2. HABITAT FOR HUMANITY OF GREATER LOWELL, FARMHOUSE RENOVATION, BEDFORD, MA

2.1 Executive Summary

Farmhouse Retrofit Prototype, Gate 3

Overview

Habitat for Humanity of Greater Lowell (HfHGL) has partnered with Building Science Corporation (BSC) on previous new construction projects. This working relationship continued with HfHGL's renovation of a mid-19th century farmhouse into affordable housing meeting Building America performance standards. BSC guided the project through the compound challenges of implementing high performance construction in the context of Habitat's construction process and in the context of a 150 year-old structure in an historic district.

BSC applied its 10-20-40-60 insulation performance guideline to the overall project plan. The guideline was met through installation of a new insulated slab, application of closed-cell spray foam insulation to the interior of the field stone foundation walls, and the addition of thick exterior insulation to the roof and wall assemblies. BSC developed details to achieve robust water management, maintain air and thermal barrier continuity, and respect the historic character of the property. The exterior of the insulating sheathing was designated to perform both as drainage plan and air barrier for the wall assembly. Comprehensive testing has evaluated the effectiveness of the air barrier system. Utility bill monitoring will provide further assessment of the overall efficacy of the high performance renovation.

Key Results

Analysis of the completed project incorporating testing results show modeled savings of 35% relative to the Building America benchmark. Air infiltration testing raised doubt about the effectiveness of exterior insulating sheathing as an air barrier for this type of project. BSC conducted remedial air sealing and succeeded in achieving acceptable air leakage results. On concurrent and subsequent retrofit projects, BSC is exploring different air barrier strategies. Many of the water management details developed for this project can be adapted for typical retrofit situations. Observing the construction of this project has helped to reinforce the need for standard details and practices for the application of thick exterior insulation.

Gate Status

Table 2.1: Stage Gate Status Summary

"Must Meet" Gate Criteria	Status	Summary
Source Energy Savings	Fail	This affordable housing retrofit prototype home does not meet the projected source energy savings target of 40% savings relative to the Building America Benchmark.
Prescriptive-Based Code Approval	Pass	All modifications to the existing structure comply with prescriptive code requirements

Quality Control Requirements	Pass	Continued successful implementation of exterior insulating sheathing and drainage plane will require inclusion of developed details in project plans and demonstration of proper techniques. Retrofit projects will require on-site monitoring due to unique conditions.

"Should Meet" Gate Criteria	Status	Summary
Neutral Cost Target	Pass	Estimated annual energy savings relative to incremental finance costs for energy performance measures yields a positive cash flow.
Quality Control Integration	Pass	Process is in place to document lessons learned in the prototype and apply these to a community-scale development It is recommended that Habitat for Humanity of Greater Lowell continue to participate in third-party verification programs due to the sparse continuity of workers
Gaps Analysis	Pass	Additional details and construction sequence guidance is expected to resolve some common water management issues. Continued site involvement will be needed for retrofits. Methods of implementing effective retrofit air barriers need to be developed and tested. Vinyl exterior finish systems should only be applied if they can be made to be compatible with the cladding attachment and water management systems More cost effective ignition barrier solutions are needed to improve the feasibility of retrofit ruble wall foundation insulation.

Conclusions

Thorough and effective water management strategies appear to still require significant support. This is not unique to retrofit situations nor to high-performance construction rather, this appears to result from general industry practices that do not consistently implement robust water management. Effective water management strategies are particularly important to retrofit situations where the "system" of the building operation – in terms of drying mechanisms, wetting mechanisms, and energy flows – is perturbed and where super insulation strategies typically reduce assembly drying potential. BSC continues to develop and identify specific water management strategies applicable to general retrofit situations.

Implementation of a robust air barrier is often one of the most cost effective energy performance measures in a retrofit. However, it can also be extremely challenging to achieve the level of air barrier performance needed to achieve high levels of energy performance. The experience of this project has revealed challenges inherent in the approach taken. Ongoing and future work will focus on alternative techniques.

The project demonstrates the attainment of massive energy use reductions in an affordable retrofit project. Despite not meeting the stage gate target for prototype energy reductions relative to the Building America benchmark, the project achieved significant projected savings. This reduction relative to a static benchmark can be viewed as a success given 1) significant energy performance improvement relative to previously existing conditions, 2) that this is an affordable housing renovation, 3) that the renovation was implemented largely with volunteer labor, 4) the challenges posed by a 150 year old structure, and 5) the fact that it does not include mechanical cooling. The lessons learned and techniques proven in this project are helping the Team move forward in its quest to identify and develop high performance retrofit guidance that can be scaled up to wide-scale retrofit application.

2.2 Introduction

2.2.1. Project Overview

Habitat for Humanity of Greater Lowell (HfHGL) acquired control of a lot located in Bedford, MA (Cold/Zone 5A) with the possibility to accommodate 7 new units of affordable housing. The site is near an historic district and included a barn and an 1850's-era farmhouse. HfHGL decided to also renovate the existing farmhouse as another affordable housing unit. Building Science Corporation, having collaborated with HfHGL on previous new construction projects, worked with HfHGL to develop plans to renovate the existing farmhouse to Building America performance levels.

This is a project of particular interest as it demonstrates massive energy use reductions in a type and age of building that accounts for a significant portion of residential energy use in the region. The project also affords research and testing of high performance techniques applied to an older building. By respecting and maintaining the historic character of the building and elevating its aesthetics, the project also allays concerns that a high performance retrofit threatens the character and appeal of a neighborhood.

2.2.1.1. Existing Conditions

When HfHGL acquired the property, the farmhouse had already been altered and adapted many times to suit the changing needs and means of occupants. Some of the additions were poorly constructed (e.g., south-facing sunroom), and were demolished (see Figure 2.1 through Figure2.2).

Figure 2.1: South elevation showing added sunroom and rear addition demolished prior to retrofit

Figure 2.2: South elevation showing demolition and new rear addition

Figure 2.3: Existing rear addition

Figure 2.4: Rebuilt rear addition

Figure 2.5 shows the multiple layers removed during the demolition process, including the existing vinyl siding, thin-profile foam sheathing underlayment, building paper, wood clapboard, another layer of building paper, and the original board sheathing. For the most part, the existing board sheathing and the structure were in excellent condition.

Figure 2.6 shows an interior of the basement, which is a rubble wall foundation; this type of foundation wall construction is a particular challenge for retrofit insulation, due to its uneven surface and questionable water-stopping abilities. The brick seen at the upper portion of the wall is non-structural infill. The exposed above-grade portion of the foundation is large (~5' long) granite block, supporting a timber (8x8) sill beam.

Figure 2.5: Demolition photo showing multiple layers of exterior wall cladding

Figure 2.6: Existing rubble stone foundation

2.2.1.2. Construction Process Operational Context

In addition to the challenges of a house renovation, the organizational structure was quite unusual, which sometimes posed problems. Although Habitat for Humanity was the client and builder, much of the construction was done by volunteer labor (some skilled, some moderately skilled), as well as a local technical high school. This meant that at times, the chain of command was not very clear, and the construction team could get ahead of the design team, especially when information was not being correctly relayed between the two. This is discussed in section 2.3.1 "Construction Overview."

One programmatic change accommodated during the construction phase involved a decision to renovate the farmhouse as part of an attached duplex with the second unit to be new construction. This required the construction of demising wall separations and the reconfiguration of already installed plumbing and mechanical systems. The Building America prototype presented in this report is limited to the farmhouse renovation and excludes the new construction duplex unit addition.

2.2.1.3. High Performance Renovation Strategy

The renovated thermal performance of the building enclosure closely follows BSC's residential thermal performance mantra 10-20-40-60. Two inches (R10) of XPS insulation is placed under and around the perimeter of a new concrete slab floor in the basement. Two-to-three inches of closed-cell spray foam insulation is applied to the interior of the field stone foundation walls and sill beam. Thick exterior insulation is added over the roof and wall sheathing with new batt insulation installed in the roof framing cavities and new blown-in cellulose installed in the wall framing cavities. All of the windows in the renovated home are high performance, double glazed, low-e vinyl framed windows.

The face of the exterior insulating sheathing applied to the walls was detailed as an air barrier and drainage plane. This required BSC to developed special details to achieve robust water management and maintain air and thermal barrier continuity. Application of vinyl cladding and trim (at the insistence of the construction team) also required special detailing to work with the thick exterior insulation.

The strategy of applying significant exterior insulation over existing sheathing presents several advantages for high performance renovations. The thermal resistance added to the exterior of the sheathing lowers the condensation potential for the existing sheathing and enclosed structure. The continuous exterior insulation also significantly reduces the incidence of thermal bridging within the building enclosure. The flat surface of board stock insulating sheathing also provides a consistent plane for drainage plane and air barrier detailing. This type of approach is a logical choice when roof or wall cladding replacement is already planned.

The well insulated enclosure system together with the infiltration control expected, reduced the design heating load to a point where the load could be meat with relatively small equipment. For this resource-constrained renovation a high efficiency furnace/air handler was selected as the heating system. This system has the advantage of providing the indoor air quality necessities of ventilation and mixing without the need for a separate system or separate equipmenet to achieve this. The 40 kBTU-input multispeed furnace is expected to be able to meet the vast majority of the heating load at its low fire setting)

The completed project serves as a model for renovations of similar construction types that can provide major energy reductions. The experience of designing this renovation and guiding its implementation also provides lessons that can inform other renovation projects aspiring to achieve major energy reductions.

Figure 2.7: Bedford Farmhouse Retrofit nearing completion

2.2.2. 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	[…]
Company Type	Nonprofit
Community Name	Bedford Site (130 North Road)
City, State	Bedford, MA
Climate Region	Cold (5A)

SPECIFICATIONS	
Number of Houses	1 (+7 new construction houses at same site)
Municipal Address(es)	130 North Road, Bedford, MA 01730

House Style(s)	Single family, affordable
Number of Stories	2
Number of Bedrooms	3
Plan Number(s)	n/a
Floor Area	1504 ft^2
Basement Area	804 ft^2
Estimated Energy Reduction	35% over BA Benchmark
Estimated Energy Savings	$928 per year
Estimated Cost	$135,000 for construction (net of building and land acquisition)
Construction Start	Demolition began mid-2008
Expected Buildout	October 2009

2.2.3. Targets and Goals

The goal of this project was to meet the Building America goals of a 40% savings relative to the Benchmark; this was expected to be a particular challenge in the context of a retrofit. As described above, it is hoped that this project will serve as a model for future deep energy reduction renovations. It has also resulted in guidance on details and procedures supporting deep energy retrofits.

2.3 Whole-House Performance and Systems Engineering

2.3.1. Energy Analysis Summary

Table 2.2: Estimated Whole House Energy Use for Farmhouse Renovation, Bedford, MA

ESTIMATED HOUSE ENERGY NET GENERATION		
Source (10^6 BTU/yr)	Site (10^6 BTU/yr)	Area + Bsmt (sq ft)
128	75	1504 + 804
	% Electric	No. of Bedrooms
	27%	3

With the enclosure and mechanical characteristics presented in Table 1.3, this plan achieves a performance level of 28% reduction relative to the Building America Benchmark.

2.3.1.1. Parametric Energy Simulations

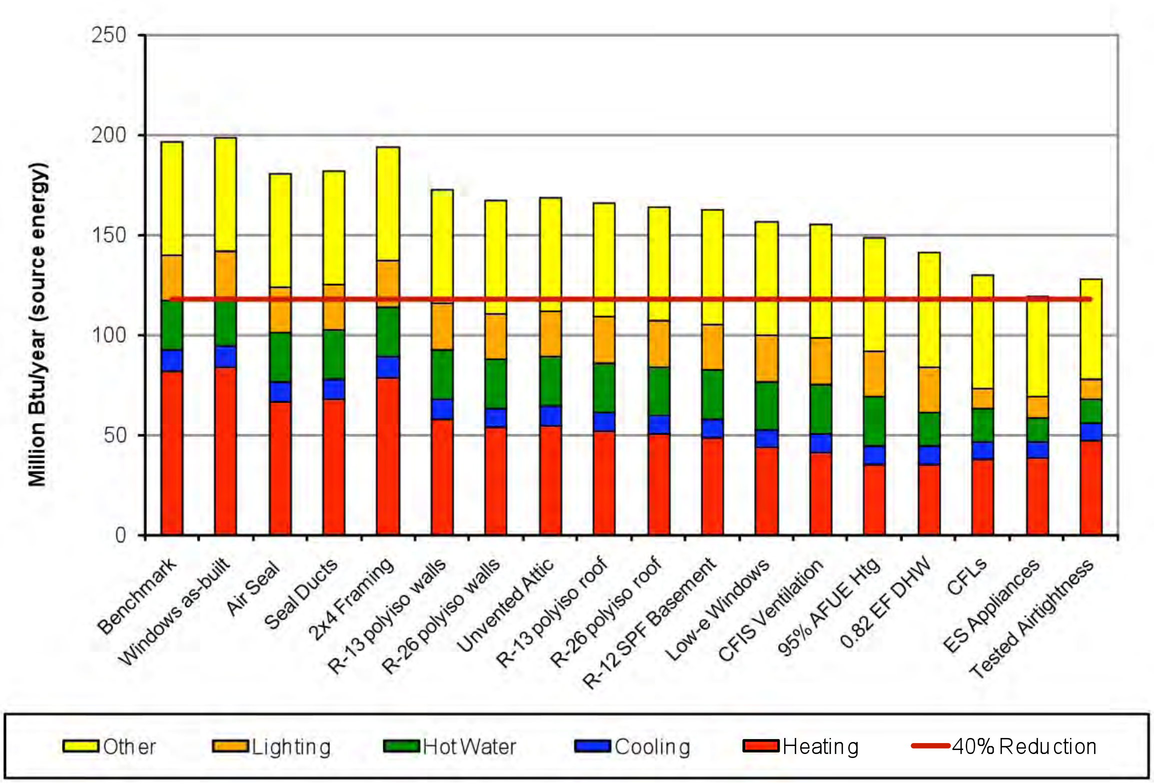

Figure 2.8: Parametric energy simulations

2.3.1.2. End-Use Site and Source Energy Summaries

Table 2.3: Summary of End-Use Site-Energy

	Annual Site Energy			
	BA Benchmark		Prototype 1	
End-Use	kWh	therms	kWh	therms
Space Heating	505	694	323	362
Space Cooling	909	0	670	0
DHW	0	224	0	110
Lighting*	2008		911	
Appliances + Plug	4009	98	3659	73
OA Ventilation**	34		408	
Total Usage	7464	1016	5971	545
Site Generation	0	0	0	0
Net Energy Use	7464	1016	5971	545

Table 2.4: Summary of End-Use Source-Energy and Savings

			Source Energy Savings	
	Estimated Annual Source Energy		Percent of End-Use	Percent of Total
	BA Benchmark	Prototype 1	Prototype 1 savings	Prototype 1 savings
End-Use	106 BTU/yr	106 BTU/yr		
Space Heating	82	43	47%	19%
Space Cooling	10	8	26%	1%
DHW	24	12	51%	6%
Lighting*	23	10	55%	6%
Appliances + Plug	57	50	12%	3%
OA Ventilation**	0	5	-1118%	-2%
Total Usage	197	128	35%	35%
Site Generation	0	0		0%
Net Energy Use	197	128	35%	35%

This retrofit prototype achieves a reduction of 35% relative to the Building America benchmark.

2.3.2. Discussion

2.3.2.1. Enclosure Design

Table 2.5 (below) summarizes the building enclosure assemblies used for this project.

Table 2.5: Enclosure Specifications

ENCLOSURE		SPECIFICATIONS
Ceiling		
	Description -	Sawn full-dimension rafter (2" x 7") with fiberglass insulation; 2 layers polyisocyanurate board insulation exterior to roof sheathing
	Insulation -	R-25 fiberglass in rafter bays, 2 layers 2" polyisocyanurate (R-26)
Walls		
	Description -	Existing full dimension 2x4 framing with cellulose with polyisocyanurate insulating sheathing
	Insulation -	R-14 (4") cellulose with 2" (R-13) or 4" (R-26) polyisocyanurate insulating sheathing
Foundation		
	Description -	Existing rubble stone and granite full basement interior insulated with high density urethane spray foam; XPS under new concrete slab
	Insulation -	R-13+ (2-3" high density urethane spray foam) on foundation walls R-10 2" XPS underneath and around perimeter of new concrete slab
Windows		
	Description -	Double Pane Vinyl Frame Spectrally Selective Low Emissivity Argon
	Manufacturer -	Andersen Silverline 3000 Series
	U-value -	0.31
	SHGC -	0.32

ENCLOSURE	SPECIFICATIONS
Infiltration	
Specification -	2.5 in^2 leakage area per 100 ft^2 enclosure (1334 cfm50, 3.6 ACH50)
Performance test -	4.2 in^2 leakage area per 100 ft^2 enclosure (2,260 cfm50, 6.15 ACH50) Including inter-unit leakage

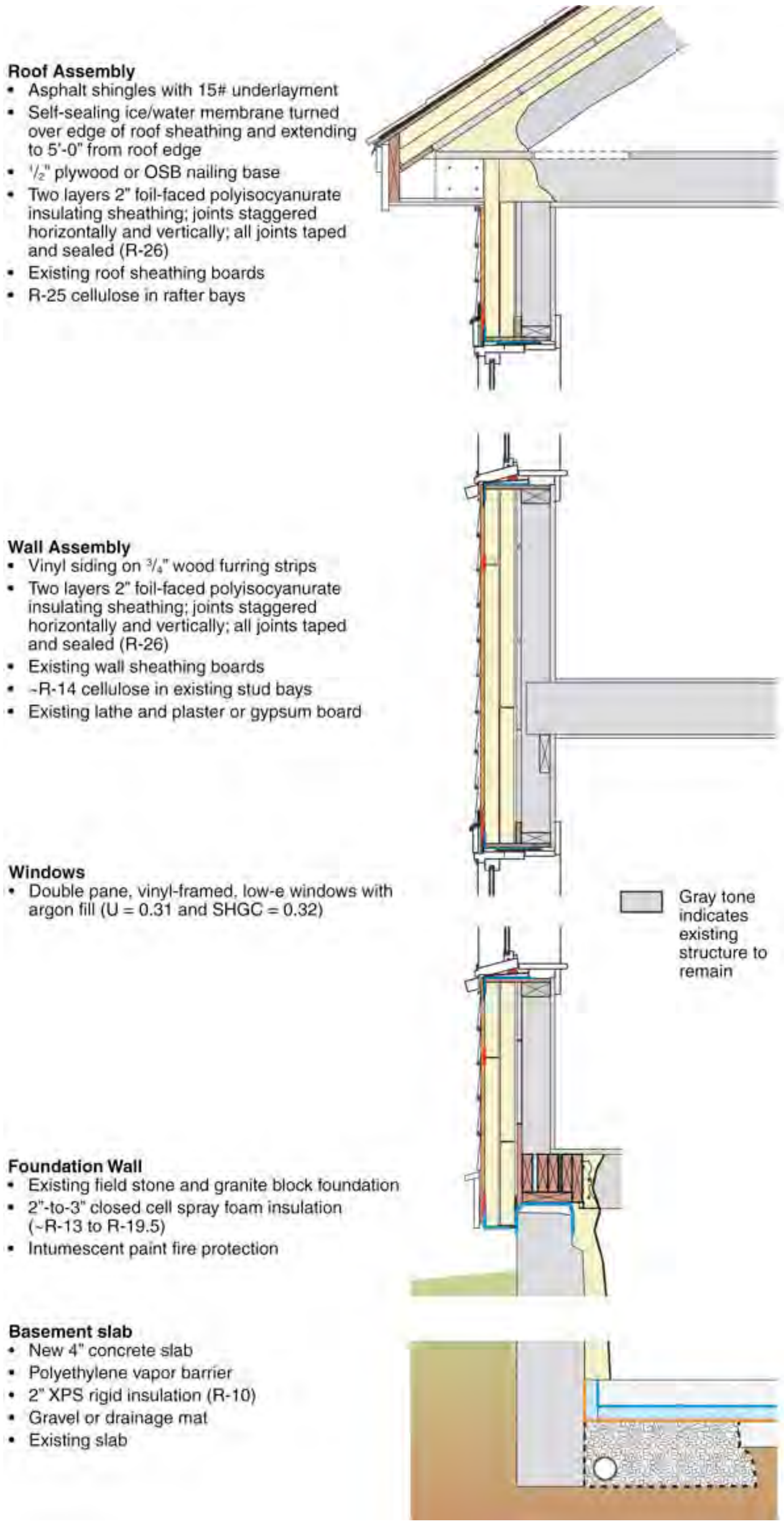

Figure 2.2: Enclosure Building Section

The enclosure upgrades are discussed in greater detail below.

- **Ceiling:** The original roof was insulated at second floor ceiling plane with loose-fill (cellulose) insulation, underneath the attic floorboards. One possible retrofit method could have been to remove the floorboards, perform air sealing at the ceiling plane, and refill with loose fill insulation. However, this method was not chosen for this retrofit.

  One reason was that the attic was poorly vented (with no eave vents, and multiple poorly-functioning "button" vents cut in), and the framing geometry would have made it difficult to add venting. Also, the existing structure included a walk-up attic stair. Initially, the plan was to maintain the narrow stair to the attic. This would have entailed significant challenges to air barrier implementation. During the construction process, the construction team decided to remove the existing attic stair and install a new pull-down attic stair/hatch. With this hatch, the many service penetrations, and the likelihood of use of the attic, there remained sufficient concern about the long term integrity of the air and thermal barrier to warrant including the attic within the thermal enclosure and implementing the air and thermal boundaries at the outer enclosure. Another consideration is that, an attic space within the thermal enclosure provided an amenity for the residents that would otherwise be precluded from Habitat for Humanity projects..

  The design intent was for air barrier to be at the existing roof deck layer (using a skim coat of spray foam on the underside of the roof deck and WRB roof wrap above); with details to transition the wall air barrier through the rake and eaves. For a review of the fate of air barrier measures in construction refer to section 2.4.1 below.

  The decision to insulate the roof at the roof deck level was not without its challenges. Budget constraints on the project would not allow use of full-depth spray foam to achieve the desired thermal performance in this unvented, "compact" roof assembly. The limited rafter depth (7") of the existing framing would accommodate roughly an R-25 cavity insulation. This is substantially less than the R-35 used in the Benchmark and well below the performance target that BSC had established for this project. Therefore, in addition to the rafter cavity insulation, two 2" layers (R-13 × 2 = R-26) of rigid foil-faced polyisocyanurate was needed outboard of the existing roof sheathing. This required another layer of structural sheathing applied as a nail base. Also, the thick insulation layer on top of the roof sheathing (together with the thick insulation layer added to the wall) required the rafters to be extended in order to maintain the soffit depth, soffit height, and size of eave fascia that were important to the visual character of the home.

  Although adding this much insulation over the roof presented challenges to the retrofit design and construction, it actually entails some significant performance advantages, particularly in a retrofit situation. The 2009 International Residential Code (§R806.4 Unvented attic assemblies) allows an unvented assembly in climate zone 5 provided that (among other conditions) the assembly includes air impermeable insulation having an R-value of 20 *either* directly below or directly above the roof sheathing. The reason for this air impermeable insulation layer is condensation control: to prevent interior moisture laden air from reaching a surface that is likely to be below the dew point of the interior air under normal winter time operating conditions. While insulating entirely to the inside of the roof deck with air impermeable insulation would prevent interior air from depositing moisture on the roof deck, it would still leave the roof deck in a situation where it is exposed to higher fluctuations of temperature and higher relative humidity. Since the equilibrium moisture content of wood rises with relative humidity, the potential to encounter decay mechanisms also rises with humidity. Having the air impermeable insulation to the outside of the structure with air permeable (and vapor permeable) insulation to the inside, subjects the structure to less temperature fluctuations and keeps it within a generally lower relative humidity environment.

Thus, providing a significant portion of the assembly R-value to the exterior in this way helps to stabilize an existing structure. Relative to prior conditions, temperature and humidity fluctuations are reduced, local relative humidity is generally lower, and drying potential to the inside is maintained. For an existing structure that has already been in service for a good number of years, it is important to ensure that the structure is maintained within conditions that are no worse that the conditions in which it had served for a number of years.[1]

The impact of exterior insulation on building durability, although difficult to quantify, should be taken into account in any evaluation of the "cost effectiveness" of different insulation strategies. The roof insulation strategy represented only a 3% modeled source energy improvement relative to the Building America Benchmark case with insulation at the attic floor. By this annual energy use metric, the roof insulation strategy would seem to be a relatively costly, perhaps even extravagant, upgrade. In terms of building longevity and the value of maintaining the structure within the community, the roof insulation strategy employed may be viewed as a more fundamental investment.

- **Walls**: The existing 2x4 walls were previously insulated with blown-in cellulose. It was blown in from the exterior. Early in the project, a narrow strip the interior plaster was removed to allow for electrical work. The design intention was to leave the majority of the plaster wall finish undisturbed.

  Although this is a great improvement over uninsulated cavities, it is nowhere near the performance level required to obtain 40% reductions, especially when thermal bridging is included in calculations. Therefore, the exterior of the wall was insulated with two 2" layers of rigid foil-faced polyisocyanurate on the old portion of the house. However, on the new wing, only 2" of polyisocyanurate was specified, due to logistical constraints, and the fact that the rear 8 feet are framed with 2x6s 24" o.c. The taped surface of foam is detailed as drainage plane and is also used as air barrier. This aspect is covered in much greater detail in section 2.3.2.2, "Development of Air Barrier and Drainage Plane Details"

  This method has several advantaged over using a Larsen truss and batt or loose fill insulation to perform an exterior insulation retrofit. The insulation material itself is air impermeable (increasing airtightness), and it reduces the likelihood of wintertime interstitial condensation by raising the temperature of the interior side of the board sheathing. In addition, this rigid foam approach has greater insulation density (R-6.5 vs. ~R-3.5 per inch) than cavity fill insulation, and its surface functions effectively as a drainage plane without the addition of further materials (i.e., housewrap).

  These upgrades taken together give roughly a 7% improvement relative to Benchmark.

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[1] In retrofit of valuable structures "***Primum non nocere***" (First do no harm), should be a guiding edict.

- **Foundation:** As mentioned earlier, rubble stone foundations are a particular challenge for retrofit insulation. One of the approaches recommended in "Building Science Digest 103: Understanding Basements" by Joseph W. Lstiburek, Ph.D., P.Eng. (based on his *ASHRAE Journal* article, "Understanding Basements," July 2006) is interior urethane spray foam insulation. This air-impermeable and vapor-impermeable material prevents air and vapor diffusion based condensation of interior moisture, and greatly reduces the transmission of ground-sourced moisture to the interior of the basement. It is a system with excellent performance; in addition, the exposed rim joist at the basement can be sprayed simultaneously, greatly improving condensation control and airtightness. This sprayed-on system has no problem with the uneven surface of a rubble stone foundation. A 2-3" layer of spray foam (R-13 to R-19.5) is specified.

  However, this measure should not be done in a basement where there are sustained and continuing bulk water (i.e., groundwater or rainwater leakage) problems at the walls. Another issue with this solution is that spray foam cannot be left exposed in occupied spaces, due to fire concerns. This is normally addressed by using gypsum board (preferably non-paper faced) to the interior of the foam layer, on steel framing. However, in this case, we have specified an intumescent coating (Flame Seal Products FX-100® Fire Retardant Coating) as a lower cost alternative.

  At R-13 (nominal worst case), this measure results in a 0.8% improvement relative to Benchmark; however, remember that the Benchmark insulation level is R-9.2. Again, this does not include the airtightness associated with this spray foam installation.

- **Windows:** The intent of this renovation was to replace the windows, for both aesthetic and performance reasons.

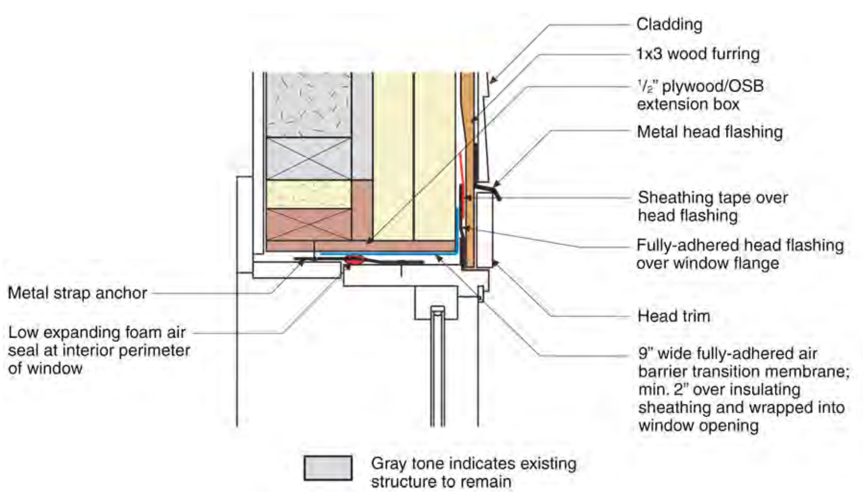


Figure 2.12: Air barrier and water management at window head of new window in existing wall with 4" exterior insulation

- *Exterior Retrofit Insulation Moisture Evaluation*," this exterior insulation retrofit described above reduces the drying potential of this wall, by placing a moisture vapor impermeable layer at the exterior of the wall. In order to control risks of moisture damage, it is a prudent measure to replace these windows, and install a replacement window with a complete pan flashing system drained to the exterior. Vinyl frame double glazed low-emissivity argon filled units were specified.

This item was a 3.8% improvement relative to the Benchmark (changing from U=0.56 to U=0.31). However, there was a larger difference relative to the original single-glazed wood frame windows. They were not modeled here, but for reference, we would estimate their performance with storms windows at roughly U=0.62, SHGC=0.72 (U=0.95, SHGC=0.80 without storm windows).

- **Air leakage:** The single largest line item upgrade was the improvement in airtightness (at 9.4% 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 (e.g., an additional 4.7% by reducing infiltration to 1.5 in^2 leakage area per 100 ft^2 envelope). All of the measures described above (roof, walls, basement, and window) cause improvements in airtightness, so reasonably, this improvement can be apportion to the savings associated with these other items. The specifics of the air barrier are covered in section 2.3.2.2, "Development of Air Barrier and Drainage Plane Details"

2.3.2.2. Development of Air Barrier and Drainage Plane Details

As mentioned previously in sections 2.2.1 "Project Overview," and 2.3.2.1 "Enclosure Design" the development of effective air barrier details and connections in this retrofit of exterior insulation to walls and the roof was particularly critical. Achieving airtightness levels well beyond Building America targets would be an excellent proof of performance, and would demonstrate the level of care and detail required to achieve substantial energy reductions in retrofit construction. Having demonstrably good airtightness results would be another strong argument for this exterior insulation retrofit method, showing its benefits in addition to the associated increase in R-value.

The nature of the existing structure left the roof structure and foundation exposed to the interior. It is, therefore possible to implement an air barrier within these assemblies. For the wall assembly, the only realistic option for an air barrier would be one added to the outside of the wall. An exterior air barrier and drainage plane strategy which this team has used is foil-faced polyisocyanurate insulating sheathing with all seams sealed by the application of sheathing tape.

Of course, the retrofit of insulation and air barrier on the exterior walls of the house required details that result in a correctly-connected drainage plane. These details must address the challenge of portraying the construction (and constructability) of a robust drainage system simultaneous with a robust air barrier system at such typically challenge areas as roof-wall connections, foundation connections, and window details.

Air barrier and drainage plane details were developed over several iterations; the final results are shown in the plan set (A-6 through A-16 on "2008-11-04 Farmhouse Drawing Set.pdf"). Air barrier and drainage system solutions for major critical areas are discussed below.

Foundation-to-Wall Interface

At this location, the air barrier of the foundation wall insulation system – 2-3" closed-cell spray foam – must be connected to the air barrier of the wall system, i.e. the outer face of the insulating sheathing. This must be accomplished without raising the possibility of exacerbating damage that might result from water leaking into the assembly (if—or perhaps when—this occurs).

A layer of self-sealing ice/water membrane placed beneath the sill (see section 2.3.2.4 "*Sill Beam Evaluation and Replacement*" below) serves as both a capillary break membrane and an air barrier transition membrane. It effectively transfers the air barrier from the inside of the foundation to the exterior of the foundation at the top of the foundation wall. The insulating sheathing and cladding of the wall system is designed to extend over the foundation wall past the sill in order to provide a measure of protection from rain water splashback for the sill, as well as some measure of the thermal protection. It was determined that sealants and caulks would not provide a reliable and durable air barrier transition from the foundation wall to the insulating sheathing. This is due to the irregular surface of the foundation wall, which may present gaps too large for sealants to close. Furthermore, the injection of sealant at the underside of the wall assembly would be very difficult to verify.

A membrane air barrier transition provides a more robust and durable air barrier and is compatible with the sequence of construction, including discrete inspection steps. In the solution developed, one side of a self-adhered flashing membrane (DuPont StraightFlash™ VF "Versatile Flange") is sealed to the bottom of the wall sheathing and the capillary break membrane mentioned above. The proper installation of this membrane piece can then be verified. Then, after installation of the insulating sheathing, the free side of flashing membrane is folded up and sealed to the face of the insulating sheathing with another piece of flashing membrane. The seal can be verified when the top edge of the flashing membrane is then taped to the outer foil facing to ensure drainage plane continuity, and prevent low-angle shear de-adhesion issues common to vertical membrane flashings.

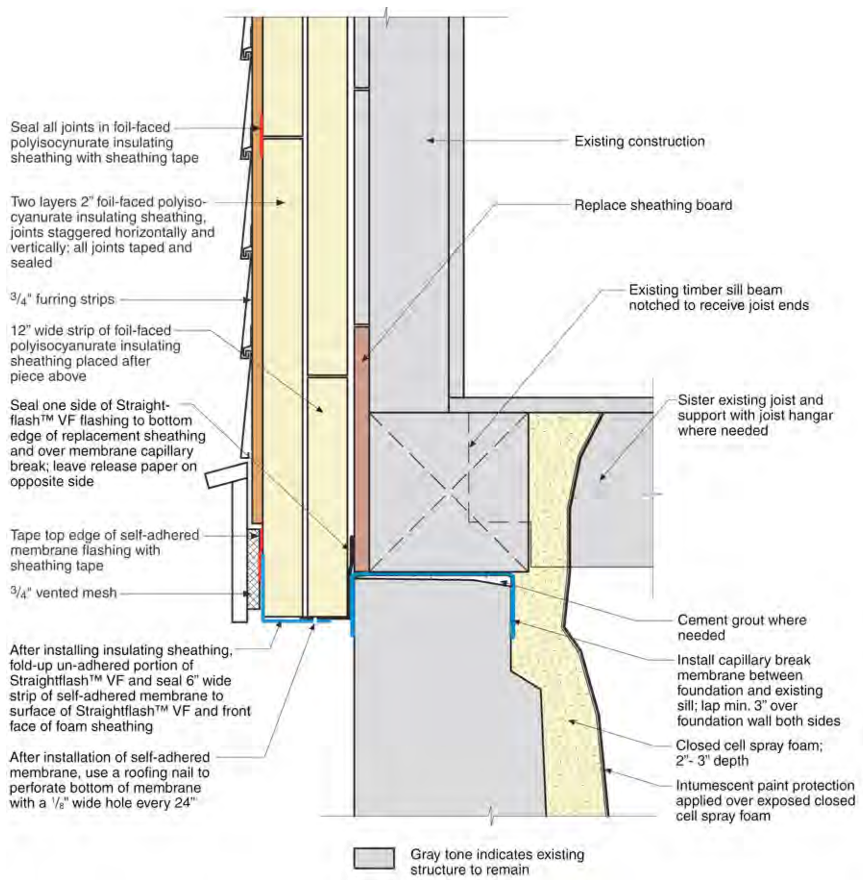


Figure 2.9: Air barrier and water management detail at sill

This use of membrane flashing—while providing a robust and inspectable air barrier transition from the foundation to the wall—also creates a U-shaped or "gutter" profile which could potentially trap incident water and direct it to the inside. Experience has shown that taped foil faced insulating sheathing behind rain-shedding cladding is an effective drainage plane, especially with a ¾” drainage gap. However, given the often unpredictable nature of retrofit situations and the admirably abundant application of volunteer labor on the project, the team felt it necessary to account for the possibility (however remote) of water on the inside face of the insulating sheathing or between pieces or layers of insulating sheathing.

The simple solution to this water management conundrum that the team selected is to puncture the low point of the air barrier transition membrane (e.g. with a nail) at intervals to allow trapped water to “weep” out of the assembly. BSC conducted empirical trials to verify that a small water column is sufficient to push water through this drainage hole. The 4” height difference between the top of the inside leg of the air barrier transition flashing and the low point is easily sufficient to ensure that any water which happens to find its way to the inside of the drainage plane could exit through the small nail hole at the bottom of the air barrier transition. The impact on air barrier performance of these nail holes is deemed to be inconsequential for the retrofit situation.

Wall-to-lower roof transition

This transition is detailed in a manner similar to the base of the wall at the foundation. One important difference, however, is that there is no clearance underneath the wall insulating sheathing to manipulate the flashing membrane. This requires that the two piece flashing membrane air barrier transition be pre-assembled. It is then adhered to a 3’ wide (roll width) piece of ice/water membrane that is adhered to the existing board sheathing of the wall. This ice/water membrane on the wall seals to the air barrier membrane of the roof (fully adhered ice/water membrane turned up the wall at the roof-wall interface) and provides ample protection against water that might penetrate the outer face of the foam sheathing and back up the wall due to, for example, snow accumulation against the wall.

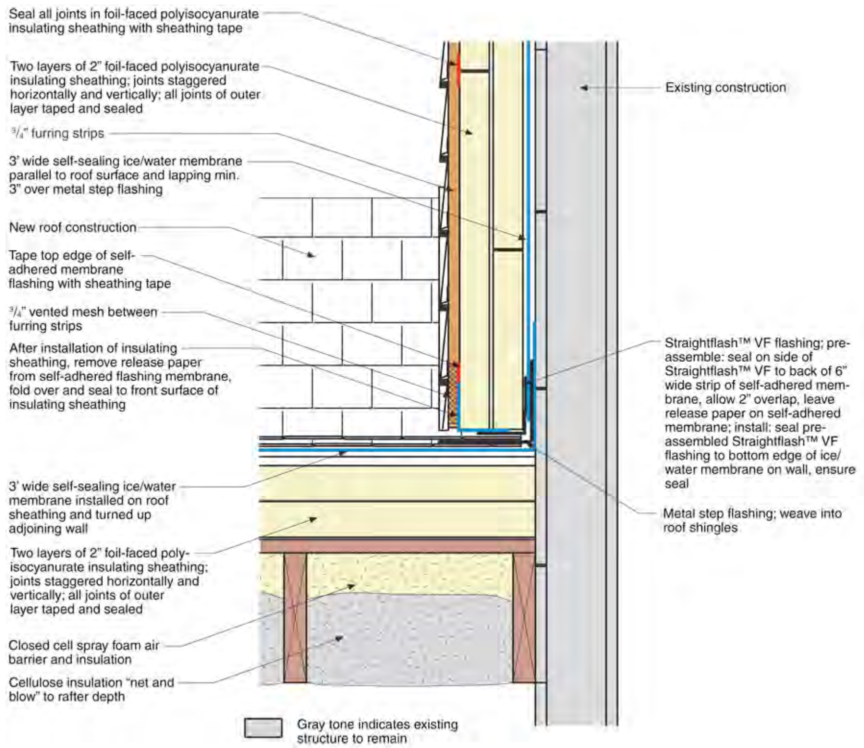


Figure 2.10: Air barrier and water management detail at wall-to-lower roof interface

Top of wall-to-roof transition

Except for the gable end of the single story addition, the air barrier continuity at this interface relies upon the application of spray foam to transfer the air barrier from the insulating sheathing to the air tight roof system. At the gable end of the single story addition (a portion of the building that represents new construction), the two sided adhesive flashing membrane (StraightFlash VF) is used to transfer the air barrier from the insulating sheathing to the structural sheathing from which it is then transferred to the roof system.

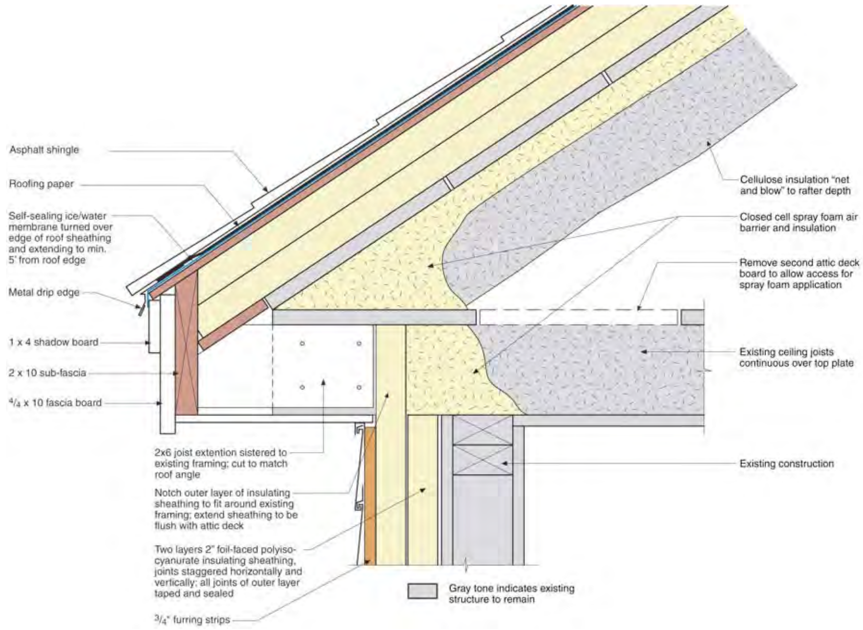


Figure 2.11 Air barrier detail at top of wall, existing roof eave

Windows

Wide strips of self-adhered membrane are used to transfer the air barrier from the face of the insulating sheathing into the opening where expanding foam sealant – inspectable from the interior – transfers the air barrier to the window frame at the inside perimeter. A separate membrane flashes the drainage plane to the head and jamb flanges of the window.

