1. 18 WILLIAMS AVE, WESTFORD, MA & 130 NORTH ROAD, BEDFORD, MA

1.1 Introduction

1.1.1. Project Overview

Habitat for Humanity of Greater Lowell bought the land on which to build the Westford House from the Town of Westford for $1. Since acquiring that land, the nonprofit organization has worked with Building Science Corporation (BSC), the community, as well as many manufacturers, distributors and donors in the effort to create a comfortable, healthy, durable, and energy efficient single family home. See Figure 1.1 for an image from the Dedication Ceremony that took place at the Westford House on October 5th, 2008.

This home is part of a scattered site community that includes seven houses that are to be built in Bedford, MA. These other seven homes, along with a farmhouse retrofit and a home in another community will provide affordable housing for a total of 10 families. All of the homes will have enclosure and mechanical specifications similar to the Westford House. However, since the other homes have not yet started construction, the analysis presented in this report refers only to the Westford House.

Figure 1.1: Dedication ceremony at 18 Williams Ave in Westford

The Westford House's plans and specifications were designed and developed by architects and engineers at BSC. See below for exterior and interior photos and the drawing set included in the Appendices section.

Figure 1.2: Southeast view

Figure 1.3: Northwest view

Figure 1.5: Kitchen

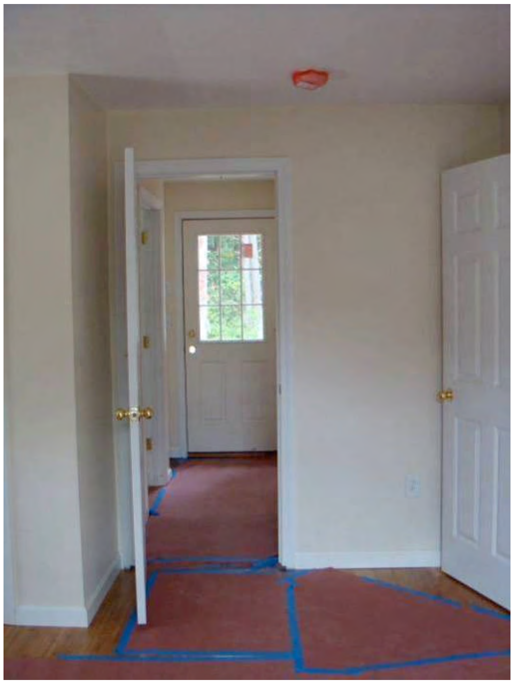

Figure 1.6: Hall from the master bedroom

The goal of this project was to create a home with a high R-value enclosure, a right-sized mechanical system, energy efficient lighting, appliances, windows and doors, and also have the possibility of adding site-generated power at some point in the future. To ensure that solar-generated power could be successfully installed, the house was sited with a large south facing sloped roof. The high R-value enclosure was achieved through 4" of rigid foam insulation on the interior of the basement walls, the exterior of the stud walls and on top of the roof rafters. Many details (in particular, window and door installation) needed to be developed in order to ensure Habitat's volunteer labor could successfully implement the critical water management and air barrier details. See the figures below for construction photos showing the window installation with 4" of rigid foam.

Figure 1.7: Exterior view of plywood "box" detail used at windows

Figure 1.8: Interior view of plywood "box" details used at windows

Not only is the Westford House part of the Building America Program, but it is also registered as part of the Builders Challenge. Habitat additionally sought third-party verification of their comfortable, healthy, durable and energy efficient home by seeking LEED for Homes Platinum certification as well as ENERGY STAR certification.

1.1.2. Project Information Summary Sheet

PROJECT SUMMARY	
Company	Habitat for Humanity of Greater Lowell
Company Profile	Habitat for Humanity of Greater Lowell (HFHGL) is a nonprofit 501(c)(3) organization that works to strengthen families and communities through affordable homeownership opportunities. HFHGL works in partnership with corporations, like-minded community groups, faith-based organizations, and individual volunteers to develop communities with people in need by building and renovating simple, decent, energy efficient, affordable homes. Since its founding in 1991, HFHGL has built or renovated a total of 20 homes in Billerica, Concord, Lowell, Reading, and Westford. To date, HFHGL's largest completed project was a 3-duplex, located at Harmony Way in Lowell. HFHGL projects have placed more than 50 people into quality housing.
Contact Information	Dana Owens, Executive Director (dowens@lowellhabitat.org) Jim Comeau, Construction Manager (jcomeau@lowellhabitat.org) 66 Tadmuck Road Suite 5 Westford, MA 01886 P: (978) 692-0927 F: (978) 692-3430
Division Name	n/a
Company Type	Nonprofit
Community Name	n/a
City, State	Westford, MA and Bedford, MA
Climate Region	Cold (5A)

SPECIFICATIONS	
Number of Houses	8 (1 in Westford and 7 in Bedford)
Municipal Address(es)	18 Williams Avenue, Westford, MA 01886 130 North Road, Bedford, MA 01730
House Style(s)	Single family, affordable

Number of Stories	1 _ (Westford) and 2 (Bedford)
Number of Bedrooms	3
Plan Number(s)	Plan 1 (Westford)
Floor Area	1340 sf (Westford)
Basement Area	816 sf (Westford)
Estimated Energy Reduction	44.4% over BA Benchmark (Westford)
Estimated Energy Savings	$1,259/year (Gas $1.40/therm; Electricity $0.18/kWh) (Westford)
Estimated Cost	$160,000 (Westford)
Construction Start	March 2008 (Westford)
Expected Buildout	October 2008 (Westford)

1.1.3. Targets and Goals

The goal of the Westford House was to achieve a 40% whole house energy reduction relative to the Building America benchmark. Specifying and building a high R-value enclosure was integral in achieving this goal. This house is meant to serve as an example of how to build high R-value enclosures in cold climates.

