Retrofit of a Multi-Family Mass Masonry Building in New England

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Kohta Ueno, Phil Kerrigan, Jr., Honorata Wytrykowska, Randy Van Straaten

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Abstract:

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

BUILDING TECHNOLOGIES PROGRAM

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Task 9: Evaluation of Community Scale Implementation of Retrofit Energy Efficiency Packages (Deliverable 9.1.3)

Merrimack Valley Habitat for Humanity Technical Report: Retrofit of a Multi-Family Mass Masonry Building in New England

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Definitions

ACH	Air changes per hour
ACH 50	Air changes per hour at 50 Pascal test pressure
ASHRAE	American Society of Heating, Refrigeration and Air-Conditioning Engineers
ASTM	American Society for Testing and Materials
BA	Building America Program
BEopt	Building Energy Optimization Program
BSC	Building Science Corporation
ccSPF	Closed-cell Spray Polyurethane Foam
CFL	Compact fluorescent
CFM	Cubic feet per minute
CFM 50	Cubic feet per minute at 50 Pascal test pressure
CSA	Canadian Standards Association
DOE	U.S. Department of Energy
DHW	Domestic Hot Water
FT	Freeze-Thaw
HERS	Home Energy Rating System
HRV	Heat Recovery Ventilator
HVAC	Heating, Ventilation, and Air-Conditioning
MVHfH	Merrimack Valley Habitat for Humanity
NREL	National Renewable Energy Labs
RESNET	Residential Energy Services Network
S_{crit}	Critical degree of saturation

SEER	Seasonal Energy Efficiency Ratio
SHGC	Solar heat gain coefficient
WUFI	Wärme- und Feuchtetransport instationär
XPS	Extruded Polystyrene

Executive Summary

Merrimack Valley Habitat for Humanity (MVHfH) has partnered with Building Science Corporation to provide high performance affordable housing for 10 families in the retrofit of an existing brick building (a former convent) into condominiums.

The condominium conversion project will contribute to several areas of space conditioning, water heating, and enclosures research. Enclosure items include insulation of mass masonry building on the interior, airtightness of these types of retrofits, multi-unit building compartmentalization, window selection and roof insulation strategies. Mechanical system items include combined hydronic and space heating systems with hydronic distribution in small (low load) units, and ventilation system retrofits for multifamily buildings.

One of the initial questions in this renovation project was whether the existing mass masonry walls could be retrofitted with insulation without durability problems. To understand these risks, the team performed a site assessment followed by material property testing and hygrothermal simulations. This section covering the analysis includes a summary of the material property testing results, a description of the hygrothermal computer simulations, and an interpretation of the results. Key findings included the following:

- In both wall assemblies simulated, at normal rain exposures, brick freeze-thaw risk is predicted to be minimal with or without the thermal insulation retrofit;
- The existing brickwork damage is likely due to the combination of rain water concentrations due to poor maintenance and details (e.g., gutter/downspout failures); and
- Addressing the rain water management issues associated with the existing areas of damage must be addressed as the thermal insulation retrofit will exacerbate such problems.

Applying the results of the masonry retrofit analysis to a wider array of projects is beyond the scope of this report; an overview of the topic is covered by Straube et al. (2012). An analysis of the applicability of material property testing to similar projects is covered in an upcoming BSC report, which examines test results with other variables such as project geographic location, vintage, and other readily available properties (density, water uptake).

BEopt parametric analysis was performed for insulation options for the wall retrofit in order to determine the energy performance for each wall system and the most cost effective measure. The project team decided to explore the following options for the wall retrofit: three layers of 2" XPS rigid insulation, two layers of 2" XPS rigid insulation, 5" of ccSPF and 2" of ccSPF with batt insulation. Advantages and disadvantages of each wall system were explored.

The proposed 6" XPS rigid insulation on the interior of the masonry was selected as one of the best performing options. The energy analysis determined this option is not the most cost effective measure; however, it was selected due to the financial model of Habitat for Humanity, which includes volunteer labor and donated materials.

The cost of a project typically increases with the improved performance, but local incentives as well as state and federal tax credits can offset some of the cost. By performing an energy analysis of the project, homeowners and builders were able to make the early decisions on which measures are the most suitable and feasible. The results of this research provide information on what level of efficiency can be achieved within budget constraints. REM/*Rate* energy analysis software was used to determine the predicted energy savings for each housing unit by implementing the advanced retrofit packages. This work was driven by Massachusetts incentives of over $1000 per unit (ENERGY STAR Qualified Homes, Version 3 Tier II).

Effective air barriers are an important component for good energy performance, good indoor air quality, and control of interstitial condensation. In addition, an effective air barrier between units of multifamily housing reduces transmission of sound, odors, and smoke, lowers fire spread risk, and helps control stack-driven airflows. Therefore, BSC established targets for air barrier and compartmentalization performance on this project, and developed multiple details for airtightness (interior-to-exterior) and compartmentalization (unit-to-unit) strategies.

The planned research intended to analyze the effectiveness of air barrier strategies implemented in this multifamily retrofit; however, no units have been completed to date, so effectiveness has not yet been measured. However, some information is available on the secondary question, of the difficulties in implementing these air barrier details.

Use of individual unit space heating and domestic hot water systems greatly limits the distribution losses associated with these systems, at a comparable or lower net cost to centralized systems. The use of individual unit HRV (heat recovery ventilation) systems greatly improves compartmentalization, and based on preliminary analysis, provides substantial first cost savings relative to a large centralized HRV system. Use of individual tankless water heaters and HRV units in each condominium will also provide the homeowners with the ability to control the settings according to their particular lifestyle and desired comfort levels. Therefore, BSC developed a mechanical design with individual mechanical systems for each apartment unit, and for the common areas of the MVHfH multi-family building. However, no mechanical systems have been installed to date, nor have any quotes been received for the design. Therefore, the cost impacts cannot be determined at this point, but details on the current HVAC design are available.

BEopt software was used to evaluate the cost effectiveness of the retrofit measures proposed for this project as well as the predicted site energy use. One representative unit was chosen for energy modeling (Unit 8, on the second floor). Several options for wall insulation, window types, air leakage, and mechanical systems were modeled in order to determine the combinations of measures that are the most cost effective. The difference in source energy use between the "Existing" and "Minimum Cost Case" projected by BEopt was 95.0 MBtu/year, or a 52.6% reduction. However, the "Design Case" which generates a slightly higher reduction (96.2 MBtu/year or 53.3%) but at a higher cost (per BEopt) was chosen by the design team. This case includes measures that are the best approaches for this particular project and may not be the most cost-effective in all cases because of the financial model of Habitat for Humanity.

The retrofit work on the apartment units is ongoing and the project is slated for a completion date in December of 2014. Therefore, the utility bills were not available for the comparison of the predicted and actual energy use. No additional work is planned for this project in the subsequent years due to the termination of funding at the end of 2012.

1 Introduction

Merrimack Valley Habitat for Humanity (MVHfH) has partnered with Building Science Corporation to provide high performance affordable housing for 10 families in the retrofit of an existing brick building (a former convent) into condominiums.

The research performed for this project provides information regarding advanced retrofit packages for multi-family masonry buildings in Cold climates. In particular, this project demonstrates safe, durable, and cost-effective solutions that will potentially benefit millions of multi-family brick buildings throughout the East Coast and Midwest (Cold climates). The retrofit packages provide insight on the opportunities for and constraints on retrofitting multi-family buildings with ambitious energy performance goals but a limited budget.

The condominium conversion project will contribute to several areas of research on enclosures, space conditioning, and water heating. Enclosure items include insulation of mass masonry building on the interior, airtightness of these types of retrofits, multi-unit building compartmentalization, window selection, and roof insulation strategies. Mechanical system items include combined hydronic and space heating systems with hydronic distribution in small (low load) units, and ventilation system retrofits for multifamily buildings.

This report is divided into the following sections:

- Evaluating the risks of freeze-thaw to the masonry walls and identifying the suitability of the building for retrofit of insulation
- Exploring several wall retrofit strategies, to determine the most cost effective solution that will achieve specific thermal performance
- Energy analysis to determine the incentive levels the project is able to qualify for
- Development of specific guidance on establishing an air barrier for each of the housing units in the building, as well as identifying difficulties in developing robust air sealing and compartmentalization details for the proposed wall retrofit design and their implementation
- Comparison of the cost and performance of the proposed measures to be implemented on the project.

The following research questions were covered in this project.

- Does the addition of high levels of interior insulation present a risk of freeze-thaw damage to the mass masonry walls in this building?
- What are the predicted energy performance and cost impacts of the proposed wall retrofit design (6" of XPS) vs. the other considered strategies (spray foam, flash and batt)?

- How do rebates and incentives impact the decision making process of the builder, especially in cases of budget constrained construction projects? In addition, how do these impact the overall energy performance?
- What is the effectiveness of air barrier strategies implemented in this multifamily retrofit project, and what were the difficulties in implementation?
- What are the cost impacts of implementing a compartmentalized ventilation strategy with individual apartment HRV systems vs. a traditional large single central HRV system?
- What are the cost impacts of using individual unit combination space heating/hot water units, including distribution piping design and installation specifics?
- How does the actual energy performance (i.e. utility bills) compare to the BEopt predicted site energy use?

1.1 Background

The former St. Patrick Convent (Figure 1) was purchased by MVHfH from the city of Lawrence in early 2008 for $300,000. The building consists of two parts, the original building (circa 1906 construction) and a rear addition (circa 1930 construction); a small third addition was demolished as part of the renovation (Figure 2). The building was divided into ten 3-bedroom units with designated common meeting and storage spaces. The sale price for the 3-bedroom units is predicted to be between $125,000 and $130,000 with 35-year mortgages.

Figure 1: Merrimack Valley Habitat for Humanity retrofit building in Lawrence, MA

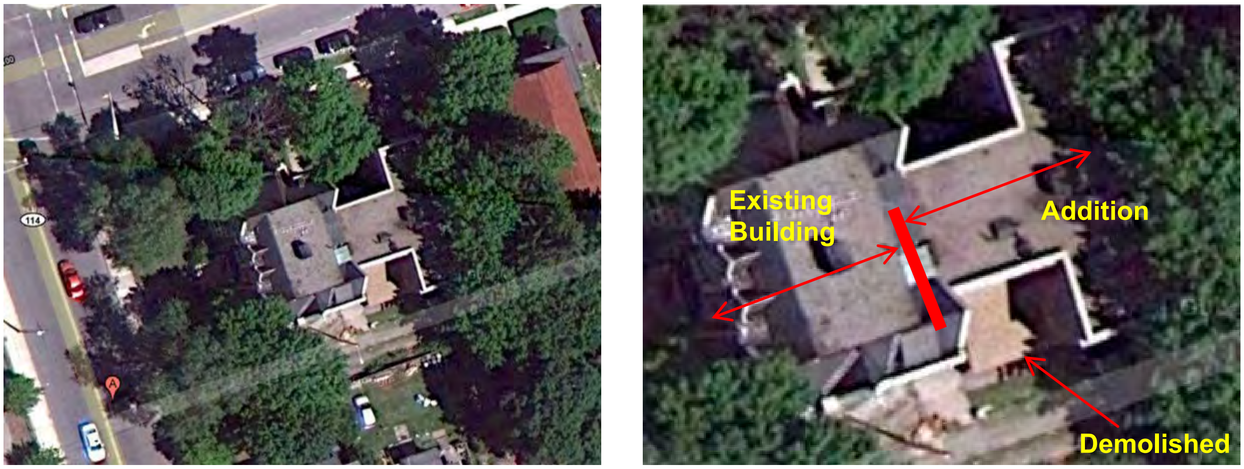


Figure 2: Merrimack Valley Habitat for Humanity retrofit building aerial views

The total budget for the project has been set for $1,000,000. The project heavily relies on the donated materials as well as volunteer labor, but there are several components of the retrofit that require various industry professionals, such as roofers, electricians, plumbers, HVAC technicians, and brick repair contractors.

The original plan for the project was a “phased” approach, completing contiguous blocks of units in groups. The plan was to have three phases: three units and the common space in Phase I, four units in Phase II, and the last three units (located in the addition) in Phase III.

However, the project team is now seeking a loan from the Federal Home Loan Bank of Boston for the amount of $200,000, and the terms of the loan dictate the completion date in December 2014. Dividing the project into phases would slow the schedule, because it would require the team leaders to teach volunteers the same skills in all three phases, and coordinate the work with the different trades. The final decision on phasing the project has yet to be made.

Before the building was acquired by MVHfH, it had been left vacant and unheated for two or three years. After purchase, the interior of the building was completely gutted, including all HVAC, plumbing, electrical, partition walls, and interior finishes. There were several issues that needed to be addressed with this retrofit project before proceeding with the installation of the high performance and energy efficient measures. Repair and remediation of structural members took priority and have been completed. Structural issues associated with the settling of brick walls were evaluated by a Boston-based structural firm, and are being addressed as well. The roof leak in the rear addition also has been addressed before proceeding with any interior work in that area of the building.

The original energy efficient retrofit goals for the project were to provide an R-60 roof, R-40 above grade walls, R-20 basement walls, R-10 basement slab and R-5 windows, as promulgated by National Grid (2009), and similar to targets proposed by Straube (2011). The building section shown in Figure 3 illustrates the retrofit approaches to be implemented on this project.

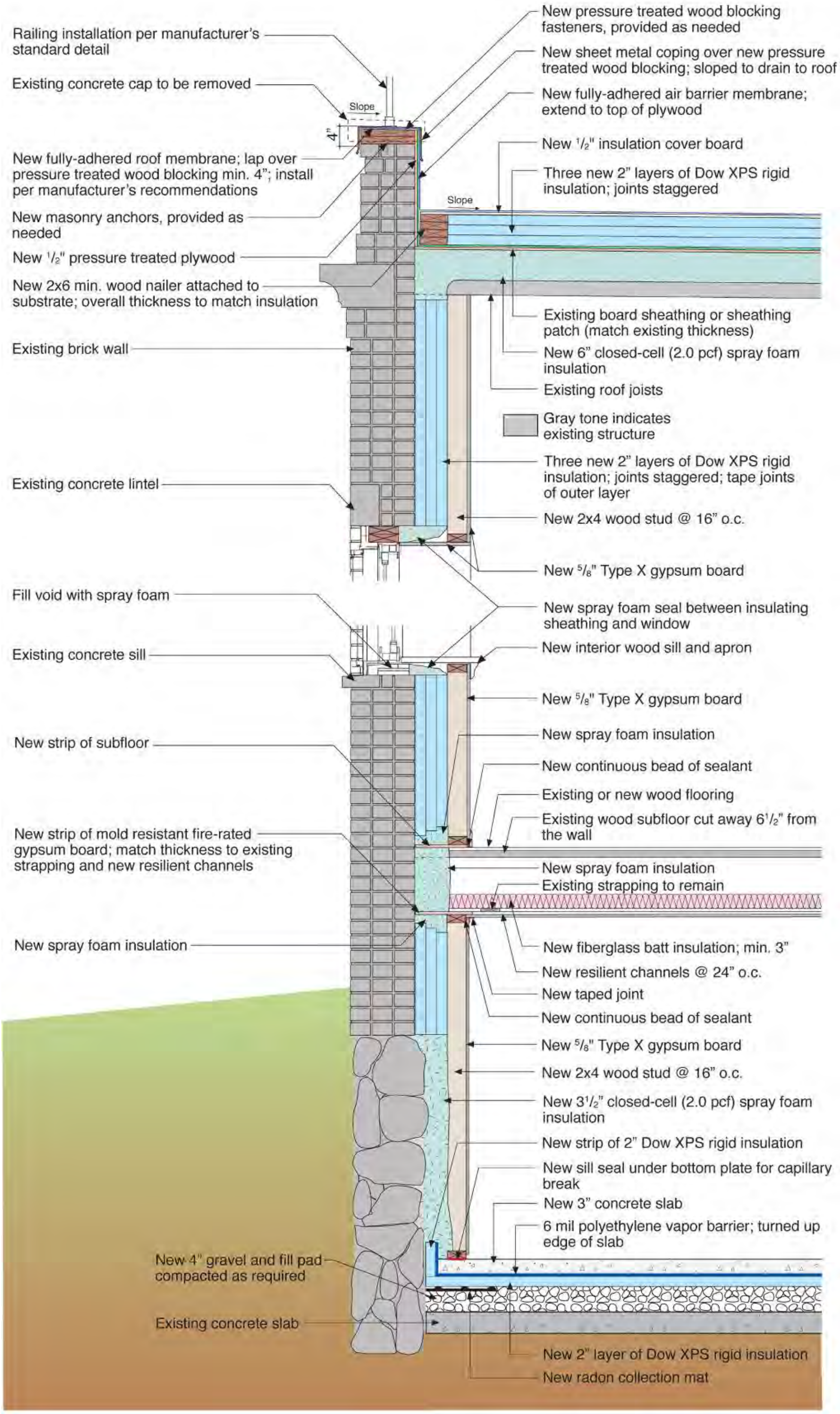


Figure 3: Merrimack Valley Habitat for Humanity building section

2 Brick Material Property Testing and Hygrothermal Simulations

One of the initial questions in this renovation project was whether the existing mass masonry walls could be retrofitted with insulation without durability problems (see Straube et al. 2012). To understand these risks, the team performed a site assessment (documented in Appendix A), followed by material property testing and hygrothermal simulations. The latter two tasks involved laboratory testing of sample bricks, and hygrothermal computer simulations to diagnose the cause of current issues and predict the effect of potential interior insulation retrofit. This section includes a summary of the material property testing results, a description of the hygrothermal computer simulations, and an interpretation of the results.

The brick samples were collected from the building by BSC staff during a site visit on August 3, 2011. Two brick samples each were collected from the interior and exterior of the original and addition sections of the building (for a total of eight). These bricks were taken directly from the wall assembly. Additional samples were also taken which were sitting on the roof and part of a small demolition of an added structure. These additional samples were not used since their origin could not be determined.

2.1 Material Property Testing

The brick samples were subjected to a series of material property tests to facilitate the hygrothermal simulations and inform the assessment of freeze-thaw risk. The material properties, test method and results are summarized in the sections that follow. Further information on the testing procedures can be found in Straube et al. (2012).

2.1.1 Dry Density

Dry density is a fundamental material property that is used as a basic input for all hygrothermal simulation programs. Dry density is used to predict how much heat and moisture are stored in a material over a given time period.

To determine dry density, the brick samples are dried in a gravity oven and periodically weighed using a precision scale. Drying continues until there is no longer any change in mass. This process can take many days to complete. The volume of each brick sample is then determined using a liquid displacement method. The dry density is simply the quotient of the dry mass and the volume. The test results are given in : Brick material property testing .

2.1.2 Water Absorption or Uptake Coefficient (A-value)

The water absorption coefficient or uptake (A_w or A-value) characterizes the capillary uptake of the material. The value is used in hygrothermal simulation programs to predict the movement of liquid water under capillary suction and redistribution.

The liquid water uptake test follows the method set out in DIN 52617. Carefully cut and oven-dried brick ‘chunks’ (approximately half a brick in size) are placed so that their exposed face (i.e. the outside face of the brick) is just in contact with a pool of water. The samples are periodically removed from the water, weighed using a precision scale, and placed back in contact with the water surface. The measured mass is plotted against the square root of the time of the measurements and normalized for cross-sectional area. The A-value is determined from the slope of this graph and has the rather unusual units of $lb/in^2s^{1/2}$. The test results are given in : Brick material property testing .

2.1.3 Free Water Saturation

The free water saturation is practical maximum moisture content for masonry units in the field. Higher moisture contents can only be reached in the presence of dissolved salts or conditions that would cause condensation to occur within the empty pores. The value is part of the information used in hygrothermal simulation to estimate the relationship between moisture storage and relative humidity for the masonry units.

The free water saturation values were approximated from cold soak moisture contents. This is the moisture content of the brick after being left in a lab temperature water bath for at 24 hours. The test results are given in : Brick material property testing .

2.1.4 Vacuum Saturation

The vacuum saturation moisture content is used to estimate the maximum amount of moisture that can be held in the brick when all of its open pores are filled with water (W_{max}). This characteristic value is used to determine the degree of saturation when assessing the resistance to freeze-thaw action.

Carefully cut brick 'slices' (approximately 10 mm or 3/8 in. in thickness) are oven-dried, then placed in a desiccator, and a vacuum pump is used to remove any remaining water vapor molecules and 99.9% of the air. The vacuum pump is shut off and water is supplied to the desiccator. Nearly 100% of the open pores in the material are filled with water in this process. The brick slices are said to be 'vacuum saturated'. The vacuum saturation moisture content is the difference of the mass of the water when saturated and the mass of the dry sample. The test results are given in : Brick material property testing .

2.1.5 Critical Degree of Saturation

The critical degree of saturation is the moisture content at which the material becomes susceptible to freeze-thaw damage. The degree of saturation is the fraction of saturation relative to complete vacuum saturation. For example, at 0.5 degrees of saturation, the brick contains 50% of the moisture that it would at vacuum saturation. Fagerlund (1977) showed that below some critical degree of saturation (S_{crit}), no freeze-thaw damage is possible, regardless of the number of temperature excursions below freezing. Similarly, very few freezing cycles are needed to cause damage if the moisture content is above Scrit.

Brick slices are carefully prepared to present clean measurement surfaces. The pre-test length of each slice is measured using a precision micrometer. The slices are then brought to various degrees of saturation (e.g. 0.7, 0.8, 0.9, etc.) and sealed in packaging so that moisture does not enter or escape. The sealed slices are allowed to 'rest' for several hours so that internal moisture can distribute uniformly throughout each slice. The slices are then immersed in a controlled temperature bath and subjected to at least 6 freeze-thaw cycles. The slices are brought back to room temperature, and removed from the bath. The post-test length is measured, and the change in dimension or dilation is used to identify freeze-thaw damage. Numerous tests are performed on slices from each brick sample to facilitate an estimate of S_{crit}, the critical degree of saturation. The test results are given in Table 1.

Table 1: Brick material property testing results

Sample	24 hr. Cold Soak MC wt.	5 hr. Boil MC wt.	Dry Density pcf	A-Value $lb/ft^2s^{1/2}$	Vacuum Saturation pcf	S_{crit} %Vac Sat
Original Building, Exterior 1	5%	7%	130	0.0103	13	NA
Original Building, Exterior 2	3%	4%	155	0.0058	15	0.80
Original Building, Interior 1	3%	3%	179	0.0075	17	0.80
Original Building, Interior 2	2%	2%	99	0.0079	9	0.80
Addition Building, Exterior 1	4%	5%	118	0.0066	11	NA
Addition Building, Exterior 2	3%	3%	145	0.0037	13	0.75
Addition Building, Interior 1	3%	6%	135	0.0013	12	0.85
Addition Building, Interior 2	3%	3%	136	0.0021	12	0.75

These results can be put in context with qualitative descriptions by Lstiburek (2010), who considered "poor" S_{crit} values to be in the 0.4 or lower range, and "good" S_{crit} values to be in the 0.8 or higher range. The results appear to indicate good freeze-thaw resistance for the tested brick.

Several of the S_{crit} values are listed as "NA." In those cases, the sample dilation at high moisture content was below the repeatability range of the length measurement. In other words, the expansion of the sample after freeze-thaw cycling was too small to be measured effectively. Although these results are inconclusive, an interpretation could be that it suggests the brick is more resistant to freeze-thaw cycling damage.

2.2 Hygrothermal Simulations

The WUFI hygrothermal computer simulation model was used to simulate the effects of insulating the walls on the moisture and temperature conditions of the masonry walls. WUFI is one of the most advanced commercially available hygrothermal moisture programs in use today. Its accuracy has been verified (by the Fraunhofer Institut fur Bauphysik in Holzkirchen, Germany) against numerous full-scale field studies of enclosure performance (roofs, walls, foundations, parking garage decks, etc.) over a number of years. Much of the field verification work supporting the model has been solid masonry wall systems.

WUFI is one of the few models in the public domain that can properly account for rain absorption and different water absorption/redistribution for arbitrary material data and boundary conditions. Given the appropriate material data, WUFI calculates heat and moisture flow every hour under the influence of sun, rain, temperature and humidity. The analysis is, however, only as accurate as the assembly data, the material properties, and the interior and exterior conditions input.

2.2.1 Air Leakage

The WUFI computer model has the capacity to predict interstitial air leakage-induced wetting and drying; however, we have not made use of this feature because the leakage path and driving forces are unknown, and are generally unique. The time scale of wind-induced air leakage is also much shorter than one hour. Note that this is specifically leakage of air from the interior into the insulated assembly (e.g., into the interface between the insulation and the masonry, causing condensation). This does not address the larger energy topic of interior-to-exterior air leakage.

In all of the cases studied in this project it has been assumed that air leakage across the enclosure has been essentially controlled using appropriate air sealing materials and techniques, such as using interior spray foam insulation. It would be highly risky to design a retrofit that allows a significant amount of air leakage. However, experience has shown that air barrier systems formed by careful taping, caulking, use of spray polyurethane products and fully-adhered membranes are quite likely to achieve airtightness when properly installed using standard quality control measures.

2.2.2 Climate Data

WUFI includes climate data files for dozens of cities around the world. These climate files are typically generated from airport or other major weather station data. For the purposes of the Merrimack Valley Habitat for Humanity simulations we have used the Boston, MA ‘cold’ year weather file that is included in WUFI, summarized in Figure 4 and Figure 5. The existing interior conditions were simulated assuming heating only, as shown in Figure 6.

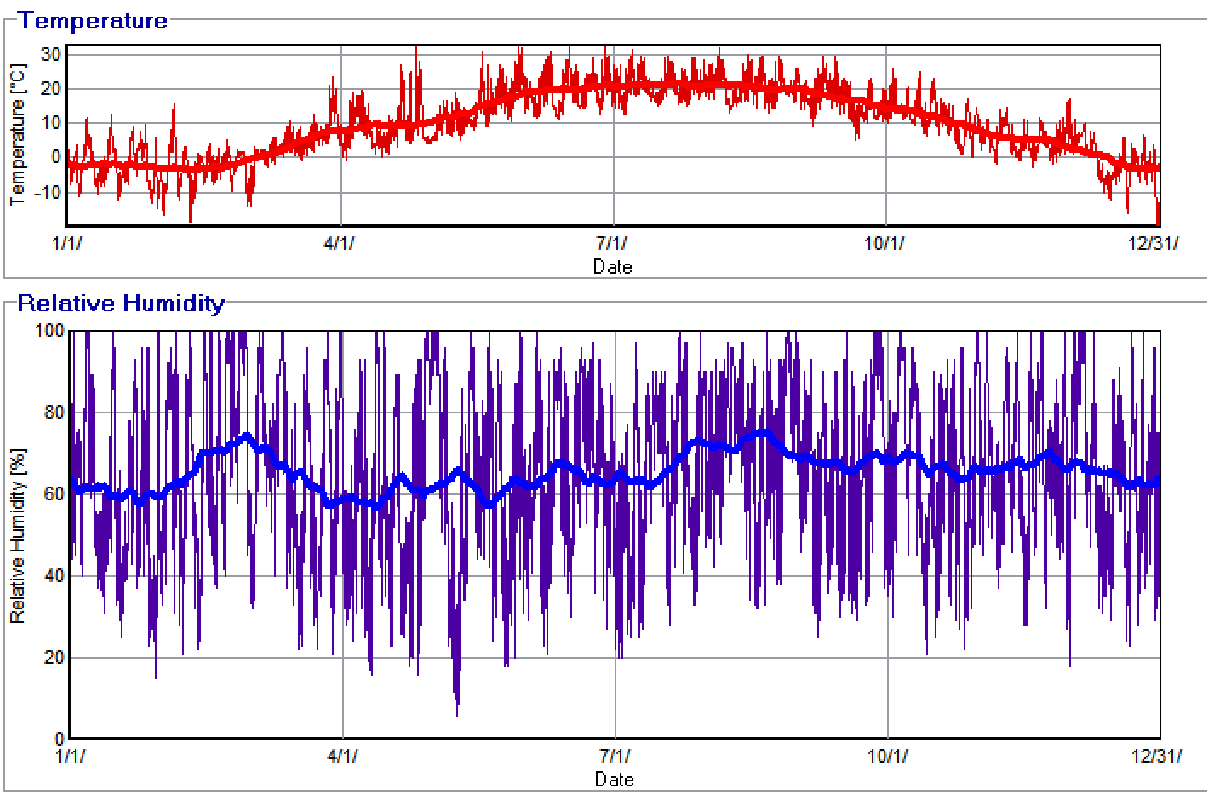


Figure 4: WUFI 5.1 Pro temperature and humidity for a ‘typical’ cold year in Boston, MA

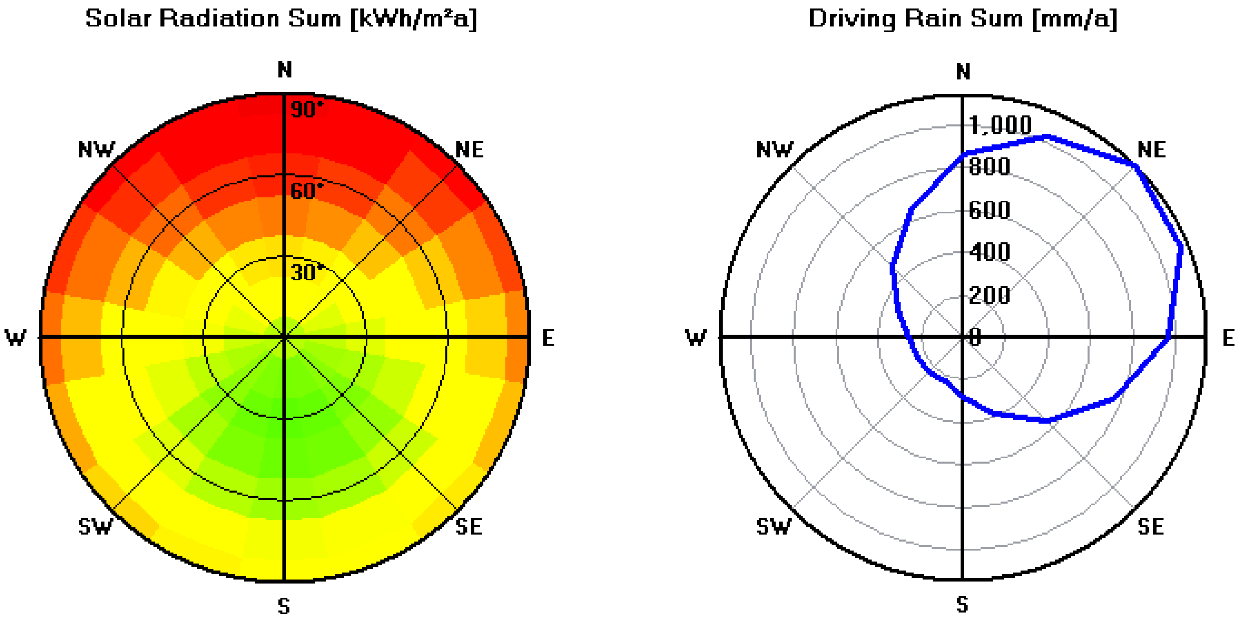


Figure 5: WUFI 5.1 Pro climate summary for a 'typical' cold year in Boston, MA

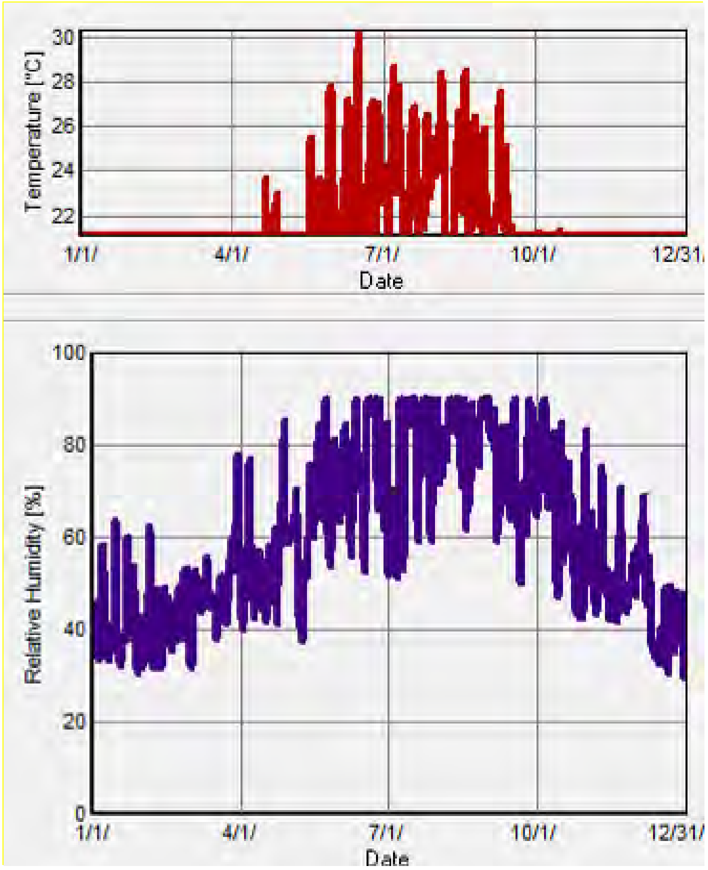


Figure 6: Indoor Conditions Used in WUFI Simulation (temperature and relative humidity)

2.3 Material Properties

It is often not convenient (or even possible) to determine the many material properties necessary for hygrothermal simulations, so WUFI includes a database of several hundred common materials. However, hygrothermal computer simulations are only as reliable as their input data, and it is advisable to measure and use key material properties whenever this can practically done.

For the purposes of the MVHfH simulations, we have derived the key masonry properties from laboratory testing and used existing data from the WUFI database for the remaining masonry properties and for other materials.

2.3.1 Assessing Freeze-Thaw Degradation Risk

The freeze-thaw degradation risk is assessed by predicting the masonry moisture content during incidents where the material temperature drops below 23°F (-5°C). The moisture content levels are plotted in a histogram and compared to range of critical degree of saturation values found in our laboratory testing. For the middle bricks, only one sample was provided so we are assuming a similar range of critical degree of saturation as the exterior bricks.

Within the masonry industry, physical pass-fail testing of individual bricks is commonly considered to be the best measure, despite the fact that the ASTM and CSA standards often rejects bricks found from experience to be durable and sometimes accepts bricks that fail in the field (Vickers 1993, Arnott and Maurenbrecher 1990, Robinson et al. 1995). The approach used in this study is more intensive but provide a more accurate and exposure specific assessment of freeze-thaw degradation risk.

2.3.2 Enclosure Assemblies Modeled

Figure 7 shows the WUFI model for the typical existing masonry enclosure wall assembly in the original building sections of 100 Parker St. The various materials used in the wall assembly are represented by different colors. In this image, one can see the red clay exterior brick, followed by a layer of grey mortar, the two interior brick wythes, and mortar layers. The wall assembly modeled for the addition section of the building has hollow clay tile replacing the two interior wythes, as shown in Figure 8. The clay tile is shown with thin outer layers (beige) and an interior cavity (blue).

The addition of 6" of extruded polystyrene foam board and drywall was evaluated for both wall assemblies as shown in Figure 9 and Figure 10.

Within these models the exterior face brick is divided into four volumes with relative thin inner and outer layers as shown. A 5 mm (~¼ in.) volume was modeled at the exterior of the face brick. Just inside of this a 10 mm (~3/8 in.) thick subsurface volume was modeled. This is often a location where freeze-thaw damage is observed. Next, another 10 mm (~3/8 in.) volume was modeled at the interior (i.e. back) of the face brick. Two layers were modeled in the backup brick: one 10 mm (~3/8 in.) volume at the exterior and interior face of the outer backup brick or the tile.

In each case the potential for freeze-thaw is assessed by considering the predicted hourly moisture content and temperature for each study volume.

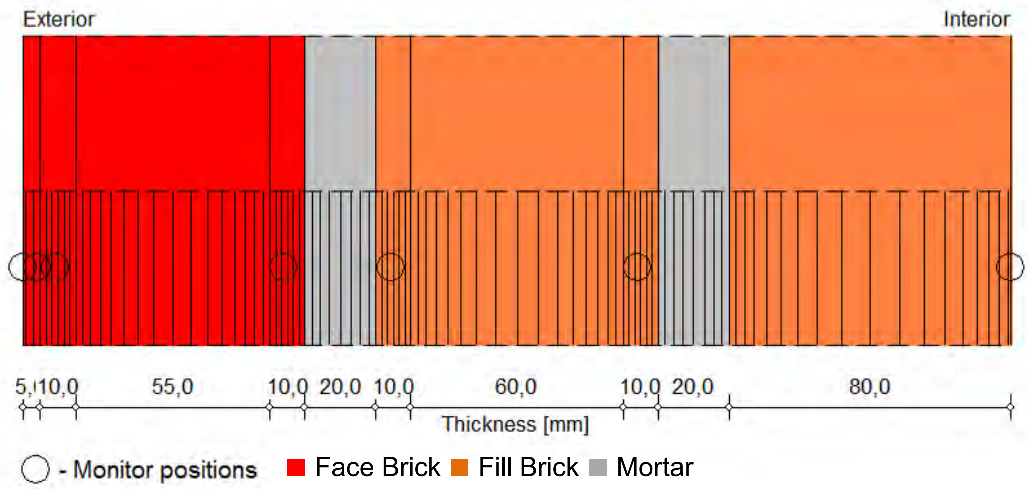


Figure 7: WUFI model of existing original building masonry wall assembly (solid brick wythes)

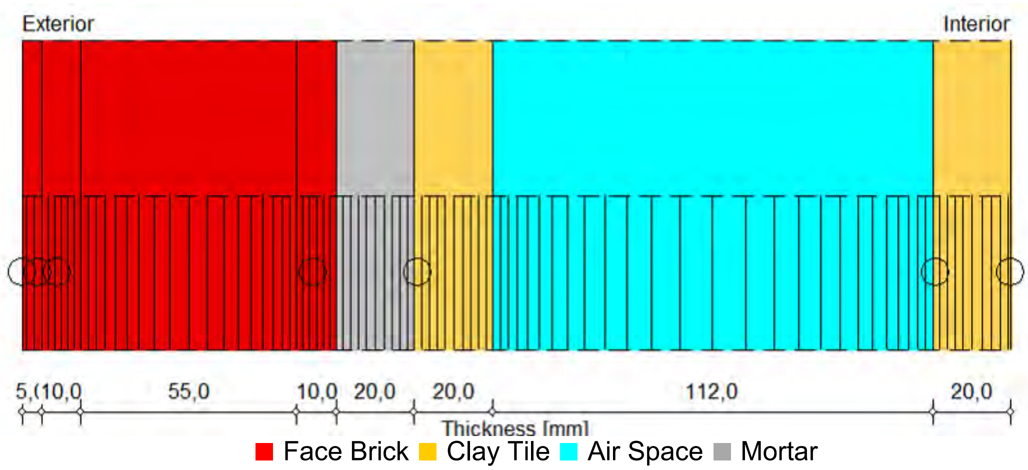


Figure 8: WUFI model of existing addition masonry wall assembly (hollow clay tile backup)

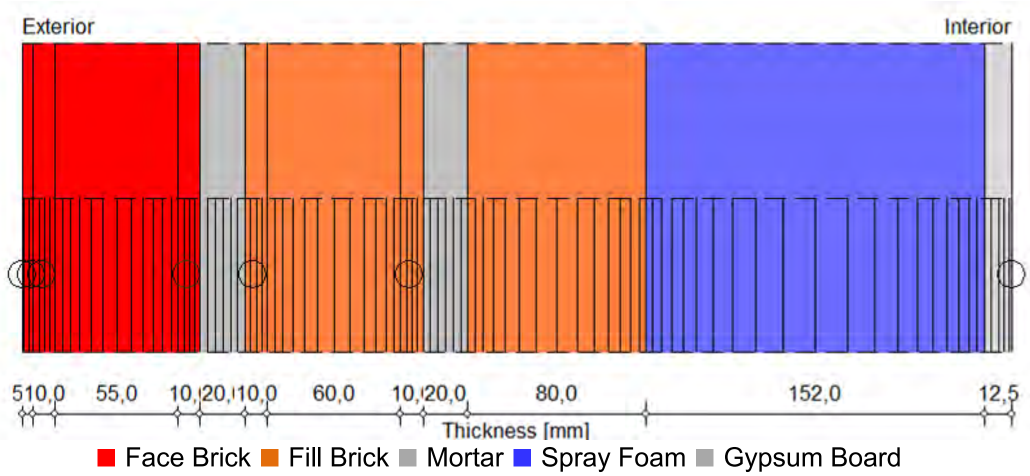


Figure 9: WUFI model of addition masonry wall assembly with insulation retrofit

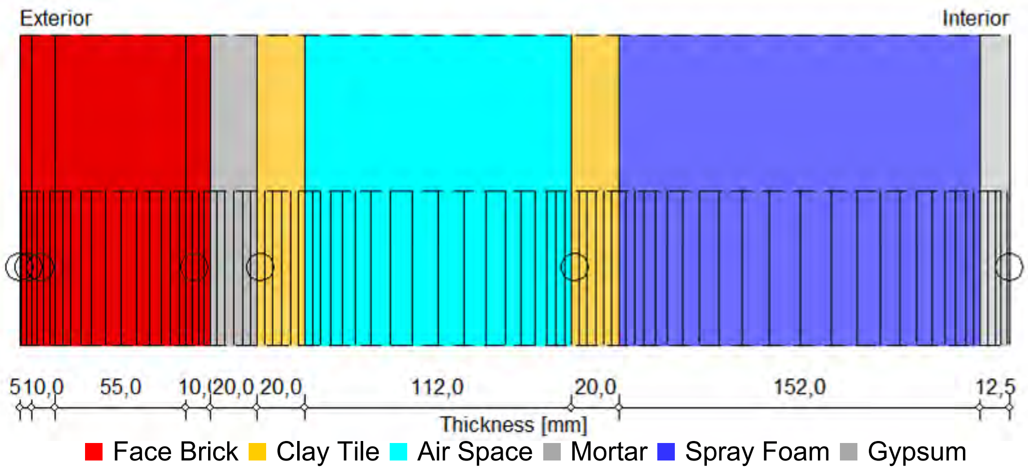


Figure 10: WUFI model of original building masonry wall assembly with insulation retrofit

2.4 Hygrothermal Simulation Results

The simulations results for the existing original building and the addition wall assemblies are plotted in Figure 12 and Figure 13. These simulations were repeated for the same wall assemblies and exposures after insulation, as plotted in Figure 14 and Figure 15. The multiple column graphs correlate with key vulnerable layers within the masonry assembly, as shown in Figure 11.

Within the plots, the moisture content is expressed in degrees of saturation (i.e. fraction of vacuum saturation). The column in the graph represents the number of hours (during freezing) that the moisture content in the control volume is predicted to be between 0 and 0.1 degrees of saturation; the second column represents hours between 0.1 and 0.2 degrees of saturation; the column space hours between 0.2 and 0.3 degrees of saturation and so on. Note that the frequencies are plotted on a logarithmic scale.

The blue shaded areas on the right of the plot show the lower and upper bounds of the critical degree of saturation (i.e. the moisture content above which damage is predicted to occur should temperatures cycle below some freezing threshold – usually -5°C or 23°F). The left edge of the light blue shaded area represents the lowest estimate of critical degree of saturation from the brick samples tested while the left edge of the dark blue shaded area represent the highest estimate. The potential for freeze-thaw damage is greatest when the predicted moisture content exceeds the critical degree of saturation during freezing. On these graphs this would be represented by hourly distribution columns in the shaded zone.

No freeze-thaw cycles are predicted for any of the simulated conditions. However, the cases with the thermal insulation retrofit generally show greater moisture contents during freezing conditions. Previous simulations of many other mass masonry buildings indicate that the exterior layers of the exterior brick are the most vulnerable, and that greater rain exposure increases risk. The pattern of damage on the building generally correlated with rain exposure, such as damage at areas around missing downspouts. It is assumed that these areas are seeing much greater rain exposure than predicted in the model. It should be noted that addressing the rain water management issues associated with the existing areas of damage must be addressed, as the thermal insulation retrofit will exacerbate such problems.

