basement, partially within insulated mechanical space; upper apartment distribution entirely within conditioned space.

❹ **DHW:** 0.95 EF, gas-fired, condensing, on-demand water heater, one for each apartment located in insulated mechanical space in unconditioned basement.

Lighting: ENERGY STAR® CFL or LED lighting throughout.

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

Construction

The staging of the project required that exterior wall retrofit measures and interior work for the first floor apartment be essentially complete before work could commence on the renovation and addition of the 2nd and 3rd floors.

The project budget did not allow for detaching the open porches at the rear of the building in order to allow the air and thermal control to be applied in a continuous layer behind the porch connection. To address the concern for airflow control and insulation, the builder cut back a strip of porch roof adjacent to the exterior wall of the building so that spray foam could be applied against the wall and around the porch roof framing.

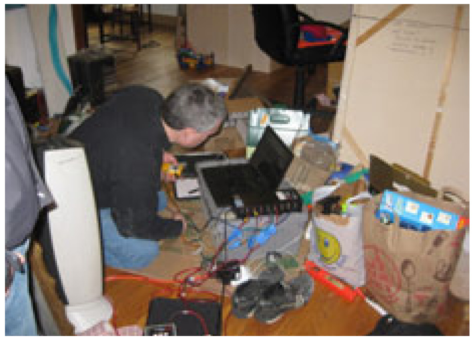
The installation of windows over strapping rather than in plane with the face of exterior insulation created challenges for proper flashing of the windows. A sequencing problem emerged where vertical strapping adjacent to windows prevented window head flashing from being connected back to the drainage plane. To provide head flashing across the top of the window, the adjacent vertical strapping would have to be cut and the upper piece temporarily removed.

At both the newly constructed roof at the 3rd floor and existing lower roofs over conditioned space, projecting rafters created a condition of thermal bridging and difficult airflow control transitions. At the newly constructed roof, exterior insulating sheathing was notched around rafters and extended up to the underside of the roof sheathing. This allowed the closed-cell spray foam of the roof system to seal between roof sheathing and wall insulating sheathing and the framing top plate. At the overhang of existing roof sections where there was not access from the interior, the transition of airflow control was more challenging. At these locations, exterior insulating sheathing was notched around projecting rafters in order to allow one-part foam sealant to seal between the projecting framing and the exterior insulation.

Testing and On-Site Technical Support

BSC conducted site visits to review construction details with the builder, point out errors to repair in flashing or other elements, and to identify viable simplifications to the project.

BSC conducted blower door testing to assess the air leakage of the structure both before retrofit work and after substantial completion of the project. Because the plan for this two-family structure excluded the basement from the thermal enclosure, BSC also performed a series of diagnostic tests to assess the significance of leakage across the basement separation relative to the air leakage of the thermal enclosure as a whole.



The pre-retrofit fully unguarded test of the apartment space found it to be rather air leaky at 8730 cfm50 or 26 ACH50. Comparison to guarded testing of the apartment space and basement suggests that about 45% of the combined apartment leakage is at the basement-apartment separation. After substantial completion of the retrofit scope, BSC found the unguarded leakage measurement for the combined apartment enclosure to be 3586 cfm50 or 7.3 ACH50 with leakage across the basement-apartment separation at least 1750 cfm50.

Moving Forward

Much was learned from this project in terms of, for example, the effectiveness of basement separation, the importance of sequence in windows installation and flashing, and connections between roof and wall assemblies. Because of the experience of this project and measurements that BSC was able to provide, the builder has revised assumptions about basement insulation and adopted a different approach to window installation on subsequent DER projects.

Design Challenge: Whether to Include or Exclude Basements

Basements present a host of challenges to high performance retrofit. Basements tend to be cool, damp and musty spaces. Often low framing heights render the spaces unsuitable for habitable space. Basements can also be a source of soil gas or other air borne contaminants. What is often not adequately appreciated is that basements tend to have fairly strong airflow connections to living spaces above.

Insulation and air sealing at the ceiling over the basement may initially seem a more cost effective thermal enclosure retrofit than properly insulating the entire basement. However, many factors make it difficult to provide effective airflow control between a basement and adjacent spaces.