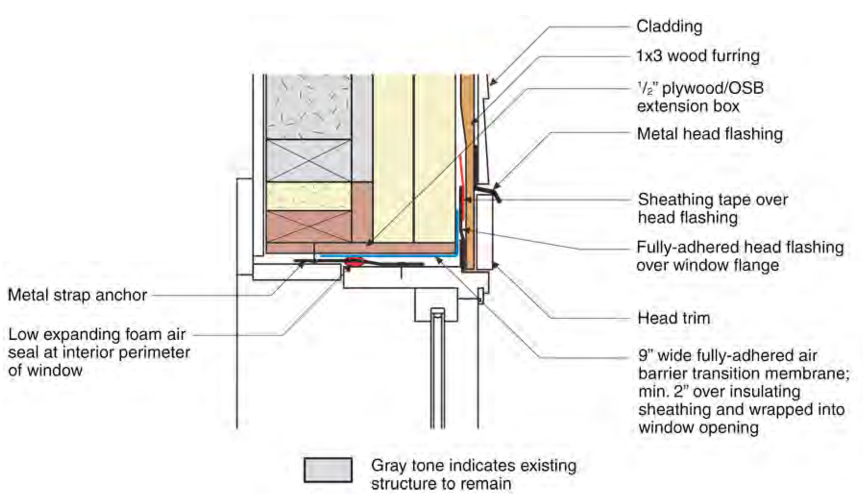


Figure 2.12: Air barrier and water management at window head of new window in existing wall with 4" exterior insulation

2.3.2.3. Exterior Retrofit Insulation Moisture Evaluation

One concern with this scheme of exterior insulation was whether or not it might increase the risk of moisture damage in the wall assembly. For the most part, the assembly as proposed would actually **improve** durability of the assembly, for the following reasons:

- The outer cladding will be mounted on ¾" thick furring strips with a drained and ventilated cavity behind it. This assembly is highly resistant to rain penetration and accumulation: rain tends to cling to the backside of the clapboard siding, and will drain back out the front of the cladding over several courses.

- When rain gets through the exterior drained cavity, the interior assembly has multiple levels of redundancy. Most of the water will be shed from the outer surface of the foil-faced polyisocyanurate (with taped joints). Water that passes through that layer will be intercepted by the staggered joints of the second layer of foam.

- The presence of an airspace cavity behind the cladding results in "ventilation drying" of the cladding. In other words, the siding is able to dry from both sides, as opposed to being "sandwiched" against the building sheathing.

- The addition of the polyisocyanurate foam on the exterior of the wall reduces the risk of wintertime condensation inside the insulated cavity (i.e., interstitial condensation).

On the other hand, the one danger associated with this retrofit measure is that the foil-faced foam is impermeable to water vapor. In the current assembly, some incidental moisture that gets into the wall can dry to the exterior (through the sheathing, building paper, and shingles). However, the retrofit will largely eliminate this drying to the exterior. In addition, all of the exterior airtightening may or may not decrease drying due to air movement through the wall.

As a result, for instance, a window might be leaking water into the wall currently, but might be able to dry (to both sides) quickly enough to avoid damage. However, by removing the drying to the outside with the addition of foam, it might result in enough accumulation to cause damage.

To gain some intuition to the level of detail required, one-dimensional hygrothermal simulations were run in a Massachusetts climate on the wall before or after the retrofit (see "2008-08-05 Foam Retrofit WUFI Simulations.pdf").

The plots below show a selection of the WUFI output, comparing the original wall (**Figure 2.**14) and the retrofit wall (Figure 2.15), with 0.5% penetration of incident rainfall. The following measurements are plotted:

- Exterior temperature (orange light dotted line), to show seasonal patterns

- North wall sheathing moisture content (%) (blue)

- South wall sheathing moisture content (%) (red or gold)

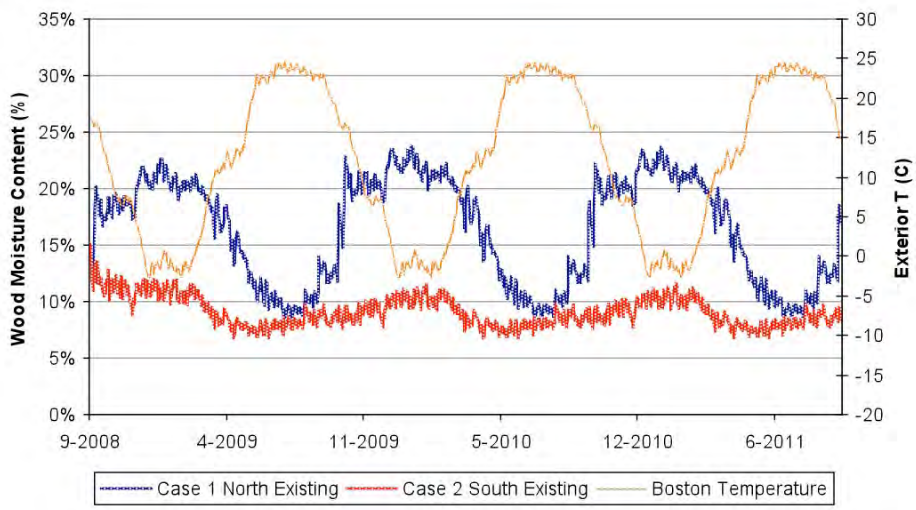


Figure 2.14: 0.5% rainfall penetration in original wall

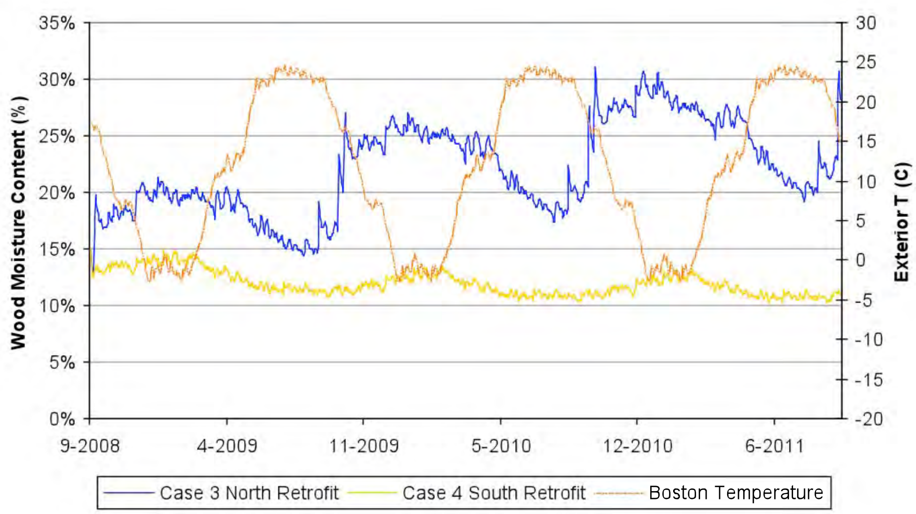


Figure 2.15: 0.5% rainfall penetration in retrofit wall

The south wall (warmed by solar radiation) has safe behavior in both cases. Although there is a slight rise in moisture content during the winter, it is well within safe range.

In contrast, in the original assembly the north wall sheathing moisture content rises to roughly 22%. When the same rainfall entry rate is applied to the renovated wall, moisture content rises continually every season, for the three year simulation. However, if the rain penetration is reduced to 0.25%, the moisture content of the north side sheathing stays at safe levels.

Overall, the results showed that this technique does indeed increase risks: a wall that had a small rain leak into the stud bay cavity (0.5% of incident rain) would cycle from dry to wet seasonally; after the retrofit, this same amount of rain resulted in a seasonally rising pattern. However, cutting the rain leakage to 0.25% (by half) of the incident rainfall resulted in safe behavior. This indicates that rain penetration of the structure is an increased risk due to this retrofit; however, improvement of the rain management details done concurrently can safely address these concerns. Note that many assumptions are built into this model, and that this is not meant to be some type of definitive metric of "allowable leakage"—basically, any rain leakage into the wall assembly that is occurring might cause a problem.

These results were used to demonstrate that if an exterior foam retrofit is done, it is vital to assure that windows and mechanical penetrations are flashed properly. Also, during disassembly/stripping of cladding, any signs of water damage should be investigated and dealt with. If new windows are to be installed in rough openings, a pan flashing draining to the exterior should be installed (as shown in A-16 and A-17 on "2008-11-04 Farmhouse Drawing Set.pdf").

2.3.2.4. Sill Beam Evaluation and Replacement

In light of the increase in moisture risks due to the retrofit of insulation described earlier, the condition of the sill beam was of particular interest. This framing member is exceptionally vulnerable, given its location. The moisture sources at play include the following:

- Capillarity: the wooden sill beam is in direct contact with the stone or masonry foundation. Liquid capillary water can rise in the foundation, potentially creating high relative humidity conditions at the wood-masonry interface, raising the risks of moisture damage.

- Sorption isotherm behavior: the stone foundation is highly thermally conductive; therefore, during wintertime, the sill-foundation interface will be very cold. At typical dewpoint conditions, the interface will be at a high relative humidity. The sorption isotherm (material response to relative humidity) shows that RH determines moisture content, so at these conditions, the moisture content will rise.

- Splashback: the base of the wall is particularly susceptible to moisture damage due to splashback, or rain water hitting the ground and "bouncing" to the moisture-sensitive portions of the wall. Bulk water is typically a greater risk for causing moisture damage than vapor diffusion and capillary forces.

- Bulk water/flashing: similarly, at the base of the wall, incorrect flashing details can direct bulk rainwater into the foundation, similarly causing accelerated damage.

Due to these concerns, the design team and the contractor consultant visited the site, to evaluate the risks (see **Figure 2.17** and **Figure 2.18**). One goal was to determine whether or not we require the lifting of the sill beam to place a capillary break (peel & stick membrane) between the sill and the foundation.

Figure 2.17: Evaluation of foundation risks

Figure 2.18: Evaluation of foundation risks

It was determined that risks were high, so this "lift" procedure was undertaken. During the initial disassembly and lift, it was immediately noted that there was decay damage at multiple locations at the sill beam (see **Figure 2.19** and **Figure 2.20**).

Figure 2.19: Sill beam decay visible after removal of board sheathing

Figure 2.20: Sill beam decay noted at foundation-contact portions

The damage pattern of the sill is a topic worthy of further study; the damage patterns of the removed sill beam can be used to evaluate which of the previously mentioned mechanisms were the greatest risk factors. Also, thermal simulations could be used to gauge contributions of cold temperatures at interface (i.e., the sorption isotherm issue).

Damage of the sill was sufficiently widespread to require replacement of the sill beam. This necessitated design of a replacement sill. The existing sill was an 8x8 timber, which was notched to receive floor joist tenons.

There were several reasons why replacement with a similar timber was not pursued: first, timbers of the size required would be expensive. Second, the limited availability of such timbers would impose scheduling problems. And, third, wood of such dimensions is very difficult to dry properly and is unlikely to arrive of site with an acceptable moisture content.[2]

The team determined that standard kiln-dried 2x dimension lumber provided the best option for the material of the replacement sill. The replacement beam needed to achieve similar dimensions to the existing beam in order to maintain the elevation of the house and in order to be able to support the floor joist ends. The support condition for the sill is highly variable, seldom level and also leaves the inner 2-3" of the sill overhanging the support (to the interior). The replacement of the sill also had to consider the balloon framing conditions.

Although a capillary break membrane was to be installed over the top of the foundation and the exterior wall system was to provide robust rain water protection, the sill would still need to be able to withstand high relative humidity because of the sorption isotherm behavior noted above. High relative humidity would be unavoidable at the top of the foundation wall due to the thermal conductivity of the foundation wall material and its exposure to ambient conditions. The team determined that the sill design must use a preservative pressure treated 2x plate on top of the foundation wall while regular KD lumber would suffice for the rest of the sill. The existing joists (and existing joists with added sister joists) would be supported by joist hangers attached to the sill beam. As an added measure of safety, the pressure treated bottom plate was to be separated from the joist hangers, to avoid any corrosion issues.

The builder contracted an engineer to design the sill beam with these considerations. The resulting design is as depicted in Figure 2.21 below.

[2] The closed-cell spray foam designed for interior foundation insulation system and foil-faced polyisocyanurate insulating sheathing system were designed to extend over the sill at the interior and exterior, respectively. This would have virtually eliminated any drying potential for the sill. As a provision for the option of installing a replacement timber sill, the team designed a vapor permeable interior foundation insulation system as well as an air-tight and vapor permeable detail for the lower 12' of the exterior insulation assembly. Due to the other factors that precluded the use of the heavy timber, these designs were not used.

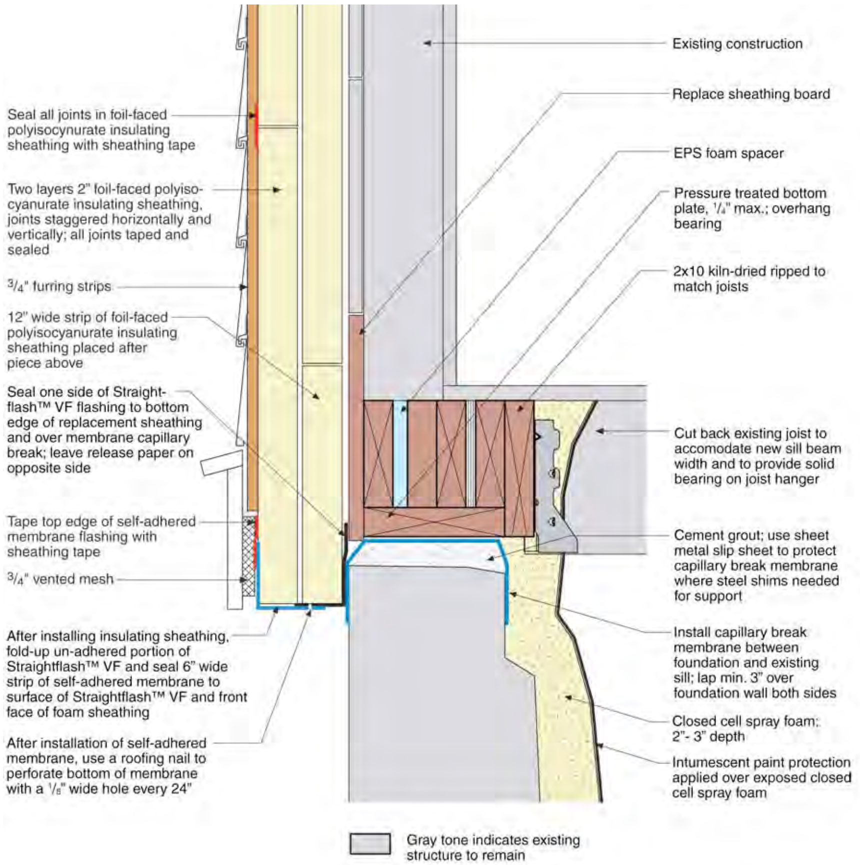


Figure 2.21: Replacement sill detail

Figure 2.22: LVL used as lifting beam for sill replacement

Figure 2.23: Toenailing of existing studs to replaceme beam

Figure 2.24: Built-up sill assembly, showing capillary break under beam

Figure 2.25: Built up sill, showing metal connector plates from sill to stud

2.3.2.5. Mechanical System Design

Table 2.6 (below) summarizes the mechanical systems used by this project.

Table 2.6: Mechanical system specifications

MECHANICAL SYSTEMS	SPECIFICATIONS
Heating	
Description -	95 AFUE furnace
Manufacturer & Model -	Goodman GMV95 0453BXB
Cooling (outdoor unit)	
Description -	None installed
Manufacturer & Model -	
Cooling (indoor unit)	
Description -	None installed
Manufacturer & Model -	
Domestic Hot Water	
Description -	0.82 EF on-demand gas water heater
Manufacturer & Model -	Rinnai R75LSi
Distribution	
Description -	R-4.2 flex duct runouts in conditioned space
Leakage -	5.8% (50 cfm @ Pa 25) leakage to outside
Ventilation	
Description -	Central Fan-Integrated Supply-only system integrated with AHU, 75 CFM 33% duty cycle; 10 minutes on; 20 minutes off
Manufacturer & Model -	Aprilaire model 8126 Ventilation Control System
Return Pathways	
Description -	Transfer grilles at bedrooms, central return

MECHANICAL SYSTEMS	SPECIFICATIONS
Dehumidification	
Description -	None installed
Manufacturer & Model -	
PV System	
Description -	None installed
Manufacturer & Model -	
Solar Hot Water	
Description -	None installed
Manufacturer & Model -	

Retrofitting ductwork into existing houses can often be difficult, especially if it is a goal to keep all ductwork within the conditioned space. However, in this house plan, it was not an exceptional challenge to accomplish this, as demonstrated on the M-1 Mechanical Plan (see "2008-11-04 Farmhouse Drawing Set.pdf"). Most of the rooms are accessible from the basement (on the first floor); therefore, the majority of the space could be fed by a basement trunk and runout system. Three registers were required on the second floor; a furred out chase in the dining room and a duct in an interior wall fed these locations. The dining room chase is also used for the outdoor air duct.

One challenge that arose during construction was the need to reconfigure the ductwork when the decision was made to proceed with a duplex design. The ductwork had been installed at this time. The main supply trunk was cut back inside of the new demising wall. One upstairs room was divided into rooms creating the need to have one branch duct take off of a branch duct. Despite this reconfiguration of the ductwork, supply at each register was within an acceptable range.

2.3.2.6. Lighting and Miscellaneous Electrical Loads

Compact fluorescent lighting and ENERGY STAR appliances represented substantial improvements in energy performance (3.2% and 3.7% respectively), for the building as a whole. The building includes an ENERGY STAR refrigerator, dishwasher, and clothes washing machine. Nearly all of the lighting is CFL.

2.3.2.7. 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 (see **Error! Reference source not found.**). The long axis is oriented east-west, giving a large second-story solar exposure roof at an 8:12 roof pitch (34 degrees, relative to 36° optimal angle, as noted in *Building America Best Practices Series, Volume 6: Solar Thermal & Photovoltaic Systems*, NREL 2007).

Figure 2.26: Original site, showing barn (red) and farmhouse (blue)

Figure 2.27: Solar Pathfinder™ representation of the relatively unobstructed exposure of the South-facing roof

Prior to framing cavity insulation and drywalling, the builder installed a metal conduit in a continuous run from the basement to the attic in order to facilitate a future PV system installation. If budget or a donation becomes available, this house would likely be the strongest candidate at the site for the addition of renewable energy sources.

2.4 Construction Support

2.4.1. Construction Overview

For some time, the project start was not assured due to financing and other concerns. Because of the uncertainty of the project, the team refrained from developing construction details for a project that might not move forward. When the project did break ground in the early fall of 2008, construction proceeded rapidly with volunteer labor eager to contribute and a technical school carpentry program eager to complete exterior work before winter.

While the progress of construction was not steady through the project, there were also changes to the project direction along the way. The renovation was initially designed as a 3 bedroom single family residence with a barrier-free-adaptable master bedroom and bath housed in a first floor additional (partly original but substantially reconstructed). During the course of construction – after finish cladding and trim was installed – it was decided that the building would be configured as a duplex. The first floor addition containing the barrier-free-adaptable bedroom and bath is to be a part of a unit that is under construction at the time of this writing. The layout of the existing farmhouse was changed to divide one of the 2nd floor bedrooms into two rooms and to increase the size of the 2nd floor bathroom. It was also decided during construction that a porch would be added at one of the entries.

It is reasonable to assume that a retrofit project situation will require more project oversight as construction and demolition inevitably reveal conditions have not been anticipated. On top of this impetus for construction support, volunteer labor and technical school student involvement bring the need for a high frequency of support visits to ensure that design stays ahead of construction and that construction follows design.

In many cases, construction proceeded ahead of design, or differently than the specific details of the design. In these cases the team consulted with the builder and revised details in order to preserve the performance objectives. The roof-wall interface detail in **Figure 2.30** shows an example of a detail created for one of these situations. **Figure 2.28** also shows a detail that was revised after construction followed a different direction than indicated on the project drawings. The revision was formulated and agreed to in a discussion with the site supervisor during a site visit. It was necessary to provide an alternative method of achieving air barrier continuity at this location, when the earlier solution was not implemented.

Figure 2.28: Step flashing applied behind intended location of drainage plane

Figure 2.29: Corrected step flashing integrated with the drainage plane

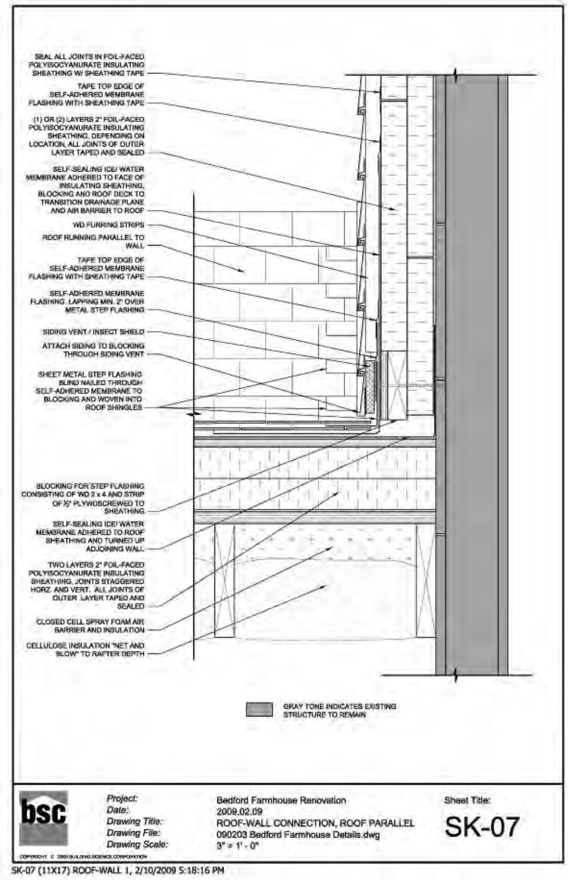


Figure 2.30: Roof-wall intersection detail drawn to guide correction of drainage plane and air barrier transition

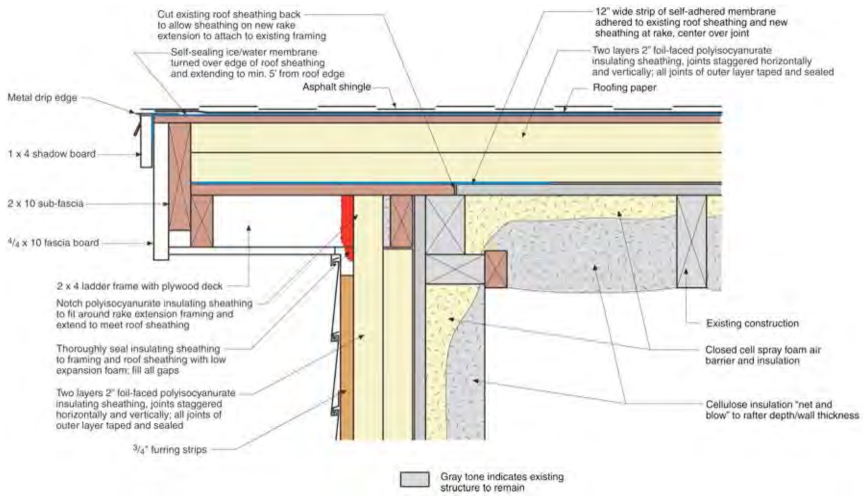


Figure 2.31: Air barrier detail at top of wall, existing roof rake

Of significant benefit to this project is the fact that the builder and site supervisor have been working with BSC on a recently completed Building America project. Many of the techniques employed in this project are familiar to the builder. For example, the builder was quite amenable to upgrading to 4" of exterior insulation due to the successful implementation of this system on the Westford House prototype. Similarly, the team did not need to convince the builder of the feasibility of the mechanical system, as identical components have been installed and are functioning well at the previous project. Still, the retrofit situation introduced unanticipated situations that required creative solutions.

In order to ensure the successful implementation of critical details, BSC was on site to provide construction guidance during initial implementation of these details. BSC conducted a demonstration (described below) of the window sequence before crews installed windows on the rest of the house. In addition to in-person site visits, BSC personnel were frequently in contact with the site supervisor and sub contractors in order to provide support.

2.4.2. Educational Events and Training

BSC conducted an on-site demonstration of the window installation for the vocational program students who were to install the remaining windows. This was deemed useful because the installation of a window in a wall assembly with thick exterior insulation is different than more typical window installation. It is also important to the performance objectives that the window be properly flashed – and it is BSC's observation that typical installation practices do not generally include proper flashing.

Figure 2.32: Carpentry program students rapt with window installation demonstration

Figure 2.33: BSC engineer demonstrating window flashing

2.4.3. Systems Testing

After the major construction had been completed but before the building was turned over to the residence, BSC scheduled a site visit to perform 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.

The total air distribution system leakage was higher than expected given the efforts to seal the ducts. The HVAC contractor installing the system had used mastic on joints and connections. As a follow up effort, duct pressurization was used to help volunteers and BSC staff locate and seal duct leakage. The system leakage measured was 285 cfm at 25 Pa The system leakage test measuring leakage to the outside found 50 cfm leakage to the outside.

BSC conducted building air tightness testing (blower door testing) on September 22nd and found that the building air tightness failed to meet the Building America target. On September 30th, several BSC staff returned to the site with testing equipment as well as air sealing supplies. BSC conducted a guarded blower door test with the room and basement area of the yet-to-be-constructed duplex unit depressurized to the same pressure as the test house. The blower door was then used to aid in locating leakage areas as well as to verify effectiveness of air sealing treatment. The end results were still below our target for new homes but deemed a significantly positive achievement for this retrofit situation.

	CFM 50 measurement	Leakage Ratio (EqLA/ 100 s.f.)	ACH 50	Notes
Initial Unguarded Test	3302	6.2	8.9	
Initial Guarded Test	2560	4.8	7.0	
Measured inter-unit leakage	507			
Process Test 1	2800			Remedial sealing of

(unguarded)				bulkhead door, crawlspace, bsmt demising
Process Test 2	2500			Eave froth pack application 1, air sealing of small attic
Final Test (unguarded)	2260	4.2	6.2	
Reduction from treatments	1042			
Estimated Final Inter-unit leakage	101-406			
Estimate Final Net Leakage	2159 - 1854	4.0 - 3.5	5.9-5.0	

2.4.4. Monitoring

The team is in negotiation with Habitat for Humanity of Greater Lowell to allow BSC to request access to utility billing data for this home.

2.5 Project Evaluation

The following sections evaluate the research project results based on the ability to integrate advanced systems with production building practices in prototype homes. References are made to the results from field tests and energy simulations, which are included as an appendix to this report.

2.5.1. Source Energy Savings

Requirement:	*Final production home designs must provide targeted whole house source energy efficiency savings based on BA performance analysis procedures and prior stage energy performance measurements.*
Conclusion:	***Fail;***

Performance analysis confirms that the projected performance of the completed home, as tested achieves projected savings of 35% relative to Building America Benchmark. Principal energy savings strategies include:

- ***Super insulated enclosure*** – achieved by compact roof assembly with R-26 polyisocyanurate insulation on the roof deck in combination with framing cavity insulation, thick insulating sheathing on the walls in combination with cellulose framing cavity insulation, continuous spray foam insulation of foundation walls, as well as strategic spray foam insulation at locations where batt or cellulose insulation would not provide desired performance.

- ***Low-e windows*** – Double glazed vinyl frame windows with a U-value of 0.31 and SHGC of 0.32.

- ***High performance heating system*** – High efficiency sealed-combustion condensing furnace with variable speed blower.

- ***High efficiency, sealed combustion on-demand water heater –*** Propane water heater at 0.86 EF. .

- ***CFL lighting***
- ***Full ENERGY STAR appliance package***

Despite of these measures, the project did not achieve the target savings relative to the Building America benchmark.

2.5.2. Prescriptive-based Code Approval

Requirement:	*Must meet prescriptive or performance safety, health and building code requirements for new homes.*
Conclusion:	***Pass***

All modifications to the home met prescriptive code requirements. Some elements, e.g. a basement access stair, could not be made to meet current code requirements and so were left unaltered.

2.5.3. Quality Control Requirements

Requirement:	*Must define critical design details, construction practices, training, quality assurance, and quality control practices required to successfully implement new systems with production builders and contractors.*
Conclusion:	***Pass***

The BSC team encountered many critical performance details on this project that required specific design and construction solutions. Because of the variety of construction methods encountered in retrofit projects it would not be practical to develop standard details able to anticipate every situation. However, BSC was able to identify several commonly recurring situations and has developed details or construction sequences to address these.

The Farmhouse Retrofit participated in a LEED-for Homes certification program. This entailed many inspections and verifications of energy performance and durability features.

2.5.4. Neutral Cost Target

Requirement:	*The incremental annual cost of energy improvements, when financed as part of a 30 year mortgage, should be less than or equal to the annual reduction in utility bill costs relative to the BA Benchmark.*
Conclusion:	***Pass***

Relative to the previously existing conditions at this home, the completed retrofit is expected to offer substantial energy cost savings. The costs of the energy performance measures on this project are particularly difficult to estimate due to the preponderance of volunteer and student labor. If the project were to capitalize the market rate costs for all measures related to the Building America performance goals it is expected that the financing cost for this investment would be less than the energy cost savings.

2.5.5. Quality Control Integration

Requirement:	*Health, Safety, Durability, Comfort, and Energy related QA, QC, training, and commissioning requirements should be integrated within construction documents,*

	contracts and BA team scopes of work.
Conclusion:	***Pass***

Window details demonstrated for this project have been included in construction documents for the duplex unit to be constructed adjacent and connected to the farmhouse retrofit.

It is expected that future HfHGL projects will participate in ENERGY STAR Homes certification programs. It is possible that HfHGL may also continue participation in the LEED for Homes program. Both of these would entail on-site quality control inspections to supplement the builder's quality control practices.

2.5.6. Gaps Analysis

Requirement:	*Should include prototype house gaps analysis, lessons learned, and evaluation of major technical and market barriers to achieving the targeted performance level.*
Conclusion:	***Pass***

Conditions encountered in retrofit projects are bound to be more variable than conditions in new construction. Within a particular locality construction practices will tend to vary by period. Many existing buildings have been constructed before the unifying effects of building codes moderated the variations between individual builders. Because of this it will be difficult to generate a set of retrofit solutions that are applicable to a broad cross section of buildings.

Work on this prototype retrofit project has revealed some lessons that are expected to be generally applicable to high-performance retrofit projects. These relate to:

- Execution of drainage plane at the face of exterior insulating sheathing
- Implementation of air barrier at the face of exterior sheathing
- Integration of vinyl components
- Thermal protection for foundation wall insulation

Drainage Plane at Face of Insulating Sheathing – Coordination of water management and flashing with the insulating sheathing proved a challenge in this project. Many of the difficulties encountered results from the fact that implementation of the drainage plane at the exterior face of insulating sheathing, presents sequencing needs that are different from conventional construction. It is also clear that conventional construction practices may not include water management and flashing practices that are adequately robust for high performance construction. BSC has developed several details to address common flashing situations and to demonstrate how these are implemented with exterior insulating sheathing applied in a retrofit situation. These details must be included in drawing sets before these are reviewed for bidding by contractors. It is also apparent that the location of the drainage plane must be thoroughly explained and understood be all involved before the construction commenced.

Air Barrier at Face of Insulating Sheathing – The wall air barrier approach initially envisioned for this project involved a house wrap applied over the existing sheathing and connected to other components of the air barrer system. Initial plans for the retrofit called for the existing interior plaster wall finishes to remain in place. After existing cladding was removed from the walls to expose the wall sheathing boards, house wrap was applied to the walls. As construction progressed this housewrap became badly torn. The decision to implement the air barrier of the wall assembly at the exterior face of the insulating sheathing rather than to attempt to repair or re-apply the house wrap.

As construction progressed, it became apparent that successful implementation of the exterior insulating sheathing as an air barrier was very much dependent upon workmanship. Without attention to maintaining very tight joints in the insulating sheathing, gaps between the sheathing panels create air flow pathways. This proved a particularly serious compromised the performance of the air barrier at transitions between the wall and other assemblies.

On current and future retrofit projects, BSC will research techniques that establish the primary building air barrier at the face of the existing exterior wall sheathing.

Integration of Vinyl Finish System Components – Habitat for Humanity of Greater Lowell opted to use vinyl siding on this retrofit project. The standard components of a vinyl siding, window and trim systems are generally not designed to be installed over furring strips. The vinyl frame windows with an integrated channel to receive siding panels, for example, can not readily receive the siding panels when the siding is installed over furring strips. Furring strips are generally considered to be necessary for cladding attachment over thick exterior insulation although it is possible to directly attach vinyl siding through thick exterior insulation.

Where vinyl exterior finish systems are used in conjunction with furring strips, it is advisable not to use windows with an integrated siding channel.

Thermal Protection for Foundation Insulation – Closed-cell spray foam insulation is regarded by the team as the most practical and effective foundation wall insulation solution where a foundation wall is irregular such as it would be with rubble stone foundations. This is a common foundation type in older homes. While the closed-cell spray foam has definite advantages in its ability to conform to the irregular wall, provide control of bulk water and water vapor, provide an effective air barrier, and provide the thermal performance needed, there is a disadvantage in that a spray-polyurethane insulation will typically require an ignition barrier if left exposed. The typical options for an ignition barrier are:

1. Construct a frame wall and attach gypsum wall board, or

2. Apply an intumescent ignition barrier paint.

The frame wall option represents a considerable expense in both labor and materials. The intumescent paints approved for application as an ignition barrier over polyurethane foam can cost upwards of $0.50/s.f. for the material alone. The ignition barrier requirement adds significantly to the cost of foundation insulation. Improvements in the cost and availability of intumescent coatings appears the most likely path to reduce this associated cost burden of foundation insulation.

2.6 Conclusions/Remarks

Successful retrofit of an existing structure – particularly one that has been in service for many years – requires an understanding of the mechanisms that allowed that structure to perform. The workings of these mechanisms – of wetting and drying, of energy transfer, etc. – are undoubtedly changed in a high performance retrofit. Therefore the successful retrofit plan must also be aware of how the retrofit measures change conditions of drying, wetting and energy flows for the structure. The changes to the building must not put the structure in a condition that is in anyway worse than it had been prior to the retrofit (*primum non nocere*).

The complexity of systems and mechanisms acting on a building would suggest the need for considerable application of expertise to each retrofit project. The reliance on this application of expertise would limit the scalability of high performance retrofits.

It is the hope of this Building America team, that continued research into and application of high performance retrofit technique will lead to a body of standard retrofit practices that, in combination with generally acceptable levels of workmanship and good construction practices, will yield replicable high performance retrofits.

2.7 Appendices

2.7.1. Drawings and Specifications

2.7.2. Mechanical System Design

2.7.3. Example Site Visit Report

2.7.4. Complete SK Set

2.7.5. Project Guidance Memoranda

2.7.6. Observations from In-Process Air Barrier

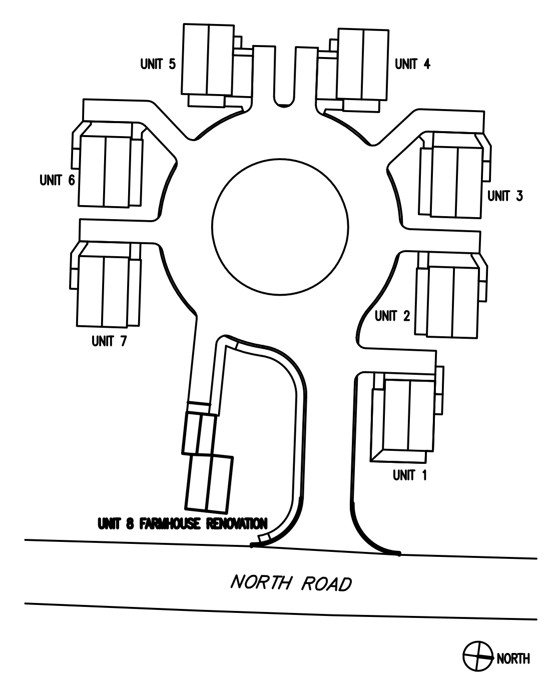
Appendix D.2.7.1
Drawings and Specifications

HABITAT FOR HUMANITY of GREATER LOWELL

130 North Road, Bedford, MA

FARMHOUSE RENOVATION

DRAWING LIST



4 NOVEMBER 2008

BUILDING SCIENCE CORPORATION
30 FOREST STREET SOMERVILLE, MASSACHUSETTS 02143
P: 978-589-5100 F: 978-589-5103

REVISED SET 10/20/2008
REVISED WINDOW DETAILS 10/21/2008
REVISED MECHANICAL, LAUNDRY RM AND SILL DETAILS 10/28/2008
REVISED DETAILS AND NEW DETAILS 11/4/2008

BUILDING SCIENCE CORPORATION

HABITAT FOR HUMANITY
FARMHOUSE RENOVATION
130 NORTH RD, BEDFORD

TITLE SHEET
SCALE AS NOTED

A-0

GENERAL REQUIREMENTS

1. ALL WORK SHALL COMPLY WITH FEDERAL, STATE AND LOCAL BUILDING CODES AND REGULATIONS.

2. MECHANICAL, ELECTRICAL AND PLUMBING WORK REQUIRED OF THIS PERMIT APPLICATION TO BE PERFORMED BY SUBCONTRACTOR LICENSED IN THE STATE IN WHICH WORK IS BEING PERFORMED.

3. SUBCONTRACTOR SHALL PROVIDE CERTIFICATION OF GENERAL LIABILITY INSURANCE AND WORKMAN'S COMPENSATION COVERAGE, AS REQUIRED BY THE GENERAL CONTRACTOR.

4. CONTRACTOR SHALL COORDINATE AND/OR OBTAIN ALL BUILDING PERMITS REQUIRED FOR CONSTRUCTION AND CERTIFICATES OF OCCUPANCY.

5. CONTRACTOR SHALL BE SOLELY RESPONSIBLE FOR ALL CONSTRUCTION MEANS, METHODS, TECHNIQUES, AND PROCEDURES.

6. CONTRACTOR SHALL BE RESPONSIBLE FOR ALL ASPECTS OF SAFETY DURING BUILDING CONSTRUCTION AND SHALL PROVIDE ADEQUATE SHORING AND BRACING TO ENSURE SUCH SAFETY.

7. ALL DIMENSIONS AND SITE CONDITIONS TO BE FIELD VERIFIED AND SHALL BE THE RESPONSIBILITY OF THE CONTRACTOR. NOTIFY BUILDING SCIENCE CORPORATION OF AN DISCREPANCY PRIOR TO COMMENCEMENT OF WORK.

8. IT SHALL BE THE RESPONSIBILITY OF THE CONTRACTOR TO LOCATE ALL EXISTING UTILITIES WHETHER INDICATED ON PLANS OR NOT, AND TO PROTECT THEM FROM DAMAGE.

9. ALL DETAILS, SECTIONS, NOTES, OR REFERENCE TO OTHER DRAWINGS ARE INTENDED TO BE TYPICAL.

10. DURING CONSTRUCTION, AND PRIOR TO THE INCORPORATION OF ANY CHANGES, REVISIONS, MODIFICATIONS AND/OR DEVIATIONS FROM THE CONSTRUCTION DOCUMENTS, CONTRACTOR SHALL BRING TO THE ATTENTION OF BUILDING SCIENCE CORPORATION AND OBTAIN APPROVAL FROM THE GOVERNING BUILDING OFFICIAL BEFORE PROCEEDING WITH THE WORK.

11. THE MANUFACTURERS, PRODUCTS AND EQUIPMENT LISTED ESTABLISH PERFORMANCE REQUIREMENTS. SUBSTITUTIONS OF EQUAL PERFORMANCE MAY BE SUBMITTED FOR BUILDING SCIENCE CORPORATION'S APPROVAL.

12. ALL MATERIALS SHALL BE INSTALLED PER MANUFACTURER'S INSTRUCTIONS/SPECIFICATIONS UNLESS OTHERWISE SPECIFIED BY BUILDING SCIENCE CORPORATION.

13. SPECIFIC NOTES AND DETAILS ON DRAWINGS SHALL TAKE PRECEDENCE OVER GENERAL NOTES AND TYPICAL DETAILS. WHERE NO DETAILS ARE SHOWN, CONSTRUCTION SHALL CONFORM TO SIMILAR WORK ON THE PROJECT.

BUILDING AMERICA PERFORMANCE CRITERIA

REQUIREMENTS: DESIGN

RESIDENCES MUST REDUCE WHOLE HOUSE ENERGY USE (HVAC, HOT WATER, LIGHTING, AND ALL APPLIANCES/PLUG LOADS) AS STIPULATED IN THE TABLE BELOW:

PROJECT TYPE	PERCENT REDUCTION	ENERGY STAR INDEX
SINGLE HOMES	40%	60–65
COMMUNITIES	30%	70–75

WHOLE-HOUSE DILUTION VENTILATION: A MECHANICAL VENTILATION SYSTEM MUST BE INSTALLED TO BE CAPABLE OF MEETING ASHRAE STANDARD 62.2 WHICH STIPULATES A VENTILATION RATE OF 7.5 CFM PER PERSON (COUNTED AS THE NUMBER OF BEDROOMS PLUS ONE) PLUS 0.01 CFM PER SQUARE FOOT OF FLOOR AREA. WHILE 62.2 STIPULATES THAT OPERATION OF THE VENTILATION SYSTEM IS AT THE OCCUPANT'S DISCRETION AND THE STANDARD IS SILENT REGARDING WHOLE HOUSE DISTRIBUTION OF VENTILATION AIR, THIS PERFORMANCE CRITERIA STIPULATES THAT THE 62.2 VENTILATION FLOW RATE BE DELIVERED AT LEAST ONE-THIRD OF THE TIME AND THAT WHOLE HOUSE DISTRIBUTION IS REQUIRED.

LOCAL EXHAUST VENTILATION: INTERMITTENT SPOT EXHAUST OF 100 CFM MUST BE PROVIDED FOR EACH KITCHEN (RECIRCULATING COOKTOP HOODS ARE NOT PERMITTED). INTERMITTENT SPOT EXHAUST OF 50 CFM OR CONTINUOUS EXHAUST OF 20 CFM WHEN THE BUILDING IS OCCUPIED MUST BE PROVIDED FOR EACH ROOM HAVING A TOILET, BATH, OR SHOWER.

VENTILATION INTAKE LOCATIONS: WHEN A SUPPLY-ONLY OR BALANCED VENTILATION SYSTEM IS USED, THE INTAKE MUST GO THROUGH AN OUTSIDE WALL AND NOT THE ROOF (DUE TO PROXIMITY TO EXHAUST/VENT POLLUTANTS, AND HEATED AIR/VOC'S/ODORS FROM THE ROOF). WALL INTAKES SHOULD BE LOCATED AT LEAST 10 FEET FROM, AND NOT DIRECTLY ABOVE, ANY WALL EXHAUST OR VENT.

ALL COMBUSTION APPLIANCES (EXCEPT A GAS STOVE, COOKTOP OR OVEN) IN THE CONDITIONED SPACE MUST BE SEALED COMBUSTION. SPECIFICALLY, ANY FURNACE INSIDE CONDITIONED SPACE MUST BE A SEALED-COMBUSTION 90%+ AFUE UNIT. ANY WATER HEATER INSIDE CONDITIONED SPACE MUST BE DIRECT-POWER-VENTED. ANY BOILER INSIDE A CONDITIONED SPACE MUST BE SEALED COMBUSTION.