1.2 Whole-House Performance and Systems Engineering

1.2.1. Energy Analysis Summary

With the enclosure and mechanical characteristics presented in Table 1.3 and Table 1.4, this plan achieves a performance level of 44.4% reduction relative to the Building America Benchmark. Note that this assumes the installation of a 14 SEER cooling system; without cooling, the savings are reduced to 44.1%.

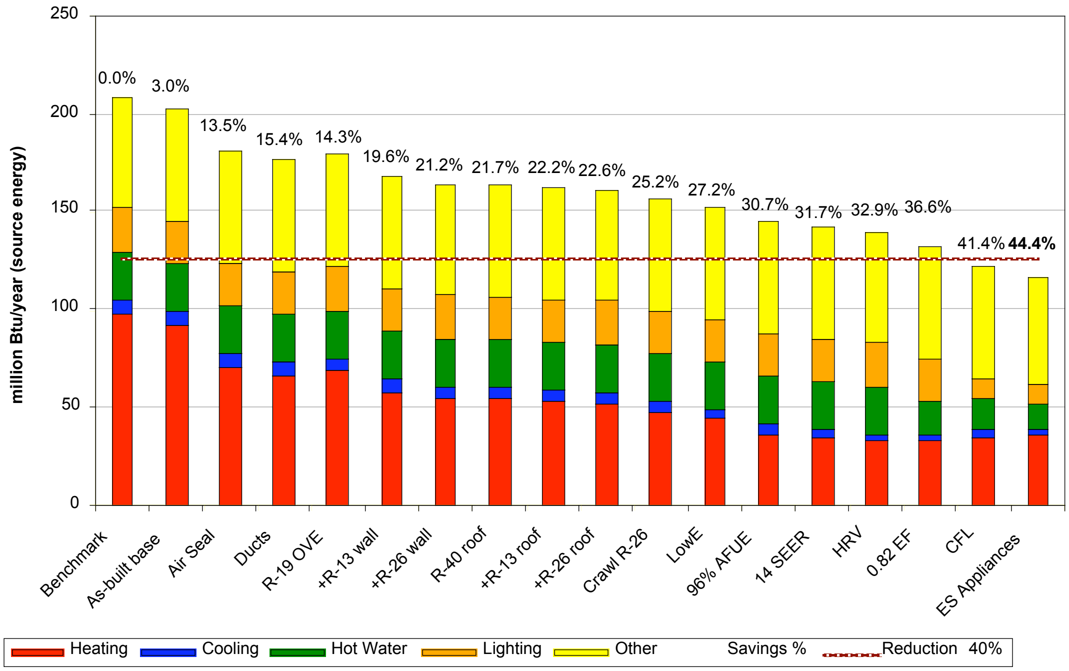

Figure 1.9: Parametric energy simulations for Westford House

Table 1.1: Summary of End-Use Site-Energy

	Annual Site Energy			
	BA Benchmark		**Prototype**	
End-Use	kWh	therms	kWh	therms
Space Heating	603	829	195	298
Space Cooling	646		284	
DHW	0	223	0	123
Lighting*	1917		895	
Appliances + Plug	4984	0	4655	0
OA Ventilation**	62		95	
Total Usage	8212	1052	6124	421
Site Generation	0	0	0	0
Net Energy Use	8212	1052	6124	421

*Lighting end-use includes both interior and exterior lighting

**This OA Ventilation energy consumption is for fan energy only, space conditioning is included in Space Heating and Cooling

Table 1.2: Summary of End-Use Source-Energy and Savings

	Estimated Annual Source Energy		Source Energy Savings	
			Percent of End-Use	Percent of Total
End-Use	**BA Benchmark** 10^6 BTU/yr	**Prototype** 10^6 BTU/yr	**Prototype savings**	**Prototype savings**
Space Heating	91	32	**64%**	**30%**
Space Cooling	7	3	**56%**	**2%**
DHW	23	13	**45%**	**5%**
Lighting*	21	10	**53%**	**6%**
Appliances + Plug	54	50	**7%**	**2%**
OA Ventilation**	1	1	**-53%**	**0%**
Total Usage	196	109	**44%**	**44%**
Site Generation	0	0		**0%**
Net Energy Use	196	109	**44%**	**44%**

Notes:

The "Percent of End-Use" columns show how effective the prototype building is at reducing energy use in each end-use category.

The "Percent of Total" columns show how the energy reduction in each end-use category contributes to the overall savings.

1.2.2. Discussion

1.2.2.1. Enclosure Design

Table 1.3 (below) summarizes the building enclosure assemblies used for this project.

Table 1.3: Enclosure Specifications

ENCLOSURE		**SPECIFICATIONS**
Ceiling		
	Description -	Unvented attic framed with 2x12 roof rafters at 24” o.c.
	Insulation -	2 layers 2” foil-faced polyisocyanurate insulating sheathing (R-26) on top of rafters with unfaced batt insulation (R-40) within rafter bay
Walls		
	Description -	2x6 advanced framed walls at 24” o.c.
	Insulation -	2 layers 2” foil-faced polyisocyanurate insulating sheathing (R-26) on outside of studs with unfaced batt insulation (R-19) within stud bay and second floor rim joist area
Foundation		
	Description -	Conditioned basement with concrete foundation walls and concrete slab
	Insulation -	2 layers 2” foil-faced polyisocyanurate insulating sheathing (R-26) on inside face of foundation wall with 2” XPS rigid insulation (R-10) under slab and 2” high density spray foam (R-13) at first floor rim joist area
Windows		
	Description -	Double Pane Vinyl Spectrally Selective LoE_ Argon filled
	Manufacturer -	Harvey Industries, Inc. Vicon Classic Double Hung w/ L-Fin Adapter
	U-value & SHGC-	U=0.33, SHGC=0.28
Infiltration		
	Specification -	2.5 sq in leakage area per 100 sf envelope
	Performance test -	964 CFM 50/3.1 ACH 50 1127 CFM 50/3.6 ACH 50 target)

The enclosure upgrades are discussed in greater detail below.