The difficulties in achieving a robust separation despite strong efforts were evident in this project. Although the overall leakage of the basement space was significantly reduced as a result of the retrofit measures, the basement remained nearly three times more leaky to the apartment spaces than to the outside directly.

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10.6 Appendix F: Case Study, National Grid Deep Energy Retrofit Pilot Program, Cape Basement Renovation Turned Comprehensive DER (Test Home 4)

See attached.

Case Study

National Grid Deep Energy Retrofit Pilot Program

Cape Basement Renovation Turned Comprehensive DER

Newton, Massachusetts

Overview

The owners of this single family home initially set out to remodel the basement into conditioned space and upgrade the heating and water heating systems. Working with a builder oriented toward high performance construction, the owners decided to expand the project and turn it into a Deep Energy Retrofit (DER) after the builder introduced them to the National Grid DER pilot program.

Original project scope already included thick interior insulation for the foundation walls, a new insulated basement slab, new boiler and water heater. The expanded comprehensive DER scope included exterior and interior insulation and recladding of the walls and roof, new triple- and double-glazed windows, replacement of the central air conditioning system with a high efficiency air-source heat pump, and provision of a Heat Recovery Ventilator (HRV) for mechanical ventilation.

This test home provides an example of a thoroughly comprehensive retrofit that did not involve major additions or changes to the building footprint but, nonetheless expanded living space by including the basement within the thermal enclosure.

The retrofit was also implemented while the home was occupied. The renovation took 10 months to complete and the house was completely turned back over to the homeowners in June of 2011.

COLD & VERY COLD CLIMATES

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Project Profile

Project Team:
V.O. Design-Build, Inc., Builder and DER Lead; Building Science Corporation, Consultants and DER Technical Support; National Grid, Massachusetts, DER Pilot Program Administrator/Sponsor

Location:
Newton, Massachusetts

Description:
2,044 ft^2 (including conditioned basement), three bedroom, two bathroom, $1^1/_2$ stories plus full basement, single family Cape

Completion Date:
June 2011

Estimated Annual Energy Savings:
Projected 31% energy use reduction compared to pre-retrofit conditions

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Builder Profile

V.O. Design-Build is a one-stop shop for residential design and construction services specializing in healthy, energy efficient homes in the greater Boston area.

With years of professional experience V.O. Design-Build engages in major additions and remodels, new construction projects as well as deep energy retrofits of existing homes.

Participating Programs & Certifications

U.S. Department of Energy's Building America Program

U.S. Environmental Protection Agency ENERGY STAR® Program

Deep Energy Retrofit Pilot Program
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Design