WINDOWS WITH THE FOLLOWING CLIMATE-SPECIFIC PERFORMANCE VALUES MUST BE USED:

CLIMATE ZONE	MAXIMUM U-VALUE	MAXIMUM SHGC
ZONES 1–3	0.40	0.35
ZONES 4–8	0.35	0.40

ALL DUCTS AND AIR HANDLING EQUIPMENT MUST BE IN THE CONDITIONED SPACE.

MAJOR APPLIANCES (REFRIGERATOR, CLOTHES WASHER, AND DISHWASHER) MUST ACHIEVE ENERGY STAR PERFORMANCE IN THE TOP ONE-THIRD OF THE DOE ENERGY GUIDE RATING SCALE.

ALL LIGHTING MUST BE ENERGY STAR QUALIFIED WITH THE FOLLOWING EXCEPTIONS: MOTION-SENSITIVE OUTDOOR SPOTLIGHTS AND SOLAR-POWERED ACCENT AND PATHWAY LIGHTING. LED TECHNOLOGY IS CURRENTLY NOT CERTIFIED BY ENERGY STAR. HOWEVER, LEDS ARE ACCEPTABLE.

CARBON MONOXIDE DETECTORS (HARD WIRED UNITS) MUST BE INSTALLED (AT ONE PER EVERY APPROXIMATE 1000 SQUARE FEET) IN ANY HOUSE CONTAINING COMBUSTION APPLIANCES OR AN ATTACHED GARAGE.

REQUIREMENTS: TESTING

BUILDING AMERICA TESTING OF THE HOUSE MUST BE COMPLETED AS PART OF THE COMMISSIONING PROCESS.

IN A PRODUCTION SETTING, EACH MODEL TYPE (I.e., FLOOR PLAN) MUST BE TESTED UNTIL TWO CONSECUTIVE HOUSES OF THIS MODEL TYPE MEET TESTING REQUIREMENTS. ADDITIONALLY, TESTING OF THIS MODEL TYPE CAN BE REDUCED TO A SAMPLING RATE OF 1 IN 7 (I.e., 1 TEST, WITH 6 "REFERENCED" HOUSES). SMALL ADDITIONS TO A FLOOR PLAN (e.g., BAY WINDOW, CONVERSION OF DEN TO BEDROOM) ARE CONSIDERED TO BE THE SAME MODEL TYPE; MAJOR CHANGES (e.g., BONUS ROOM OVER THE GARAGE, CONVERSION OF GARAGE INTO A HOBBY ROOM, ETC.) MUST BE CONSIDERED A SEPARATE MODEL TYPE. UNIQUE OR CUSTOM HOUSE PLANS MUST BE INDIVIDUALLY TESTED.

AIR LEAKAGE (DETERMINED BY PRESSURIZATION TESTING) MUST BE LESS THAN 2.5 SQUARE INCHES/100 SQUARE FEET SURFACE AREA LEAKAGE RATIO (CGSB, CALCULATED AT A 10 PA PRESSURE DIFFERENTIAL); OR 1.25 SQUARE INCHES/100 SQUARE FEET LEAKAGE RATIO (ASTM, CALCULATED AT A 4 PA PRESSURE DIFFERENTIAL); OR 0.25 CFM/SQUARE FOOT OF BUILDING ENCLOSURE SURFACE AREA AT A 50 PASCAL AIR PRESSURE DIFFERENTIAL. THE CALCULATION OF THE BUILDING ENCLOSURE AREA INCLUDES THE FOUNDATION OR BELOW GRADE SURFACE AREAS. IF THE HOUSE IS DIVIDED INTO MULTIPLE CONDITIONED ZONES, SUCH AS CONDITIONED ATTICS OR CONDITIONED CRAWL SPACE, THE BLOWER DOOR REQUIREMENT MUST BE MET WITH THE ACCESS TO THE SPACE OPEN, CONNECTING THE ZONES.

TOTAL SPACE CONDITIONING SYSTEM DUCT LEAKAGE MUST BE LESS THAN FIVE PERCENT OF THE TOTAL AIR HANDLING SYSTEM RATED AIR FLOW AT HIGH SPEED (NOMINAL 400 CFM PER TON) DETERMINED BY PRESSURIZATION TESTING AT 25 PA. TWO COMPLIANCE MECHANISMS ARE ACCEPTABLE: (1) TEST TOTAL DUCT LEAKAGE AT FINISH STAGE, OR (2) TEST TOTAL DUCT LEAKAGE AT DUCT ROUGH-IN STAGE. WHEN MORE THAN ONE AIR HANDLER EXISTS, EACH AIR HANDLING SYSTEM MUST INDIVIDUALLY MEET THE REQUIREMENT. IF ZONING IS USED, ALL ZONE DAMPERS MUST BE OPEN. MANUAL OR MOTORIZED OUTSIDE AIR VENTILATION DAMPERS MUST BE CLOSED.

LOCAL AND WHOLE-HOUSE MECHANICAL VENTILATION SYSTEM AIRFLOWS MUST BE TESTED DURING COMMISSIONING OF THE BUILDING.

FORCED AIR SYSTEMS THAT DISTRIBUTE AIR FOR HEATING MUST BE DESIGNED TO PROVIDE BALANCED AIRFLOW TO ALL CONDITIONED SPACES AND ZONES (BEDROOMS, HALLWAYS, BASEMENTS). BALANCED AIRFLOW IS DEFINED AS A SYSTEM THAT CONTROLS INTER-ZONAL AIR PRESSURE DIFFERENCES WHEN DOORS ARE CLOSED TO LESS THAN 3 PA USING PASSIVE TRANSFER GRILLES, JUMP DUCTS, DOOR UNDERCUTS OR ACTIVE RETURN DUCTS OR ANY COMBINATION THEREOF.

SYSTEM EXTERNAL STATIC PRESSURE MUST BE WITHIN MANUFACTURERS SPECIFICATIONS (0.5 WIC/125 PA MAXIMUM TYPICAL).

GENERAL CONSTRUCTION NOTES

CIVIL NOTES:

DEBRIS – REMOVE DEBRIS WITHIN 2'-0" OF BUILDING.

EXTERIOR GRADE – SLOPE GRADE 5% TO DRAIN AWAY FROM BUILDING.

SOIL GAS CONTROL – ALL WALLS, ROOF AND FLOORS IN CONTACT WITH THE GROUND SHALL BE CONSTRUCTED TO RESIST THE LEAKAGE OF SOIL GAS FROM THE GROUND TO THE BUILDING. A PASSIVE SUB-SLAB DEPRESSURIZATION SYSTEM IN ACCORDANCE WITH THE SUPPLEMENTARY GUIDELINES SHALL BE PROVIDED, 1 VENT PIPE, MIN. 3" DIAMETER, PER 1500 SF OF SLAB AREA. VENT STRAIGHT UP THRU ROOF.

STRUCTURAL NOTES:

CONCRETE – ALL CONCRETE TO HAVE A WATER/CEMENT RATIO OF LESS THAN 0.5 AND 10% FLY ASH PORTLAND CEMENT REPLACEMENT.

FOOTINGS – ALL FOOTINGS SHALL REST ON NATIVE, UNDISTURBED SOIL AND WILL BE A MIN. OF 48" BELOW FINISHED GRADE OR IN ACCORDANCE WITH LOCAL BUILDING CODE. APPLY LIQUID APPLIED CAPILLARY BREAK (MUST DRY TACK FREE) ON TOP OF FOOTING PRIOR TO PLACING/CASTING CONCRETE FOUNDATION WALL.

STEP FOOTINGS – HORIZONTAL STEP = 24" MAX.
– VERTICAL STEP = 24" MAX.

FOUNDATION WALLS – 8" WIDE CONCRETE WALL WITH 2 1/2" DEEP VERTICAL SAW-CUT CONTROL JOINTS ON INTERIOR FACE OF WALL. LOCATE JOINTS 18" FROM EVERY CORNER AND 20' MAX. ALONG LENGTH OF WALL SEGMENT.

DRAIN TILE – 4" DIA. PIPE, 3/4" CRUSHED STONE (NO FINES), 6" MIN. PIPE COVER. LOCATE 4" DIA. DRAIN TILE CONNECTION PIPE THROUGH BASE OF FOOTING WITHIN 5' OF EVERY CORNER AND EVERY 15' MAX. ALONG LENGTH OF WALL SEGMENT WITH MIN. 1 PER WALL SEGMENT.

CRAWLSPACE FLOOR – 6 mil POLYETHYLENE SHEET ON 6" CLEAN CRUSHED STONE PAD.

CRAWLSPACE WALL – 8", 2200 P.S.I. POURED CONCRETE W/ BITUMINOUS DAMPPROOFING.
– FILL AND SEAL ALL TIE HOLES.
– TOP OF FOUNDATION WALL TO BE 8" MIN. ABOVE FINISHED GRADE.

SILL PLATE – 2x6 TREATED SILL PLATE WITH 1/2" DIA. ANCHOR BOLTS 12" LONG, SET MIN. 4" INTO CONCRETE AND SPACED AT 6' O.C MAX. PROVIDE CAPILLARY BREAK BETWEEN SILL PLATE AND CONCRETE, 6 mil POLY OR EQUAL.

ANCHOR BOLTS – PROVIDE 1/2" DIA. ANCHOR BOLTS 12" LONG, SET MIN. 4" INTO CONCRETE SPACED AT 6' O.C. MAX. TWO BOLTS MIN. PER PLATE SECTION WITH ONE BOLT LOCATED NOT MORE THAN 12" OR LESS THAN SEVEN BOLT DIAMETERS FROM EACH END OF THE PLATE SECTION.

BEARING STUD PARTITION – 2x6 STUDS AT 24" O.C.

STEEL COLUMN – 3" DIA. HSS ON 3'-0" x 3'-0" x 12" CONCRETE PAD W/ (4) #5 REBAR EACH WAY.

CONCRETE SLAB – 4" CONCRETE SLAB WITH SAW-CUT CONTROL JOINTS SPACED AT 20' MAX. AND SAW-CUT COLUMN ISOLATION JOINTS.

PORCH SLAB – 4" CONC. SLAB – 4650 P.S.I. @ 28 DAYS, 5–8% AIR ENTRAINMENT ON COMPACTED CRUSHED STONE. SLOPE SLAB 1" MIN. AWAY FROM HOUSE.

GARAGE SLAB – 4" CONC. SLAB ON COMPACTED CRUSHED STONE WITH FIBERMESH REINFORCING – 4650 P.S.I. @ 28 DAYS, 5–8% AIR ENTRAINMENT, SLOPE SLAB 3" MIN TO FRONT.

BEAMS AND LINTELS – SUPPORT FULL WIDTH TO FOUNDATION.

ARCHITECTURAL NOTES:

EAVESTROUGH – ALUMINUM EAVESTROUGH ON 2x6 WOOD FASCIA BOARD.

DRIP EDGE – PROVIDE 1" DRIP EDGE ON FLASHING OVER OPENINGS IN EXTERIOR WALLS.

ATTIC ACCESS – OPENING 20" x 28" MIN. WITH WEATHERSTRIPPING AND INSULATION.

WOOD PROTECTION – WOOD FRAMING MEMBERS THAT ARE NOT PRESSURE TREATED WITH A WOOD PRESERVATIVE AND WHICH ARE SUPPORTED ON CONCRETE IN CONTACT WITH THE GROUND SHALL BE SEPARATED FROM THE CONCRETE BY AT LEAST 6 mil POLY FILM OR EQUAL.

STAIR DIMENSIONS (ALL INT. AND EXT. STAIRS – REFER TO DRAWINGS FOR ACTUAL STAIR DIM.)
- MIN. RISE – 5"
- MAX. RISE – 8 1/4"
- MIN. RUN – 8 1/4"
- MAX. RUN – 1'-1 7/8"
- MIN. TREAD – 10"
- MAX. TREAD – 1'-1 7/8"
- MAX. NOSING – 1"
- MIN. HEADROOM – 6'-6"
- MIN. WIDTH – 2'-10"

HANDRAILS AND GUARDS
- MIN. HEIGHT – 2'-10" (HANDRAILS), 3'-0" (GUARDS)
- MAX. HEIGHT – 3'-2" (HANDRAILS)
- A CLEARANCE OF NOT LESS THAN 1 1/2" SHALL BE PROVIDED BETWEEN HANDRAIL AND ANY SURFACE BEHIND IT.

BEDROOM EGRESS – MIN. ONE WINDOW PER BEDROOM SHALL HAVE A MIN. NET CLEAR OPENING OF 5.7 SF, A MIN. NET CLEAR OPENING HEIGHT OF 20", A MIN. NET CLEAR OPENING WIDTH OF 24", AND A SILL HEIGHT OF NOT MORE THAN 44" FROM THE FLOOR UNLESS OTHERWISE SPECIFIED IN WINDOW SPECIFICATION (NOT APPLICABLE IF THERE IS A DOOR W/ DIRECT ACCESS TO THE EXTERIOR ON THAT LEVEL).

INTERIOR DOORS – UNDERCUT ALL DOORS 3/4" MIN.

COAT CLOSETS – (1) ROD AND (1) SHELF MIN.

LINEN CLOSETS – (4) SHELVES MIN. AND 1'-2" DEEP MIN.

MINIMUM HEADROOM – 6'-5" BELOW ALL BEAMS AND DUCTS.

ACCESS HATCH – PLYWOOD WITH AIR SEAL GASKET AND LATCH.

MECHANICAL, ELECTRICAL, AND PLUMBING NOTES:

EXHAUST FANS – VENT TO EXTERIOR.

RANGE HOODS – VENT TO EXTERIOR W/ NON-COMBUSTIBLE DUCT.

DRYER VENT – CAPPED AND SCREENED DRYER VENT, DUCTING INSTALLED TO SLOPE TO EXTERIOR.

SMOKE DETECTORS – LOCATE ON EACH FLOOR LEVEL AND INTERCONNECT.

CARBON MONOXIDE DETECTORS – LOCATE (1) IN EACH BEDROOM.

CONSTRUCTION ASSEMBLIES

CONSTRUCTION SHALL CONFORM TO BUILDING AMERICA SPECIFICATIONS (UNITED STATES DEPARTMENT OF ENERGY) AND ASSEMBLIES AS LISTED BELOW:

FOUNDATION WALLS – FOUNDATION WILL BE A CONDITIONED BASEMENT. EXISTING BASEMENT WALLS ARE FIELDSTONE. EXISTING BASEMENT WALL WILL BE COVERED WITH FULLY ADHERED ICE AND WATER SHIELD. 2" OF HIGH DENSITY TWO COMPONENT SPRAY FOAM WILL BE INSTALLED ON THE EXISTING BASEMENT WALL OVER THE ICE AND WATER SHIELD. NEW BASEMENT WALLS WILL BE CAST-IN-PLACE CONCRETE W/ 2" OF HIGH DENSITY TWO COMPONENT SPRAY FOAM INSTALLED OVER THE CONCRETE WALL. 1 5/8" STEEL STUDS WILL BE SHEATHED WITH PAPERLESS DRYWALL WALL RATED TO BE EXPOSED FOR FLAME SPREAD AND SMOKE DEVELOPED.

BASEMENT FLOOR – EXISTING SLAB FLOOR TO BE COVERED WITH 4" OF 3/4" CRUSHED GRAVEL. 2" EXTRUDED POLYSTYRENE TO BE INSTALLED OVER THE GRAVEL BED. 6 MIL POLYETHYLENE VAPOR BARRIER BARRIER TO BE INSTALLED OVER XPS. A VERTICAL 6" SECTION OF 2" WIDE XPS TO BE INSTALLED 8" IN FROM IN FROM INSIDE FACE OF BASEMENT WALLFLOOR AT PERIMETER – SEE BUILDING SECTIONS 1 AND 2 ON SHEET A-11. INTERIOR PERIMETER DRAIN TO BE INSTALLED IN BOTH EXISTING AND NEW BASEMENT WALL SECTION AND WILL BE CONNECTED TO NEW SUMP PUMP.

FRAME WALL CONSTRUCTION – EXISTING 2X4 FRAMED WALL CAVITY TO BE INSULATED WITH BLOWN IN CELLULOSE THROUGH EXISTING WALL BOARD SHEATHING. NEW EXTERIOR WALLS SHALL BE FRAMED WITH 2X6 STUDS AT 24" O.C., STAGGER TOP AND BOTTOM PLATE SPLICES. CAVITY SHALL BE INSULATED WITH CELLULOSE TO R-19. ALL EXTERIOR WALLS SHALL BE SHEATHED WITH 2" RIGID FOIL-FACED POLYSOCYANURATE SHEATHING (R-13). 1/2" OSB OR PLYWOOD AND 1.5" RIGID FOIL-FACED POLYISOCYANURATE SHEATHING SHALL BE INSTALLED AT THE CORNERS. USE BUILDER'S SHEATHING TAPE AT HORIZONTAL AND VERTICAL JOINTS AND CORNERS (DOW WEATHERMATE CONSTRUCTION TAPE OR EQUAL) AT EXTERIOR FACE OF SHEATHING. 1x3 WOOD FURRING SHALL BE APPLIED ON TOP OF INSULATING SHEATHING AND BELOW CLADDING.

ROOF CONSTRUCTION – EXISTING ROOF SHALL BE UNVENTED WITH 6" NETTED BLOWN CELLULOSE AT ROOF DECK. 15# FELT SHALL BE INSTALLED BETWEEN THE WALL TOP PLATE AND THE ADJACENT ROOF SHEATHING. HIGH DENSITY TWO COMPONENT SPRAY FOAM WILL BE INSTALLED OVER THE FELT TO PROVIDE AN AIR BARRIER AT THE ROOF PERIMETER. EXISTING ROOF ASSEMBLY SHALL BE SHEATHED WITH TWO (2) LAYERS 2" FOIL-FACED POLYISOCYANURATE (R-26). 1/2" OSB OR PLYWOOD SHEATHING TO BE INSTALLED BOTH ABOVE AND BELOW RIGID FOAM INSULATION. FIRST FLOOR ROOF SHALL BE VENTED WITH R-36 BLOWN CELLULOSE INSTALLED AT THE CEILING PLANE. A FULLY ADHERED WATERPROOFING MEMBRANE SHALL BE INSTALLED AT THE ROOF PERIMETER. MEMBRANE SHALL EXTEND FROM THE EDGE OF THE ROOF TO 5' IN HORIZONTALLY FROM THE EXTERIOR WALL FACE. 15# FELT UNDERLAYMENT SHALL BE INSTALLED OVER THE UPPER 1/2" OSB. COMPOSITION SHINGLES SHALL BE INSTALLED OVER THE 15# FELT UNDERLAYMENT.

DOOR SPECIFICATION

A. EXTERIOR ENTRY DOORS:
1. INSULATED STEEL AND WEATHERSTRIPPED
2. OPEN FROM INSIDE WITHOUT KEY
3. PROVIDE VIEWER UNLESS TRANSPARENT GLASS IS PROVIDED IN DOOR OR SIDELITE

B. INTERIOR DOORS:
1. HOLLOW CORE

NEW DOOR SCHEDULE

SIZE	TYPE	QUANTITY
3068	EXTERIOR	3
3068	INTERIOR	4
2668	INTERIOR	3
4068	INTERIOR BIFOLD	1

WINDOW SPECIFICATION

ALL WINDOWS SHALL BE SPECTRALLY SELECTIVE LOW-E DOUBLE GLAZED WOOD FRAMED WITH THE FOLLOWING PERFORMANCE VALUES FROM THE NATIONAL FENESTRATION RATING COUNCIL (NFRC):

CLIMATE ZONE 5:
U-VALUE = 0.33 OR LESS
SOLAR HEAT GAIN COEFFICIENT (SHGC) = 0.30 OR LESS

1. CONFIRM R.O. SIZES WITH WINDOW MANUFACTURER AND ADJUST WALL FRAMING ACCORDINGLY.

2. REPLACEMENT WINDOWS SHALL BE SIZED ACCORDING TO THE EXISTING R.O. SIZE.

3. 21046 DOUBLE HUNG WINDOWS MUST MEET MA BUILDING CODE (780 CMR) SECTION 5310 REQUIREMENTS FOR EMERGENCY ESCAPE AND RESCUE OPENINGS.

NEW WINDOW SCHEDULE

SIZE	TYPE	QUANTITY
21046	DOUBLE HUNG	6
210210	DOUBLE HUNG	3

PRODUCT SPECIFICATION

	Product Type	Specified Product
A	Adhesive	
	Construction Adhesive	Polyseamseal All Purpose Adhesive Caulk, PL 200® Construction Adhesive or Equal
	Foam-Compatible Construction Adhesive	Liquid Nails Foamboard & Projects Adhesive (LN-604), PL 300® Foam Board Adhesive or Equal
B	Backer Board	
	Cement Backer Board	USG Durock, WonderBoard Cement Backerboard or Equal
	Fiber Cement Backer Board	James Hardie HardieBacker Cement Board or Equal
C	Capillary Break (Footing-Liquid Applied)	W.R. Meadows SEALMASTIC Emulsion-Type or Solvent-Type Dampproofing or Equal
	Capillary Break (Sill)	
	Polyethylene	6 mil Polyethylene or Equal
	Foam	Dow Styrofoam Sill Seal, Owens Corning FoamSealR or Equal
	Cellulose Insulation (Borate-Treated Product Only)	
	Damp Sprayed	US GreenFiber INS735 Cocoon2 Stabilized Borate Formula-30 lbs. or Equal
	Loose Blown	US GreenFiber INS735 Cocoon2 Stabilized Borate Formula-30 lbs. or Equal
	Cladding Vent	Cor-A-Vent Siding Vent SV-3/5 or Equal
D	Dampproofing (Liquid Applied Bituminous)	W.R. Meadows SEALMASTIC Emulsion-Type or Solvent-Type Dampproofing or Equal
E	Expanding Polyurethane Foam Sealant	
	High Expansion	Dow Great Stuff Big Gap Filler or Equal
	Low Expansion	Dow Great Stuff Window & Door or Equal
	Extruded Polystyrene Foam (XPS)	Dow Styrofoam or Owens Corning Foamular
F	Filter Fabric	DuPont Landscape PRO Professional Grade Landscape Fabric or Equal
	Flashing	
	Metal Flashing	York Manufacturing Soleil® Copper-Aluminum Flashing or Equal
	Pre-Manufactured Sill Pan Flashing	Dow Weathermate Sill Pan or Equal
	Self Adhered Flashing	
	Formable Flashing	DuPont FlexWrap, Dow Weathermate Flexible Flashing or Equal
	Straight Flashing	W.R. Grace Vycor Plus, DuPont StraightFlash, Dow Weathermate Straight Flashing or Equal
	Fiberglass Insulation	
	Batts	Owens Corning PINK FIBERGLAS® Unfaced, Johns Manville Formaldehyde-free™batts Unfaced, Certainteed High-Performance Batts Unfaced
	Loose Fill	Owens Corning PINK FIBERGLAS®, Johns Manville Formaldehyde-free™ Climate Pro®/Attic Protector®, Certainteed InsulSafe® or Equal
	Foundation Drainage Mat	Cosella-Dorken Delta-MS, System Platon or Equal
	Fully-Adhered Waterproofing Membrane	W.R. Grace Ice and Water Shield or Equal
G	Gypsum Wall Board (GWB)	
	Paper Faced Gypsum Wall Board (GWB)	Sheetrock Brand Gypsum Panels or Equal
	Paperless Gypsum Wall Board (PGWB)	Georgia Pacific DensArmor Plus
H	Housewrap (Non-Micro Perforated Plastic)	
	Draining Housewrap	DuPont Tyvek Drainwrap
	Housewrap	DuPont Tyvek Homewrap, Fiberweb Typar HouseWrap, Dow Weathermate Plus, Johns Manville Gorilla Wrap, Fortifiber WeatherSmart
K	Kick-Out Diverter	Berger Kick-Out Diverter or Equal
R	Ridge Vent	Cor-A-Vent X-5 Extreme Ridge Vent, Trim Line Ridge Vents or Equal
	Rigid Polyisocyanurate	
	Foil Faced	Dow Tuff-R or Thermax
	Glass Fiber Faced	Dow Quik-R or Equal
S	Sealant	
	Air-Barrier Sealant	Tremco Acoustical Sealant or Equal
	Paintable Sealant	Polyseamseal All Purpose Adhesive Caulk, Sashco Sealants Big Stretch, Geocel ProCOLOR™ Tripolymer Sealant or Equal
	Urethane Sealant	Bostik Chem-Calk 955-SL Polyurethane Sealant or Equal
	Spray Polyurethane Foam	
	Closed Cell Spray Foam	Demilec Heatlok 2lbs/cubic foot or Equal
	Open Cell Spray Foam	Icynene 0.5 lbs/cubic foot or Equal
T	Tape	
	Builder's Sheathing Tape	Tyvek Tape, Dow Weathermate Construction Tape, 3M Contractor's Tape or Equal
	Foil Tape	3M Aluminum Foil Tape 1449 or Equal
	Thin Profile Sheathing	Thermoply or Equal

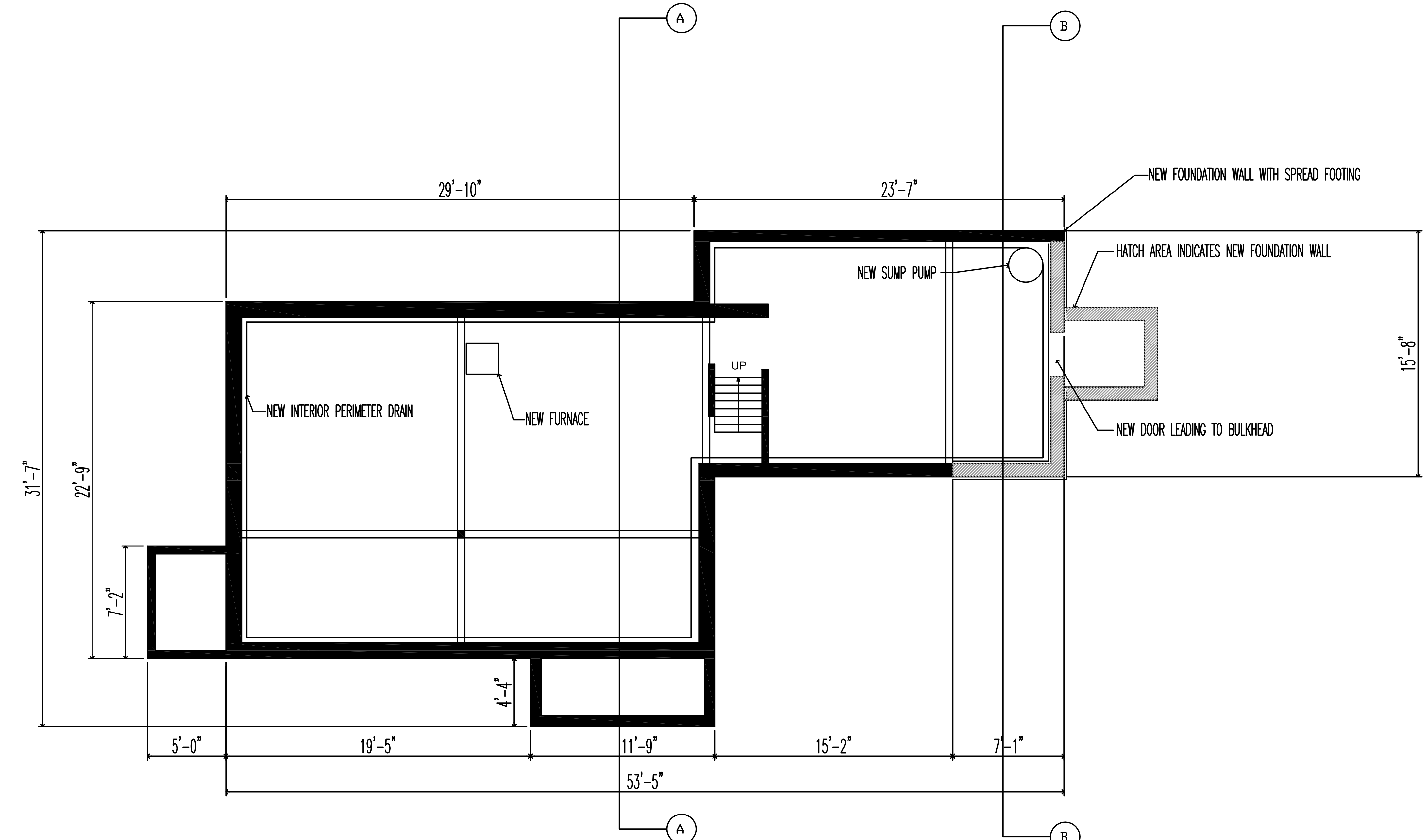
BUILDING SCIENCE CORPORATION

HABITAT FOR HUMANITY
FARMHOUSE RENOVATION
130 NORTH RD, BEDFORD

NOTES

SCALE AS NOTED

N-1



BASEMENT PLAN
SCALE 1/8" = 1'-0"

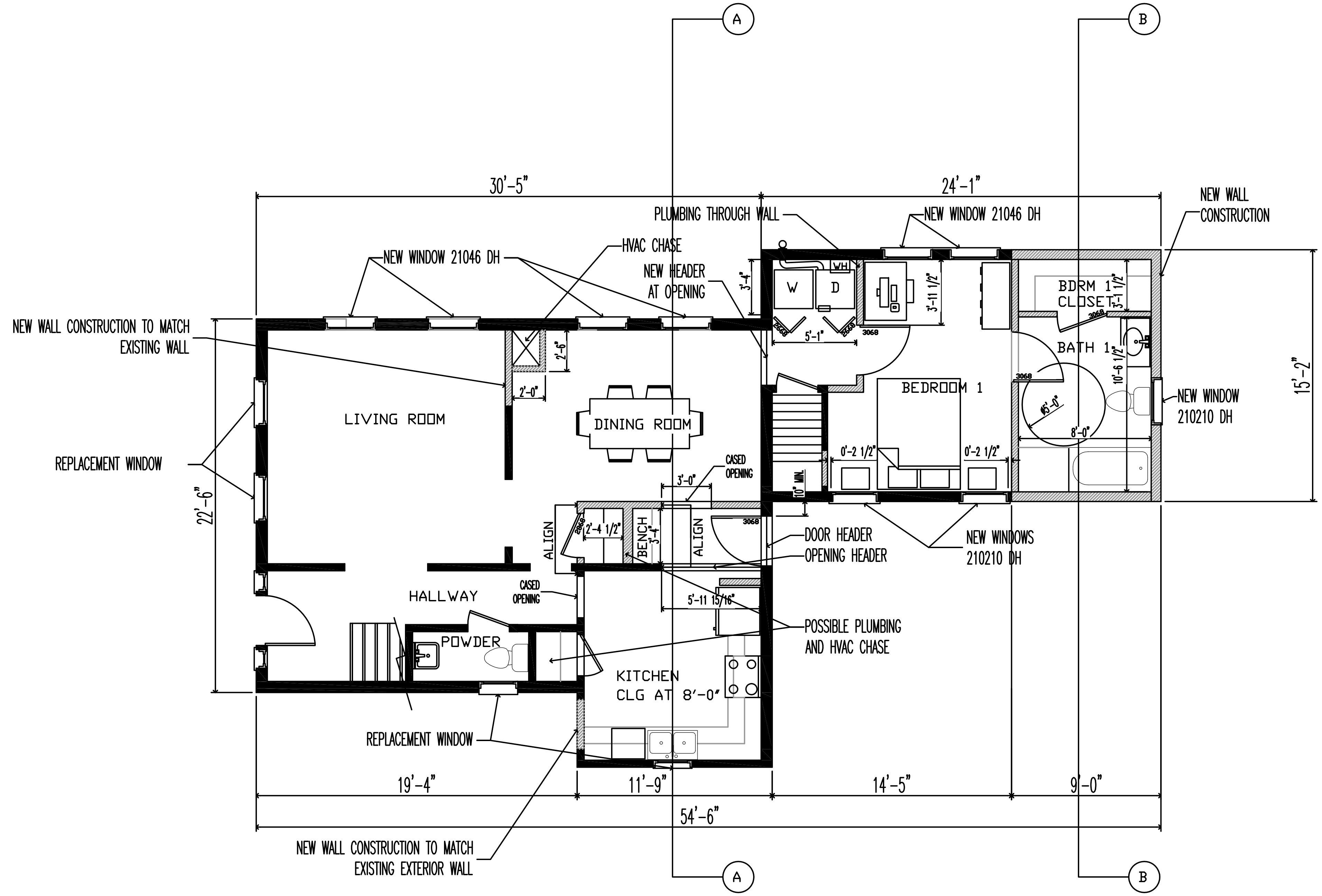
REVISED SET 10/20/2008
REVISED WINDOW DETAILS 10/21/2008
REVISED MECHANICAL, LAUNDRY RM AND SILL DETAILS 10/28/2008
REVISED DETAILS AND NEW DETAILS 11/4/2008

MEMBER:
BUILDING SCIENCE CORPORATION

HABITAT FOR HUMANITY
FARMHOUSE RENOVATION
130 NORTH RD, BEDFORD

BASEMENT FLOOR PLAN
SCALE AS NOTED

A-1



NOTE: INSIDE DIMENSIONS ARE TO FACE OF DRYWALL

FIRST FLOOR PLAN

SCALE 1/8" = 1'-0"

REVISED SET 10/20/2008
REVISED WINDOW DETAILS 10/21/2008
REVISED MECHANICAL, LAUNDRY RM AND SILL DETAILS 10/28/2008
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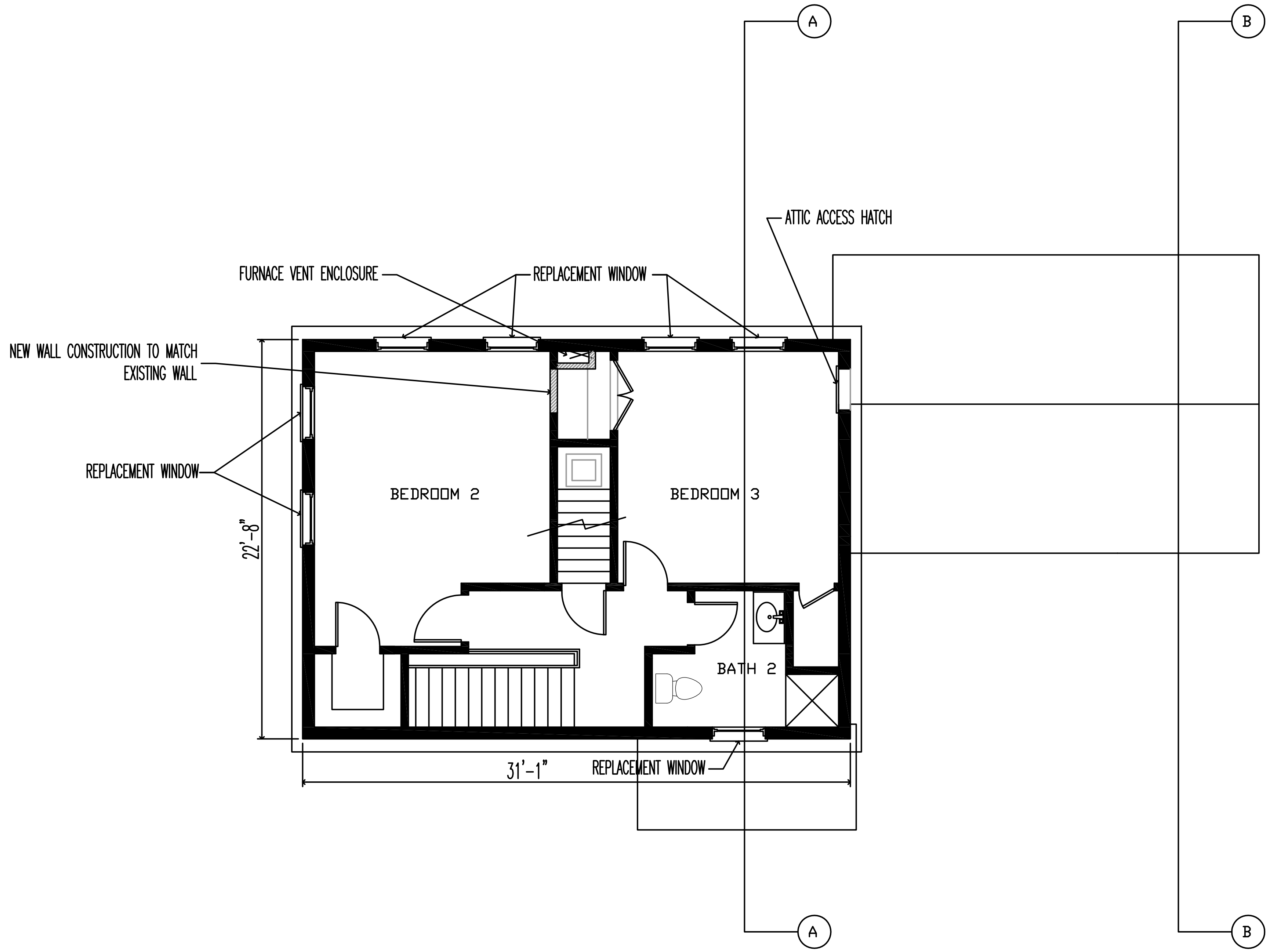
BUILDING SCIENCE CORPORATION

HABITAT FOR HUMANITY
FARMHOUSE RENOVATION
130 NORTH RD, BEDFORD

FIRST FLOOR PLAN

SCALE AS NOTED

A-2



SECOND FLOOR PLAN
SCALE 1/8" = 1'-0"

REVISED SET 10/20/2008
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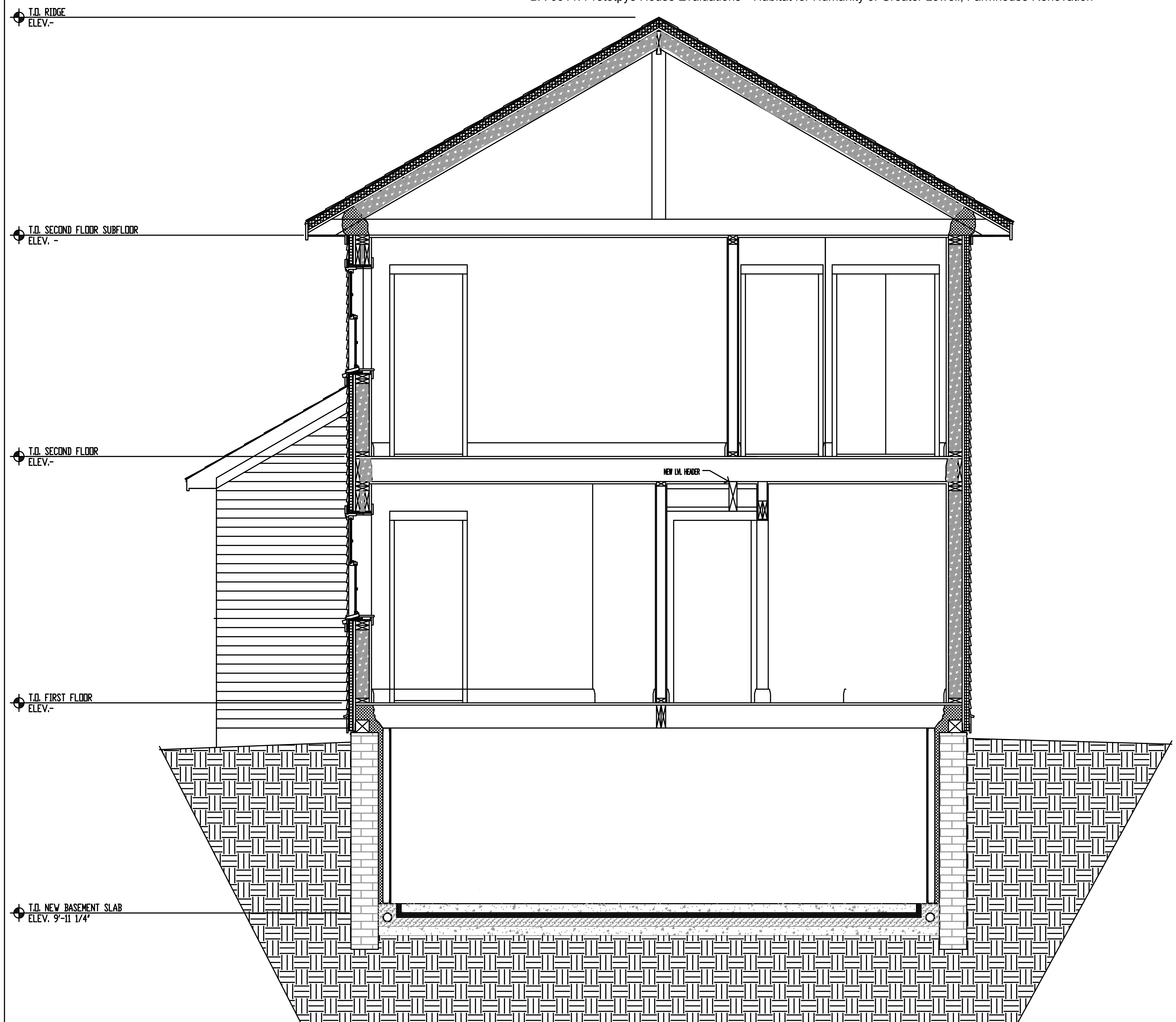
HABITAT FOR HUMANITY
FARMHOUSE RENOVATION
130 NORTH RD, BEDFORD

SECOND FLOOR PLAN

SCALE AS NOTED

A-3



BUILDING SECTION A-A
SCALE 1/8" = 1'-0"