- **Ceiling:** The house plan is set up to maximize the amount of usable square footage per enclosure area, by "building up" into the triangular roof area, using dormers and kneewalls. In a complex design such as this with multiple roof lines, it would be very difficult to provide acceptable roof ventilation while not compromising the air barrier. Therefore, the decision was made to use an unvented or "compact" roof assembly, insulated at the roof deck line.

  Although R-40 insulation could be provided in the roof rafter cavities, this assembly would be vulnerable to moisture damage. Therefore, exterior foam insulation was added to provide condensation control, as per requirements of the 2007 Supplement to the International Residential Code (§R806.4 Unvented attic assemblies). In Zone 5A, this code requires R-20 air-impermeable insulation, which is provided by two layers of 2" polyisocyanurate (R-13 _ 2 = R-26). An additional layer of structural sheathing was required as a nail base to the exterior of the foam.

  Taken together, these upgrades were a 1.4% improvement relative to the Benchmark, not counting any contribution to the airtightness of the building as a whole. This measure is an effective, albeit relatively costly upgrade.

- **Walls**: BSC's approach to a high-R value wall in this project was to start with a 2x6 advanced framing stick-built wall with cavity fill insulation (R-19 cellulose), and then to add 4" of foil-faced polyisocyanurate insulating sheathing, in two staggered 2" layers (to reduce the effect of airflow). This approach almost triples the R-value of the wall without insulating sheathing: R-13.6 for the frame wall (at 16% framing factor), vs. R-39.6 for the wall as a whole. In addition, by placing 2/3 of the insulating value exterior to the cavity insulation, the chances of wintertime interstitial condensation are greatly reduced.

  However, many details were required for window and door installation, cladding attachment, structural/shear requirements, and drainage. This development work is covered in section 1.2.2.3, "Development of High-R Value Wall Details."

  These upgrades taken together give roughly a 6% improvement relative to Benchmark.

- **Foundation:** The approach of interior foundation wall insulation was taken in this project; the walls were insulated with two layers of 2" polyisocyanurate. Two inches of extruded polystyrene (XPS) were installed under the basement slab; both assemblies are shown in Figure 1.17. These assemblies not only provide good thermal performance, but they also provide excellent resistance to moisture damage and to soil moisture ingress to the basement; which are critical aspects to foundation insulation design. Insulation underneath the slab is not intended as an energy measure; instead, it limits the coupling of the slab to the soil temperatures, reducing the risks of summertime condensation due to thermal lag.

  Some specifics of these assemblies are covered in section 1.2.2.3, "Development of High-R Value Wall Details."

  This upgrade gives a 2.5% improvement relative to Benchmark.

- **Windows:** Vinyl-frame, double glazed, low emissivity, argon-filled, spectrally selective windows were specified for this project, with performance noted in Table 1.3. This item represented a 2% improvement from the Benchmark.

- **Air leakage:** The single largest line item upgrade was the improvement in airtightness (at 10.5% relative to Benchmark). This clearly shows the importance of this attribute: in fact, further simulations showed that further reductions in infiltration can still have significant benefits.

  The ability to meet airtightness targets is directly related to the air barrier detailing; a great level of detail is shown in the plan set (see Appendix) specifically A-7, A-12, and A-13, which include window installation details. Spray foam was used at critical locations (foundation rim joist area) to ensure air barrier continuity at these "built up" pieces (i.e., with connection seams), and to tie together air barrier enclosure elements (e.g., interior foundation insulation to sill plate and rim joist).

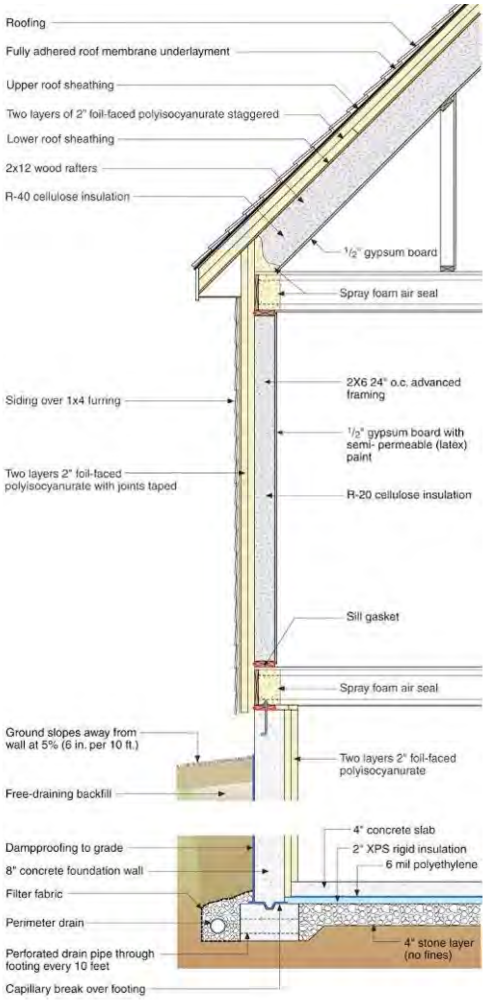

Figure 1.10: Westford House building section

1.2.2.2. Mechanical System Design

Table 1.4 (below) summarizes the mechanical systems used by this project.