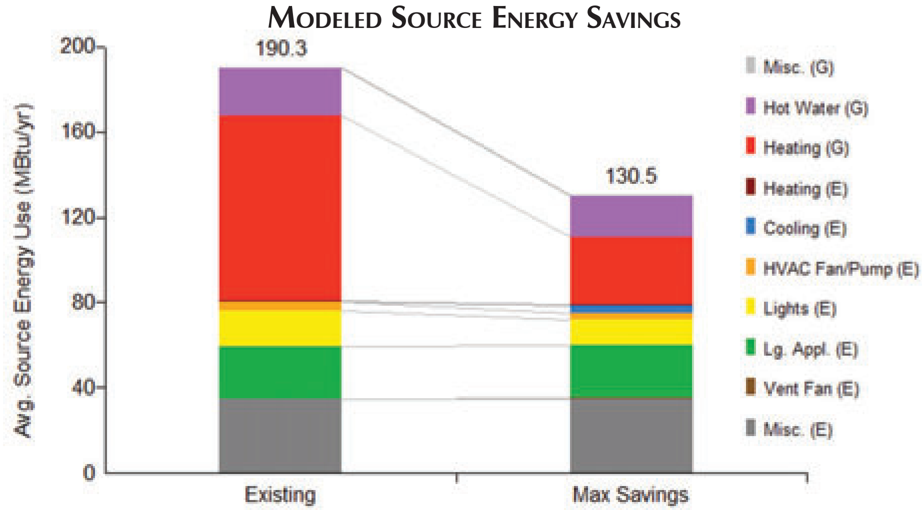


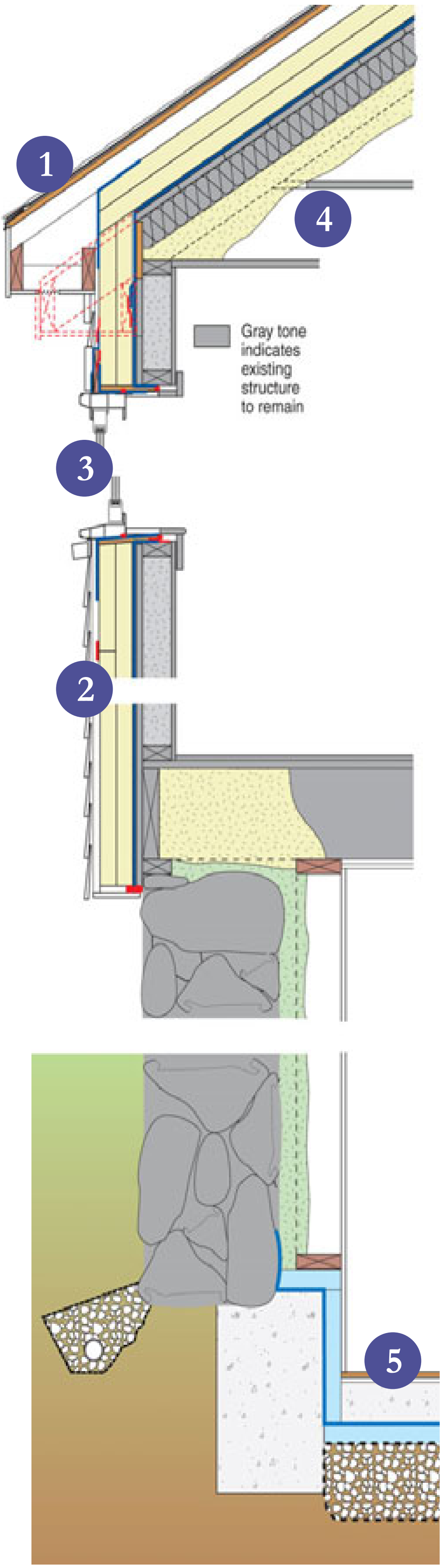
Image from BSC generated by NREL's BEOpt 1.1 for retrofits

Retrofit of exterior walls by applying thick layers of insulating sheathing can be pursued without necessary disruption to the interior. The homeowners, who occupied the home throughout the project, decided to take upon this approach. Cavity insulation was installed or supplemented where missing or inadequate.

A significant design direction pursued by this project is the "chain saw" retrofit approach to the roof-wall transition of the main roof. In this approach, the eave and rake overhangs of the roof are removed to allow the air and thermal control layers of the roof to connect directly to the corresponding control layers of the wall system. The "chain saw" approach allows for a simple transition of airflow control and also eliminates thermal bridging of roof framing at eaves and rake transitions. This approach is compatible with re-roofing and reconstruction of roof overhangs such as is often recommended with wall retrofit in order to provide adequate overhang. The necessary reconstruction of overhangs also provides an opportunity to address aesthetic goals and to increase protection of walls.

In order to allow a lower slab, the design involved excavation of the existing basement floor and installation of a concrete underpinning wall beneath the existing rubble stone foundation wall. The design, demonstrates a connection of foundation wall water control to the sub-slab drainage system. Polyethylene sheet vapor retarder placed between rigid insulation and the new concrete slab continues up the face of the underpinning wall to the base of the rubble stone wall. The polyethylene is embedded in the closed-cell SPF applied to the foundation wall. Should liquid water pass through the foundation wall, it would be directed by the closed cell insulation and then by the polyethylene sheet to the sub slab drainage. Irregularities in the surface of the concrete provide drainage pathways for liquid water to reach the sub-slab drainage system.