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REVISED MECHANICAL, LAUNDRY RM AND SILL DETAILS 10/28/2008

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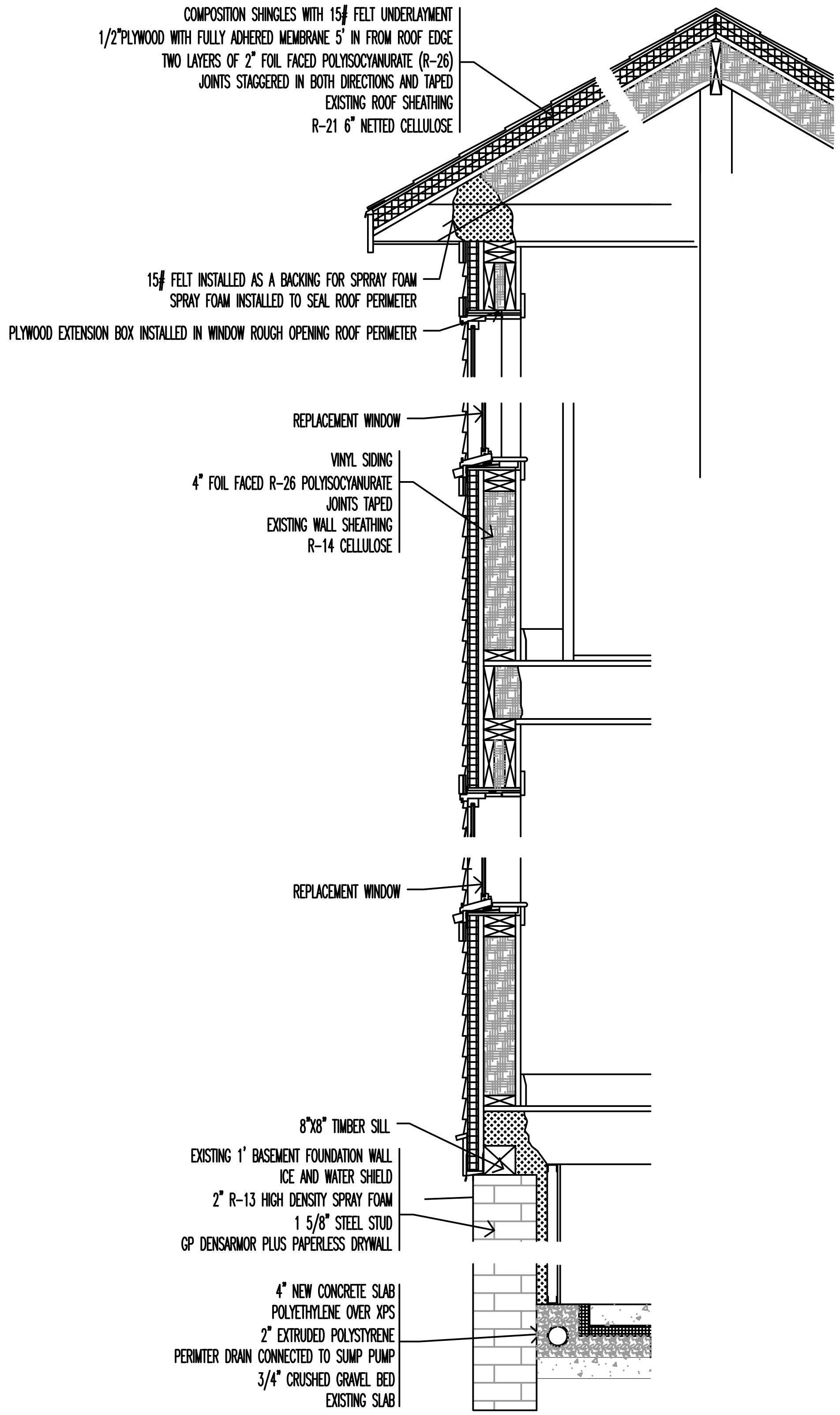
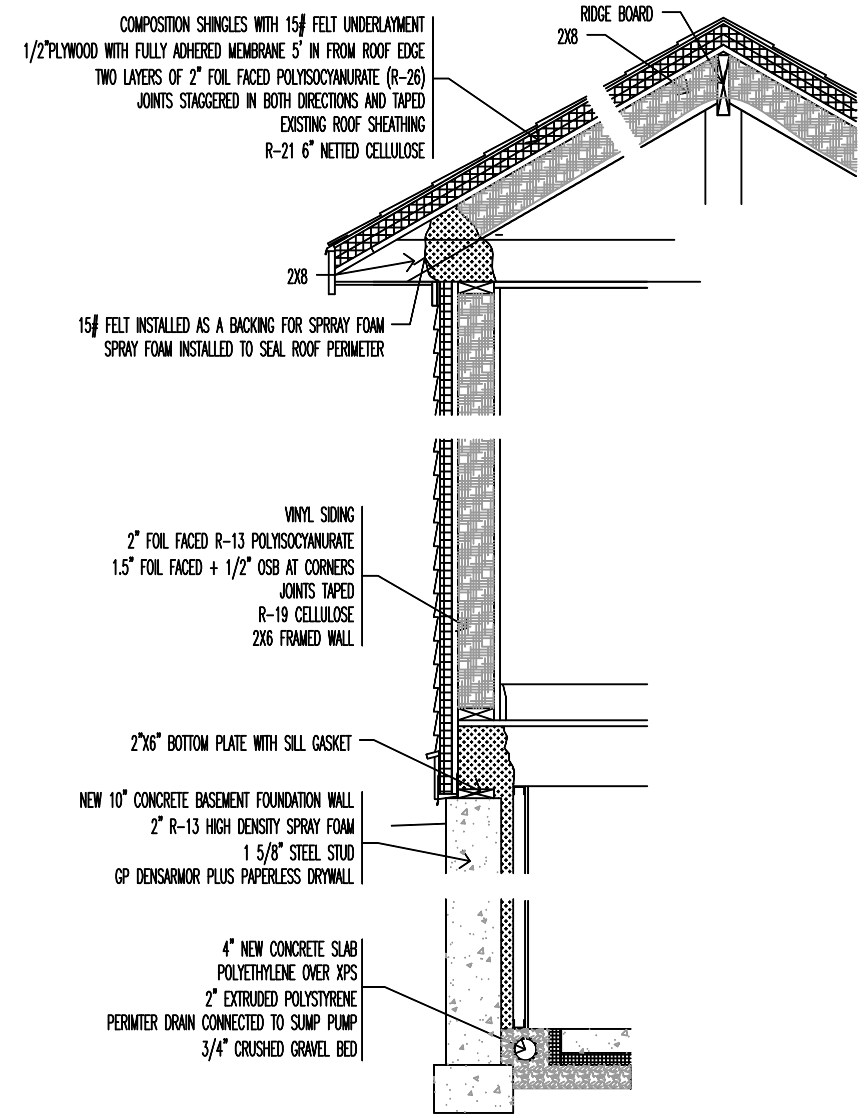
HABITAT FOR HUMANITY
FARMHOUSE RENOVATION
130 NORTH RD, BEDFORD

BUILDING SECTION
SCALE AS NOTED

A-4



BUILDING SECTION A-A
SCALE 3/8" = 1'-0"



BUILDING SECTION B-B
SCALE 3/8" = 1'-0"

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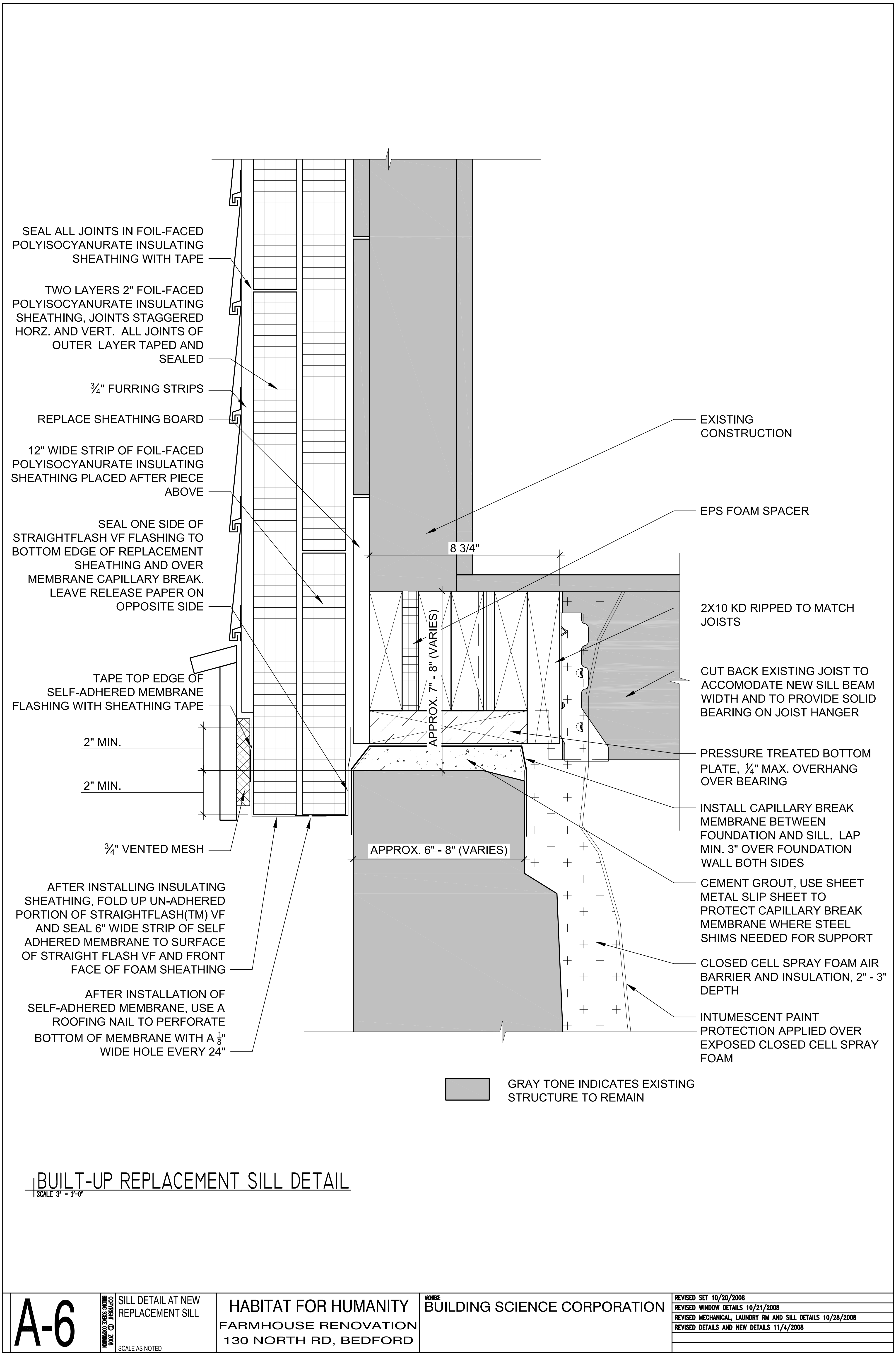
REVISED WINDOW DETAILS 10/21/2008
REVISED MECHANICAL, LAUNDRY RM AND SILL DETAILS 10/28/2008

BUILDING SCIENCE CORPORATION

HABITAT FOR HUMANITY
FARMHOUSE RENOVATION
130 NORTH RD, BEDFORD

WALL SECTIONS
SCALE AS NOTED

A-5


SEAL ALL JOINTS IN FOIL-FACED POLYISOCYANURATE INSULATING SHEATHING WITH TAPE
TWO LAYERS 2" FOIL-FACED POLYISOCYANURATE INSULATING SHEATHING, JOINTS STAGGERED HORZ. AND VERT. ALL JOINTS OF OUTER LAYER TAPED AND SEALED
¾" FURRING STRIPS
REPLACE SHEATHING BOARD
12" WIDE STRIP OF FOIL-FACED POLYISOCYANURATE INSULATING SHEATHING PLACED AFTER PIECE ABOVE
SEAL ONE SIDE OF STRAIGHTFLASH VF FLASHING TO BOTTOM EDGE OF REPLACEMENT SHEATHING AND OVER MEMBRANE CAPILLARY BREAK. LEAVE RELEASE PAPER ON OPPOSITE SIDE
TAPE TOP EDGE OF SELF-ADHERED MEMBRANE FLASHING WITH SHEATHING TAPE
2" MIN.
2" MIN.
¾" VENTED MESH
AFTER INSTALLING INSULATING SHEATHING, FOLD UP UN-ADHERED PORTION OF STRAIGHTFLASH(TM) VF AND SEAL 6" WIDE STRIP OF SELF ADHERED MEMBRANE TO SURFACE OF STRAIGHT FLASH VF AND FRONT FACE OF FOAM SHEATHING
AFTER INSTALLATION OF SELF-ADHERED MEMBRANE, USE A ROOFING NAIL TO PERFORATE BOTTOM OF MEMBRANE WITH A ⅛" WIDE HOLE EVERY 24"
EXISTING CONSTRUCTION
EPS FOAM SPACER
8 3/4"
APPROX. 7" - 8" (VARIES)
2X10 KD RIPPED TO MATCH JOISTS
CUT BACK EXISTING JOIST TO ACCOMODATE NEW SILL BEAM WIDTH AND TO PROVIDE SOLID BEARING ON JOIST HANGER
PRESSURE TREATED BOTTOM PLATE, ¼" MAX. OVERHANG OVER BEARING
INSTALL CAPILLARY BREAK MEMBRANE BETWEEN FOUNDATION AND SILL. LAP MIN. 3" OVER FOUNDATION WALL BOTH SIDES
APPROX. 6" - 8" (VARIES)
CEMENT GROUT, USE SHEET METAL SLIP SHEET TO PROTECT CAPILLARY BREAK MEMBRANE WHERE STEEL SHIMS NEEDED FOR SUPPORT
CLOSED CELL SPRAY FOAM AIR BARRIER AND INSULATION, 2" - 3" DEPTH
INTUMESCENT PAINT PROTECTION APPLIED OVER EXPOSED CLOSED CELL SPRAY FOAM
GRAY TONE INDICATES EXISTING STRUCTURE TO REMAIN
BUILT-UP REPLACEMENT SILL DETAIL
SCALE 3" = 1'-0"
A-6
SILL DETAIL AT NEW REPLACEMENT SILL
SCALE AS NOTED
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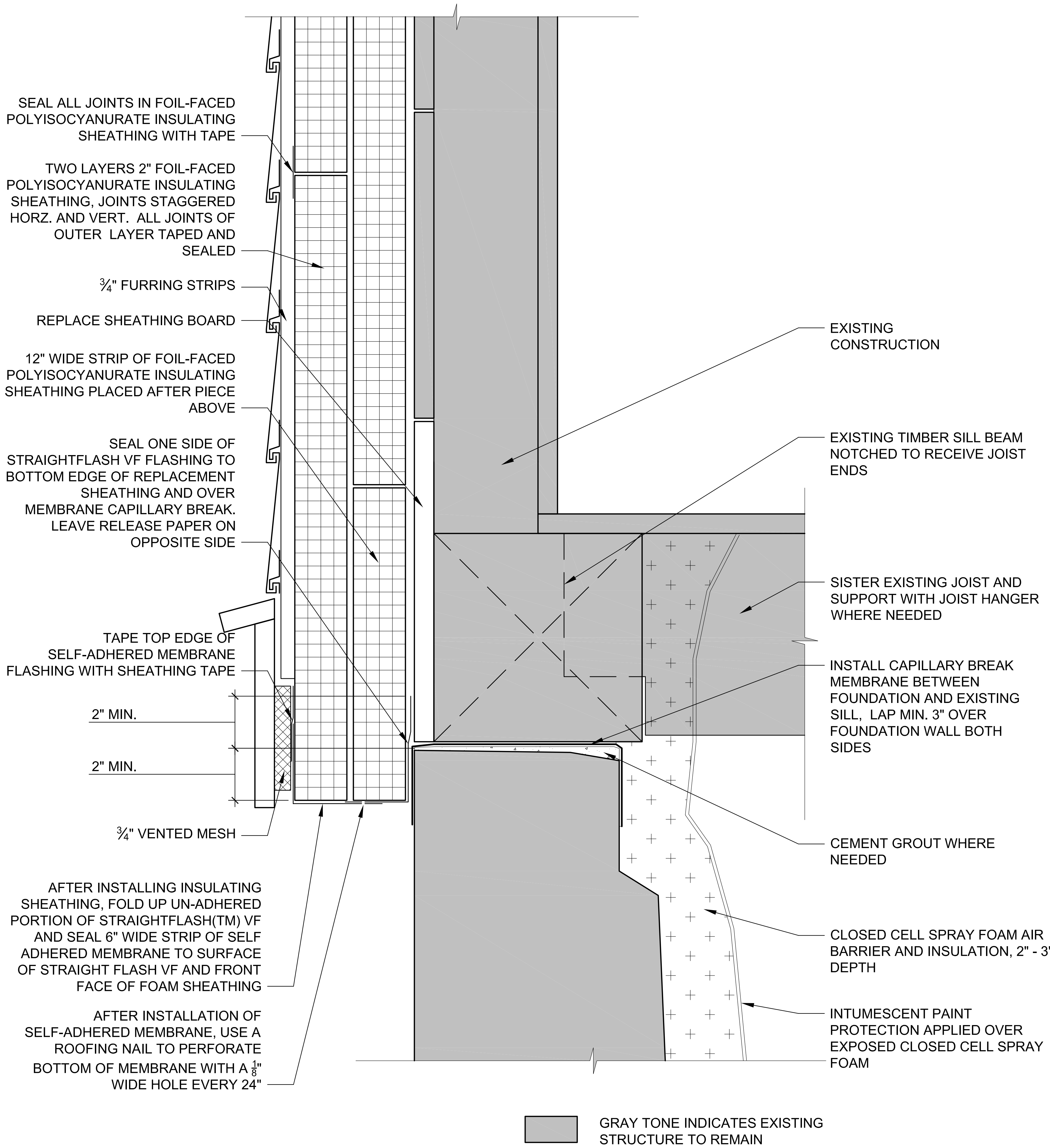
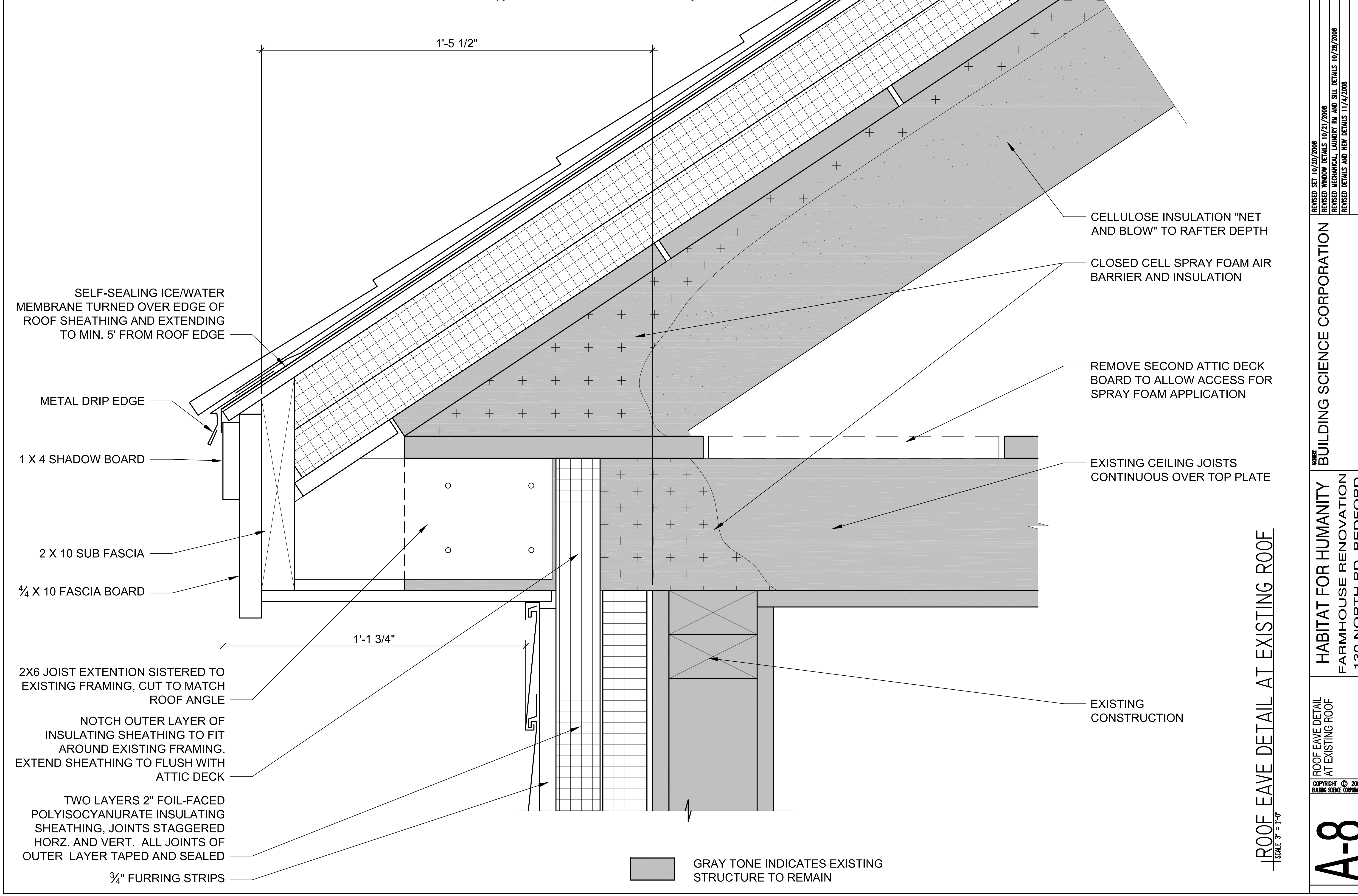


SILL DETAIL AT EXISTING TIMBER SILL TO REMAIN

SCALE 3" = 1'-0"

A-7	SILL DETAIL AT EXISTING SILL SCALE AS NOTED COPYRIGHT © 2008 BUILDING SCIENCE CORPORATION	HABITAT FOR HUMANITY FARMHOUSE RENOVATION 130 NORTH RD, BEDFORD	ARCHITECT: BUILDING SCIENCE CORPORATION	REVISED SET 10/20/2008 REVISED WINDOW DETAILS 10/21/2008 REVISED MECHANICAL, LAUNDRY RM AND SILL DETAILS 10/28/2008 REVISED DETAILS AND NEW DETAILS 11/4/2008


1'-5 1/2"
CELLULOSE INSULATION "NET AND BLOW" TO RAFTER DEPTH
CLOSED CELL SPRAY FOAM AIR BARRIER AND INSULATION
REMOVE SECOND ATTIC DECK BOARD TO ALLOW ACCESS FOR SPRAY FOAM APPLICATION
EXISTING CEILING JOISTS CONTINUOUS OVER TOP PLATE
EXISTING CONSTRUCTION
SELF-SEALING ICE/WATER MEMBRANE TURNED OVER EDGE OF ROOF SHEATHING AND EXTENDING TO MIN. 5' FROM ROOF EDGE
METAL DRIP EDGE
1 X 4 SHADOW BOARD
2 X 10 SUB FASCIA
5/4 X 10 FASCIA BOARD
1'-1 3/4"
2X6 JOIST EXTENTION SISTERED TO EXISTING FRAMING, CUT TO MATCH ROOF ANGLE
NOTCH OUTER LAYER OF INSULATING SHEATHING TO FIT AROUND EXISTING FRAMING. EXTEND SHEATHING TO FLUSH WITH ATTIC DECK
TWO LAYERS 2" FOIL-FACED POLYISOCYANURATE INSULATING SHEATHING, JOINTS STAGGERED HORZ. AND VERT. ALL JOINTS OF OUTER LAYER TAPED AND SEALED
3/4" FURRING STRIPS
GRAY TONE INDICATES EXISTING STRUCTURE TO REMAIN
ROOF EAVE DETAIL AT EXISTING ROOF
SCALE 3" = 1'-0"
REVISED SET 10/20/2008
REVISED WINDOW DETAILS 10/21/2008
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FARMHOUSE RENOVATION
130 NORTH RD, BEDFORD
ROOF EAVE DETAIL AT EXISTING ROOF
SCALE AS NOTED
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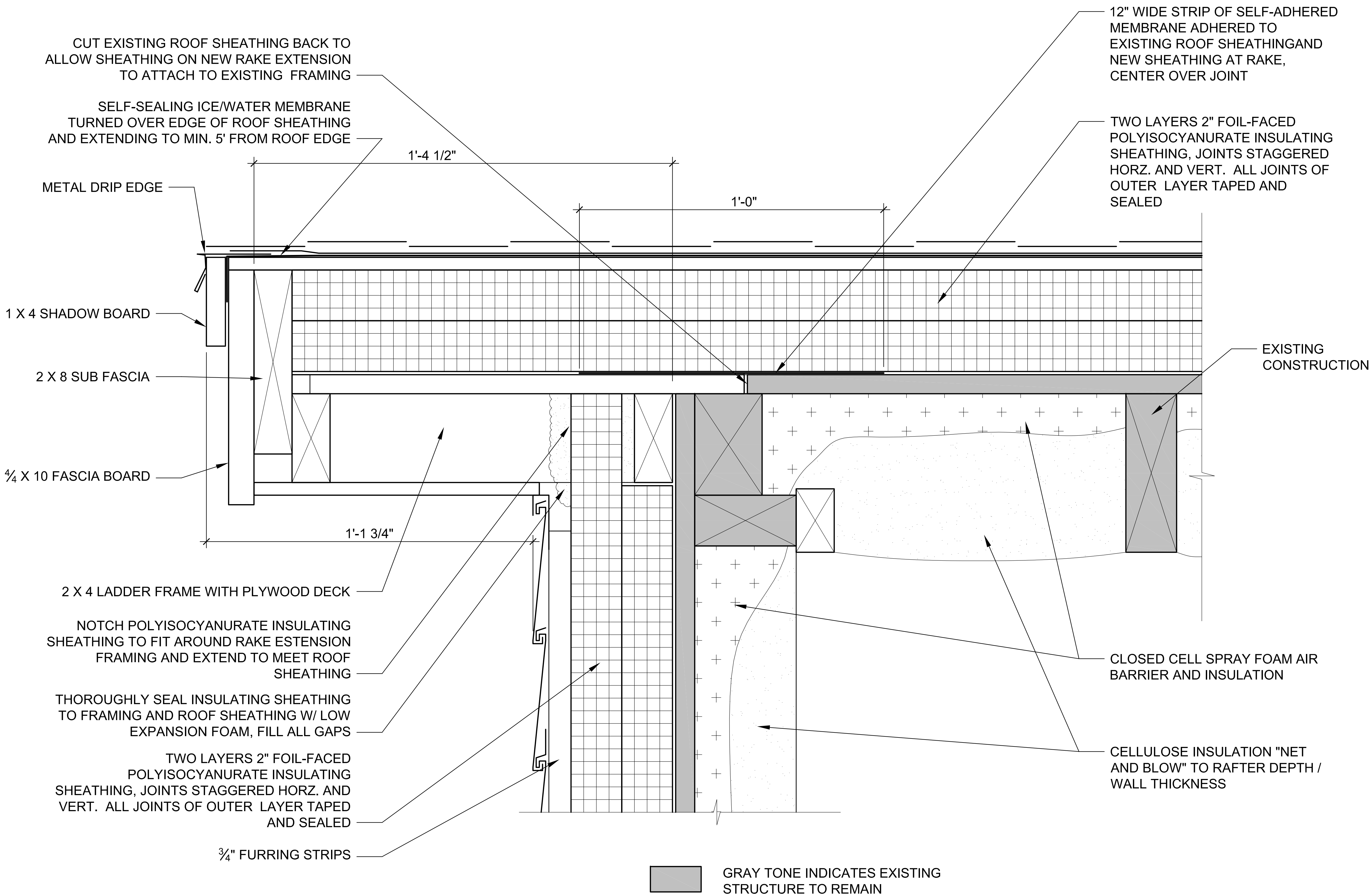
A-8



ROOF RAKE DETAIL AT EXISTING ROOF
SCALE 3" = 1'-0"

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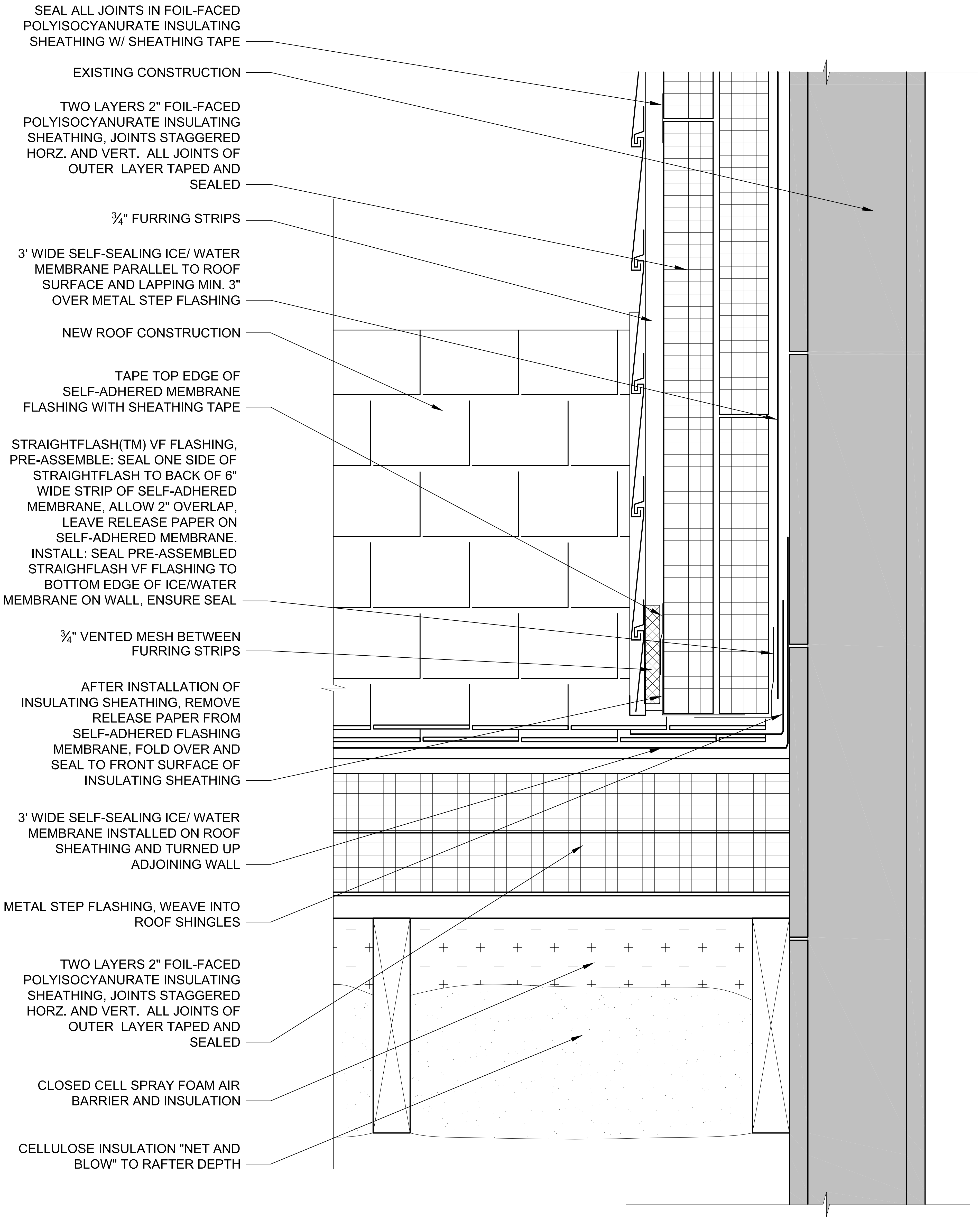
HABITAT FOR HUMANITY
FARMHOUSE RENOVATION
130 NORTH RD, BEDFORD

ROOF RAKE DETAIL AT EXISTING ROOF
SCALE AS NOTED

A-9



ROOF-WALL INTERSECTION

SCALE 3" = 1'-0"

GRAY TONE INDICATES EXISTING STRUCTURE TO REMAIN

A-10

ROOF-WALL INTERSECTION

SCALE AS NOTED

HABITAT FOR HUMANITY
FARMHOUSE RENOVATION
130 NORTH RD, BEDFORD

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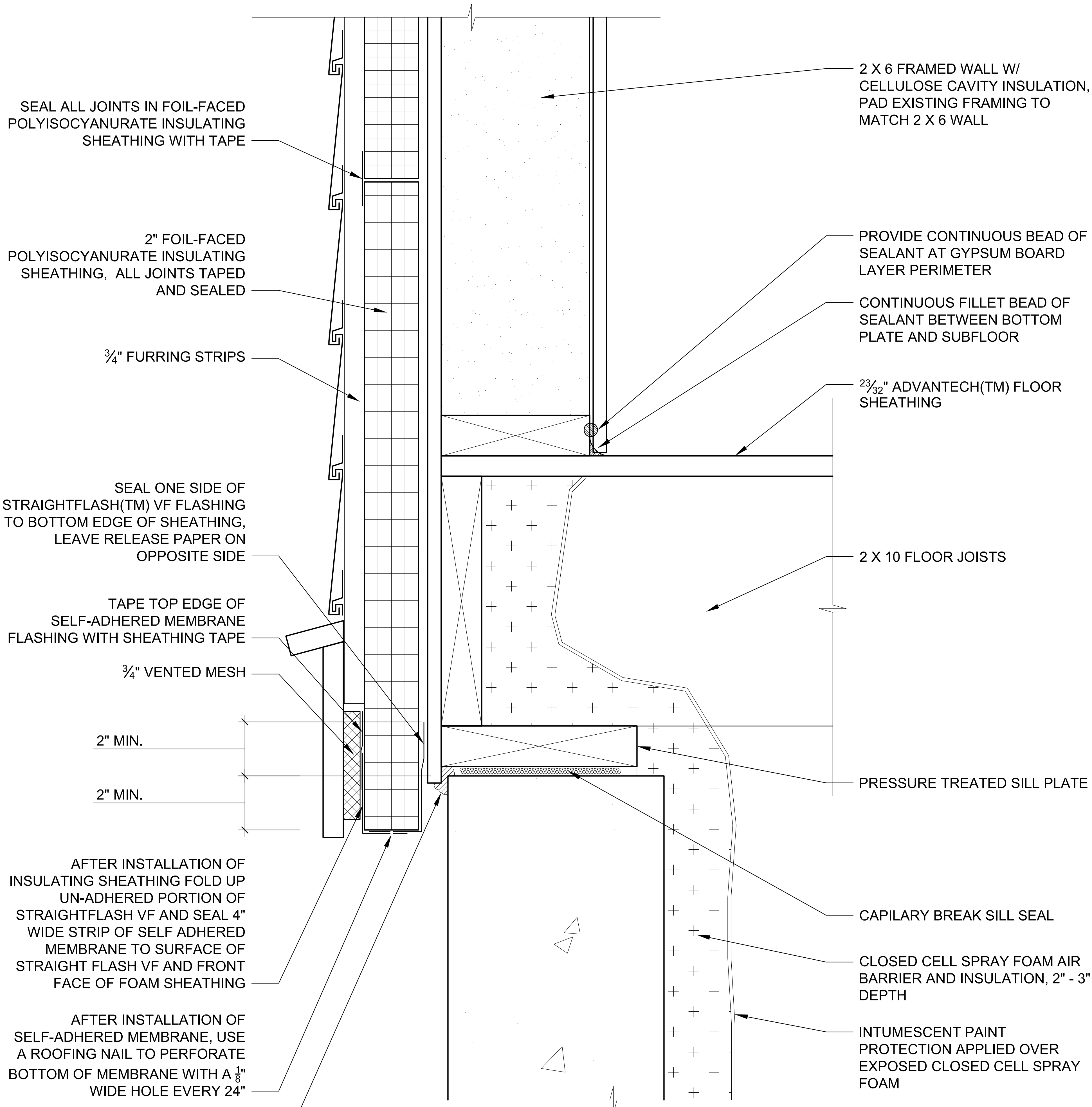

NOTE: FRAMING CONDITIONS TO INSIDE OF PLYWOOD SHEATHING MAY BE DIFFERENT AT EXISTING CONSTRUCTION PORTIONS OF REAR ADDITION. WATER MANAGEMENT AND AIR BARRIER DETAILS TO BE SIMILAR.

SILL DETAIL AT SINGLE STORY REAR ADDITION

SCALE 3" = 1'-0"

A-11

SILL DETAIL AT REAR ADDITION

SCALE AS NOTED

HABITAT FOR HUMANITY
FARMHOUSE RENOVATION
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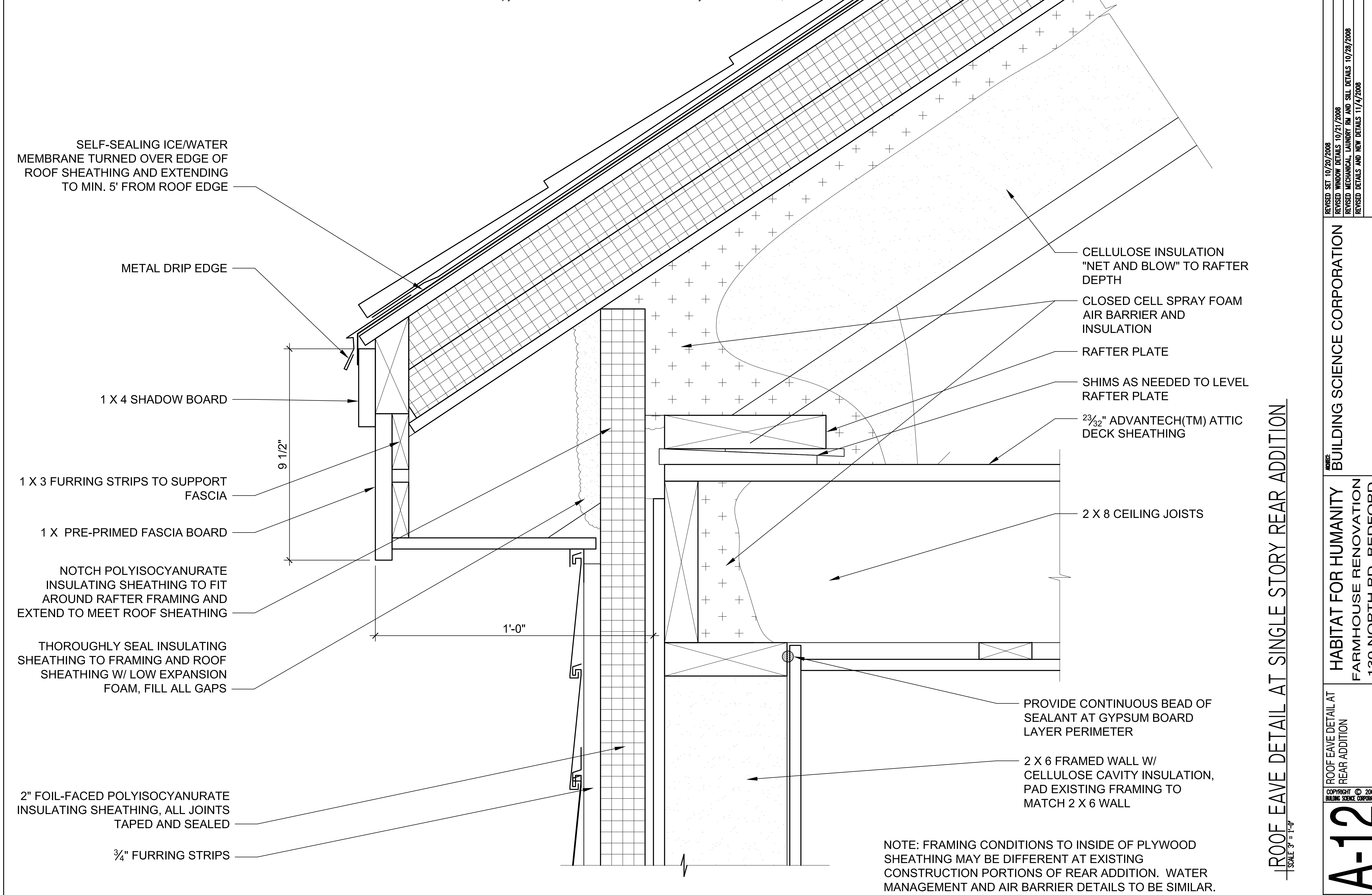

SELF-SEALING ICE/WATER MEMBRANE TURNED OVER EDGE OF ROOF SHEATHING AND EXTENDING TO MIN. 5' FROM ROOF EDGE
METAL DRIP EDGE
1 X 4 SHADOW BOARD
1 X 3 FURRING STRIPS TO SUPPORT FASCIA
1 X PRE-PRIMED FASCIA BOARD
NOTCH POLYISOCYANURATE INSULATING SHEATHING TO FIT AROUND RAFTER FRAMING AND EXTEND TO MEET ROOF SHEATHING
THOROUGHLY SEAL INSULATING SHEATHING TO FRAMING AND ROOF SHEATHING W/ LOW EXPANSION FOAM, FILL ALL GAPS
2" FOIL-FACED POLYISOCYANURATE INSULATING SHEATHING, ALL JOINTS TAPED AND SEALED
¾" FURRING STRIPS
9 1/2"
1'-0"
CELLULOSE INSULATION "NET AND BLOW" TO RAFTER DEPTH
CLOSED CELL SPRAY FOAM AIR BARRIER AND INSULATION
RAFTER PLATE
SHIMS AS NEEDED TO LEVEL RAFTER PLATE
23⁄32" ADVANTECH(TM) ATTIC DECK SHEATHING
2 X 8 CEILING JOISTS
PROVIDE CONTINUOUS BEAD OF SEALANT AT GYPSUM BOARD LAYER PERIMETER
2 X 6 FRAMED WALL W/ CELLULOSE CAVITY INSULATION, PAD EXISTING FRAMING TO MATCH 2 X 6 WALL
NOTE: FRAMING CONDITIONS TO INSIDE OF PLYWOOD SHEATHING MAY BE DIFFERENT AT EXISTING CONSTRUCTION PORTIONS OF REAR ADDITION. WATER MANAGEMENT AND AIR BARRIER DETAILS TO BE SIMILAR.
ROOF EAVE DETAIL AT SINGLE STORY REAR ADDITION
SCALE 3" = 1'-0"
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REVISED WINDOW DETAILS 10/21/2008
REVISED MECHANICAL, LAUNDRY RM AND SILL DETAILS 10/28/2008
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FARMHOUSE RENOVATION
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ROOF EAVE DETAIL AT REAR ADDITION
SCALE AS NOTED
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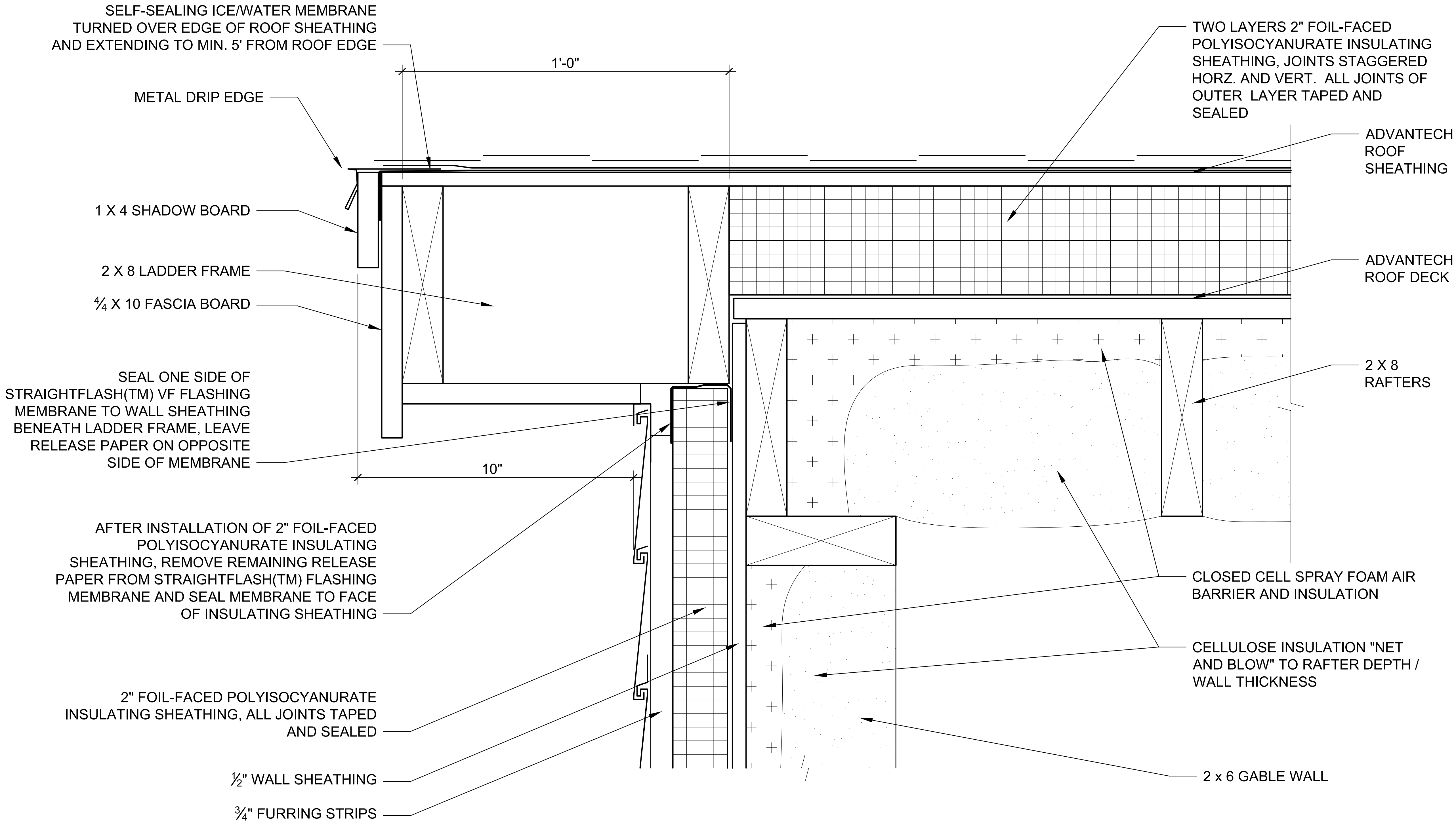
A-12