Table 1.4: Mechanical system specifications

MECHANICAL SYSTEMS	SPECIFICATIONS
Heating	
Description -	95% AFUE condensing gas furnace with ECM motor
Manufacturer & Model -	Goodman GMV950453BXBB
Cooling (outdoor unit)	
Description -	None installed
Manufacturer & Model -	n/a
Cooling (indoor unit)	
Description -	Split system evaporator cased coil, R-410A or R-22 Refrigerant
Manufacturer & Model -	Goodman CAPF1824B6CA
Domestic Hot Water	
Description -	Instantaneous/tankless 0.82 EF gas water heater
Manufacturer & Model -	State GTS-505-NI 100, 199 kBtu/hr
Distribution	
Description -	Sheet metal trunk and runouts in conditioned space
Leakage -	None to outside (5% or less target)
Performance test -	145 cfm total leakage at 25 Pa; no leakage to outside
Ventilation	
Description -	Energy recovery ventilator with timer switch control
Manufacturer & Model -	Fantech SE704N, 70 CFM nominal (50 CFM measured) 33% duty cycle
Return Pathways	
Description -	Transfer grilles at bedrooms with first floor central return
Dehumidification	
Description -	None
Manufacturer & Model -	n/a
PV System	
Description -	None
Manufacturer & Model -	n/a
Solar Hot Water	
Description -	None
Manufacturer & Model -	n/a

The mechanical system upgrades are discussed in greater detail below.

- **Heating and cooling:** A 95% AFUE condensing gas furnace with an ECM motor was installed; this measure had an associated savings of 3.5%. Cooling was not installed; however, an interior coil was installed by the HVAC contractor for future use.

  One issue noted was that with an ultra-insulated small house, equipment capacities are substantially larger than calculated design loads. Specifically, the wintertime design load for this house is 19.3 kBtu/hr, while the smallest furnace available in this series has a 45.0 kBtu/hr output. However, it was a two-stage unit; during installation, the wiring was set to have a single stage thermostat only call for heating on the "low fire" stage, resulting in an output of 30.8 kBtu/hr. This change will reduce the extent of short-cycling of the unit.

- **Duct leakage:** With this house plan, the ductwork could easily be located within conditioned space, with a main trunk running the length of the basement, and runouts feeding the second floor through interior walls and chases. Duct leakage reductions were associated with a 2% savings from the Benchmark.

  During testing, the leakage to exterior was small enough to be immeasurable. However, total duct leakage was still high (145 CFM, or 20% of nominal flow), which is typical for sheet metal systems. Despite multiple attempts at air sealing with mastic, these results were not reduced during this project; yet register flows were still within specified ranges.

- **Domestic hot water:** A gas instantaneous tankless water heater was installed, with combustion and exhaust air directly through the rim joist (concentric vent). A 3.7% savings relative to Benchmark was associated with this change.

- **Ventilation:** An energy recovery ventilator was donated to this project; it was a small (70 CFM nominal) unit with no control capability (i.e., on/off). Installing an ERV (not HRV) without a defrost cycle was considered somewhat risky. Discussions between company principals and the manufacturer determined that at the specified operating conditions (interior humidity limited by exhaust ventilation, 33% duty cycle) that frost-up was a relatively low risk. This duty cycle was achieved using a hard-wired 110 V electromechanical timer switch (Intermatic/Grasslin KM2ST-1G). In addition to timer operation, this switch has the ability to be turned completely off or completely on. These modes dovetail well into "vacation mode," and a mode to be used when higher ventilation rates than normal are needed.

  The system was installed as a "semi distributed" setup, with a single point drawn (from the second floor), and a single point supply, located next to the central air handler return (see Figure 1.21). A fan cycling controller is installed on the air handler, set to run at 16% duty cycle (5 minutes on/25 minutes off). Therefore, the ventilation air provided by the ERV will have some distribution throughout the house, due to this fan cycling operation.

  The ERV was a 1.3% improvement over the nominal Benchmark ventilation system, with no heat recovery and 0.5 W/CFM fan power.

Figure 1.11: Installed energy recovery ventilator

Figure 1.12: Central return, with ERV supply "soft connected" near return

1.2.2.3. Development of High-R Value Wall Details

Developing constructible, durable, and aesthetically acceptable high R-value wall assemblies is a challenge that has been researched by BSC since 2007 and earlier, using the approach of significant amounts (4") of insulating foam sheathing to the exterior of the frame. The principal conceptual obstacle, of course, is that the foam sheathing has no structural strength or ability to act as a nail base; many of the details below needed to be developed to make up for this shortcoming. The wall, as constructed, is shown in Figure 1.13.