The wall assembly for this project establishes the exterior face of the insulating sheathing as the drainage plane while the housewrap serves as the primary air control layer. The multiple layers of materials in this system provide additional control. The thickness of exterior insulation also places the rain shedding layer further from water sensitive structure.



Enclosure Design

➊ **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.

➋ **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.

➌ **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.

➍ **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 ruble stone foundation wall, taped rigid insulation at concrete underpinning wall; new concrete slab.

➎ **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.

Mechanical Design

❶ **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.

❷ ❸ **Ventilation:** Bryant Energy Recovery Ventilator (ERV) ducted to central air handler located in the attic.

❹ **Space Conditioning Distribution:** Ductwork entirely inside the conditioned space.

❺ ❻ **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.

Construction

During the course of construction, the builder devised solutions for conditions of continuous exterior insulation. A strip of plywood was used at the top of the gables to support a rake overhang that was otherwise aligned with exterior insulation of the roof. The added thickness of the roof would have brought the roof surface too close to the sill of dormer windows. The insulation was thickened at the face of the dormer to align the face with the wall below and to allow the eave overhang to break at the dormer.

In other areas the application of exterior insulation presented challenges. Installation of exterior insulation over the housewrap, before making critical airflow control connections complicated many of the airsealing details (see Design Challenge). The builder purchased windows with an integral trim channel designed to receive lapped siding. Windows were installed to blocking on top of the exterior insulation in order to align the window's receiving channel with the siding (which is installed over furring strips to create a ventilation/drainage space as well as for attachment). Installing the windows this way created significant challenges to the implementation of proper flashing and airflow control.

A common mistake with exterior insulating sheathing used as the drainage plane is to place step flashing at the plane of the existing sheathing rather than at the face of the insulating sheathing. In the photo on the left, the roof-wall flashing is not at the face of the drainage plane and the drip edge creates a condition where water may be directed in behind the drainage plane. This situation was corrected for this home.

Testing and On-Site Technical Support

BSC conducted site visits to review construction details with the builder and to offer technical guidance. During one such visit, BSC guided the builder and his crew through a mock up window installation to ensure proper installation of flashings and connections of the air control layers. BSC also worked with the builder to develop a detail to protect the bottom of the insulating sheathing from the weather and rodents while still permitting the assembly to drain.

BSC performed a post-retrofit air leakage testing to assess the air leakage reduction relative to pre-retrofit conditions. The pre-retrofit air leakage measurement was 11.2 ACH50 and the post-retrofit measure was 4.9 ACH50.

Because the results were somewhat disappointing, BSC conducted an additional site visit to identify major sources of air leakage. With the house alternately depressurized and pressurized, BSC inspected the enclosure with a both a small handheld smoke generator and a larger theatrical smoke machine. While no significant problems were observed in the enclosure construction, BSC did find a problem with outside air dampers on the ERV that requires remediation.

Moving Forward

Monthly gas and electric bills will be collected from the homeowners to gauge performance of the retrofit strategies employed.

The builder plans to correct the set up of the ERV to ensure the dampers are powered properly and close when the ERV is not operating.

Design Challenge: Airtightness of the Enclosure

Implementation sequence was a critical factor in air flow control. The housewrap – intended to be the primary airflow control – and exterior insulation had been installed prior to removing the existing windows. This made it difficult to transition the air flow control layer into the window opening and to provide connection to the new window. To make the connections, sections of insulating sheathing around the windows had to be removed to allow pieces of air control membrane (house wrap or adhered membrane) to attach to in-place housewrap. Also, the housewrap had not been sealed to the base of the wall prior to installation of exterior insulation leaving limited options for a robust connection there.

While the builder pursued a "chain saw" approach at the roof-wall interface, porches were left attached thus precluding continuous air control and insulation layers at these locations. Sealing around the intervening framing and roof decks proved challenging.

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10.7 Appendix G: Case Study, National Grid Deep Energy Retrofit Pilot Program, Second Floor Reframing Comprehensive Retrofit of 19th Century Small Colonial (Test Home 5)

See attached.