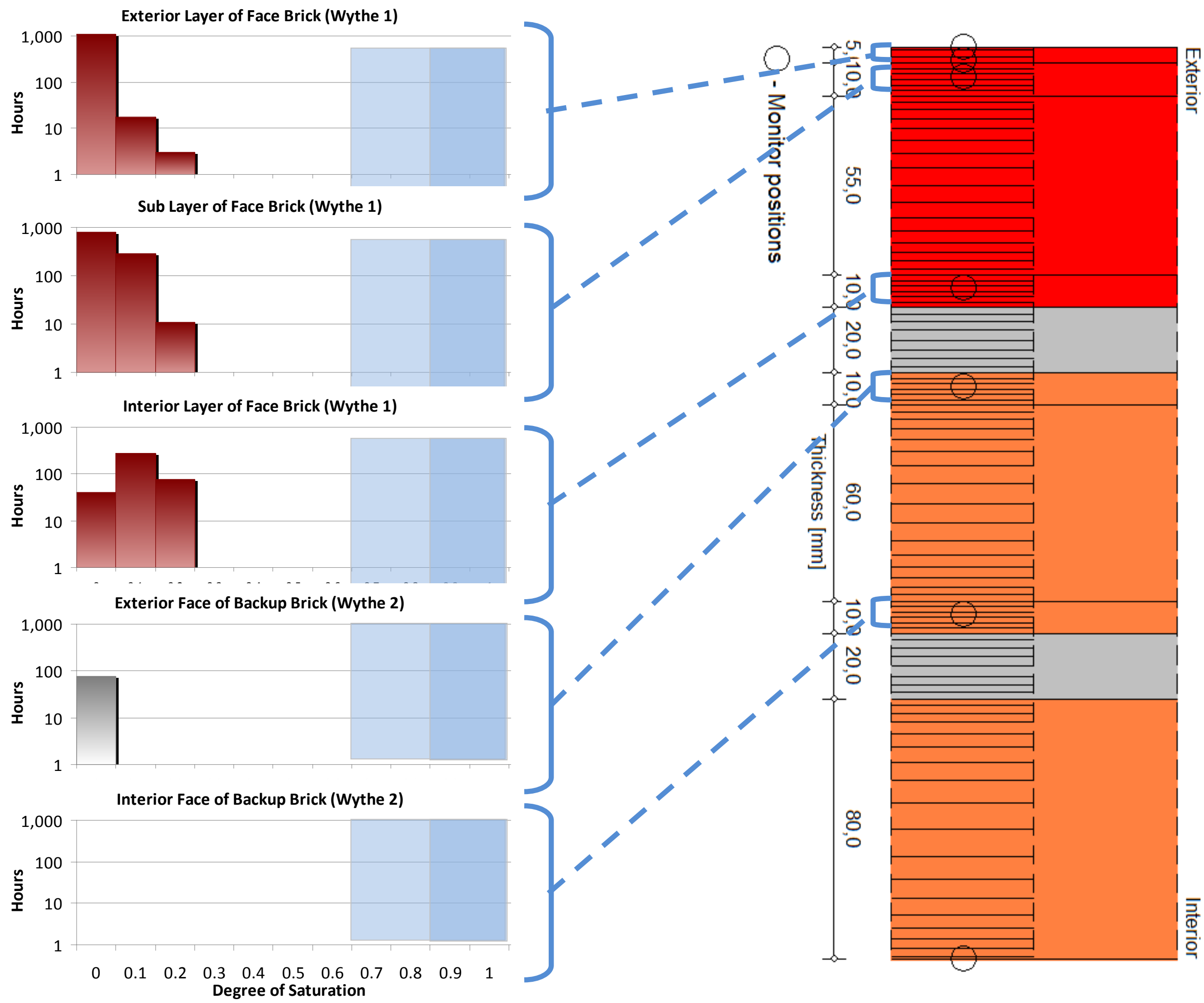


Figure 11: Example moisture content plot, correlated with assembly layers

2.5 Conclusions

The material property testing and hygrothermal simulations conducted for the MVHfH project indicate the following:

- In both simulated wall assemblies, at normal rain exposures, brick freeze-thaw risk is predicted to be minimal with or without the thermal insulation retrofit
- The existing brickwork damage is likely due to the combination of rain water concentrations due to poor maintenance and details (e.g., gutter/downspout failures)
- Addressing the rain water management issues associated with the existing areas of damage must be addressed, as the thermal insulation retrofit will exacerbate such problems

Wall assembly	Original (solid brick)
Wall condition	Uninsulated
Orientation	East
Rain exposure	Normal
Int. conditions	Heated

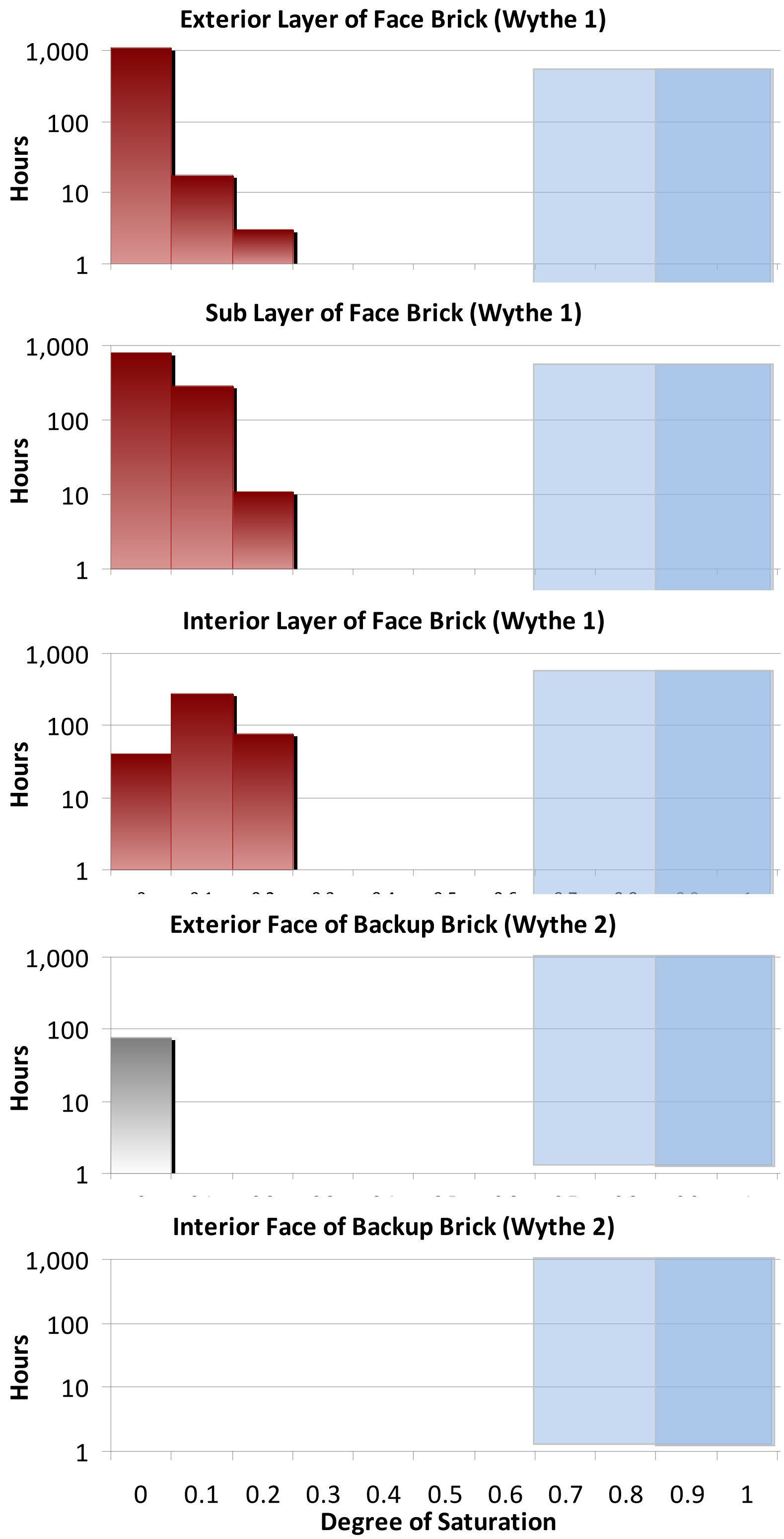
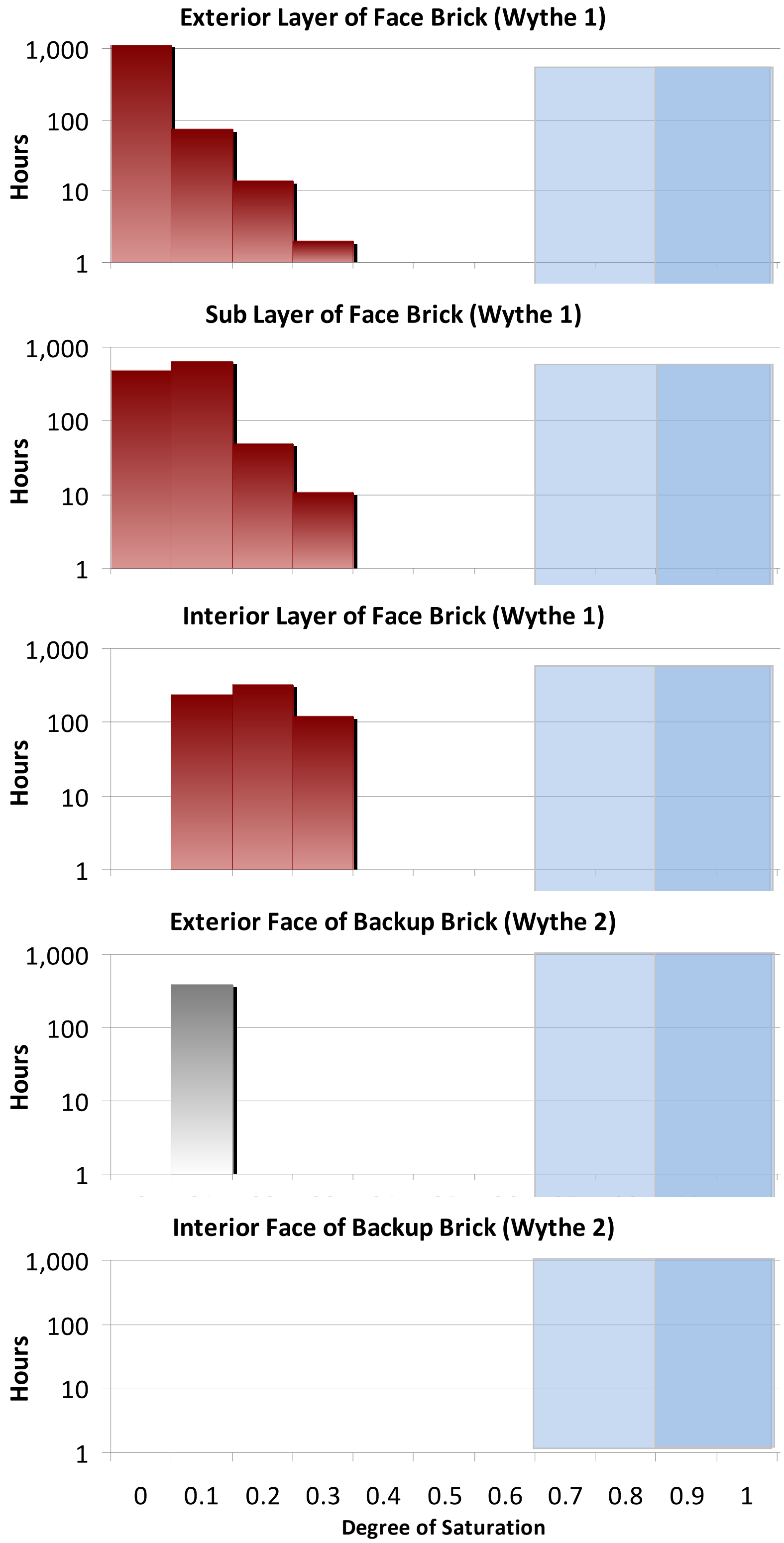


Figure 12: Predicted moisture distribution during freezing temperatures: Existing Original Building Wall Assembly, Normal Exposure, East Facing, Heating Only



Wall assembly	Addition (clay block)
Wall condition	Uninsulated
Orientation	East
Rain exposure	Normal
Int. conditions	Heated

Figure 13: Predicted moisture distribution during freezing temperatures: Existing Addition Wall Assembly, Normal Exposure, East Facing, Heating Only

Wall assembly	Original (solid brick)
Wall condition	Insulated 6" XPS
Orientation	East
Rain exposure	Normal
Int. conditions	Heated

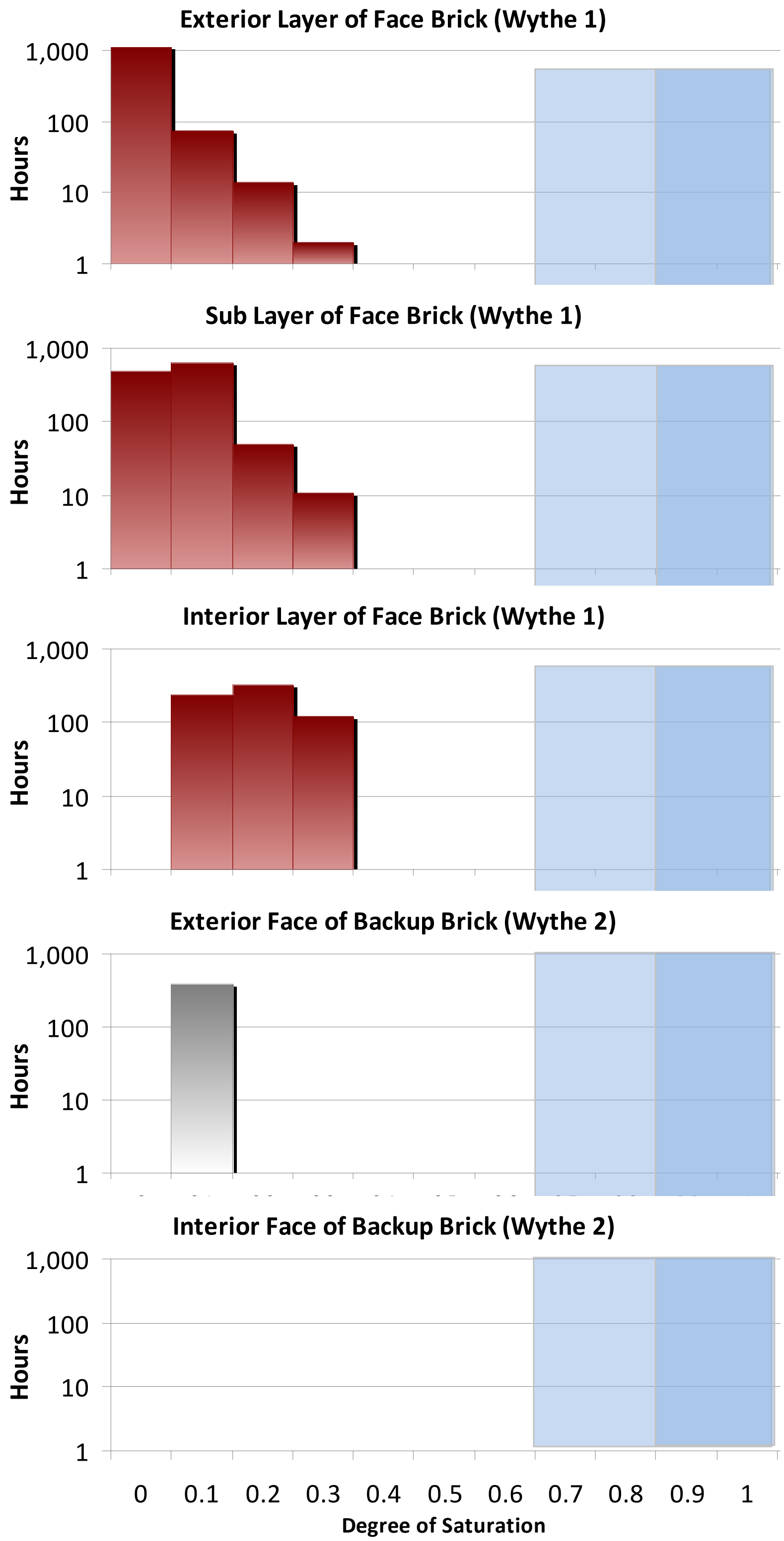
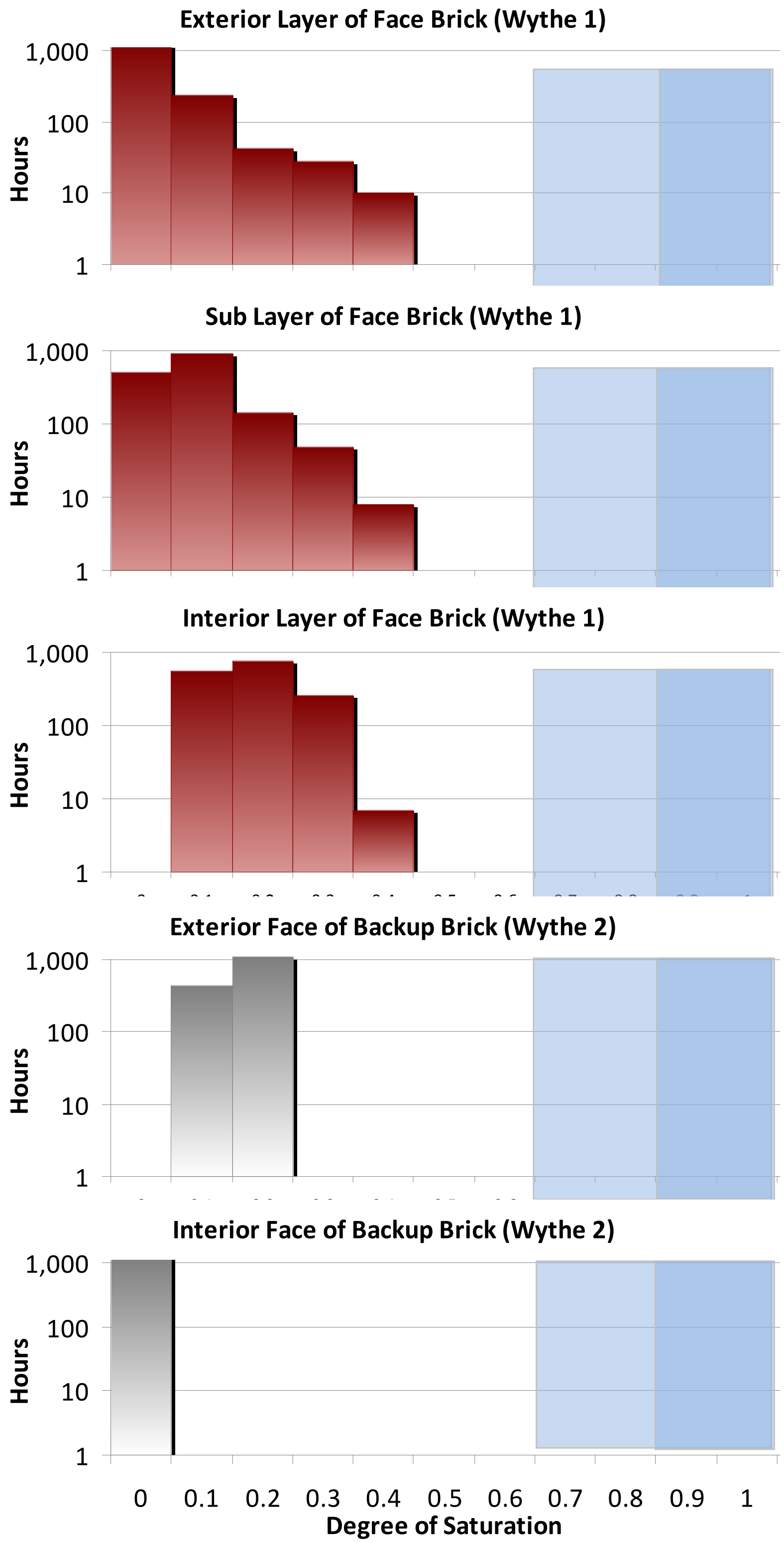


Figure 14: Predicted moisture distribution during freezing temperatures: Retrofit Original Building Wall Assembly, Normal Exposure, East Facing, Heating Only



Wall assembly	Addition (clay block)
Wall condition	Insulated 6” XPS
Orientation	East
Rain exposure	Normal
Int. conditions	Heated

Figure 15: Predicted moisture distribution during freezing temperatures: Retrofit Addition Wall Assembly, Normal Exposure, East Facing, Heating Only

3 Predicted Energy Performance and Cost Impacts of Proposed Wall Retrofit Design

Upon the completion of the freeze-thaw analysis, the project team began to work through all of the possible choices for the wall retrofit. There were a number of suitable insulation options for this masonry building, including: XPS (extruded polystyrene) rigid insulation, closed cell spray foam (ccSPF) or a hybrid approach of ccSPF or XPS with fiberglass batt or cellulose insulation.

Both the strict budget and the energy performance goals were important factors driving this extensive retrofit. The project team considered a number of key items while selecting the wall system, such as the cost of materials and labor, constructability of the system, as well as the performance aspects of each option.

3.1 Wall Retrofit Options

The project team examined the following options for the wall retrofit; R-values are summarized in Table 2.

- Three layers of 2” XPS rigid insulation (2x4 stud wall inboard of insulation)
- Two layers of 2” XPS rigid insulation (2x4 stud wall inboard of insulation)
- 5” of ccSPF (2x4 stud wall inboard of insulation)
- 2” of ccSPF with 5.5” fiberglass batt (fiberglass in 2x6 stud wall inboard of ccSPF)

There are advantages and disadvantages associated with each wall system. The benefit of using the XPS rigid insulation in this specific case is that both material and labor are free. The MVHfH team secured a donation from Dow Chemical Company for the rigid foam, as well as the adhesive used for attaching the foam to the masonry walls (further discussed in Section 4 of the report). As a Habitat for Humanity organization, the labor is provided by unpaid volunteers. The disadvantage of using rigid sheet goods (such as XPS) compared to a monolithic material (such as spray foam) is the challenges of establishing a continuous air barrier, as well as the implementation of the drawn details. Also, given that the work is carried out by volunteers, the construction process is significantly slower.

Spraying 5” of closed cell foam onto the masonry walls will contribute to the air tightness of the assembly and will result in excellent condensation and vapor diffusion control. The work has to be performed by an industry professional and can, therefore, be completed in a shorter amount of time. The drawback, however, is the cost of material and labor.

The option of spraying 2” of ccSPF and installing batt insulation in the wall cavities creates a “hybrid” assembly that uses each material to its best advantage. The spray foam creates a robust air barrier and controls interstitial condensation risks, while the batt insulation is a more affordable product that raises the R-value of the assembly. However, the disadvantage is, again, the cost of materials for both the ccSPF and the fiberglass insulation. Volunteers are able to install the fiberglass batt insulation, but the spray foam insulation must be installed by a professional.

3.2 BEopt Parametric Analysis

In order to provide an economic analysis that is representative of a typical construction market, the BEopt analysis for this project was performed. BEopt, the Building America performance analysis tool, which features options for retrofit projects, was used to analyze the energy use and the cost effectiveness of the wall retrofit measures considered for this project.

One representative apartment unit was chosen for energy modeling: Unit 8 located on the second floor of the rear addition (Figure 16). This particular unit was selected because of its simple geometry as well as its exposure to the exterior.

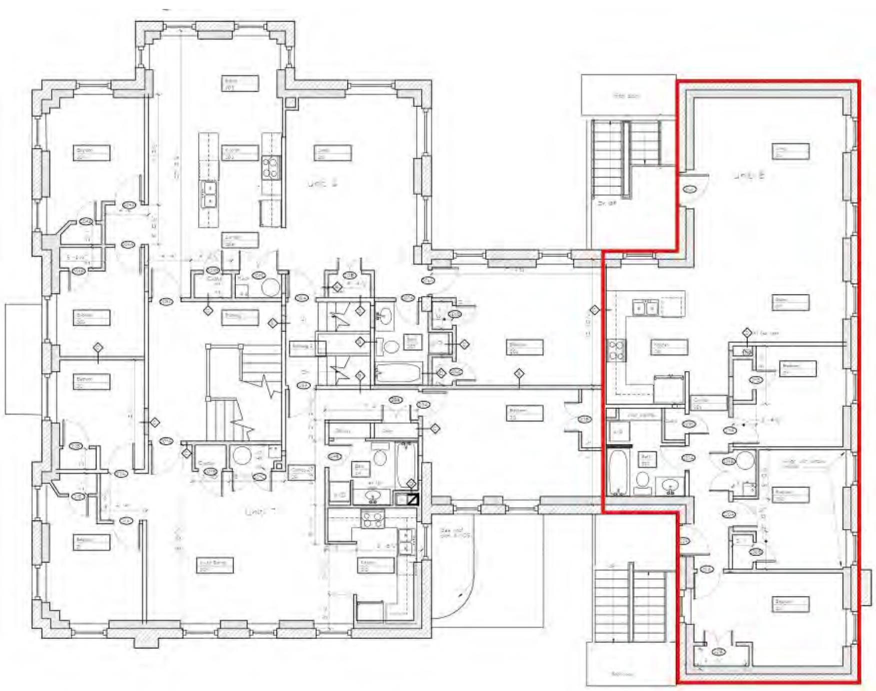


Figure 16: Unit 8 Floor Layout

Using the parametric feature in BEopt, alternate options for wall insulation were modeled in order to determine the energy performance for each option and the most cost effective measure. The default cost values for the Chicago Retrofit (a BEopt default library) were used for the majority of the inputs. Several cost values were obtained from RSMeans Reed Construction Data 2012 (Reed 2012), a cost-estimating tool, which provides the cost of materials, installations as well as overhead and profit. The cost of windows per unit was derived from the estimate provided by Harvey Industries. The utility rates used were the state average values for Massachusetts provided by BEopt.

Table 2 lists four options for the exterior wall insulation that were selected for the comparison: 6" of XPS rigid insulation, 4" of XPS rigid insulation, 5" of ccSPF and 2" of ccSPF with fiberglass batt insulation. The values include cost of materials, labor and profit. The R-values listed in Table 2 were derived from the BEopt model.

To simulate multifamily boundary conditions, an adiabatic crawlspace (with R-100 floor cavity insulation) and an attached unit wall on the south-west side were used in the modeling. A flat roof with 6” of XPS rigid insulation and 6” of ccSPF (R-66), and new ENERGY STAR qualified double pane window units (U=0.30, SHGC=0.30) were listed in the inputs. A gas boiler with 91% efficiency was also listed. For the infiltration rate of 1.7 ACH50 was used for all of the options; in addition, the two options that feature the closed cell spray foam insulation were modeled again with an air leakage of 1.2 ACH50. The rate was adjusted to reflect the reduction in air leakage by using ccSPF as compared to the other packages.

Table 2: BEopt Energy Modeling Inputs for Wall Retrofit Options

Point	Wall Retrofit Options	R-value	ACH50	RSMeans Cost Values
1	6” XPS with 2x4 stud wall	31.5	1.7	$9.46/sf
2	4” XPS with 2x4 stud wall	22.6	1.7	$7.47/sf
3	5” ccSPF with 2x4 stud wall	31.1	1.7	$7.53/sf
4	2” ccSPF+5.5” fiberglass batt with 2x6 stud wall	30.4	1.7	$5.92/sf
5	5” ccSPF with 2x4 stud wall	31.1	1.2	$7.53/sf
6	2” ccSPF+5.5” fiberglass batt with 2x6 stud wall	30.4	1.2	$5.92/sf

3.3 Results

3.3.1 Wall Retrofit Energy Performance

Figure 17 shows the average source energy use (MBtu/yr) for the selected four wall systems, generated by BEopt. The results indicate that options 1 (6” XPS rigid insulation), 3 (5” ccSPF) and 4 (2” ccSPF with batt insulation) use essentially the same amount of energy. Option 2 (4” XPS rigid insulation) uses 1.4 MBtu per year (~2%) more than the proposed 6” XPS rigid insulation. These results were expected, as the R-values of options 1, 3 and 4 are comparable. The reduced air leakage for Points 5 and 6 improved the energy usage minimally.

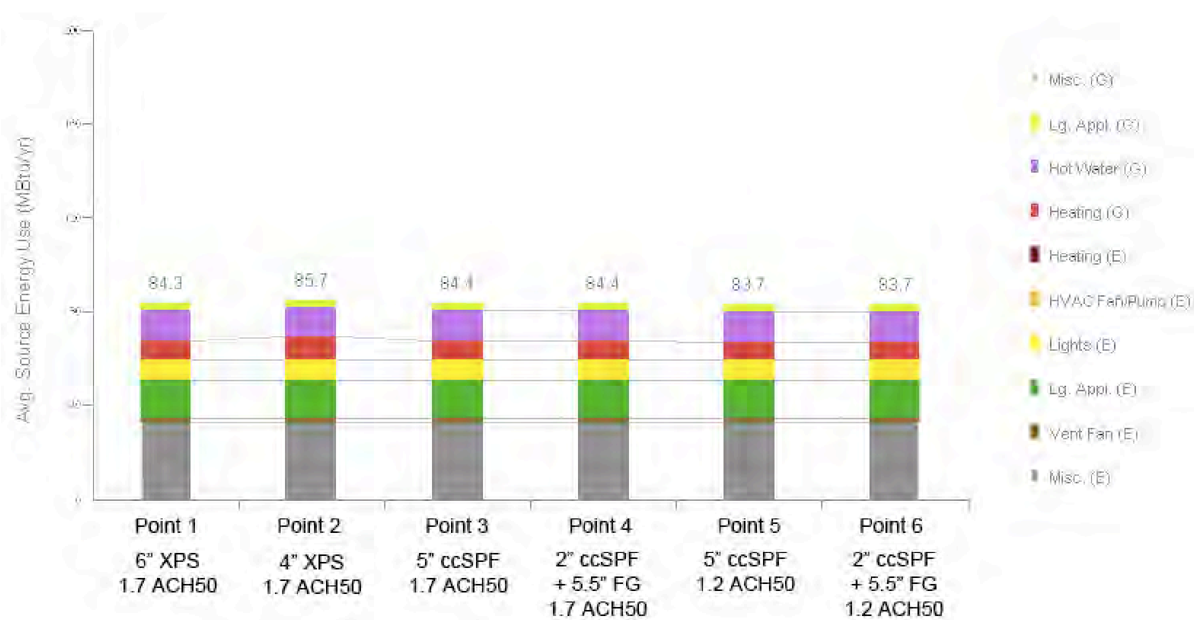


Figure 17: Unit 8 BEopt parametric results – Average Source Energy Use

3.3.2 Wall Retrofit Cost Analysis

The results of the energy modeling also indicate that the wall system selected for this project is not the most cost effective option (Figure 18). Specifically, the cost optimized wall system based off of market rates for labor and materials would be 2" ccSPF to the interior face of the masonry wall, with 5.5" fiberglass batt insulation in a 2x6 framed wall.

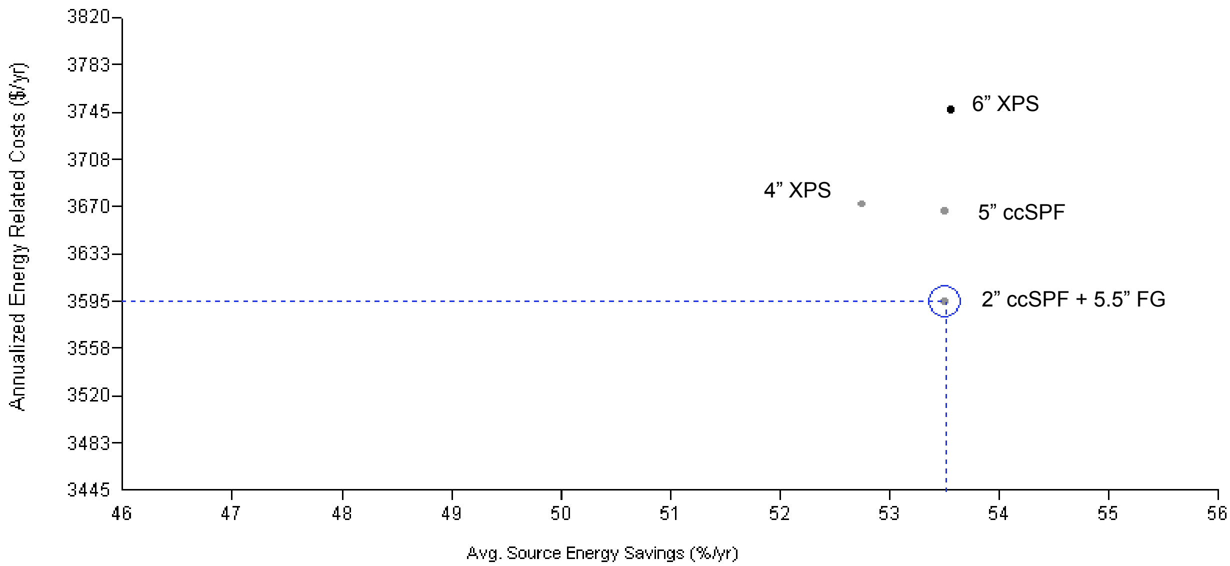


Figure 18: Unit 8 BEopt parametric results – Minimum Cost

Cost benefit calculations are complicated by the financial model of Habitat for Humanity, which includes free (volunteer) labor, some donated materials, and other materials at market rates. This can result in some distortions that result in practices that may not be the most cost-effective in all cases, but are the best approach for this particular project.

The wall assembly for this project is a representative example of such cases. Specifically, although fiberglass insulation is less expensive than extruded polystyrene on a $/R·sf basis, donated (free) XPS was less expensive than fiberglass insulation, which would need to be purchased at market rates. Therefore, 6" XPS rigid insulation on the interior of the masonry wall was selected, due to volunteer labor and donated materials.

3.3.3 BEopt Most Cost Effective Wall Option

The combination of the ccSPF and batt insulation creates a highly insulated wall (R-30 nominal) at a reasonable cost. The ccSPF is a high-priced material that requires professional application, but it offers multiple benefits. The material has a high R-value per inch, creates a robust air barrier, and controls condensation risks (at sufficient thicknesses). The fiberglass batt insulation, which is significantly cheaper, is easy to install, increases the R-value for the entire assembly, and utilizes the wood framing cavity (unlike the installed wall). This creates an affordable option that is suitable for a majority of mass masonry building in the cold climate. However, the suitability of the masonry wall for the retrofit of interior insulation must be determined, including improvement of bulk water shedding details, and determination of brick material properties (as per Straube et al. 2012).

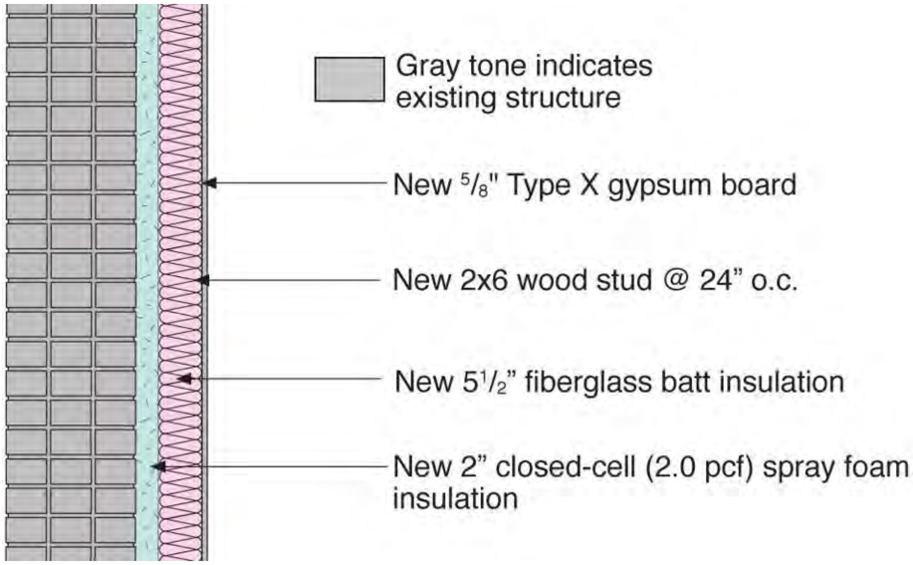


Figure 19: BEopt most cost effective wall option – 2” ccSPF + 5.5” fiberglass batt

4 Impact of Rebates and Incentives on Decision Making Process

4.1 National Grid Deep Energy Retrofit Pilot Program

MVHfH and BSC began their collaboration through the National Grid Deep Energy Retrofit Pilot Program (National Grid 2009), which provides financial incentives and technical support to participants. The program's goal is ideally to achieve at least 50% better energy performance than a code-built home. Building Science Corporation has partnered with National Grid, providing technical guidance and support for the program.

The project team was interested in submitting an application to the program in order to qualify for the incentives; however, it was later determined that National Grid was neither the gas or electricity provider for the building. Even though the project was not able to participate in the program, the enclosure retrofit goals of providing an R-60 roof, R-40 above grade walls, R-20 basement walls, R-10 basement slab and R-5 windows remained part of the retrofit strategy for the building.

4.2 ENERGY STAR Qualified Homes

4.2.1 Program Information

The project is pursuing the ENERGY STAR certification for each of the apartment units through the ENERGY STAR Qualified Homes, Version 3 program. Eligible homes or units are able to obtain the certification through either the Prescriptive or the Performance Path.

The program requirements for Climate Zone 5 are as follows (Mass Save 2012):

- Cooling equipment shall have SEER rating greater or equal to 13; or for air source heat pumps with 14.5 SEER; all cooling equipment must be sized according to the latest editions of ACCA Manuals J and S, ASHRAE 2001 Handbook of Fundamentals, or an equivalent computation procedure; the maximum over sizing limit for air conditioners is 15%, 25% for heat pumps; documentation must be provided to the HERS Rater
- Heating equipment shall have greater or equal to 90 AFUE gas furnace; 85 AFUE oil furnace; 85 AFUE boiler or an air source heat pump with 9.25 HSPF/14.5 SEER/12 EER with electric backup
- Ventilation – at least one of the following devices must be installed: one bath fan rated for continuous use ≤ 1.5 sones and controlled by a 24-hour programmable timer; or one whole house mechanical ventilation system; or a balanced supply and exhaust system without heat recovery; or a multi-port exhausts only system with a remote mounted fan
- Envelope – insulation levels shall meet or exceed 2009 IECC levels and achieve Grade I installation per Residential Energy Services Network (RESNET) standards
- Infiltration rate shall be determined by a Rater using a RESNET approved testing protocol
- Windows shall have U-value 0.30 and any SHGC
- Doors – opaque: 0.21 U-Value, No SGHC Rating; ≤½ lite: 0.27 U-Value, 0.30 SHGC; >½ lite: 0.32 U-Value, 0.30 SHGC

- Water Heater – installed heating and domestic hot water systems must generate positive energy savings
- Thermostat – programmable thermostats shall be installed unless thermostat controls a zone with electric radiant heat
- Ductwork – supply ducts in unconditioned space shall have insulation ≤ R-8; all other ducts in unconditioned space shall have insulation ≤ R-6; total duct leakage shall be ≤ 8 CFM25 per 100 sq. ft. of conditioned floor area; duct leakage to outdoors shall be ≤ 4 CFM25 per 100 sq. ft. of conditioned floor area
- Lighting – ENERGY STAR qualified light bulbs or fixtures shall be installed in 80% of RESNET-defined Qualifying Light Fixture Locations
- All installed appliances must be ENERGY STAR qualified

There are three incentive levels within the program, Tier I, II and III (Table 3). All Tiers have to achieve a certain percentage savings above the User Defined Reference Home (UDRH). The energy savings for each tier have associated incentive amounts that builders are able to receive for qualified projects.

Table 3: ENERGY STAR Tier Levels

Tier Level	Percent Savings	Incentive Amount for Multi-Family (2-99 Units)
Tier I	20%	$650
Tier II	30%	$1,150
Tier III	45%	$4,000

4.2.2 Building Energy Analysis

Part of the ENERGY STAR certification process is to determine the HERS Index Target for each of the units. A RESNET certified HERS Rater, hired by the project team, performed the energy analysis for the building with the REM/*Rate* software package, which was created by Architectural Energy Corporation.

Four representative units were modeled to calculate estimated energy savings of the proposed measures. Unit 2 is located in the basement of the addition, Unit 3 is located on the first floor of the original building, Unit 8 is located on the second floor of the addition and Unit 9 is located on the third floor of the original building. The four units selected for the analysis have different geometries as well as solar exposures. Enclosure and equipment specifications listed in Table 4 were used as inputs for the energy modeling.

Table 4: REM/*Rate* Energy Modeling Inputs

Component	Characteristics
Roof - flat	6” XPS plus 6” ccSPF
Roof - sloped	6” ccSPF in rafter cavity
Wall	6” XPS inboard of masonry, with stud frame wall
Basement Wall	3”-3-½” closed-cell spray foam (ccSPF)
Basement Slab	2” XPS
Windows	New double glazed vinyl windows U=0.30, SHGC=0.30

Component	Characteristics
Infiltration	2.0 ACH50
Heating and Cooling	Gas-fired tankless water heater (91% CAFUE) per unit, with baseboard radiation heating loop; no cooling provided
DHW	Gas-fired tankless water heater, per unit
Ventilation	Heat recovery ventilator (HRV), individual units (50% of ASHRAE 62.2)
Lighting	100% CFL lighting
Appliances	Energy Star refrigerator, dishwasher, clothes washer

Table 5 summarizes the potential energy savings, HERS rating and whether or not the unit qualifies for ENERGY STAR Qualified Homes, Version 3 Tier II incentives. Detailed reports showing calculations of heating, cooling, hot water, lighting and appliance energy loads for the selected units are included in Appendix C.

Table 5: REM/*Rate* Modeling Results

Unit Number	Percent Savings over User Defined Reference Home	HERS	ENERGY STAR v3 Tier II
Unit 2	30.7%	68	Yes
Unit 3	33.3%	66	Yes
Unit 8	43.5%	50	Yes
Unit 9	38.2%	55	Yes

All units qualify for Tier II (30% savings), but they do not qualify for Tier III incentives (45%). In order for each apartment to reach that savings level, significant upgrades to the proposed measures were required. A solar domestic hot water system is an example of the type of measure required to meet Tier III; upgrades of this magnitude were not accounted for in the project budget.

4.3 Window Performance Analysis

The existing windows at the building were vinyl double glazed (clear) insert replacement windows (U≈0.5); they were a circa 1980’s replacement, and appeared to be in reasonable condition (Figure 20). The initial decision for the window retrofit was to retain these existing vinyl units, and add low-e storm windows to bring up the overall U-value of the assembly (U≈0.34).

At that time, the energy analysis was performed to determine the Tier levels the apartment units would be able to qualify for. All units were able to reach Tier II incentives with the addition of low-e storms. Construction details were drawn to show the removal of the existing windows, installation of flashing at the wood framed window openings and reinstallation of the existing units. See Appendix B for the retrofit construction details, and Figure 21 for a test installation of these retrofit details.

Figure 20: Existing vinyl double glazed (clear) insert replacement windows

Figure 21: Test retrofit installation of flashing at the wood framed window openings

Estimates for purchasing low-e storm windows were provided by Harvey Industries. The team asked the manufacturer to calculate the cost of new ENERGY STAR qualified windows as well. The quote included pricing for 120 windows of various sizes. Table 6 lists cost for adding single glazed, hard coat low-e storms, and double glazed, low-e, argon filled vinyl windows (U=0.30, SHGC=0.30).

Table 6: Window Cost Comparison

Manufacturer	Low-e Storm Window	ENERGY STAR Qualified Vinyl Window
Harvey Industries	$18,768.62	$23,804.45

The cost difference between adding low-e storm windows and installing new ENERGY STAR qualified units is approximately $5,000, or a 27% increase. The average cost for a low-e storm window is $156 and for a new double glazed vinyl unit the cost is $198.

However, due to the budget constraints for this extensive retrofit the project team began considering only keeping the existing windows and omitting the low-e storm windows. Retaining the existing windows would impact the ability for each of the apartments to qualify for the Tier II; therefore, additional energy analysis was performed using REM/*Rate* software to compare three alternatives for the window retrofit:

- Retain the existing windows
- Add low-e storms (to improve the overall U-value of the existing windows)
- Replace the existing units with new ENERGY STAR qualified windows.

The results of the analysis are shown in Table 7.

Table 7: Window Performance Energy Analysis

Window Options	% Savings over UDRH										Tier Levels		
	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7	Unit 8	Unit 9	Unit 10	Total Tier I	Total Tier II	Total Tier III
U=0.49 SGHC= 0.60	24.3%	22.7%	23.4%	27.5%	28.0%	25.5%	27.7%	38.2%	34.0%	33.9%	7	3	0
U=0.34 SGHC= 0.48	31.1%	30.7%	33.2%	35.6%	36.9%	35.1%	35.6%	43.5%	39.3%	38.7%	0	10	0
U=0.30 SGHC= 0.30	30.2%	30.1%	33.5%	36.2%	37.3%	35.6%	36.0%	43.0%	37.1%	37.5%	0	10	0

The analysis showed that either adding low-e storms or replacing the existing windows would qualify all ten units for the Tier II (30%+) incentive. However, retaining the existing windows resulted in only three units meeting Tier II.

In October of 2012, the MVHfH board of directors met in order to determine the budget for the window retrofit. The members were presented with the information above, and based on the results of the analysis (as well as the window estimates), the board decided to approve the funds to replace the existing windows with ENERGY STAR qualified vinyl units.

The replacement of the existing windows with new construction vinyl units will be a much more straightforward process for the volunteers, compared to retrofit flashing of the existing window openings (Figure 21). The project team often works with volunteers that have little or no construction experience, and may be on site for a short amount of time; therefore, the team leaders have to train new volunteers on a regular basis.

The new plan for the retrofit of the windows will involve the preparation of the existing window openings to receive new construction (flanged) windows, which are considered simpler for volunteer installation. Two considered options include removal of the existing wood frame in the window openings, followed by installation of new 2x pressure treated rough bucks, or the installation of new blocking on the existing wood frames. The rough opening would then be waterproofed, including the installation of a sill pan flashing draining to the exterior sill. The project team is currently trying to secure a donation of liquid applied flashing, which would simplify the treatment of window rough opening by unskilled volunteers, and as a result, improve quality and accelerate the construction process.

4.4 Other Incentives

Habitat for Humanity is a nonprofit organization and is, therefore, allocated under a certain tax criteria. As a result, the project may not able to qualify for state and federal tax credits related to energy efficiency. However, there a number of state and federal tax credits that other projects may be eligible for. There are also local rebates and zero financing loans that can help offset or finance the cost of energy efficient improvements (Mass Save 2012).

The project team sought other alternatives for financing the implementation of retrofit measures in the building. The MVHfH team applied for a $200,000 grant through the Federal Home Loan Bank of Boston to complete structural work, water main repairs, and other essential fixes related to the basic function of the building. The terms of the grant dictate that the project also applies for a matching loan from a partner bank.

5 Retrofit Air Barrier Strategies and Assemblies

The importance of air barriers and the reduction of uncontrolled air leakage has been well established (Wilson 1961, Straube and Burnett 2005, Lstiburek 2005a, ASHRAE 2009). Effective air barriers are an important component for good energy performance, good indoor air quality, and control of interstitial condensation. In addition, an effective air barrier between units of multifamily housing reduces transmission of sound, odors, and smoke, lowers fire spread risk, and helps control stack-driven airflows (Lstiburek 2005b).

Therefore, BSC established targets for air barrier and compartmentalization performance on the MVHfH project, and developed multiple details for airtightness (interior-to-exterior) and compartmentalization (unit-to-unit) strategies. A full detail set is provided in Appendix B. These details had to be developed with the knowledge that they would be implemented by volunteer crews, who might be untrained and/or only on the site for a short duration (i.e., little chance for improvement over time). In addition, these air barrier and compartmentalization details had to be developed for the specifics of this project, which involves an interior insulation retrofit of a multifamily mass masonry building.

The planned research intended to analyze the effectiveness of air barrier strategies implemented in this multifamily retrofit; however, no units have been completed to date, so effectiveness has not been measured. However, some information is available on the secondary question, of the difficulties in implementing these air barrier details.

5.1 Exterior Wall Air Barrier

The construction of the masonry walls at this project include both multi-wythe solid brick walls, and exterior brick with a hollow clay block infill/backup wall, as shown in Figure 22. These photos show conditions after demolition of the interior furring, lath, and plaster.

Figure 22: Exterior wall conditions at solid brick (left) and hollow clay block infill (right) conditions

Although these assemblies appear to be monolithic from the interior and exterior, there are a variety of interconnected air spaces, such as the incompletely filled collar joints between brick wythes (Figure 23, left). In addition, the hollow clay blocks provide a major interconnected airflow network laterally across the wall (Figure 23, right).

Figure 23: Wall section at solid brick (left) and at hollow clay block infill (right) conditions

Wilson (1961) documented that bare masonry is a source of air leakage, as shown in Table 8. The measured air leakage (3.1 square inches/100 square feet surface area) is higher than the base leakage rate requirements in many energy efficiency programs (e.g., 2.5 square inches/100 square feet surface area). However, an air barrier (such as a 3-coat plaster parge) renders the air leakage through the assembly negligible.

Table 8: Air leakage through masonry materials (Wilson 1961)

Assembly	Equivalent Orifice, Areas, sq. in.
13-inch porous brick wall, no plaster, 100 sf	3.1
Wall as above, 3 coat plaster, 100 sf	0.054

Options for retrofitting an air barrier at a mass masonry wall include the application of a liquid-applied or membrane air barrier on the interior side, or the use of an insulation material that creates an air barrier. The selected retrofit strategy was to use multiple layers of rigid foam board insulation inboard of the masonry to provide both insulation and an air barrier. The use of rigid board foam as an interior retrofit of masonry walls has been covered by Straube et al. (2012), and Natarajan and Klocke (2011). Having an effective air barrier at this interior retrofit is critical for both energy performance, and for durability, to avoid wintertime air leakage condensation at the insulation-masonry interface (Straube et al. 2012).

The retrofit assembly consists of three 2” layers of XPS (extruded polystyrene) rigid insulation (with staggered seams), adhered to the masonry and between layers with a single-component polyurethane adhesive. The outermost and innermost layers of rigid insulation have joints taped to create an air barrier. Wood 2x4 framing is installed inboard of these layers, with no insulation in the stud bay cavities, for interior finishes and to provide space for running services.

The adhesive used for the rigid insulation was Dow Insta-Stik, which is currently in use in United States as a commercial roof adhesive (adheres compatible roof insulation boards to roof decks and substrates in new roof and roof replacement applications). The adhesive is formulated to have a quick curing time (board can be held in place until adhesion occurs), and minimal expansion (does not push board off of wall), while providing some gap-filling properties. It is specified to work over a wide range of temperatures (33-111° F or 0.5-43° C). It is currently used in Europe to adhere plasterboard and rigid insulation to existing masonry assemblies (Dow Building Solutions, 2007).

The installation of the rigid foam board is shown in Figure 24, including the application of adhesive. The adhesive bead is applied in a manner that provides some degree of isolation and compartmentalization of the gap between the masonry and insulation, thus reducing the extent of convective looping.

Figure 24: Test installation of foam on masonry (left) and use of polyurethane adhesive (right)

The completed insulation installation with taped seams is shown in Figure 25 (left). A small-scale mockup was built to provide volunteers with a visual example of the retrofit assembly geometries (Figure 25, right).

Figure 25: Multiple layers of insulation (left) and mockup for volunteer education (right)

The framing inboard of the insulation is shown in Figure 26 (left); note that the framing is only installed after complete installation of the rigid insulation. Therefore, access for taping seams of the air barrier layer is not hampered by the framing.

Although the layers of taped rigid foam provide an effective air barrier in the field of the wall, the penetrations through this layer are a potential failure point for air barrier continuity. For instance, at the windows (Figure 26, right), air barrier continuity needs to be achieved from the foam to the window unit. The air spaces between the layers of foam have the potential to form a three-dimensional network of airflow paths.

Figure 26: Framing installed inboard of insulation (left) and conditions at window opening (right)

The solution detail uses two-component spray foam kits to "cap" the exposed foam edges, and connect them to the window rough opening, as shown in Figure 27. The window opening flashing materials (membrane or liquid-applied) are in turn connected to the window unit using low-expansion foam.

However, the precise window details are still in flux. For instance, Figure 27 shows the existing double-glazed vinyl frame insert window, with an exterior low-E storm. Since drafting that detail, the plan has changed to retrofit new construction low-E double glazed windows (Energy Star-rated) into the openings. In addition, the Habitat for Humanity team has pushed to change to flanged windows, due to ease of installation by volunteers (as opposed to two-stage caulk joint required for insert window units, as shown in Figure 27). BSC plans to work with Habitat to develop further details, but they will include the air barrier detail of a fillet of spray foam connecting the edges of the rigid insulation board to window rough opening.

Other wall penetrations, such as the outside air supply/exhaust duct for the unit-by-unit heat recovery ventilators, will be treated in a similar way, with a spray foam seal between the duct and the rigid foam board.

Roof-to-wall connections and compartmentalization details (including wall-to-floor details) are covered in following sections.

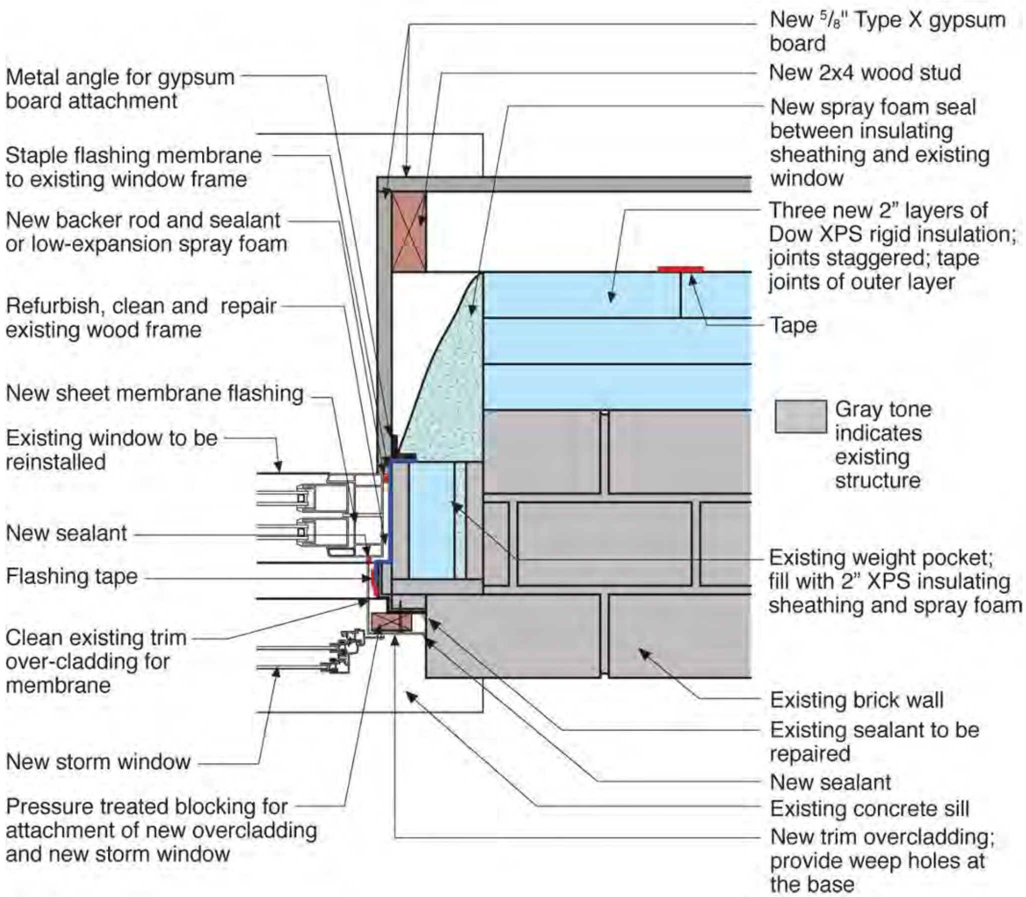


Figure 27: Window jamb retrofit detail, showing spray foam "fillet" for air barrier continuity

5.2 Roof and Roof-to-Wall Air Barrier

The existing roofs on this building included low-slope built-up roofs with aggregate (gravel) topping, and slate roofing on the sloping portions. There is a "lower" flat roof (ceiling of 2nd floor) with a parapet, and a smaller "upper" flat roof (ceiling of the 3rd floor), as shown in Figure 28.

Figure 28: Lower roof, showing upper roof (left) and upper roof (right)

All of these roofs were reported to be at end of service life, so a complete roof replacement was executed. Two critical aspects for the roof replacement were good air barrier continuity at the roof-to-wall interface, and an effective air barrier at the underside of the layers of rigid insulation. This latter requirement prevents interior air leakage into the "sandwich" of insulation and roof membrane layers, which could result in wintertime condensation and moisture buildup issues (see Lstiburek 2009, 2011).

The assembly for the lower flat roof (which has a masonry parapet) is shown in Figure 29. It shows that the air barrier connection from the wall (rigid insulation) to the roof is made via 2 pound/cubic foot closed-cell spray foam, which "caps" the edge of the rigid insulation and connects it to the underside of the roof deck and the masonry parapet.

On the top side, a layer of self-adhered membrane is installed under the layers of rigid insulation and wrapped up the parapet, to provide an air barrier at the underside of the "roof sandwich" discussed above. This air barrier is actually somewhat redundant, given the spray foam installed from the underside; however, it was selected due to some of the specifics of this project.