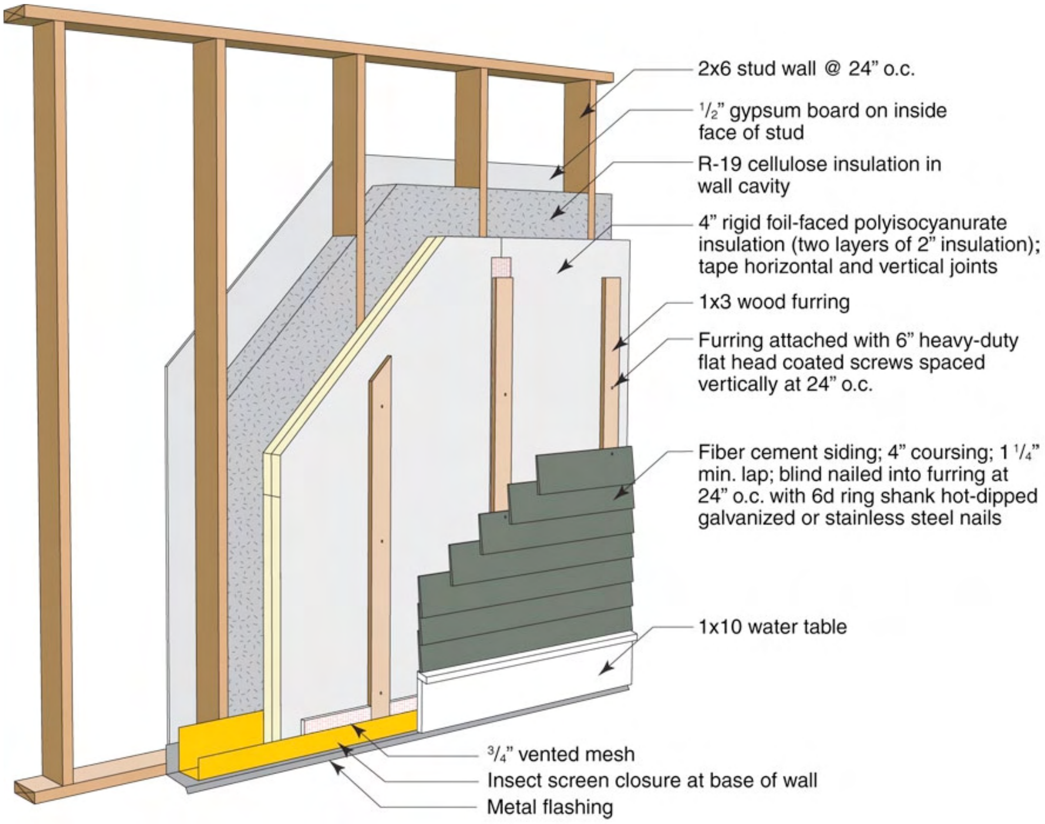

Figure 1.13: 4" foam wall, showing cladding and drainage

Previous work included the construction of a mockup for test and demonstration purposes at the company's Westford site in August 2007 (see Figure 1.22), as well as a mockup demonstration at the Build Boston 2008/Residential Design 2008 conference in April 2008 (see Figure 1.23). The former was particularly instructive, by providing concrete examples of the issues that need to be addressed when building these assemblies in the field. For instance, sequencing issues proved to be important: installing vertical strapping on the entire wall eliminates the clearances required to install all window flashing elements. Therefore, details were developed showing omission of the strapping near the window, until after window installation.

Figure 1.14: Exterior mockup construction (wood and vinyl siding attachment)

Figure 1.15: Mockup demonstration at Build Boston 2008/Residential Design 2008

BSC developed details to deal with the following items:

- Cladding and trim attachment
- Window installation (and flashing)
- Door installation (and flashing)
- Deck/porch attachment
- Porch roof attachment
- Interior basement 4" foam attachment

The full set of details is shown in the plan set (see Appendix) and are referenced in the text below. The development of these details was an iterative process, involving construction personnel and the design team.

Cladding: the use of vertical furring strips to create a drainage and ventilation space (a.k.a. "vented rainscreen") behind cladding is a well-established practice, and has been used as a remedial measure for moisture/paint blowoff issues (for instance, see "Rain-Screen Walls: a Better Way to Install Siding," *Fine Homebuilding Magazine*, February 2001). This assembly is a significant durability upgrade, as it holds rainwater away from the sheathing (i.e., rainwater tends to wick along the back side of the cladding), and provides an air space that removes moisture by ventilation drying.

In the case of these 4" foam walls, this type of furring is needed to provide a nail base for cladding attachment, as well as to act as a "large washer" to hold the foam firmly to the framing. One issue was to find acceptable fasteners; six inch screws proved to be sufficient to penetrate all layers and have adequate penetration of the framing member. Some examples include FastenMaster TimberLok screws, and Screw-Products Exterior ACQ Compatible "Star Drive" Heavy Duty Construction Screws. Although these fasteners are readily available and provide excellent performance, they are relatively expensive (53¢ and 35¢ each, respectively), which works out to roughly 13¢/sf of wall area.

Another issue was the placement of framing members required as a nail base; for instance, the furring that supports the exterior window casing requires the "wing" studs shown in Figure 1.14 and A-13.4 in the plans. Similarly, attaching the siding cornerboards required some pre-planning, to ensure that there was a bearing surface and nail penetration for the boards (see Figure 1.17).

Finally, there were some issues with code acceptance and manufacturer acceptance of this system, which required additional research. Further information on these issues can be found in the "Code Barriers" portion of this report.

Figure 1.16: Window rough opening, showing "wing" studs as nailers for trim

Figure 1.17: Overhead view of corner, showing 1x4 furring for corner board

Window: With 4" of foam exterior to the frame wall, window attachment quickly becomes an issue, as there would be inadequate structural support for the window. The solution was to build a plywood "box" (with metal reinforced corners) inside the rough opening, which is sized for this reduced dimension (see Figure 1.7, Figure 1.8, Figure 1.18 and A-13.4). The window is placed at the outside edge of the wall, which simplifies integration into the drainage plane (exterior face of the foam, in this case).

During the mockup installation, one issue was the fastening of the window: using 6" screws at the manufacturer's spacing (every other flange hole) was quickly deemed to be expensive, slow, and questionably effective. After some deliberation, an alternate detail was developed, as shown in Figure 1.19: metal straps are attached to the side of the window, and screws are driven laterally through the straps into the framing. This installation is essentially identical to window installation into a masonry opening.

The integral window flange is retained, but not used for mechanical fastening. However, the flange is used for integration into the drainage plane.

After demonstrating this in the mockup, it was fully implemented at the Westford House; team members went to the site to demonstrate these techniques.

Figure 1.18: Plywood "box" liner at window rough opening for 4" foam wall

Figure 1.19: Metal strap attachment for window-to-frame connection

Door installation: After the start of construction at the Westford House, it was realized that the window detail used previously could not be used for a door opening. The primary difference is that the sill of the opening must be strong enough to accept full weight of foot traffic. In addition, with the depth of the opening, an inswing door must be placed on the interior of the opening; otherwise, it will only open to less than 90 degrees. Finally, there are several fasteners that must penetrate the sill, which is detrimental to pan flashing integrity. A set of step-by-step details addressing all of these aspects was developed, and can be seen in Appendix E1.