Case Study

National Grid Deep Energy Retrofit Pilot Program

Second Floor Reframing Comprehensive Retrofit of 19th Century Small Colonial

Lancaster, Massachusetts

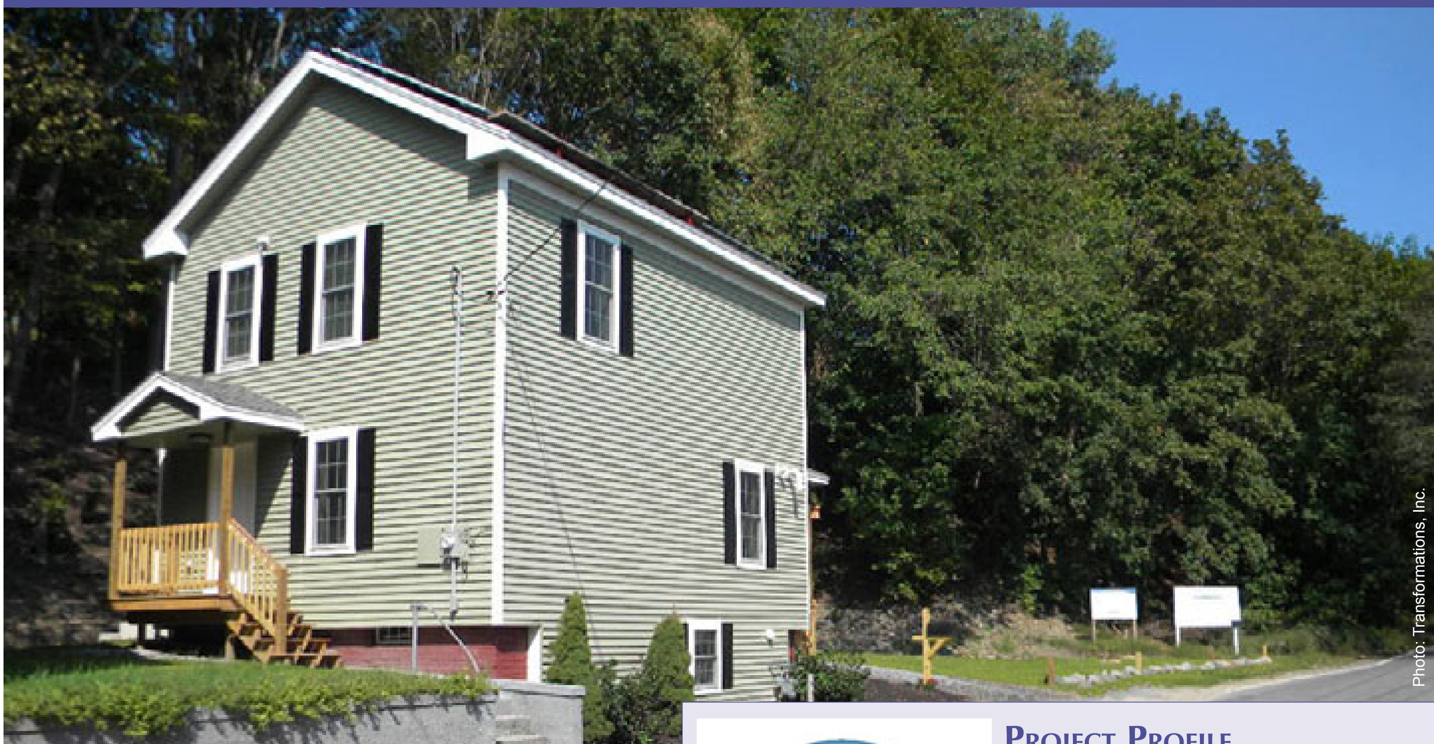

Photo: Transformations, Inc.

Overview

Habitat for Humanity North Central Massachusetts received this circa 1900 property as a donation from the Town of Lancaster. The building had been in a state of significant deterioration, yet preserving the footprint and first floor framing was essential to preserving the ability of Habitat to provide a home on the otherwise non-conforming lot. Due to programmatic requirements, the roof was removed and a new second floor and roof framed on top of the existing balloon-framed structure. Significant parts of the rubble-stone-and-brick foundation wall also required replacement. The interior of the remaining first floor was completely gutted.