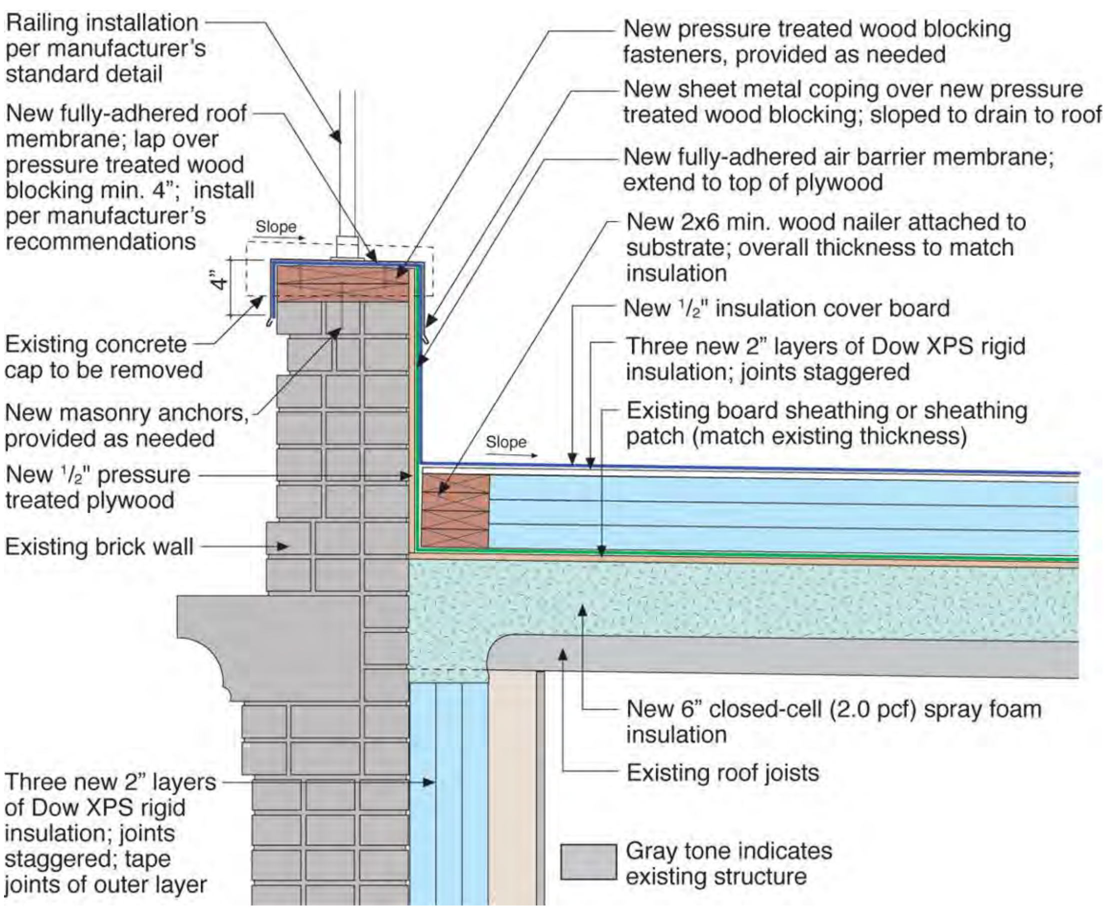


Figure 29: Lower roof retrofit detail at parapet

During the installation of the lower roof, it was found that the air barrier layer was not being installed; instead, the rigid insulation was being installed directly on the roof board sheathing

(Figure 30). The site supervisor was notified of this deficiency, and it was corrected over the weekend before completion of the roof membrane installation.

Figure 30: Insulation of lower roof, showing lack of air barrier at board sheathing

The completed lower roof is shown in Figure 31; the sloped portions of the roof were finished with asphalt shingles.

Figure 31: Lower roof, showing upper roof (left) and upper roof (right)

At the upper roof, instead of applying a layer of self-adhered membrane to the roof board sheathing as an air barrier, the existing built-up roof was left in place, patched, and used as the air barrier layer, as shown in Figure 32. Closed cells spray foam also provides air barrier continuity and insulation at the flat and sloping portions of the roof. The completed upper roof is shown in Figure 33.

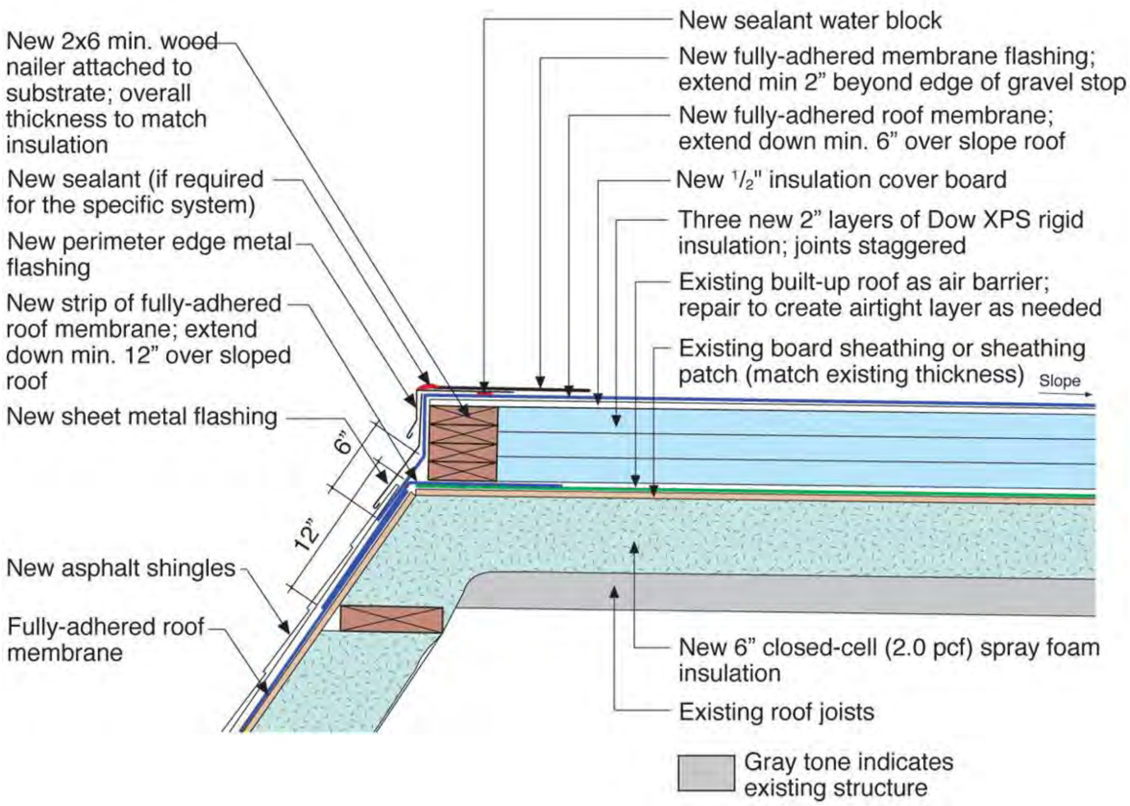


Figure 32: Upper roof retrofit detail at intersection with sloping roof


Figure 33: Upper roof typical conditions (left) and upper roof edge detail (right)

One example of the air barrier connection between the above-grade wall and sloping roof is shown in Figure 34: the wall rigid foam board was left clear of the roof, and the connection from the wall air barrier to the roof spray foam air barrier was made with closed cell spray foam. The example shown in Figure 34 was done by the volunteer crew using a spray foam insulation kit; however, it could be done instead by the professional spray foam contractor when the field of the roof is done.

Figure 34: Rigid wall insulation left clear of roof (left) and infill with spray foam kit (right)

5.3 Below Grade Air Barrier

Although the below-grade building enclosure is not commonly thought of as a major air leakage location, air barrier continuity is critical at this portion of the building. First, diffuse air leakage occurs through the soil, which is commonly air permeable (see Ueno and Lstiburek 2012). Second, the surrounding earth can be a source of air-transported contaminants such as moisture (water vapor), soil gases, and radon, which have negative effects on health, safety, and durability. Wintertime stack effect will tend to pull soil gases from the earth into the building through any air barrier imperfection.

The ideal new construction slab design is shown in Figure 35, which is taken from Lstiburek (2007). It consists of (from bottom to top) some type of granular fill/gravel to create a capillary break from the earth below, a layer of moisture-insensitive insulation, an air and vapor impermeable membrane (such as polyethylene), and the concrete slab, cast directly onto the membrane.

Figure 35: “Perfect slab,” showing polyethylene & insulation control layers (Lstiburek 2007)

The function of various layers as air barriers and vapor barriers are discussed by Lstiburek (2008). The concrete slab functions as the air barrier (and needs to be continuous), while the polyethylene functions as the vapor barrier, and can have discontinuities, holes, or tears without substantial loss of performance.

The retrofit design went through several iterations; there are existing concrete slab floors throughout the basement, but at different elevations. One proposed retrofit was to build a rigid insulation and wood sheathing-based “floating floor” on top of the existing slabs. However, this places an assembly with poor flood recoverability in a basement, which is a risky decision.

Therefore, the team decided to build a new construction basement slab over the existing slab; existing head height was sufficient to allow a greater assembly thickness. The retrofit assembly was, from bottom to top:

- Existing concrete slab (no vapor control beneath)
- Compacted earth fill
- Sand topping layer, screeded level with the highest slab
- Extruded polystyrene (2” thick)
- 6 mil polyethylene vapor barrier
- Cast concrete slab, 3” thick nominal

In the area with the highest slab, the compacted earth fill and sand were omitted, to create a level substrate for the XPS insulation.

As previously described by Lstiburek (2008), the air barrier is primarily the concrete slab. But to some degree, the polyethylene adhered to underside of the slab effectively acts in a composite or secondary role, potentially bridging gaps and cracks at the slab. The details shown below use the polyethylene to “pass” the air barrier from the slab to adjacent components, such as closed cell spray foam applied to the below-grade walls, as shown in Figure 36.

That detail shows the retrofit slab layers described above. At the slab edge, the polyethylene wraps up the edge of the slab, and an effective air barrier connection is made by the closed cell spray foam, which is directly applied to the rubble stone foundation wall (see Ueno and Lstiburek 2012).

The detail also shows the installation of a sub-slab radon collection system. No testing was done to indicate that radon is a known problem; however, the team decided to install the system. This is due to the fact that installing the sub-slab components is a simple change prior to casting of the slab, but prohibitively expensive as a retrofit. The system is currently planned as a passive stack vented through the roof, but a powered radon mitigation fan can be retrofitted if high radon levels are found in service.

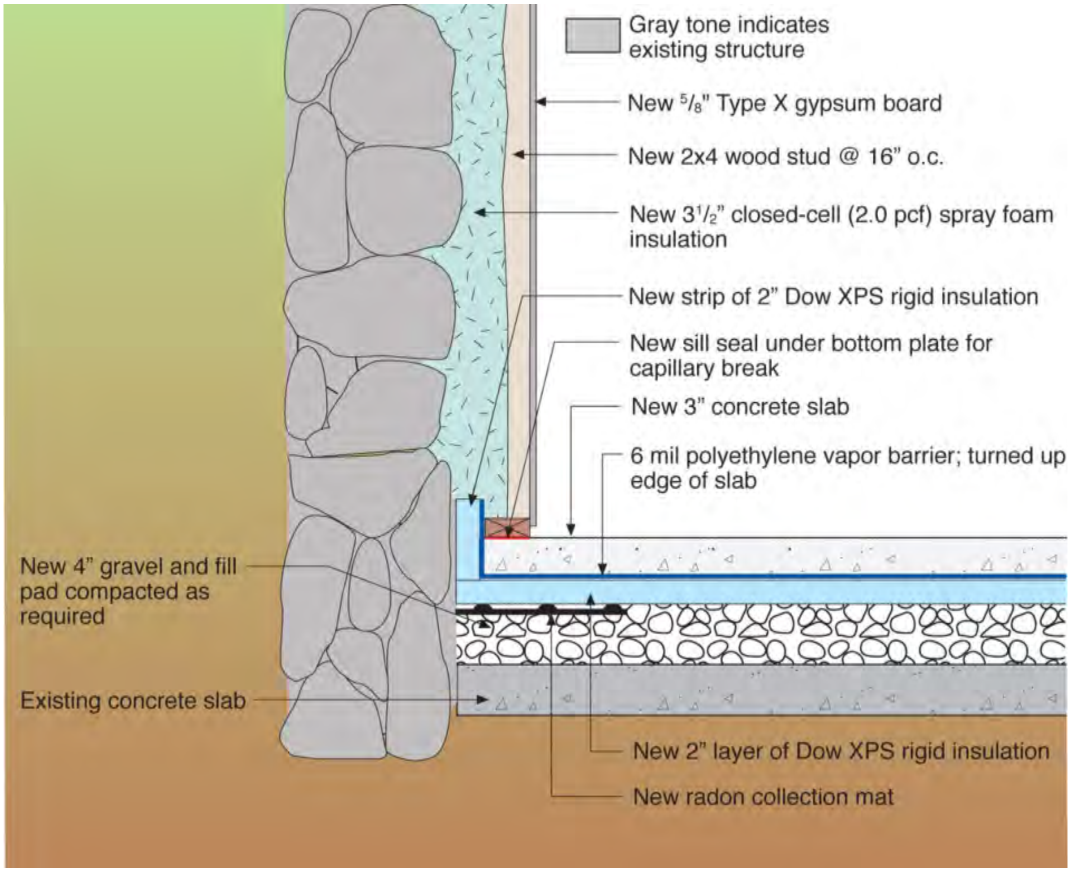


Figure 36: Typical basement slab and bottom of wall detail

The original plan was to use corrugated perforated drainage pipe for radon collection (Figure 37, left). However, accommodating this pipe in the earth fill/sand layer would result in a substantial loss in head height, and would require additional fill. Therefore, the team decided on a low-profile radon vent mat, which consists of a plastic air gap membrane mat wrapped in a geotextile sleeve (see Figure 37, right and Figure 38, left). The radon vent is installed around the perimeter of the slab (see Figure 38, right), and connected to through-slab pipe stubs.

Figure 37: 4" nominal corrugated drainage pipe (left) and low-profile radon vent mat (right)

Figure 38: Dimpled core of radon vent mat (left) and radon vent map installed under XPS (right)

The completed slab insulation work (prior to installation of polyethylene) is shown in Figure 39; the slab edge insulation is temporarily held in place by one-component polyurethane adhesive (Figure 39, right).

Figure 39: Installed sub-slab insulation at basement (left) with detail of slab edge insulation (right)

The condition of the edge detail after the casting of the slab is shown in Figure 40 (left); the polyethylene “flap” is available for an air barrier connection to the spray foam used at the bottom of the wall (at the rubble stone section at the base of the wall). Interior framing installation is shown in Figure 40 (left).

Figure 40: Edge detail after casting of slab (left) and installation of interior framing (right)

5.4 Compartmentalization Details

An effective air barrier between units of multifamily housing reduces transmission of sound, odors, and smoke, lowers fire spread risk, and helps control stack-driven airflows (Lstiburek 2005b). However, creating effective compartmentalization between units—particularly in light frame construction—is often difficult. The wall, roof, and floor assemblies in light frame buildings are not monolithic assemblies: instead, they are hollow and contain multiple layers, air gaps, and void spaces which can be interconnected by many unintentional paths. These complex three-dimensional airflow networks can defeat efforts at compartmentalization, as shown in Figure 41 (Lstiburek 2000).

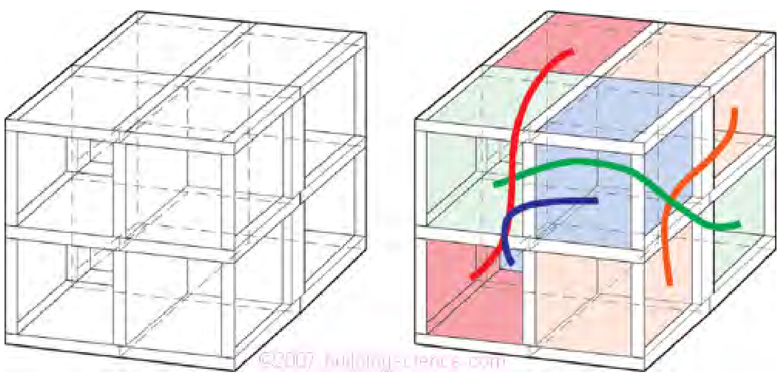


Figure 41: Three dimensional multi-layer multi-cell analogue (left) with air pressure fields connecting non-contiguous spaces (right) (Lstiburek 2000)

Therefore, details were drawn to create effective compartmentalization between units; they also had to account for constructability (including sequencing), and in particular, construction by largely untrained volunteers. In addition, many of these details also need to meet fire resistance ratings (2-hour unit-to-unit; 1 hour unit-to-hall), which adds further complications.

One unit-to-unit detail is the floor/ceiling assembly's intersection with the exterior wall; the floor/ceiling is a rated assembly, and the detail must provide air barrier continuity (unit-to-unit and unit-to-exterior). The typical detail with the floor joists perpendicular to the exterior wall is shown in Figure 42.

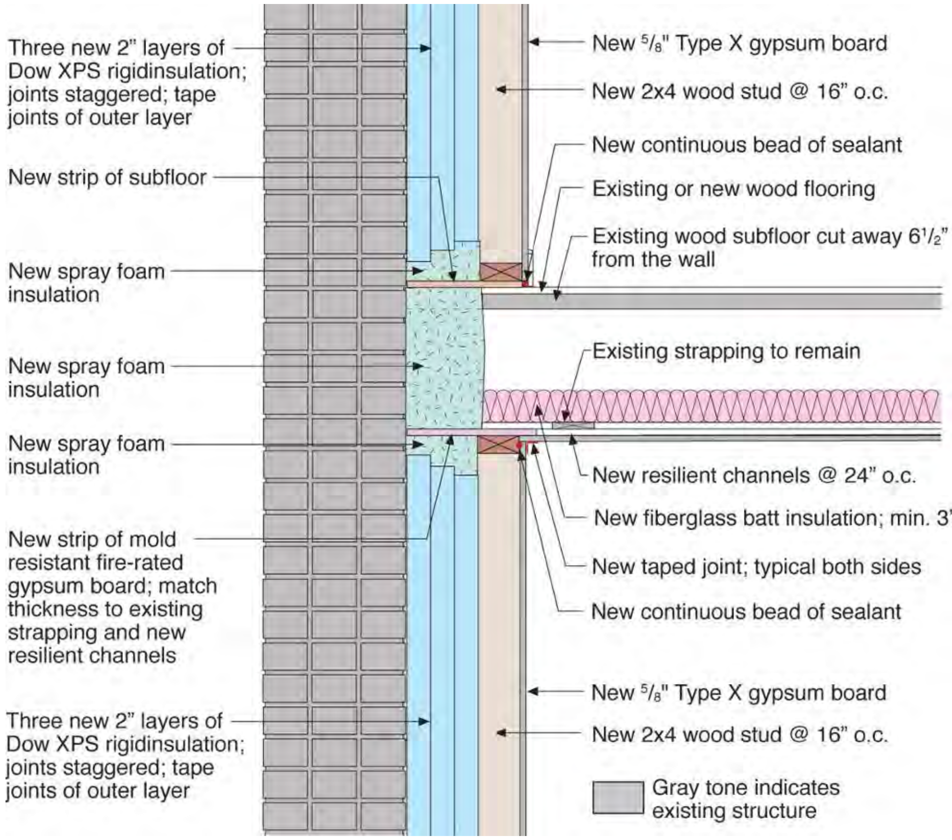


Figure 42: Unit-to-unit floor/ceiling assembly at exterior wall; joists perpendicular to wall

The interior-to-exterior air barrier is "passed" from the layers of rigid foam (XPS), through closed-cell spray foam insulation and fire resistance elements, to the rigid foam on the floor above.

The fire resistance requirements mean that the floor/ceiling assembly must be extended to the exterior wall (gypsum board and floor sheathing). Due to construction sequencing, a "strip" of each must be placed at the perimeter during wall construction, before the field of the ceiling is built. The gypsum board detail is shown in Figure 43. Note that instead of the "step back" detail and spray foam, the interior layer of rigid insulation is caulked to the face of the strip of fire separation gypsum board (Figure 43, left). Note that Figure 43 (left) shows four layers of foam; the additional layer is a strip of foam filling the web of the steel lintel over the window.

BSC recommended non-paper faced gypsum board to the team for the fire separation "strip," as it is in direct contact with the masonry. However, the team decided to use a paper-faced mold resistant gypsum board instead. This strip will in turn be tied to the ceiling gypsum board, which provides unit-to-unit separation.

Figure 43: Floor/ceiling fire separation gypsum board (left); conditions after interior framing (right)

The insulation detail at the joist ends is shown in Figure 44; instead of using spray foam to insulate and air seal (as per Figure 42), scraps of rigid foam insulation were used, adhered with polyurethane adhesive. This was due to the fact that given volunteer labor, this is a less costly approach than spray foam, and uses the available scrap.

Note that there is a generous space at the perimeter of each block, which allows effective air sealing with a spray foam kit.

Figure 44: Rim joist foam blocks (left); close-up showing clamping jig (right)

The floor detail is shown in Figure 45, showing the strip of floor sheathing at the perimeter, and the caulk seal between the subfloor and the rigid board insulation.

Figure 45: Floor edge detail, showing added floor sheathing (left) and air seal between foam and floor (right)

Given the complexity of this detail, a step-by-step construction sequence was provided to the team.

The remaining details cover unit-to-unit compartmentalization at interior framed walls and floors. Given that interior wall framing has only recently started, these details have not been built, much less tested for air leakage performance.

In general, the compartmentalization details use the interior gypsum as the air barrier, except at the exterior walls, where the rigid insulation is the air barrier. The details also note that since the gypsum board is the air barrier, all penetrations must be airtight, such as electrical boxes, and mechanical or plumbing penetrations. Through-demising-wall penetrations must be sealed to the gypsum board on both sides of the assembly.

The detail for a demising wall intersecting the exterior wall is shown in Figure 46: it is conceptually similar to the floor-ceiling intersection detail shown in Figure 42, with the “strip” of mold-resistant gypsum board where it is hidden within the exterior wall assembly, to provide continuous fire resistance to the masonry wall. Again, spray foam is used to connect the exterior wall air barrier (XPS) to the demising wall air barrier (gypsum board), and “cap” the edges. Nailers are necessary for attaching the gypsum board perpendicular to the demising wall. In addition, the end stud of the demising wall is held off of the exterior wall (with a 2” piece of mineral fiber insulation), to avoid contact between vulnerable wood framing and the cold exterior wall.

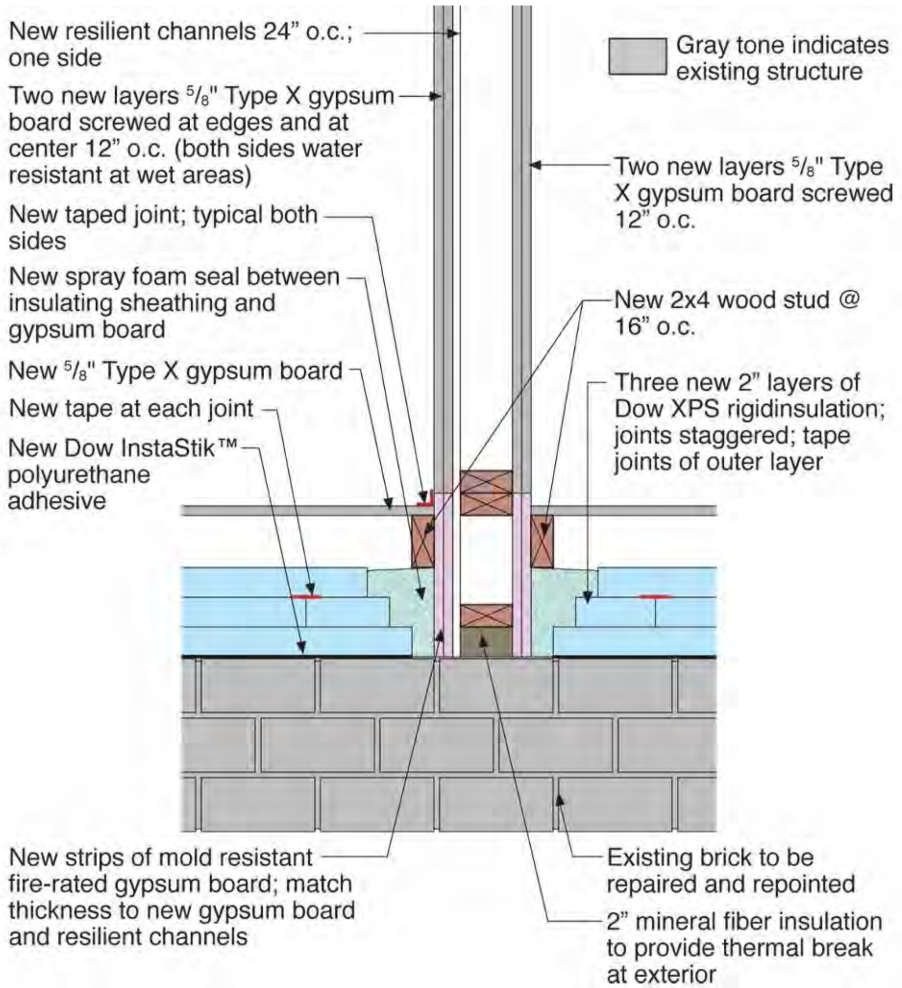


Figure 46: Rated partition intersection with exterior wall

At the floor-ceiling assembly, the air barrier is the ceiling gypsum board, given that the floor sheathing has already been installed, and/or existing flooring (tongue and groove wood) is remaining in place. Neither of these flooring options can readily be made airtight. Again, penetrations such as light fixtures must be sealed at the ceiling gypsum board. Any interior soffits (such as those being used to conceal the heat recovery ventilator/HRV ductwork) must be built with the gypsum board (or other air barrier material) continuous behind the soffit (see Figure 48, left).

In addition, interior partitions penetrate through this ceiling gypsum board, interrupting the continuity of the layer. Therefore, the air barrier must be "passed" through the top plate of the non-rated walls, as shown in Figure 47. The ceiling gypsum board is connected to the non-rated partition gypsum board with a typical taped corner joint, the wall gypsum board in turn connects to the top plate with a gasket.

Any penetrations through the top plate for electrical or plumbing services must be air sealed at the top plate, similar to an interior wall under a vented attic (see Figure 48, right).

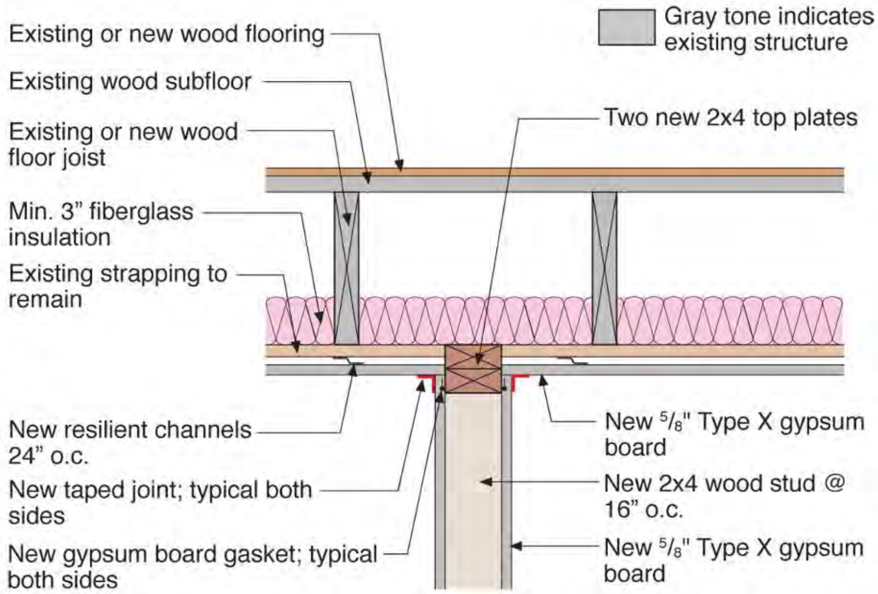


Figure 47: Within-unit (non-rated) partition wall intersection with ceiling

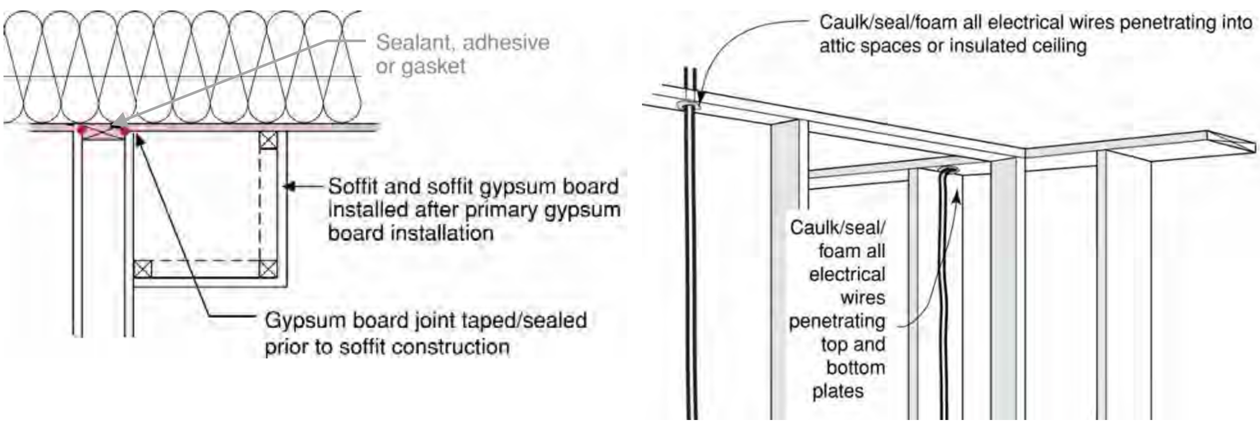


Figure 48: Soffit with air barrier continuous above (left) air sealing of top plate penetrations (right)

Demising walls between units have fire resistance rating and compartmentalization (unit-to-unit) requirements. Therefore, the fire rated partition must extend up into the floor cavity, as shown in Figure 49.

The rated wall gypsum board is sealed to the floor sheathing (at bottom and top) with fire rated sealant or expanding board: this is a somewhat "weak" air barrier connection, given that the gypsum board air barrier is "passed" through a potentially air permeable material (floor board sheathing plus existing finish floor). However, there are no other reasonable options, given the existing conditions.

At the condition where the demising wall is perpendicular to the joists (rather than parallel, as per Figure 49), the gypsum board is notched around the joists and sealed with fire-rated expanding foam.

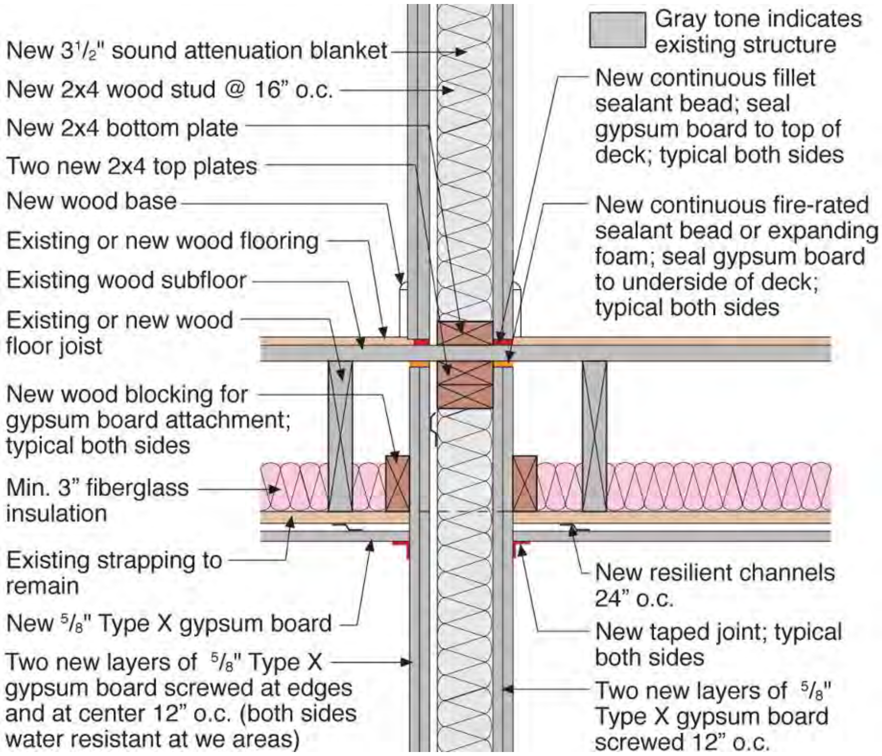


Figure 49: Unit-to-unit (rated) floor/ceiling assembly at demising wall; joists parallel to wall

The Habitat team developed these details further on site. For instance, the notched gypsum board at the demising wall above the finish ceiling was demonstrated by a senior volunteer in Figure 50 (left); sufficient space was left at the notches to air seal with fire-rated foam at the openings. At unit interior partition walls, the Habitat team found that rather than "passing" the air barrier through the top plate with air sealing details, it was simpler to run the ceiling gypsum board continuously and frame the partition below this gypsum board layer (see Figure 50 right). These images also show the use of fiberglass batt and resilient channel for acoustic separation.

Figure 50: Notched gypsum board at demising wall (left) and ceiling gypsum board continuous over unit interior partition walls (right)

To help the team to put these details in context, a table was made showing the relevant interface detail between the air barrier assemblies (wall, ceiling, and floor), as shown in Table 9.

Table 9. Air barrier connections between air barrier element detail listing

	Exterior Wall	Demising Wall	Ceiling	Floor
Exterior Wall	-	-	-	-
Demising Wall	W3	-	-	-
Ceiling	W1	W4, W5	-	-
Floor	W1	W4	n/a	-

In addition, the following outline-form narrative was included with the air barrier details, to give the team a greater understanding of the compartmentalization strategies being implemented.

- *Goals and principles of air barriers and compartmentalization*
  - *Each unit should be airtight as possible to the outside*
  - *Each unit should be isolated/airtight from another ("compartmentalization")*
  - *Each unit should be isolated/airtight from the corridor ("compartmentalization")*
  - *We are designating an airtight plane on "all six sides of the cube" (each unit)*
    - *Each plane needs to be made airtight as possible: it must be made of an airtight material, and penetrations through the air barrier layer must be sealed to the air barrier*
    - *Each plane needs to be connected to the adjacent plane in an airtight manner*
- *Exterior wall air barrier (inside-to-outside)*
  - *The XPS (extruded polystyrene) rigid foam insulation forms the air barrier at the exterior walls; the seams are taped at the outermost and innermost layers.*
  - *Closed-cell spray foam is used to connect the XPS at difficult transitions (to window opening, portions of uneven surface brick, and the joist/floor areas (see Detail W1).*
  - *Windows and doors must be connected to the air barrier layer (see Details WS, WH, WJ)*
- *Demising wall air barrier (unit-to-unit and unit-to-corridor)*
  - *The surface of the gypsum board is the air barrier layer, on each side of the demising wall*
  - *All penetrations through the gypsum board must be made airtight:*
    - *Electrical boxes should be airtight boxes, or alternately, caulked/sealed boxes*
    - *All mechanical and plumbing penetrations must be sealed to the gypsum board, where they penetrate through, on each side of the drywall*
  - *Connections to the exterior wall as per Detail W3 (spray foam connection to XPS)*
  - *Connections to the floor and ceiling air barrier to be done with caulk, sealant, or gaskets (Detail W4, W5)*

- *Ceiling (gypsum board side) air barrier*
  - *Where the ceiling gypsum board is interrupted by partition wall framing, the air barrier must be "passed" through the framing (Detail W6)*
  - *Any soffits must be built with the gypsum (or other air barrier) continuous behind the soffit (Detail A1)*
  - *All penetrations through the gypsum board must be made airtight:*
    - *Electrical boxes should be airtight boxes, or alternately, caulked/sealed boxes (Detail A3, A4)*
    - *All mechanical and plumbing penetrations must be sealed to the gypsum board, where they penetrate through, on each side of the drywall (Detail A3)*
    - *Attic hatch must be made airtight (Detail A2)*
- *Floor (flooring side) air barrier*

All penetrations through the subfloor must be sealed (e.g., plumbing and wiring penetrations) (Detail A3)

6 Retrofit Mechanical Design

Previous research has indicated that unit compartmentalization combined with individual HVAC systems result in more efficient operation and improved individual unit control (Lstiburek 2005b). Hydronic heating systems can be designed to provide good efficiency in low load residences (Siegenthaler 2011), especially by the use of low temperature distribution. Monitored data from field installations have indicated that combination space heating and domestic hot water (DHW) systems can meet the smaller demands of low load homes with high efficiencies (Rudd 2010). However, although they can be high performance, low-cost systems, some in industry posit that using DHW equipment for space heating applications result in excess complexity (Rudd et al. 2011). Data from both monitored field installations and computerized analysis indicates that while high efficiencies can be achieved with condensing boilers, a better understanding of the actual vs. predicted performance is needed (Zoeller 2011).

Use of individual unit space heating and domestic hot water systems greatly reduces the distribution losses associated with these systems, at a comparable net cost to centralized systems. The losses associated with centralized domestic hot water system distribution and recirculation have been measured at roughly a third of the total energy use for DHW (CEC 2008, Zobrist 2012). The use of individual unit HRV (heat recovery ventilation) systems greatly improves compartmentalization, and based on preliminary analysis, provides substantial first cost savings relative to a large centralized HRV system. The smaller, more compact, distribution systems will also result in fewer intrusions into the living space (e.g. dropped ceilings and vertical chases) for placing these larger systems. Use of individual tankless water heaters and HRV units in each condominium will also provide the homeowners with the ability to control the settings according to their particular lifestyle and desired comfort levels. The tradeoffs associated with this approach, however, are the challenges of locating individual tankless water heaters and HRVs in each apartment, and the placement of the entire distribution system within the fire rated assembly, to avoid the need for costly mechanical fire protection equipment (i.e., fire dampers, rated shafts, etc.).

Therefore, BSC developed a mechanical design with individual mechanical systems for each apartment unit, and for the common areas of the MVHfH multi-family building. Designs were developed for installing small HVAC systems in each apartment, including full mechanical plans with complete specifications on selected equipment. One aspect of the ventilation design (the kitchen exhaust) is to be a centralized system as incompatibilities in the floor plans did not allow individual unit kitchen exhaust ducts to be effectively placed.

This research project seeks to address two questions related to the HVAC design in this multifamily building:

- What are the performance and cost impacts of implementing a compartmentalized ventilation strategy with individual apartment HRV systems vs. a traditional large single central HRV system?
- What are the performance and cost impacts of using individual unit combination space heating/hot water units, including effects of distribution piping and installation specifics?

However, no mechanical systems have been installed to date, nor have any quotes been received for the design. Therefore, the cost impacts cannot be determined at this point, but details on the current HVAC design are available. The designs are complete and have been submitted to the MVHfH project team.

6.1 Hydronic Heating

Hydronic heating constitutes the predominant heating system in the Northeast, with either No. 2 fuel oil or natural gas as the fossil fuel energy source (EIA 2009). The existing heating system at the convent was a single large centralized oil steam boiler with cast iron radiators for distribution. Hydronic installations are usually preferred to forced hot air systems in retrofits in this region due to easier installation in an existing building. Another reason is that centralized air conditioning historically was not often installed in residential buildings in the region, which is a Cold Climate and an International Energy Conservation Code Climate Zone 5 (ICC 2009).

As part of Habitat for Humanity’s policy in this region, centralized air conditioning was not considered for this project. Therefore, hydronic heating with baseboard distribution was determined to be the most cost effective design for this building. Natural gas is available onsite and will be used for appliances; therefore, oil was not considered as the fuel source for the heating system.

A local engineer provided an initial mechanical design that included individual gas hot water boilers for each apartment and the common areas. BSC reviewed the design with a local plumbing contractor who is providing the plumbing design for the building, and further developed the design.

The gas hot water boiler that was selected was a high efficiency, sealed combustion, condensing combination space/domestic hot water heater. The original selected convectors were standard finned tube radiation baseboard.

Figure 51: Navien CH-240 combination boiler and Haydon finned tube radiator baseboard

Figure 52 shows the original heating system schematic.

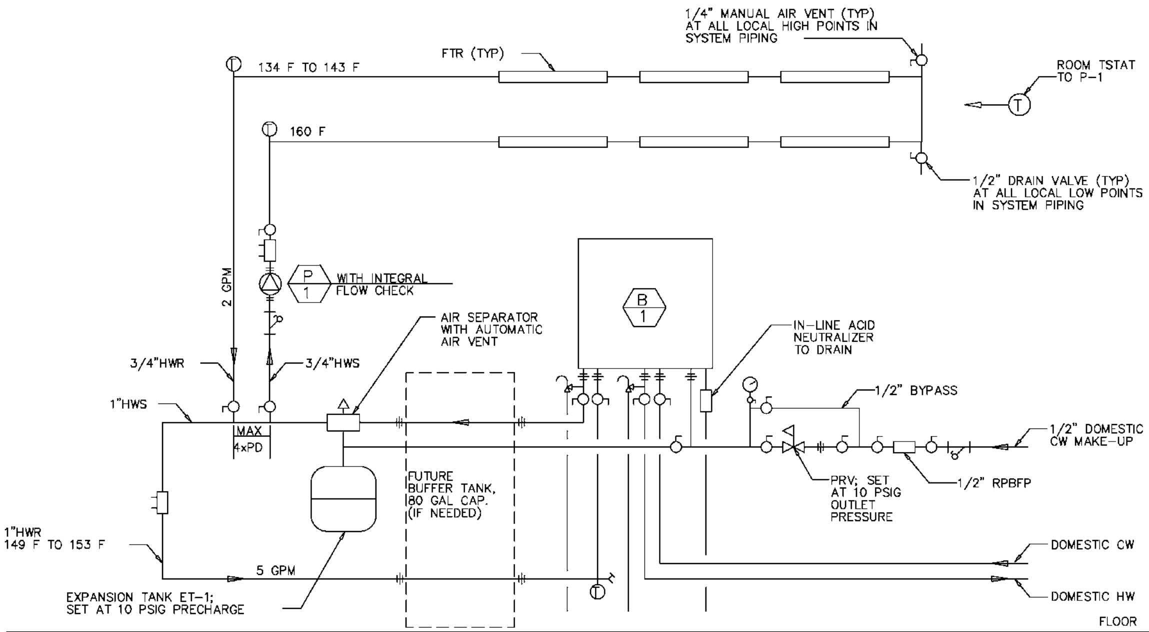


Figure 52: Original Apartment Hydronic Schematic

This design did have positive traits, but BSC identified elements that required additional development. The discussion below outlines BSC's initial evaluation of the design and recommended improvements. Some of the improvements were recommended with the knowledge that Watts Water Technologies will be donating any products in their line to Habitat for Humanity for the convent retrofit effort.

Positive

Combination heat/hot water boiler – A strong attribute for this boiler is that it has separate outlet taps for both space heating and domestic hot water. Thus, a single unit can be utilized to provide heat and hot water for the apartments without the complexities associated with converting a standard one tap boiler to serve as a combination heat and hot water unit. Those issues would include using a heat exchanger for the non-potable loop, or using potable water in the heating distribution system. While working on system design, BSC determined that the smaller model, the CH-180, is better matched to the loads of these small apartments.

Buffer Tank – The original design included an optional 80 gallon buffer tank for future installation if necessary. The purpose of this tank is to prevent severe short cycling of the boiler during part load operation. It is suspected that rapid short cycling with boilers in very low load applications can dramatically reduce the lifetime of the boiler components and can increase operating costs (McKeegan 2005). BSC remains receptive to this concept; however, the buffer tank was not selected for this project because of cost concerns–not only due to mechanical equipment, but because of the additional structural reinforcing required at each mechanical closet. The boiler manufacturer maintains that the boiler is designed to operate in part load conditions and did not recommend a buffer tank for this application.

Negative

Standard Baseboard – Standard finned tube radiators must operate at high temperatures to heat a space. The system was designed for a baseboard supply water temperature of 160° F, with the return water temperature in the range of 149 to 153° F. At these return water temperatures, it is likely that condensation will not occur at the water heater, thus reducing the operating efficiency of the boiler to that of a standard non-condensing unit (blue lines in Figure 53).

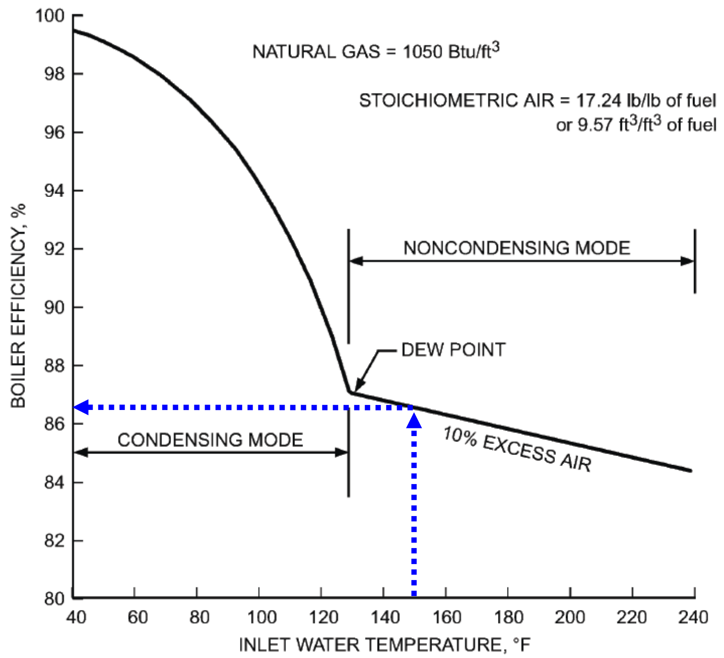


Figure 53: Thermal efficiency plot as a function of inlet water temperature (ASHRAE 2008)

The reason why standard baseboard typically operates at a high water temperature is twofold. First, standard baseboard has a low Btu output per linear foot (Btu/ft), which is intrinsic to the one pipe design. Therefore high supply temperatures are required to increase the Btu/ft to such that reasonable length of baseboard can fit in a room. Second, standard baseboard is typically not rated for supply temperatures below 120°F, which is the around the highest recommended water temperature to ensure that return temperature is low enough for condensation at the boiler. In the cases where standard baseboard is rated below 120°F, its heat output drops precipitously, thus requiring even more of a prohibitive length of baseboard to adequately heat a space.

Therefore, BSC recommended a high output, two pipe baseboard called the Heating Edge 2 from Smith Environmental (Figure 54). This baseboard is rated to supply the equivalent Btu output at 120°F as standard baseboard operating at 180°F. This increased capacity per linear foot allowed for the adequate placement of baseboard in every room in the building without having to resort to other terminations such as kickspace heaters and convectors. The local plumbing contractor with whom BSC consulted on the hydronic design has installed this baseboard in previous homes and noted that the increased gauge of the cover sheet metal material greatly improved the durability of the product relative to standard baseboard. This led to a marked decrease in callbacks to repair damaged baseboard. As a note, fan assisted panel radiators were briefly considered, but were rejected for cost reasons.

Figure 54: Smith Environmental HE2 High Capacity Hybrid Element (from Smith Environmental)

The two pipe baseboard can be installed in a number of configurations; such that supply water can flow through both pipes in parallel or can circulate through both pipes. BSC specified the parallel piping configuration for this design as it will result in the highest heat output (385 Btu/hr/ft at an Average Water Temperature of 120°F, see Figure 55)

Heating Edge™ Hot Water Performance Ratings	Flow Rate GPM	PD in ft of H20	Average Water Temperature (BTU/hr/ft @AWT in °F) 90°F	100°F	110°F	120°F	130°F	140°F	150°F	160°F	170°F	180°F	190°F	200°F	210°F
TWO SUPPLIES PARALLEL	1	0.0044	130	205	290	385	460	546	637	718	813	911	1009	1113	1215
	4	0.0481	134	224*	314*	412*	516*	626*	741*	862*	976*	1115*	1249*	1386*	1526
TOP SUPPLY BOTTOM RETURN	1	0.0088	101	165*	226*	289*	356*	426*	498*	572*	647*	725*	805*	885*	970
	4	0.0962	142	201*	271*	341*	415*	492*	569*	648*	728*	811*	894*	979*	1064
BOTTOM SUPPLY TOP RETURN	1	0.0088	99	162	221	283	349	418	488	561	634	710	788	867	957
	4	0.0962	135	195	259	305	380	464	552	634	710	793	874	959	1039
BOTTOM SUPPLY NO RETURN	1	0.0044	75	127	169	208	260	311	362	408	470	524	576	629	685
	4	0.0481	85	140	203	265	334	410	472	536	599	662	723	788	850

Figure 55: Heating Edge 2 High Capacity Baseboard Performance Ratings (from Smith Environmental)

Series Distribution – The original design (Figure 52) included a primary-secondary loop system and specified the secondary loop with the terminations (baseboard radiation) piped in a series configuration. BSC upgraded to a parallel distribution design, with homeruns from each termination connected to a stainless steel manifold (Watts Flowmeter Manifold; Figure 56). Most of these upgrades will be donated by Watts Water Technologies. A benefit to parallel distribution is the potential for individual radiator control via thermostatic radiator valves

(TRVs). In addition, a parallel design significantly reduces flow resistance (and thus pumping energy). While at this point in the design it appears to be too costly to integrate thermostat controls at each termination, adjustments can still be made at the manifold during commissioning, or an enthusiastic homeowner may regulate the flow during occupancy.

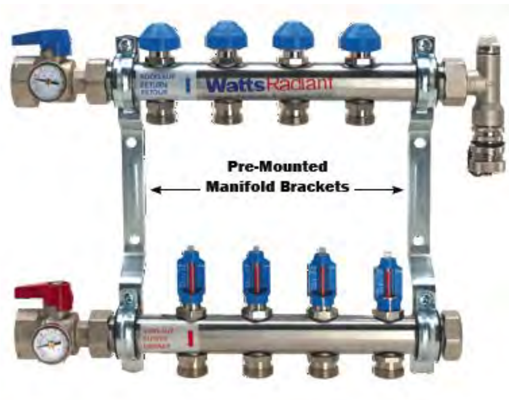


Figure 56: Watts Manifold with flow meters and balancing valves at each tap (from Watts Water Technologies)

Unnecessary plumbing devices – A number of plumbing devices in the original schematic were deemed unnecessary for this residential design. One was a bypass on the cold water line around the pressure release valve that was removed. There were also multiple balancing valves specified, one on the primary loop and one on the secondary loop. The balancing valve on the primary loop was deemed unnecessary. The balancing valve on the secondary loop was also removed as the specified stainless steel manifold has balancing valves at each of the homerun taps.

Additional Design Considerations

Variable Speed Pumps – Variable speed circulators have a number of advantages compared to standard pumps. These "smart" pumps include microprocessor-based variable speed controls that will adjust flow with an ECM motor to match the demand. This can be especially beneficial when installed in systems with thermostatic control at the terminations. Despite the fact that thermostatic control may not be installed at this building, BSC still decided to specify a variable speed pump on the secondary loop of each system. They are also inherently more energy efficient and produce less noise than standard pumps. The specified pump, the Grundfos ALPHA 2, is expected to operate at less than 30 watts under design conditions.

Figure 57: Grundfos ALPHA 2 variable speed pump (from Grundfos USA)

Updated Hydronic Schematic

BSC developed an updated schematic that represents many of the aforementioned improvements to the hydronic design (Figure 58). Appendix D provides the full set of mechanical plans, including the current hydronic design.

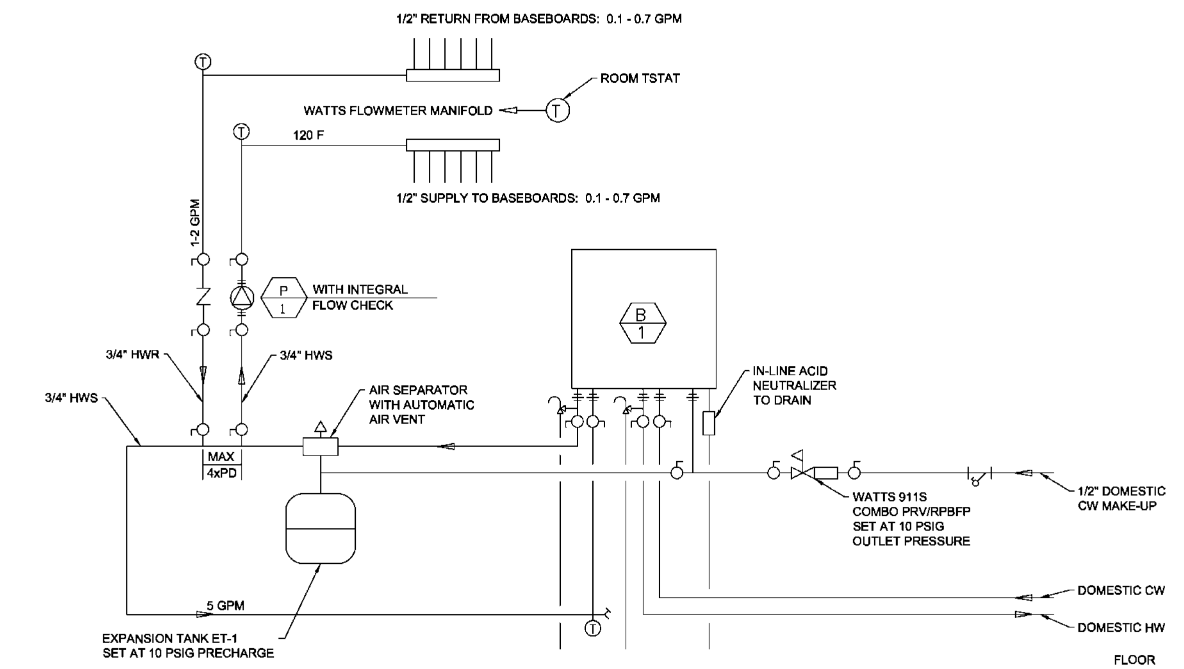


Figure 58: Updated Apartment Hydronic Schematic

Cost Comparison

Table 10 and Table 11 below compare the estimated costs of both the original and currently proposed hydronic heating designs. Product costs were established through retailers, while labor was estimated through discussions with the local plumber whom BSC has been working with.