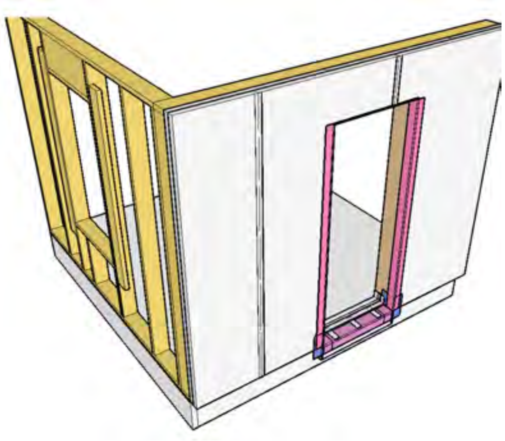

Figure 1.20: Door installation excerpt

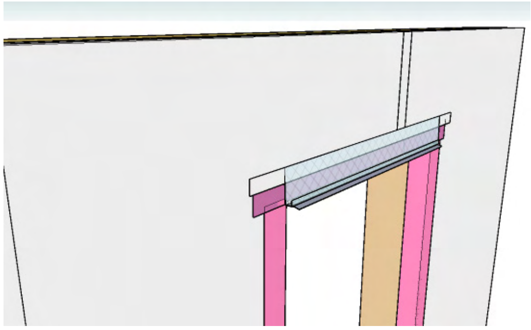

Figure 1.21: Door installation excerpt

Deck/porch attachment: Again, the use of very thick foam insulating sheathing results in difficulties when attaching a porch or deck to the rim joist. Several options were developed and drawn up, including a wood spacer, casting of "pilasters" to the exterior of the concrete foundation wall (see Figure 1.22), and using pier foundations exterior to the foundation wall. This final option was what was implemented by the Habitat for Humanity crew, as shown in Figure 1.23.

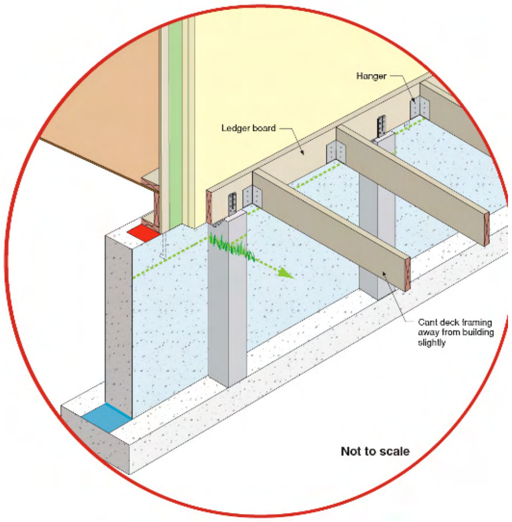

Figure 1.22: Proposed "pilaster" detail for deck support

Figure 1.23: Constructed detail for deck support (exterior foundation pier)

Porch roof attachment: Similarly, the roof over the porch must be tied back to the structure through 4" of foam. Given the compressive strength of the foam, adequate support was provided by lag bolting a 2x6 ledger through the foam, as shown in A-7.2; the porch roof rafters are hung from this ledger.

Basement wall: Finally, the installation of 4" of polyisocyanurate foam on the basement wall posed some issues. Unlike the previous problems (non-structural nature of foam), these issues were tied to the lack of fastener availability. Two issues are at odds here: the fastener must be long enough to penetrate the foam and the concrete (~5", minimum), while the structural demands are extremely low (holding 2 layers of foam to a wall). Concrete fasteners that have adequate length (e.g., Tapcon concrete screws, lag bolts with anchors) are substantially oversized for this task, and labor-intensive.

At the same time, one issue during construction was that the contractor failed to install foundation perimeter drains, believing the site to be adequately dry. We found this to be unacceptable as a risk mitigation practice.

Both of these problems were solved with the final design of the assembly: pressure treated 1x2 furring strips were directly attached to the concrete wall, creating a drainage space which was directed into the sub-slab gravel field. The two layers of 2" foam were then attached to the furring strips using conventional wood fasteners (see Figure 1.24 and Figure 1.25), and metal roofing washer plates (see Figure 1.39). These washers also provided a layer to which the gypsum board fire protection board could be attached. Of course, it was vital to ensure that the drainage cavity was air sealed from the interior to prevent indoor air quality problems. This was accomplished with spray foam.

Figure 1.24: Basement foam at stairwell (pre air sealing)

Figure 1.25: Close-up of basement foam detail (pre air sealing)

1.2.2.4. Lighting and Miscellaneous Electrical Loads

All compact fluorescent lighting and ENERGY STAR® appliances were specified and installed; these were very substantial improvements in energy performance (4.8% and 3.0% respectively), for the building as a whole.

1.2.2.5. Site-generated Renewable Energy

Given the limited budget available for Habitat for Humanity, renewable energy sources were not strongly considered during the design of this house. However, it should be noted that the house is well-situated for the addition of solar energy. The long axis is oriented east-west, giving a large second-story solar exposure roof at an 12:12 roof pitch. If budget or a donation becomes available, this house could easily be converted to accommodate solar or hot water panels and their necessary infrastructure.

1.3 Construction Support

1.3.1. Construction Overview

With BSC's office in close proximity to the Westford House site, the project team had many opportunities to go to the site and answer questions from the builder and volunteers as well as help demonstrate construction techniques and practices during the eight-month construction process. See the images below for an array of construction milestones and demonstrations.