Being a Habitat project, the project plan needed to be formed around donated materials and volunteer labor. The result is a project that serves as an impressive example of what is attainable under such circumstances. The project also developed interesting strategies to pursue ambitious performance targets with the available materials and resources.

In addition to the super-insulated enclosure, triple-glazed windows, energy-efficient mechanical systems and exceptional airtightness, the house design also includes a 3.75 kW PV array. The completed house was turned over to the new homeowners in August of 2011.

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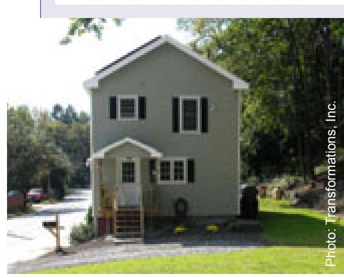

Photo: Transformations, Inc.

Project Profile

Project Team:
Habitat for Humanity North Central Massachusetts, Builder; Transformations, Inc., DER Lead and architectural design support; Building Science Corporation, Consultants and DER Technical Support; National Grid, Massachusetts, DER Pilot Program Administrator/Sponsor

Location:
Lancaster, Massachusetts

Description:
1,440 ft^2 two bedroom, one bathroom, 2 stories plus partial basement single family Colonial

Completion Date:
August 2011

Estimated Annual Energy Savings:
Projected 50% energy use reduction compared to pre-retrofit conditions

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Builder Profile

Habitat for Humanity North Central Massachusetts is a non-profit organization that works to strengthen families and communities through affordable homeownership opportunities.

Through volunteer labor and tax-deductible donations of land, money and materials, Habitat builds simple, decent and affordable homes with the help of our partner homeowners and volunteers. By investing hundreds of hours of their own labor to build their home and the homes of others, homeowners experience the pride and responsibility of homeownership right away.

Participating Programs & Certifications

U.S. Department of Energy's Building America Program

U.S. Environmental Protection Agency ENERGY STAR® Program

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Design

Modeled Source Energy Savings

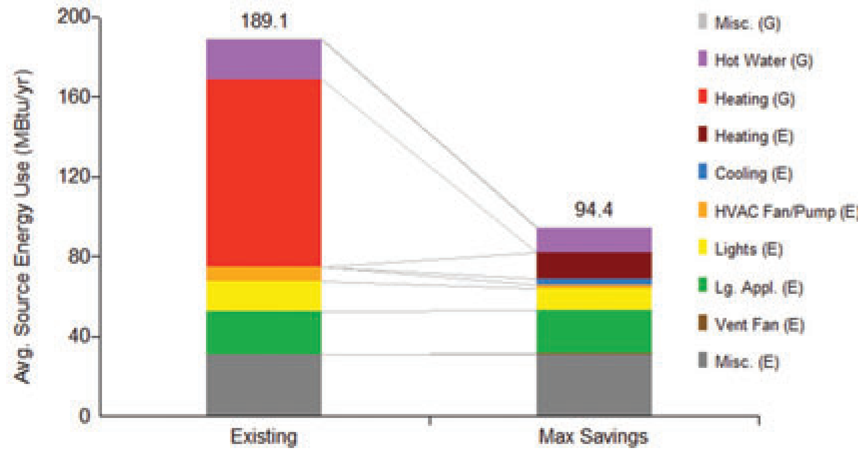
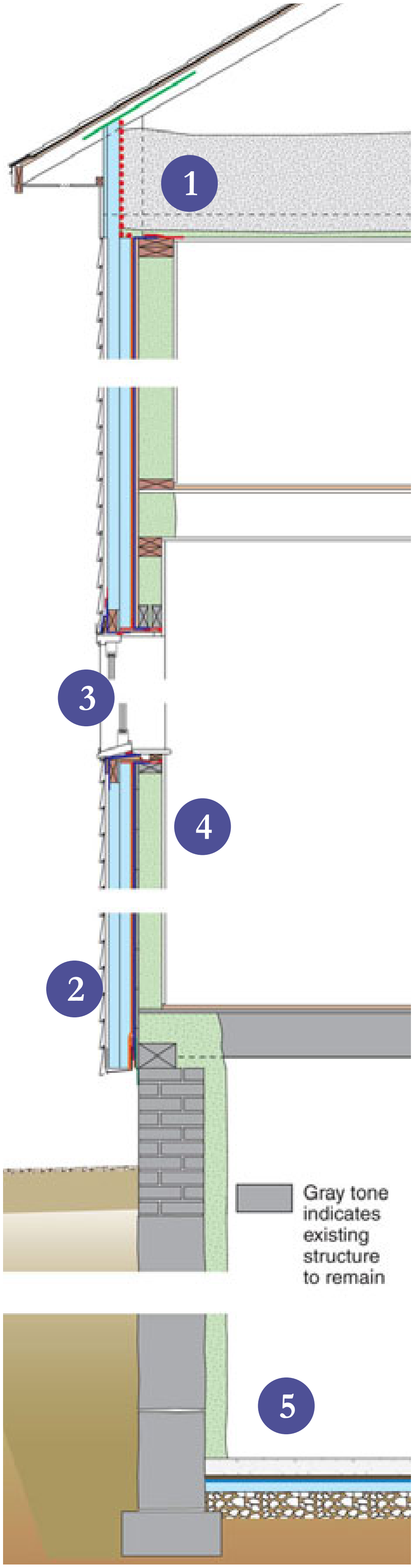