Table 10: Original Hydronic Design Cost (Whole Building)

Description	Model	#	Cost/unit	Sub Total
Apt Boiler	Navien CH-240	11	$2,200	$24,200
System Pump	Taco Model 009 F5	14	$200	$2,800
Standard Baseboard	Beacon Morris Type SF-A	514 lf	$11	$5,654
Piping	PEX and associated devices			$30,000
Labor				$50,000
Total Cost				**$112,654**

Table 11: BSC Current Hydronic Design Cost (Whole Building)

Description	Model	#	Cost/unit	Sub Total
Apt Boiler	Navien CH-180	11	$1,900	$20,900
System Pump	Grundfos ALPHA	14	$300	$4,200
High Output Baseboard	Heating Edge 2	363 lf	$30	$7,122
Piping	PEX and associated devices			$30,000
Labor				$50,000
Total Cost				**$112,222**

The current individualized design saves only a nominal amount in terms of installed cost ($430); however, the current system is expected to save around $400 a year in heating and domestic hot water costs for the entire building. This cost savings is attributed mainly to the increase in boiler efficiency as the proposed design will allow for the boiler to operate in condensing mode compared to the initial design. BEopt is unable to capture savings due to other design improvements (i.e. variable speed pumps or distribution losses).

Peak Load Analysis

A full room-by-room Manual J8 (ACCA 2011) load calculation was performed on each of the apartments and the common areas. The computerized simulation included all of the enclosure improvements, such as the added insulation and reduced infiltration rate. The linear length of HE2 baseboard in each room is sized according to the peak heating load.

6.2 Dilution Ventilation

As buildings become more airtight, mechanical ventilation is being implemented around the country as a method of maintaining healthy indoor air quality in homes. Building codes, such as the 2012 International Residential Code, are now requiring controlled mechanical ventilation for homes that achieve airtightness levels below 5 ACH 50 (ICC 2009).

The primary purpose of mechanical ventilation is to exhaust stale air and to introduce less polluted outside air. Daily exposure to pollutants is very common in residential buildings, such as excessive moisture, body odors, cooking emissions, volatile organic compound (VOC) emissions, products of combustion, radon gas, pesticides, dust particles, viruses and bacteria. Managing these pollutants improves the health and comfort of the occupant and the durability of the building (Rudd 2006). A mechanical ventilation design in a cold climate such as New England with excellent performance is continuously operated and balanced (i.e. a simultaneous combination of supply and exhaust) system. A balanced ventilation system will not affect the pressure of the interior space relative to the outdoors, thus preventing unintended airflow between units or outdoors. The simplest way to install a balanced ventilation system is to use small packaged ventilators such as heat recovery ventilators (HRVs). BSC recommends that the amount of outside air introduced to the space be consistent with the rate stipulated by the American Society of Heating, Refrigeration, and Air Conditioning (ASHRAE) *Standard 62.2: Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings* (ASHRAE 2010). The ASHRAE Standard 62.2 ventilation rates for these apartment units are in the range of 32-42 CFM.

Original Design

The engineer who provided the original hydronic heating design also submitted a ventilation design. This ventilation system consists of a single large HRV located in a mechanical room in the basement with a centralized duct system providing supply air to the main living space and exhausting stale air from the single bathroom in each apartment.

The existing design was deemed to be far too costly to install and operate for the following reasons:

- The large central HRV was oversized and specified flows to the apartments were much higher than the ASHRAE Standard 62.2 rate (140 CFM vs. 32-42 CFM). Not only is there an increased cost associated with the oversized HRV, but the over ventilation of the apartments will negatively impact energy performance and will result in increased heating costs.
- An extensive centralized system of ductwork was specified, requiring a significant amount of duct material. Also worth noting is that the large size of the ductwork requires a heavier gauge sheet metal, thus resulting in higher material costs.
- The centralized ductwork would require a significant amount of dropped ceilings in the building, increasing cost and negatively affecting the aesthetic of the living spaces.
- A series of smoke and fire dampers were specified to maintain the fire rated assembly between the apartment units, along with a controls sequence for operating the dampers in case of fire.
- The shared duct system compromises the continuity of the air barrier between the apartments, thus increasing the risk of uncontrolled air leakage between the spaces (compromising compartmentalization).
- Lack of individual ventilation control in the apartments, particularly in the bathroom as there is no option for intermittently increasing the exhaust flow if desired for odor and/or moisture removal.
- A series of duct chases are required for the centralized duct system to access all apartments.

Figure 59 shows an example of the original ventilation design in one of the units. The extensive ductwork and associated fire and smoke dampers result in a complex and costly design.

Another problem with the design is that supply flows were intentionally higher than exhaust flows, to pressurize the units, under a mistaken belief that this would prevent occupant draft complaints. Intentional pressurization of the units is likely to exacerbate air leakage condensation, resulting in durability issues.

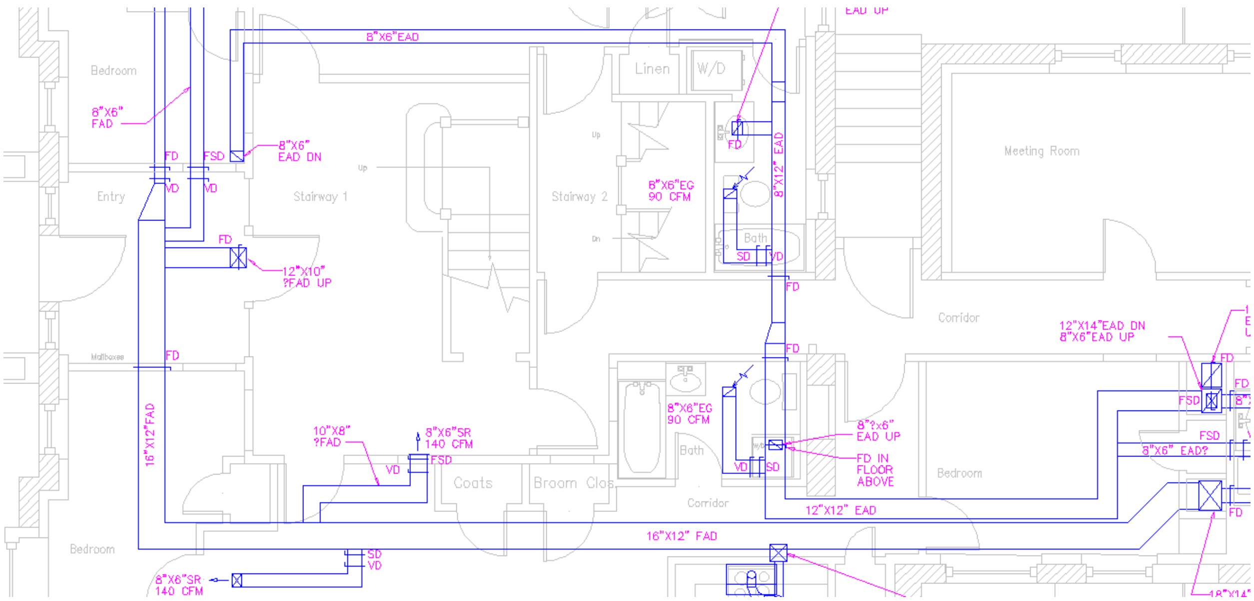


Figure 59: Existing Ventilation Design at Unit 4

BSC concluded that the design was not appropriate for a low rise, energy efficient residential building, and in keeping with the concept of compartmentalization (i.e. small individual mechanical systems), performed a full redesign of the ventilation system.

See Appendix D for the complete set of mechanical plans including the ventilation design.

Current Ventilation Design – BSC

The current ventilation strategy proposed by BSC is to specify small heat recovery ventilators in each apartment, with a small duct system for distribution. An additional HRV will ventilate the common spaces in the building. This is known as a balanced multi-point HRV system, see Figure 60.

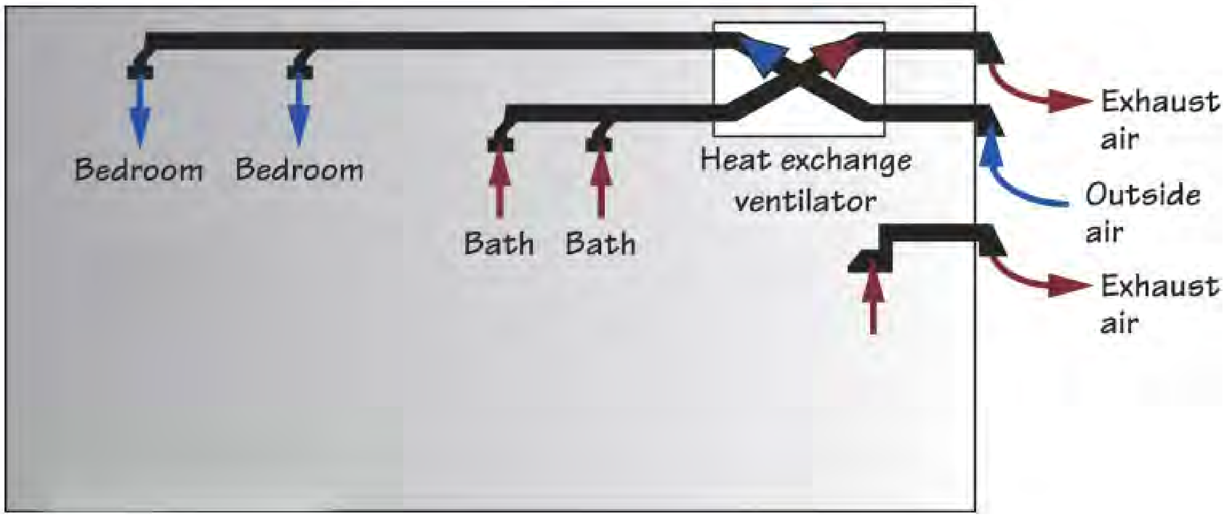


Figure 60: Ventilation Strategy Schematic

The HRV will be located in a mechanical closet in each apartment and the common areas. A small duct system will provide ventilation to the bedrooms and will draw stale air from the bathrooms. Locating the HRV exhaust in the bathroom precludes the need for a separate bath fan, the ducting of which would have been complicated to route to the outside and also would have required an additional penetration through the apartment air barrier. When configuring a recovery ventilator to exhaust air from baths, it is recommended to specify a heat recovery ventilator, not an energy recovery ventilator (ERV). There are practitioners in the industry who recommend ERVs for exhausting bathroom air, with the expectation (in a cold climate) that the moisture will be redistributed throughout the house and can increase the relative humidity in the living space during a cold and dry winter. However, BSC does not recommend this strategy in small airtight residences (especially with high continuous occupancy) in cold climates. Elevated moisture levels in the living space during the winter can increase the potential for condensation on any cold surfaces (e.g. window frames).

Each apartment has one bathroom, making the HRV exhaust ducting simple. Nine out of the ten apartments have 3 bedrooms, with the tenth unit having 2 bedrooms. An HRV supply will be located in each of the bedrooms. The registers will be positioned to not supply air directly onto the beds in order to avoid potential comfort complaints.

The specified HRV for the apartments is the Flex 100H from Fantech. The common areas will be ventilated with the VHR 2004 from Fantech (Figure 61).

Figure 61: Fantech Flex 100H and VHR 2004 heat recovery ventilators (from Fantech)

The Fantech Flex 100H HRV was selected as the HRV for the apartments as it has a number of positive characteristics:

- Compact in size and is small enough to operate continuously, in low speed, at the recommended ASHRAE Standard 62.2 ventilation rate (32-42 CFM in the apartments)
- Recirculation defrost, which warms the core by circulating interior air, rather than the traditional mode of defrost which exhausts interior air to the outside.
- Boost function – a push button timer can be used to intermittently increase airflow. This will be installed in the bathroom to allow the homeowner to increase airflow when needed for odor or moisture removal. The increased airflow will be at least 50 CFM per the intermittent point source exhaust specification in ASHRAE 62.2 (ASHRAE 2010).
- A balancing damper and airflow measurement ports are integrated with the HRV.

The compartmentalization strategy of utilizing separate HRVs in each apartment results in a much smaller, more compact, distribution system. Only 5” round sheet metal ducts are required for the distribution system. The ductwork is no longer interconnected between the apartments and common areas; therefore, fire and smoke dampers are not required. Figure 62 shows an example of the current duct layout for an apartment unit. The hatched sections indicate dropped ceilings. Where possible, the ducts will be located within the floor joist cavities to limit the area of dropped ceilings; however the floor joists are outside the fire rated assembly for the apartment. Therefore, any duct in the floor joists will need to be enclosed in a one hour rated duct wrap to maintain the integrity of the fire rated assembly.

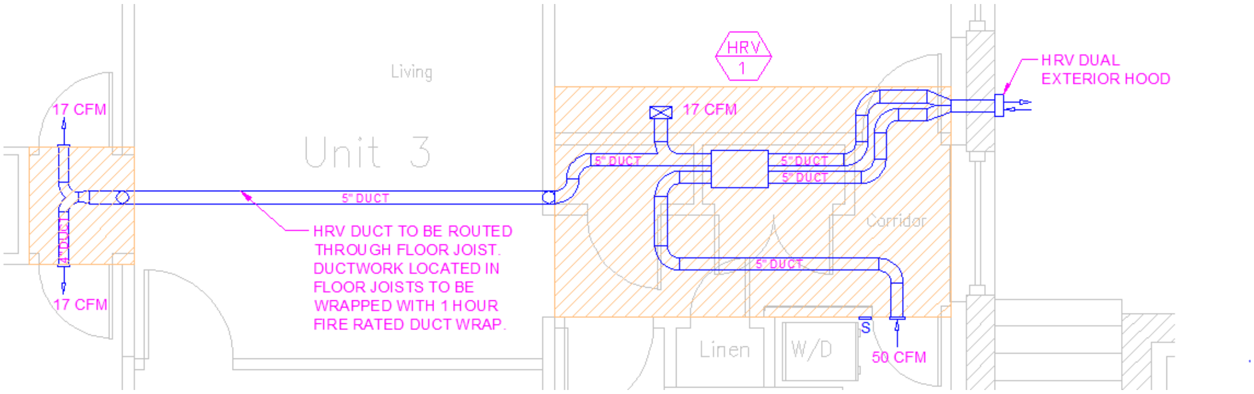


Figure 62: Example of current HRV duct layout

The exterior ducts of the HRV for the common areas and most of the apartments will be routed directly through an exterior wall (as opposed to a roof connection). Drilling holes in the existing mass masonry wall is cumbersome; therefore BSC is specifying a dual exterior hood (e.g. the Tandem Transition from Venmar) for the HRV supply/exhaust termination. This exterior hood couples the two outside HRV ducts into a single termination, thus only a single 6" hole is required (Figure 63).

Figure 63: Dual exterior hood (from Venmar)

The project team has expressed a preference for limiting the number of penetrations through the mass masonry wall where possible. Therefore, the three apartments on the top floor will have the HRV outside air ducts routed through the roof with standard roof caps as the duct terminations. As a note, there is an unvented attic space at the roof that will allow the full ducting of the HRV distribution in the attic space for these three units. The ducts will be enclosed in a 1-hour fire rated duct wrap, but no dropped ceilings will be necessary for the three apartments.

Cost Comparison

Table 12 and Table 13 below compare the estimated costs of both the existing and current HRV designs. Product costs were established through retailers, while labor was calculated per rates stipulated by the RSMeans (Reed 2012) costing source.

Table 12: Original HRV Design Cost (Centralized System)

Description	Model	#	Cost/unit	Sub Total
HRV	Renewaire HE3XINH	1	$7,000	$7,000
Electric Duct Heater	Indeeco Model QUA	1	$2,500	$2,500
Fire/ Smoke Damper	Ruskin Model FSD37	16	$400	$6,400
Smoke Damper	Ruskin Model SD37	5	$400	$2,000
Fire Damper	Ruskin Model IBD20	12	$80	$960
Control Damper	Ruskin Model CD35	22	$86	$1,892
Ductwork	Galvanized Steel	18,212 sf	$0.64	$11,601
Labor				$82,563
Total Cost				**$114,916**

Table 13: BSC Current HRV Design Cost (Individualized Systems)

Description	Model	#	Cost/unit	Sub Total
Apartment HRV	Fantech Flex 100H	10	$525	$5,250
Common Area HRV	Fantech VHR 2004	1	$743	$743
Exterior Termination	Venmar Tandem Transition	10	$125	$1,250
Main Control	Fantech EDF1 Triple Function Wall Control	10	$30	$300
Bath Control	Fantech RTS3 Pushbutton Timer	10	$25	$250
Ductwork	Galvanized Steel	13,352 sf	$0.64	$8,505
Labor				$63,066
Total Cost				**$79,364**

The current individualized design saves an estimated $36,000 compared to the original centralized design. These calculations do not include the costs of the fire-rated shafts (for the original design) or the 1-hour rated duct wrap (for the current design, at incidental penetrations of the rated assemblies. However, it is likely that the latter is a lower overall cost. It is also likely that the proposed design will require a lighter gauge sheet metal for the ductwork compared to the initial design. This cost savings was not captured in the analysis.

6.3 Kitchen Exhaust and Clothes Dryer

The original design for kitchen exhaust ventilation was a demand controlled system comprised of three central exhaust risers with connections to standard kitchen range hoods. A direct drive, variable speed roof top fan was specified at each of the risers. BSC investigated the option of changing the design to allow direct routing of the kitchen range hoods to the exterior. However, MVHfH and the architects' desire to minimize penetrations through the exterior walls influenced BSC's decision to maintain and further develop the original design.

The kitchen range hood will be an ENERGY STAR certified unit. The range hood will be connected to a 10”x10” riser via a 6” duct. In order to maintain the integrity of the fire rated assembly, an Exhausto subduct riser from Enervex will be installed at the riser connection, which is an affordable alternative to installing a fire damper (Figure 64). A subduct is a sheet metal boot that is installed inside the riser. It has a 22” vertical extension, as stipulated by the International Building Code (ICC 2012), that creates a downward-only pathway from the riser to the individual run outs. This extension serves as a barrier against potential fire/smoke entrainment from the riser to the run outs.

Figure 64: Exhausto Subduct Riser and Schematic

There will be three 10”x10” risers in the building: two of these risers will service three kitchen hoods, and the third riser will service four. All risers will terminate at the roof. A direct drive, variable speed roof top fan (GreenVent System from Greenheck) will be installed at each of the risers. This fan system is demand controlled. A pressure sensor will be installed in the riser that can detect pressure changes in the duct when a range hood is turned on, and activate the rooftop fan. The system will adjust the fan speed to maintain a constant negative pressure in the riser, thus increasing the airflow when multiple range hoods are turned on. This system also ensures that fan flow from the range hoods will not pressurize the riser duct, resulting in contaminant transfer to other units.

Each apartment will have a clothes washer and dryer unit. MVHfH will be installing condensing dryers, in order to avoid routing ductwork to the exterior.

7 Actual Energy Performance vs. Predicted Site Energy Use

7.1 Predicted Site Energy Use

BEopt software was utilized to evaluate the cost effectiveness of the retrofit measures proposed for this project. Using the optimization feature, alternate options for wall insulation, window types, infiltration and mechanical systems, were modeled in order to determine the combinations of measures that are the most cost effective. The default cost values for the Chicago Retrofit were used for the majority of the inputs. Several cost values were also obtained from RSMeans (Reed 2012) and the cost of windows per unit was derived from the estimate provided by Harvey Industries.

The BEopt software includes an optimization capability that uses user-supplied cost data and energy use information for a specified set of energy saving measures to determine combinations of measures that are optimal or near optimal in terms of cost effectiveness. BEopt uses a sequential searching technique so that not every possible combination of options is simulated.

One representative apartment unit was modeled (Unit 8, on the second floor), using the selection of enclosure and mechanical components shown in Table 14. This unit was chosen for modeling because of its simple geometry as well as its exposure to the exterior.

Table 14: Selected component options for BEopt modeling

Component	Cases
Exterior wall	6” of XPS rigid insulation 4” of XPS rigid insulation, 5” of ccSPF 2” of ccSPF with fiberglass batt insulation
Roof Insulation	6” XPS rigid insulation on the roof deck with 6” ccSPF in the rafter cavity 6” polyisocyanurate on the roof deck with 10” blown fiberglass in the rafter cavity 6” ccSPF installed only in the rafter cavity
Windows	Existing windows with new low-e storm windows (U=0.34, SHGC=0.48) New ENERGY STAR qualified double pane units (U=0.30, SHGC=0.30)
Infiltration	“Tighter” (3.3 ACH50) “Tightest” (1.7 ACH50)
Gas boiler	80% efficiency 91% efficiency

Table 15 includes a list of enclosure and equipment specifications used as inputs for the energy modeling for the "Design Case," and the options for the "Minimum Cost Case" that were selected by the program. The "Design Case" includes measures that were chosen by the design team, and bring the percent energy savings based on the lowest cost or free materials and labor. The "Minimum Cost Case" consists of selections that bring the highest percent energy savings at the lowest upfront cost. Characteristics that differ between these two cases are shown in italics.

Table 15: BEopt "Design Case" Energy Modeling Inputs

Component	Design Case	Minimum Cost Case
Roof	*6" XPS + 6" ccSPF*	*6" ccSPF*
Wall	*6" XPS inboard of masonry, with stud frame wall*	*2" ccSPF + 5-½" batt insulation*
Basement Wall	3"-3-½" closed-cell spray foam (ccSPF)	3"-3-½" closed-cell spray foam (ccSPF)
Basement Slab	2" XPS	2" XPS
Windows	*New double glazed vinyl windows U=0.30, SHGC=0.30*	*Existing windows with low-e storms U=0.34, SHGC+0.30*
Infiltration	1.7 ACH50	1.7 ACH50
Heating and Cooling	*Gas-fired tankless water heater (91%) per unit, with baseboard radiation heating loop; no cooling provided*	*Gas-fired tankless water heater (80%) per unit, with baseboard radiation heating loop; no cooling provided*
DHW	Gas-fired tankless water heater, per unit	Gas-fired tankless water heater, per unit
Ventilation	Heat recovery ventilator (HRV), individual units (50% of ASHRAE 62.2)	Heat recovery ventilator (HRV), individual units (50% of ASHRAE 62.2)
Lighting	100% CFL lighting	100% CFL lighting
Appliances	Energy Star refrigerator, dishwasher, clothes washer	Energy Star refrigerator, dishwasher, clothes washer

Figure 65 illustrates the graph that plots the average source energy savings per year against the annualized energy related costs. The optimal packages are those that form the lower bound of the plotted data points and the selected point is the "Design Case."

As discussed in Section 3 of the report, the practices that are the best approaches for this particular project may not be the most cost-effective in all cases because of the financial model of Habitat for Humanity.

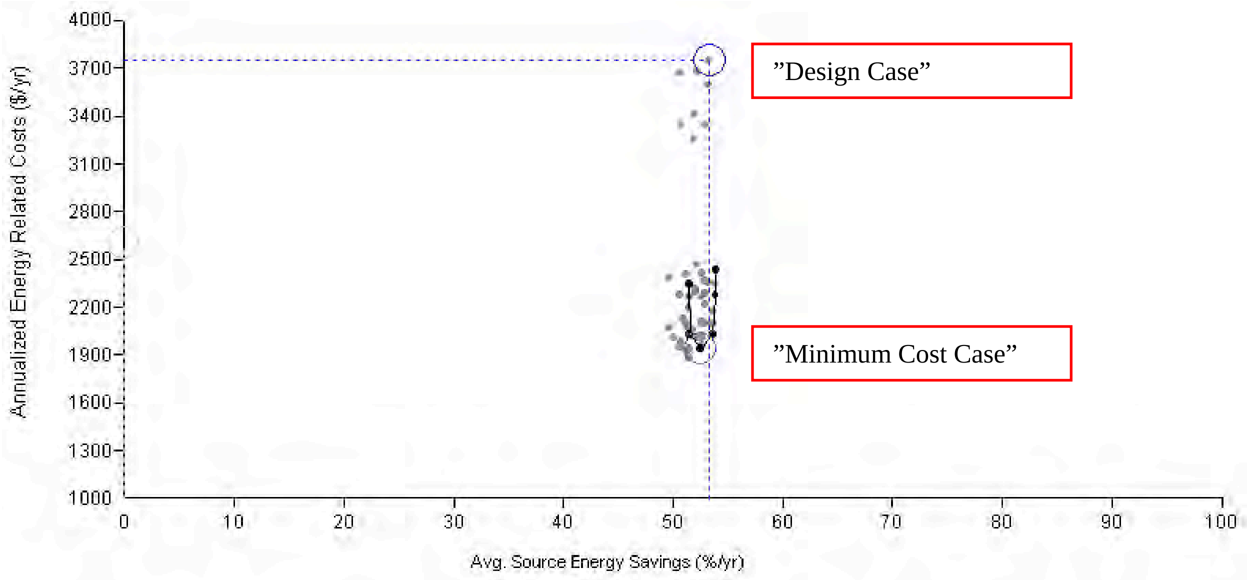


Figure 65: Unit 8 BEopt optimization results – Cost vs. Energy Use

The difference in source energy use between the "Existing" and "Design Case" projected by BEopt was 98.9 MBtu/year, or a 53.3% reduction.

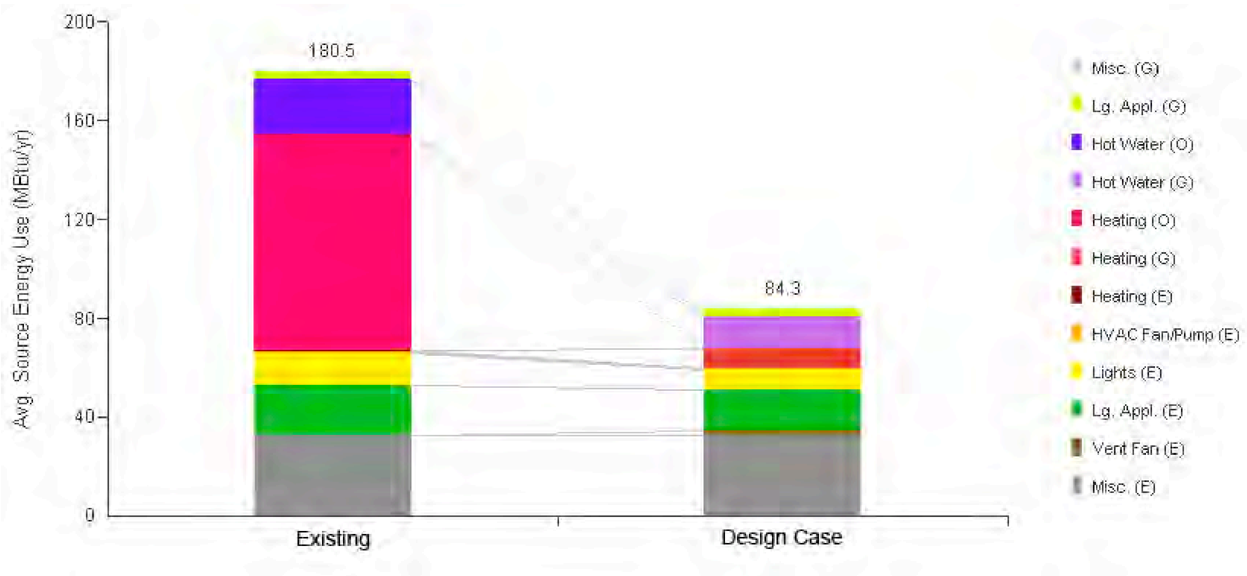


Figure 66: Unit 8 BEopt optimization results – Average Source Energy Use

7.2 Actual Energy Performance

The retrofit work on the apartment units is ongoing and the project is slated for a completion date in December of 2014. Therefore, utility bills were not available for the comparison of the predicted and actual energy use.

8 Construction Cost for Retrofit Measures

Cost values were collected from the project team for a number of the retrofit building components (Table 16). Various construction materials have been donated to the project; therefore, some of the cost values listed below could not be quantified.

Table 16: Construction Cost for Retrofit Measures

Component	Cost
Roof – sloped and flat (demolition, air barrier membrane, labor for XPS rigid insulation, cover board, EPDM roof membrane, shingles)	$53,500
Wall	N/A
Basement Wall	N/A
Basement Slab (sand and gravel, drainage mat, concrete slab)	$8,150
Windows (double glazed, argon filled, U=0.30, SHGC=0.30)	$23,804
Heating and DHW	$112,222
Ventilation	$79,364
Lighting	N/A
Appliances (combo washer and dryer)	$1,000-$1,200 per unit

Roof

The cost includes the removal of the existing roofing from both the sloped and the flat roofs, installation and product cost of the air barrier membrane, installation of the donated three layers of 2” XPS rigid insulation, installation and product cost of the insulation cover board, and the installation and product cost of the EPDM roof membrane and shingles. It does not include the cost of the 6” of spray foam shown on the retrofit plan.

Walls

The cost for the wall retrofit was not available. The three layers of 2” XPS rigid insulation and the insulation adhesive were donated. The cost of sheathing tape used for taping the seams of the rigid insulation was not available. This was due to the variety of tape products used (Dow, Tyvek, Lowes; both donated and left over from previous projects). The cost of lumber and drywall was not available.

MVHfH has received estimates for the repointing and masonry restoration/repair work that will be conducted. This measure is a requirement to control bulk water wetting of the masonry wall, due to the retrofit of interior insulation (see Straube et al. 2012). The estimates were in the range of $200,000, which is higher than the $100,000 originally budgeted for.

Basement Walls

The cost for the basement retrofit is not available. The ccSPF insulation will be donated and the team has yet to obtain the estimates.

Basement Slab

The cost for leveling the existing dirt floor and slab with sand and gravel was approximately $450. The budget for the drainage mat was set for less than $1,000. The team was able to find the product for approximately $650, but since it is not available locally the cost of shipping was going to be fairly high. The project team was able to negotiate the cost of shipping and obtain the product and accessories for approximately $800. The labor cost for casting the concrete slab was estimated at $2,850. Forty-five yards of concrete will be needed for the basement slab; the cost per yard is $100. Therefore, the cost of the concrete slab will be approximately $4,500.

Heating and DHW

The cost estimates have yet to be obtained for the designed system; therefore, product costs were established through retailers and labor was estimated through discussions with the local plumber whom BSC has been working with.

Ventilation

The cost estimates have yet to be obtained for the designed system; therefore, product costs were established through retailers, and labor was calculated per rates stipulated by the RSMeans (Reed 2012) costing source.

Lighting

The compact fluorescent light bulbs will be provided by the ENERGY STAR program. The project team will be able to obtain a portion of the lighting for the building from the MVHfH warehouse. Discontinued lines of lighting are often donated to MVHfH by a number of manufacturers. The remainder of the light fixtures will be purchased.

Appliances

The ENERGY STAR qualified refrigerators and stoves will be donated by Whirlpool, and ENERGY STAR qualified dishwashers will be supplied by the future homeowners. MVHfH will be providing clothes washers and dryers for each unit, because space restrictions and ventless drying requirements will play a major role in the selection of the units. The project team is considering the all-in-one combo ventless condensing units by LG. The retail cost for those compact units is approximately $1,600. However, the project team may have an opportunity to purchase all 10 units at a discounted price (between $1,100 and $1,200 each) from a local dealer.

9 Conclusion

9.1 Overview

In this research report, BSC has evaluated several components of the advanced efficiency package implemented in this project. Many aspects were taken into consideration while selecting the retrofit measures: occupant comfort, occupant health and safety, building and equipment durability, building code compliance, as well as building and equipment maintainability.

Due to the unique financial model of Habitat for Humanity, some enclosure retrofit measures chosen in this project may not be the most cost-effective for the majority of multi-family masonry buildings. However, because of aspects such as donated materials and volunteer labor, the selected retrofit measures were the most cost-effective in this specific case.

9.2 Brick Material Property Testing and Hygrothermal Simulations

- Does the addition of high levels of interior insulation present a risk of freeze-thaw damage to the mass masonry walls in this building?

Sample bricks were collected from the interior and exterior of the original building as well as the addition, and material property testing was performed to inform the assessment of freeze-thaw risk. Several methods of testing were implemented including dry density, water absorption coefficient (A-value), free water saturation, vacuum saturation and critical degree of saturation (S_{crit}). The S_{crit} values, which reflect the brick's resistance to freeze-thaw damage, were relatively high (~0.75-0.80), indicating good resistance to damage. The measured values were used in the WUFI software to predict the brick moisture content during freezing conditions for the existing and proposed retrofit wall assemblies under varying rain exposures.

The resultant moisture content values were compared to the tested critical freeze-thaw moisture content, to assess the risk of damage. Assuming excess external moisture sources (missing downspouts, condensate from window mounted air conditioners, etc.) are addressed, the predicted moisture contents were well below the critical threshold. Since the risk of freeze-thaw degradation was low, the team recommended retrofit of interior insulation.

Applying the results of the masonry retrofit analysis to a wider array of projects is beyond the scope of this report; an overview of the topic is covered by Straube et al. (2012). The analysis of the applicability of material property testing to similar projects is covered in an upcoming BSC report; it takes the database of critical degree of saturation (S_{crit}) measurements, and determines whether larger patterns can be found based on more easily measured material properties (dry density, porosity, liquid water uptake) or other characteristics, such as vintage, geographic location, or manufacturing method.

9.3 Predicted Energy Performance and Cost Impacts of Proposed Wall Retrofit Design

- What are the predicted energy performance and cost impacts of the proposed wall retrofit design (6" of XPS) vs. the other considered strategies (spray foam, flash and batt)?

There were a number of insulating options that would be well suited for this masonry building and were being considered for this project. The project team decided to explore the following options for the wall retrofit: three layers of 2” XPS rigid insulation, two layers of 2” XPS rigid insulation, 5” of ccSPF, and 2” of ccSPF with batt insulation. Each of those wall systems offered certain advantages and disadvantages.

Using the parametric feature in BEopt, alternate options for wall insulation were modeled to determine the energy use of each option and the most cost effective measure. Based on the energy modeling, it was determined that 6” of XPS rigid insulation wall system option would provide the best energy performance, although 5” ccSPF and 2” ccSPF with 5.5” fiberglass batt had roughly equivalent performance. However, the 6” of XPS option was found not to be the most cost effective; the 2” ccSPF with 5.5” fiberglass batt was judged to be the best value for performance. However, the 6” XPS wall was selected at this project as the best suited option, given Habitat of Humanity’s financial model, which includes volunteer labor and donated materials.

9.4 Impact of Rebates and Incentives on Decision Making Process

- How do rebates and incentives impact the decision making process of the builder, especially in cases of budget constrained construction projects? In addition, how do these impact the overall energy performance?

Due to the budget constraints for this project, the MVHfH team needed to maximize the available incentives. The team explored all of the available incentive programs in the state of Massachusetts to help fund the energy efficiency retrofit measures. It was important for the project team to establish the goals that were achievable at the start of the construction process and eliminate features that were not attainable, and would not have significant impact on the performance of the building. Through the energy modeling performed for each of the units, the project team was able to select the appropriate measures to be implemented in the building. The analysis from the modeling also helped inform decisions that will impact the overall performance of each of the units.

The most substantial incentive for this project was meeting the requirements for ENERGY STAR Qualified Homes, Version 3 Tier II. The threshold for this level is 30% better than the modeled User Defined Reference Home (UDRH); it is associated with a Massachusetts incentive of $1,150 per unit.

9.5 Retrofit Air Barrier Strategies and Assemblies

- What is the effectiveness of air barrier strategies implemented in this multifamily retrofit project, and what were the difficulties in implementation?

Effective air barriers are vital for good energy performance; compartmentalization (separation between units) is important for reducing sound, odor, and smoke transmission, and limiting stack-driven airflows. Therefore, BSC established targets and developed details for interior-to-exterior air barriers and compartmentalization, specific to an interior insulation retrofit of a multifamily mass masonry building. In addition, installation by a volunteer workforce had to be taken into account.

Air barrier details were developed using the layers of interior rigid XPS insulation as the air barrier at the walls; details were required at window and other penetrations. Retrofit roof and below-grade air barrier details were also developed. Compartmentalization details, which also met fire resistance ratings were developed, including floor-to-floor (at exterior wall), partition walls (within units), and demising walls (separating units). To help the team to put these details in context, a table was made showing the relevant interface detail between the air barrier assemblies (wall, ceiling, and floor). In addition, an outline-form narrative was included with the air barrier details, to give the team a greater understanding of the compartmentalization strategies being implemented.

9.6 Retrofit Mechanical Design

- What are the cost impacts of implementing a compartmentalized ventilation strategy with individual apartment HRV systems vs. a traditional large single central HRV system?

- What are the cost impacts of using individual unit combination space heating/hot water units, including distribution piping design and installation specifics?

Compartmentalized mechanical systems offer numerous advantages over centralized strategies, such as lower installed cost, more efficient operation and occupant control. Therefore, individual ventilation and hydronic heating strategies were developed for this retrofit building.

The hydronic/domestic hot water system consists of an individual combination space heating/domestic hot water boiler with convectors (radiators) that are rated for low supply water temperature. This design will ensure that the boiler is consistently condensing, ensuring high efficiency operation. The current design saves only a nominal amount in terms of installed cost ($430); however the current system is expected to save around $400 a year in heating and domestic hot water costs for the entire building. These predicted savings are associated with the boiler's capacity to operate in condensing mode due to the improvements in the distribution system.

The ventilation design consists of small individual HRVs installed in mechanical closets in each apartment. A small duct system serves as the distribution system. The compartmentalization of the HRV system results in a significantly cheaper design and individualized ventilation control in each apartment. The current ventilation design saves an estimated $36,000 (a 30% reduction) compared to the original centralized design. These savings can be attributed to the elimination of fire rated shafts, extensive unit-to-unit ductwork, and fire dampers (where ductwork penetrates rated assemblies).

9.7 Actual Energy Performance vs. Predicted Site Energy Use

- How does the actual energy performance (i.e. utility bills) compare to the BEopt predicted site energy use?

Energy analysis with BEopt software was performed for one of the units with several options for wall insulation, window types, infiltration and mechanical systems in order to determine the combinations of measures that are the most cost effective. The results showed a 53% reduction source energy use between the "Existing" and "Design Case".

No units have been completed to date and the project is slated for a completion date of December 2014. In order to provide a valuable data of the actual energy use, utility bills after the first full winter would need to be collected and analyzed. However, no additional work is planned for this project in the subsequent years due to the termination of funding at the end of 2012.

10 Appendices

Appendix A

MVHfH Site Assessment

Building Science Corporation

August 15, 2011

Emerson Dahmen
Merrimack Valley Habitat for Humanity
emerson@merrimackvalleyhabitat.org

Re: Building Science Consulting Services: Site Evaluation
100 Parker Street, Lawrence, MA

Dear Mr. Dahmen:

1. Summary

The existing masonry building at 100 Parker St. Lawrence MA was visited Wednesday August 3rd 2011. The general conditions of the site were inspected; the extent of the planned renovations discussed, and brick samples taken for testing.

2. Existing Conditions

The building consists of original building fronting Parker St. and a rear addition. A small third addition is being demolished as part of the renovation. The remainder of the building has now been gutted, including essentially all HVAC, plumbing, electrical, partition walls, and interior finishes. The building originally housed a convent. The rear addition has reportedly been left vacated and unheated for 2-3 recent years. The building has been purchased by Merrimack Valley Habitat for Humanity, and is in the process of being renovated to produce 10 three bedroom condominium units.

Figure 1: Aerial photo of site and parts of the building

Original Building Walls

The original building façade consists of three brick wythe mass wall construction.

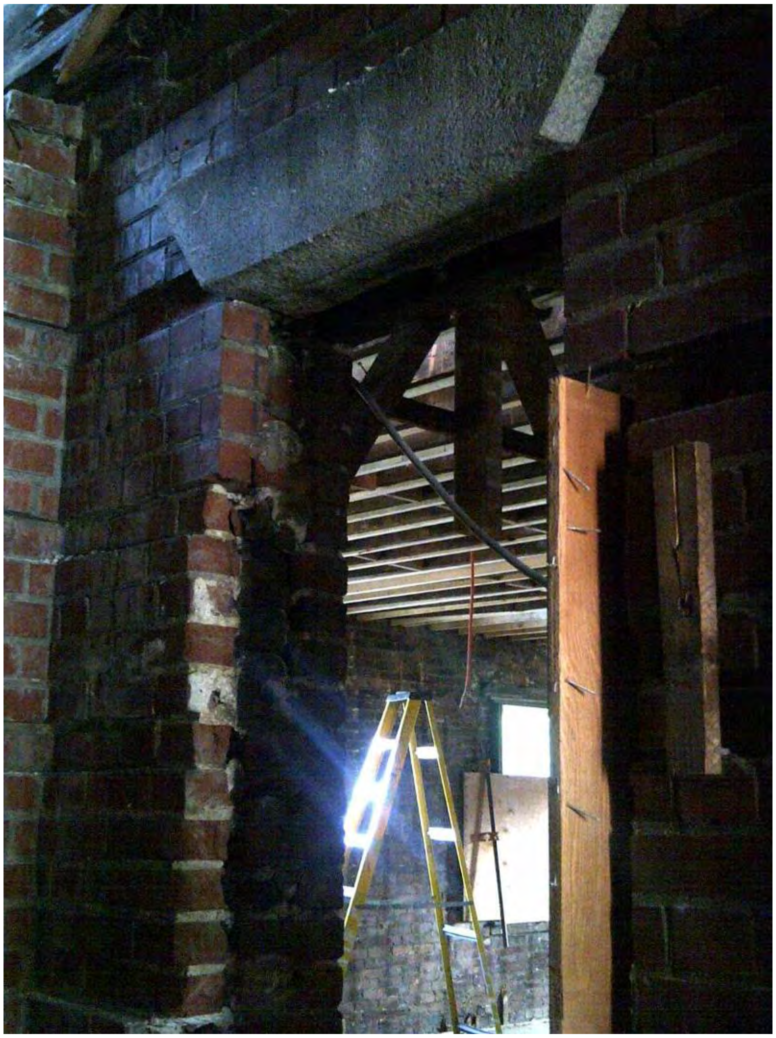


Figure 2: Original building – view of masonry wall section where doorway was shifted to interior

Figure 3: Original building –front entrance

- The front entrance is to be restored to original appearance. Although the entrance incorporates a low slope roof against the masonry, there does not appear to be brickwork damage at the interface.

Figure 4: Original building – general view of building frontage.

- A false (meaning it only extends one brick course inward) granite stone belt course extends around the top of the basement and the second story which do not have drip edges.
- The window brow headers do not appear to function to divert surface rain water from the windows.
- The window sills include sloping end dams but do not have undercut drip edges, however, excessive deterioration does not appear under the sills.

Figure 5: Original building – close up of brick courses

- Every fifth course of bricks is inset an inch.

Figure 6: Original building – façade to ground interface

- The masonry wall is buried 2 or 3 brick course below the finish grade around a significant portion of the building perimeter
- Although the original façade design has a number of troublesome details (low slope roof against façade, lack of drip edges, water concentrating window headers, stepped masonry courses) and grade is now above the bottom courses of brick, there does not appear to be associated visible damage. These observations would suggest that the building is well protected from driving rain and that the ground is well drained.

Figure 7: Original building: brickwork spalling and surface efflorescence

- A spalled brick was found sitting on the lower belt course. Suspect rain water concentration from the inadequately flashed window.

Figure 8: Original building: brickwork and mortar damage below belt course

- In Figure 8 the scupper was filled with debris and roof water was apparently running down the face of the brick and concentrating below the belt course, especial at the joints which have eroded mortar joints. The tops of the belt course are flat, and hence, water flowing down the face of the brick above flow in behind the belt course. This interface has been caulked at some point, which has been ineffective.

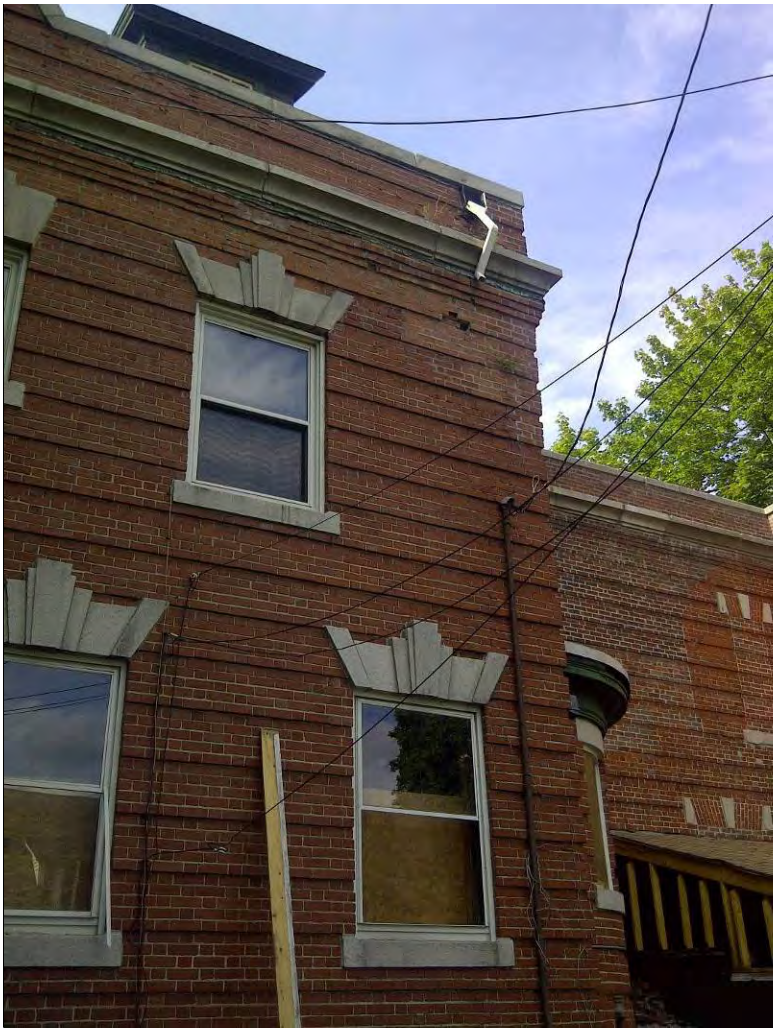


Figure 9: Original building – missing downspout

- The missing downspout should obviously been replaced and the resulting damage is clearly visible.

Original Building Roof

The sloped roof areas have slate shingles. The center of the building has a flat roof which has a small clerestory with an exhaust fan (likely intended to assist natural ventilation). The flat roof section of the building has no parapet or roof drain.

Figure 10: Original building – flat roof area

- The roof appeared in good shape beside issues with the scuppers and down spouts. The project team is planning to replace the slate shingles with "slate" like asphalt shingles. A new fully adhered EPDM membrane for all flat roof areas on the original building.

Figure 11: Original building – clerestory

- The project team is planning on replacing the clerestory with ductwork to a fire exhaust fan.

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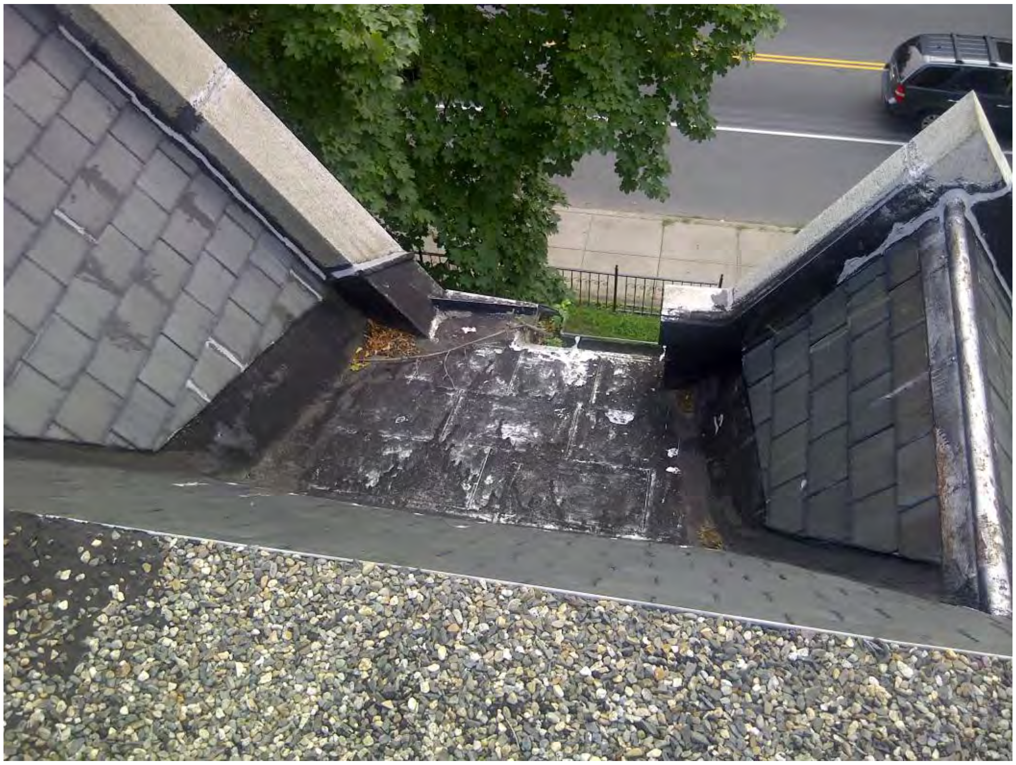

Figure 12: Roof drain filled with debris

- The rain water runs to scuppers emptying in external downspouts. The scuppers were apparently not maintained, clogged, and led to water loading on the façade contributing the damage shown in the previous figures.

Original Building Windows and Doors

The windows are a mix of double pane vinyl and wood framed windows. The windows sit within wood framing. The lintels are a mix of steel in some cases and wood in others. None of the lintels are planned for replacement, the wood framed windows are planned for replacement and the vinyl windows are currently not planned for replacement.

- The vinyl windows appear dated and do not have a low-e coating (based on simple LED light reflection test).
- The doors have single pane windows and installed in wood frame assemblies with little or no insulation or an air barrier.
- The doors and windows appear to be installed with fiberglass filling the gap between the window frames and the rough framing. Poor air tightness is suspected and these interfaces.

Original Building Interior

The interior has been brought down to masonry and subflooring exposing the structure.

Figure 13: Floor joists set in masonry wall

- Some floor joists are being sistered as shown in Figure 13 to stiffen the floor. Emerson indicated that they are planning to build a 2x4 wood on the inside but not planning to use this as a bearing wall.

Figure 14: Original building - floor joist to masonry wall interface

- There has been an attempt press mortar in around the perimeter the joist where they enter the masonry. However, cracks which are in some case substantial have formed around the mortar-wood interface at most joists.
- Floor joists are fire cut and sit in the innermost course of the bricks. The condition of the wood at the end of these joists was confirmed to be in good condition by stabbing with a flat screw driver. Emerson says he has tested the wood on samples throughout the building with good results.