Figure 1.26: Foundation walls

Figure 1.27: Basement insulation

Figure 1.38: Kohta Ueno from BSC flashing a window opening

Figure 1.29: Framing, foam and furring strips

Figure 1.30: Kohta Ueno from BSC testing a furring strip fastener

Figure 1.31: Roof insulation

1.3.2. Systems Testing

The team has performed the standard battery of performance testing, including overall air infiltration (blower door), duct leakage (total and to exterior), HVAC system static pressure and overall flow, HVAC register flows, room pressurization, and ventilation system flows. See Performance Test in Table 1.3: Enclosure Specifications and Table 1.4: Mechanical system specifications for overall air infiltration and duct leakage results. The full test results are covered in Appendix E1.

Figure 1.32: Blower door testing

Figure 1.33: Duct Blaster® testing

1.3.3. Monitoring

We are planning on collecting monthly gas and electricity bills for this house for roughly a year, at a minimum. We will then compare these results to predictions from the energy models, and if possible, disaggregate heating loads for a further comparison with the model. We may also administer the previously-developed homeowner survey, for a complete battery of data.

It will be of particular interest to compare these results with the other Habitat for Humanity of Greater Lowell houses, given the similarity between plans.

1.4 Project Evaluation

The following sections evaluate the performance of the final production building design. References are made to the results from field tests and energy simulations, which are included as an appendix to this report.

1.4.1. Source Energy Savings

With the enclosure and mechanical characteristics presented in Table 1.3 and Table 1.4, this plan achieves a performance level of 44.4% reduction relative to the Building America Benchmark.

1.4.2. Prescriptive-based Code Approval

The Westford House was designed and constructed to meet the Seventh Edition of the Massachusetts One-and Two-Family Dwelling Code, which is based on the 2003 ICC International Residential Code. The home also meets all requirements set forth by the Town of Westford's Zoning Bylaws.

In addition, this design exceeds the IECC 2006 Section 404 Compliance (adopted by Massachusetts effective October 6, 2008) by over 50%.

1.4.3. Quality Assurance and Quality Control

A Durability Checklist was developed during design and implemented during the construction process, in order to ensure that critical design details would be implemented, that design intent would be carried out through construction as well as that the finished Westford House would be one that is healthy, durable and energy efficient. Items on the Durability Checklist such as managing both interior and exterior water sources, identifying and creating an interior air barrier as well as preventing pests from entering the home were verified by team members while on site visits as well as by a third party verifier as part of the LEED for Homes certification process. See below for images of implemented quality control measures.

Figure 1.34: Gravel drainage and "no-planting zone" perimeter

Figure 1.35: High density spray foam air seal around enclosure penetration

In addition to creating the Durability Checklist, a Homeowner's Manual was developed to ensure the home would be operated as intended. This manual describes key operational and maintenance measures, describes the lighting and appliances in the home, as well as includes the makes and models of all the appliances. Both the Durability Checklist and Homeowner's Manual are included in the Appendices section of this report.

Neutral Cost Target

The specified measures, up to and including the use of Energy Star appliances, still resulted in a positive cash flow ("16 + ES Appliances"), when calculated over a 30 year mortgage with a 7% interest rate, as shown in Table 1.5. Hypothetically adding some cost for third party inspections ($700) reduced this annual positive cash flow from $373/year to $316/year.

Table 1.5: Neutral cost calculations for Westford House

Assumed Financing Rate:	7%
Assumed Financing Term (years):	30

Parametric Run	Cumulative Cost	Savings	Annual Finance Cost	Simple cash flow
16 + ES Appliances	$11,000	$1,259	$886	$373
Add third party inspections @ $700	$11,700	$1,259	$943	$316

1.4.5. Marketability

Habitat for Humanity of Greater Lowell does not market their homes in the same way as traditional homebuilders. Habitat actively reaches out to low-income families who are in need of better housing and partners with the family and the community to create a healthy, durable, comfortable and energy-efficient home. The Westford House was built into an existing neighborhood and is similar in style and size to the rest of the homes in the area. The communities in which the homes are being built very actively support the family and the home through activities such as raising money in local schools to purchase appliances, volunteering to do construction and landscaping work, and creating items such as artwork and hand-made quilts.

In addition to the benefits resulting from the partnership between Habitat, the family, and the community, local and national partnerships have led to donations of building materials that have made the Westford House affordable.

1.4.6. Market Coverage

The Westford & Bedford community is a scattered site community of affordable single-family homes built in a cold climate in the Greater Boston Area.

1.4.7. Builder Commitment

Habitat for Humanity of Greater Lowell remains committed to building affordable homes that meet the Building America performance specifications. They see that sustainable building benefits not only the environment but the family and the community as well. See "101 Benefits and Features of Your New Home" in the Homeowner's Manual for an outline of what Habitat is committed to providing in their new homes. The next phase of the Westford & Bedford community will be starting construction before the end of 2008.

1.4.8. Gaps Analysis

Throughout the design and construction process, the team identified the following issues that will need to be resolved for the next phase of the community:

1. **Ductwork and Plumbing:** The plumbing and the ductwork competed for space at the ends of the home since there is 4″ of foam on the inside face of the concrete foundation wall. The next house drawings should show both the plumbing locations in addition to the ductwork locations that we already show on the plans. See Figure 1.36 below.

Figure 1.36: Plumbing, ductwork and foam in joist bay

2. **Intake and Exhaust Locations:** Since the home has a small footprint and vents were required for the hot water, furnace and ERV intakes and exhausts as well as the dryer out through the rim joist area, special attention needed to be paid to the vent locations in relation to walkways, windows, doors and utilities in order to meet code. For future houses, it would be necessary to have an accurate site plan from the builder locating proposed driveways and walkways to ensure venting locations would not interfere with these site items. And while the plan may meet the building code, the local building inspector may have additional requirements and changes. In the case of the Westford House, the inspector asked to have 4′ between the gas main and the dryer vent; while the code deferred to the dryer manufacturer's instructions that indicated 2′ would be sufficient. See Figure 1.37 below and SK-02 located in the Appendices section of this report.