Image from BSC generated by NREL's BEOpt 1.1 for retrofits

In order to achieve the thermal performance targets set by the National Grid Deep Energy Retrofit pilot program the project decided to use closed-cell spray foam in the wall cavities in addition to donated 4" of XPS rigid foam insulation on the exterior. However, since both types of insulation are vapor impermeable BSC expressed concern for the durability of the wall assembly and offered solutions to provide better moisture management. The Habitat Construction Manager elected to install a breather mesh over the wood sheathing between a housewrap and the first layer of exterior insulation. This allows for the assembly to redistribute and dissipate moisture if small amounts of water get behind the primary drainage plane, the rigid foam.

Water control at the roof is provided by standard roofing practices. Purpose-built roof trusses enable adequate overhangs while the new rakes are extended to provide ample protection for the walls below. The wall system uses the exterior face of the insulating sheathing as the primary drainage plane with the housewrap layer behind the vapor diffusion mesh as a secondary drainage plane. A new exterior footing drain at the rear (uphill side) and a layer of gravel beneath the new basement slab are designed provide water control for the foundation.

Air flow control at the top of the building is achieved by sealing the perimeter and sealing penetrations at the top floor ceiling. Careful detailing is needed to transition the ceiling air flow control to that of the wall system. A raised heel truss allows the full depth of insulation to continue to the perimeter of the attic. Rigid foam installed up the height of the raised heel protects the ceiling insulation from windwashing or displacement. This approach accommodates very high levels of insulation at a low marginal cost. Mechanical systems and ventilation distribution are located entirely within the conditioned space and not in the vented attic.



Enclosure Design

❶ **Roof Assembly:** R-65 vented attic; 1” closed-cell spray foam on attic floor covered with 18” loose-blown cellulose.

❷ **Wall Assembly:** R-44 (nominal); existing 2x4 and new 2x6 wall cavities filled with closed-cell spray foam; housewrap; breather mesh; two layers of 2” XPS insulating sheathing; 3/4” furring strips; vinyl siding.

❸ **Window Specifications:** Paradigm triple-glazed, krypton/argon blend, low-E vinyl windows; U=0.2, SHGC=0.23; windows installed over strapping at exterior face of insulating sheathing.

❹ **Infiltration:** Taped housewrap over existing board- and new OSB sheathing; closed-cell spray foam in wall framing cavities and calking at framing joints; 1” closed-cell spray foam flash coat at attic floor; housewrap wraps over the top plate of second floor wall where closed-cell spray foam on attic floor extends over the top plate and connects to housewrap; the bottom of the housewrap is sealed to the existing board sheathing and top of foundation wall; closed-cell spray foam at foundation wall extends and seals to the new concrete slab.