ROOF RAKE DETAIL AT SINGLE STORY REAR ADDITION
SCALE 3" = 1'-0"

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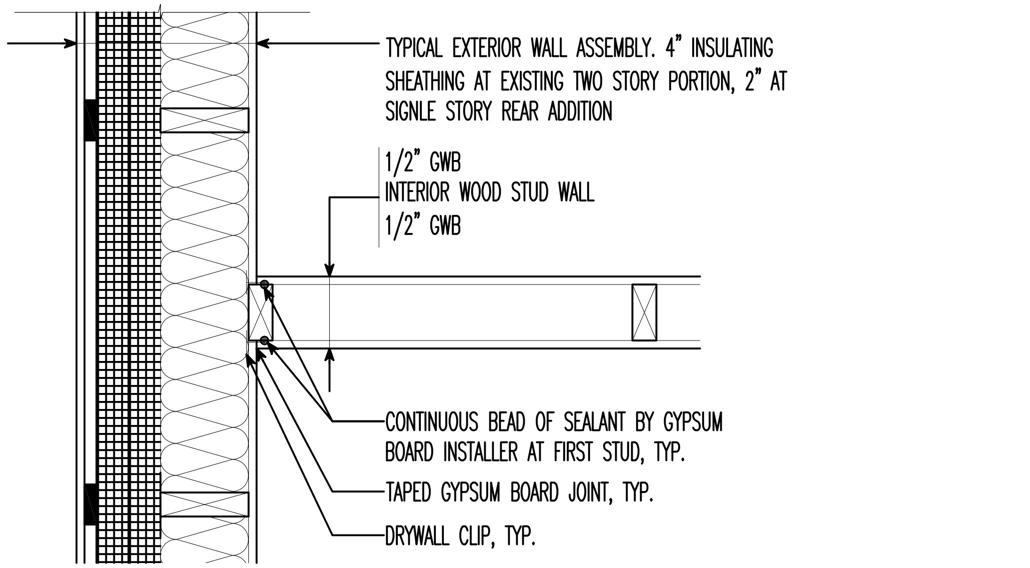
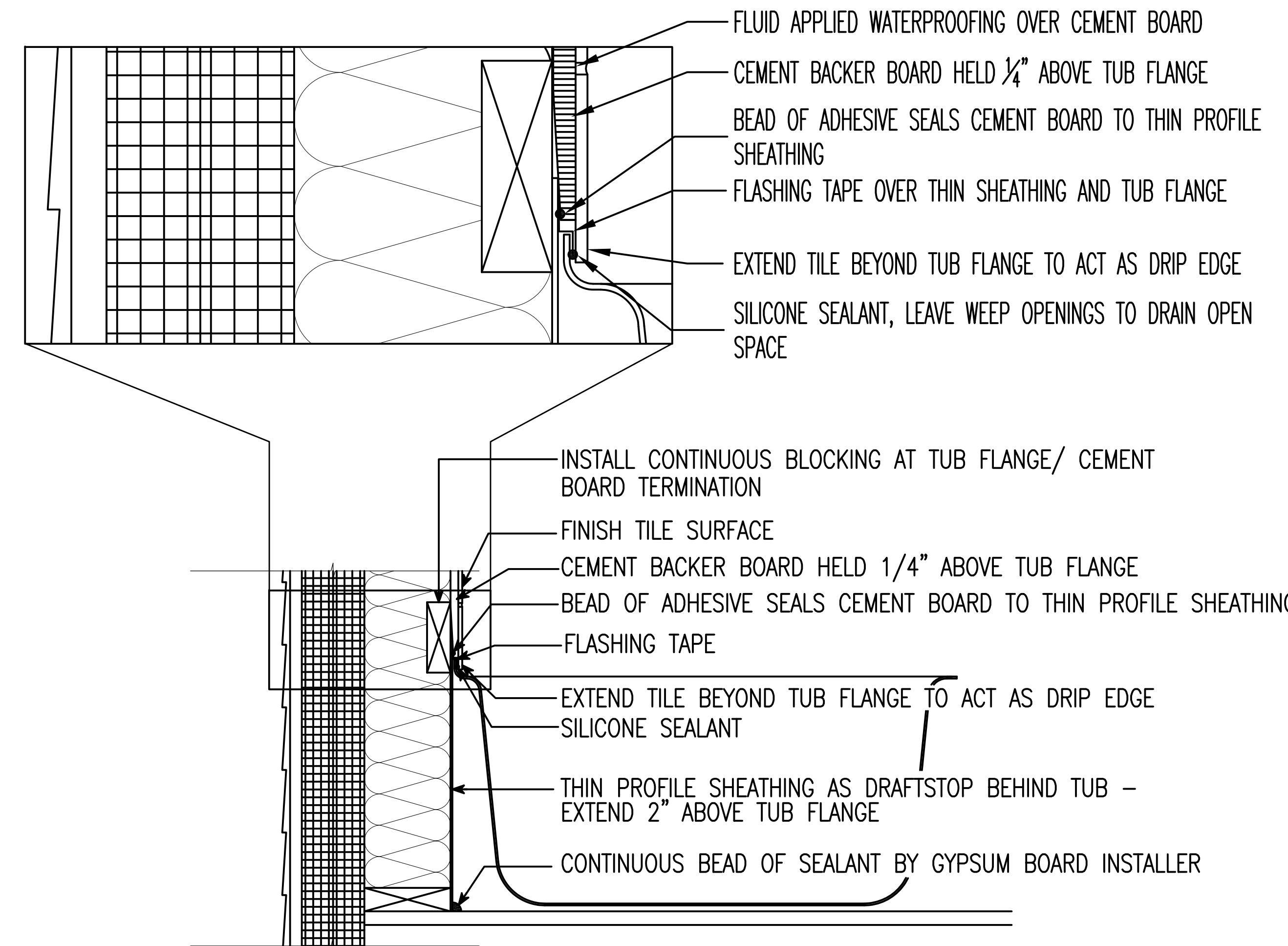
HABITAT FOR HUMANITY
FARMHOUSE RENOVATION
130 NORTH RD, BEDFORD

ROOF RAKE DETAIL AT REAR ADDITION
SCALE AS NOTED

A-13

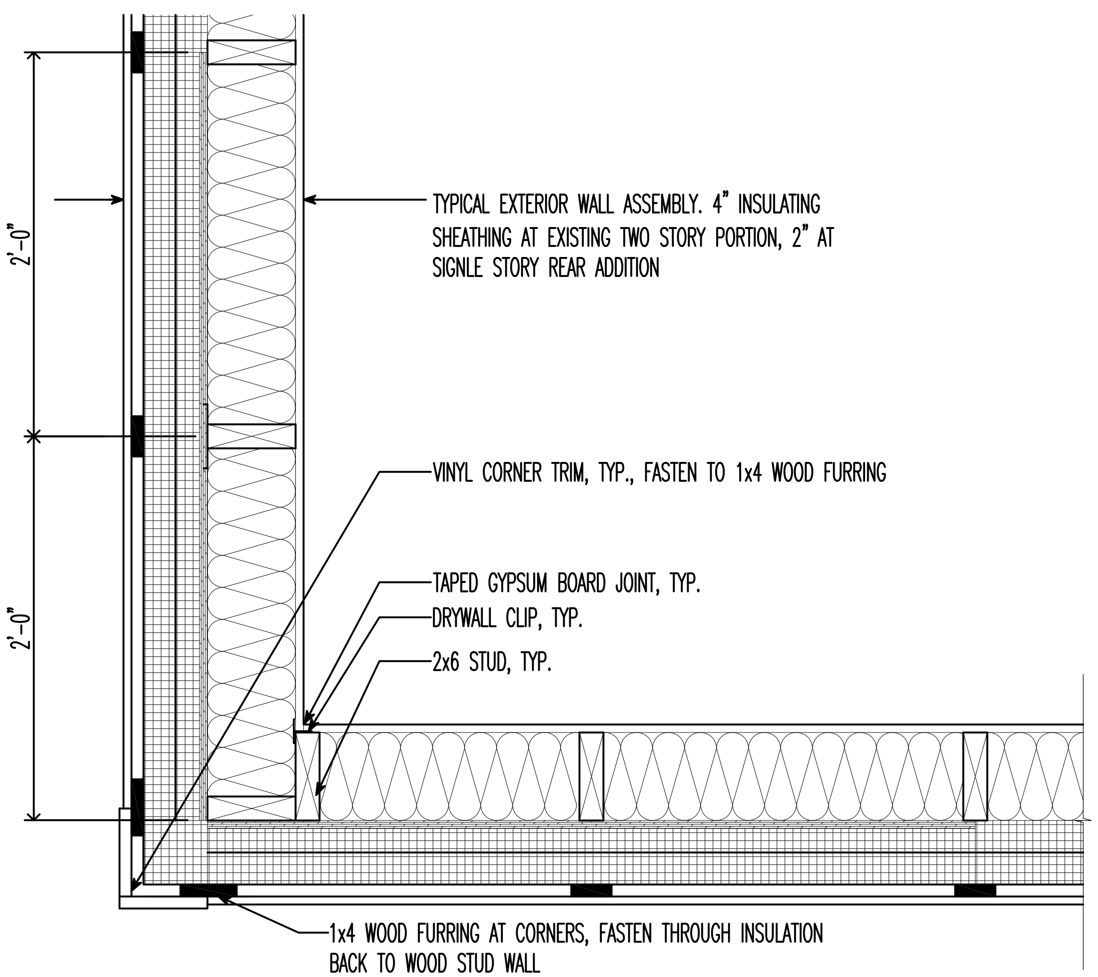


4 | PARTITION AT EXTERIOR WALL
SCALE 1" = 1'-0"

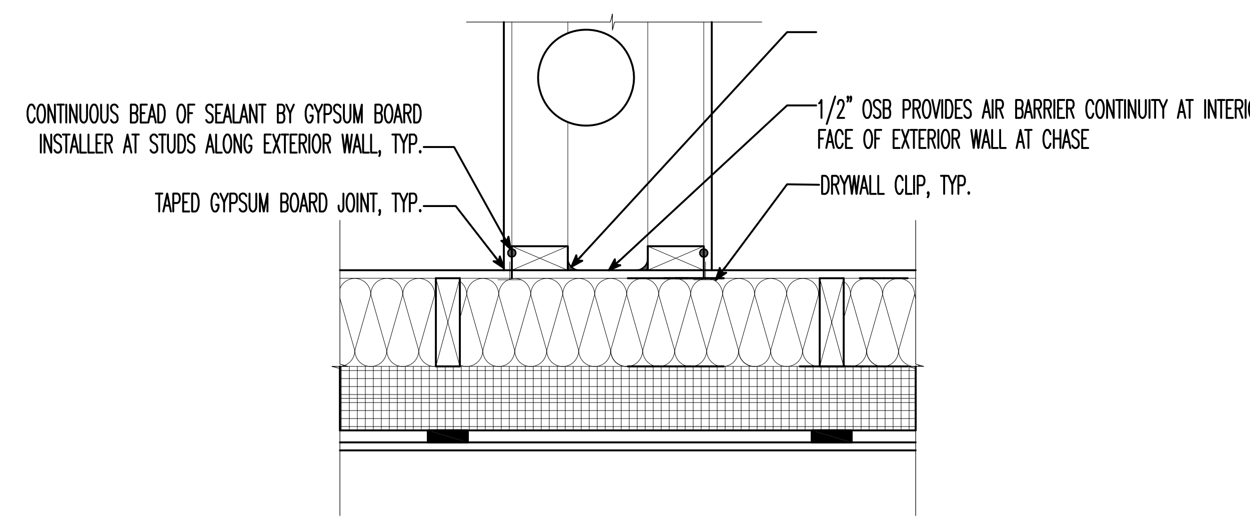


NOTE: AT FULL HEIGHT TUB ENCLOSURES, EXTEND THIN PROFILE SHEATHING TO TOP PLATE OF FRAMED WALL.

2 | EXTERIOR WALL AT TUB/SHOWER
SCALE 1" = 1'-0" LOWER, 3" = 1'-0" UPPER



3 | EXTERIOR WALL CORNER DETAIL
SCALE 1" = 1'-0"



1 | CHASE WALL AT EXTERIOR WALL DETAIL
SCALE 1" = 1'-0"

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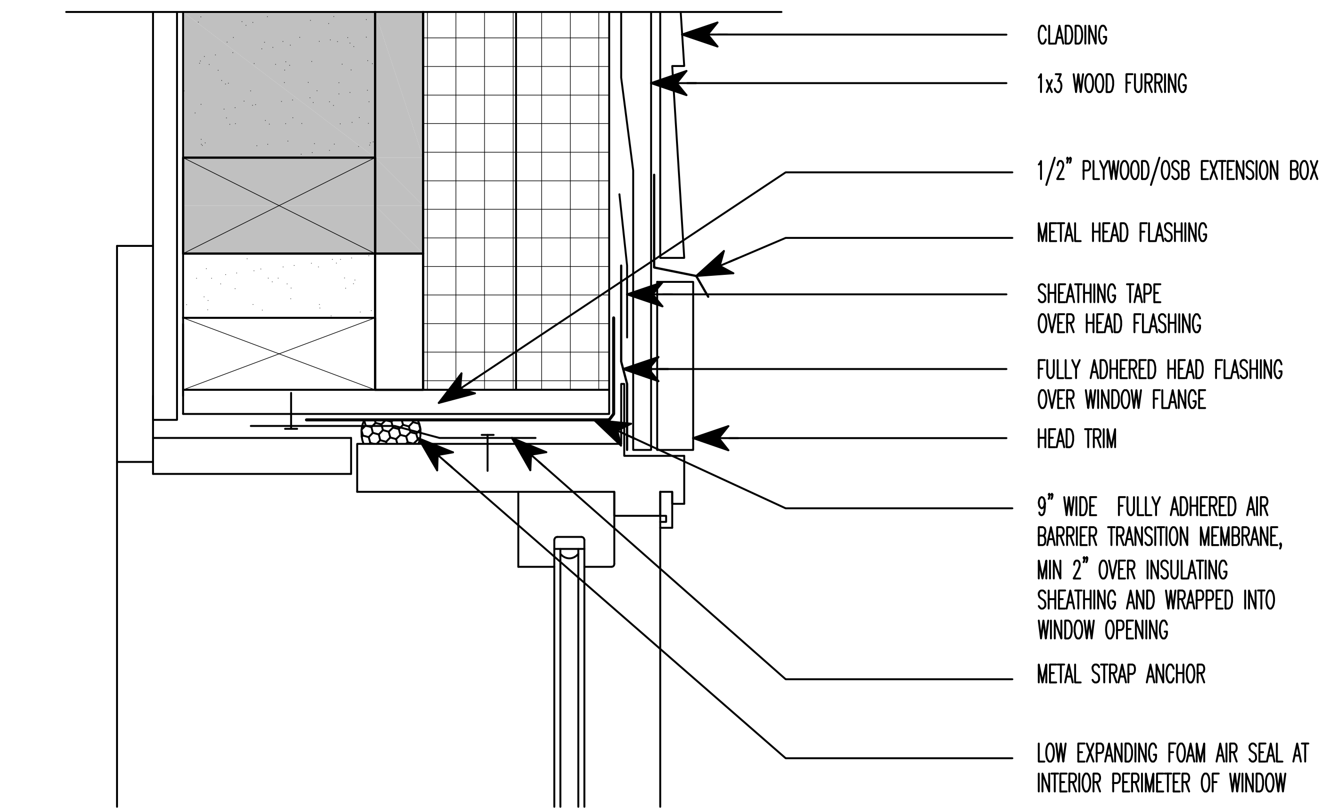
HABITAT FOR HUMANITY
FARMHOUSE RENOVATION
130 NORTH RD, BEDFORD

TYPICAL NEW CONSTRUCTION WALL DETAILS
SCALE AS NOTED

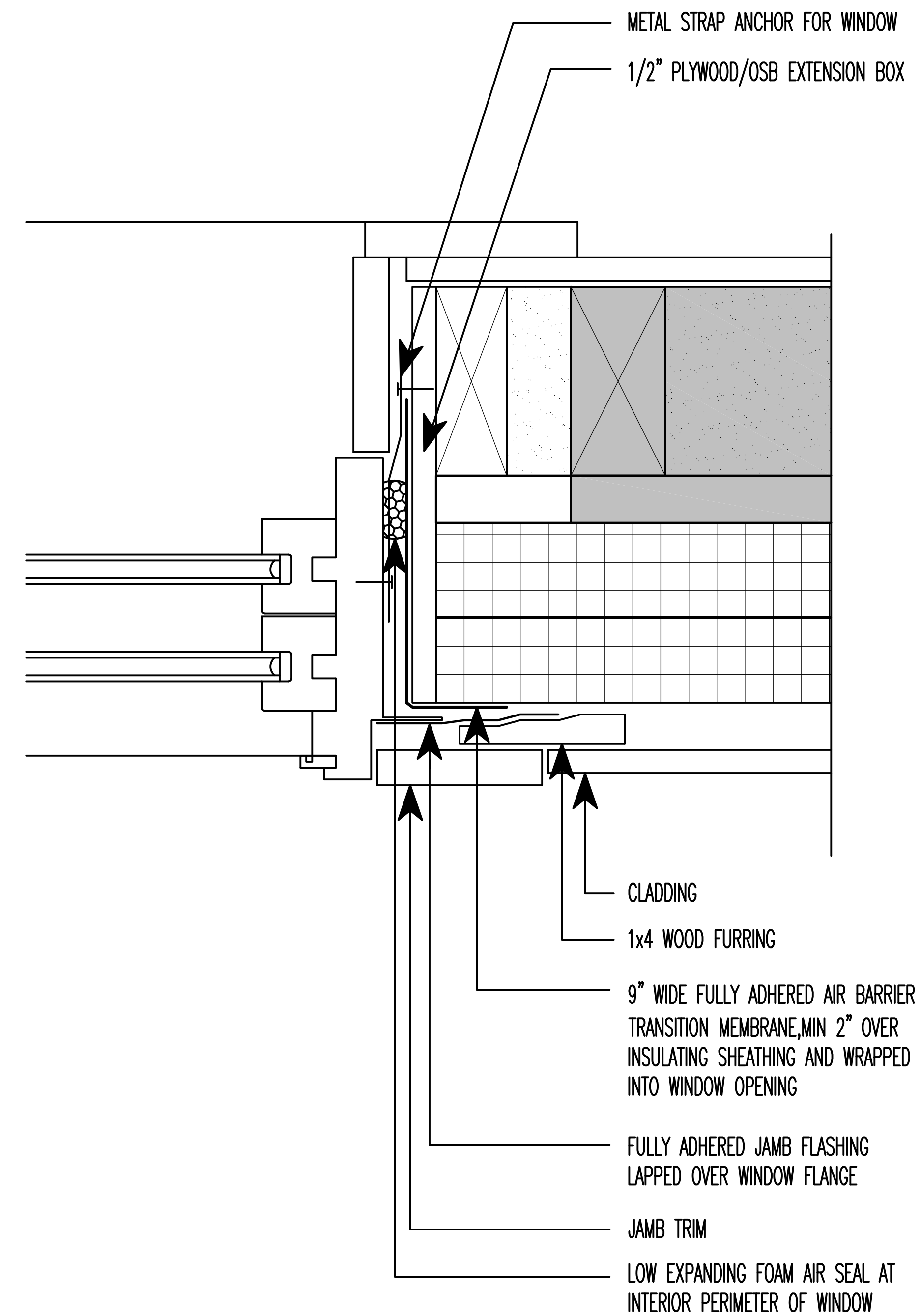
A-14

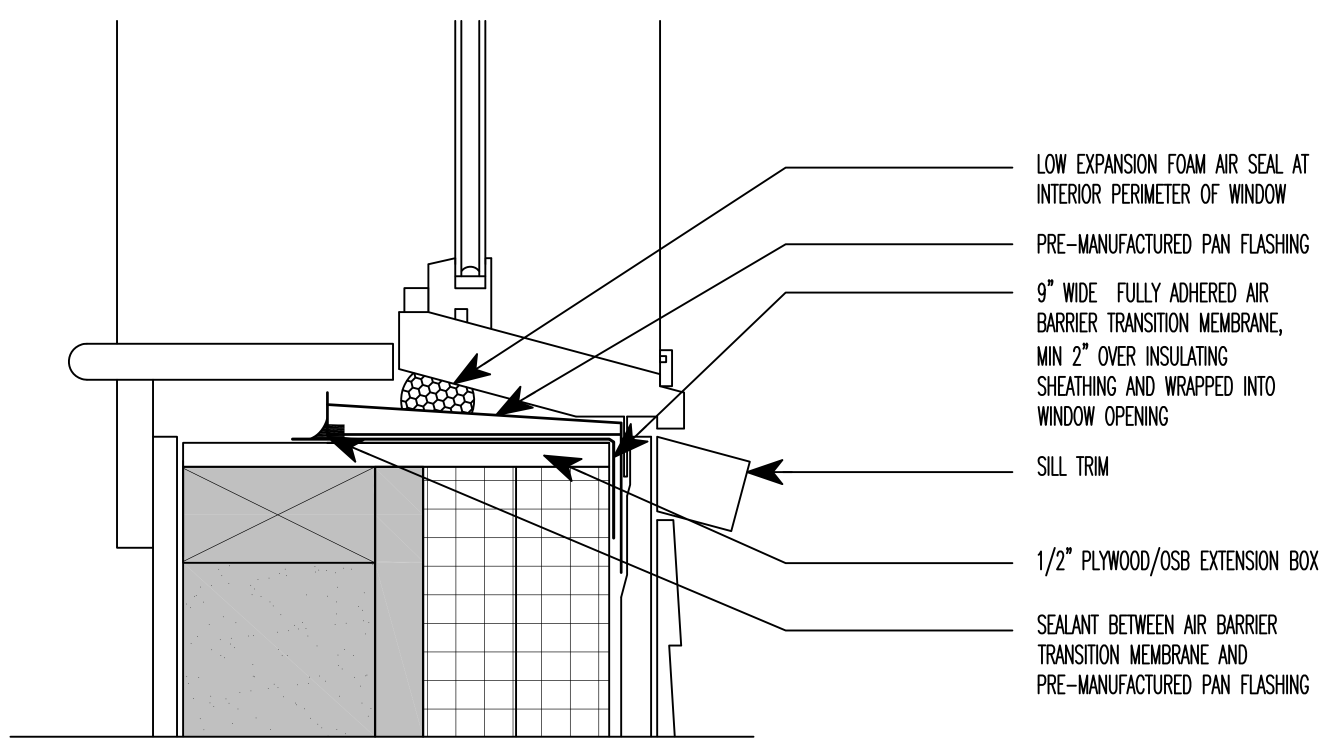


2 | WINDOW HEAD DETAIL
SCALE 3" = 1'-0"

GRAY TONE INDICATES EXISTING STRUCTURE TO REMAIN

NOTE: AT SINGLE STORY REAR ADDITION, PROJECTED 2 X 8 ROUGH OPENING FRAMING SUBSTITURES FOR WINDOW EXTENSION BOX.





3 | WINDOW SILL DETAIL
SCALE 3" = 1'-0"

1 | WINDOW JAMB DETAIL
SCALE 3" = 1'-0"

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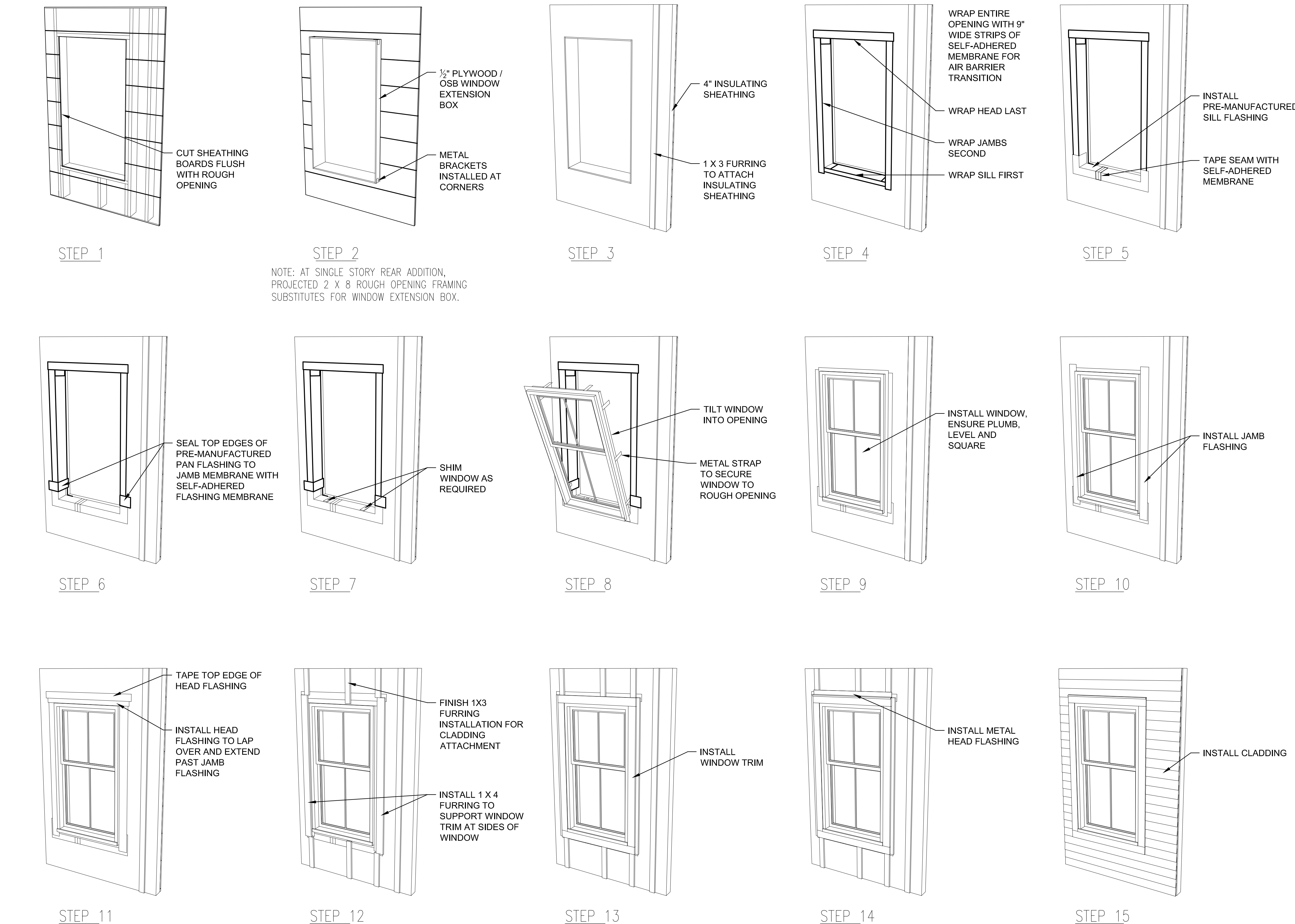
HABITAT FOR HUMANITY
FARMHOUSE RENOVATION
130 NORTH RD, BEDFORD

WINDOW DETAILS
SCALE AS NOTED

A-15



1 | WINDOW INSTALLATION SEQUENCE
NOT TO SCALE

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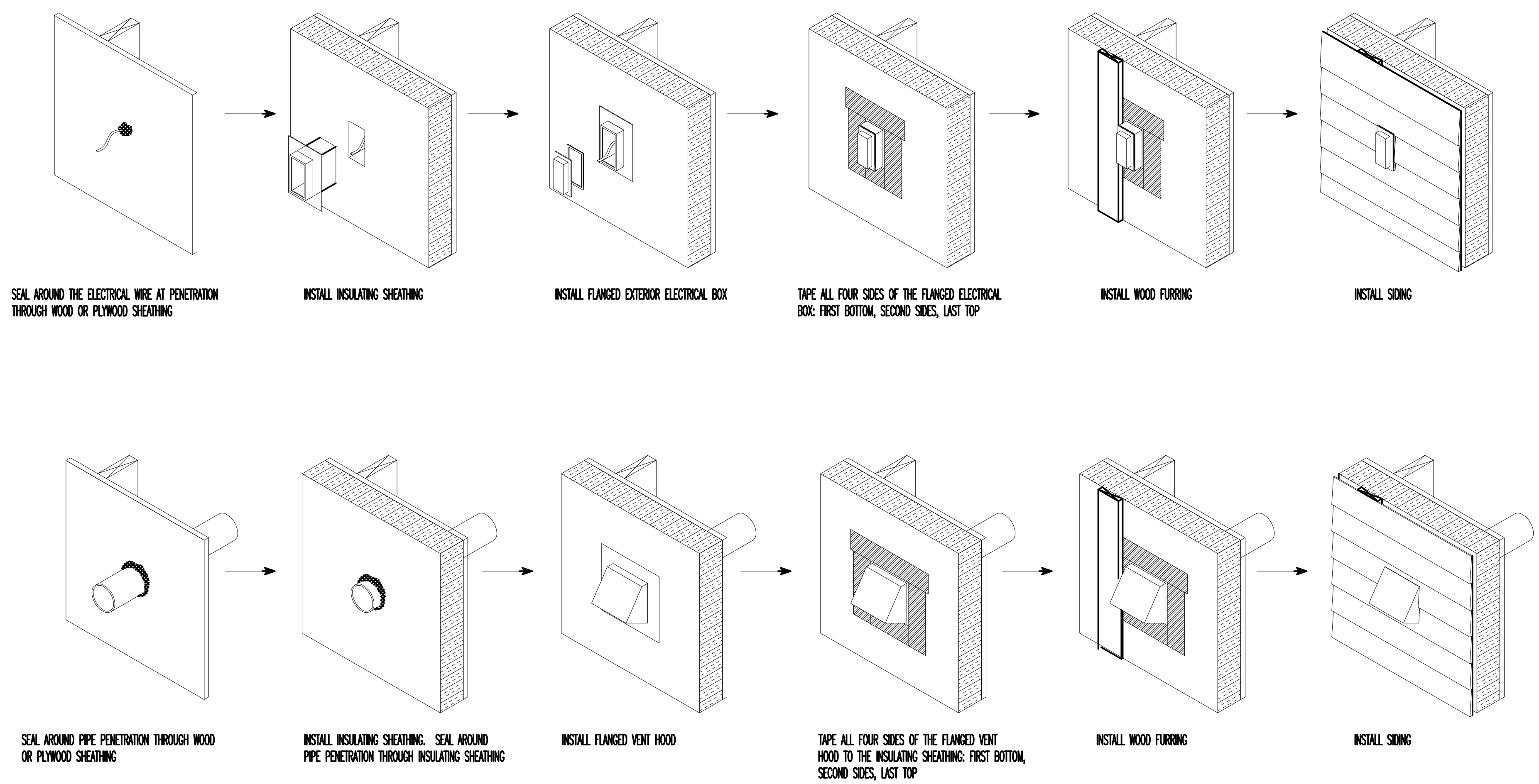
HABITAT FOR HUMANITY
FARMHOUSE RENOVATION
130 NORTH RD, BEDFORD

WINDOW INSTALLATION

SCALE AS NOTED

A-16



1 | SEALING AND FLASHING EXTERIOR WALL PENETRATIONS

NOT TO SCALE

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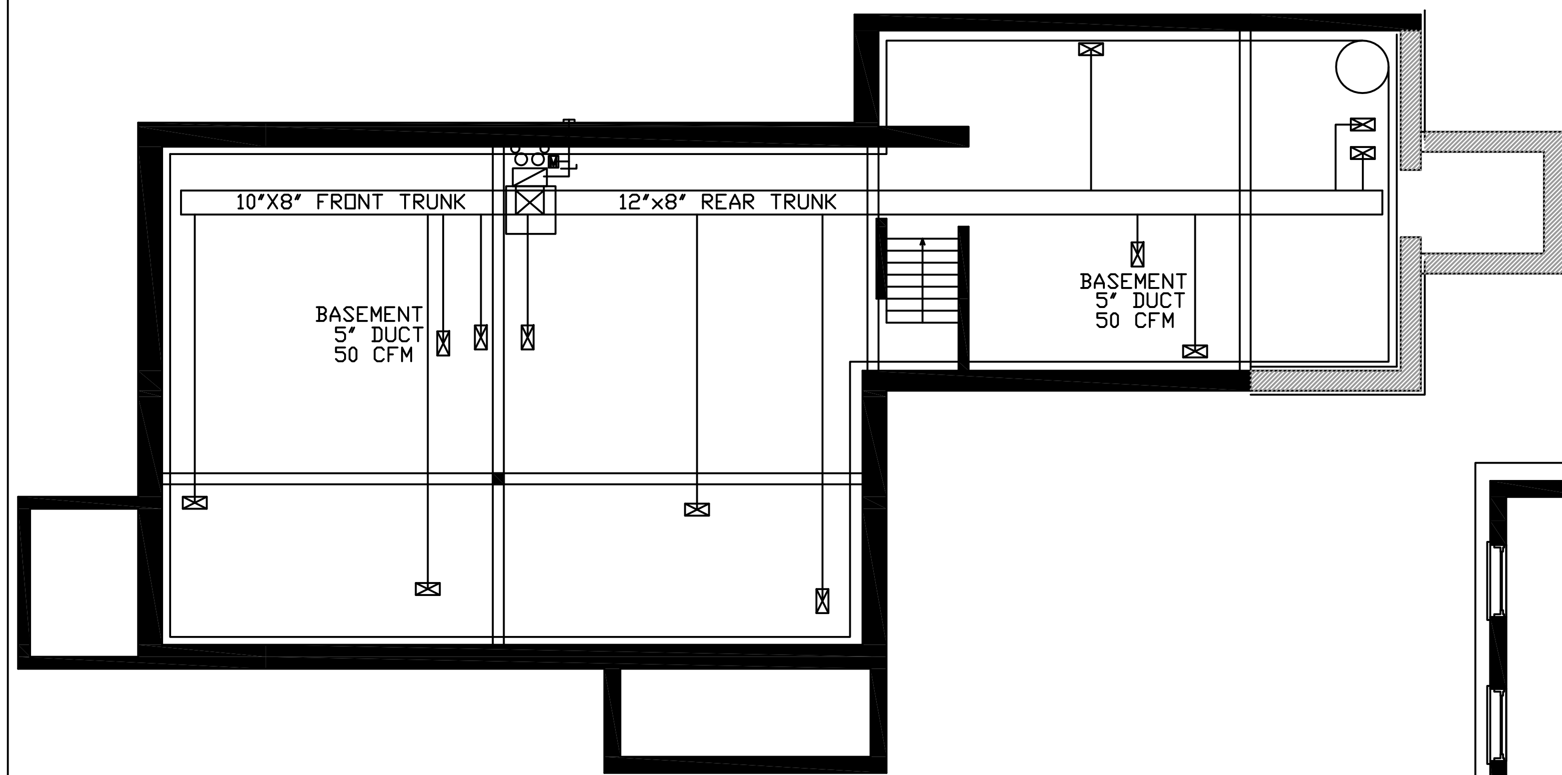
HABITAT FOR HUMANITY
FARMHOUSE RENOVATION
130 NORTH RD, BEDFORD

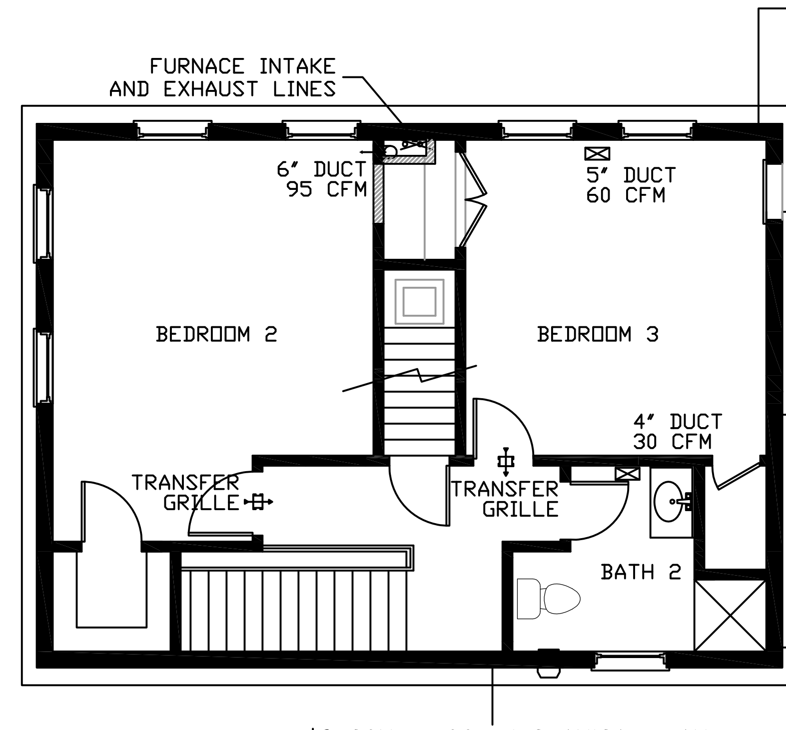
EXTERIOR WALL PENETRATIONS

SCALE AS NOTED

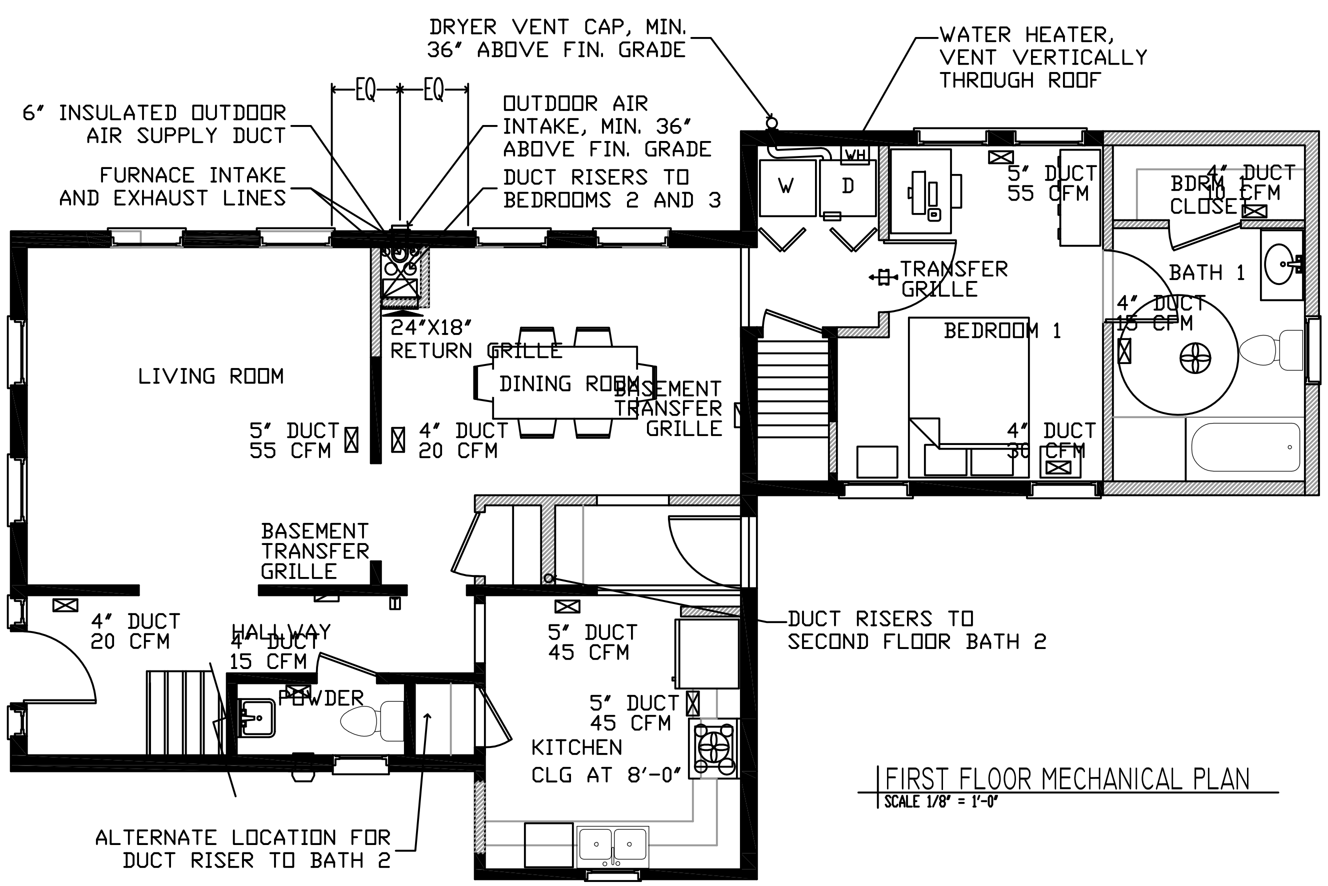
A-17



BASEMENT FLOOR MECHANICAL PLAN
SCALE 1/8" = 1'-0"



SECOND FLOOR MECHANICAL PLAN
SCALE 1/8" = 1'-0"



FIRST FLOOR MECHANICAL PLAN
SCALE 1/8" = 1'-0"

LEGEND	
⊠	SUPPLY REGISTER
	OVER DOOR TRANSFER GRILLES
⊕	TOILET EXHAUST FAN, PANSONIC FV-08VKS1
	WALL EXHAUST FAN, PANASONIC FV-08WQ1
	KITCHEN EXHAUST FAN W/ LIGHT
	THERMOSTAT SCI ERV-24 SUPER
	MOTORIZED DAMPER FOR O.A. CONTROL
	MANUAL DAMPER
	RETURN AIR FLOW

DUCT DESIGN INFORMATION	
DESIGN HEATING LOAD	29.4 kBtu/h
DESIGN COOLING LOAD	14.7 kBtu/h
COOLING SYSTEM CFM	800 CFM
MAIN SUPPLY TRUNK	16"X14"
FRONT SUPPLY TRUNK	10"X8"
REAR SUPPLY TRUNK	12"X8"
RETURN TRUNK	16"X14"
RETURN GRILLE	24"X18"
RETURN TRUNK DESIGN VELOCITY	550 FPM
RETURN GRILLE DESIGN VELOCITY	350 FPM

EQUIPMENT INFORMATION	
DESIGN HEATING LOAD	29.4 kBtu/h
FURNACE SIZE	40.0 kBtu/h
DESIGN COOLING LOAD	14.7 kBtu/h
CONDENSER SIZE (IF COOLING IS ADDED)	2 TONS
COOLING SYSTEM CFM	800 CFM

MECHANICAL NOTES:

1. DUCTS ARE SIZED FOR COOLING TO ALLOW INSTALLATION OF A CONDENSER IF SPECIFIED. SEE EQUIPMENT INFORMATION FOR COOLING LOAD.
2. ALL DUCTS TO BE SEALED WITH MASTIC AND LOCATED IN CONDITIONED SPACE.
3. ALL REGISTERS TO BE ADJUSTABLE DIRECTIONAL MOUNTED WITH DAMPER. A MANUAL DAMPER SHALL BE LOCATED AT MAIN TRUNK JUNCTION TO CONTROL FLOW.
4. TRANSFER GRILLES PROVIDE PRESSURE RELIEF / PRESSURE EQUALIZATION BETWEEN CLOSED ROOMS AND COMMON AREAS (TRANSFER GRILLES SHALL BE 10"X6")
5. DOORS TO BE UNDERCUT 1" BETWEEN TOP OF FINISH FLOOR AND UNDERSIDE OF DOOR
6. FURNACE LOCATED AND ACCESSED WITHIN INTERIOR CONDITIONED SPACE.
7. RETURN DUCTED WITH TWO OFFSETS TO REDUCE SOUND AND VIBRATION.
8. A FILTER WITH A MERV 12 RATING SHALL BE INSTALLED AT THE FURNACE.
9. OUTSIDE AIR PROVIDED TO RETURN SIDE OF SYSTEM WITH DAMPER CONTROL.
10. 6" DIAMETER INSULATED OUTSIDE AIR DUCT FROM EXTERIOR SHALL BE INSTALLED WITH A MANUAL DAMPER TO SET FLOW. APRILAIRE 6" MECHANICAL DAMPER SHALL BE INSTALLED DOWNSTREAM OF MANUAL DAMPER. APRILAIR VCS 8126 FAN CYCLER SHALL BE INSTALLED TO CONTROL MECHANICAL DAMPER. MECHANICAL DAMPER IS PROVIDED TO PREVENT EXCESS VENTILATION DURING PEAK LOAD USAGE. DAMPER SHUTS OFF DURING PEAK USE TO STOP OUTSIDE AIR FLOW TO RETURN FOR A PRESCRIBED AMOUNT OF TIME, THEREFORE PREVENTING OVERVENTILATION.