Figure 15: Original building – interior view of sloped roof

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Figure 16: Original building – interior view of sloped roof

The available thickness for insulation on the interior of the sloped roof sections is limited at window frames. Where inspected there appeared to be 8" from the existing interior trim to the underside of the sheathing.

Figure 17: Original building – basement

The basement appeared dry and no evidence of previous water leakage issues was observed.

Addition Walls

The addition façade has a matching face brick to the original building and mostly similar architectural features.


Figure 18: Addition - North Façade


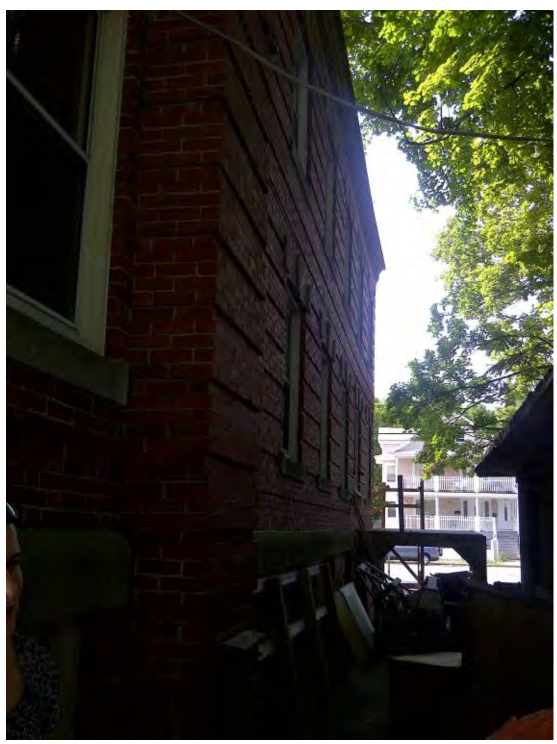

Figure 19: Addition - South Façade (left) and East Façade (right)

Figure 20: Bricks and belt course pushing out on north façade

- It is not clear from visual inspection why the façade is pushing out at the top of the north most addition façade. Emerson indicated that the structural engineer did not anticipate the problem being due to building movement. It may be due to expansion of the inner brick courses due to freeze thaw spalling pushing out the face bricks and stone course.

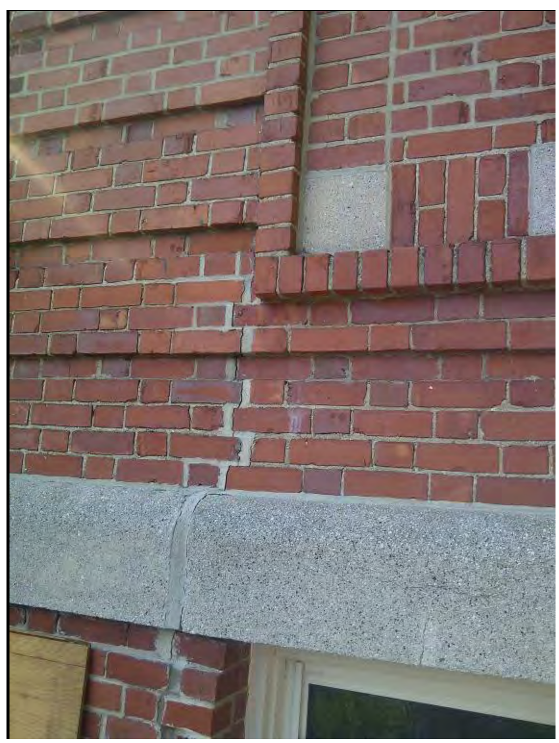

Figure 21: Addition: cracks in brickwork

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- Significant cracks have formed in masonry mostly at the edge of window sills and headers. Emerson relayed that the structural engineer's opinion was that mortaring the cracks would be adequate and that it did not appear that future building settlement or movement would cause significant further damage.

Addition Roof

The addition roof area is completely low sloped roof. The roof has a gradual slope to a center drain. The cap of the concrete parapet slopes inward. The roof is punctured by a couple of skylights and various mechanical vents. The drawings call for a new fully adhered EPDM roof and sheathing replacement/patching where needed.

Figure 22: Addition – Roof

Figure 23: Addition – limited space for insulation below door to roof (approximately 6")

- One potential limitation to amount of insulation to be added to the top of the roof in the space available below the access door (approximately 6").

Addition Windows and Doors

The addition has vinyl windows. The windows and doors have similar issues as in the original building.

Figure 24: Addition - a typical window

Addition Above Grade Interior

It can be seen from the interior that the wall system is composed of a face brick on the exterior and the interior consisting of either

1. Clay Tile
2. Concrete Block, or
3. Two Layers of Brick

Figure 25: Addition – views of various interior materials used in masonry mass walls

Figure 26: Addition – underside of roof

- A deck consisting of 2x10 boards sits below the roofing

Figure 27: Addition – floor joists sitting in masonry and window

- Roof and floor joists are set in the masonry similar to the original building.

Figure 28: Addition – interior view of a crack in the masonry mass wall

Figure 29: Addition - basement

3. Closure

There appears to be existing freeze thaw damage on the masonry façade. BSC will provide brick testing and analysis to assess the potential freeze of further damage due to recommend wall insulation options. However, insulating the walls will definitely not address the existing problems. BSC will work with the architect to architectural detailing to address these issues.

Please note that Honorata Wytrykowska will be our main contact for provide construction support.

If you have any questions regarding our assessment please feel free to call or email.

Regards,

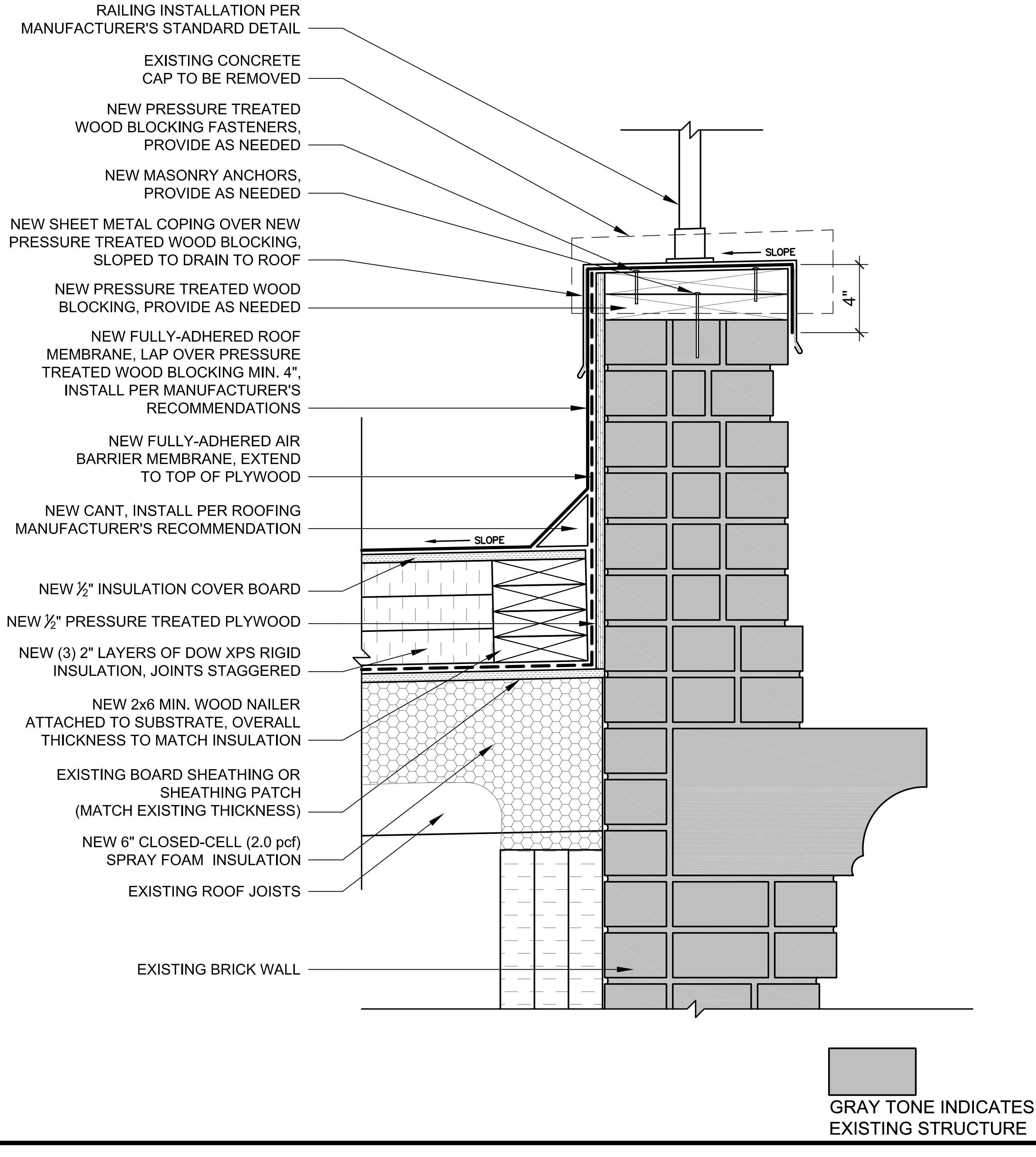
Randy V.S.

Randy Van Straaten
Building Science Consulting Inc.
167 Lexington Court, Unit 5
Waterloo, ON N2J 4R9
office 519.342.4731
cell 519.319.9773
fax: 978-589-5103

Building Science Corporation
Somerville MA | Waterloo ON
www.buildingscience.com

Appendix B

MVHfH Retrofit Construction Details



ROOF PARAPET 1

SCALE: 1 1/2" = 1'-0"

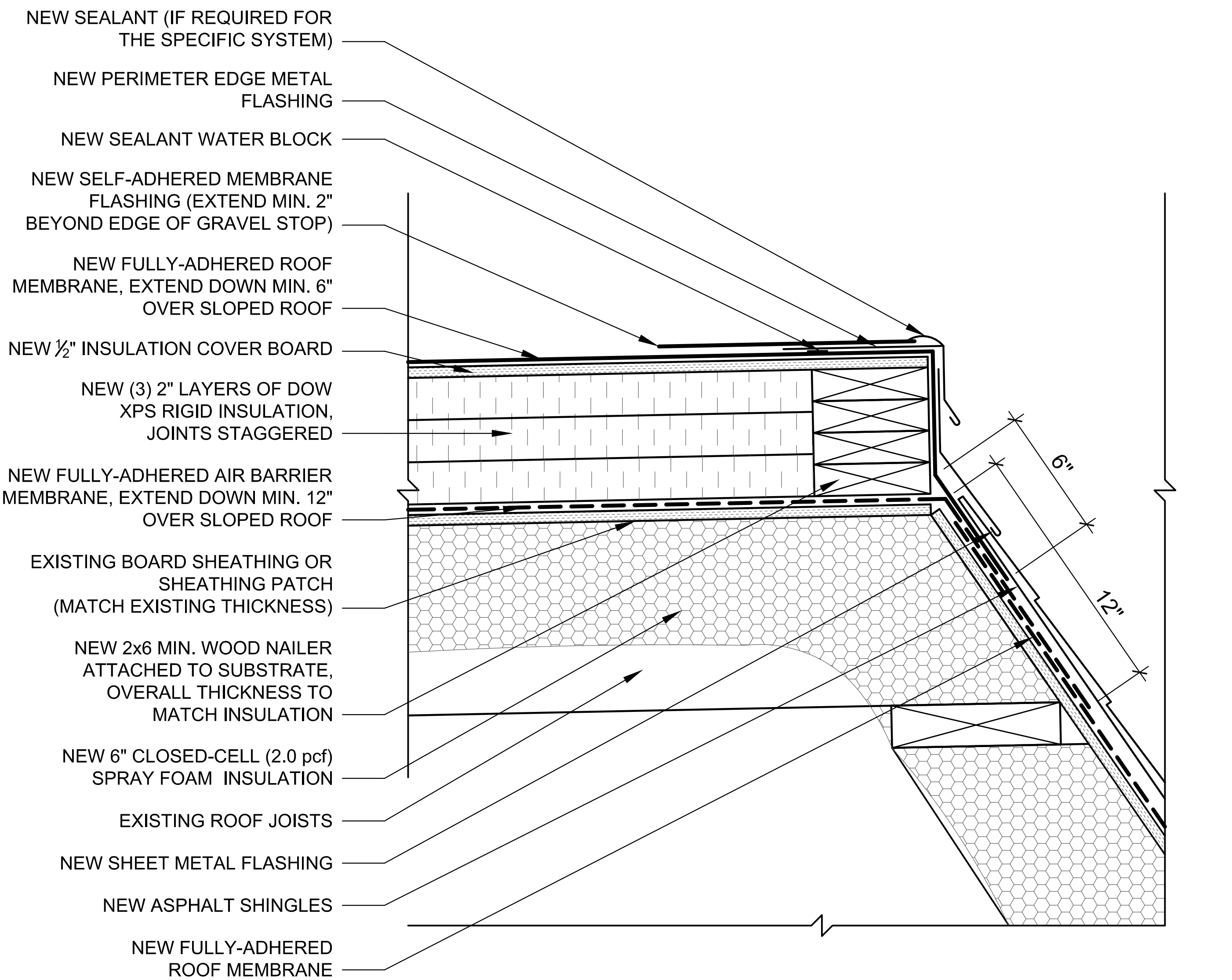
bsc with Building America U.S. Department of Energy *Research Toward Zero Energy Homes*

Merrimack Valley Habitat for Humanity
Roof Details

Date: 2012-02-06

Sheet Title:

RP1



GRAY TONE INDICATES EXISTING STRUCTURE

ROOF PARAPET 2

SCALE: 1 1/2" = 1'-0"

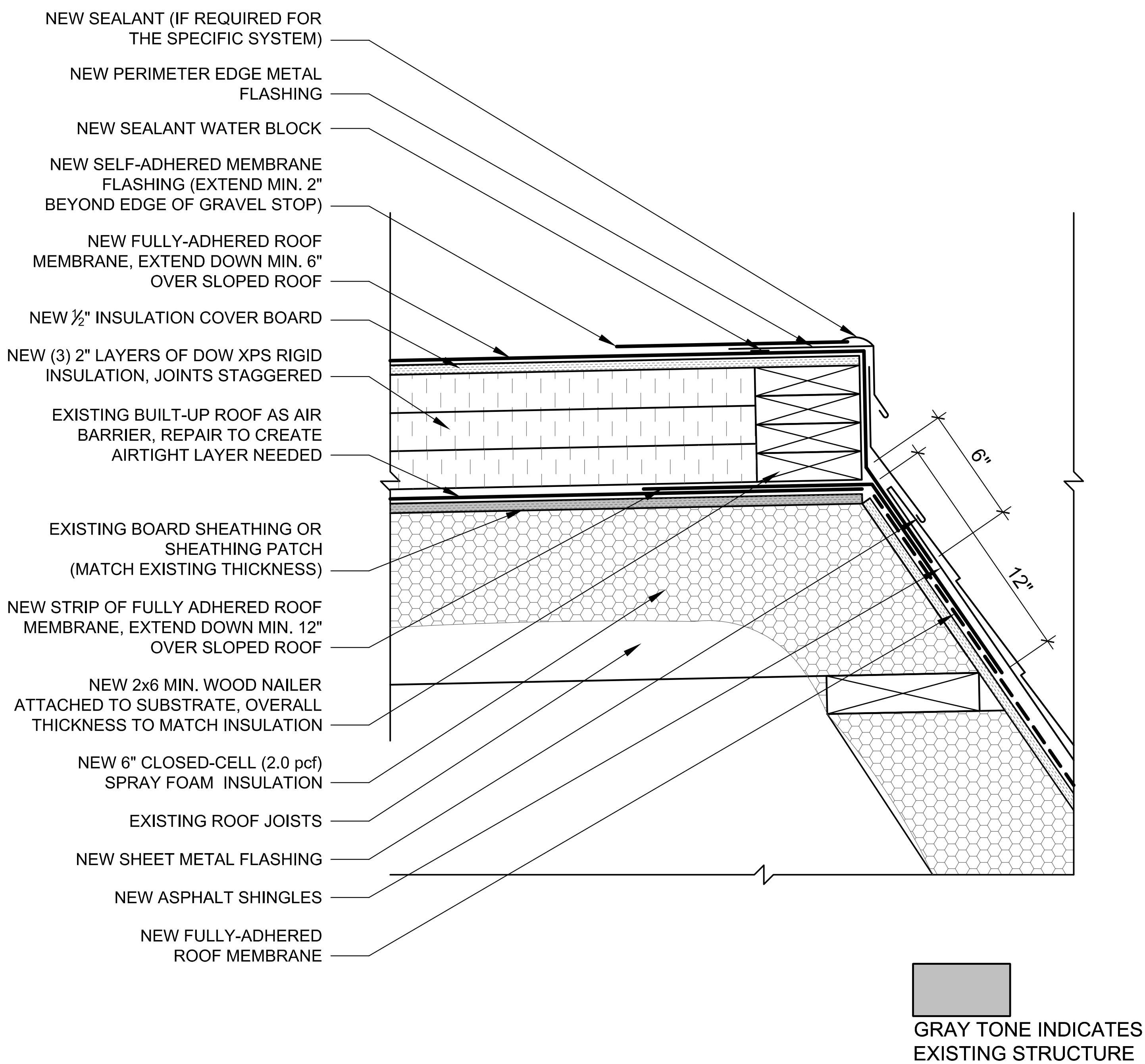
with U.S. Department of Energy
Research Toward Zero Energy Homes

Merrimack Valley Habitat for Humanity
Roof Details

Date: 2012-02-06

Sheet Title:

RP2



ROOF PARAPET 2 - ALT

SCALE: 1 1/2" = 1'-0"

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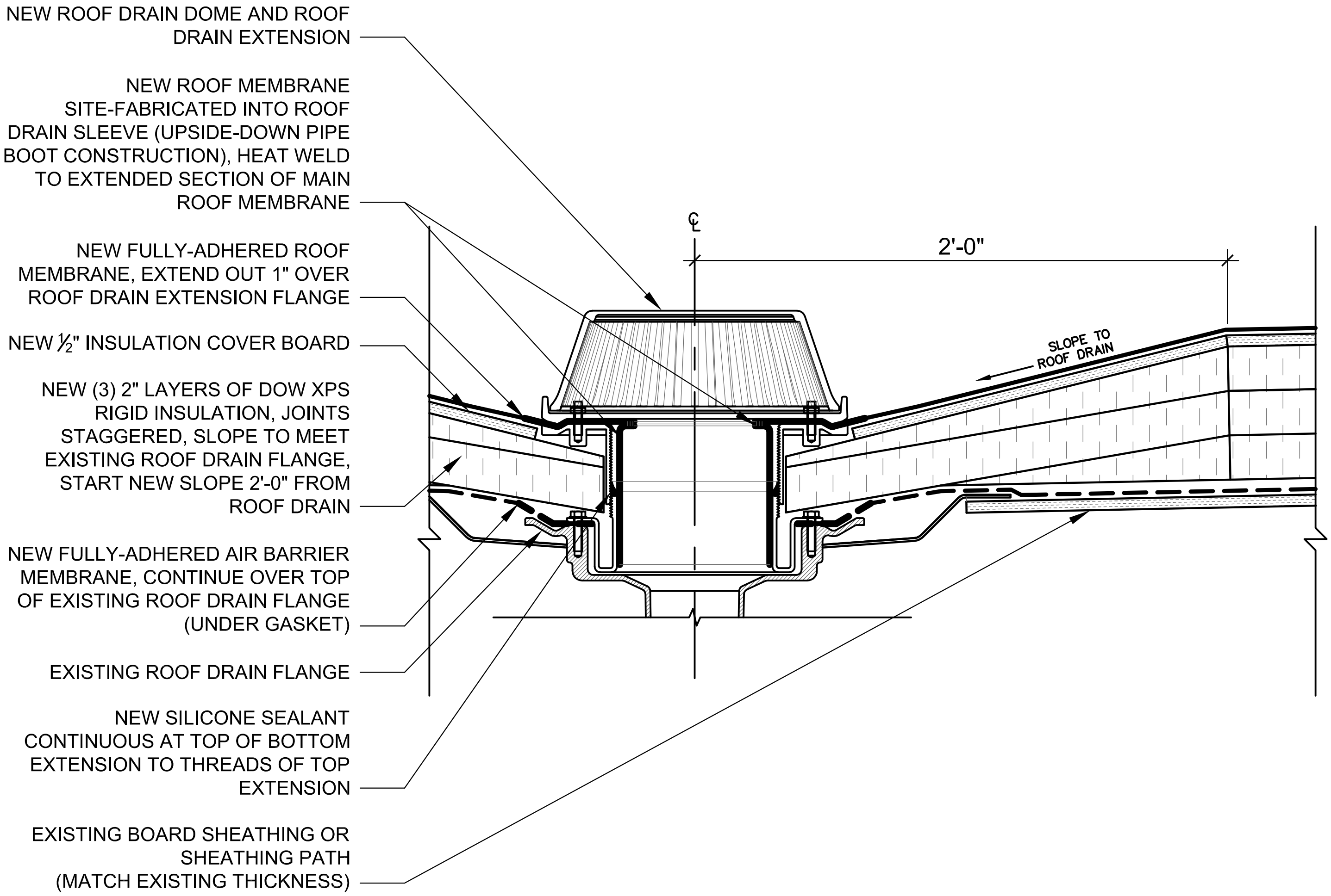
Merrimack Valley Habitat for Humanity
Roof Details

Date: 2012-02-06

Sheet Title: RP2-ALT



GRAY TONE INDICATES EXISTING STRUCTURE

ROOF EXTENSION DRAIN

SCALE: 1 1/2" = 1'-0"

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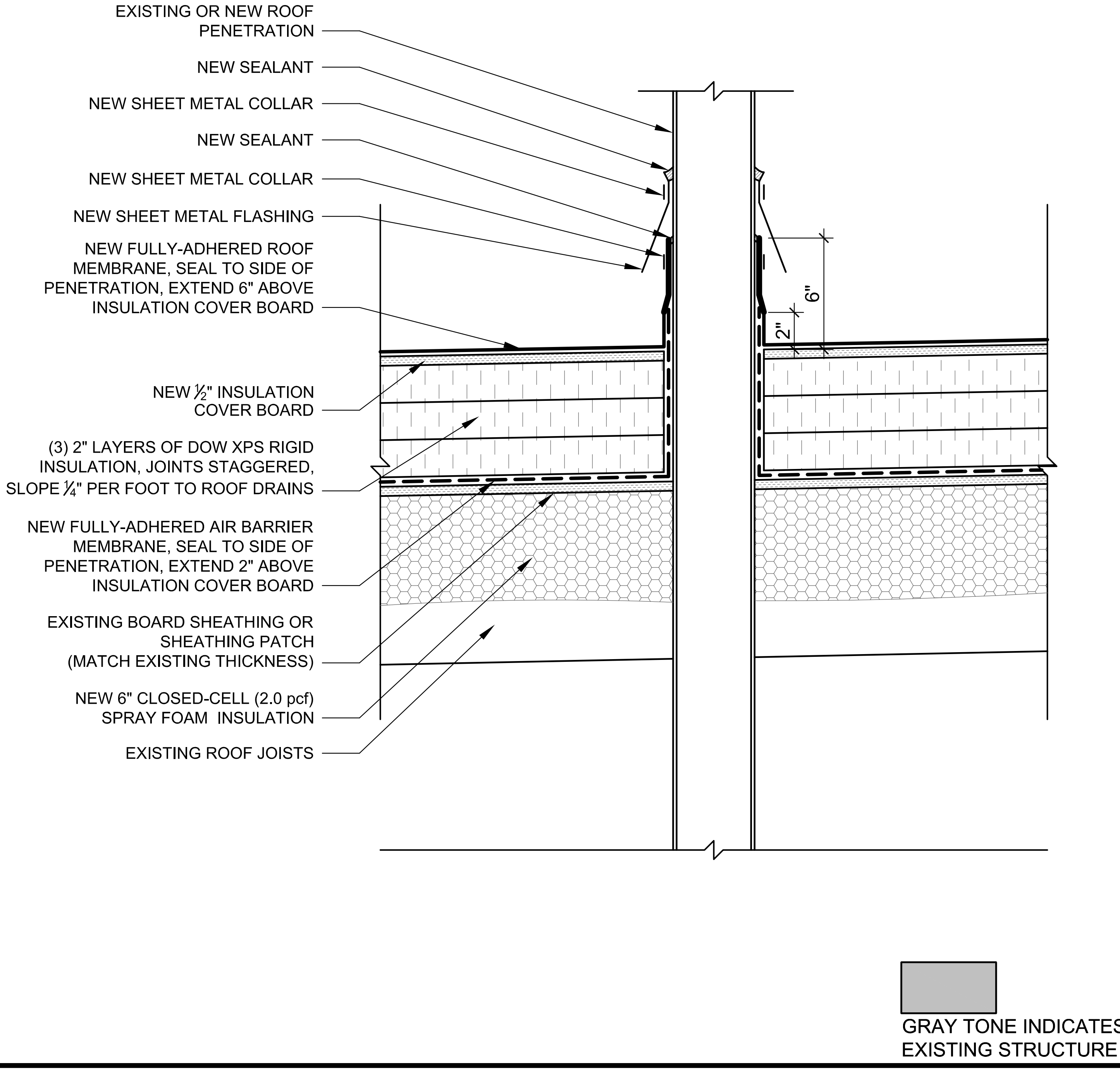
Merrimack Valley Habitat for Humanity
Roof Details

Date: 2012-02-06

Sheet Title: RD



ROOF VENT INSTALLED BEFORE ROOF COMPLETION

SCALE: 1 1/2" = 1'-0"

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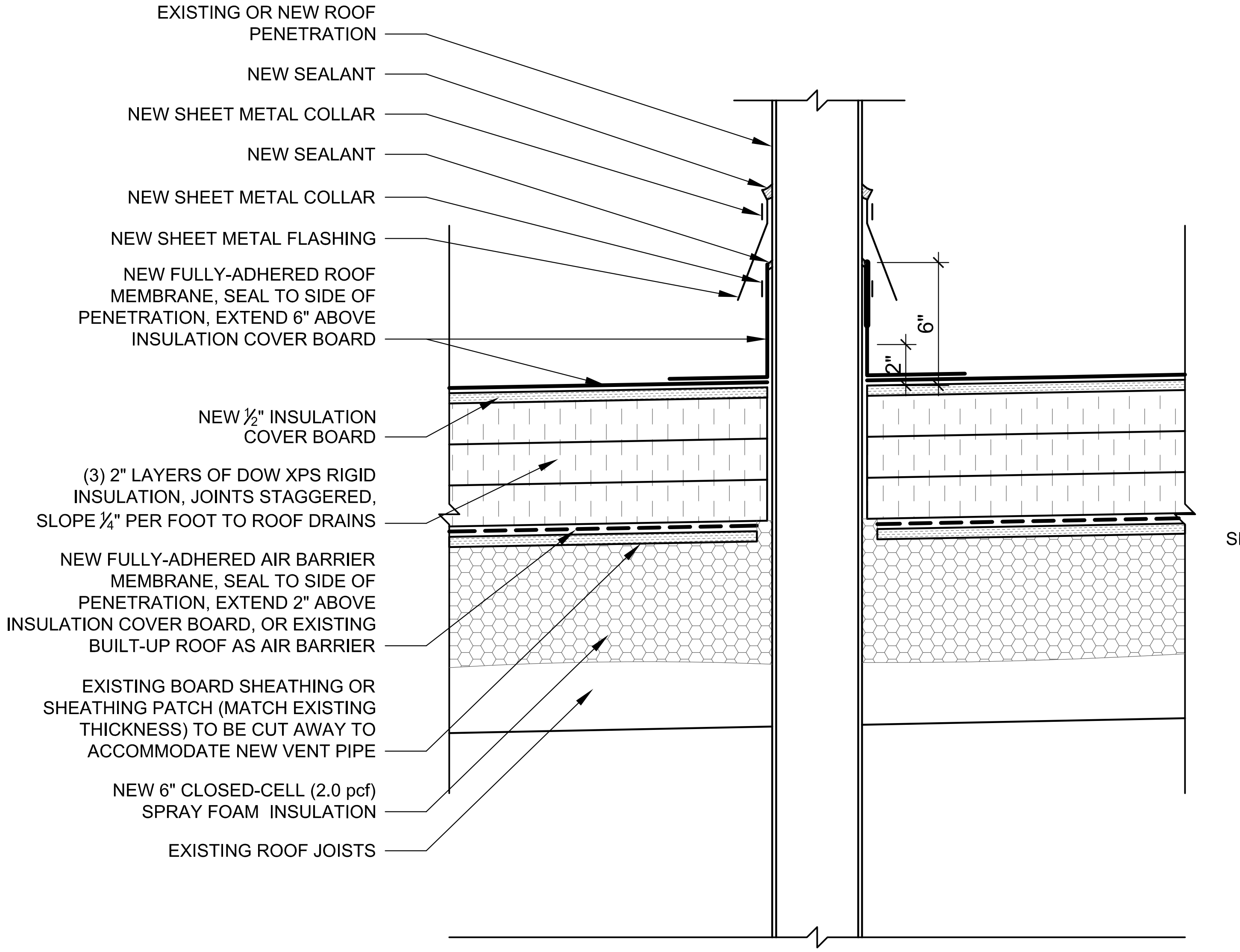
Merrimack Valley Habitat for Humanity
Roof Details

Date: 2012-02-06

Sheet Title:

RV



GRAY TONE INDICATES EXISTING STRUCTURE

ROOF VENT INSTALLED AFTER ROOF COMPLETION - ALT

SCALE: 1 1/2" = 1'-0"

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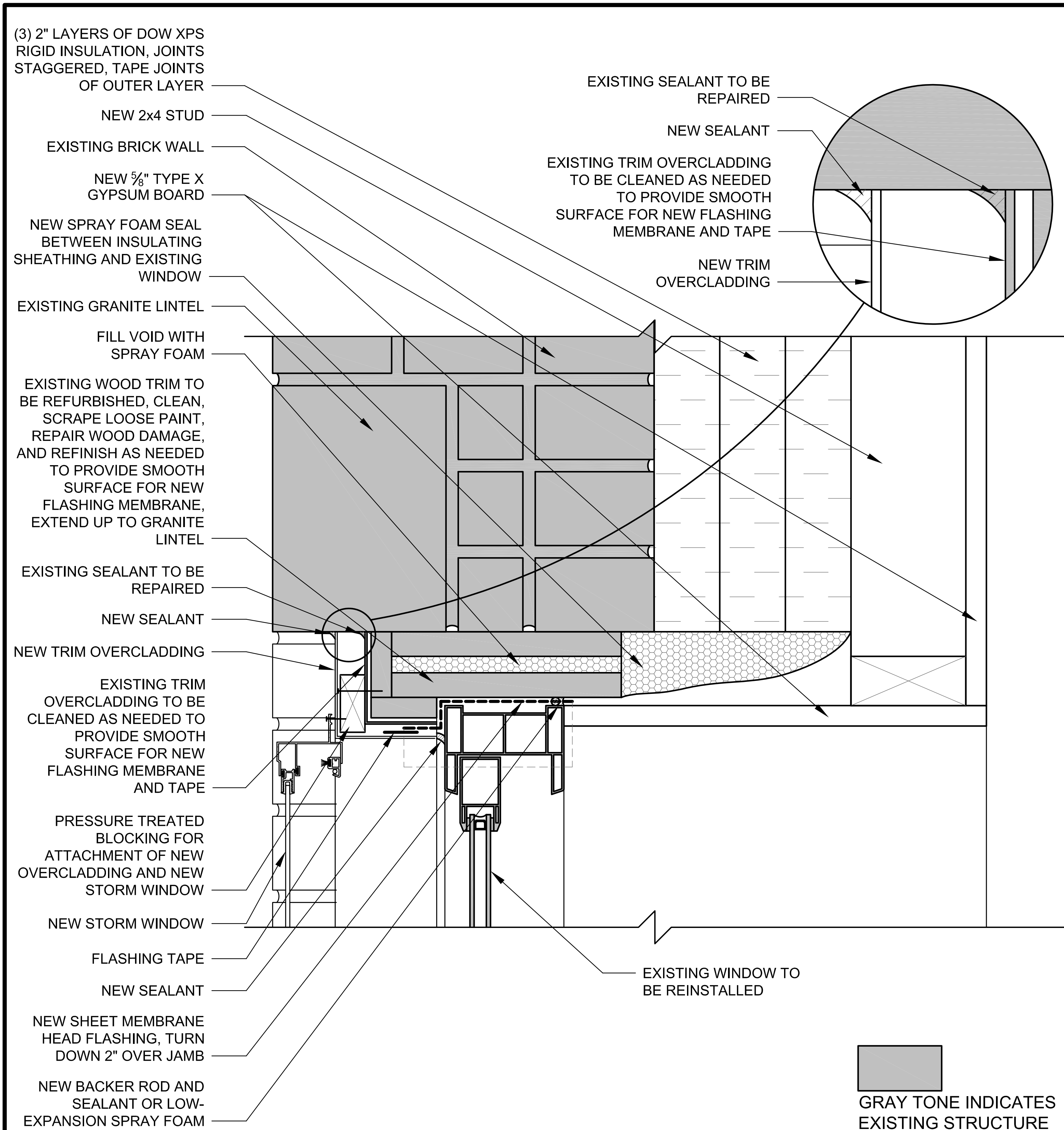
Merrimack Valley Habitat for Humanity
Roof Details

Date: 2012-02-06

Sheet Title:

RV-ALT



WINDOW HEAD

SCALE: 3" = 1'-0"

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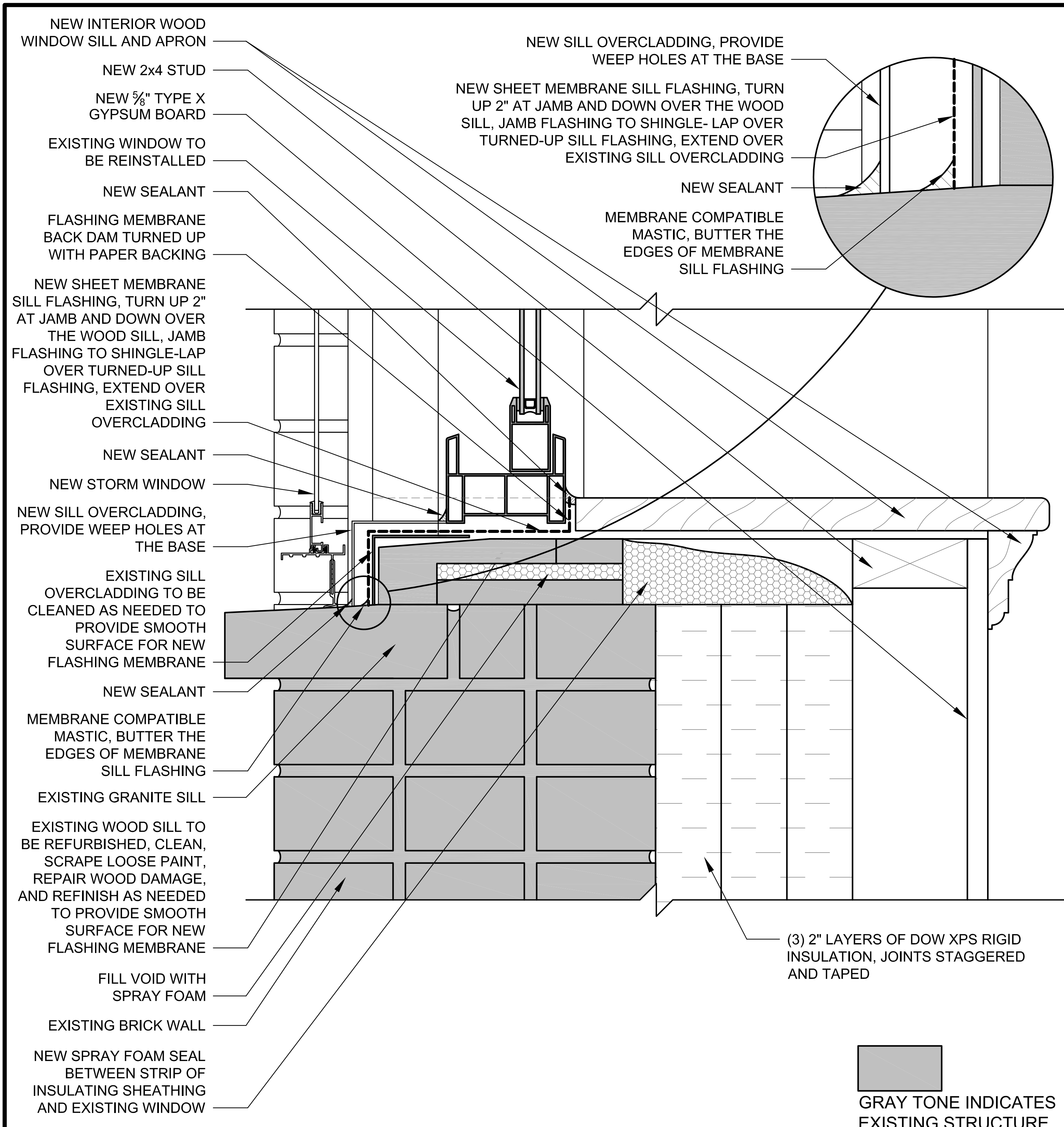
Merrimack Valley Habitat for Humanity
Window Details

Date: 2012-02-06

Sheet Title:

WH



WINDOW SILL

SCALE: 3" = 1'-0"

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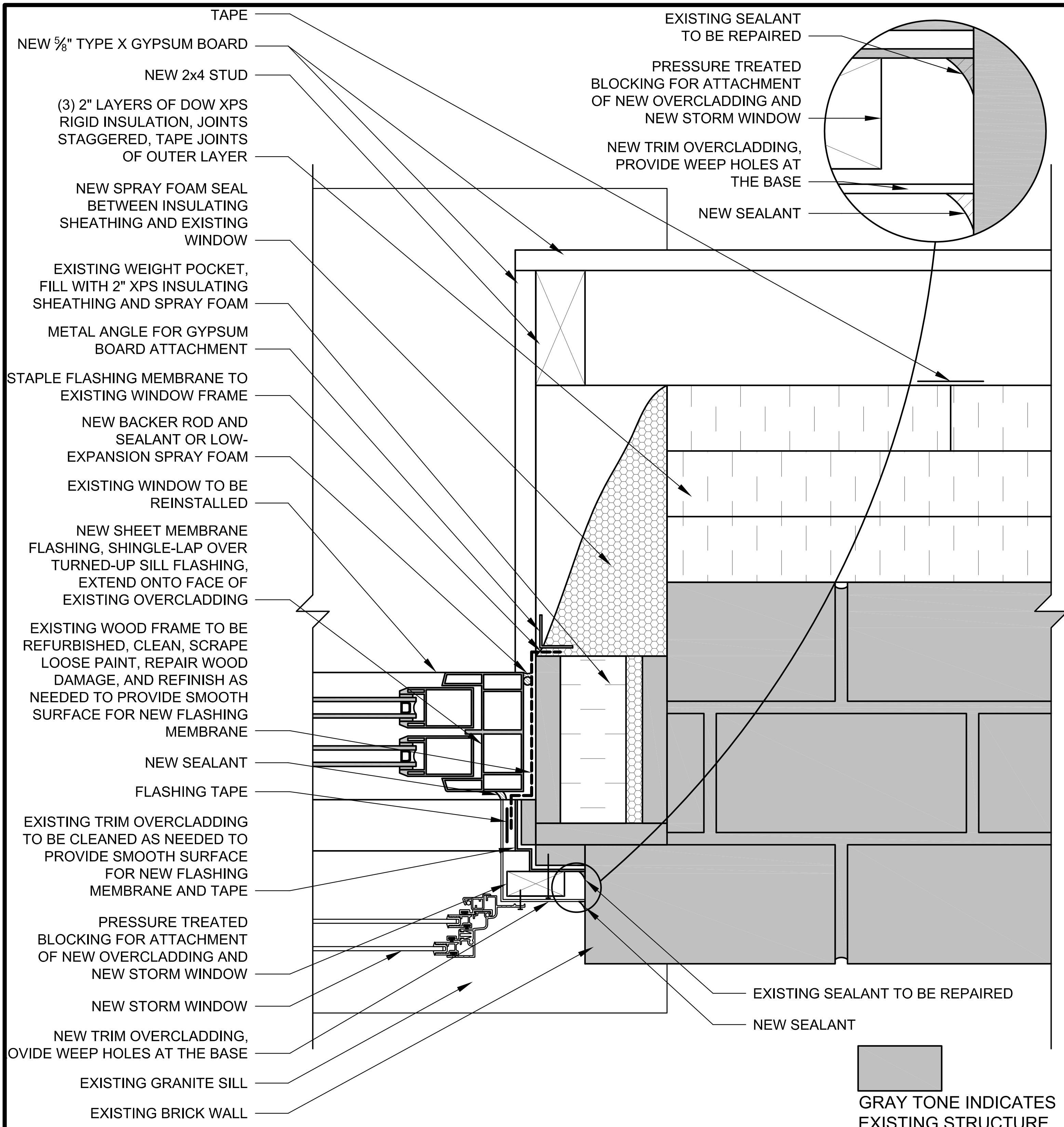
Merrimack Valley Habitat for Humanity
Window Details

Date: 2012-02-06

Sheet Title:

WS



WINDOW JAMB

SCALE: 3" = 1'-0"

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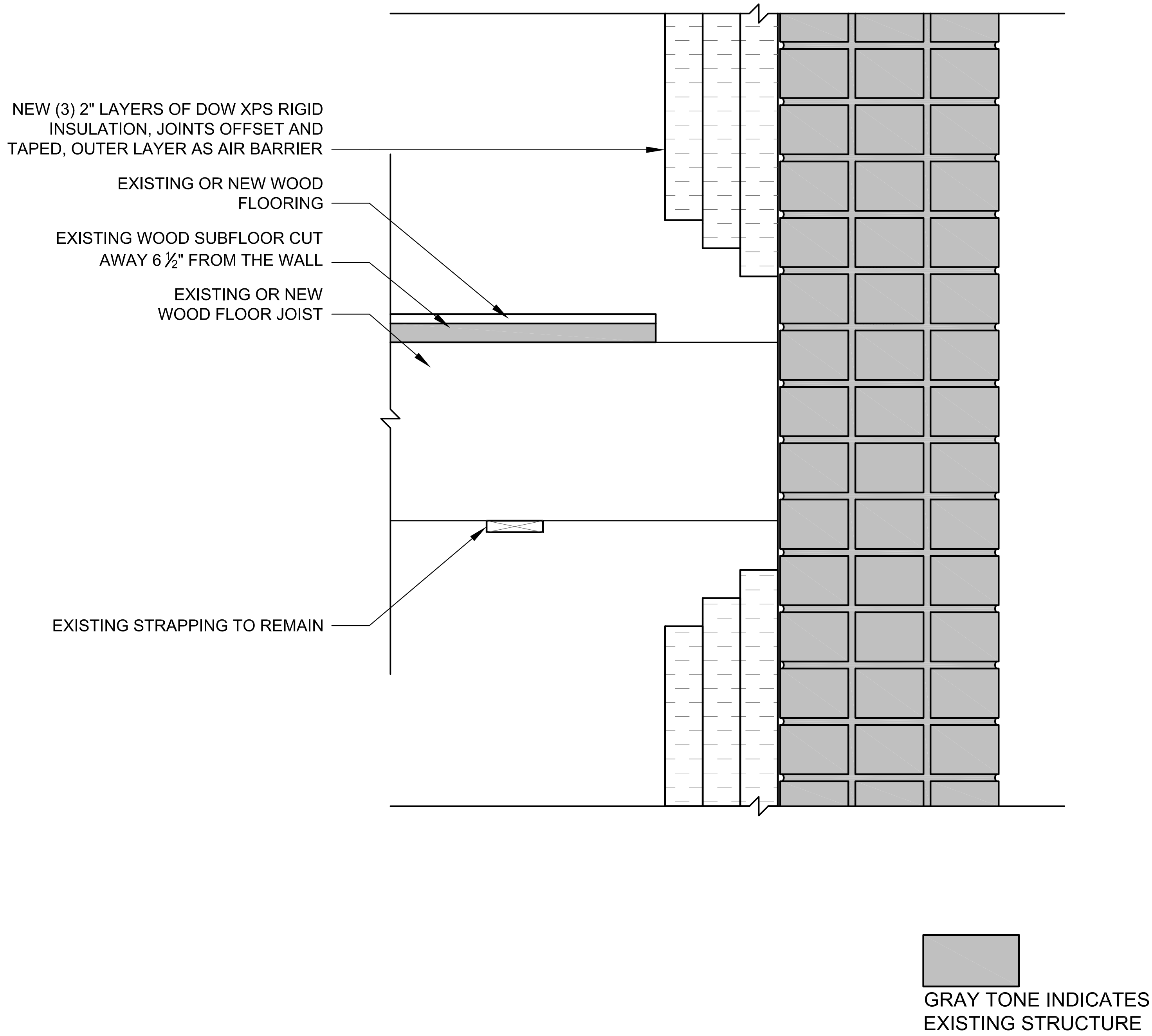
Merrimack Valley Habitat for Humanity
Window Details

Date: 2012-02-06

Sheet Title:

WJ



TYPICAL FLOOR ASSEMBLY BETWEEN UNITS - STEP 1

SCALE: 1 1/2" = 1'-0"

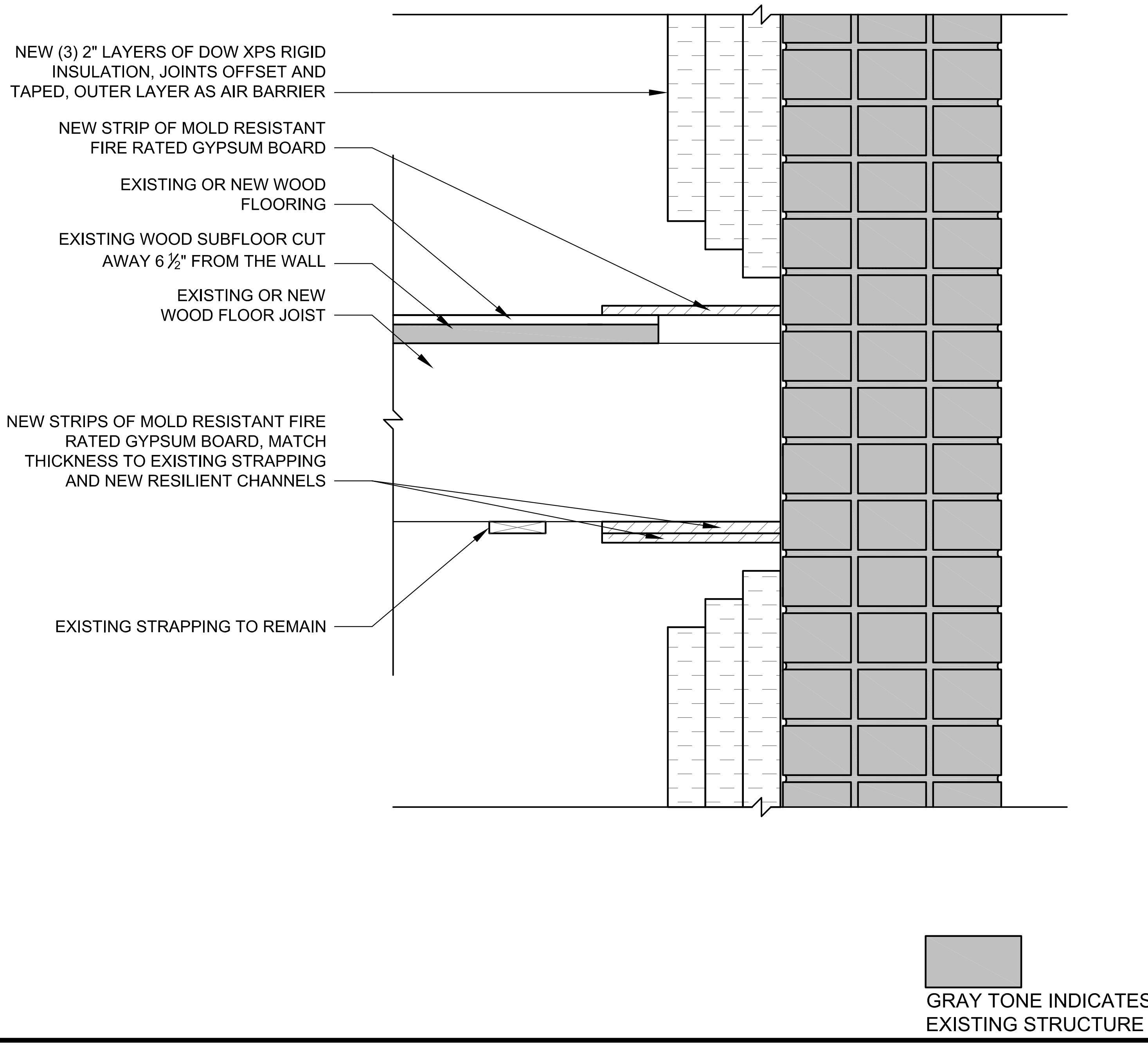
bsc with Building America U.S. Department of Energy Research Toward Zero Energy Homes

Merrimack Valley Habitat for Humanity
Wall Details

Date: 2012-02-06

Sheet Title:

W1a-1



TYPICAL FLOOR ASSEMBLY BETWEEN UNITS - STEP 2

SCALE: 1 1/2" = 1'-0"

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Merrimack Valley Habitat for Humanity
Wall Details

Date: 2012-02-06

Sheet Title:

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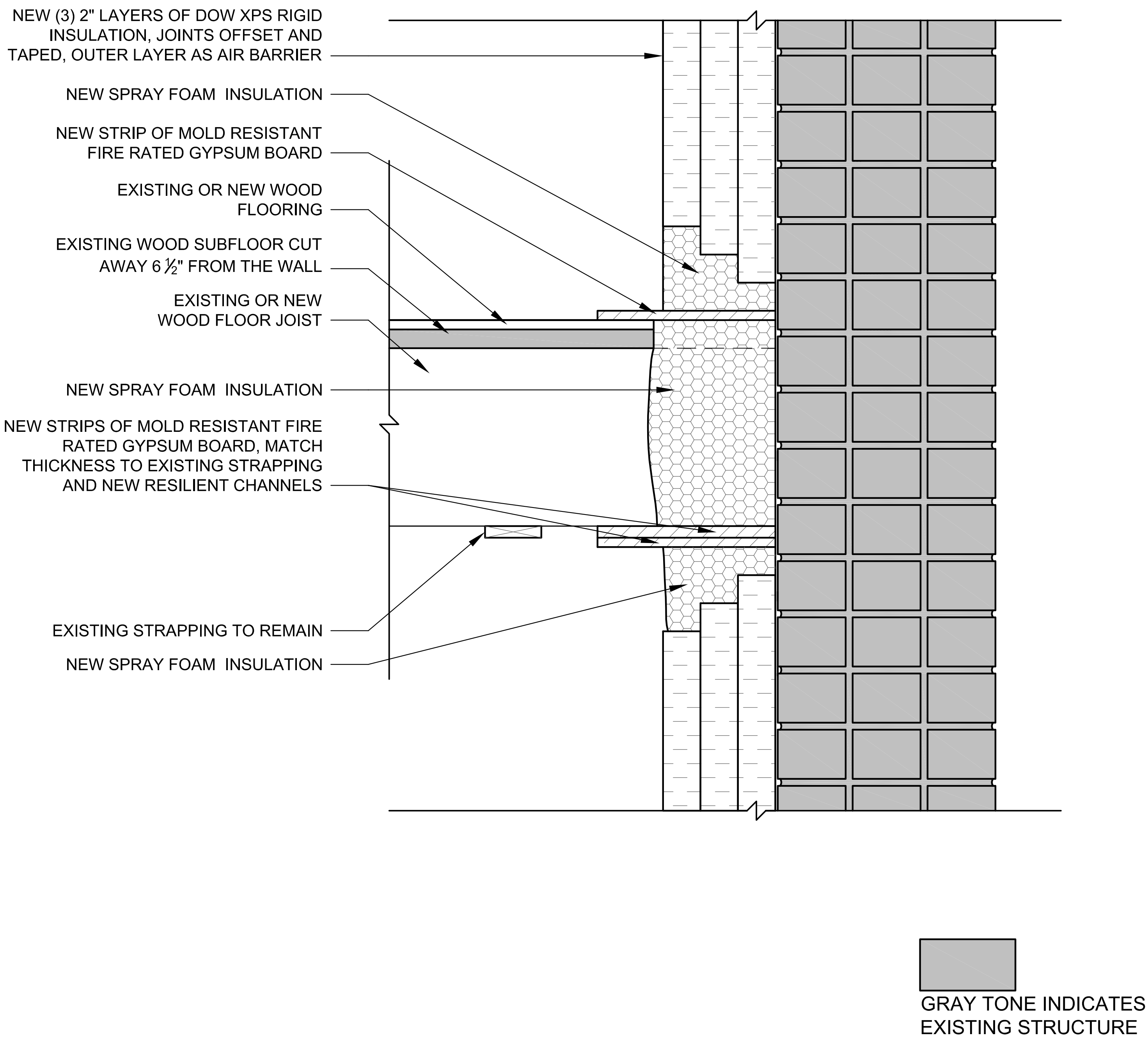