❺ **Foundation Assembly:** Conditioned basement with minimum 3” closed-cell spray foam insulation applied directly to fieldstone and brick foundation walls and to new concrete wall in rear of building; dampproofing with 2” XPS insulating sheathing below grade at exterior of new concrete foundation wall; new concrete slab cast over sand layer, polyethylene vapor barrier, 2” XPS insulation and gravel.*

*** BSC does not recommend installing a sand layer under new slabs.**

Mechanical Design

❶❷ **Heating and Cooling:** Mitsubishi Mr. Slim ductless minisplit air source heat pumps, one per floor.

❸ **Ventilation:** Ducted LifeBreath Heat Recovery Ventilator (HRV) located in the basement. Ventilation supply ducted to bedrooms, stale air exhausted from bathroom and kitchen.

❹ **Space Conditioning Distribution:** Ductless indoor section for air source heat pumps. HRV ducts inside the conditioned space with ducting configuration to provide some air mixing.

❺ **DHW:** 0.98 EF Navien gas condensing tankless water heater.

Lighting: All CFLs in light fixtures.

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

❻ **Site Generated Power:** 3.75 kW PV system

Construction

To address the challenge of connecting the air flow control layer of the wall system to that of the top floor ceiling, BSC advised the project team to wrap the wall housewrap onto the top plate and tape it to the top plate of the top floor wall prior to placement of the roof trusses. There was some concern that the placement of the roof trusses would tear the housewrap all to shreds. It appears that the housewrap has held up just fine.

The new basement slab was cast directly against the foundation wall which creates a thermal bridge and precluded establishing a direct connection between the water control function of the foundation wall with the sub-slab drainage system. What allows this system to still provide adequate control of liquid water is the exterior perimeter drain controlling ground water and the surface regarding which will improve draining of surface water away from the foundation.

The project team used a brake-formed metal guard to protect the base of the foam wall from animals. Attachment of the guard to furring strips provides a reliable slope to the outside and the simple building footprint avoid inside corners where such a flashing element along the bottom of the wall might concentrate water.

Testing and On-Site Technical Support

Prior to the start of construction, leaders of the Habitat crew participated in a mock-up window installation led by BSC. BSC conducted site visits to review construction details with the builder, point out errors to repair in flashing or other elements, and to identify viable simplifications to the project. During one such site visit, BSC noted a ventilation duct passing through the attic space and worked with the builder to identify a different routing for the duct. The duct routing was subsequently changed to maintain the duct in condition space.

Since the property was in significant disrepair prior to the retrofit, pre-retrofit values for air leakage were based on measurements obtained for a neighboring building of similar configuration. The number measured was 33 ACH 50. During the post-retrofit testing of the Habitat DER, BSC guided volunteers to identify and seal air leaks

around the house in order to meet the airtightness goal set by the National Grid DER pilot program. The final measurement came in at 1.6 ACH 50!

BSC conducted three site visits for this project to discuss various elements of the building. Installation of the windows, proper flashing, connections of the air and water control layers were discussed with the builder and the crew while on site.

Moving Forward

Monthly gas and electric bills will be collected from the homeowner to

gauge performance of retrofit strategies employed.

BSC hopes to continue working with Habitat for Humanity of North Central Massachusetts in designing and building high performance affordable homes.

Design Highlight: Vapor Impermeable Wall Assembly

This particular project employed an approach of combining 4” of exterior insulation and closed-cell SPF framing cavity insulation. The exterior foam insulation in this case is extruded polystyrene (XPS). The insulation in this assembly offers very low vapor permeability (i.e. low drying potential) to either side of the structure. This is a particular concern for a project where critical details may be implemented by unskilled volunteer labor. As a mitigation for the moisture risk a breather mesh was installed over the structural sheathing between the housewrap and the exterior rigid insulation boards. The breather mesh serves as a ***hygric redistribution layer*** to allow minor moisture concentrations to dissipate. While liquid water is able to drain over the housewrap and through the mesh layer, the mesh layer suppresses convection airflow sufficiently to avoid degradation of the thermal insulation to the exterior.

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