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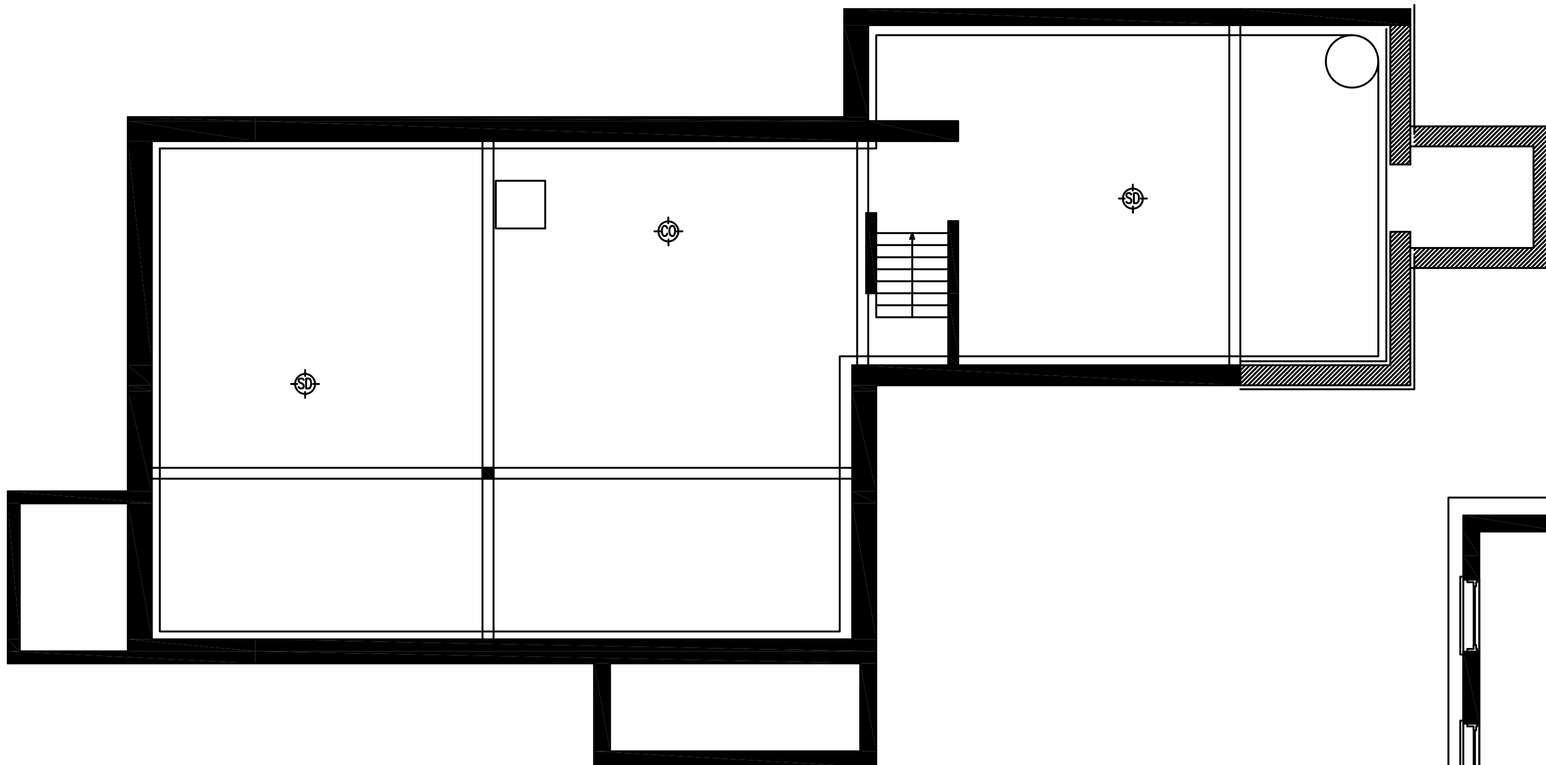
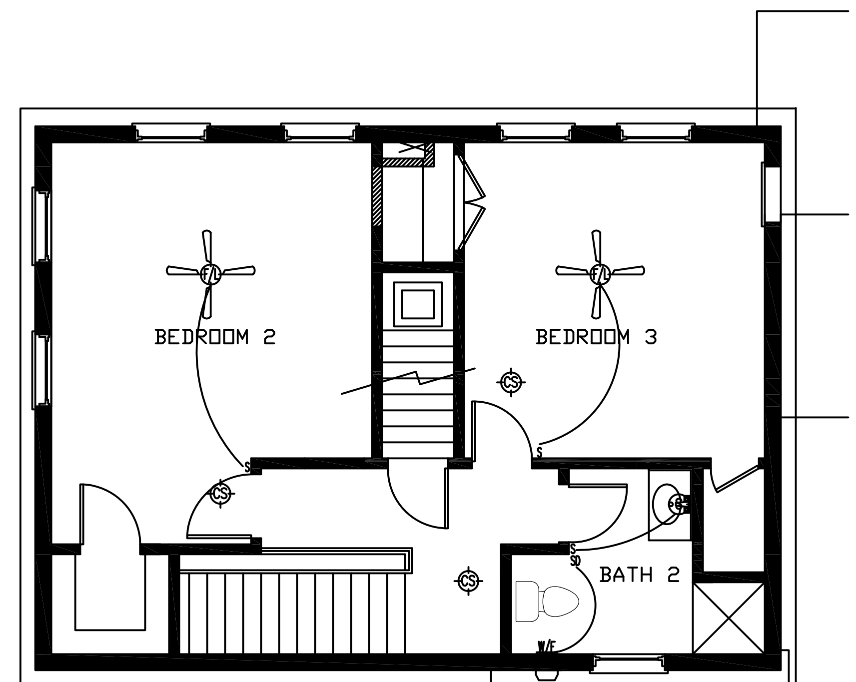
HABITAT FOR HUMANITY
FARMHOUSE

BUILDING
MECHANICAL PLAN
SCALE AS NOTED

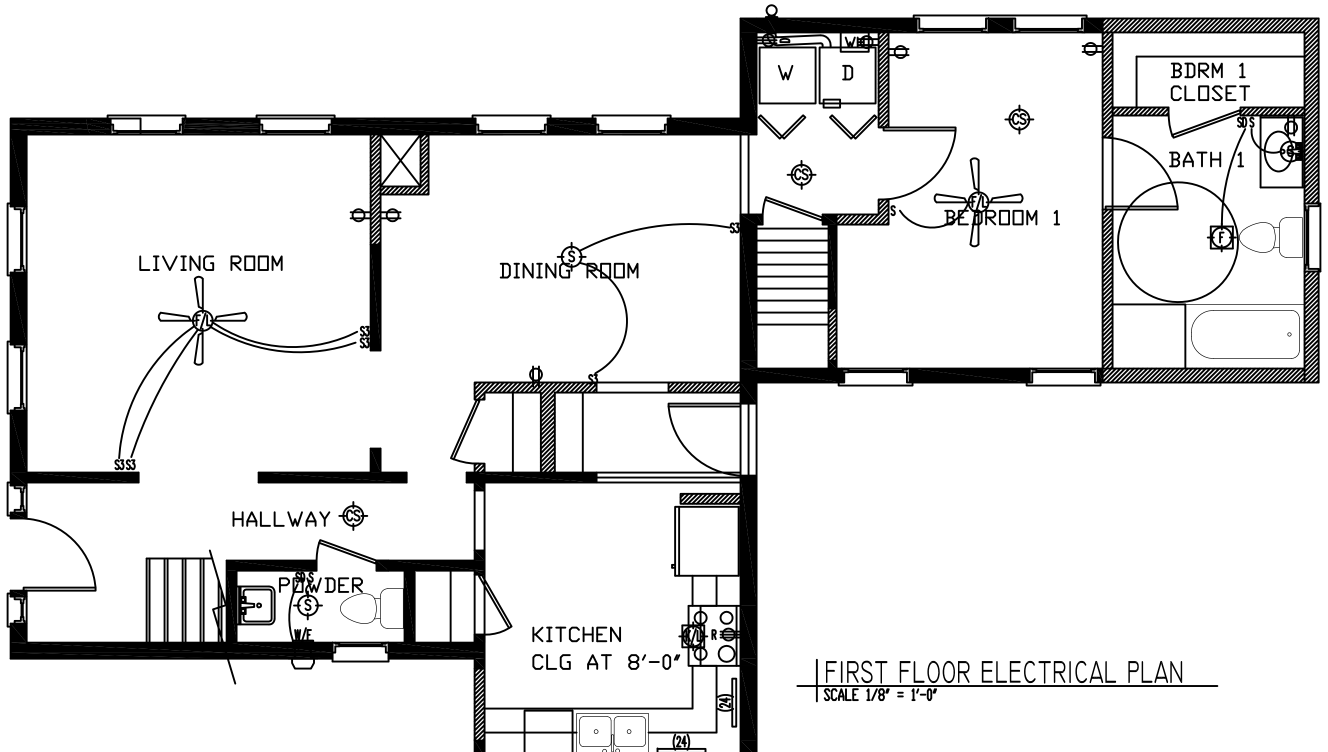
M-1



BASEMENT FLOOR ELECTRICAL PLAN
SCALE 1/8" = 1'-0"



SECOND FLOOR ELECTRICAL PLAN
SCALE 1/8" = 1'-0"



FIRST FLOOR ELECTRICAL PLAN
SCALE 1/8" = 1'-0"

NOTES:

1. EXISTING ELECTRICAL COMPONENTS ARE NOT SHOWN.
2. 20A 120V CIRCUIT TO AHU.
3. ALL WORK MUST COMPLY WITH MOST RECENT VERSION OF THE NATIONAL ELECTRIC CODE.

ELECTRICAL LEGEND

SYMBOL	DESCRIPTION
S	SURFACE MOUNTED LIGHT FIXTURE
Rc	RECESSED LIGHT FIXTURE (AIRTIGHT)
SD	SMOKE DETECTOR (INTERCONNECTED W/ BATTERY BACKUP)
CS	COMBINATION CARBON MONOXIDE/SMOKE DETECTOR (INTERCONNECTED W/ BATTERY BACKUP IF NEC.)
F	EXHAUST FAN
W/F	THROUGH-WALL FAN
F/L	KITCHEN EXHAUST FAN / LIGHT COMBINATION
(24)	FLUORESCENT STRIP LIGHT (SINGLE) (LENGTH IN INCHES)
C	CABLE TV / PHONE OUTLET
DB	DOOR BELL
T	THERMOSTAT
	110 VAC DUPLEX OUTLET
	110 VAC DUPLEX OUTLET (TOP SWITCHED)
GFI	110 VAC DUPLEX OUTLET (GROUND FAULT INTERUPTOR)
WP	110 VAC DUPLEX OUTLET (WATERPROOF)
D	DRYER OUTLET
R	RANGE OUTLET
S	SINGLE POLE SWITCH
SD	SINGLE POLE SWITCH W/ PROGRAMMABLE OFF DELAY
S3	THREE-WAY SWITCH
F/L	CEILING FAN/LIGHT COMBINATION
FUR	FURNACE

REVISED SET 10/20/2008
REVISED WINDOW DETAILS 10/21/2008
REVISED MECHANICAL, LAUNDRY RM AND SILL DETAILS 10/28/2008
REVISED DETAILS AND NEW DETAILS 11/4/2008

BUILDING SCIENCE CORPORATION

HABITAT FOR HUMANITY
FARMHOUSE

BUILDING ELECTRICAL PLAN

SCALE AS NOTED

E-1

Appendix D.2.7.2
Mechanical System Design

Project Report

General Project Information

Project Title:	MA Bedford Farmhouse Room By Room
Designed By:	Philip Kerrigan
Project Date:	04/2008
Client Name:	MA Bedford HfH
Company Name:	Building Science Corporation
Company Representative:	Philip Kerrigan Jr
Company Address:	70 Main Street
Company City:	Westford, MA 01886
Company Phone:	(978) 589-5100
Company Fax:	(978) 589-5103
Company E-Mail Address:	phil@buildingscience.com
Company Website:	www.buildingscience.com

Design Data

Reference City:		Bedford, Massachusetts
Daily Temperature Range:		Medium
Latitude:	41	Degrees
Elevation:	133	ft.
Altitude Factor:	0.995	
Elevation Sensible Adj. Factor:	1.000	
Elevation Total Adj. Factor:	1.000	
Elevation Heating Adj. Factor:	1.000	
Elevation Heating Adj. Factor:	1.000	

	Outdoor Dry Bulb	Outdoor Wet Bulb	Indoor Rel.Hum	Indoor Dry Bulb	Grains Difference
Winter:	3	0	30	72	30
Summer:	91	72	50	75	23

Check Figures

Total Building Supply CFM:	535	CFM Per Square ft.:	0.164
Square ft. of Room Area:	3,257	Square ft. Per Ton:	2,337
Volume (ft³) of Cond. Space:	30,380	Air Turnover Rate (per hour):	1.1

Building Loads

Total Heating Required With Outside Air:	29,415	Btuh	29.415	MBH
Total Sensible Gain:	12,544	Btuh	85	%
Total Latent Gain:	2,163	Btuh	15	%
Total Cooling Required With Outside Air:	14,708	Btuh	1.23	Tons (Based On Sensible + Latent)
			1.39	Tons (Based On 75% Sensible Capacity)

Notes

Calculations are based on 8th edition of ACCA Manual J.
All computed results are estimates as building use and weather may vary.
Be sure to select a unit that meets both sensible and latent loads.

Miscellaneous Report

System 1 Heating System Input Data	Outdoor Dry Bulb	Outdoor Wet Bulb	Indoor Rel.Hum	Indoor Dry Bulb	Grains Difference
Winter:	3	0	30	72	29.84
Summer:	91	72	50	75	22.98

Duct Sizing Inputs

	Main Trunk		Runouts	
Calculate:	Yes		Yes	
Use Schedule:	Yes		Yes	
Roughness Factor:	0.00300		0.01000	
Pressure Drop:	0.1000	in.wg./100 ft.	0.1000	in.wg./100 ft.
Minimum Velocity:	500	ft./min	450	ft./min
Maximum Velocity:	750	ft./min	500	ft./min
Minimum Height:	0	in.	0	in.
Maximum Height:	0	in.	0	in.

Outside Air Data

	Winter		Summer	
Infiltration:	0.100	AC/hr	0.100	AC/hr
Above Grade Volume:	X 23,976	Cu.ft.	X 23,976	Cu.ft.
	2,398	Cu.ft./hr	2,398	Cu.ft./hr
	X 0.0167		X 0.0167	
Total Building Infiltration:	40	CFM	40	CFM
Total Building Ventilation:	48	CFM	48	CFM

---System 1---

Infiltration & Ventilation Sensible Gain Multiplier:	17.52	= (1.10 X 0.995 X 16.00 Summer Temp. Difference)
Infiltration & Ventilation Latent Gain Multiplier:	15.55	= (0.68 X 0.995 X 22.98 Grains Difference)
Infiltration & Ventilation Sensible Loss Multiplier:	75.54	= (1.10 X 0.995 X 69.00 Winter Temp. Difference)

Load Preview Report

Scope	Has AED	Net Ton	Rec Ton	ft.²/Ton	Area	Sen Gain	Lat Gain	Net Gain	Sen Loss	Sys Htg CFM	Sys Clg CFM	Sys Act CFM	Duct Size
Building		1.23	1.39	2,337	3,257	12,544	2,163	14,708	29,415	337	535	535	
System 1	No	1.23	1.39	2,337	3,257	12,544	2,163	14,708	29,415	337	535	535	9x13
Ventilation						837	743	1,581	3,611				
Zone 1					3,257	11,707	1,420	13,127	25,804	337	535	535	9x13
1-Basement 1					694	119	18	137	3,473	45	5	5	1-4
2-Basement 2					370	83	12	95	2,257	29	4	4	1-4
3-Living Room					228	1,184	51	1,235	2,269	30	54	54	1-5
4-Dining Room					236	410	32	442	1,401	18	19	19	1-4
5-Hallway 1					100	518	28	546	957	12	24	24	1-4
6-Powder					32	165	13	178	446	6	8	8	1-4
7-Kitchen					149	2,023	452	2,475	1,184	15	92	92	1-6
8-Stairs 1					46	24	6	30	110	1	1	1	1-4
9-Laundry					22	677	15	692	295	4	31	31	1-4
10-Bedroom 1					188	1,219	438	1,657	2,022	26	56	56	1-5
11-Bed 1 Closet					42	88	22	110	429	6	4	4	1-4
12-Bath 1					83	355	32	387	796	10	16	16	1-4
13-Bedroom 2					235	1,733	64	1,797	2,981	39	79	79	1-6
14-Bed 2 Closet					32	144	22	166	475	6	7	7	1-4
15-Hallway 2					135	367	20	387	658	9	17	17	1-4
16-Bath 2					73	465	28	493	1,016	13	21	21	1-4
17-Bedroom 3					230	879	44	923	1,950	25	40	40	1-4
18-Storage 1					245	765	62	827	1,682	22	35	35	1-4
19-Storage 2					117	488	61	549	1,403	18	22	22	1-4

Total Building Summary Loads

Component Description	Area Quan	Sen Loss	Lat Gain	Sen Gain	Total Gain
Wood LoE: Glazing-MA Bedford Replacement/New Windows Wood Double Glazed Spectrally Selective LoE2 Glass, outdoor insect screen with 100% coverage, light color drapes with medium weave with 50% coverage, u-value 0.35, SHGC 0.37	295.4	7,137	0	4,027	4,027
Thermatru R-7: Door-MA Bedford Farmhouse Renovation	40.2	388	0	152	152
15B0-10sf-6: Wall-Basement, , R-10 board insulation to floor, no interior finish, 6' floor depth	1129.8	4,191	0	163	163
R-13 2x4 + R-20: Wall-Frame, , MA Bedford Farmhouse Existing Wall True 2x4 16"o.c. (R-14) Cellulose 2" Foil Faced Polyisocyanurate (R-20) Sheathing	2798.9	7,532	0	1,419	1,419
R-21 + R-20 Rigid: Roof/Ceiling-Roof Deck (roofing, wood, insulation) or SIP Panels Supported on Beams, Custom, MA Bedford Farmhouse Renovated Roof 2x4 Existing Rafters + R-21 Spray Foam 2 Layers of 1.5" Foil Faced Polyisocyanurate R-20	1233.8	2,146	0	2,207	2,207
21B-20: Floor-Basement, Concrete slab, any thickness, 2 or more feet below grade, R-3 or higher insulation installed below floor, any floor cover, shortest side of floor slab is 20' wide	1063.7	1,394	0	0	0
Subtotals for structure:		22,788	0	7,968	7,968
People:	4		800	920	1,720
Equipment:			0	1,800	1,800
Lighting:	0			0	0
Ductwork:		0	0	0	0
Infiltration: Winter CFM: 40, Summer CFM: 40		3,016	620	701	1,321
Ventilation: Winter CFM: 48, Summer CFM: 48		3,611	743	837	1,581
AED Excursion:		0	0	318	318
Total Building Load Totals:		29,415	2,163	12,544	14,708

Check Figures

Total Building Supply CFM:	535	CFM Per Square ft.:	0.164
Square ft. of Room Area:	3,257	Square ft. Per Ton:	2,337
Volume (ft³) of Cond. Space:	30,380	Air Turnover Rate (per hour):	1.1

Building Loads

Total Heating Required With Outside Air:	29,415	Btuh	29.415	MBH
Total Sensible Gain:	12,544	Btuh	85	%
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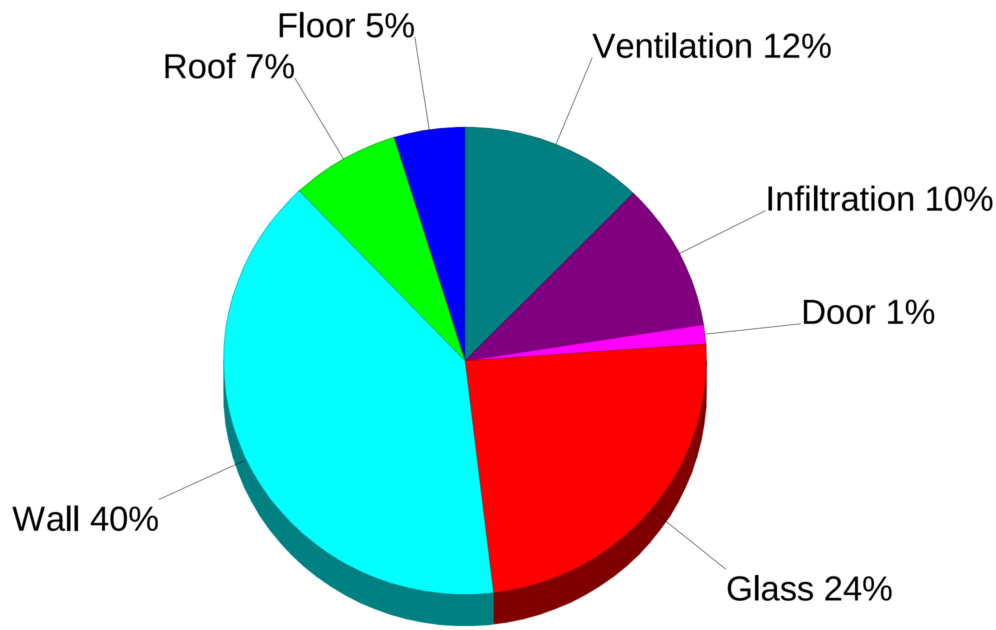
Total Cooling Required With Outside Air:	14,708	Btuh	1.23	Tons (Based On Sensible + Latent)
			1.39	Tons (Based On 75% Sensible Capacity)

Notes

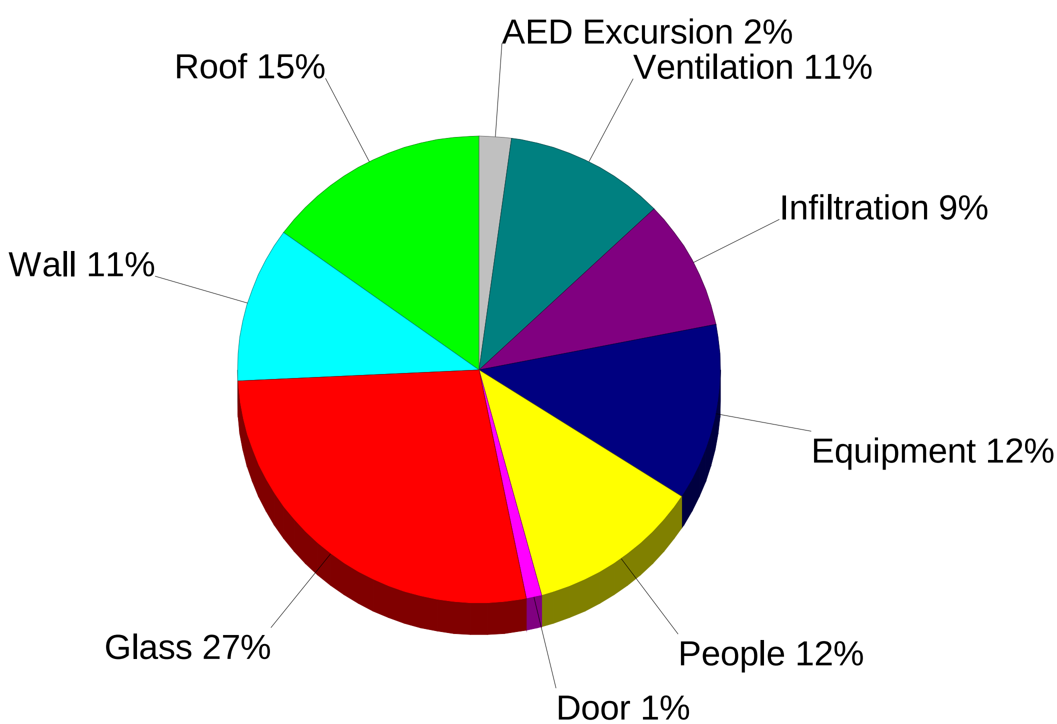
Calculations are based on 8th edition of ACCA Manual J.
All computed results are estimates as building use and weather may vary.
Be sure to select a unit that meets both sensible and latent loads.

Building Pie Chart

Building
Loss
29,415
Btuh



Building
Gain
14,708
Btuh



MA Bedford Farmhouse: Bedford, MA

Duct Layout

Orientation of Front of House: W

	RHVAC program output					
	Heating Load (kBtu/h)	29.4	**BSC Spec**	**BSC Spec**	**Air Velocity**	**BSC Spec**	**Air Transfer**
	Sensible Cooling Load (kBtu/h)	12.5					
	Latent Cooling Load (kBtu/h)	2.2	**Propos Qty**	**Propos Dia**	**FPM Average**	**Flow per Register**	**Free Area**
	Total Cooling Load (kBtu/h)	14.7					
				(in)	(ft/min)	(CFM)	(in^2)
	Room Air Flow (cfm)						
1	Basement 1	5	1	4	57	5	
2	Basement 2	20	1	4	229	20	
3	Living Room	54	1	5	396	54	
4	Dining Room	19	1	4	218	19	
5	Hallway 1	24	1	4	275	24	
6	Powder	8	1	4	92	8	
7	Kitchen	92	1	6	469	92	
8	Stairs 1	1	1	4	11	1	
9	Laundry	31	1	4	355	31	
10	Bedroom 1	56	1	5	411	56	25
11	Bed 1 Closet	4	1	4	46	4	
12	Bath 1	16	1	4	183	16	
13	Bedroom 2	79	1	6	402	79	30
14	Bed 2 Closet	7	1	4	80	7	
15	Hallway 2	17	1	4	195	17	
16	Bath 2	21	1	4	241	21	
17	Bedroom 3	40	1	4	458	40	6
18	Storage 1	35	1	4	401	35	
19	Storage 2	22	1	4	252	22	

Totals:	551
Front Supply	366
Rear Supply	185

Main System Duct and Grille Sizing

	Width	Height		
Main Supply Trunk	14.40	12		**14x12 Main Trunk**
Front Supply Trunk	10.54	10		**11x10 Front Trunk**
Rear Supply Trunk	6.66	8		**7x8 Rear Tru**
Return Trunk	13.09	12		**13x12 Return Trun**
Return Grille	17.14	18		**17x18 Return Grille**
Condensing Unit Size				**1.5 Ton Condenser**
Airhandler Size				**1.5 Ton Airhandler**
Return Airflow at (400 cfm/ton)			600	
Return Grille Design velocity (FPM)			350	
Return Grille free area (%)			80%	
Supply Trunk Design velocity (FPM)			500	
Return Trunk Design velocity (FPM)			550	

Appendix D.2.7.3
Example Site Visit Report

Memo of Record

From:	Ken Neuhauser, Building Science Corporation	Date:	October 30, 2008
To:	Betsy Pettit, Building Science Corporation	Re:	Bedford Farmhouse Renovation Site Visit Report

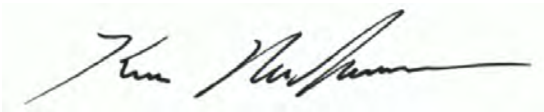
Betsy-

Here's a couple of things I want to bring to your attention regarding the Bedford farmhouse:

1. The addition at the back is about 20" *narrower* than we have in our plans. I believe we can still accommodate a 3-0 door into the barrier free bedroom by adjusting the laundry closet depth (with the water heater above, we only need enough space behind the machines for the dryer exhaust) and having the door be closer to the North wall. As long as the homeowners don't have a sleigh bed in that bedroom, there should still be room to get around to both sides of the bed with at least 2'-8" clear to each side of the bed. I'm going to redraw the plan presently.
2. The Bedroom 1 bath is framed at 8'-0" x 10'-7" inside the framing. This is as we have it drawn. However, this leaves the closet at only 38" wide. At this width the closet door will need to open into the bathroom. We have room to widen the closet 8" and still keep the 3-0 bathroom door 6'-8" from the North wall (to accommodate the bed).
3. The opening between the main house and the back addition does not have a header. It should. The opening is 35" clear between two studs that do not support anything (see attached photos "opening to addition"). There is 41" between posts that appear to be doing work so I think it would be possible to support a header at the opening and still have 36" clear into the back addition.
4. Jim indicated that he intends to drop a ceiling over the kitchen to about 8' to give room for plumbing. This could probably also accommodate the duct to the upstairs bath and eliminate the need for a plumbing and HVAC chase that we had right next to the rear/side entry.
5. The framing above the dining room is running East-West and the ceiling is already opened up. It looks like it would be able to accommodate the duct to Bedroom 3 (Southwest). However, there is a 6x6 beam in the ceiling between dining room and living room that would preclude a duct running to Bedroom 2 (Southeast) in the joist space. I think we should simply take the Bedroom 2 duct up through the chase in the closet (where we plan to run the furnace vent and intake) and then have a wall register into Bedroom 2. I ran this by Phil and he informed me that Armin would prefer we use wall registers instead of floor registers where feasible.
6. We did not previously detail the air barrier at roof-wall intersections (e.g. addition roof meeting wall, kitchen bump-up meeting wall). I have a plan for this. In most cases it will be similar to the air barrier transition. Where we have roof rake returns over the wall(ref. photo "Wall_roof at addition_3" attached), I'll have to think of something.
7. Shawsheen was installing the roof rake extension framing on the main roof. The way they installed the framing (e.g. not exactly like the drawing) will require a different air

barrier transition than I had drawn. Jim and I discuss how the air barrier transition would be achieved. I will draw it.

Field notes also attached.



-Ken

Field Notes

Organizations/Personnel on site:

Shawsheen – Senior construction crew (~10), Rick (project manager),

Whole Foods volunteers (~10)

Habitat – Jim Comeau,

Principal activities ongoing:

Shawsheen – eave extension framing, roof rake construction on main house, framing openings in 1st floor South wall of main house

Volunteers – splitting wood, covering lumber with plastic

Habitat – volunteer coordination

Decisions/agreements with construction crew:

1. capillary break membrane to be affixed directly to bottom of sill (new or existing) and will be on top of grout
2. where metal shims are used, a slip sheet of metal flashing will be used above the shim to protect the capillary break membrane.
3. rake and eave will use 1x12 soffit board. This shortens the overhang “by an inch or so”.

Questions to resolve/items to confirm:

1. Air barrier at main roof rake. Actual construction differs from detail. An alternate solution discussed with Jim Comeau
2. Air barrier at addition eave
3. Air barrier at addition gable
4. Air barrier at roof wall intersections especially with rake of addition roof returning over the wall of the main house.

Actionable requests: none

Observations:

1. Opening to addition lacks a header. Existing vertical framing 35” apart with the vertical bearing members spaced wider at 41” apart.
2. Width of addition inside framing 14’-1 ½”. This is 1’-8 ½” *narrower* than shown on our plans.
3. Bath 1 is 8’-0” deep inside framing
4. Closet 1 is 38 ½” wide inside framing. This is ~1’-8” narrower than shown on our plans

5. Opening between kitchen and side entry already has 6x6 beam where our drawing calls for a header
6. Jim Comeau plans to drop a ceiling over the kitchen to ~8'. Ceiling in adjacent dining room is ~8'-9".
7. Framing above dining room runs East-West and appears able to accommodate a duct between joists to Bedroom 3.
8. A beam (~6x6) is in the ceiling between Living Room and Dining room. This appears to preclude running a duct in the joist space to Bedroom 2.

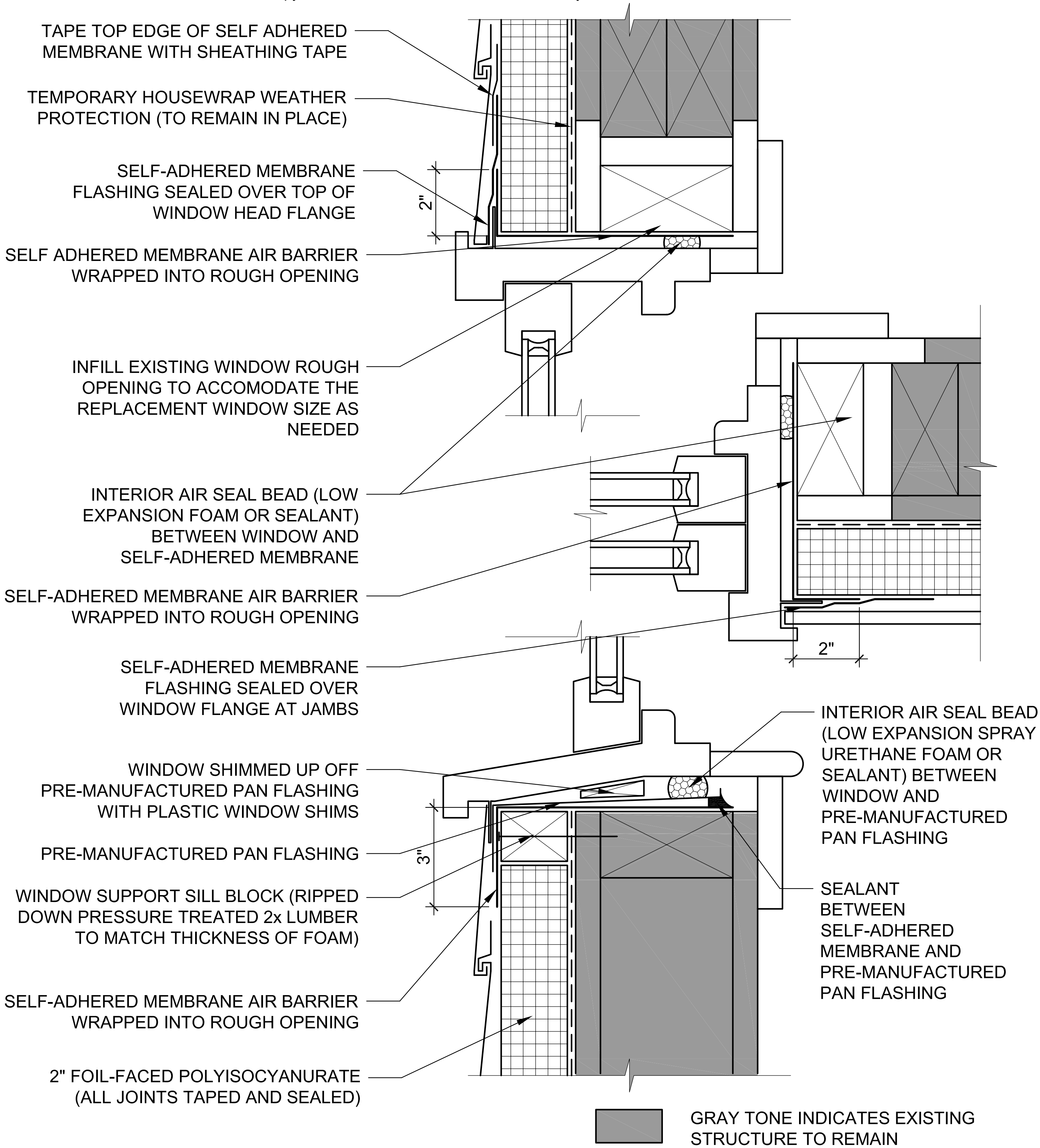
Figure 1: Opening to addition_1.JPG

Figure 2: Opening to addition_2.JPG

Figure 3: Opening to addition_3.JPG

Figure 4: Wall_roof at addition_3

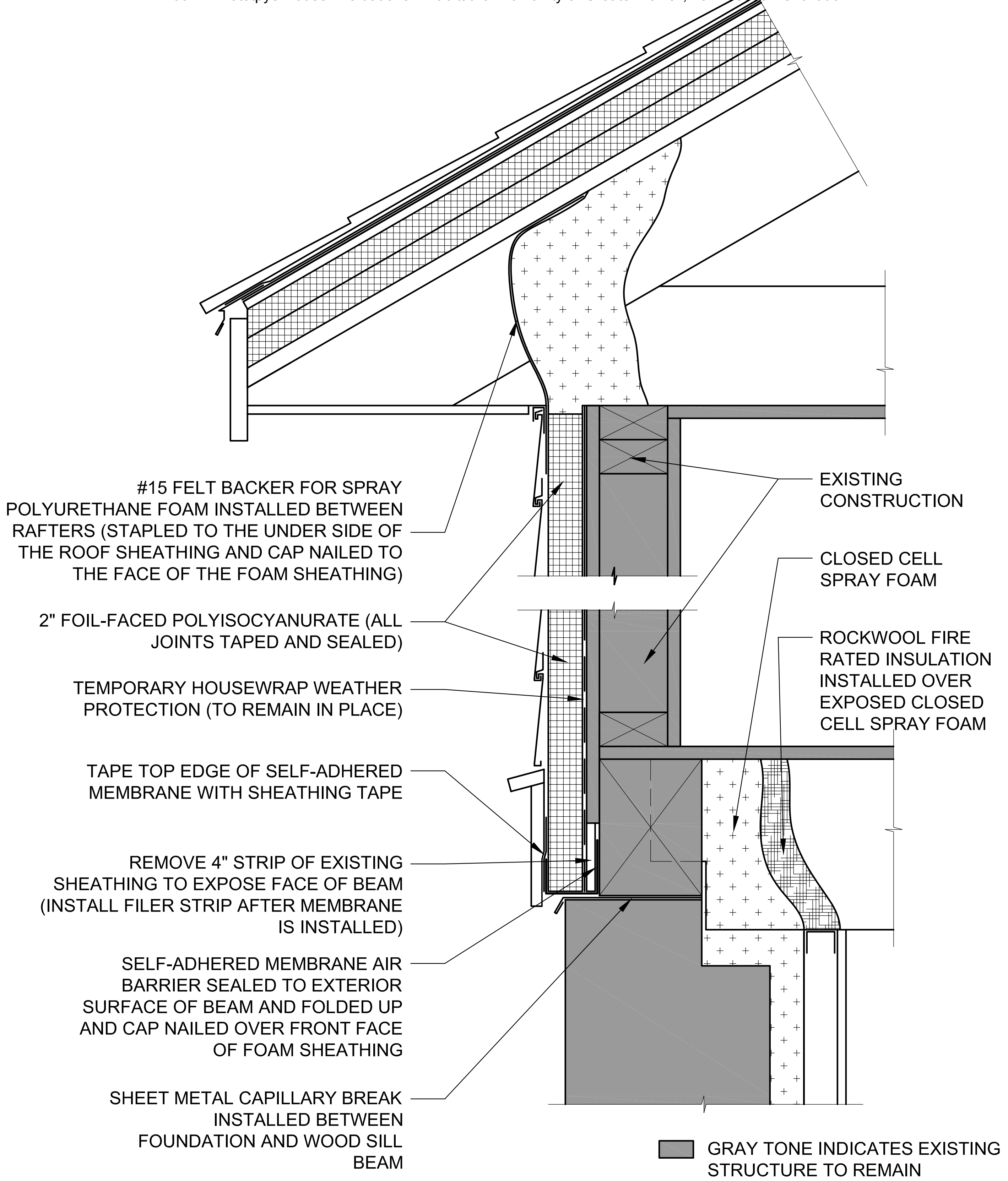
Appendix D.2.7.4
Complete SK Set



Project: BEDFORD FARMHOUSE RENOVATION
Date: 2008-09-23
Drawing Title: REPLACEMENT WINDOW DETAILS
Drawing File: 080923 Bedford Farmhouse
Drawing Scale: 3" = 1' - 0"