TYPICAL FLOOR ASSEMBLY BETWEEN UNITS - STEP 3

SCALE: 1 1/2" = 1'-0"

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Merrimack Valley Habitat for Humanity
Wall Details

Date: 2012-02-06

Sheet Title:

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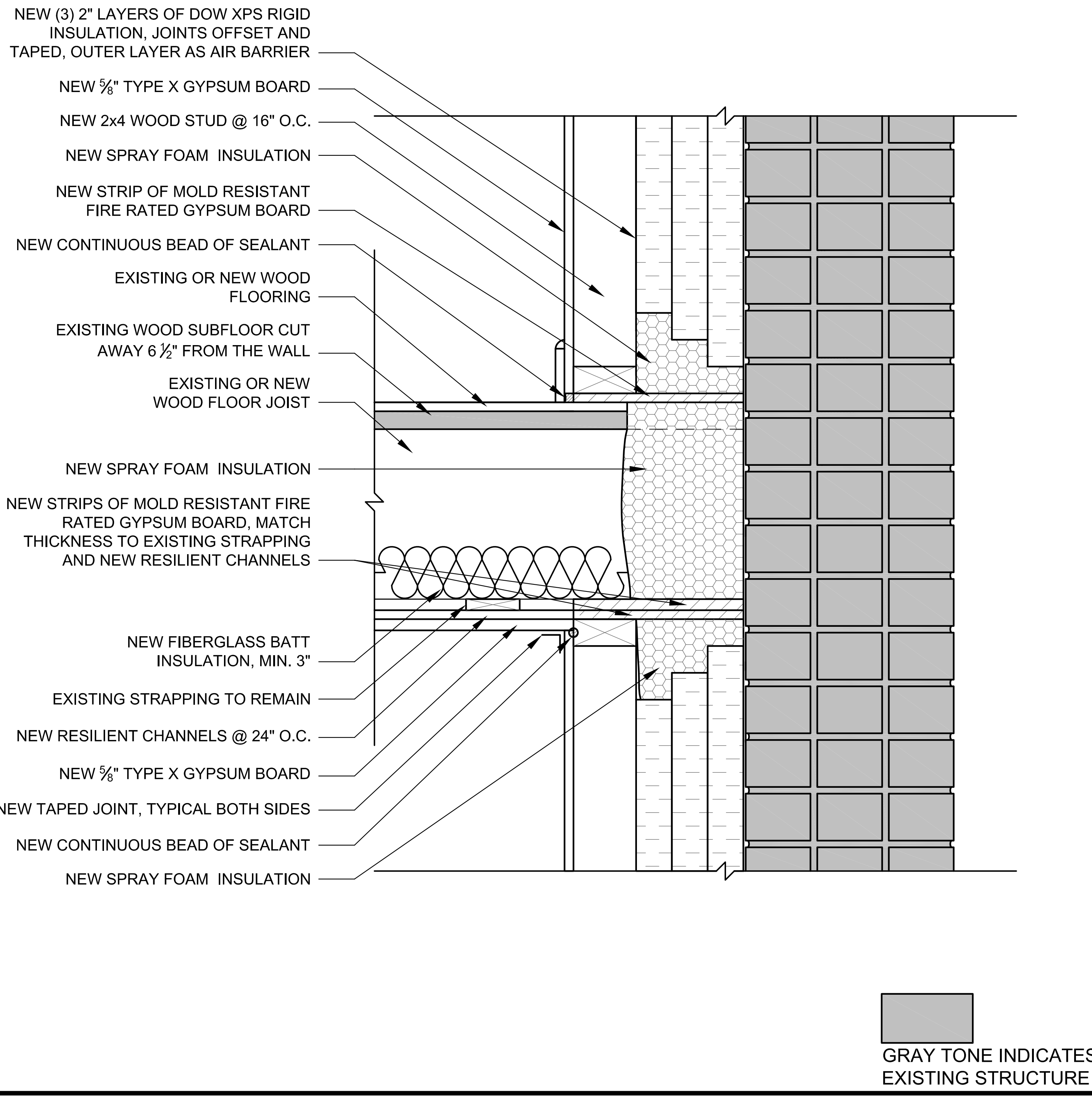


TYPICAL FLOOR ASSEMBLY BETWEEN UNITS - STEP 4

SCALE: 1 1/2" = 1'-0"

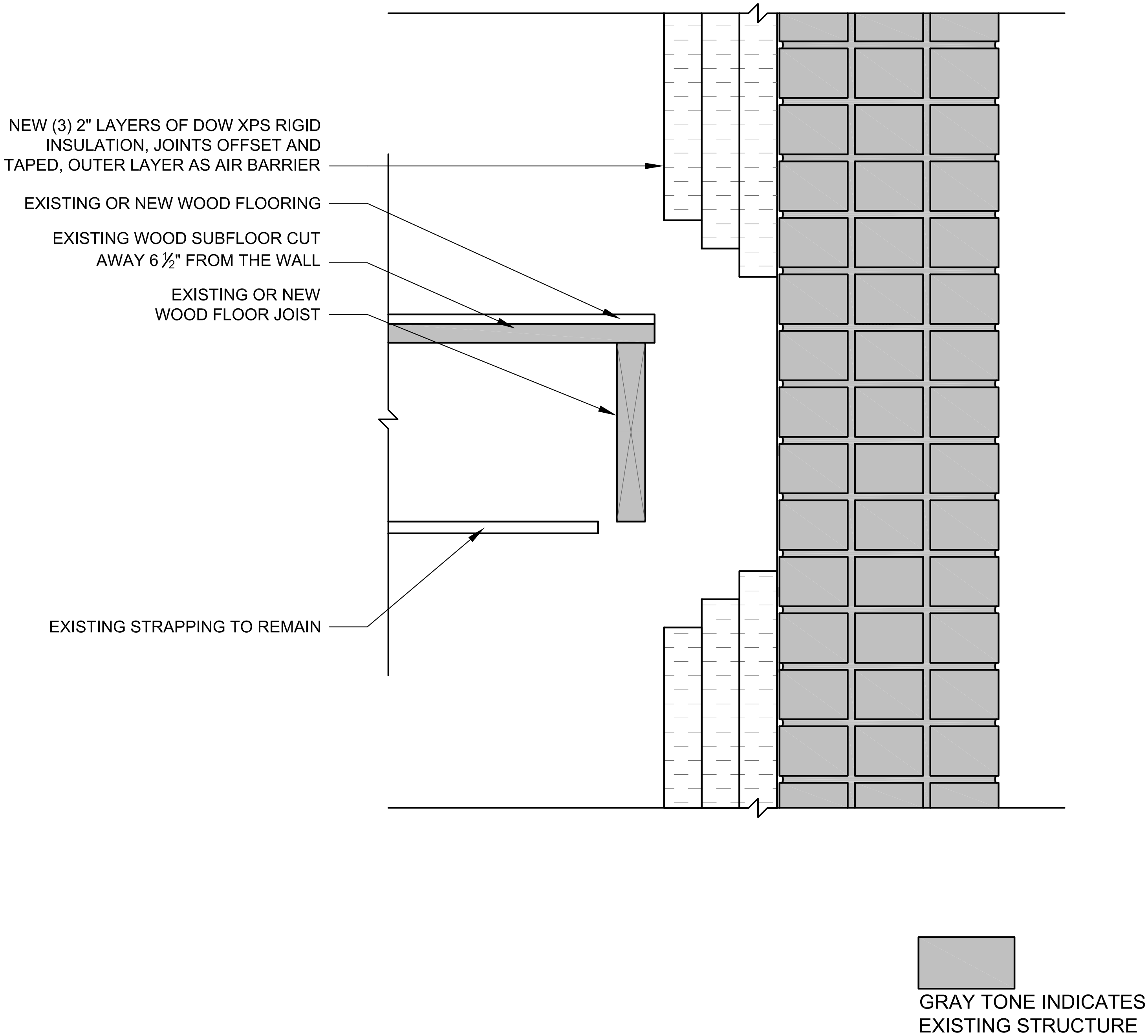
bsc with Building America U.S. Department of Energy Research Toward Zero Energy Homes

Merrimack Valley Habitat for Humanity
Wall Details

Date: 2012-02-06

Sheet Title:

W1a-4



TYPICAL FLOOR ASSEMBLY BETWEEN UNITS - STEP 1

SCALE: 1 1/2" = 1'-0"

with

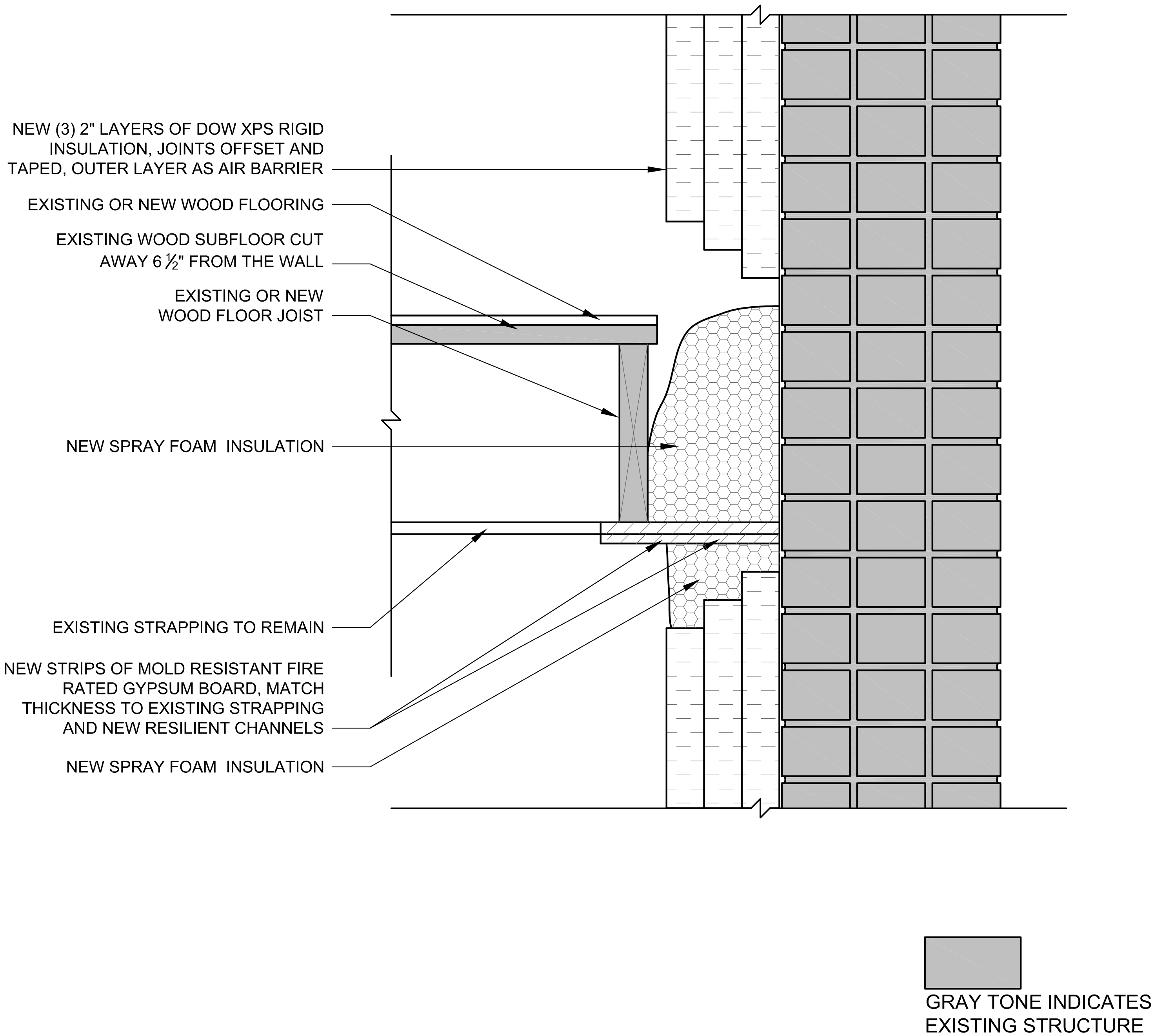
Building America
U.S. Department of Energy
Research Toward Zero Energy Homes

Merrimack Valley Habitat for Humanity
Wall Details

Date: 2012-02-06

Sheet Title:

W1b-1



TYPICAL FLOOR ASSEMBLY BETWEEN UNITS - STEP 2

SCALE: 1 1/2" = 1'-0"

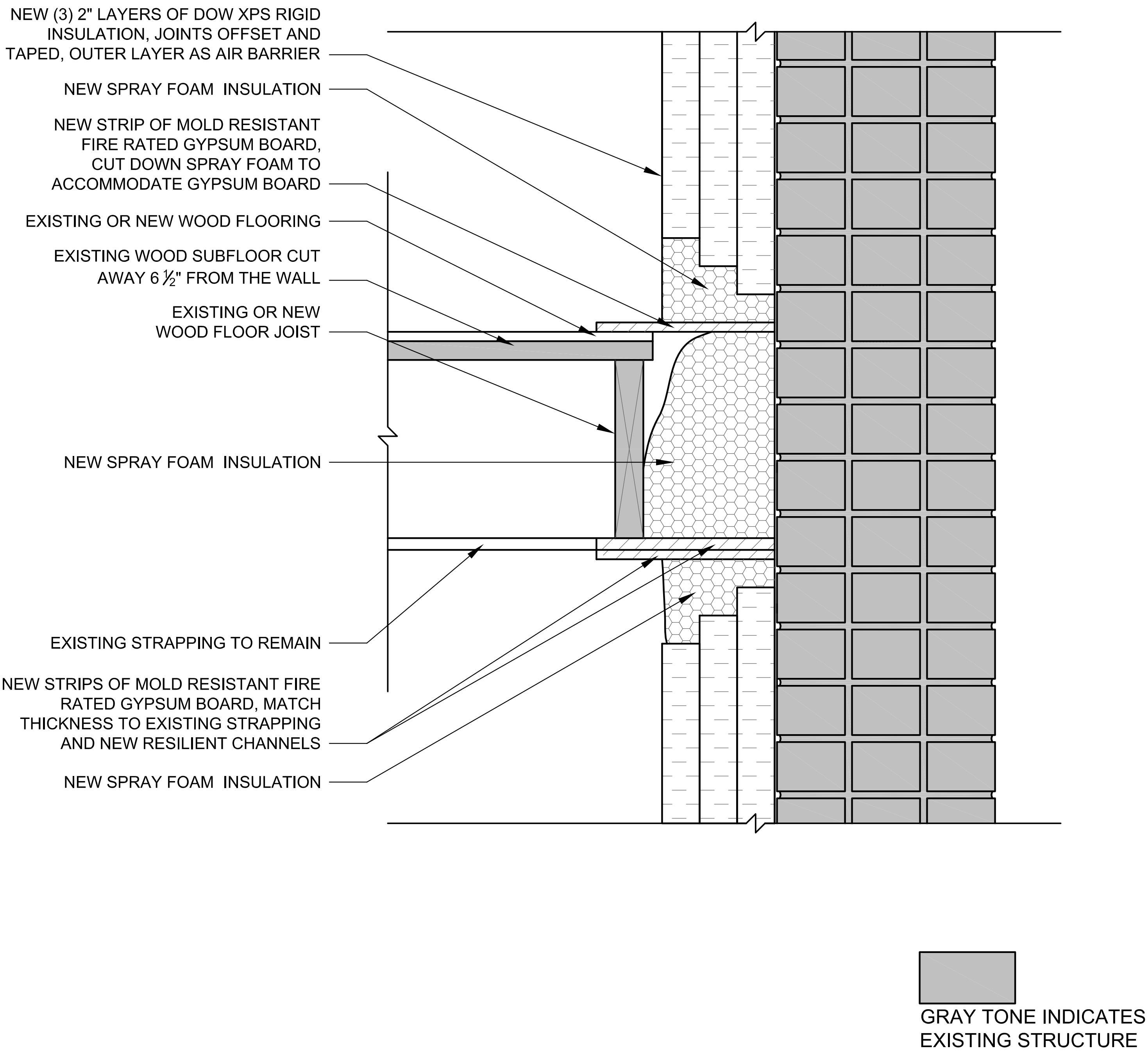
bsc with Building America U.S. Department of Energy Research Toward Zero Energy Homes

Merrimack Valley Habitat for Humanity
Wall Details

Date: 2012-02-06

Sheet Title:

W1b-2



TYPICAL FLOOR ASSEMBLY BETWEEN UNITS - STEP 3

SCALE: 1 1/2" = 1'-0"

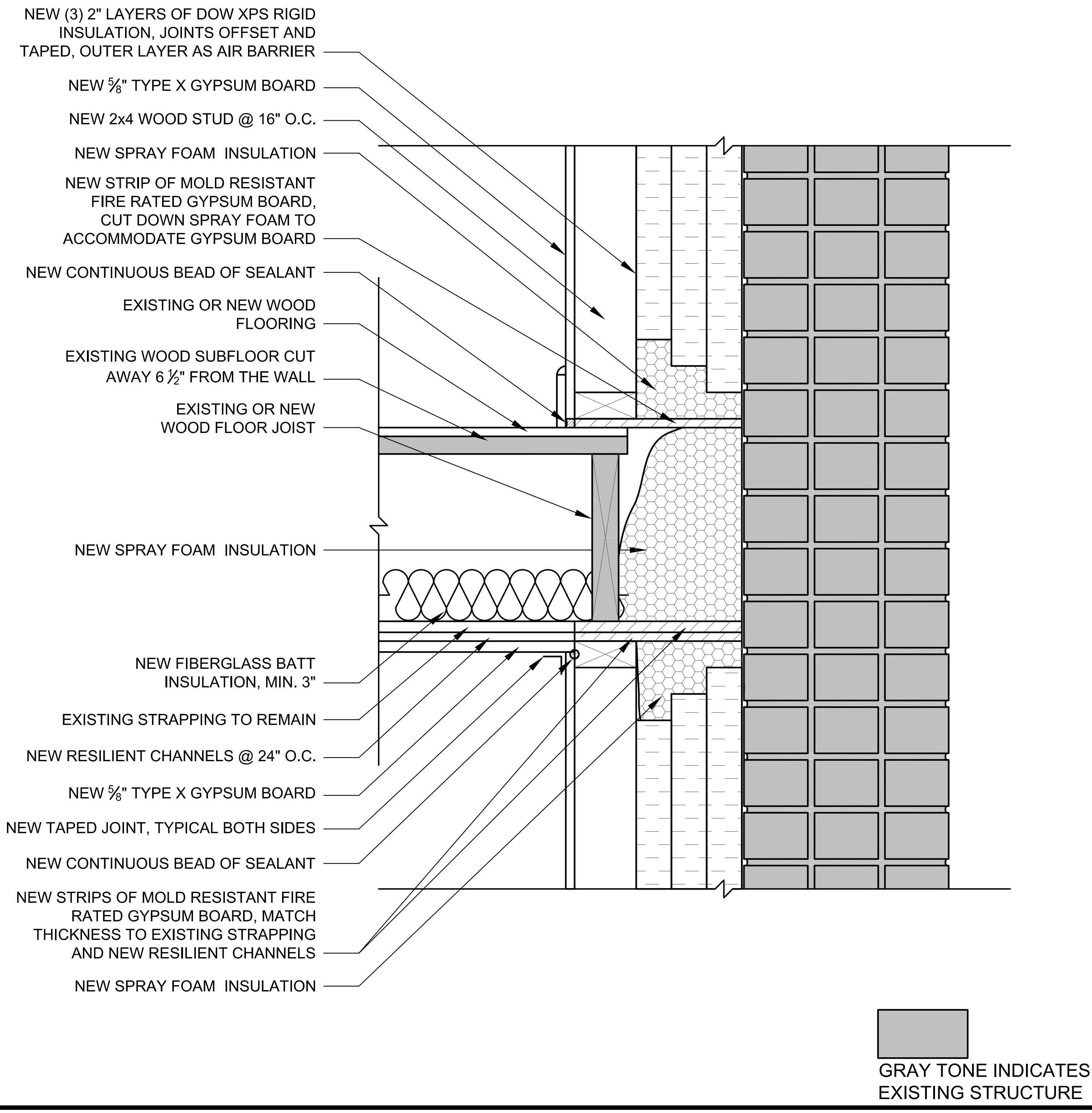
bsc with Building America U.S. Department of Energy Research Toward Zero Energy Homes

Merrimack Valley Habitat for Humanity
Wall Details

Date: 2012-02-06

Sheet Title:

W1b-3



TYPICAL FLOOR ASSEMBLY BETWEEN UNITS - STEP 4

SCALE: 1 1/2" = 1'-0"

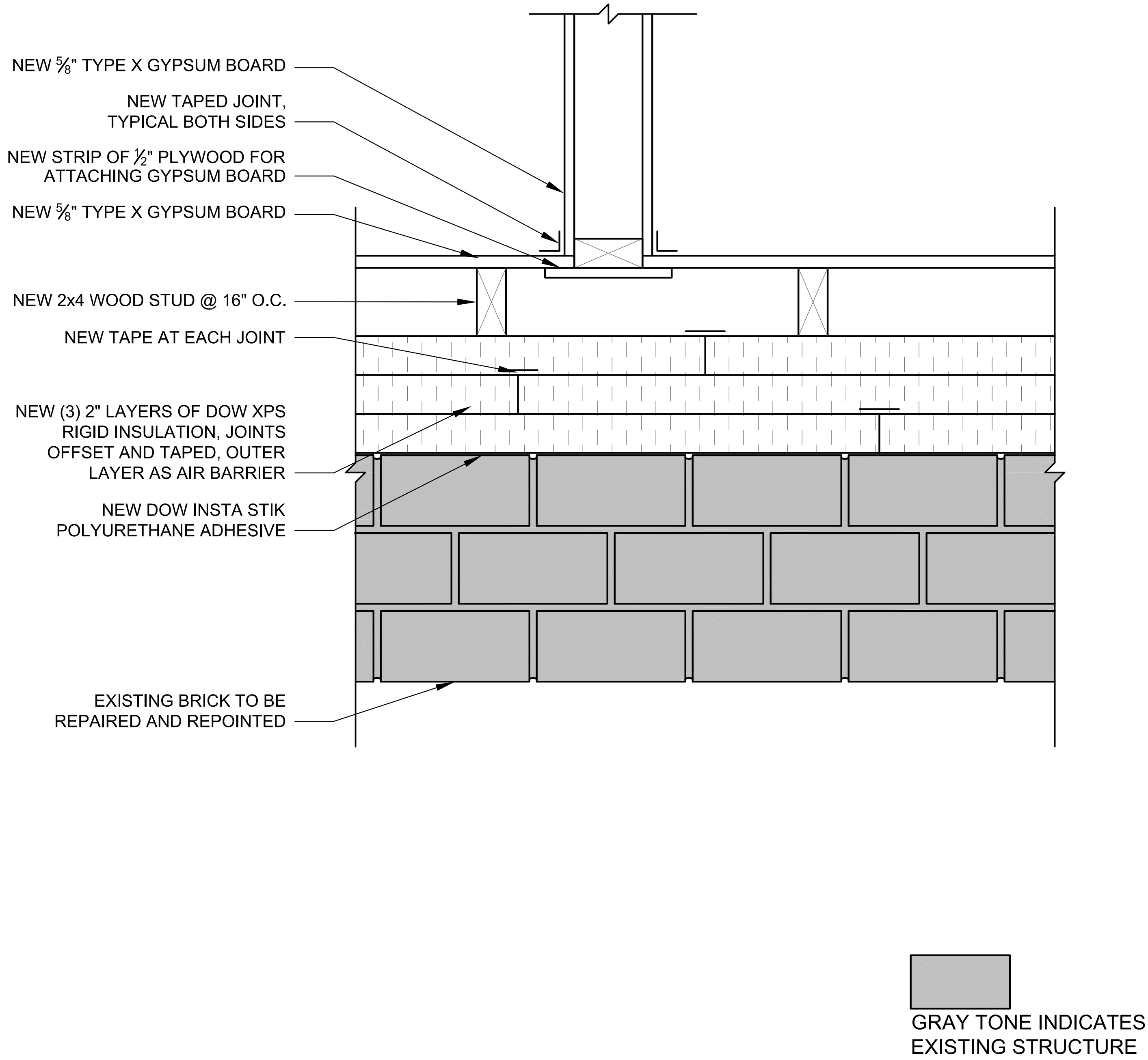
bsc with Building America U.S. Department of Energy Research Toward Zero Energy Homes

Merrimack Valley Habitat for Humanity
Wall Details

Date: 2012-02-06

Sheet Title:

W1b-4



WALL - TYPICAL INTERIOR PARTITION - PLAN

SCALE: 1 1/2" = 1'-0"

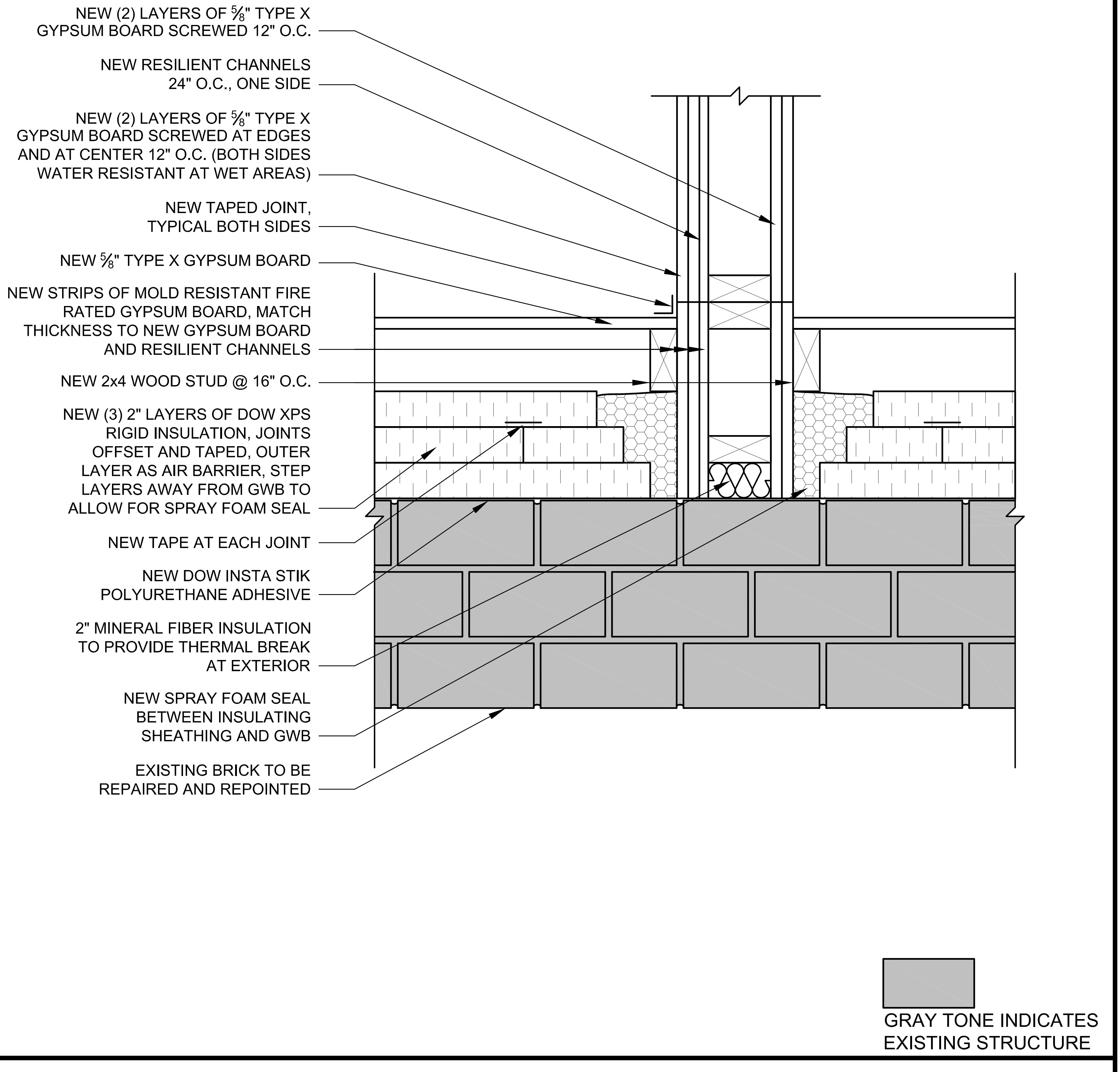
with Building AMERICA U.S. Department of Energy Research Toward Zero Energy Homes

Merrimack Valley Habitat for Humanity
Wall Details

Date: 2012-02-06

Sheet Title:

W2



WALL - TYPICAL DEMISING PARTITION - PLAN

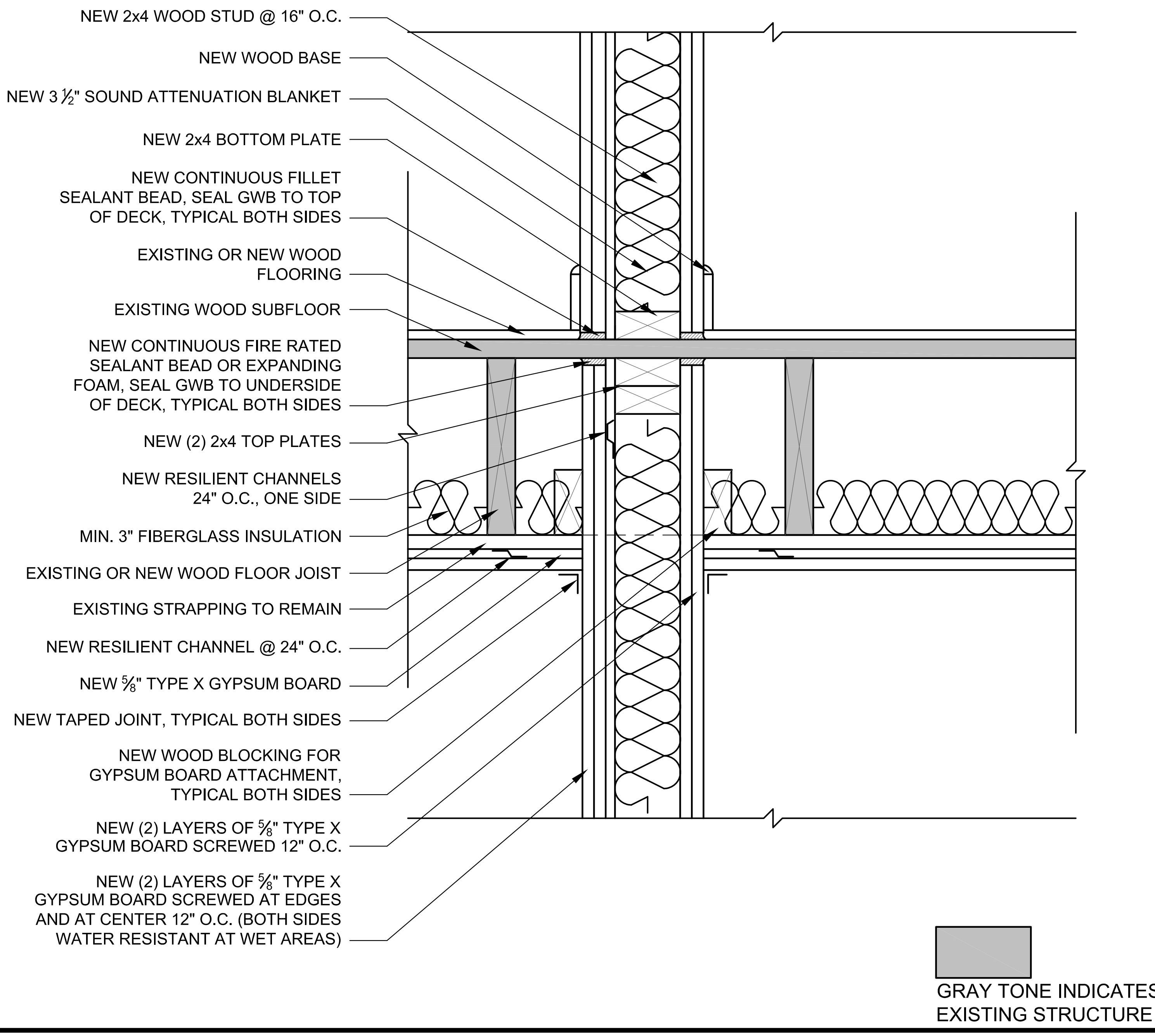
SCALE: 1 1/2" = 1'-0"

bsc with Building America U.S. Department of Energy Research Toward Zero Energy Homes

Merrimack Valley Habitat for Humanity
Wall Details

Date: 2012-02-06

Sheet Title: W3



WALL - TYPICAL DEMISING PARTITION - SECTION 1

SCALE: 3" = 1'-0"

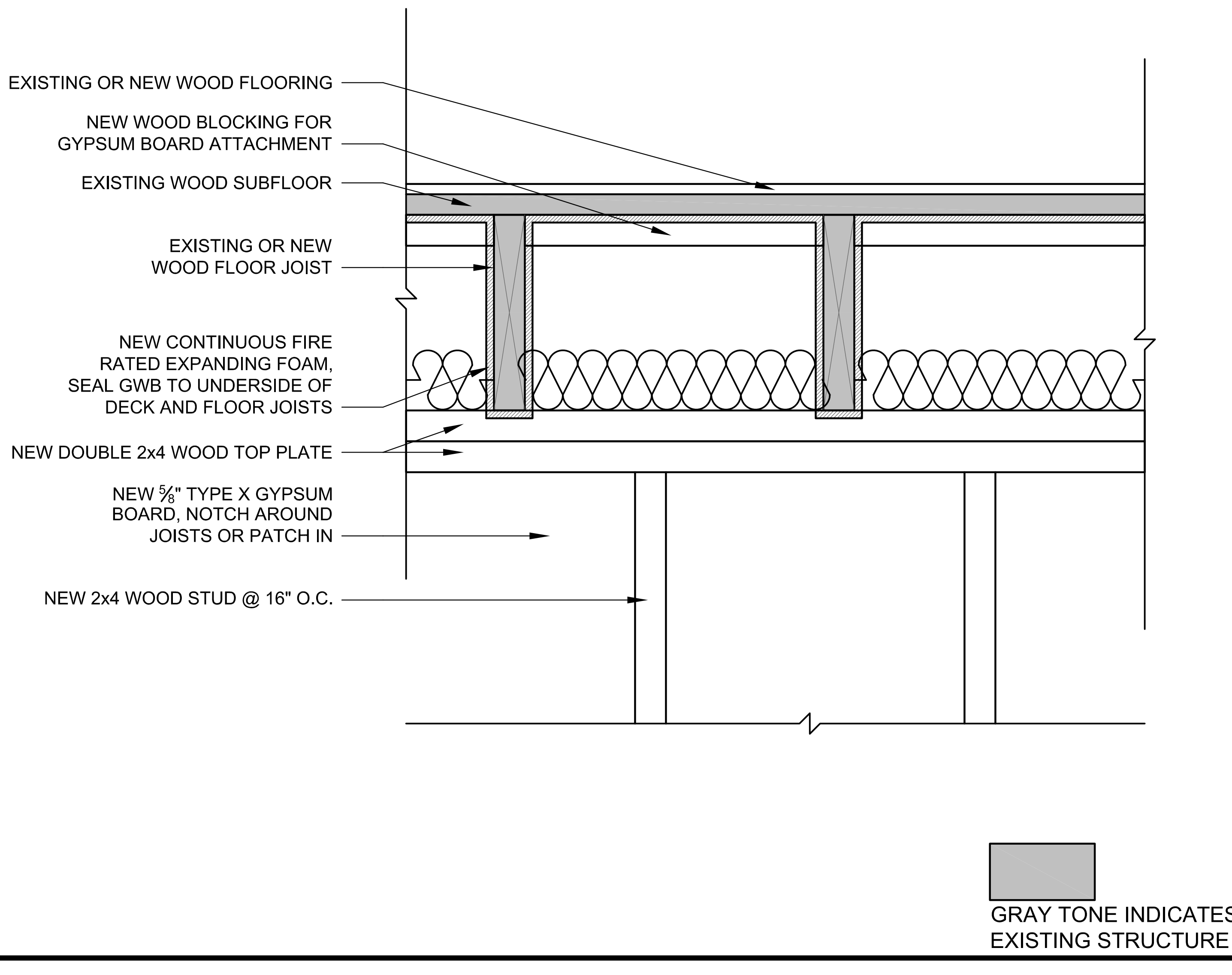
bsc with Building America U.S. Department of Energy Research Toward Zero Energy Homes

Merrimack Valley Habitat for Humanity
Wall Details

Date: 2012-02-06

Sheet Title:

W4



WALL - TYPICAL DEMISING PARTITION - SECTION 2

SCALE: 3" = 1'-0"

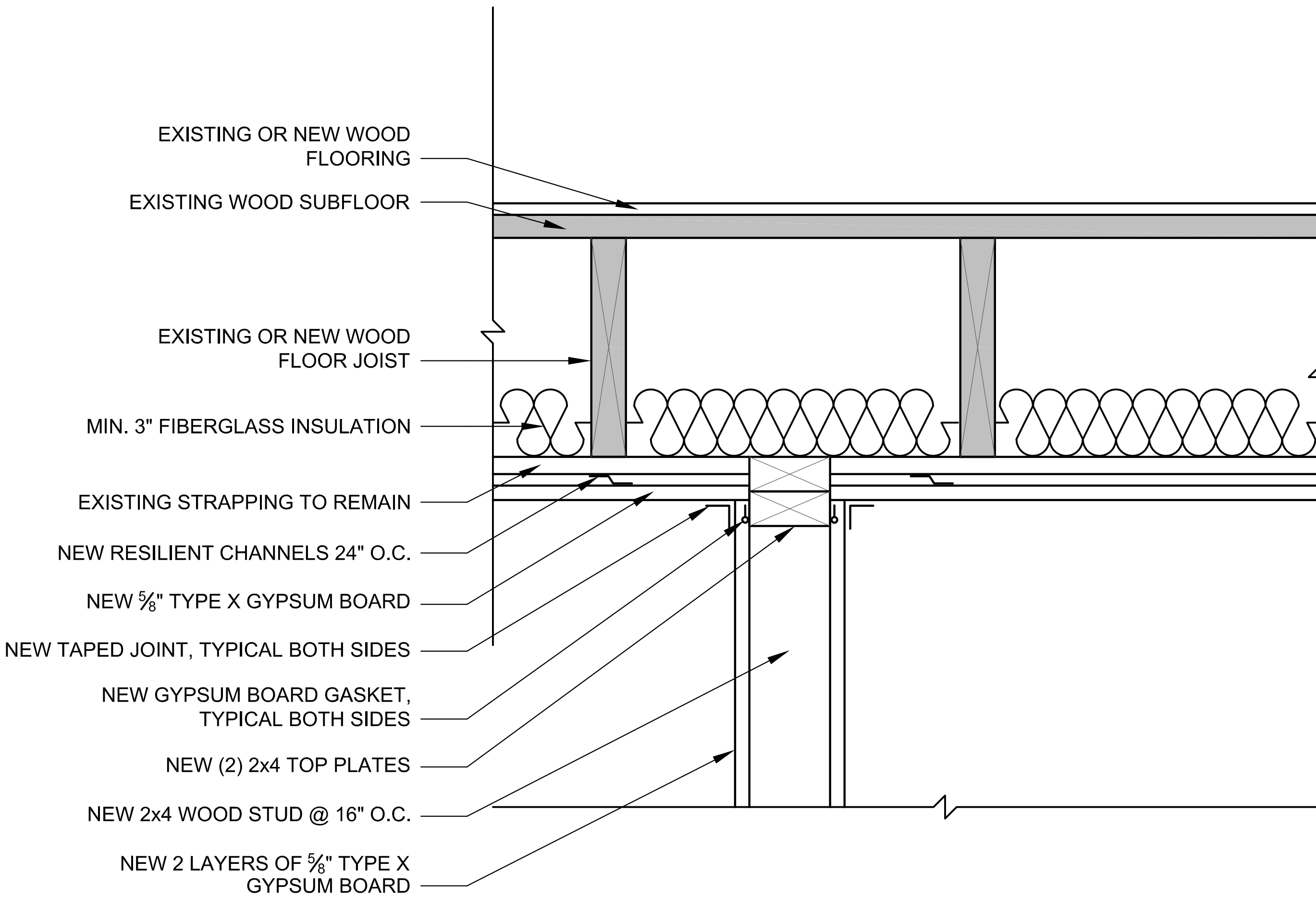
bsc with Building America U.S. Department of Energy Research Toward Zero Energy Homes

Merrimack Valley Habitat for Humanity
Wall Details

Date: 2012-02-06

Sheet Title:

W5



GRAY TONE INDICATES
EXISTING STRUCTURE

WALL - TYPICAL INTERIOR PARTITION - SECTION 3

SCALE: 3" = 1'-0"

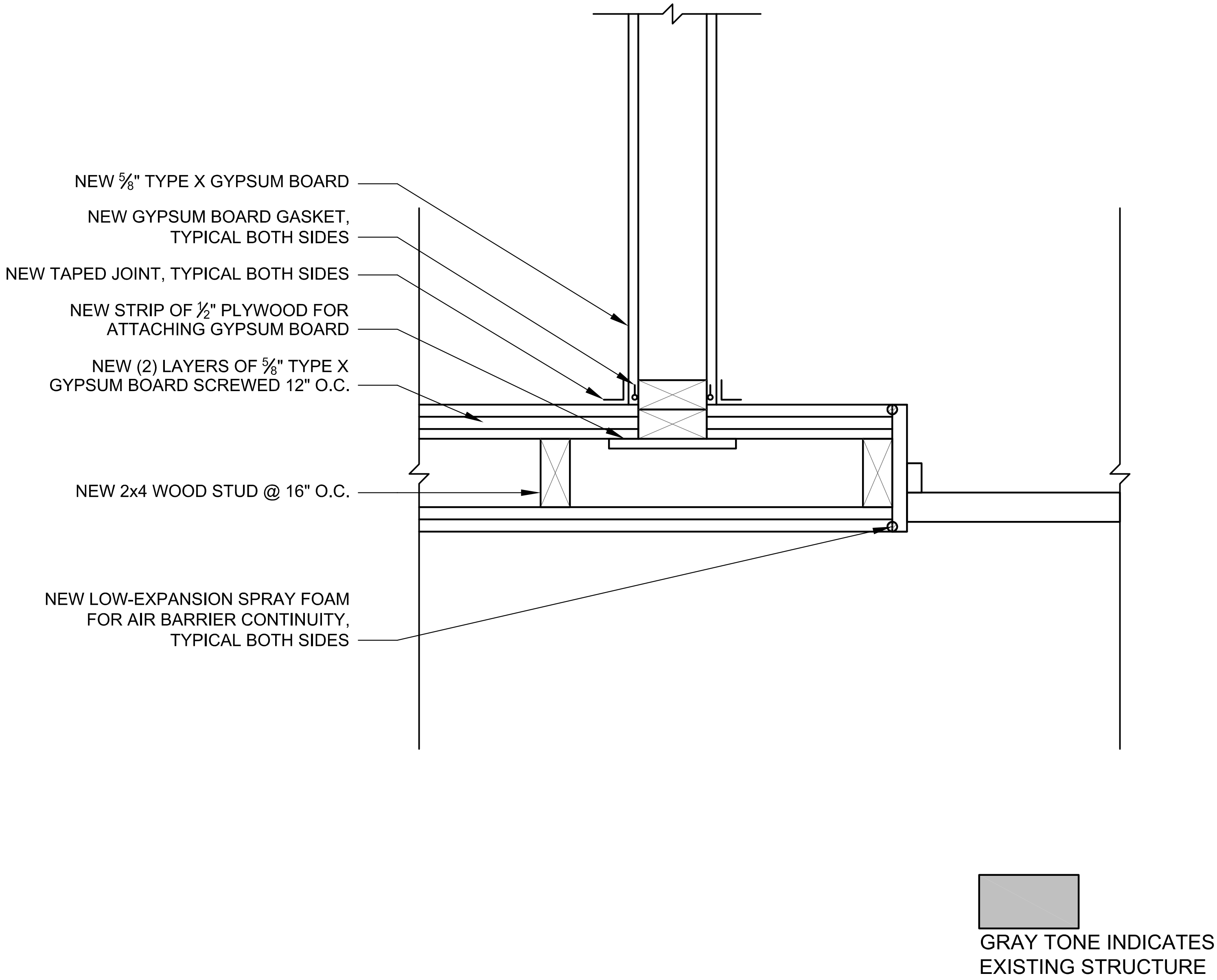
bsc with Building America U.S. Department of Energy Research Toward Zero Energy Homes

Merrimack Valley Habitat for Humanity
Wall Details

Date: 2012-02-06

Sheet Title:

W6



WALL - TYPICAL INTERIOR TO DEMISING PARTITION - PLAN

SCALE: 3" = 1'-0"

bsc with Building America U.S. Department of Energy Research Toward Zero Energy Homes

Merrimack Valley Habitat for Humanity
Wall Details

Date: 2012-02-06

Sheet Title:

W7

Air Barrier Strategy

Goals and principles of air barriers and compartmentalization

- Each unit should be airtight as possible to the outside
- Each unit should be isolated/airtight from another (“compartmentalization”)
- Each unit should be isolated/airtight from the corridor (“compartmentalization”)
- We are designating an airtight plane on “all six sides of the cube” (each unit)
    - Each plane needs to be made airtight as possible: it must be made of an airtight material, and penetrations through the air barrier layer must be sealed to the air barrier
    - Each plane needs to be connected to the adjacent plane in an airtight manner

Exterior wall air barrier (inside-to-outside)

- The XPS (extruded polystyrene) rigid foam insulation forms the air barrier at the exterior walls; the seams are taped at the outermost and innermost layers.
- Closed-cell spray foam is used to connect the XPS at difficult transitions (to window opening, portions of uneven surface brick, and the joist/floor areas (see sequence Details W1a and W1b).
- Windows and doors must be connected to the air barrier layer (see Details WS, WH, WJ)

Demising wall air barrier (unit-to-unit and unit-to-corridor)

- The surface of the gypsum board is the air barrier layer, on each side of the demising wall
- All penetrations through the gypsum board must be made airtight:
    - Electrical boxes should be airtight boxes, or alternately, caulked/sealed boxes
    - All mechanical and plumbing penetrations must be sealed to the gypsum board, where they penetrate through, on each side of the drywall
    - Door frames to each unit should be sealed to the gypsum board with low-expansion spray foam (Detail W7)
- Connections to the exterior wall as per Detail W3 (spray foam connection to XPS)
- Connections to the floor and ceiling air barrier to be done with caulk, sealant, or gaskets (Details W4, W5)
- Where the interior wall meets the demising wall, the air barrier must be "passed" through the framing (Detail W7)

Ceiling (gypsum board side) air barrier

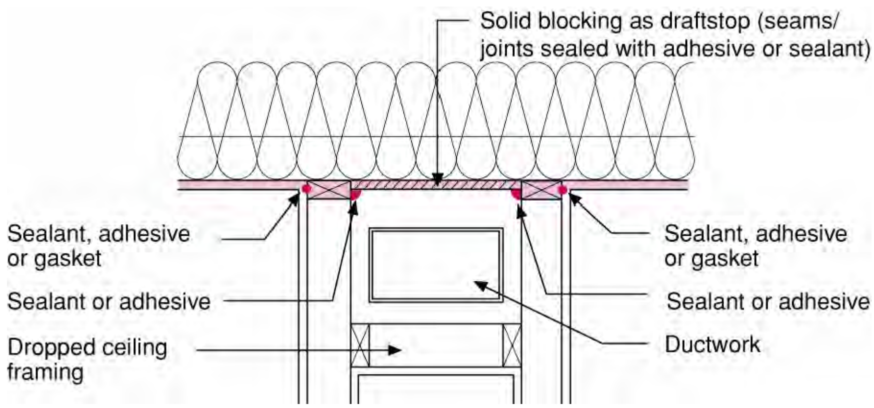
- Where the ceiling gypsum board is interrupted by partition wall framing, the air barrier must be “passed” through the framing (Detail W6)
- Any soffits must be built with the gypsum (or other air barrier) continuous behind the soffit (Detail A1)
- All penetrations through the gypsum board must be made airtight:
    - Electrical boxes should be airtight boxes, or alternately, caulked/sealed boxes (Detail A3)
    - All mechanical and plumbing penetrations must be sealed to the gypsum board, where they penetrate through, on each side of the drywall (Detail A3)
    - Attic hatch must be made airtight (Detail A2)

Floor (flooring side) air barrier

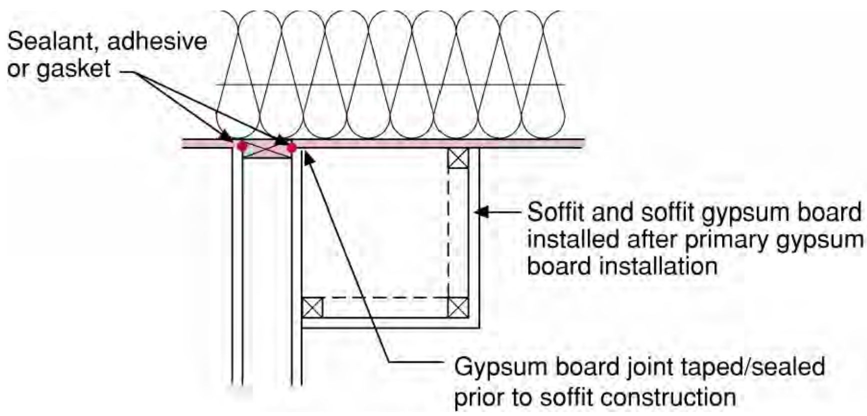
- All penetrations through the subfloor must be sealed (e.g., plumbing and wiring penetrations) (Detail A3)