Figure 1.37: ERV intake and exhaust

3. **Door Details with 4″ of Foam:** Our drawing set did not include how to detail the door openings with 4″ of foam on the exterior of the studs. The team worked out details with the builder on site and will need to have details drawn for the houses to be built in Bedford.

4. **Basement Spray Foam:** The high-density spray foam in the rim joist area could not be left exposed in the basement. The team suggested that mineral wool insulation (Roxul), which would serve as the thermal barrier required by code, be installed over the spray foam. The builder was concerned at first about how the Roxul would fit in the joist bay. In the end, the spray foam was trimmed back, and friction fit Roxul was successfully installed within each joist bay. See Figure 1.38 below.

Figure 1.38: Roxul insulation over spray foam at rim joist

5. **Basement Foil-Faced Foam Installation:** The 4" of foil-faced foam was difficult to attach to the concrete foundation wall. Therefore, wood furring strips were fastened to the foundation wall and the foam was then attached to the furring strips using roofing washers. This worked out reasonably well and the team would likely use this same detail in future projects. See Figure 1.39 below.

Figure 1.39: Roofing washers fastening foil-faced foam to furring strips

6. **Basement Foil-Faced Foam Thermal Barrier:** The foil-faced polyisocyanurate installed in the basement could not be left exposed to the interior without a thermal barrier. It should be noted, however, that a different type of foil-faced polyisocyanurate (Dow Thermax) is rated to be left exposed (ICC-ES NER-681). To solve this problem, the team suggested installing 1/2" gypsum board over the foam to serve as the thermal barrier, using drywall screws driven into the metal roofing washers mentioned previously. A paper-faced mold-resistant gypsum board was used. See Figure 1.40 below.

Figure 1.40: Gypsum board over foil-faced foam

7. **Air-Barrier Above Second Floor Ceiling:** The original design of the air barrier at the second floor ceiling was to run the drywall (air drywall approach) on the underside of the rafters. However the collar ties and strapping for the second floor ceiling were installed before this drywall was installed, as seen in Figure 1.41 below. With the strapping installed, it would have been very difficult to install the drywall. Even without the strapping installed, the drywall would have to have been cut and notched around the collar ties to serve as an effective air barrier. The air barrier plane was transitioned from the interior gypsum (on the first floor) to the roof sheathing, with foam sealant at the soffit.

   However, during testing of the house, we saw a significant amount of air leakage in the attic coming in through the soffit at the second floor dormer (as discussed in Appendix E1. In the future, details are required for a more effective air-barrier without using drywall above the collar ties. See Figure 1.41 below.

Figure 1.41: Second floor strapping and collar ties

8. **Electrical Service Entrance:** The main electrical box and wires are located on the front of the house and run up the side of the house and along the front gable wall. Aesthetically, the team would have preferred not to have the wires on the front of the house. For future houses, it would be necessary to have an accurate utility plan from the builder locating utility connections to the house to ensure utility connections would be in our preferred locations (if the site allows). See Figure 1.42 below.

Figure 1.42: Electrical service on front of house

9. **12:12 Roof Pitch:** The 12:12 roof pitch and the dormers were difficult for the volunteer crew to build. Not many volunteers wanted to go up on the steeply pitched roof to work on the roofing and dormers, see Figure 1.43 below. The next house plans to be built in Bedford will have lower sloped roofs and not have any dormers, to accommodate Habitat's volunteer labor force.

Figure 1.43: Dormer

10. **Volunteer Labor:** It was difficult to make sure that each volunteer understood how their particular task affected the air-tightness, energy performance, indoor air quality and durability of the house – all of which are critical items that affect the overall performance of the house. A particular volunteer may only be on the site one or two days a week, or even once during the entire construction process. And while they are on site, they may be involved in a variety of tasks. Habitat does not have the construction support crew that can make sure the volunteers fully understand their task and how it affects the overall performance of the house. For example, volunteers were having a hard time getting a continuous seal around the

perimeter of the window with a caulking gun. There were gaps in the seal that would affect the air-tightness of the home. Other volunteers were using mastic to seal the sheet metal ducts and left holes that required a second application of mastic, see Figure 1.44 below. For future houses, it would be necessary to have more demonstrations with the volunteers being sure to explain how their work affects the home's performance. It is time consuming to have to repeat tasks and there is always the possibility that the builder may forget to go back. It is also necessary to continue to have good communication between the team and the builder to ensure we are on site at critical times.

Figure 1.44: Air leakage location in sheet metal duct

1.5 Conclusions/Remarks

A family moved into the new affordable, comfortable, healthy, durable and energy-efficient Westford House in early November. It was through the partnership of Building Science Corporation and our partners, Habitat for Humanity, the community of Westford and the family that made this project not only possible but also extremely successful.

Four inches of rigid foam was used to create a high R-value enclosure, right-sized mechanical systems were installed, and energy efficient lighting, appliances, windows and doors were installed all contributing to a 44.4% estimated energy reduction over the Building America benchmark. This energy reduction will save the homeowner approximately $1,700 a year on their energy bills (relative to the Building America Benchmark).

While the volunteer labor presented some difficulties during construction, overall, they successfully tackled installing window and doors in 4″ of foam, fiber cement siding over furring strips, low-expansion foam around windows and doors, and foam sealant at the rim joist locations.

The BSC team is excited to continue to work with Habitat for Humanity on their new and retrofit housing projects. We believe that we can continue to improve on the energy efficiency of these homes. Higher efficiency leads to more savings that is especially significant in our affordable housing projects.

Figure 1.45: Community gathering before Westford House Dedication