Sheet Title:

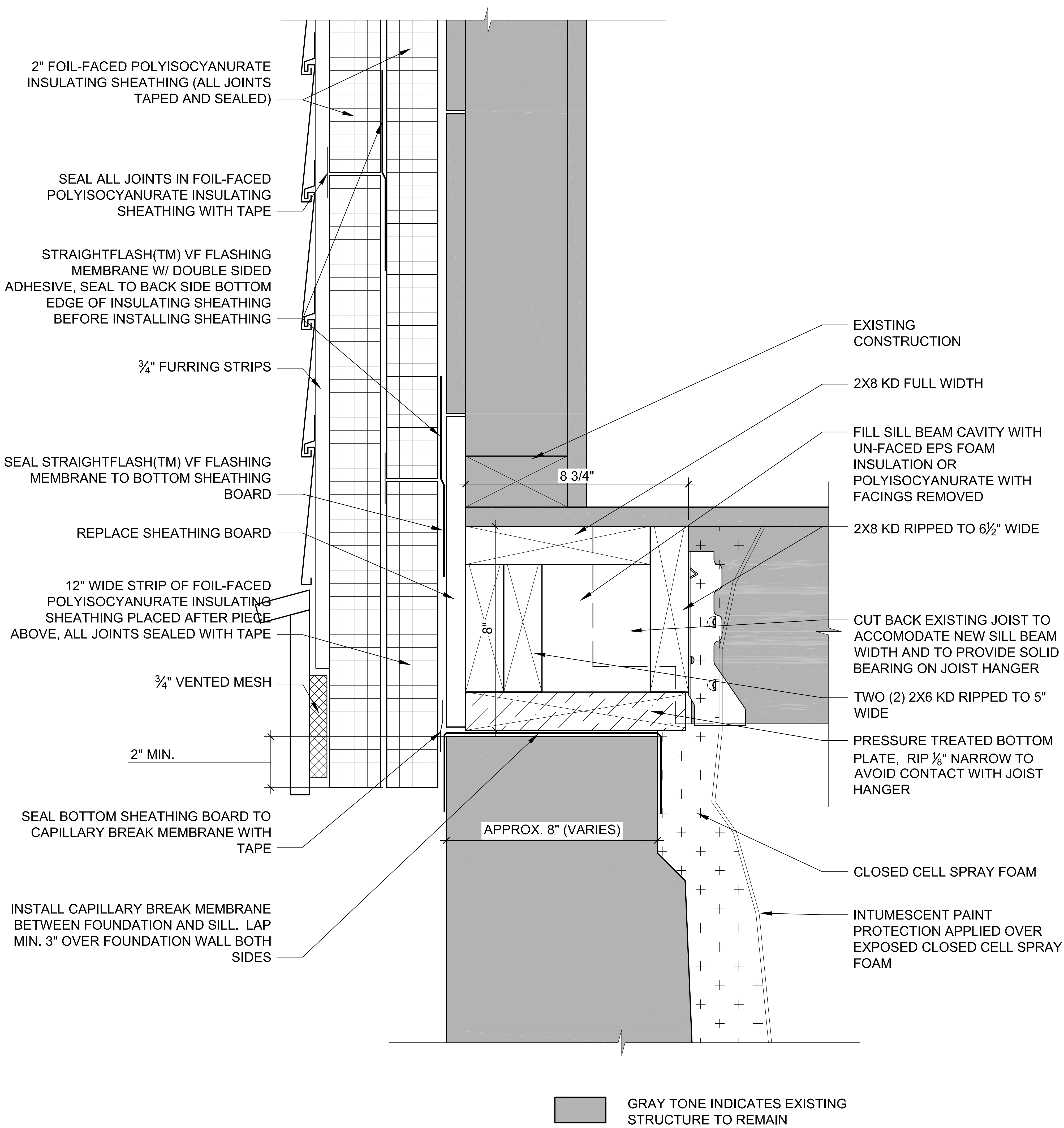
SK-01



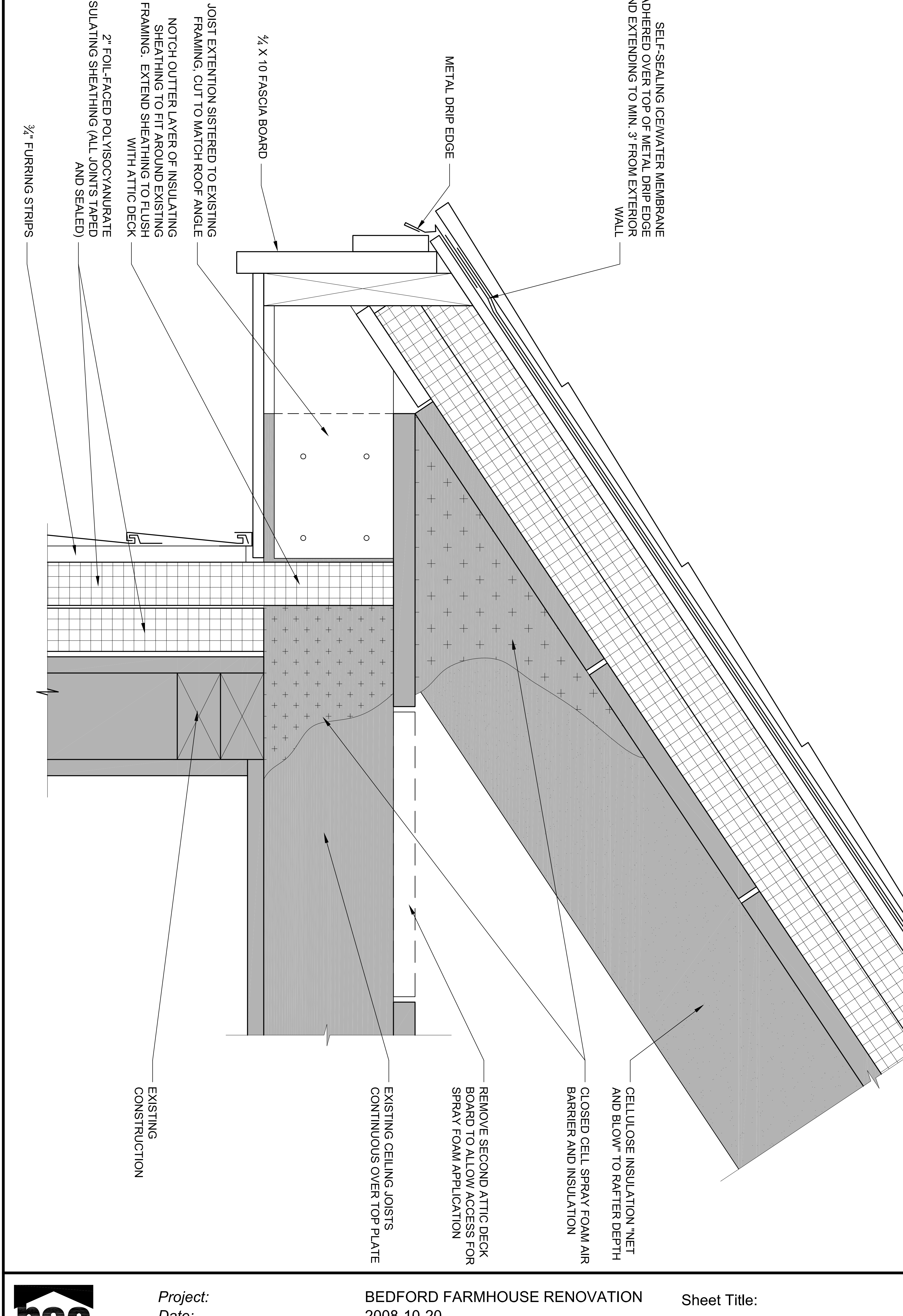
Project:	BEDFORD FARMHOUSE RENOVATION
Date:	2008-09-23
Drawing Title:	INSULATING SHEATHING WALL DETAIL
Drawing File:	080923 Bedford Farmhouse
Drawing Scale:	1 1/2" = 1' - 0"

Sheet Title:

SK-02



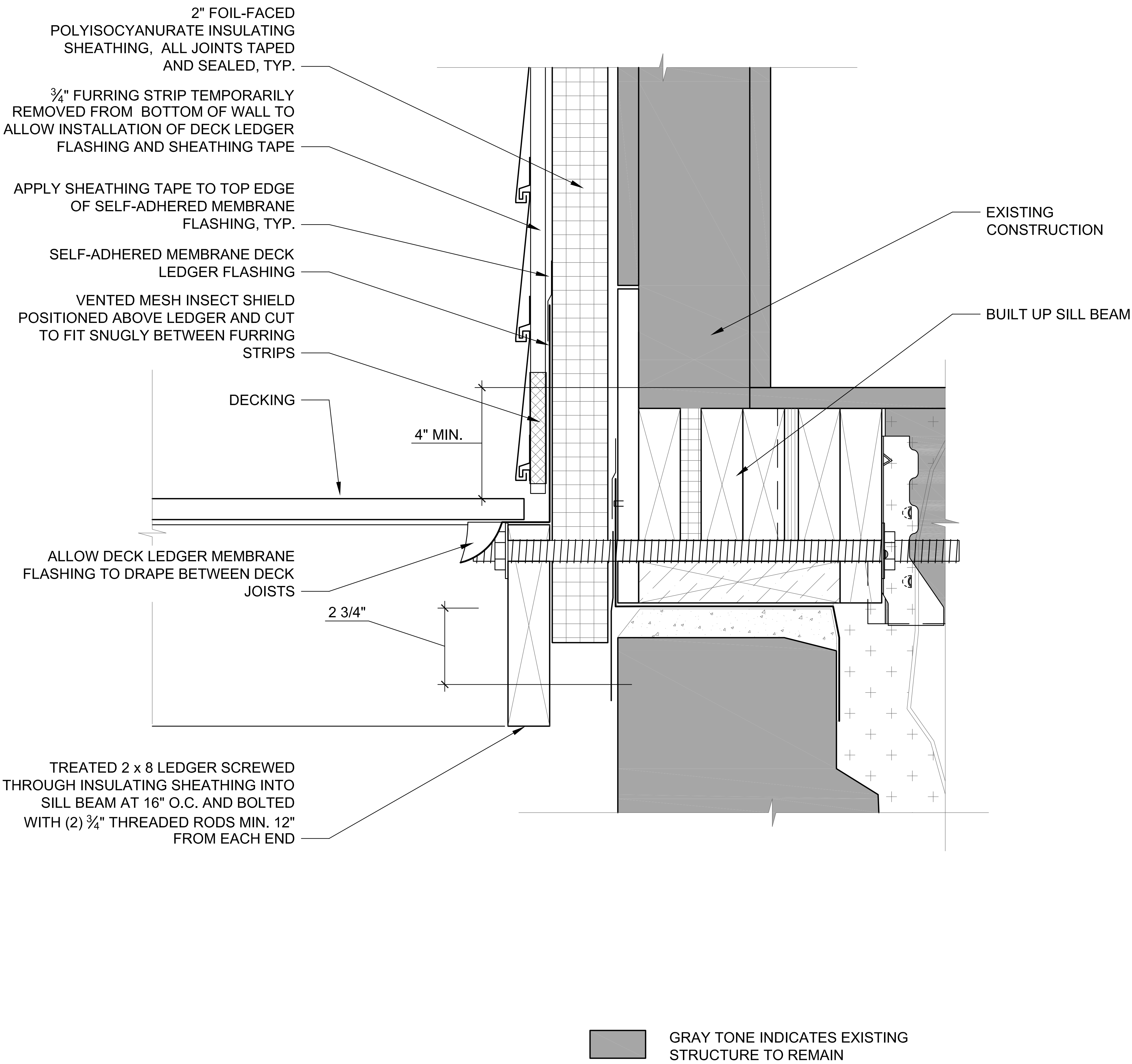
Project:	BEDFORD FARMHOUSE RENOVATION	Sheet Title:
Date:	2008-10-20	SK-03
Drawing Title:	SILL AND BASE OF WALL DETAIL	
Drawing File:	081013 Bedford Farmhouse	
Drawing Scale:	3" = 1' - 0"	



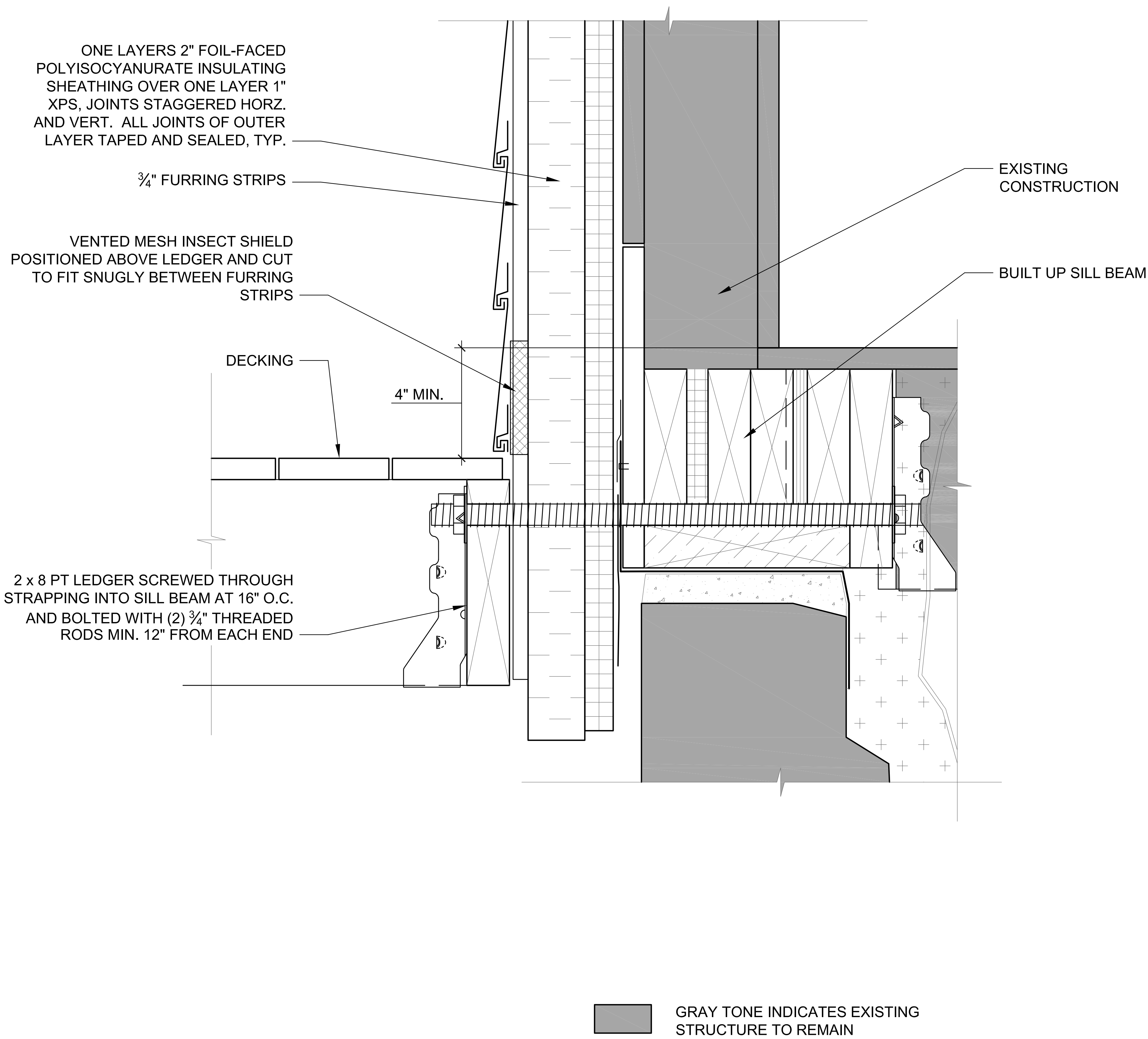
Project:	BEDFORD FARMHOUSE RENOVATION
Date:	2008-10-20
Drawing Title:	UPPER ROOF EDGE DETAIL
Drawing File:	081013 Bedford Farmhouse
Drawing Scale:	3" = 1' - 0"

Sheet Title:

SK-04



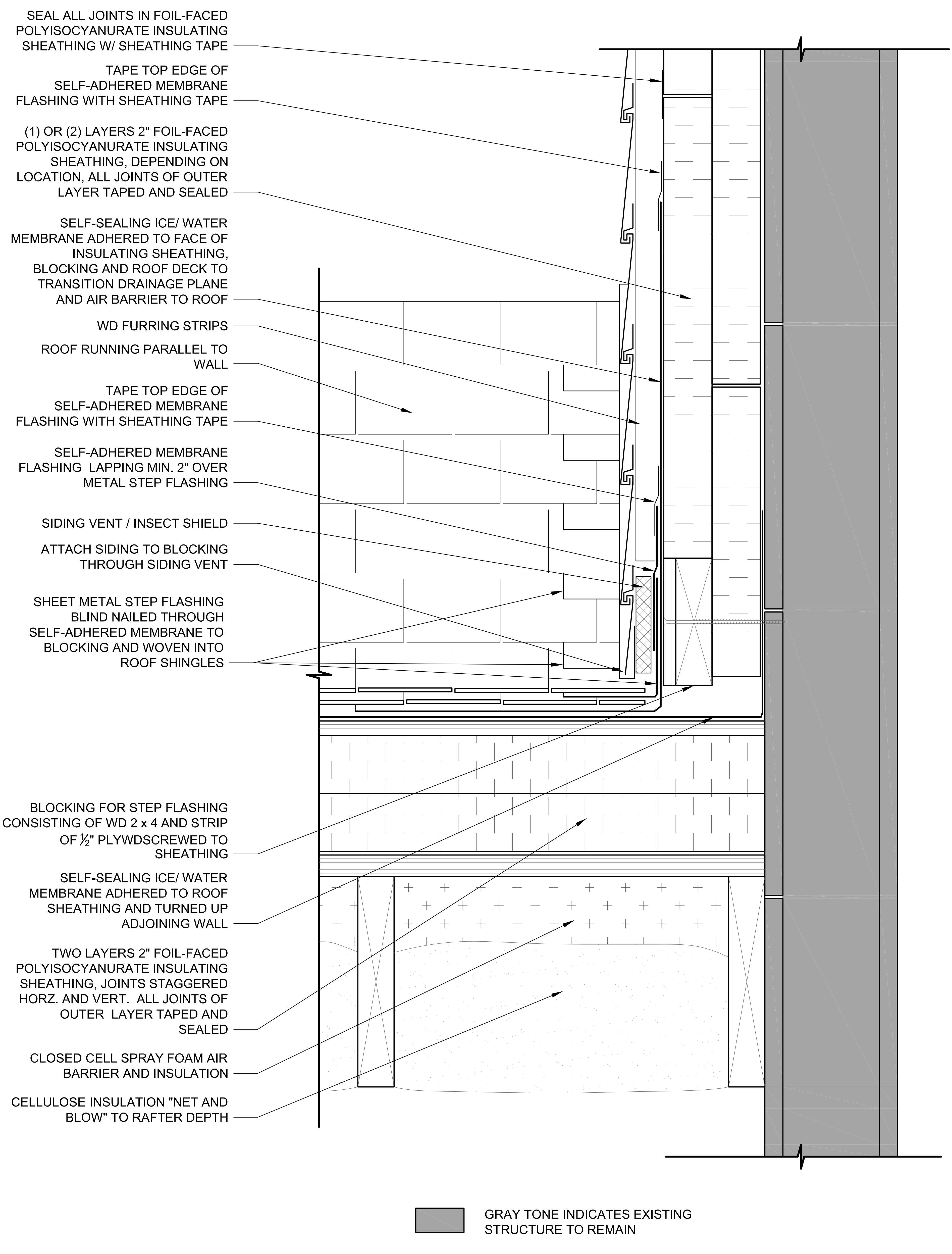
Project:	Bedford Farmhouse Renovation	Sheet Title:
Date:	2009.02.05	SK-05
Drawing Title:	DECK LEDGER AT WEST (KITCHEN) WALL	
Drawing File:	090203 Bedford Farmhouse Details.dwg	
Drawing Scale:	3" = 1' - 0"	



Project:	Bedford Farmhouse Renovation
Date:	2009.02.05
Drawing Title:	DECK LEDGER AT NORTH (ADDITION) WALL
Drawing File:	090203 Bedford Farmhouse Details.dwg
Drawing Scale:	3" = 1' - 0"

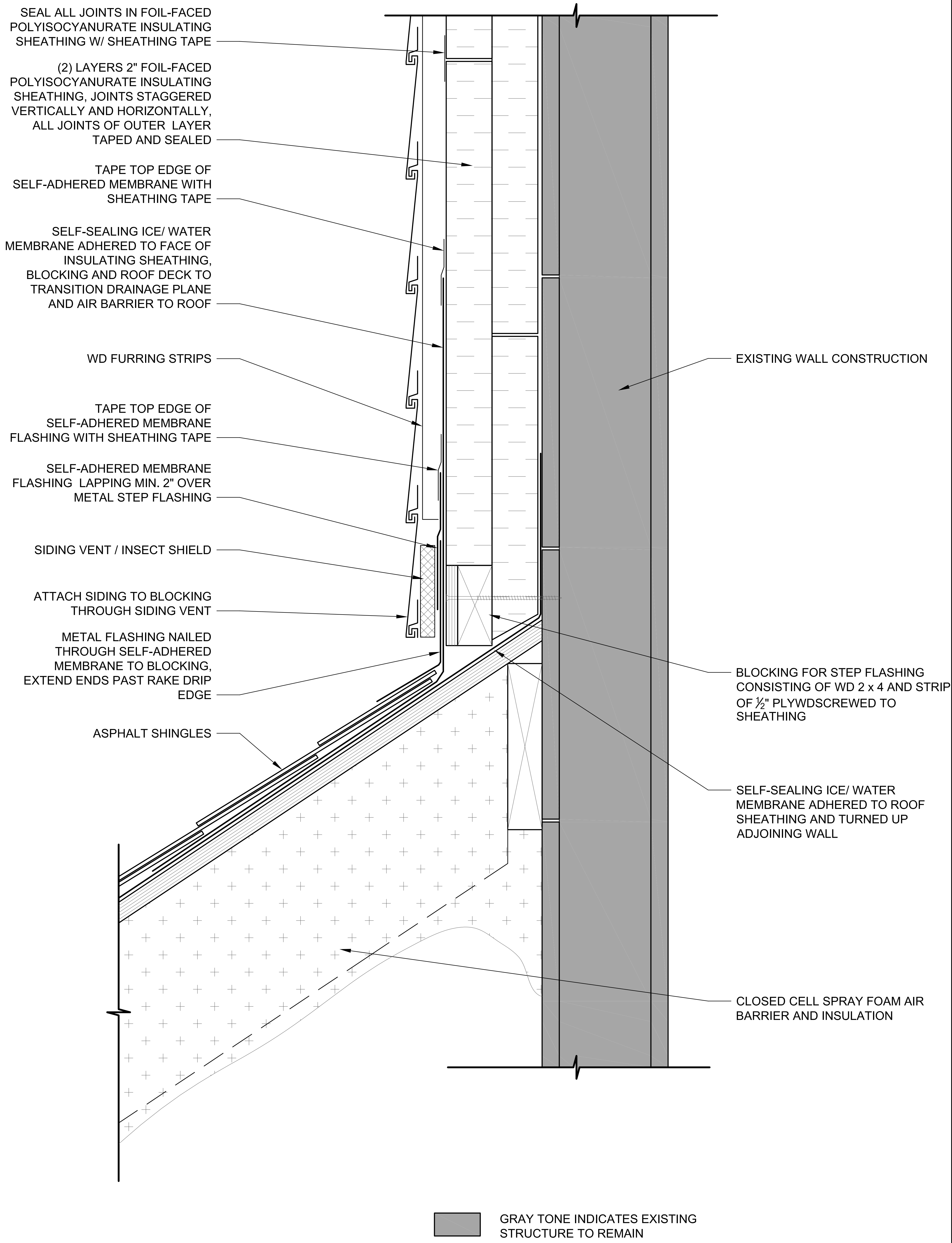
Sheet Title:

SK-06

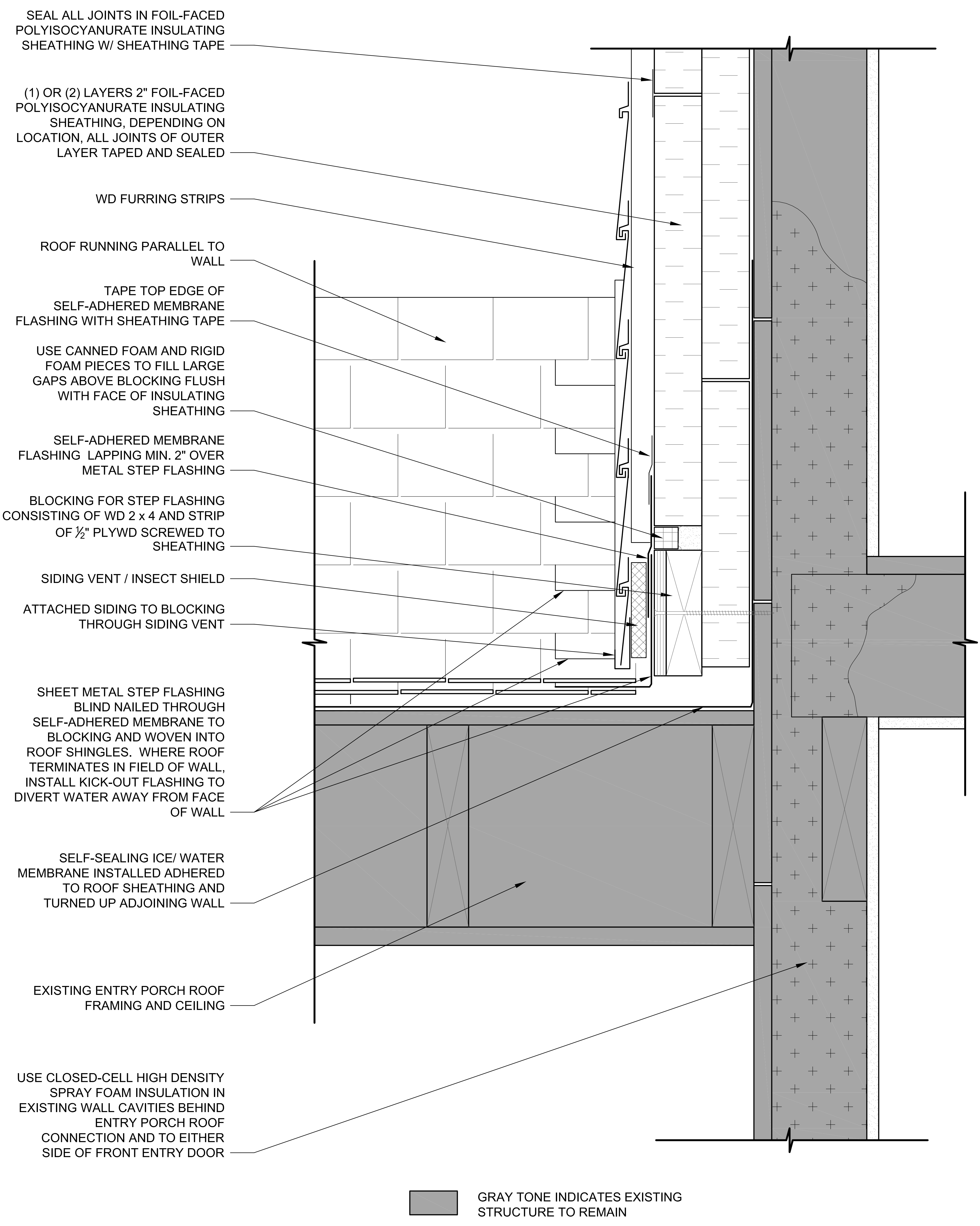


bsc

Project:	Bedford Farmhouse Renovation	Sheet Title:
Date:	2009.02.09	SK-07
Drawing Title:	ROOF-WALL CONNECTION, ROOF PARALLEL	
Drawing File:	090203 Bedford Farmhouse Details.dwg	
Drawing Scale:	3" = 1' - 0"	



Project:	Bedford Farmhouse Renovation	Sheet Title:
Date:	2009.02.09	
Drawing Title:	ROOF-WALL CONNECTION AT KITCHEN ROOF	SK-08
Drawing File:	090203 Bedford Farmhouse Details.dwg	
Drawing Scale:	3" = 1' - 0"	

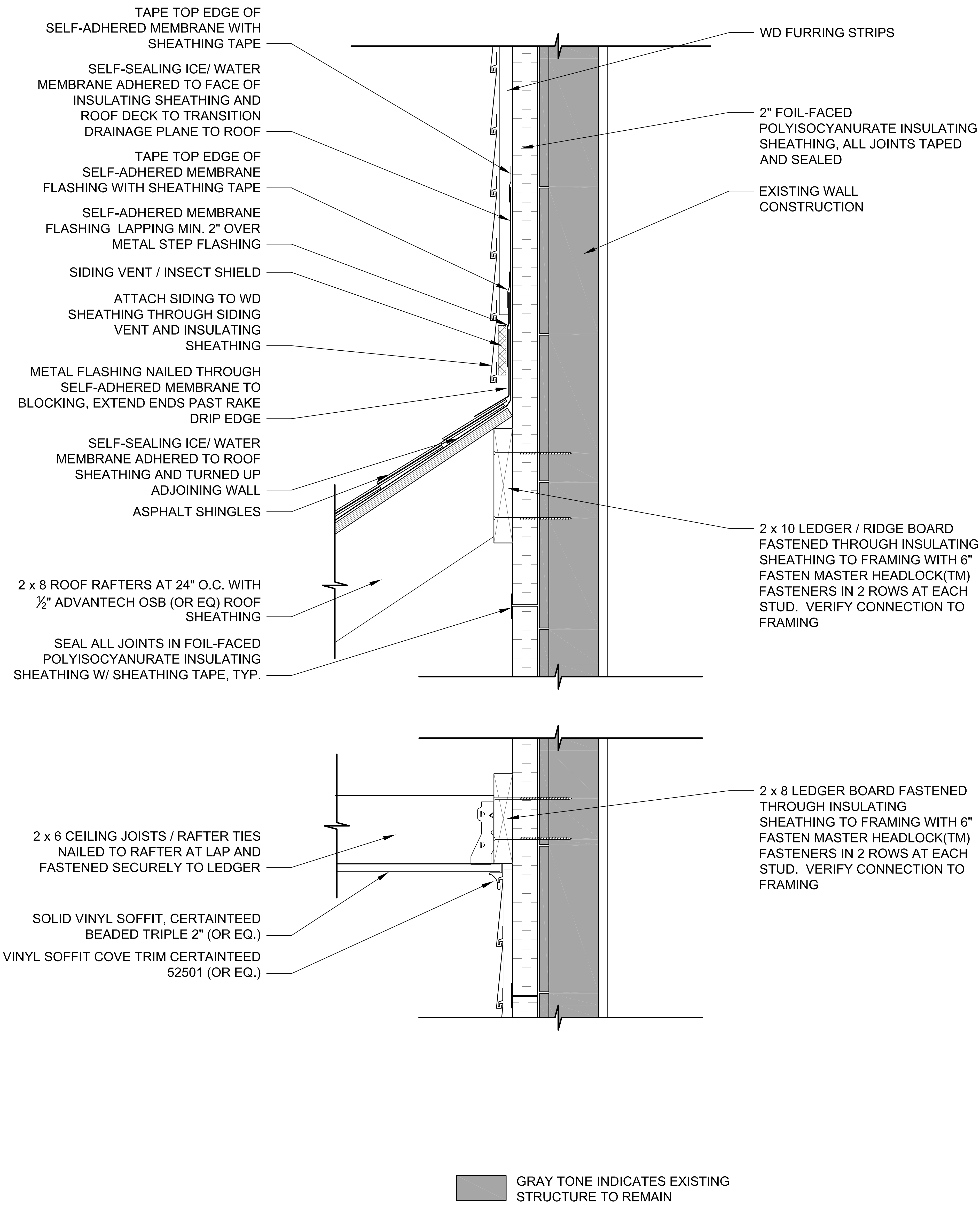


bsc

Project:	Bedford Farmhouse Renovation
Date:	2009.02.09
Drawing Title:	ROOF-WALL CONNECTION AT FRONT ENTRY
Drawing File:	090203 Bedford Farmhouse Details.dwg
Drawing Scale:	3" = 1' - 0"

Sheet Title:

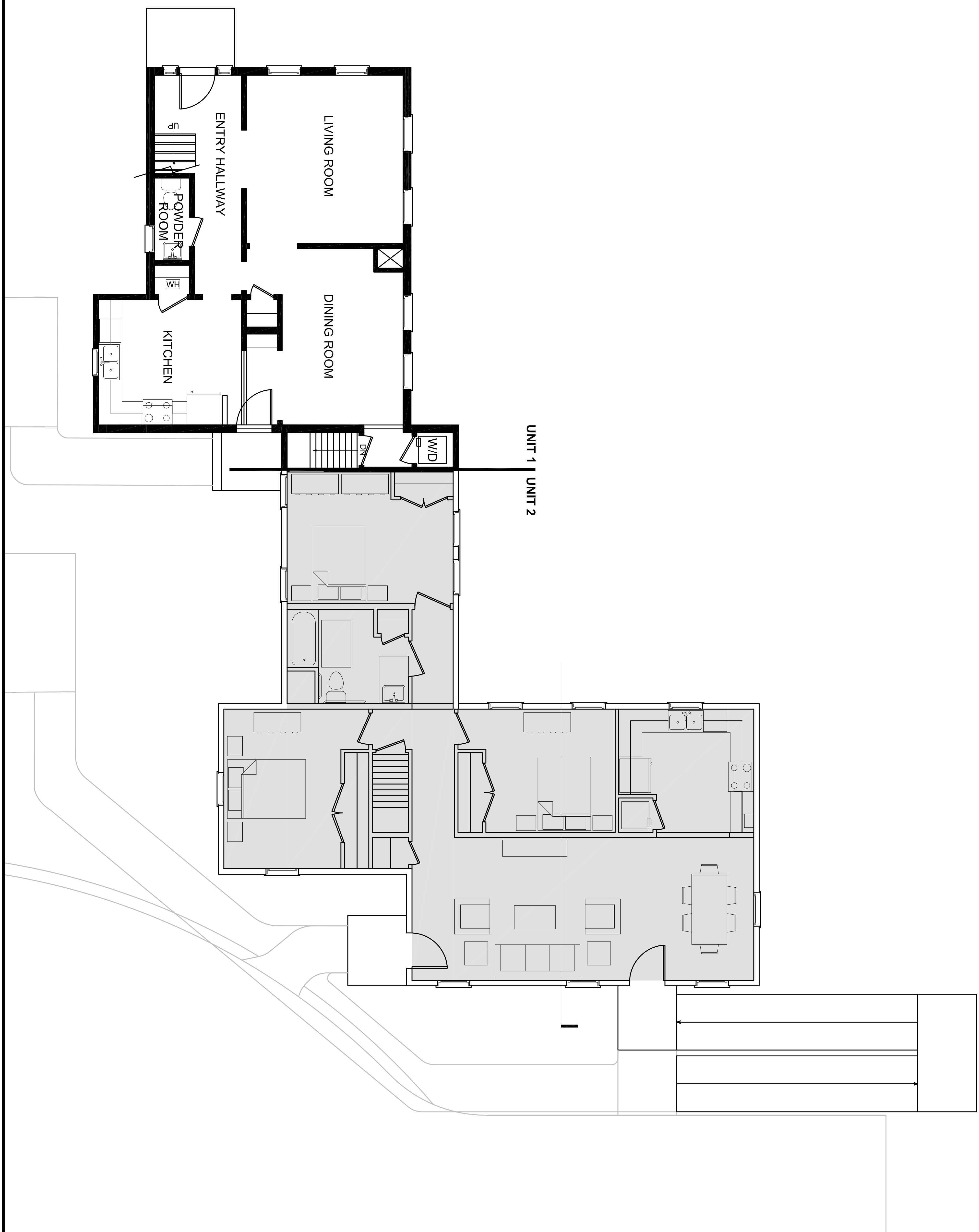
SK-09



Project:	Bedford Farmhouse Renovation
Date:	2009.02.09
Drawing Title:	ROOF-WALL ABOVE KITCHEN ENTRY
Drawing File:	090203 Bedford Farmhouse Details.dwg
Drawing Scale:	1 1/2" = 1' - 0"

Sheet Title:

SK-10



Project:	BEDFORD FARMHOUSE RENOVATION
Date:	2009-05-12
Drawing Title:	REVISED UNIT 1 FIRST FLOOR LAYOUT
Drawing File:	PP_MA Farmhouse
Drawing Scale:	1/8" = 1' - 0"

Sheet Title:

SK-11

Appendix D.2.7.5
Project Guidance Memoranda

Project Memorandum

From:	Ken Neuhauser, Building Science Corporation	Date:	February 04, 2009
To:	Jim Comeau, Habitat for Humanity of Greater Lowell	Re:	Bedford Farmhouse Renovation – 1) Kitchen entry deck support 2) Roof-wall water management 3) Air barrier implementation 4) HVAC design implementation 5) Siding at windows 6) Radon vent routing
Cc:	Betsy Pettit, Building Science Corporation		

Dear Jim Comeau:

This is to follow up on discussions we had on site Monday, February 2 and address some of your questions raised since then. If you have any questions, you can reach me as per the contact information below.

Thank you,

Ken Neuhauser
ken@buildingscience.com
617 800 2633 x5279

Kitchen Entry Deck Support

The deck ledger is not to provide structural support for deck. Footings, as constructed for the side entry of the Westford project, are needed to support the deck. We will provide a sketch of approximate footing location and deck framing.

Water Management at Roof-Wall Connections

On Monday, I noted that some of the water management details at roof-wall connections had not been properly implemented.

Roof Running Parallel to Wall

This occurs at the front entry, where the one-story addition meets the two story section and for a small portion where the rake of the roof over the kitchen returns over the rear wall of the house.

Figure 1 - Roof over front entry

A kick-out flashing is needed where the wall terminates in the field of the wall.

At the roof over the front entry, the drainage plane is not transferred to the roof. Where the ice and water membrane is currently installed, it could direct water into the wall assembly. To remedy this condition, membrane should be installed over the vertical leg of the step flashing, adhered to the wood blocking and continue up the foil facing. The top edge of the membrane is then taped.

Where the top of the roof terminates over the field of the wall, as at the rake return of the roof over the kitchen, there should be a saddle flashing.

Shed Roof Running Perpendicular to the Wall

This occurs over the kitchen and where the roof of the first story addition returns over the South wall of the two story section. Ideally the drainage plane and air barrier of the wall (face of foam) would be transitioned directly from the face of the foam to the roof. The shed roof over the kitchen as well as the wall over the one story addition was shingled and flashed back to the wood wall sheathing as per conventional practice. This is not a conventional practice structure. The fix for the shed roof connection (not ideal, but acceptable) is the following:

1) Install a metal flashing flush with the foil facing and over the current wall-roof flashing. The metal flashing must extend past the rake edge that terminates in the field of the wall.

2) Apply membrane from face of foam over the metal flashing.
3) Tape top edge of membrane.

Where the new roof piece over the kitchen entry connects to the wall we have the opportunity to transition the drainage plane and air barrier from the face of the foam to the roof deck.

Air Barrier Implementation

In general, it appears that the air barrier concept has not caught on with the crews. There are several places with large gaps between sheets of foam. The foam corners are very loose with no membrane applied. In some cases, furring would need to be removed to apply membrane over the corners.

Figure 2 - Gaps in Foam Sheathing

Figure 3 - Foam Sheathing Corner

The front gable wall does appear to be handled very well in terms of the air barrier. In this area, there are two layers of foam sheathing, the second layer was notched into the rake framing, and the rake soffit panel was removed to allow sealing of the foam sheathing to the framing and roof deck. The roof eaves have a good system where the wall sheathing foam extends up past the wall and is notched into the roof framing. At these locations, spray foam applied from the interior will connect the wall air barrier to the roof.

Other roof wall connections, such as that shown in Figure 4, show a lapse in the air barrier continuity. The air barrier foam sheathing should be air sealed to the underside of the roof sheathing where possible. Where this is not possible, the air barrier foam sheathing should be sealed to roof framing and these framing members then sealed to the roof sheathing.

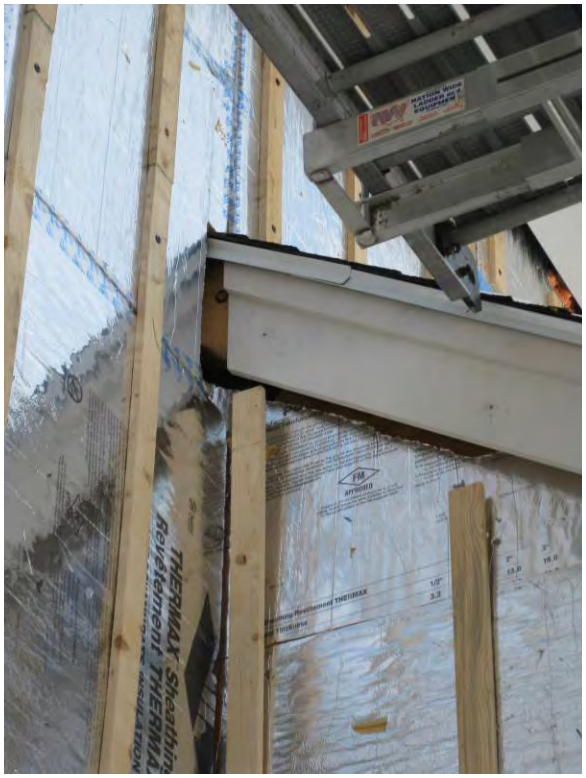


Figure 4 - Wall to Roof Connection

HVAC Design Implementation

The Shawsheen HVAC faculty mentioned that somebody in his shop is doing the load and sizing calculations. We have already done these and designed the system accordingly. If the Shawsheen folks want to build the system differently than we have designed it, then we should have a conversation to resolve any discrepancies.