AIR BARRIER STRATEGY

NOT TO SCALE



DROPPED CEILING



INTERIOR SOFFIT INSTALLED
AFTER GYPSUM BOARD INSTALLED

INTERIOR SOFFIT AND DROPPED CEILING AIR SEALING

NOT TO SCALE

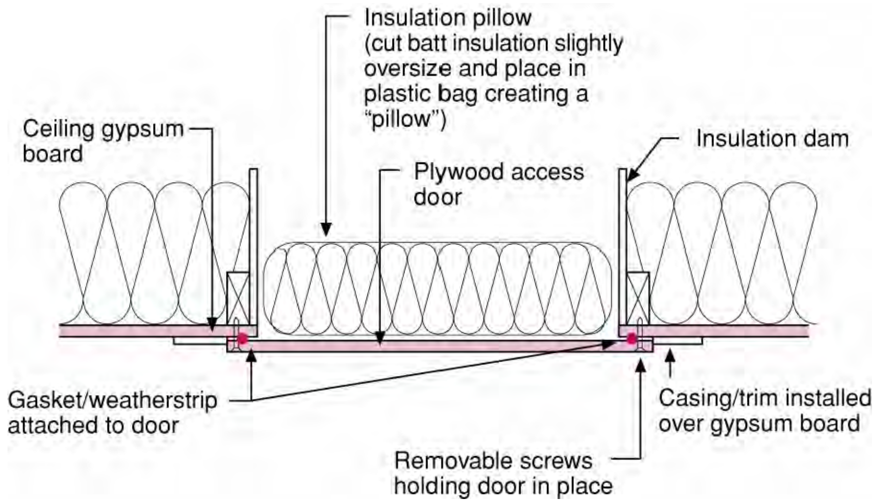
bsc with Building America U.S. Department of Energy Research Toward Zero Energy Homes

Merrimack Valley Habitat for Humanity
Air Sealing Details

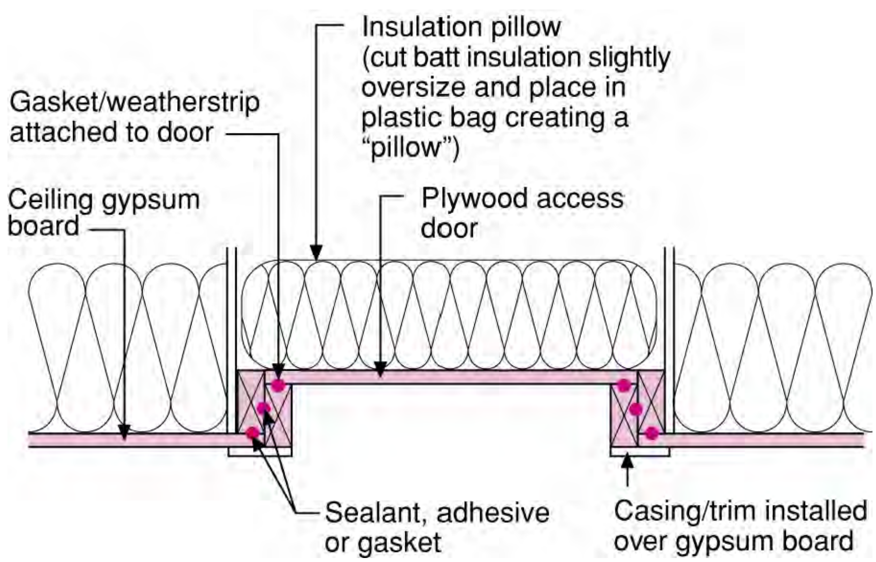
Date: 2012-02-06

Sheet Title:

A1



ATTIC ACCESS OR REMOVABLE COVER



ATTIC ACCESS VIA SCUTTLEHOLE

ATTIC ACCESS AIR SEALING

NOT TO SCALE

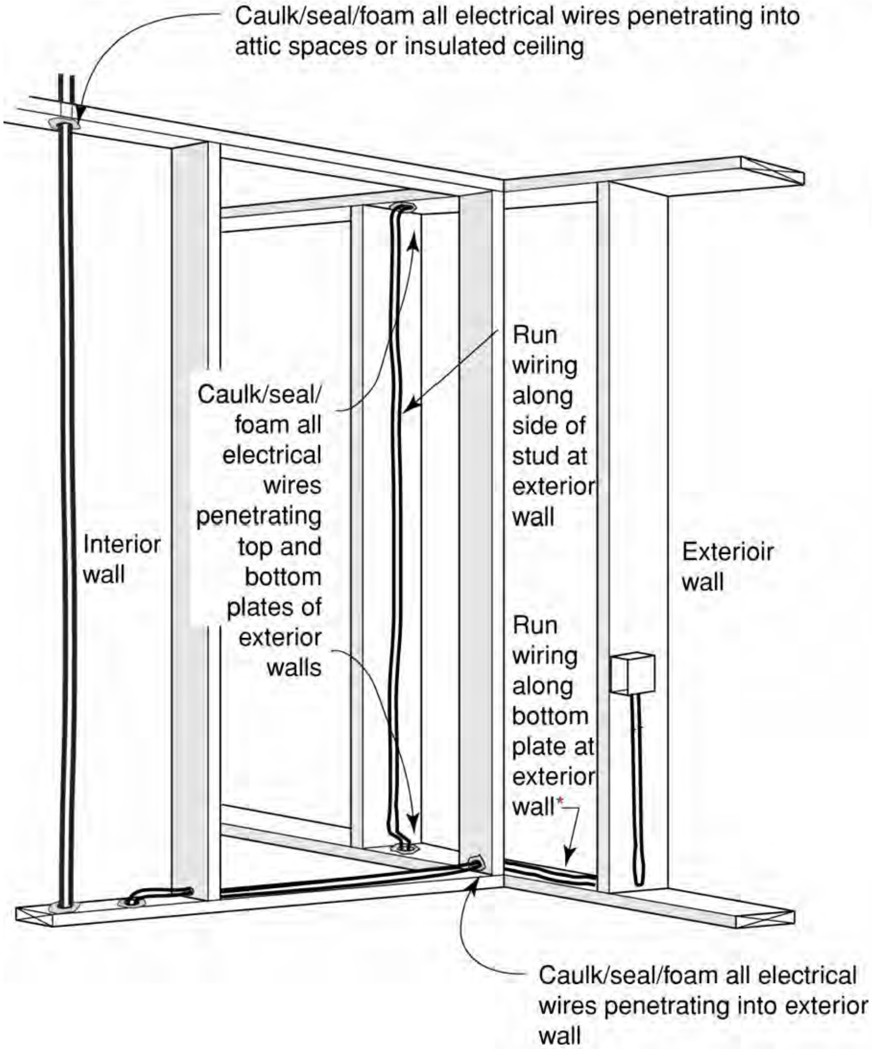
bsc with Building America U.S. Department of Energy Research Toward Zero Energy Homes

Merrimack Valley Habitat for Humanity
Air Sealing Details

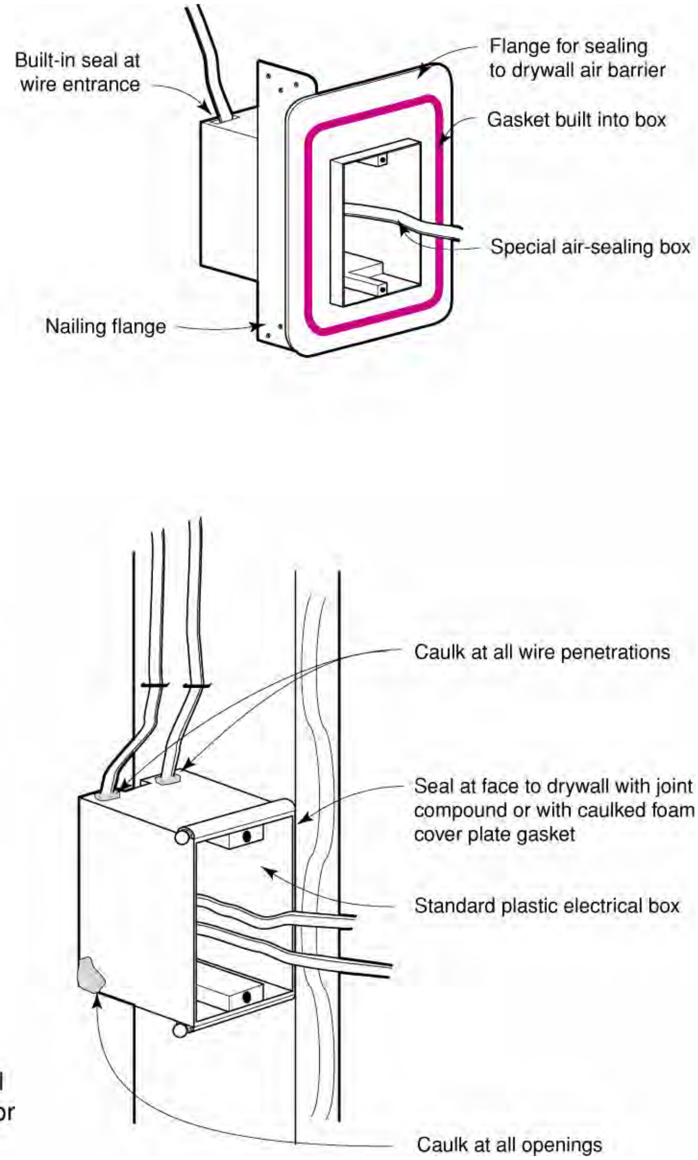
Date: 2012-02-06

Sheet Title:

A2



SEALING ELECTRICAL WIRES



ELECTRICAL BOXES
AT DEMISING WALLS

ELECTRICAL WIRES AND BOXES AIR SEALING

NOT TO SCALE

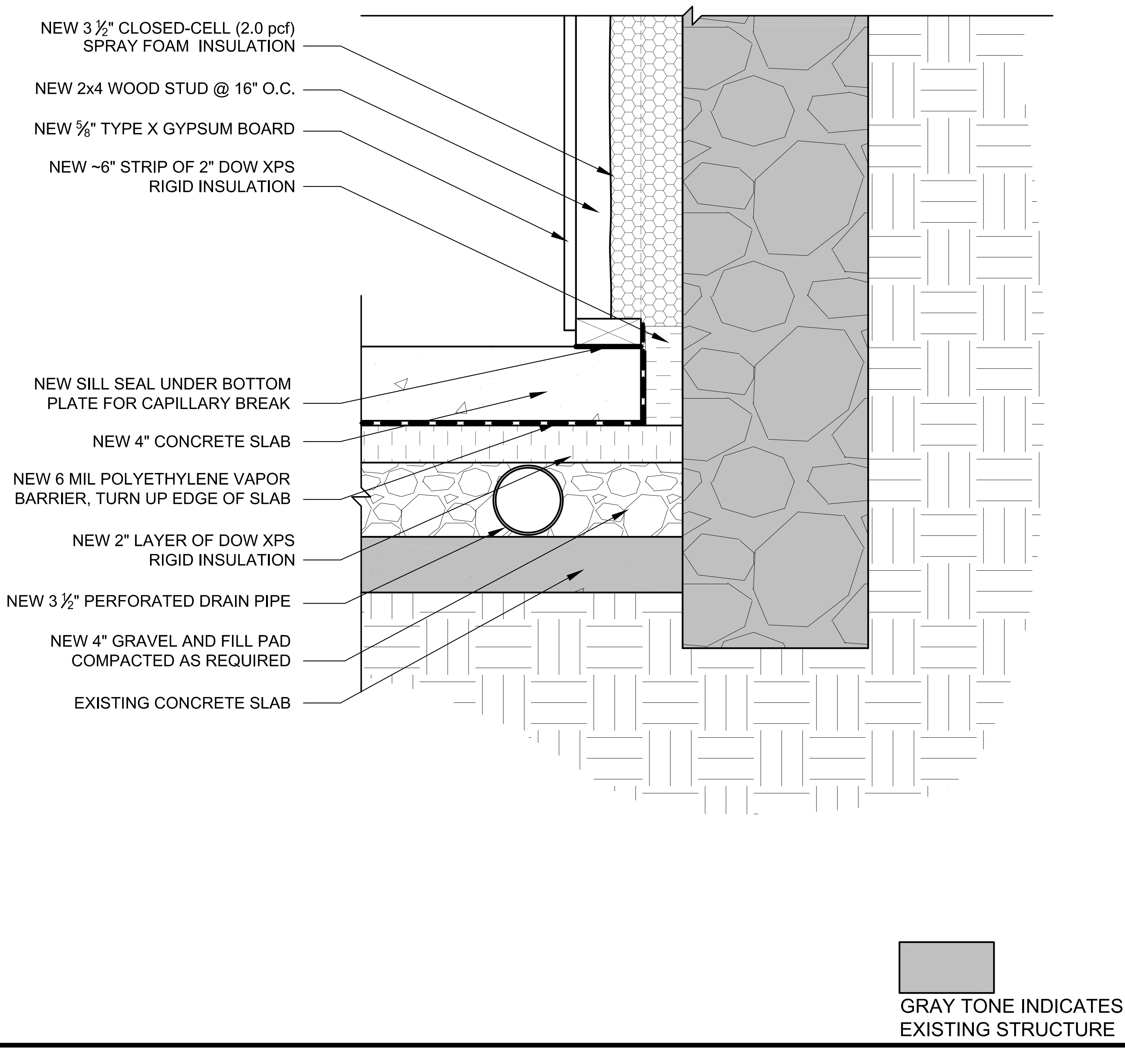
with Building America U.S. Department of Energy Research Toward Zero Energy Homes

Merrimack Valley Habitat for Humanity
Air Sealing Details

Date: 2012-02-06

Sheet Title:

A3



BASEMENT SLAB AND WALL 1

SCALE: 1 1/2" = 1'-0"

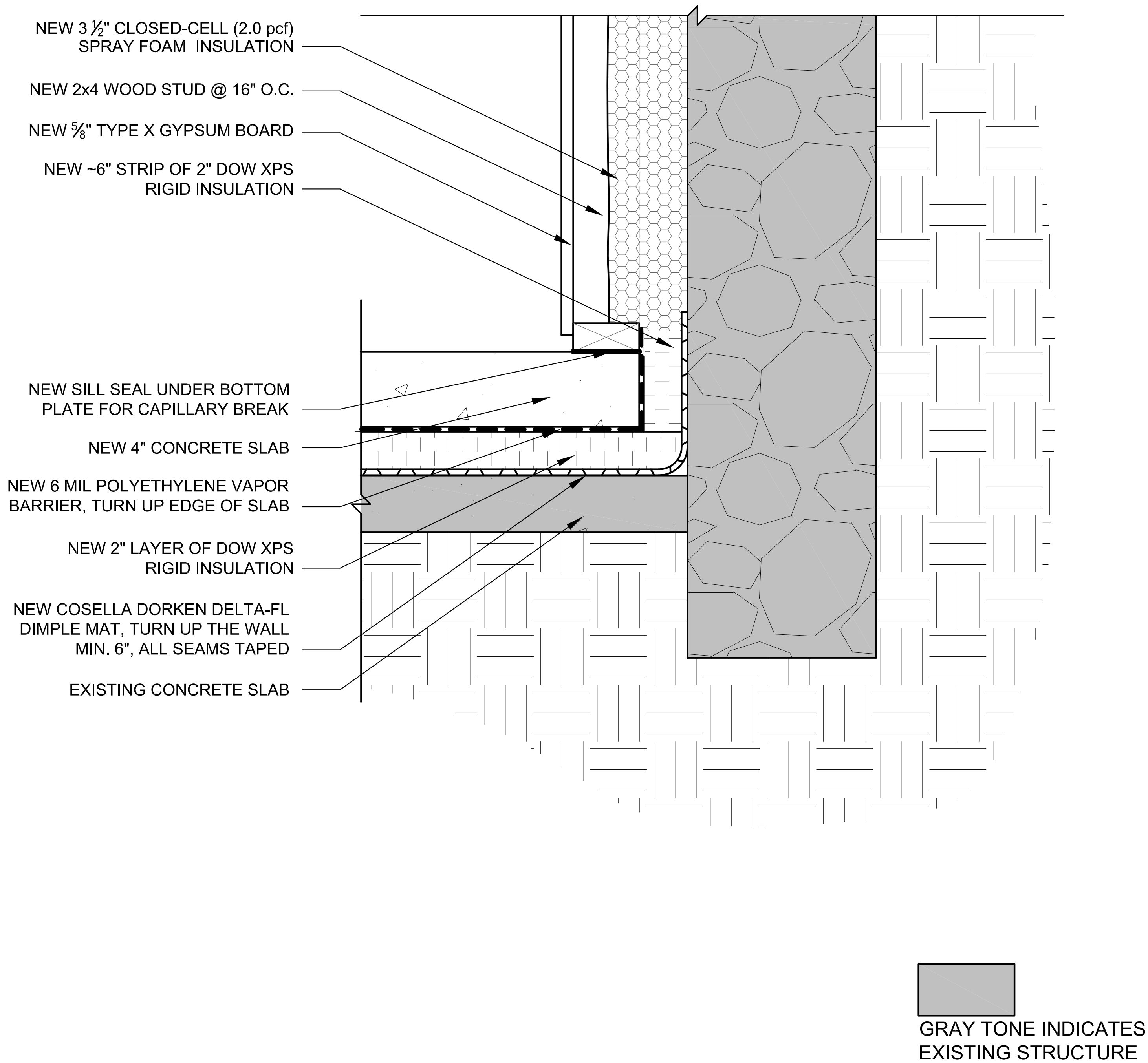
bsc with Building America U.S. Department of Energy Research Toward Zero Energy Homes

Merrimack Valley Habitat for Humanity
Basement Details

Date: 2012-06-26

Sheet Title:

B1



BASEMENT SLAB AND WALL 2

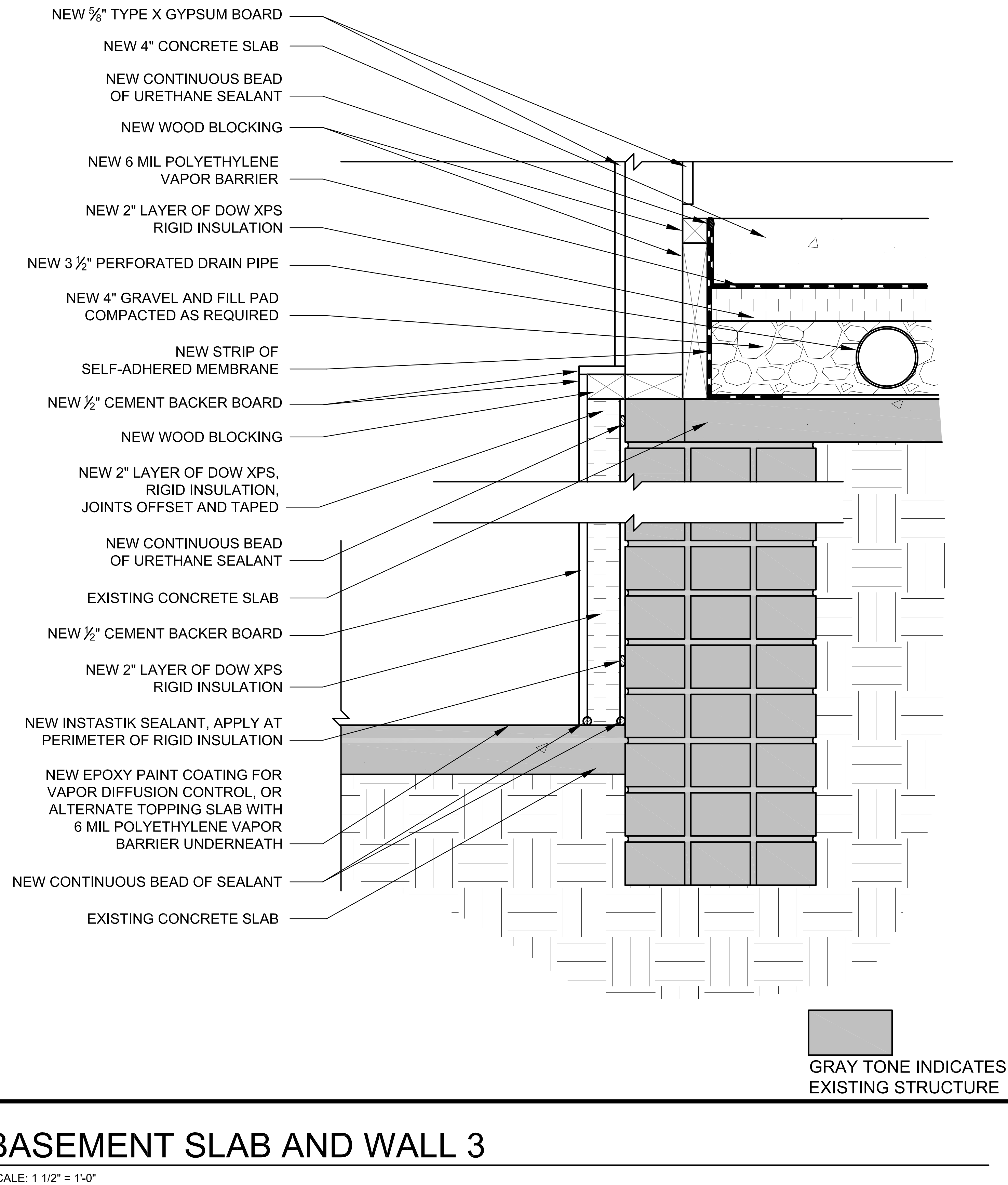
SCALE: 1 1/2" = 1'-0"

bsc with Building America U.S. Department of Energy Research Toward Zero Energy Homes

Merrimack Valley Habitat for Humanity
Basement Details

Date: 2012-06-26

Sheet Title: B2



BASEMENT SLAB AND WALL 3

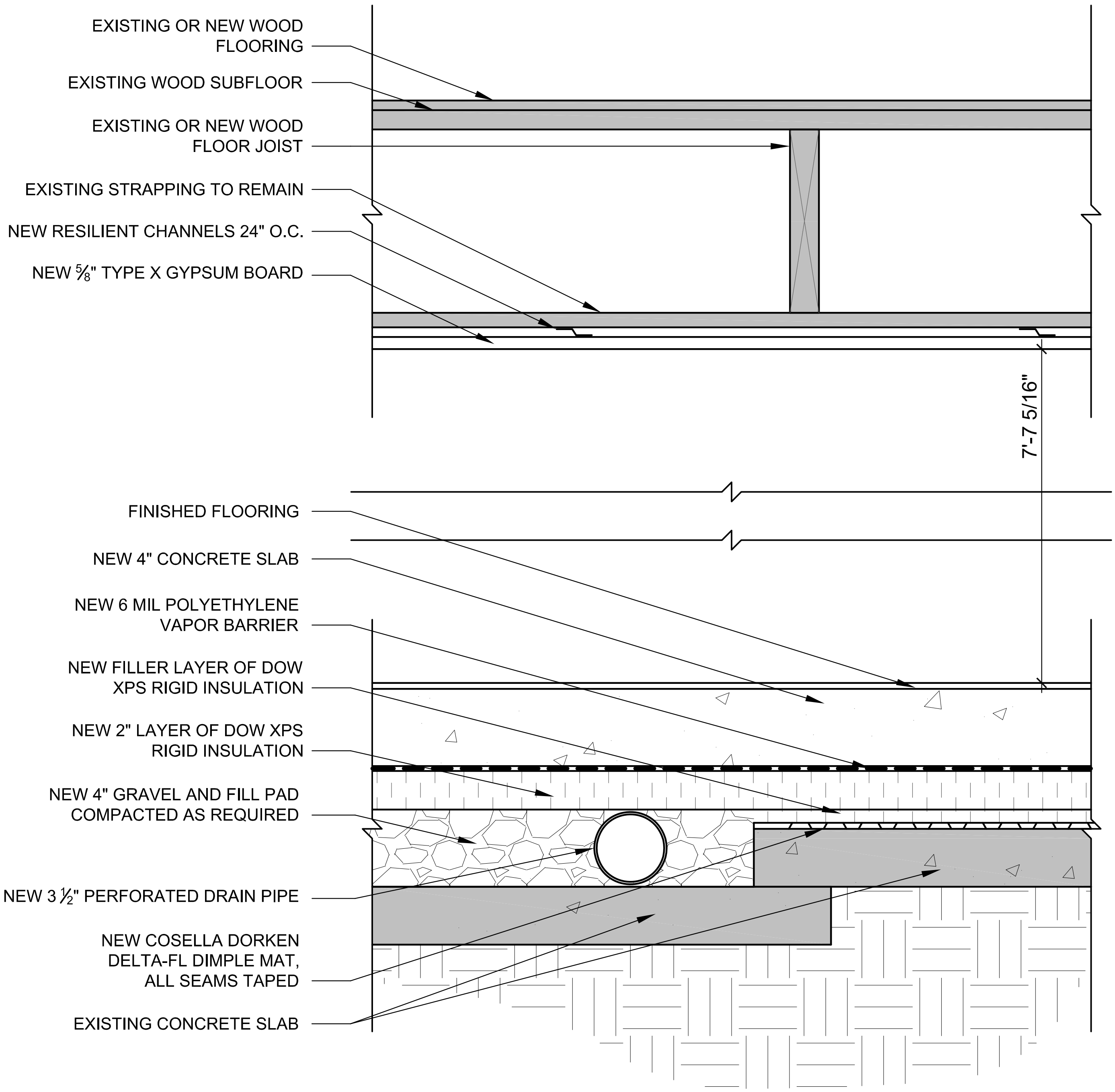
SCALE: 1 1/2" = 1'-0"

bsc with Building America U.S. Department of Energy Research Toward Zero Energy Homes

Merrimack Valley Habitat for Humanity
Basement Details

Date: 2012-06-26

Sheet Title: B3



GRAY TONE INDICATES EXISTING STRUCTURE

BASEMENT EXISTING AND NEW SLAB CONNECTION

SCALE: 1 1/2" = 1'-0"

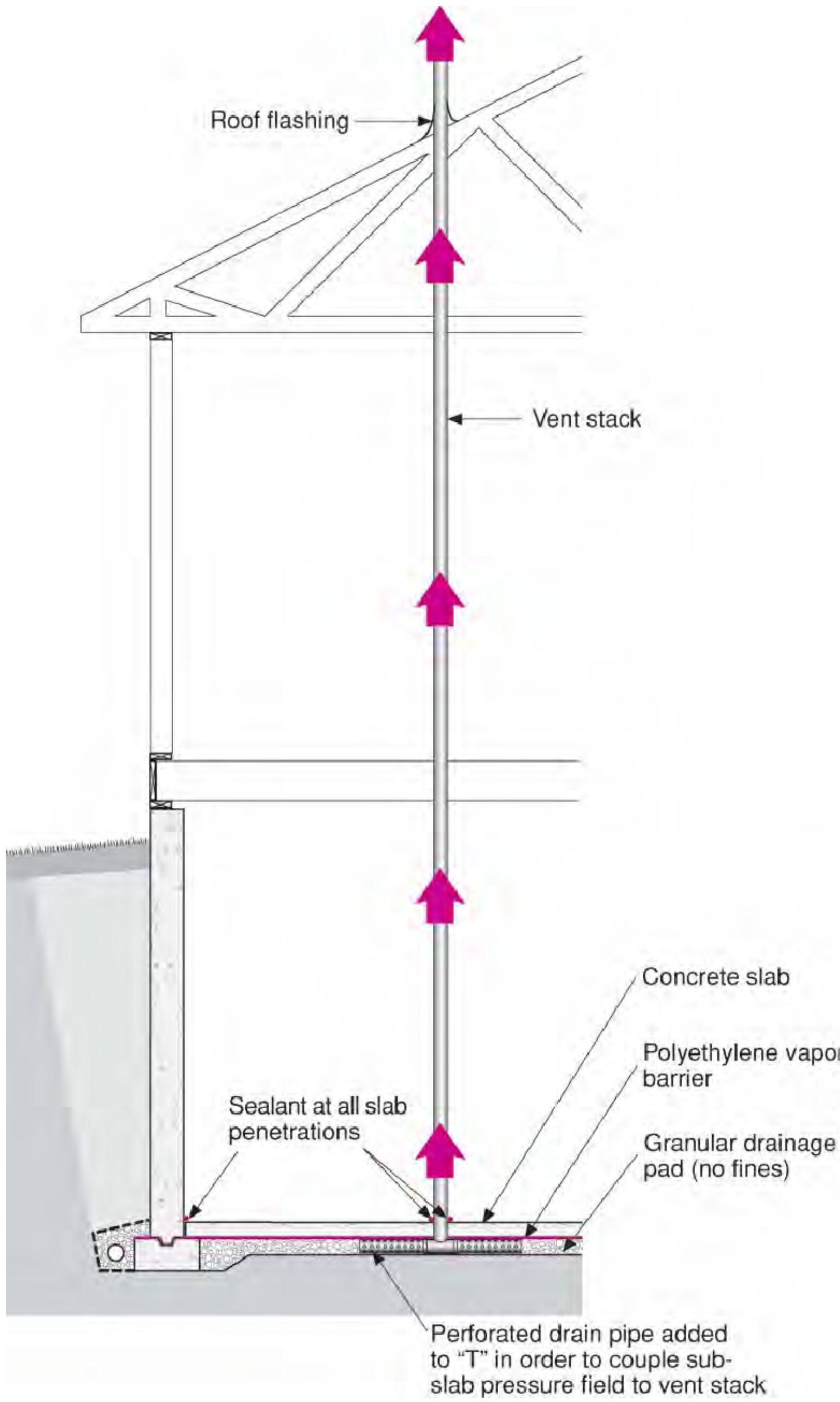
with

Merrimack Valley Habitat for Humanity
Basement Details

Date: 2012-06-26

Sheet Title:

B4



SOIL GAS VENT

SCALE: 1 1/2" = 1'-0"

bsc with Building America U.S. Department of Energy Research Toward Zero Energy Homes

Merrimack Valley Habitat for Humanity
Basement Details

Date: 2012-06-26

Sheet Title:

B5

Appendix C

MVHfH REM/Rate Energy Modeling Results

ENERGY STAR VERSION 2 HOME VERIFICATION SUMMARY

Date:	October 29, 2012	Rating No.:	
Building Name:	MV Habitat Convent	Rating Org.:	Advanced Building Analysis LLC
Owner's Name:	U=0.49 SHGC=0.60	Phone No.:	(978) 270-3911
Property:	100 Parker Street	Rater's Name:	Michael A. Browne
Address:	Lawrence, MA 01843	Rater's No.:	3992602
Builder's Name:	MV Habitat for Humanity		
Weather Site:	Lawrence, MA	Rating Type:	Based On Plans
File Name:	Convent Unit 2 - Design Spec.blg	Rating Date:	12/7/2011

Building Information

Conditioned Area (sq ft):	1398	Housing Type:	Apartment, end unit
Conditioned Volume (cubic ft):	12972	Foundation Type:	Conditioned basement
Insulated Shell Area (sq ft):	2841	HERS Index:	63 *****+
Number of Bedrooms:	3		

Building Shell

Ceiling w/Attic:	None	Window/Wall Ratio:	0.19
Vaulted Ceiling:	None	Window Type:	U:0.30, SHGC:0.30
Above Grade Walls:	R39,FG1,4-16,D U=0.031	Window U-Value:	0.300
Found. Walls (Cond):	MV Hab Convent Fnd R=20.0	Window SHGC:	0.300
Found. Walls (Uncond):	None	Infiltration:	Htg: 2.00 Clg: 2.00 ACH50
Frame Floors:	None	Duct Leakage to Outside:	NA
Slab Floors:	R10P,R10U,24W U=0.044	Total Duct Leakage:	NA

Mechanical Systems

Heating:	Fuel-fired hydronic distribution, 136.5 kBtuh, 91.0 % EFF.
Water Heating:	Instant water heater, Gas, 0.91 EF.
Programmable Thermostat:	Heat=No; Cool=No

Note: Where feature level varies in home, the dominant value is shown.

This home MEETS OR EXCEEDS the EPA's requirements for an ENERGY STAR Home.

REM/Rate - Residential Energy Analysis and Rating Software v12.96

ENERGY STAR VERSION 2 HOME VERIFICATION SUMMARY

Date:	October 29, 2012	Rating No.:	
Building Name:	MV Habitat Convent	Rating Org.:	Advanced Building Analysis LLC
Owner's Name:	U=0.49 SHGC=0.60	Phone No.:	(978) 270-3911
Property:	100 Parker Street	Rater's Name:	Michael A. Browne
Address:	Lawrence, MA 01843	Rater's No.:	3992602
Builder's Name:	MV Habitat for Humanity		
Weather Site:	Lawrence, MA	Rating Type:	Based On Plans
File Name:	Convent Unit 3 - Design Spec.blg	Rating Date:	12/8/2011

Building Information

Conditioned Area (sq ft):	940	Housing Type:	Apartment, end unit
Conditioned Volume (cubic ft):	9971	Foundation Type:	Apartment above conditioned space
Insulated Shell Area (sq ft):	1112	HERS Index:	60 *****+
Number of Bedrooms:	3		

Building Shell

Ceiling w/Attic:	None	Window/Wall Ratio:	0.27
Vaulted Ceiling:	None	Window Type:	U:0.30, SHGC:0.30
Above Grade Walls:	MV Hab Convent R30I U=0.029	Window U-Value:	0.300
Found. Walls (Cond):	None	Window SHGC:	0.300
Found. Walls (Uncond):	None	Infiltration:	Htg: 2.00 Clg: 2.00 ACH50
Frame Floors:	None	Duct Leakage to Outside:	NA
Slab Floors:	None	Total Duct Leakage:	NA

Mechanical Systems

Heating:	Fuel-fired hydronic distribution, 136.5 kBtuh, 91.0 % EFF.
Water Heating:	Instant water heater, Gas, 0.91 EF.
Programmable Thermostat:	Heat=No; Cool=No

Note: Where feature level varies in home, the dominant value is shown.

This home MEETS OR EXCEEDS the EPA's requirements for an ENERGY STAR Home.

ENERGY STAR VERSION 2 HOME VERIFICATION SUMMARY

Date:	October 29, 2012	Rating No.:	
Building Name:	MV Habitat Convent	Rating Org.:	Advanced Building Analysis LLC
Owner's Name:	U=0.49 SHGC=0.60	Phone No.:	(978) 270-3911
Property:	100 Parker Street	Rater's Name:	Michael A. Browne
Address:	Lawrence, MA 01843	Rater's No.:	3992602
Builder's Name:	MV Habitat for Humanity		
Weather Site:	Lawrence, MA	Rating Type:	Based On Plans
File Name:	Convent Unit 8 - Design Spec.blg	Rating Date:	12/8/2011

Building Information

Conditioned Area (sq ft):	1384	Housing Type:	Apartment, end unit
Conditioned Volume (cubic ft):	12444	Foundation Type:	Apartment above conditioned space
Insulated Shell Area (sq ft):	2736	HERS Index:	48 *****+
Number of Bedrooms:	3		

Building Shell

Ceiling w/Attic:	None	Window/Wall Ratio:	0.12
Vaulted Ceiling:	MV Habi Convent Flat U=0.016	Window Type:	U:0.30, SHGC:0.30
Above Grade Walls:	MV Hab Convent R30I U=0.029	Window U-Value:	0.300
Found. Walls (Cond):	None	Window SHGC:	0.300
Found. Walls (Uncond):	None	Infiltration:	Htg: 2.00 Clg: 2.00 ACH50
Frame Floors:	None	Duct Leakage to Outside:	NA
Slab Floors:	None	Total Duct Leakage:	NA

Mechanical Systems

Heating:	Fuel-fired hydronic distribution, 136.5 kBtuh, 91.0 % EFF.
Water Heating:	Instant water heater, Gas, 0.91 EF.
Programmable Thermostat:	Heat=No; Cool=No

Note: Where feature level varies in home, the dominant value is shown.

This home MEETS OR EXCEEDS the EPA's requirements for an ENERGY STAR Home.

REM/Rate - Residential Energy Analysis and Rating Software v12.96

This information does not constitute any warranty of energy cost or savings.

ENERGY STAR VERSION 2 HOME VERIFICATION SUMMARY

Date:	October 29, 2012	Rating No.:	
Building Name:	MV Habitat Convent	Rating Org.:	Advanced Building Analysis LLC
Owner's Name:	U=0.49 SHGC=0.60	Phone No.:	(978) 270-3911
Property:	100 Parker Street	Rater's Name:	Michael A. Browne
Address:	Lawrence, MA 01843	Rater's No.:	3992602
Builder's Name:	MV Habitat for Humanity		
Weather Site:	Lawrence, MA	Rating Type:	Based On Plans
File Name:	Convent Unit 9 - Design Spec.blg	Rating Date:	8/31/2011

Building Information

Conditioned Area (sq ft):	1127	Housing Type:	Apartment, end unit
Conditioned Volume (cubic ft):	12084	Foundation Type:	Apartment above conditioned space
Insulated Shell Area (sq ft):	2443	HERS Index:	53 *****+
Number of Bedrooms:	3		

Building Shell

Ceiling w/Attic:	None	Window/Wall Ratio:	0.13
Vaulted Ceiling:	MVH Convent Cath U=0.034	Window Type:	U:0.30, SHGC:0.30
Above Grade Walls:	MV Hab Convent R30I U=0.029	Window U-Value:	0.300
Found. Walls (Cond):	None	Window SHGC:	0.300
Found. Walls (Uncond):	None	Infiltration:	Htg: 2.00 Clg: 2.00 ACH50
Frame Floors:	None	Duct Leakage to Outside:	NA
Slab Floors:	None	Total Duct Leakage:	NA

Mechanical Systems

Heating:	Fuel-fired hydronic distribution, 136.5 kBtuh, 91.0 % EFF.
Water Heating:	Instant water heater, Gas, 0.91 EF.
Programmable Thermostat:	Heat=No; Cool=No

Note: Where feature level varies in home, the dominant value is shown.

This home MEETS OR EXCEEDS the EPA's requirements for an ENERGY STAR Home.

REM/Rate - Residential Energy Analysis and Rating Software v12.96

This information does not constitute any warranty of energy cost or savings.

Appendix D

MVHfH Mechanical Design

LEGEND	
TANDEM TRANSITION DUAL EXTERIOR HOOD	
HIGH WALL SUPPLY REGISTER	
CEILNG SUPPLY REGISTER	
HIGH WALL RETURN REGISTER	
CEILING RETURN REGISTER	
HRV BOOSTER PUSHBUTTON	S
BASEBOARD X = LINEAR FEET	X LF HE2
BOILER FLUE	

GENERAL NOTES:

1. PERFORM WORK IN ACCORDABCE WITH THE MASSACHUSETTS BUILDING CODE AND LOCAL ORINANCES.

2. ALL EQUIPMENT AND MATERIALS SHALL BE APPROVED BY THE ENGINEER PRIOR TO PURCHASE.

3. THE VENTILATION SYSTEM DESIGN PRESENTED ON THESE PLANS IS BASED ON THE USE OF DUCTLESS CLOTHES DRYERS IN THE BUILDING. DUCTED CLOTHES DRYERS SHALL NOT BE INSTALLED WITHOUT A FULL RE-DESIGN OF THE VENTILATION SYSTEM.

BASIS OF DESIGN:

DILUTION VENTILATION

EACH APARTMENT UNIT SHALL BE ISOLATED AND AIRTIGHT FROM ANOTHER UNIT AND THE CORRIDOR.

EACH APARTMENT AND THE COMMON AREAS SHALL HAVE A SMALL HEATING RECOVERY VENTILATOR (HRV) THAT WILL BE WALL HUNG IN A MECHANICAL CLOSET. THE HRV WILL OPERATE CONTINUOUSLY IN LOW SPEED (~40 CFM FOR THE APARTMENTS AND 175 CFM IN THE COMMON SPACES) TO MEET THE RESIDENTIAL VENTILATION RATES AS MANDATED BY ASHRAE STANDARD 62.2 AND THE INTERNATIONAL MECHANICAL CODE. A 150 CFM INLINE FAN WILL BE INSTALLED ON THE FIRST FLOOR MEETING ROOM AND WILL OPERATED WITH A WALL MOUNTED SWITCH.

POINT SOURCE VENTILATION

A WALL MOUNTED TIMER SHALL BE INSTALLED IN EACH BATHROOM THAT WILL ALLOW AN OCCUPANT TO INTERMITTENTLY BOOST THE HRV FLOW INTERMITTENLY.

THE KITCHEN EXHAUST SHALL BE CONNECTED TO ONE OF THREE COMMON RISERS. ROOF MOUNTED VARIABLE SPEED DIRECT DRIVE FANS WILL EXHAUST AND SHALL BE OPERATED BY A CONTROLLER THAT DETECTS PRESSURE CHANGES IN THE RISER DUCT AND ADJUSTS THE FAN SPEED. A SUBDUCT RISER SHALL BE INSTALLED AT THE ROUND DUCT KITCHEN HOOD / COMMON RISER JUNCTION TO MAINTAIN THE FIRE RATED INTEGRITY OF THE RISER.

THE DUCTWORK SHALL BE MADE OF SHEET METAL AND SHALL BE LOCATED ENTIRELY IN CONDITIONED SPACE IN A SYSTEM OF DROPPED CEILINGS WITH SOME RUNS LOCATED IN FLOOR JOISTS OR UNVENTED ATTIC SPACE. ANY DUCTWORK LOCATED IN FLOOR JOISTS AND UNVENTED ATTIC SPACE WILL NEED TO BE WRAPPED IN A FIRE RATED DUCT WRAP.

THE HRV OUTSIDE DUCTS FOR UNITS 1-7 AND THE COMMON AREAS SHALL PENETRATE THE MASONRY WALL WITH A DUAL EXTERIOR HOOD. THIS WILL ALLOW BOTH DUCTS TO BE ROUTED THROUGH A SINGLE PENETRATION. THE HRV OUTSIDE DUCTS FOR UNITS 8-10 SHALL BE ROUTED SEPARETLY THROUGH THE ROOF.

HYDRONIC HEATING

ROOM BY ROOM MANUAL J8 CALCULATIONS HAVE BEEN PERFORMED FOR EACH APARTMENT AND THE COMMON AREAS. THE HEATING LOAD FOR EACH APARTMENT IS AROUND 11-16 KBTUH.

EACH UNIT SHALL HAVE A WALL HUNG MODULATING HIGH EFFIENCY CONDENSING BOILER. THE BOILER SHALL HAVE SEPARATE TAPS FOR BOTH HYDRONIC AND DOMESTIC HOT WATER.

THE TERMINATIONS SHALL BE A HIGH OUTPUT TWO-PIPE BASEBOARD.

THE DISTRIBUTION SYSTEM SHALL BE A PRIMARY/SECONDARY LOOP PIPE INSTALLATION. THE PRIMARY LOOP WILL BE OPERATED WITH A PUMP THAT IS INTEGRATED IN THE BOILER. THE SECONDARY LOOP SHALL HAVE VARIABLE SPEED CONFIGURABLE CIRCULATOR THAT WILL ALLOW FOR THE INSTALLER TO ADJUST THE FLOW SETTINGS DURING SYSTEM COMMISSIONING.

A STAINLESS STEEL MANIFOLD WITH BALANCING VALVES AND FLOW METERS/ISOLATIONS VALVES SHALL BE INSTALLED AT THE SECONDARY LOOP. HOMERUN PEX PIPING WILL BE CONNECTED TO EACH BASEBOARD.

INSTALLATION NOTES:

1. INSTALL BOILERS, CONFIGURE BOILER CONTROLS AND START-UP BOILERS IN STRICT ACCORDANCE WITH BOILER MANUFACTURER INSTRUCTIONS.

2. THE FLOOR OF EACH MECHANICAL CLOSET SHALL BE FITTED WITH A FULL SIZE DRIP PAN WITH PLUMBED DRAIN. PAN SHALL BE MIN 0.0276" THICK GALVANIZED STEEL, 0.032" THICK ALUMINUM OR 0.0625" THICK PLASTIC. HGT SHALL BE MIN 1-1/2" WITH ROLLED EDGE.

3. PROVIDE FLEXIBLE PIPE CONNECTORS AT PUMPS. ??

4. ADJUST CALIBRATED BALANCING VALVES AT EACH PUMP TO OBTAIN INDICATED FLOW RATE.

5. HEAT TRANSFER FLUID IS PLAIN WATER (NO GLYCOL).

6. FLEXIBLE DUCT SHALL NOT BE PERMITTED.

7. SEAL ALL DUCTWORK SMOKE-TIGHT.

8. PROVIDE DUCT ACCESS DOOR EVERY 25 FEET IN FRESH AIR DUCTS AND BATHROOM EXHAUST DUCTS. DUCT ACCESS DOORS SHALL BE MINIMUM 6" X 6".

9. INSULATE ALL FRESH AIR DUCTWORK (INCLUDING FRESH AIR DUCTWORK IN SPACES ABOVE CEILINGS) TO R-8. INSULATE ALL HOT AND COLD WATER PIPING. ALLOW MIN 2" CLEARANCE BETWEEN INSULATED PIPING, INSULATED DUCTWORK, AND OTHER BUILDING COMPONENTS.

10. BOILER FLUE PIPING SHALL NOT EXCEED 100 FEET EQUIVALENT STRAIGHT LENGTH PER BOILER. BOILER COMBUSTION AIR PIPING SHALL NOT EXCEED 100 FEET EQUIVALENT STRAIGHT LENGTH PER BOILER. 90 DEG ELBOW = 5 FEET, 45 DEG ELBOW = 3 FEET, CONCENTRIC VENT KIT = 3 FEET. HORIZONTAL BOILER FLUE PIPING SHALL PITCH UP 1/4 INCH PER FOOT AWAY FROM BOILER. SUPPORT BOILER FLUE AND COMBUSTION AIR PIPING 5 FEET ON CENTER.

11. INSTALL ALL PIPING AND DUCTWORK TO MAINTAIN MAXIMUM HEADROOM.

12. FIELD MEASURE SPACES BEFORE ORDERING FINNED TUBE RADIATION.

EQUIPMENT SPECIFICATIONS (FORCED HOT WATER SYSTEM)

FINNED TUBE RADIATION (FTR)
SMITHS ENVIRONMENTAL HEATING EDGE HE2 BASEBOARD
589 BTU/HR/FT @ 120 DEG F EWT
TWO SUPPLIES PARALLEL PIPE CONFIGURATION
3/4" COPPER TUBE/ALUMINUM FIN

EXPANSION TANK ET-1 (APARTMENTS)
WATTS REGULATOR MODEL ET-15
NON-POTABLE WATER, 60 PSIG CWP
MINIMUM ACCEPTANCE VOLUME = 1.0 GALLONS

EXPANSION TANK ET-2 (COMMON AREAS)
WATTS REGULATOR MODEL ET-30
NON-POTABLE WATER, 60 PSIG CWP
MINIMUM ACCEPTANCE VOLUME = 2.5 GALLONS

AIR SEPARATOR
WATTS REGULATOR MODEL AS-MB, 1" SIZE

AUTOMATIC AIR VENT
WATTS REGULATOR "DUOVENT"

PRESSURE REDUCING VALVE/BACKFLOW PREVENTER
WATTS 911S COMBINATION FILL VALVE/BACKFLOW PREVENTER

TEMPERATURE/PRESSURE GAUGE
WATTS MODEL 705100
60 TO 320 DEG F, 0 TO 200 PSI

MANIFOLD
WATTS FLOWMETER MANIFOLD
STAINLESS STEEL, 1" WITH TRUNK ISO KIT

BOILERS B-1 (APARTMENTS AND COMMON AREA)
NAVIEN MODEL CH-180
NAT. GAS-FIRED MODULATING CONDENSING
COMBINATION WATER HEATER/BOILER
150 MBH MAX / 17 MBH MIN INPUT,
120 DEG F HWS*, 100 DEG F HWR, 5 GPM
120 DEG F DOMESTIC HOT WATER*
* CONTROLLED PARAMETER
SPECIFY OUTDOOR RESET??

FTR SYSTEM PUMP P-1 (APARTMENTS)
GRUNDFOS ALPHA 15-55F, 3/4" FLANGE
CAST IRON CASING, INTEGRAL FLOW CHECK
115/1/60

DOMESTIC HOT WATER LOOP
PRESSURE RELIEF VALVE:
WATTS REGULATOR 3L(M7), 150 PSIG

HYDRONIC SPACE HEATING LOOP
PRESSURE RELIEF VALVE:
WATTS REGULATOR 374A, 30 PSIG

PRESSURE RELIEF VALVE:
WATTS REGULATOR 374A, 30 PSIG

PIPING SPECIFICATIONS:

1. WATER PIPE AND FITTINGS - WATTS WATERPEX WPFP08 WITH WATTS PEX FITTING. MORE DETAIL NEEDED?

2. BALL VALVE - WATTS REGULATOR, BRASS OR BRONZE, FULL PORT, STAINLESS STEEL BALL.

3. BALANCING VALVE - WATTS REGULATOR CSM-61, LINE SIZE

4. STRAINER - WATTS REGULATOR, WYE TYPE, BRASS OR BRONZE

5. IN-LINE ACID NEUTRALIZER
JJM BOILER WORKS MODEL JM-2, 1/2"

6. FLUE GAS CONDENSATE DRAIN PIPING - ASTM D-1785, SCHEDULE 40, SOCKET WELDED, POLYVINYL CHLORIDE (PVC) PLASTIC PIPE AND FITTINGS.

7. BOILER FLUE PIPING AND COMBUSTION AIR PIPING - ASTM F-441, SCHEDULE 40, SOCKET WELDED, CHLORINATED POLYVINYL CHLORIDE (CPVC) PLASTIC PIPE AND FITTINGS.
CELLULAR (FOAM) CORE PLASTIC PIPE SHALL NOT BE PERMITTED.

EQUIPMENT SPECIFICATIONS (VENTILATION SYSTEM)

APARTMENT HEAT RECOVERY VENTILATOR (HRV) HRV-1
FANTECH FLEX 100H
ALUMINUM HEAT RECOVERY CORE
2 EBM MOTORS WITH RADIAL CURVED BLADES
INTERNAL RECIRCULATION DEFROST
2 WASHABLE ELECTROSTATIC AIR FILTERS

COMMON AREA HEAT RECOVERY VENTILATOR (HRV) HRV-2
FANTECH VHR 2005R
ALUMINUM HEAT RECOVERY CORE
2 EBM MOTORS WITH RADIAL CURVED BLADES
INTERNAL RECIRCULATION DEFROST
2 WASHABLE ELECTROSTATIC AIR FILTERS

MEETING ROOM EXHAUST FAN EX-1
MR. WHISPER (SUPPLIED BY HABITAT)

KITCHEN HOOD KH-1
BROAN MODEL QSE1 SERIES, ALLURE - ENERGY STAR RATED
2-SPEED, 6" DUCT
INTEGRATED BACKDRAFT DAMPER
140 CFM AT NORMAL SPEED
220 CFM AT MAXIMUM SPEED
1.8 AMPS, 120/1/60

KITCHEN EXHAUST SYSTEMS
GREENHECK GREENVENT SYSTEM
VARI-GREEN CONSTANT PRESSURE CONTROL
MODEL CUE-090-VG EXHAUST FAN, DIRECT DRIVE UPBLAST
WITH GPI ROOF CURB
STACK 1 - 400 CFM, STACKS 2 & 3 - 300 CFM EACH
1/4 HP, 120/1/60

SUBDUCT RISER
EXHAUSTO SDR 06
6" DUCT CONNECTION
26 GAUGE GALVANIZED STEEL

HRV ROOF TERMINATION
AMERICAN ALDES MODEL RCR 22 436
12" EXTENSION

HRV WALL TERMINATION
VENMAR TANDEM TRANSITION

DUCTWORK SPECIFICATIONS:

1. ALL DUCTWORK SHALL BE CONSTRUCTED OF G26 GALVANIZED STEEL. DUCTWORK SHALL BE FABRICATED IN ACCORDANCE WITH THE 2009 INTERNATIONAL RESIDENTIAL CODE AND ENERGY STAR VERSION 3.

2. ALL DUCTWORK SHALL HAVE SMOOTH TRANSITIONS. ALL SEAMS AND JOINTS SHALL BE FULLY AIRSEALED WITH A BRUSH APPLIED MASTIC (RCD MASTICS #6 OR APPROVED EQUIVALENT) TO A MINIMUM THICKNESS OF 60 MILS.

3. DUCT INSULATION - ALL OUTSIDE DUCTS (TWO PER HRV) SHALL BE INSULATED. DUCT INSULATION SHALL BE FIBERGLASS WITH PSK FACING AND RATED R-8.

4. ALL DUCT SYSTEMS SHALL BE PERFORMACE TESTED PER ENERGY STAR VERSION 3 PROTOCOL AND ACCA STANDARD 9 HVAC QUALITY INSTALLATION VERIFICATION PROTOCOLS.

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	05/30/12	HRV DUCT LAYOUT DRAFT
MARK	DATE	DESCRIPTION
ISSUE:	08/17/12	PLUMBER HYDRONIC REVIEW

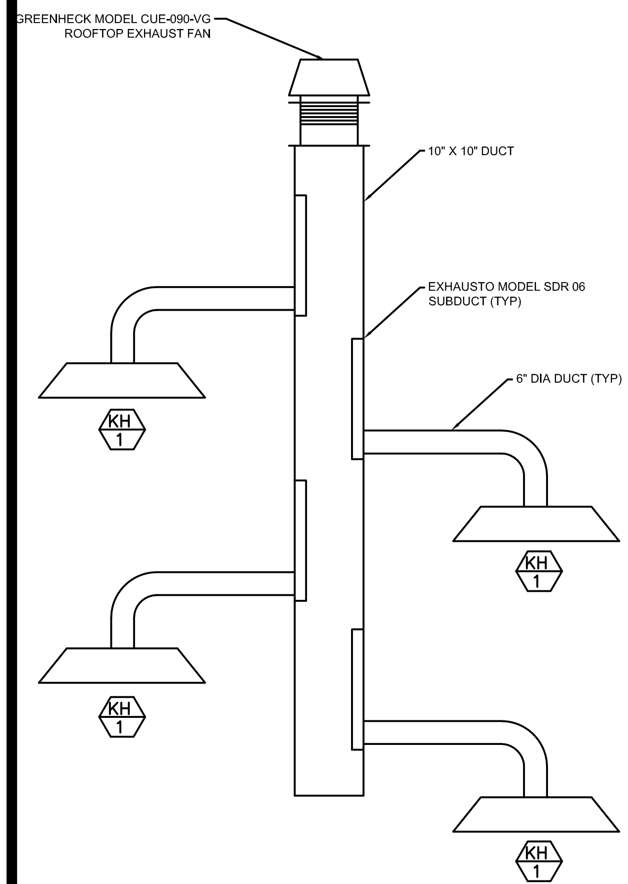
PROJECT NO:
CAD DWG FILE: MVHfH HVAC_BSC.dwg
DRAWN BY: P KERRIGAN
CHECKED BY:

SHEET TITLE:

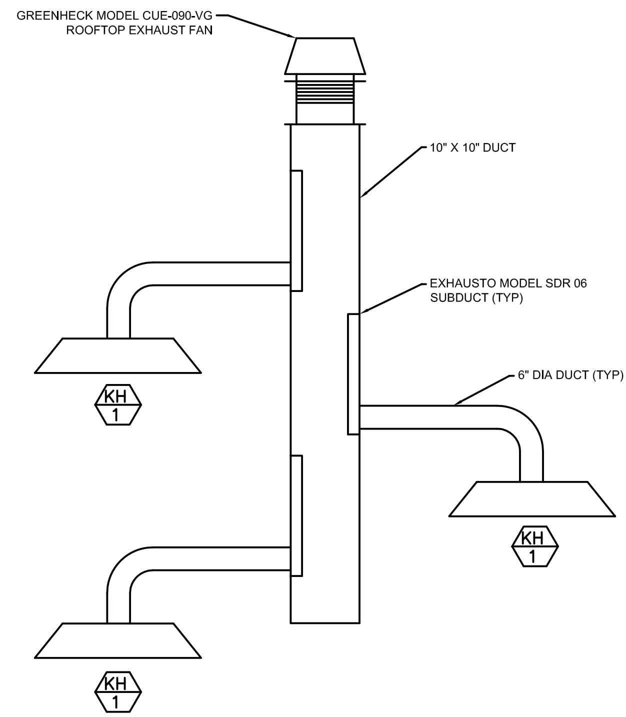
GENERAL NOTES
HVAC DESIGN

SCALE AS NOTED

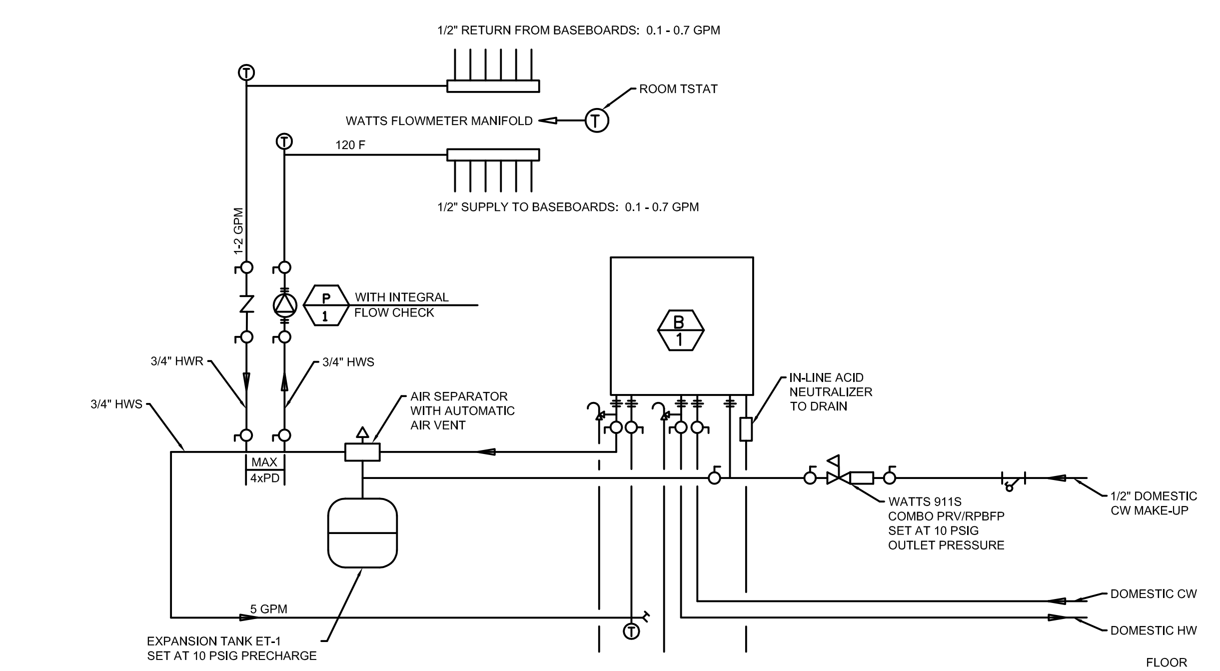
M-0



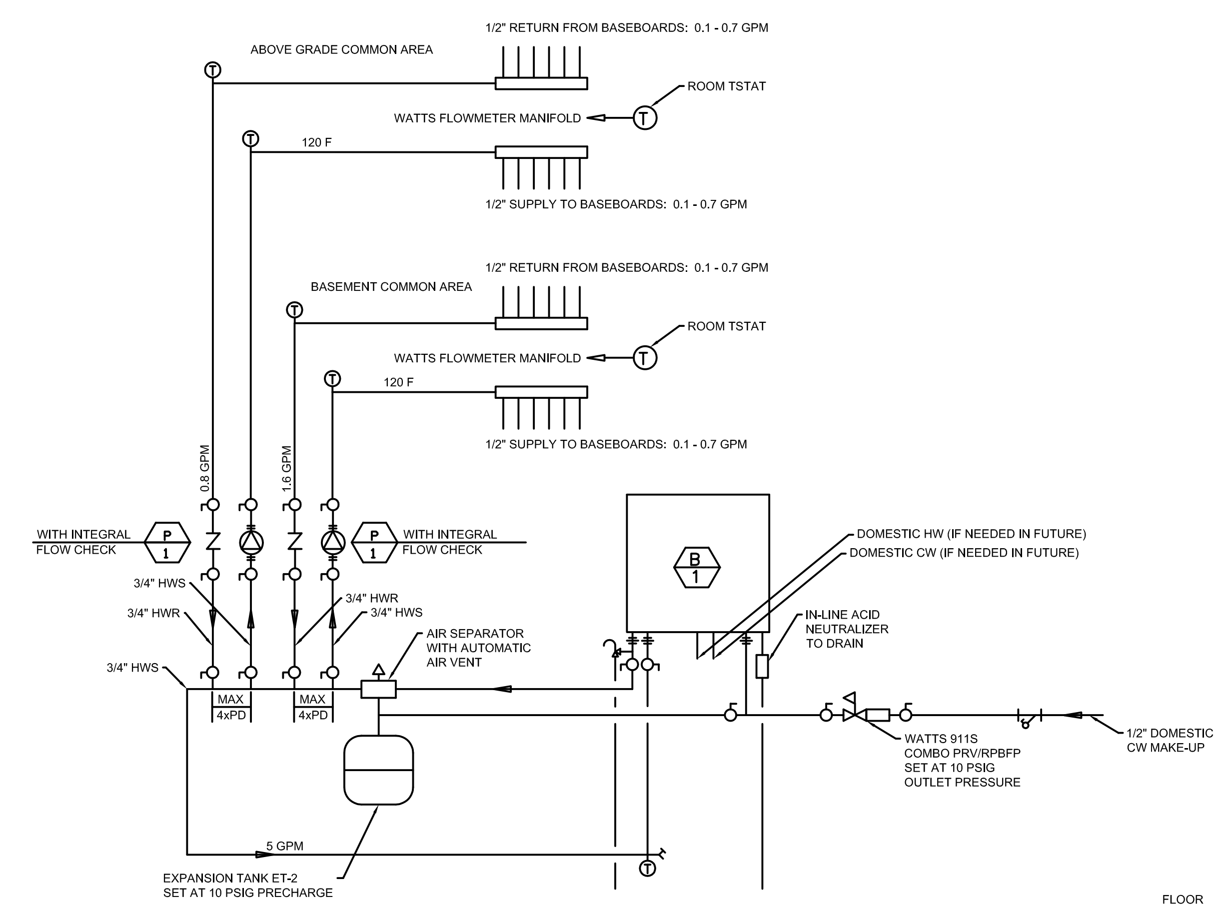
KITCHEN EXHAUST STACK #1



KITCHEN EXHAUST STACK #2 AND #3



APARTMENT HEATING SYSETM - TYPICAL WATER PIPING SCHEMATIC



COMMON AREAS HEATING SYSETM - TYPICAL WATER PIPING SCHEMATIC

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DRAWN BY: P KERRIGAN
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SHEET TITLE:

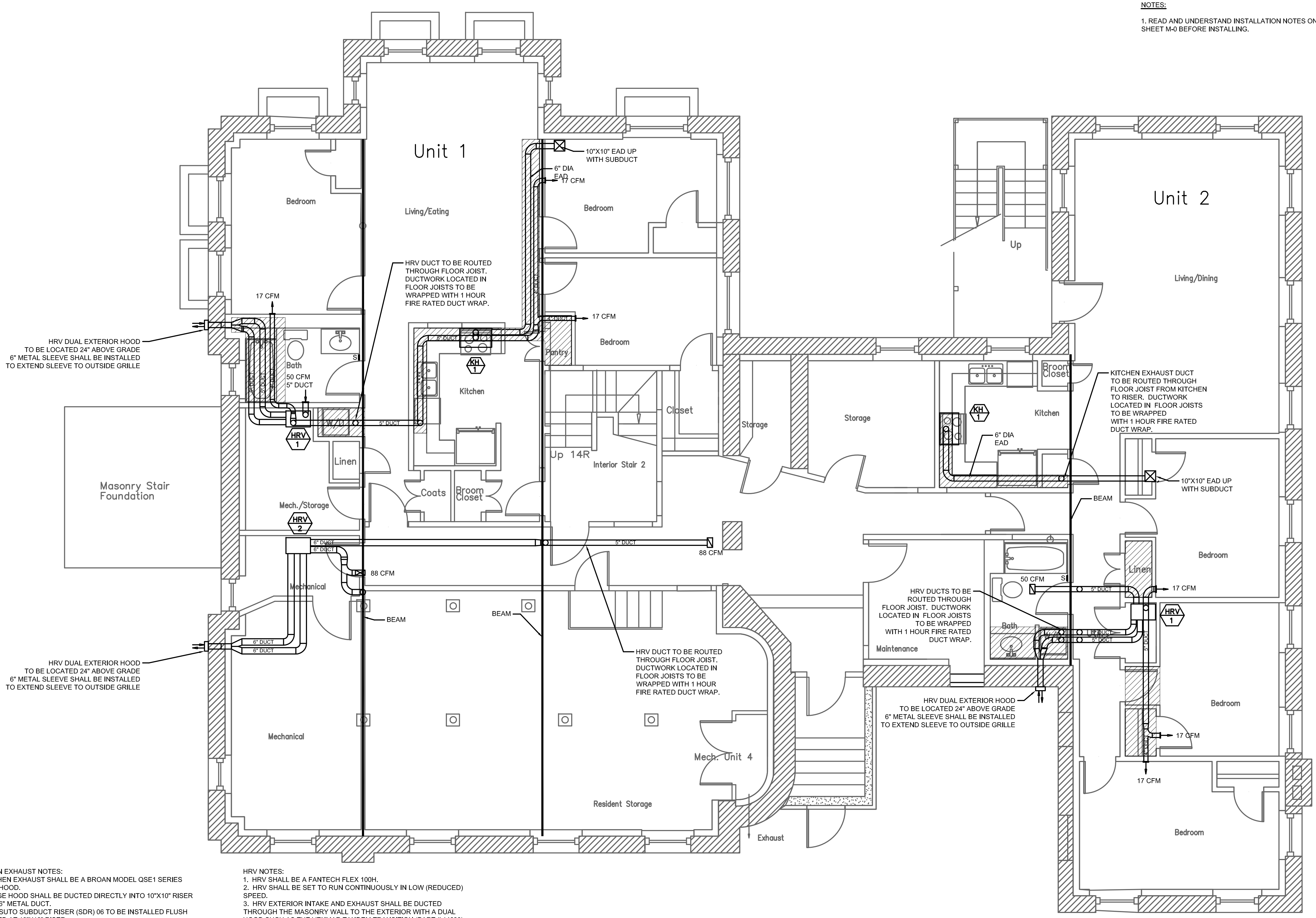
HVAC SCHEMATICS

SCALE AS NOTED

M-1

NOTES:

1. READ AND UNDERSTAND INSTALLATION NOTES ON SHEET M-0 BEFORE INSTALLING.



KITCHEN EXHAUST NOTES:
1. KITCHEN EXHAUST SHALL BE A BROAN MODEL QSE1 SERIES RANGE HOOD.
2. RANGE HOOD SHALL BE DUCTED DIRECTLY INTO 10"X10" RISER WITH A 6" METAL DUCT.
3. EXHASUTO SUBDUCT RISER (SDR) 06 TO BE INSTALLED FLUSH MOUNTED AT 10"X10" RISER.

COMMON AREA HRV NOTES:
1. HRV SHALL BE A FANTECH VHR 2005R.
2. HRV SHALL BE SET TO RUN CONTINUOUSLY IN HIGH SPEED AND BALANCED TO 175 CFM BALANCED FLOW.
3. HRV EXTERIOR INTAKE AND EXHAUST SHALL BE DUCTED THROUGH THE MASONRY WALL TO THE EXTERIOR WITH A DUAL HOOD SUCH AS THE VENMAR TANDEM TRANSITION (PART # 14690).
4. ALL DUCTS SHALL BE METAL WITH SMOOTH TRANSITIONS. ALL SEAMS AND JOINTS SHALL BE FULLY AIRSEALED WITH A BRUSH APPLIED MASTIC (RCD MASTICS #6 OR EQUIVALENT) TO A MINIMUM THICKNESS OF 60 MILS.
5. BOTH OUTSIDE DUCTS SHALL BE EXTERNALLY INSULATED TO R-8.

HRV NOTES:
1. HRV SHALL BE A FANTECH FLEX 100H.
2. HRV SHALL BE SET TO RUN CONTINUOUSLY IN LOW (REDUCED) SPEED.
3. HRV EXTERIOR INTAKE AND EXHAUST SHALL BE DUCTED THROUGH THE MASONRY WALL TO THE EXTERIOR WITH A DUAL HOOD SUCH AS THE VENMAR TANDEM TRANSITION (PART # 14690).
4. HRV SHALL OPERATE CONTINUOUSLY IN LOW SPEED WITH A PUSH BUTTON SWITCH (FANTECH MODEL RST2) IN THE BATHROOM TO ALLOW FOR INTERMITTENTLY INCREASED AIRFLOW. THIS INCREASED AIRFLOW MUST BE AT LEAST 50 CFM.
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6. BOTH OUTSIDE DUCTS SHALL BE EXTERNALLY INSULATED TO R-8 WITH AN FSK FACED FIBERGLASS DUCT WRAP.
7. SUPPLY GRILLES IN BEDROOMS SHALL BE DIRECTED AWAY FROM BEDS.

!!!DROPPED CEILING NOTES ABOUT PROPER INSTALLATION!!!

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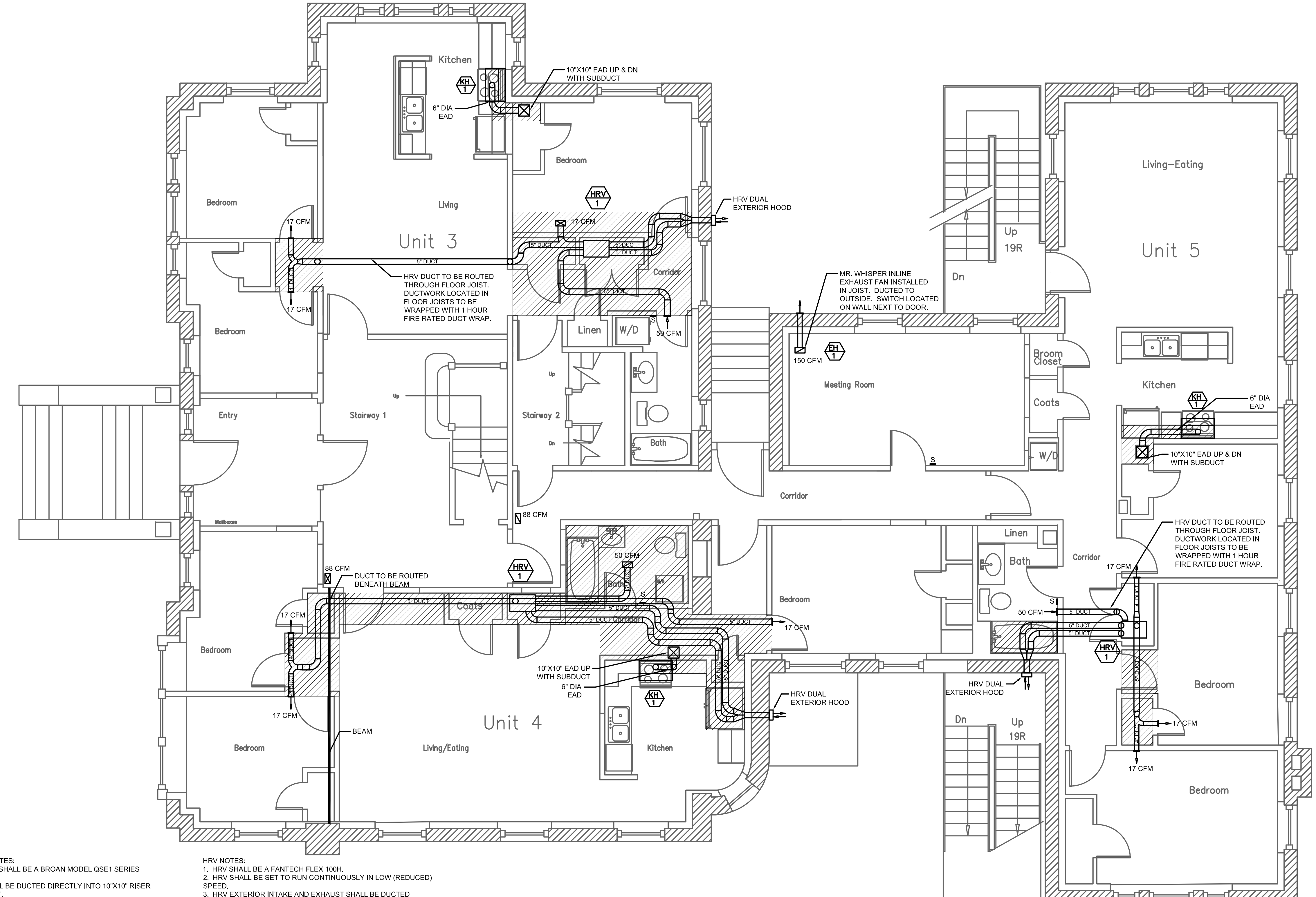
SHEET TITLE:

BASEMENT
HRV / KITCHEN
EXHAUST LAYOUT

SCALE AS NOTED

M-2



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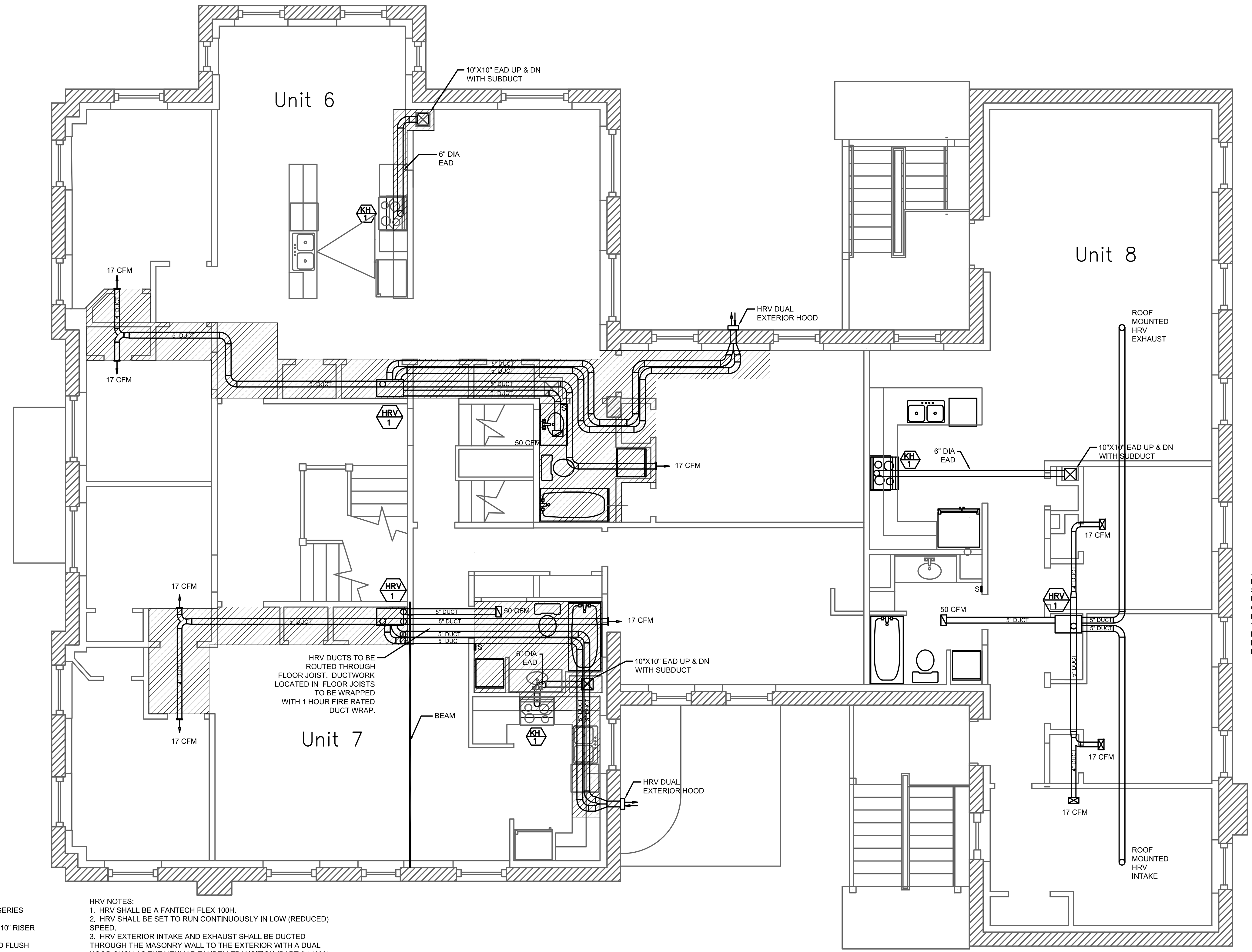
SHEET TITLE:

FIRST FLOOR
HRV / KITCHEN
EXHAUST LAYOUT

SCALE AS NOTED

M-3



ALL HRV AND KITCHEN EXHAUST DUCTS IN UNIT 8 SHALL BE LOCATED IN THE UNVENTED SUSPENDEND CEILING SPACE. ALL DUCTWORK TO BE WRAPPED WITH 1 HOUR FIRE RATED DUCT WRAP. HRV EXTERIOR DUCTS TO BE ROUTED THROUGH THE ROOF.

KITCHEN EXHAUST NOTES:

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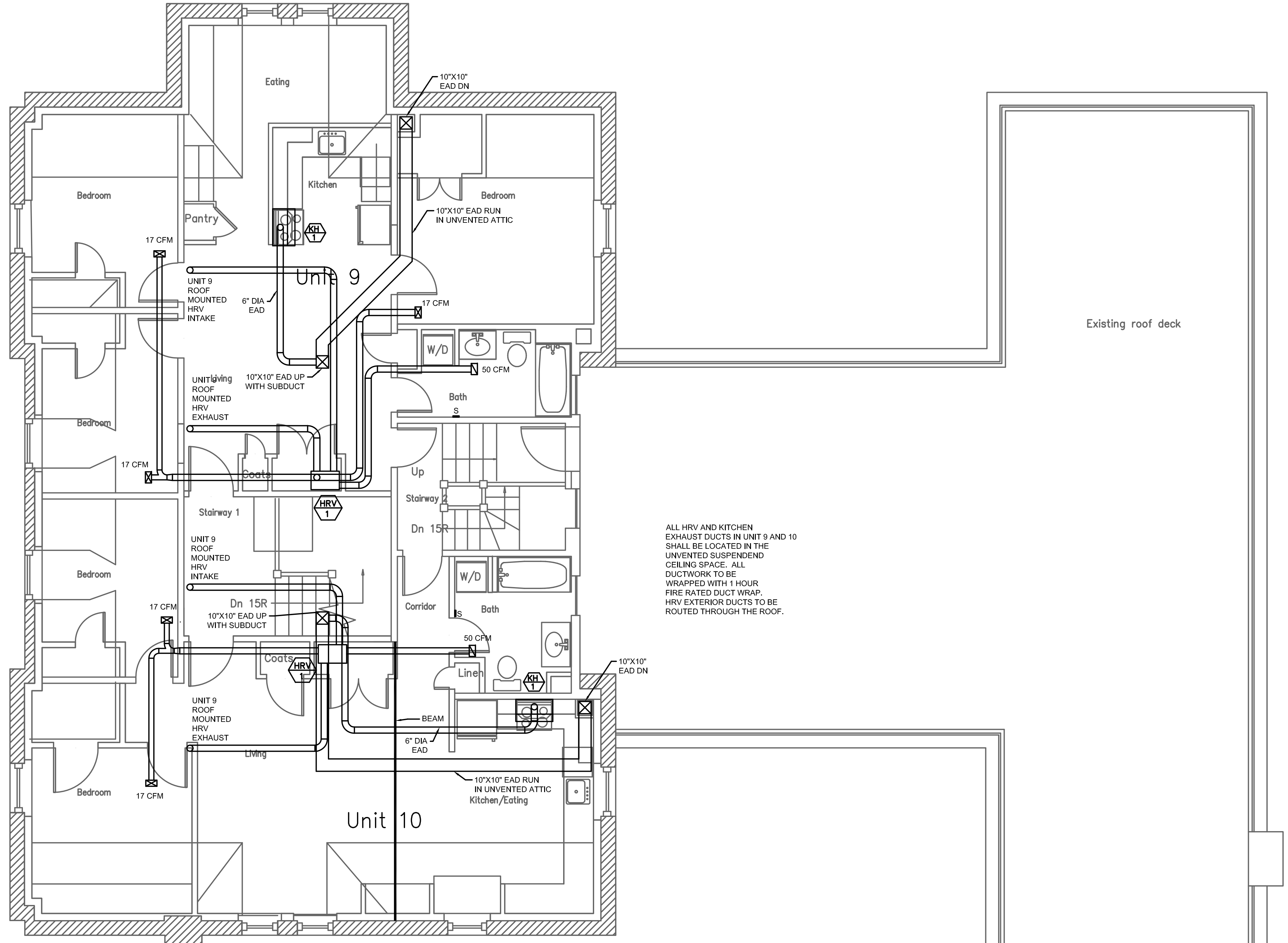
SHEET TITLE:

SECOND FLOOR
HRV / KITCHEN
EXHAUST LAYOUT

SCALE AS NOTED

M-4



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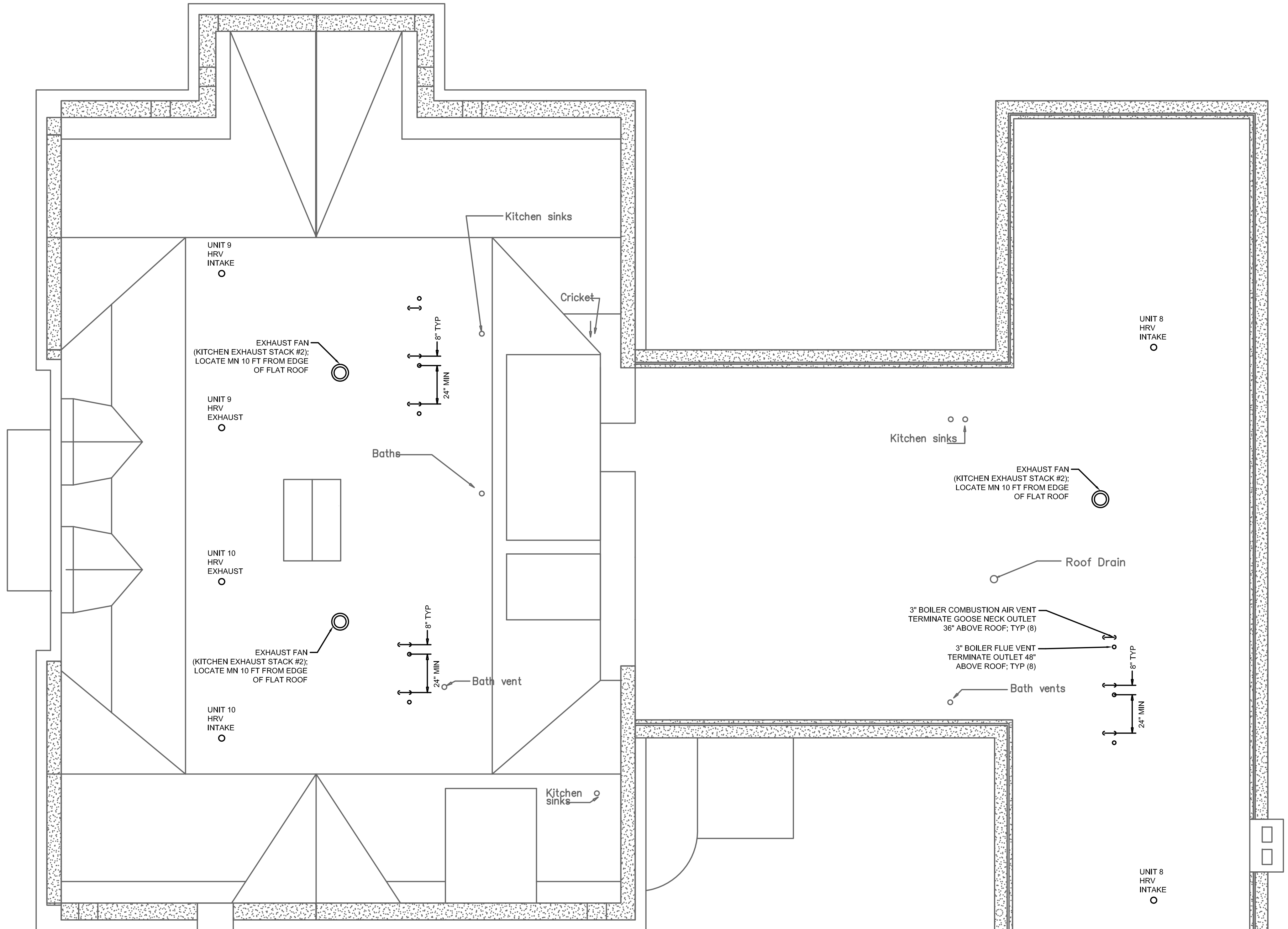
SHEET TITLE:

THIRD FLOOR
HRV / KITCHEN
EXHAUST LAYOUT

SCALE AS NOTED

M-5



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ROOF TERMINATION NOTES:
1. ROOF HRV INTAKES SHALL BE LOCATED 10 FT AWAY FROM APPLICANCE OR PLUMBING VENT OPENINGS. INTAKES SHALL BE LOCATED 2 FT ABOVE THE ROOF SURFACE.
2. ROOF HRV INTAKE AND EXHAUST TERMINATIONS SHALL BE A 6" ROUND ROOF CAP SUCH AS AMERICAN ALDES MODEL RCR-22 436. ROOF CAP SHALL HAVE AT LEAST A 12" EXTENSION TO AVOID SNOW ACCUMULATION.
3. ALL ROOF PENETRATIONS SHALL BE PROPERLY AIR AND WATER SEALED PER THE ARCHITECTURAL FLOOR PLANS AND DETAILS.

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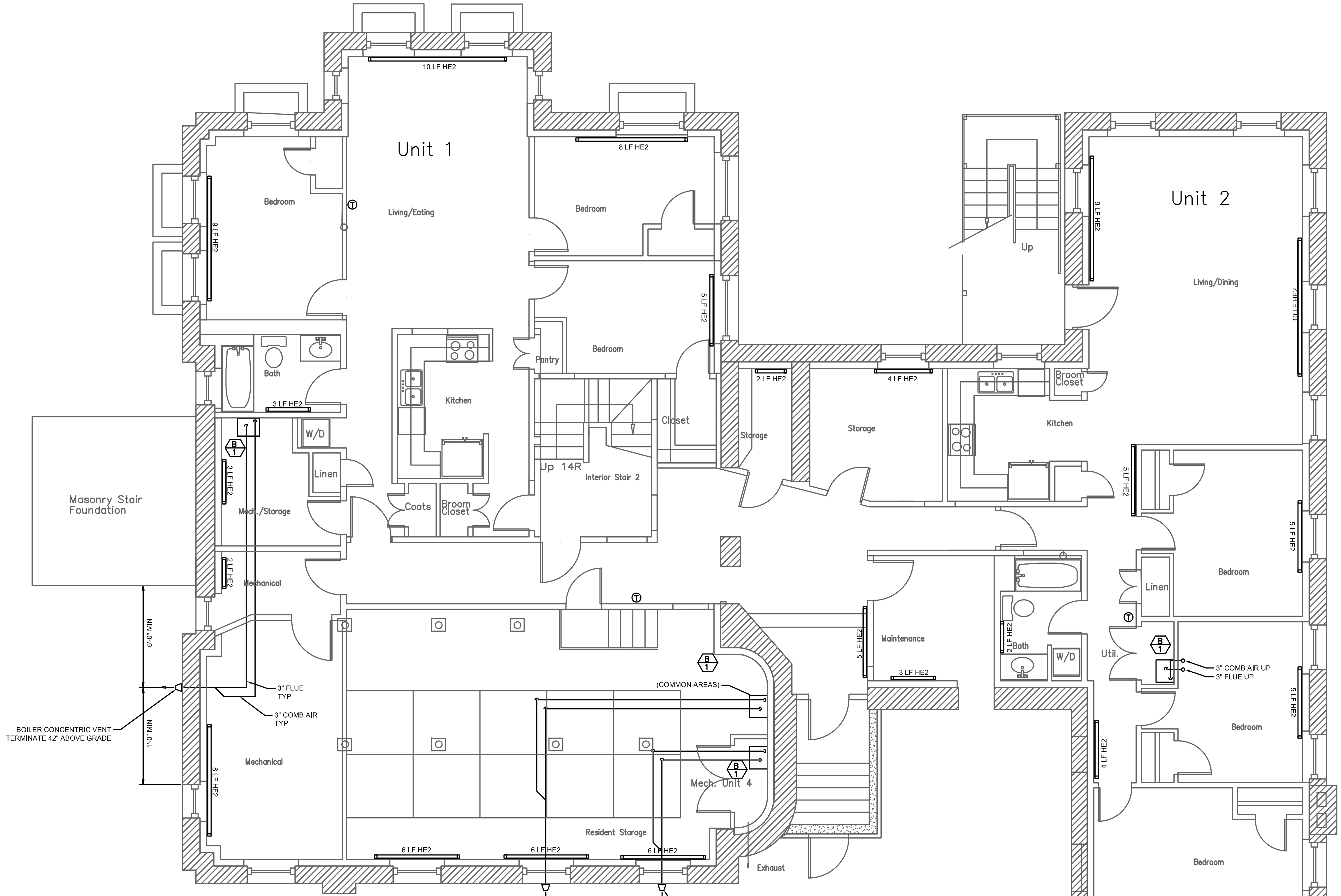
SHEET TITLE:

ROOF
HRV / KITCHEN
EXHAUST LAYOUT

SCALE AS NOTED

M-6



HYDRONIC NOTES:
1. X LF HE2 = X LINEAR FEET HEATING EDGE TWO BASEBOARD.
2. HEATING EDGE 2 BASEBOARD SHALL BE PIPED IN THE TWO SUPPLIES PARALLEL CONFIGURATION.
3. BOILER HYDRONIC AND DHW SUPPLY TEMPERATURE SHALL BE SET TO 120 DEGREES F.
4. VARIABLE SPEED PUMP SHALL BE CONFIGURED DURING INSTALLATION TO OPERATE AT LOWEST RATE.
5. FLOW RATES TO INDIVIDUAL HOME RUN BASEBOARD SHALL BE ADJUSTED AT THE MANIFOLD DURING INSTALLATION.

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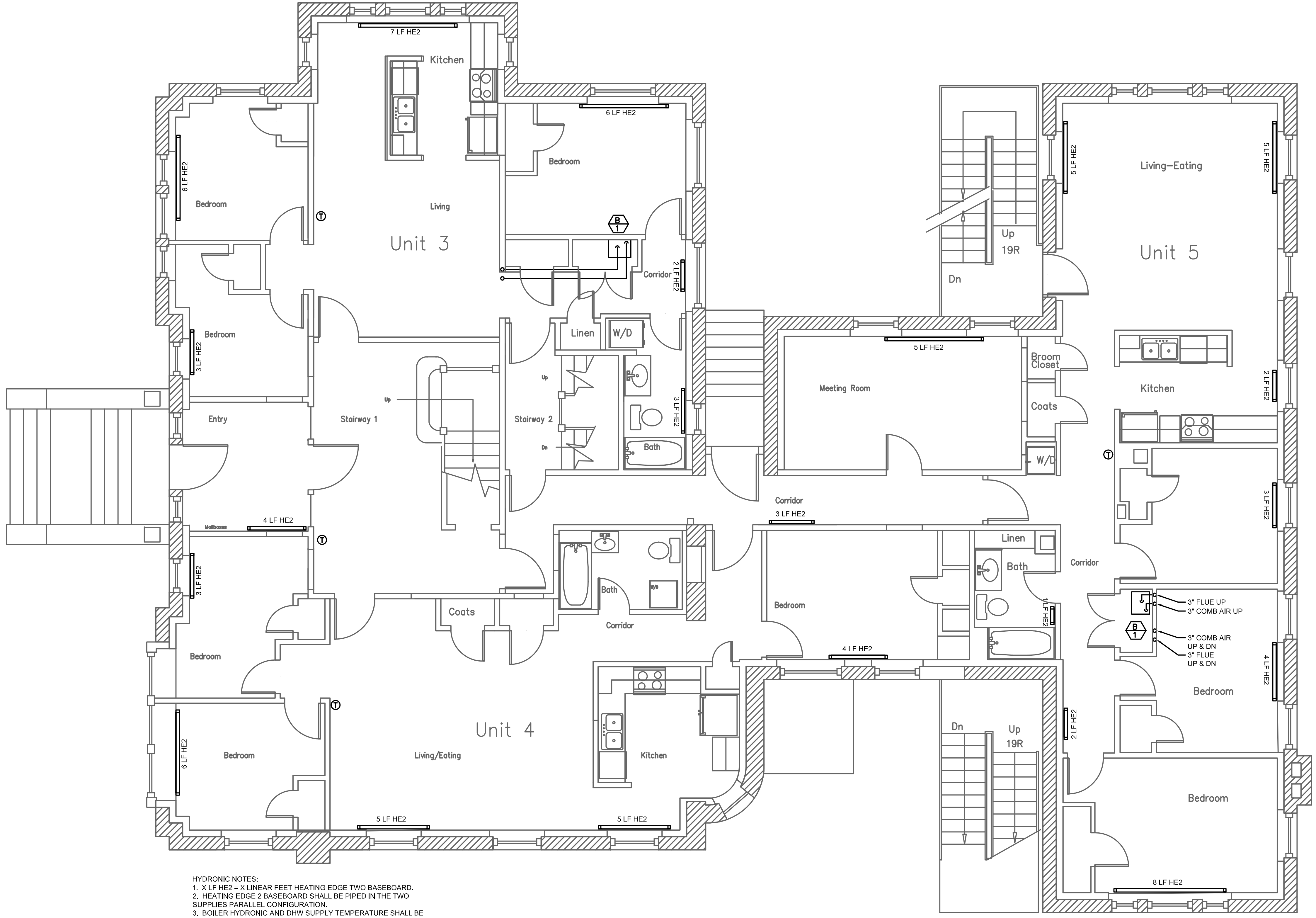
CHECKED BY:

SHEET TITLE:

BASEMENT HYDRONIC LAYOUT

SCALE AS NOTED

M-7



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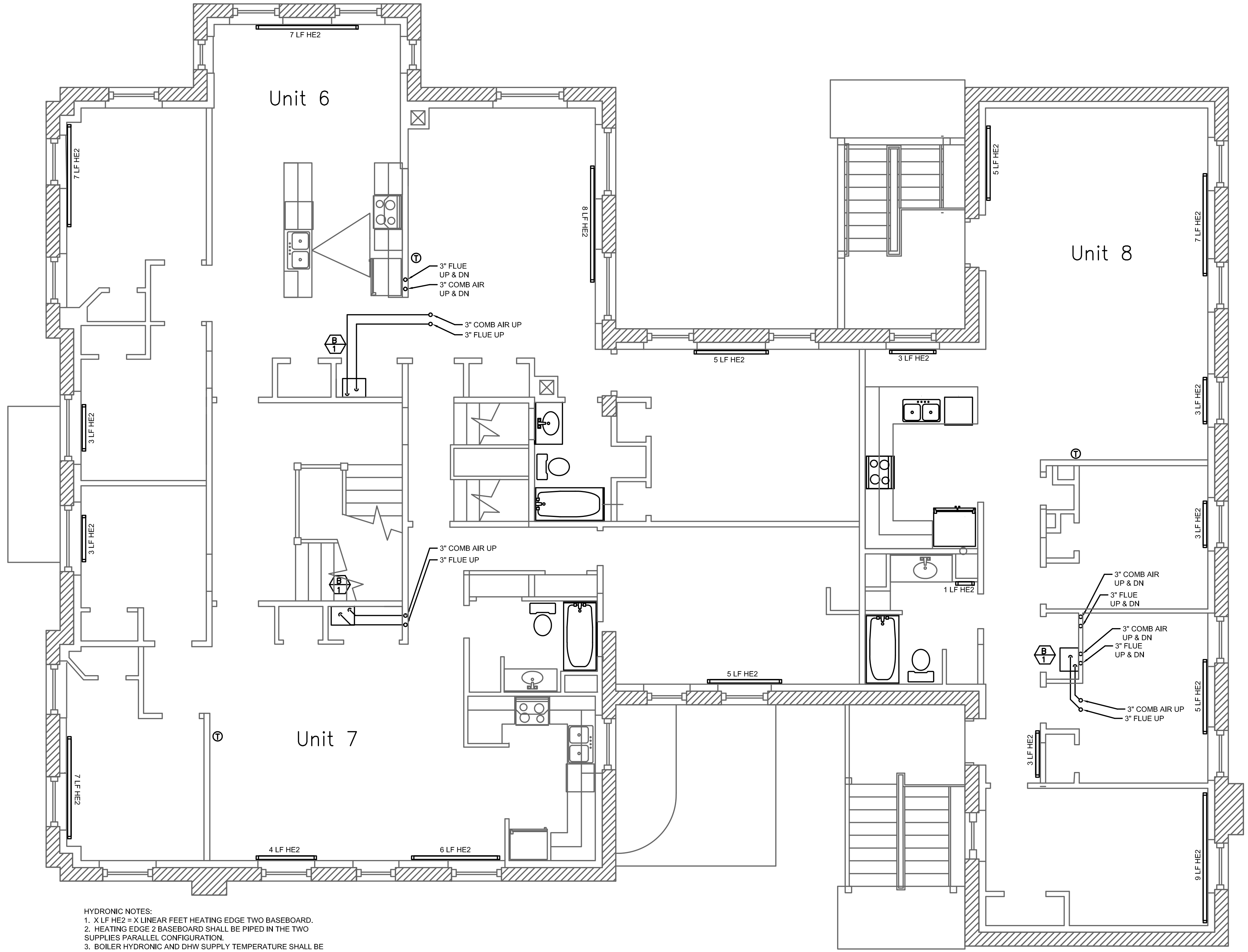
FIRST FLOOR HYDRONIC LAYOUT

SCALE AS NOTED

M-8



HYDRONIC NOTES:
1. X LF HE2 = X LINEAR FEET HEATING EDGE TWO BASEBOARD.
2. HEATING EDGE 2 BASEBOARD SHALL BE PIPED IN THE TWO SUPPLIES PARALLEL CONFIGURATION.
3. BOILER HYDRONIC AND DHW SUPPLY TEMPERATURE SHALL BE SET TO 120 DEGREES F.
4. VARIABLE SPEED PUMP SHALL BE CONFIGURED DURING INSTALLATION TO OPERATE AT LOWEST RATE.
5. FLOW RATES TO INDIVIDUAL HOME RUN BASEBOARD SHALL BE ADJUSTED AT THE MANIFOLD DURING INSTALLATION.

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MARK	DATE	DESCRIPTION
ISSUE:	08/17/12	PLUMBER HYDRONIC REVIEW

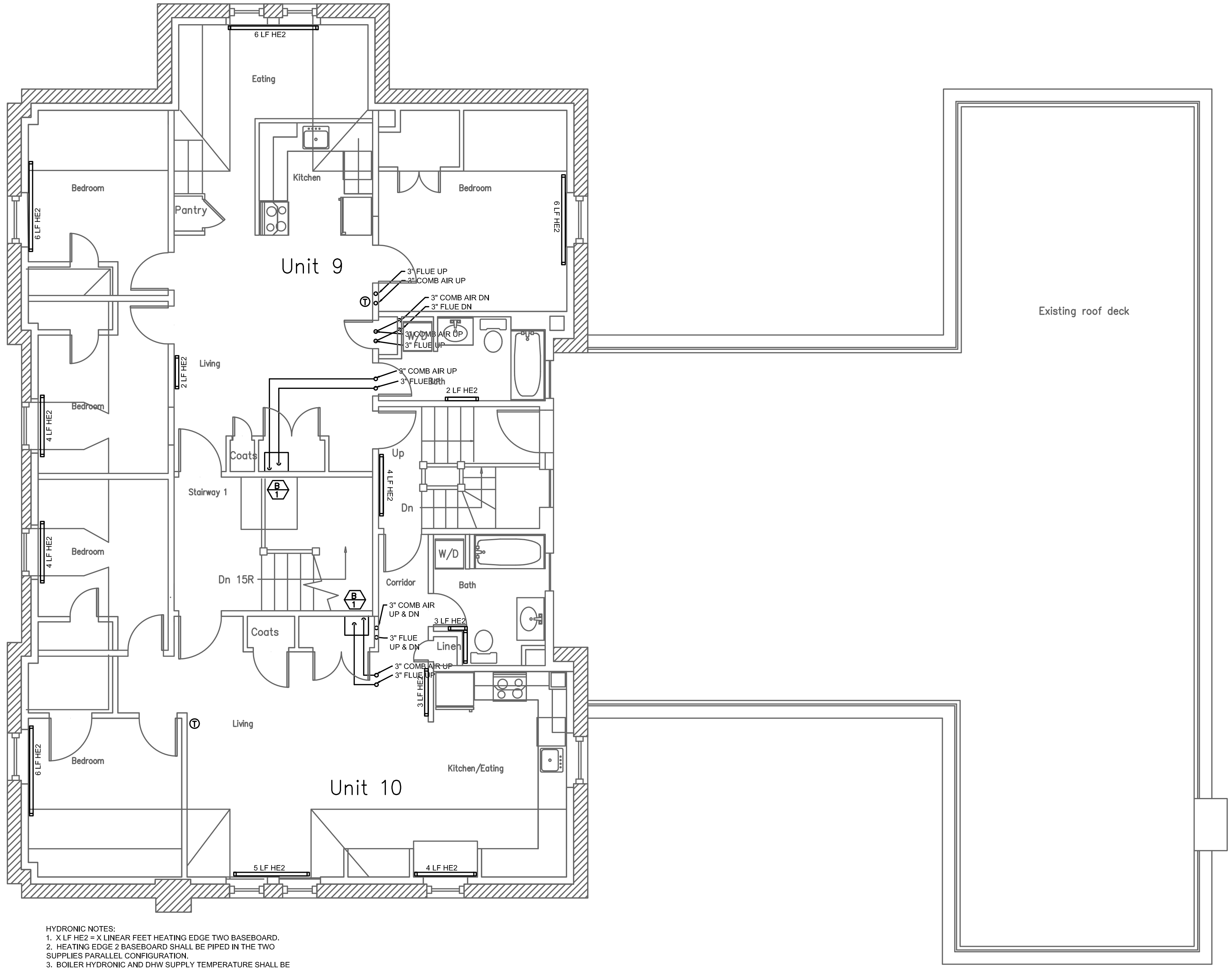
PROJECT NO:
CAD DWG FILE: MVHfH HVAC_BSC.dwg
DRAWN BY: P KERRIGAN
CHECKED BY:

SHEET TITLE:

SECOND FLOOR HYDRONIC LAYOUT

SCALE AS NOTED

M-9



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MARK	DATE	DESCRIPTION
ISSUE:	08/17/12	PLUMBER HYDRONIC REVIEW

PROJECT NO.:
CAD DWG FILE: MVHfH HVAC_BSC.dwg
DRAWN BY: P KERRIGAN
CHECKED BY:

SHEET TITLE:

THIRD FLOOR
HYDRONIC
LAYOUT

SCALE AS NOTED

M-10

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About this Report

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