Siding at Windows

It was demonstrated on Monday that siding would tend to bow out if inserted into the siding channels of the windows. You and I had previously discussed that, although the siding channel are designed to work with vinyl siding in conventional installations, the siding channel of these windows is not made in a way that is compatible with the use of furring strips such as we have on this project. We maintain that there needs to be some other means to close the siding around the windows.

Radon Vent Routing

You had expressed concern about how the plumber is routing the radon vent citing several 90 degree bends and horizontal runs. The Plumber must run the pipe in accordance with the Environmental Protection Agency guide titled "Building Radon Out" available at http://www.epa.gov/radon/rrnc/index.html or ASTM 1465 "Standard Practice for Radon Control Options for the Design and Construction of New Low-Rise Residential Buildings". While the EPA guide recommends that the vent run be as straight and direct as possible, I do not find any prohibition of bends or horizontal runs. Specifically, the guide recommends the following:

- 45 degree fittings to reduce friction
- horizontal sections sloped back to drain 1/8" per foot

- insulate the pipe through unheated areas (e.g. if you had a vented attic space which we don't at the farmhouse but will in the new construction houses)
- label the pipe at minimum 1) where it exists the slab, 2) where it is visible in closets, 3) where it runs through attics
- 1/4 inch mesh screen on pipe discharge

Project Memorandum

From:	Ken Neuhauser – Building Science Corporation	Date:	February 11, 2009
To:	Jim Comeau – Habitat for Humanity of Greater Lowell	Re:	Bedford Farmhouse Renovation – 1) Sequence for implementation of roof-wall details (SKs 07-10) 2) Non-bearing beam penetration above kitchen entry 3) Water management at ends of roof over front entry
Cc:	Betsy Pettit, Peter Baker, Kohta Ueno – Building Science Corporation		

Dear Jim Comeau:

This is to follow up on discussions we had on site today regarding additional guidance on implementation of the roof-wall connection details we reviewed. The memo also provides guidance to address other specific water management and air barrier details. If you have any questions, please do not hesitate to contact me as per the contact information below or on my cell phone (978 793 3999).

Thank you,

Ken Neuhauser

ken@buildingscience.com

617 800 2633 x5279

Sequence for Implementation of Roof-Wall Connections

In going over the roof-wall connection details at the Farmhouse site today, we agreed that I would write down and send you the implementation sequence we discussed. Below is the implementation sequence addressing drainage and air barrier for each of the 4 roof-wall connection details we reviewed today. I guess it goes without saying that these descriptions are intended to supplement - not replace – the information in the drawings.

SK-07 Roof-Wall Connection at the Addition Roof

When the addition roof was finished, the foam sheathing of the adjoining wall was not in place and as a result, the step flashing was not installed at the proper location. The remediation shown in SK-07 can be implemented following these steps (note that this work should be coordinated with the work described for SK-10 Roof-Wall Connection for New Roof over Kitchen Entry below):

1. Remove step flashing and roofing shingles within about 1 foot of the wall to expose the roof ice and water membrane. As you observed, shingles will be removed to the location of the new valley where the kitchen entry roof is framed over the addition roof.
2. Re-install insulating foam sheathing on the wall above the roof deck.
    - Insulation should be tight to the roof deck
    - Blocking for metal flashing can be installed where the wall has 2 layers of foam sheathing. Blocking should not be installed where there is only a single 2” layer of foam sheathing.
3. Seal the foam sheathing with sheathing tape and canned foam. Apply canned foam in gaps big enough to accommodate the canned foam applicator nozzle.

The remaining steps can be implemented after the roof over the kitchen entry is framed and sheathed:

4. Install ice and water membrane to face of foam min. 18” above roof deck and lapping onto roof ice and water membrane. Membrane should be adhered to the face of the foam and to the roof ice and water membrane as well.
5. Tape top edge of ice and water membrane to face of foam.
6. Install metal flashing / step flashing and roof shingles.
7. Install membrane flashing over top edge of metal flashing / step flashing (min. 2” overlap).
8. Tape top edge of membrane flashing to ice and water membrane on wall foam.

Rake to Wall Detail at Kitchen Roof

This water management and air barrier fix should be implemented before the Roof-Wall Connection at Kitchen roof described below.

There should be a membrane flashing or metal corner flashing at the vertical inside corner where the rake meets the face of the foam (Figure 1 below). This is to be installed after the gaps around the rake penetration are foamed in. Cut the rake drip edge at the face of the foam sheathing to let in this inside corner flashing. Tape the side edges of the inside corner flashing. As usual, the top edge of this flashing that extends up the face of the foam should be taped.

Figure 1 - Kitchen Roof Rake at Adjoining Wall

SK-08 Roof-Wall Connection at Kitchen Roof

Like the addition roof, this roof was finished before the insulating sheathing was installed. This is another area where the drainage plane and air barrier should be fixed before the siding is installed. The remediation shown in SK-08 can be implemented following these steps:

1. Remove a section of foam sheathing above the roof-wall intersection
   - Make straight cuts for easier re-install later
   - Stagger cuts in successive layers
2. Remove metal flashing and roofing shingles within about 1 foot of the wall to expose the roof ice and water membrane.
3. Re-install insulating foam sheathing on the wall above the roof deck.
   - Insulation should be tight to the roof deck
   - Install blocking for metal flashing at base of outer layer of foam.
4. Seal the foam sheathing with sheathing tape and canned foam. Apply canned foam in gaps big enough to accommodate the canned foam applicator nozzle.
5. Install ice and water membrane to face of foam min. 18" above roof and lapping onto the ice and water membrane of the roof. Membrane should be adhered to the face of the foam and turn to adhere over the roof ice and water membrane as well. Note that membrane will turn the corner where the wall passes an outside corner. A piece of flexible membrane (e.g. flexwrap) should be installed to cover the base of the corner before the ice and water membrane is installed.
6. Tape top edge of ice and water membrane to face of foam.
7. Install metal flashing / step flashing and roof shingles. Metal flashing must extend past edge of roof at each side.

8. Install membrane flashing over top edge of metal flashing / step flashing (min. 2” overlap).
9. Tape top edge of membrane flashing to ice and water membrane on wall foam.

SK-09 Roof-Wall Connection at Front Entry

Note that the water management described below for Water Management at Ends of Roof over Front Entry should be implemented before this remediation.

SK-09 depicts a fix to the water management at the roof over the front entry that was also described in a Project Memorandum of February 4th. It can be implemented following these steps:

1. Add kick-out flashing where roof terminates in field of wall. Kick-out must direct water out and away from the vinyl wall cladding.
2. Add metal flashing above shingles where roof extends past the Northeast corner of the building.
3. Remove furring strips above the entry roof.
4. Fill gaps between wood blocking and foam sheathing with canned foam to flush with foam sheathing.
5. Install membrane flashing over top edge of metal flashing / step flashing (min. 2” overlap). Adhere to face of foam sheathing, blocking and metal flashing.
6. Tape top edge of membrane flashing to face of insulating sheathing.

SK-10 Roof-Wall Connection for New Roof over Kitchen Entry

This is an area where Shawsheen’s crews got ahead of the plans. Unfortunately, some of the Shawsheen work will need to be removed in order for the drainage plane and air barrier of the wall to be restored:

1. Remove rafter ledger that is installed directly against wood sheathing.
2. Re-install insulating foam sheathing on the wall.
3. Seal the foam sheathing with sheathing tape and canned foam. Apply canned foam in gaps big enough to accommodate the canned foam applicator nozzle.
4. Restore drainage and air barrier around the penetration of the gable side beam:
    a. Foam in around penetration of beam to full depth of foam sheathing with canned foam.
    b. (after canned foam cures) Apply membrane flashing at the vertical inside corner where the beam meets the face of the foam. Extend the flashing membrane past the top of the beam. Cut a slit into the flashing to allow one leg to fold over the top of the beam and the other to continue up the wall.
    c. Tape the side edges of the inside corner flashing.
    d. Apply saddle flashing over top of beam. This can be a piece of membrane flashing that is cut ~2” wider than the beam. It is adhered to the wall and top of the beam. The corners are allowed to drape down at either side of the beam.
    e. Tape the top edge of saddle flashing.

The above should restore the air barrier and drainage plane of the wall system for the wall above the kitchen entry. After this is completed, the roof and porch ceiling ledgers can be installed:

5. Install roof rafter ledger and porch ceiling joist ledger as described in SK-10.

This roof can then be framed and sheathed after which the water management implementation continues:

6. Install ice and water membrane on roof. At top of roof, turn membrane up wall to minimum 18” above roof deck.
7. Tape top edge of ice and water membrane to face of foam.
8. Install metal flashing / step flashing and roof shingles. Metal flashing must extend past rake edge of roof.
9. Install membrane flashing over top edge of metal flashing / step flashing (min. 2” overlap).
10. Tape top edge of membrane flashing to ice and water membrane on wall foam.

Water Management at Ends of Roof over Front Entry

Where the ends of the roof over the front entry meet the wall, water management implementation will require particular attention.

Front Entry Roof at Northeast Corner

Where the bottom of the porch roof meets the wall at the corner (Figure 2 below), it can be flashed similar to the rake of the kitchen roof:

1. Foam in the gaps between the fascia return and the foam sheathing.
2. Install a membrane flashing or metal corner flashing at the vertical inside corner where the rake meets the face of the foam. Cut the rake drip edge at the face of the foam sheathing to let in this inside corner flashing.
3. Tape the top edge of this flashing that extends up the face of the foam as well as the side edges of the membrane.

Figure 2 - Front entry porch roof at corner

Front Entry Roof Meeting Front Wall

Where the bottom of the roof over the front entry meets the front wall in the field of the wall (Figure 3 below), the existing wood work presents a challenge to implementation of the water management and siding. To address these challenges I offer the following (note that this interface is to be sheltered by a kick-out flashing):

1. Leave roof sheathing and fascia intact but cut away the drip edge and crown moulding beneath the drip edge at a point that is even with the face of the vinyl siding to be installed later.
2. Remove the drip edge and crown moulding to the wall side of the cut.
3. Paint the cut end of the crown moulding with wood primer or sealer.
4. Foam in the gap between the fascia board and the foam sheathing with canned foam to flush with the foam sheathing.
5. Install a membrane flashing or metal corner flashing at the vertical inside corner where the fascia board meets the face of the foam.
6. Tape the side edges of the inside corner flashing.

Figure 3 – Roof over front entry at front wall

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Project Memorandum

From:	Ken Neuhauser – Building Science Corporation	Date:	February 20, 2009
To:	Jim Comeau – Habitat for Humanity of Greater Lowell	Re:	Bedford Farmhouse Renovation – Entry roof return at NE corner of building
Cc:	Betsty Pettit – Building Science Corporation		

Dear Jim Comeau:

In our phone conversation of last Thursday, you had expressed concern about the resolution of the front corner where the front entry porch roof returns over the corner. You suggested cutting the roof return off so that the corner piece could be continuous at the corner. Since you have agreed to hold off on cutting the roof until we have had a chance to look at the situation, I have designed a solution for this front corner that I believe addresses how the trim is supported and the drainage plane maintained. Below is a step-by-step description of this proposed solution.

I look forward to discussing this with you when we meet at the site on Tuesday. If you have any questions before then, please do not hesitate to contact me as per the contact information below or on my cell phone (978 793 3999).

Thank you,

Previous Existing Conditions

As shown in the image below, the earlier cladding of the building included wide corner boards (I'm guessing around 8-9"). It is also apparent that the front entry roof did return over the corner board. We will use cues from the earlier configuration to guide historically appropriate exterior trim.

Figure 1 - Earlier trim details revealed during demolition

Step 0 – Current, in-process, condition

- **Foam held back to flush with front wall wood sheathing below roof soffit**
- **Wood trim below support beam left in place**

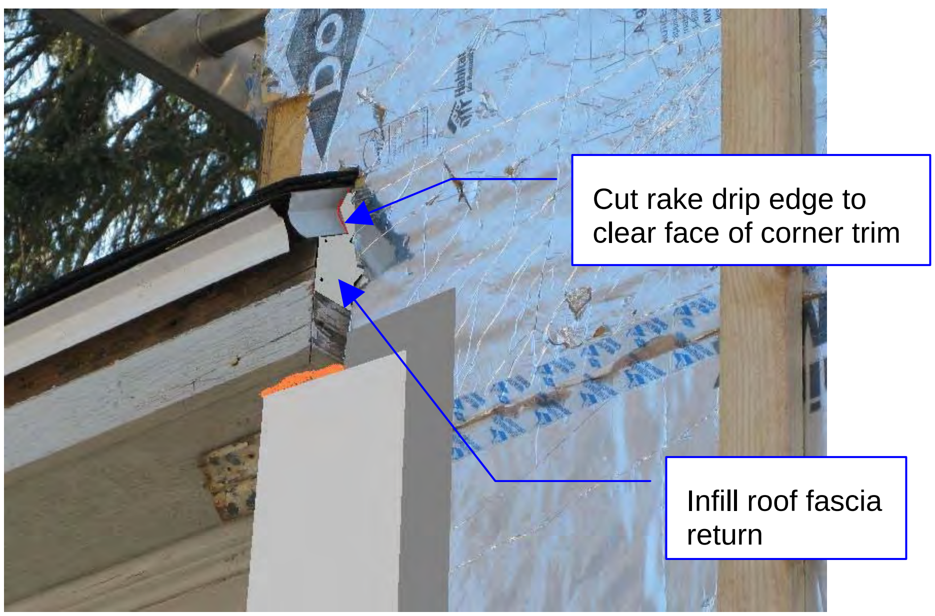
Step 1 – Install membrane at corner below roof

- **Carefully remove trim moulding below roof support beam. If pieces can be removed intact, save for later use.**
- **Install self-adhered membrane from face of foam sheathing, over exposed edges and adhere to wood sheathing of Front wall.**

Step 2 – Install 4" insulating foam sheathing below roof

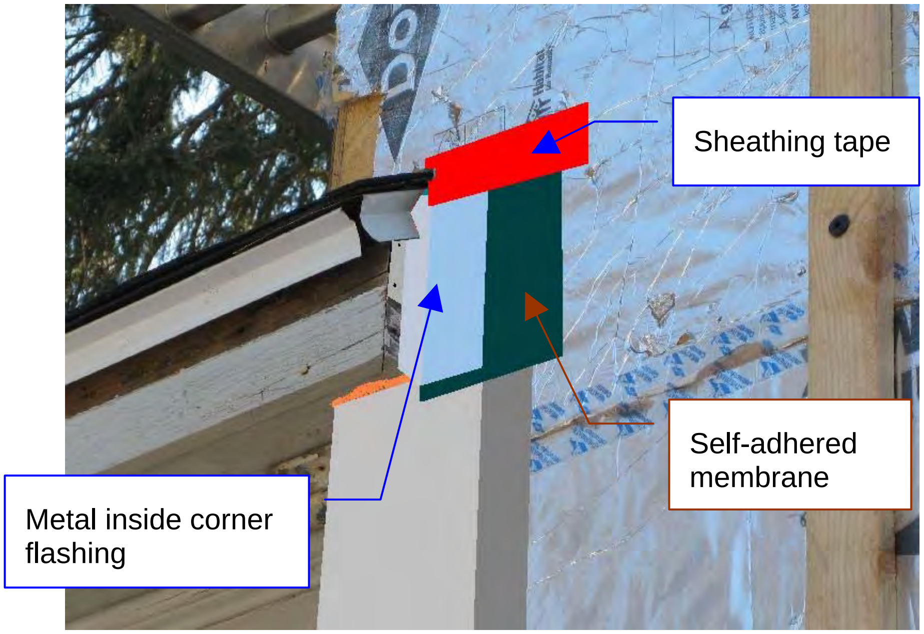
- **Install (2) 2" layers of insulating sheathing to front wall below entry roof. Use XPS foam as spacer as needed over wood trim below support beam.**
- **Foam sheathing is notched around roof support beam enclosure.**
- **Foam stops 1" shy of flush with inside face of support beam in order to accommodate installation of exterior jamb extension for front door.**
- **Canned foam applied at junction of foam sheathing to existing wood trim helps to hold foam sheathing in place.**

Step 3 – Install membrane over edge of foam, prepare for flashing return-wall connection



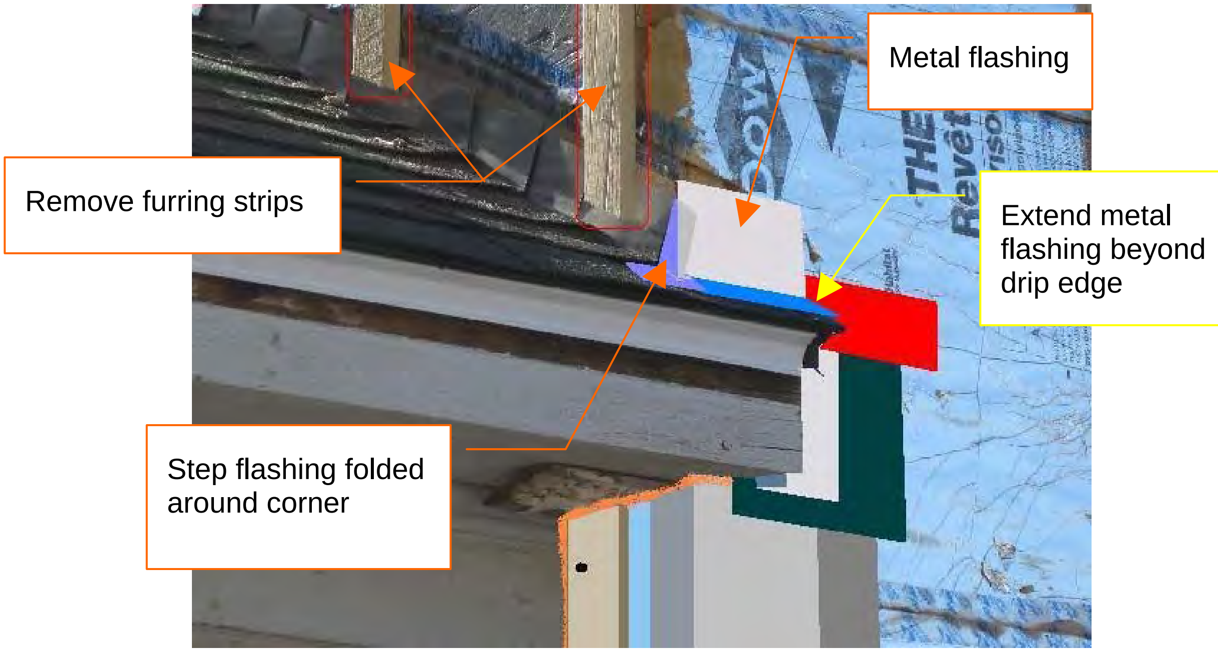
- **Install self-adhered membrane over edges of new foam sheathing pieces. Adhere to face of new foam pieces, across edges, and to membrane of earlier step.**
- **Cut rake/return drip edge to accommodate corner trim.**
- **Infill roof fascia return.**
- **Install wide furring strip on front face to provide nailing for corner trim and wood trim below support beam. Notch furring strip around support beam enclosure.**

Step 4 – Install inside corner flashing at fascia return-wall



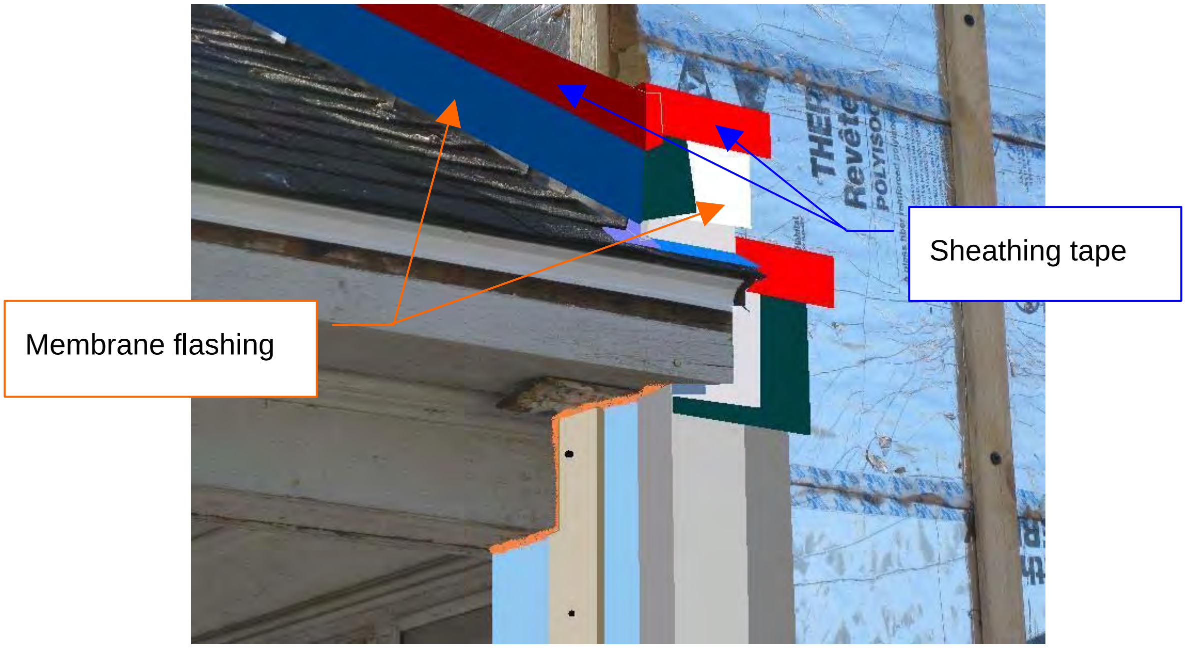
- **Install self-adhered membrane over insulating sheathing and turn onto fascia return. Trim unsupported lower tab.**
- **Install metal inside corner flashing over self-adhered membrane and tight to roof sheathing.**
- **Apply sheathing tape over top edge of metal flashing and self-adhered membrane.**

Step 5 – Install metal flashing at roof



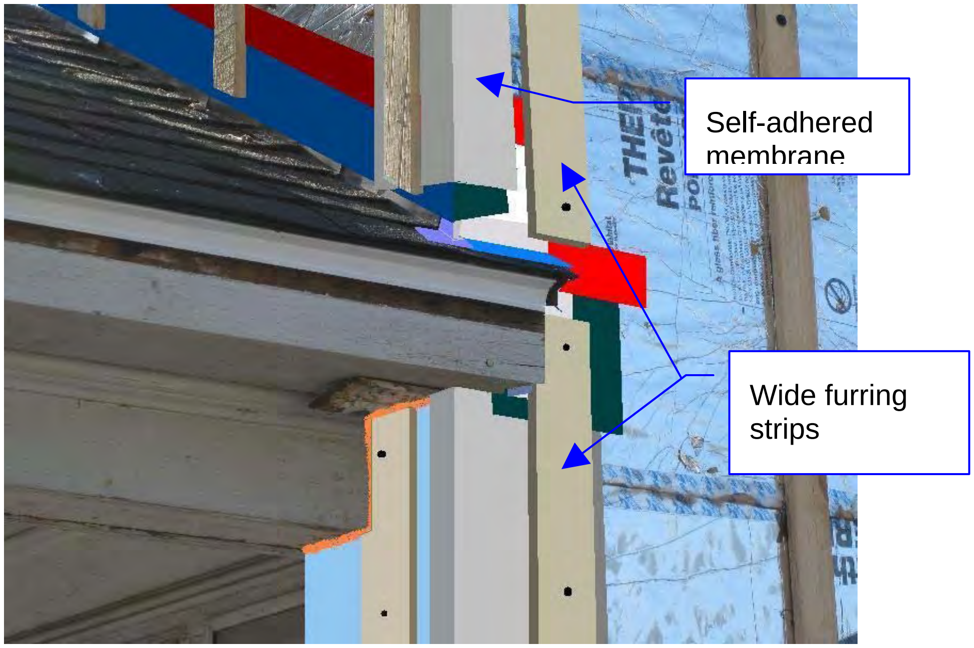
- **Install metal flashing at roof-wall interface**
- **Metal flashing at roof return must extend past edge of rake drip edge.**
- **Remove furring strips extending over step flashing to allow installation of flashing membrane over step flashing.**

Step 6 – Install membrane over top of metal roof flashing



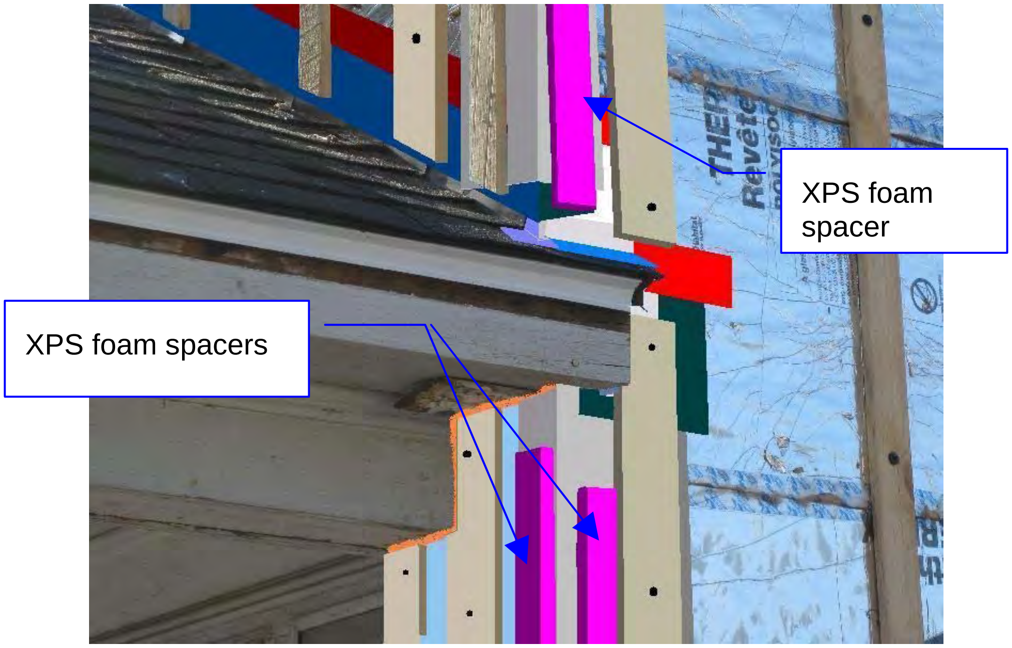
- **Install membrane flashing over top edge of metal step flashing with min. 2" overlap.**
- **Apply sheathing tape over top edge of flashing membrane.**

Step 7 – Install membrane at corner above roof, install furring to support corner trim and siding



- **Install self-adhered membrane over corner of insulating sheathing above roof.**
- **Re-install furring strips removed previously.**
- **Install wide furring strips on side wall and front wall. Furring strips to be wide enough to support both 7 ¼" corner trim and siding.**

Step 8 – Install spacers to support corner trim

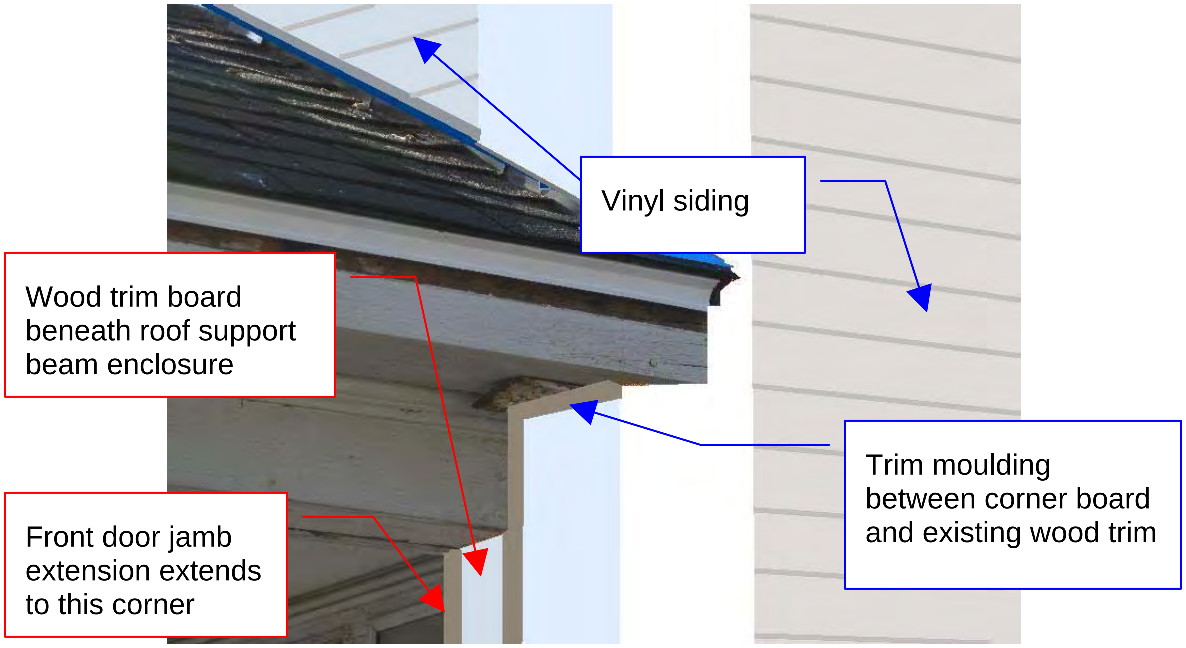


- **Tack or tape spacers at corner to support corner trim. Spacers to be same thickness as furring strips.**

Step 9 – Install corner trim

- **Install cellular PVC corner trim boards. Trim boards nominal 5/4" x 8" (CertainTeed part number 11060820005 or equal). Siding channel to be field routed.**
- **Corner trim to extend 7 ¼" to each side.**
- **Notch side wall corner board around metal roof flashing.**
- **Corner trim to front side below roof to fill from corner to face of roof support beam enclosure.**

Step 10 – Install siding, install wood trim at front entry



- **Vinyl siding installed with ends inserted into routed channel of corner boards.**
- **Trim moulding covers joint between corner boards and existing wood trim.**
- **Existing wood moulding trim used beneath and at sides of support beam enclosure if existing trim is salvageable.**

Appendix D.2.7.6
Observations from In-Process Air Barrier

Project Memorandum

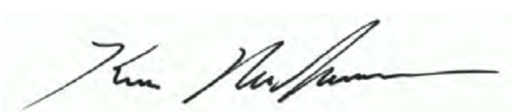
From:	Ken Neuhauser – Building Science Corporation	Date:	May5th, 2009
To:	Betsy Pettit, Joe Lstiburek, Kohta Ueno	Re:	Bedford Farmhouse Renovation – 1) Blower door assisted air barrier quality control and remediation 2) Duct blaster assisted duct sealing quality control and remediation
Cc:	Cathy Gates, Katie Gunsch, Honorata Wytrykowska		

Dear Betsy, Joe, Kohta:

This is to convey some of my observations from field operations at the Bedford Farmhouse site conducted Thursday, April 30th. These field operations include 1) blower door assisted air barrier remediation, and 2) duct blaster assisted duct sealing remediation. BSC personnel Katie Gunsch, Cathy Gates and Honorata Wytrykowska assisted me in setting up equipment, operating equipment, and explaining the procedures. Volunteers from Cisco conducted the air sealing and duct sealing.

I envision that the report below will comprise a portion of our Building America quality control reporting.

Thank you,



Ken Neuhauser

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Summary

Blower door and duct blaster equipment assisted in locating air leaks and in making air leaks recognizable. Little change was observed in the air leakage measurement (rough CFM50 for house and CFM25 for duct system) as a result of the air sealing and duct sealing work. Observations of air flow (haptic observations) suggest that the sill air barrier design is effective where properly executed and that gaps in the insulated sheathing may provide air flow pathways. Overall, air leakage observations were consistent with areas of concern noted during construction.

Background

The insulation system we had designed for the Bedford Farmhouse retrofit included a mix of dense-packed or damp-spray cellulose and closed cell spray foam. The close cell spray foam was indicated at roof-wall areas to provide air barrier transition.

Jim Comeau obtained a price quote from Anderson Insulation for the insulation work. The price was well in excess of what had been budgeted. Jim asked us to consider ways that the farmhouse might still meet its performance goals but save money on the insulation.

One area we considered is the roof eaves. Upon visual inspection, these appear to be well sealed with foam sheathing extending between rafter framing to the roof sheathing and canned foam applied around the perimeter of the foam sheathing (refer to Figure 1and Figure 2 below).

Figure 1 - air sealing at addition roof eave

Figure 2 - air sealing at existing roof eave

Despite the presence of copious canned foam at the eaves I was concerned that there might still be detrimental air leakage at these locations. I suggested that we use blower door fans to depressurize the building in order to be able to better assess (qualitatively) the air sealing at the eaves and in order to guide further air sealing at these location. Jim Comeau expressed interest in this operation as a means to provide assurance that spray foam at the eaves could safely be omitted. He further asked if we could bring duct blaster equipment to the site to assess the duct work and guide duct sealing.

The field operations involving blower door and duct blaster equipment would constitute Quality Control measures for both the building air barrier and the duct sealing. Although Habitat volunteers would conduct the air sealing and duct sealing work, the operation was projected to impact the builders understanding of air barrier and duct sealing performance and to demonstrate the application of instrumented quality control measures. Through these field operations BSC personnel without prior field experience would be exposed to field testing procedures and building forensic techniques. It was projected that the building depressurization would also yield an assessment, if only qualitative, of the retrofit air barrier system performance.

Building Set-Up

Building Depressurization for Air Barrier QC

The building was in a condition where the basement was very much open to the exterior and the first floor was open to the basement. It was decided to separate the basement from the rest of the building rather than attempt to separate the basement from the exterior. Not only was this more practical, but also the basement did not represent an opportunity for quality control of the air barrier system as the air barrier system for the basement (closed cell spray foam from sill to new concrete slab) had not yet been implemented. Further, the basement air barrier system is one whose performance would be reasonably assured upon visually verifiable implementation.

The major connection between the basement and the rest of the building was a floor opening for the basement stairs. Other large connections were noted at plumbing penetrations. Openings in the floor assembly containing ductwork also represented holes to the basement. Systemic connections between the basement and the first floor include the sometimes-open joint between floor sheathing and the sill beam as well as the leakiness of the floor system itself. The stair opening was closed with a large piece of extruded polystyrene cut to fit in the opening, supported

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by a blower door frame, and taped to adjacent framing. Rags and foil-faced fiberglass insulation were used to increase the air flow constriction at major plumbing penetrations. Other connections between the basement and the rest of the builder were left as they were.

Figure 3 - XPS blocking at stair opening

Note: Blocking at stair opening shown before application of tape and before installation of a second blower door frame used to prevent the foam board from being lifted out of place.

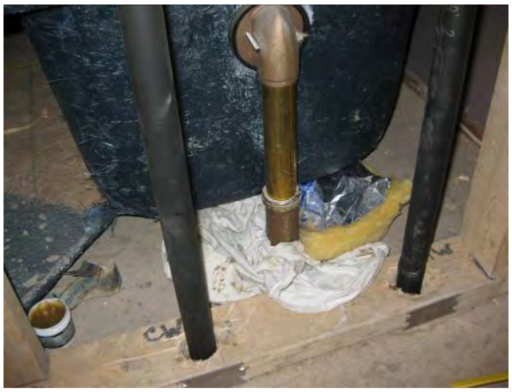

Figure 4 - hole at tub trap

Figure 5 - plumbing and ductwork holes

Blower door equipment was installed in a first floor window in order to allow the front door (the only operational door on the first floor) to be used for access to the building. Initially one blower door fan was installed to depressurize the building. This was found to not provide a strong enough signal in locating air leakage. A second blower door fan was installed in a second floor window.

Figure 6 - blower door installation

Figure 7 - blower door from exterior

Note sheltering of outdoor reference tap.

Duct Pressurization and Depressurization for Duct Sealing QC

Volunteers assisted by applying duct mask to duct boots. In addition to the duct boots and transfer ducts, duct mask was applied to the outside termination of the outdoor air intake duct. The duct blaster fan was connected to the duct system at the air handler cabinet.

Figure 8 - duct blaster installation at air handler in basement

Observations

Building Air Barrier

It was expected that air leakage sites would be rendered obvious by building depressurization. In some cases, air leakage was easily identified and located. Initially a single blower door fan was used to depressurize the building to approximately -20 Pa with respect to (WRT) the exterior.

The first air sealing task of the volunteers was to seal any leakage felt or observable (by use of a smoke stick or movement of dust particles) at the main roof eaves. Volunteers Nitash and Sri accepted this task. Use of the blower door did not appear to offer a clear signal of air leakage at the eave due to the front door being frequently opened and consistently left open during this part of the operation. Nonetheless, the volunteers proceeded to apply canned foam to all joints of types where observations suggested the possibility of air leakage.

Figure 9 - additional air sealing at existing roof eaves

Later in the day, a second blower door fan was added to provide greater depressurization. Upon the suggestion of the builder, the front door was deadbolted closed from the interior. This allowed for a steady ~50 Pa depressurization relative to the exterior. This depressurization provided a clearer signal of air leakage locations. A second pair of volunteers conducted air sealing with the guidance of this depressurization. The following areas represent where air leakage was noted or where the depressurization allowed assessment of air barrier performance.

Narrow rafter bay at addition roof – Air leakage was observed at a narrow rafter bay located where the addition roof extends just past the Southwest corner of the existing two story structure. It is conceivable that the rafter bay is not sealed at the eave and/or that it is connected to the rake extension which is outside of the plane of the air barrier system. Images of this location during construction show that the wall air barrier was not transitioned to the roof deck along the rake. Also, the roof rake had been installed at this location prior to installation of the insulating sheathing. The rake trim, therefore, interrupts the air barrier where it meets the wall of the existing structure. Carpentry students working in this area were instructed to use canned foam to connect the air barrier of the foil facing to roof deck, framing and trim. It is possible that the implementation was not robust.

Tight spacing of framing in this location did not allow access with canned foam in order to seal this bay.

Figure 10 – observation of air flow at narrow rafter bay at addition roof rake

Figure 11 - addition roof rake during construction prior to air sealing remediation

Roof eaves at addition – Generally, the eaves appeared well sealed (see Figure 1 above). Some leaks were observed and sealed.

Roof eaves at existing roof – with the greater depressurization, no air leakage was observed at a sample of locations along the existing roof eaves.

***West facing roof rake* –** significant air leakage was felt at the top of the West-facing gable wall of the existing structure. In a quick pass over suspected trouble spots, air leakage was not felt at the top of the East-facing gable. Different construction suggests an explanation for this difference in observed air barrier performance. The East gable has two layers of foam with the second layer notched to fit around rake extension framing and then foamed to framing and roof deck. On the West gable, there is a single layer of foam. This single layer of foam is butted against ledger of rake extension framing with a less-than-convincing attempt to seal the edge of the foam sheathing to the rake extension framing.

Figure 12 - insulating sheathing at West gable

***Building Sill* –** Significant design effort was devoted to air barrier transition at the building sill. In general, the designed appeared to be implemented successfully. At some locations, it was clear that one particular brand of membrane used in the design failed to adhere to the substrate. At a location on the Northeast corner, repair of the lower sheathing was carried out without using a new piece of the Straight Flash VF which had been adhered to the sheathing.

Figure 13 - sill to wall air barrier transition

Figure 14 - sill to wall air barrier transition from below

Figure 15 - flashing membrane did not adhere to the StraightFlash VF transition membrane

Note, the builder has indicated that the membrane shown in this photo was subsequently replaced with membrane that proved to have better adhesion to the substrates.

Figure 16 - transition membrane at Northeast corner failed to re-adhere after replacement of sheathing board

With the building depressurized to approximately 50 Pa WRT the exterior, I examined significant portions of the sill that were accessible. This examination gave particular attention to areas that were known to have had problems with the sill-to-wall air barrier transition. At some locations, notably at the Northeast corner, I felt some air movement above the joint between the sheathing board and the built up sill. Particles of saw dust and cobweb were also observed to be moving on top of the built-up sill. The signal was not clear because of the much greater air flow emanating from the gap between the floor sheathing and the built up sill. To reinforce the air barrier performance, I applied canned urethane foam along lengths of sill where I suspected air leakage at the sheathing-to-sill joint.

Figure 17 - air movement observed at sill

Front door – portions of the wall to one side of the front door lack wood sheathing. Air barrier transition where the insulating sheathing terminates adjacent to the door opening has been left off to allow for adjustment of the opening upon installation of the replacement door. The side of the door near the Northeast corner of the building also lacks insulating sheathing. The sill-to-wall air barrier design could not be implemented at this location due to the presence of a concrete stoop that remains in place. (see Figure 16 above) Clearly discernable air leakage in the wall around the existing door, particularly at the building sill, support the decision to use closed cell foam insulation in wall cavities at this location.

Sheathing near inside corner – air leakage was observed at a gap between wood sheathing boards near an inside corner at the Southwest corner of the existing 2 story structure. The location shown in Figure 18 below is also below the addition roof rake depicted in Figure 11 above. As seen in Figure 11, the there are gaps between the foam sheathing boards in the field of the wall. There were also gaps between insulating sheathing boards at the inside corner. The outside corner nearby was lacking the required strip of membrane at the time of the photo. The builder had assured that gaps larger than a finger width would be foamed and that membrane would be applied at each corner before the installation of siding. BSC obtained visual confirmation of this on some but not all areas of the building enclosure.

From the observation of air flow at a gap between wood sheathing boards, I derive the suggestion (but not a conclusion) that air flow networks within the double foam layer allow air to flow within the exterior insulation assembly to points where these air flow networks connect with gaps between the wood sheathing boards.

Figure 18 - air flow observed between sheathing boards near inside corner

Duct Sealing

Prior observations of the ductwork installation noted what appears, visually, to be reasonably thorough duct sealing. At the request of the builder, the duct system was tested at its rough stage to establish whether performance targets were obtainable. The builder also requested that duct blaster equipment be used to help volunteers locate and seal duct leaks.

Figure 19 - duct work as observed at earlier site visit

After an initial baseline depressurization test of the duct system, volunteers spent a considerable amount of time locating and applying mastic to duct leaks. During this operation, the duct system was pressurized.

Figure 20 - Habitat volunteers and a BSC staffer locating duct leaks

Figure 21 - Habitat volunteers locating and sealing duct leaks

After the volunteers had completed this work in the basement, first floor, second floor and attic, a second test of the duct system was conducted. Puzzlingly, the additional duct sealing work resulted in a decrease in measured duct leakage of only about 5%. No registers were found to be un-masked during this follow-up test. The total duct leakage measured at 25 Pa seems large relative to the system capacity and nominal air flow. However, conferring with other BSC staff suggests that such total duct leakage is within the realm of expected performance for Building

America projects of this size. The total duct leakage at 25 Pa is less that 10% of the conditioned floor area.

Figure 22 - duct leakage test results after duct sealing