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Building America Report - 1505
January 2015
Sravanthi Musunuru and Betsy Pettit

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

BUILDING TECHNOLOGIES OFFICE

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Building America
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Prepared for:

The National Renewable Energy Laboratory

On behalf of the U.S. Department of Energy's Building America Program

Office of Energy Efficiency and Renewable Energy

15013 Denver West Parkway

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NREL Contract No. DE-AC36-08GO28308

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Prepared under Subcontract No. KNDJ-0-40337-05

January 2015

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Definitions

DEER	Deep Energy Enclosure Retrofit
ccSPF	Closed-cell spray-applied polyurethane foam
IECC	International Energy Conservation Code
IRC	International Residential Code for One and Two Family Dwellings
S_{crit}	Critical degree of saturation
sf	Square foot area
XPS	Extruded polystyrene

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Progression Summary: Masonry Wall Interior Insulation Retrofit

ASSESS THE BUILDING

Perform a site assessment of the building, to find existing problems (such as improper water management, rising damp, air leakage, etc.) that must be addressed before insulating. Fixing a leaking downspout is more important than any further testing and analysis. This might be followed by material property testing and hygrothermal simulations to determine the freeze-thaw risks associated with interior insulation.

Do Not Proceed if:

- The masonry wall is not structurally sound
- The house contains hazardous materials that pose a risk to occupants or workers
- The house has active water leaks that will not be resolved by the retrofit projects
- The wood members connected to masonry wall display signs of rot or decay
- Insect/pest damage/activity is discovered.

REMOVE INTERIOR FINISHES

1 **Remove interior finishes.** Remove any interior furring, lath and plaster.

REMOVE WINDOWS AND DOORS

2 **Remove windows and doors.** Remove windows and doors as needed to allow flashing of openings and air control transitions into openings.

INSTALL RIGID FOAM BOARD

3 **Install rigid foam board.** Install rigid foam board with staggered joints by applying adhesive bead, and tape the seams of the innermost board to act as an air control layer.

RE-INSTALL WINDOWS AND DOORS

4 **Re-install windows and doors.** Re-install windows and doors or install new windows and doors in properly flashed openings.

INSTALL FIRE SEPARATION GYPSUM BOARD

5 **Install fire separation gypsum board.** Install fire separation gypsum board and caulk the interior layer of rigid insulation to the face of the strip.

SEAL ALL TRANSITIONS

6 **Seal all transitions.** Seal all transitions including wall-to-window, wall-to-roof, wall-to-floor and joist ends using spray foam for air barrier continuity and to avoid thermal bridging.

INSTALL FRAMING

7 **Install framing.** Install framing inboard of the insulation.

INSTALL GYPSUM BOARD

8 **Install gypsum board.** Install interior gypsum board.

1 Introduction

This Measure Guideline provides design and construction information for a deep energy enclosure retrofit (DEER) solution for insulating mass masonry buildings on the interior. It describes the retrofit assembly and the strategies and procedures for an interior retrofit of masonry wall with the use of rigid insulation.

An exterior retrofit is generally more favorable than an interior retrofit because it improves building durability, by reducing the likelihood of cold weather condensation within the structure (Straube et al. 2012). Exterior retrofits are also less disruptive to the living space, and typically allows a structure to remain occupied during the project.

Despite the advantages of exterior insulation, many buildings must be retrofitted on the interior, for reasons such as historic preservation, zoning or space restrictions, or aesthetics (Figure 1). Load-bearing masonry buildings often (not always) have historic significance and highly valued aesthetics that preclude exterior retrofits.

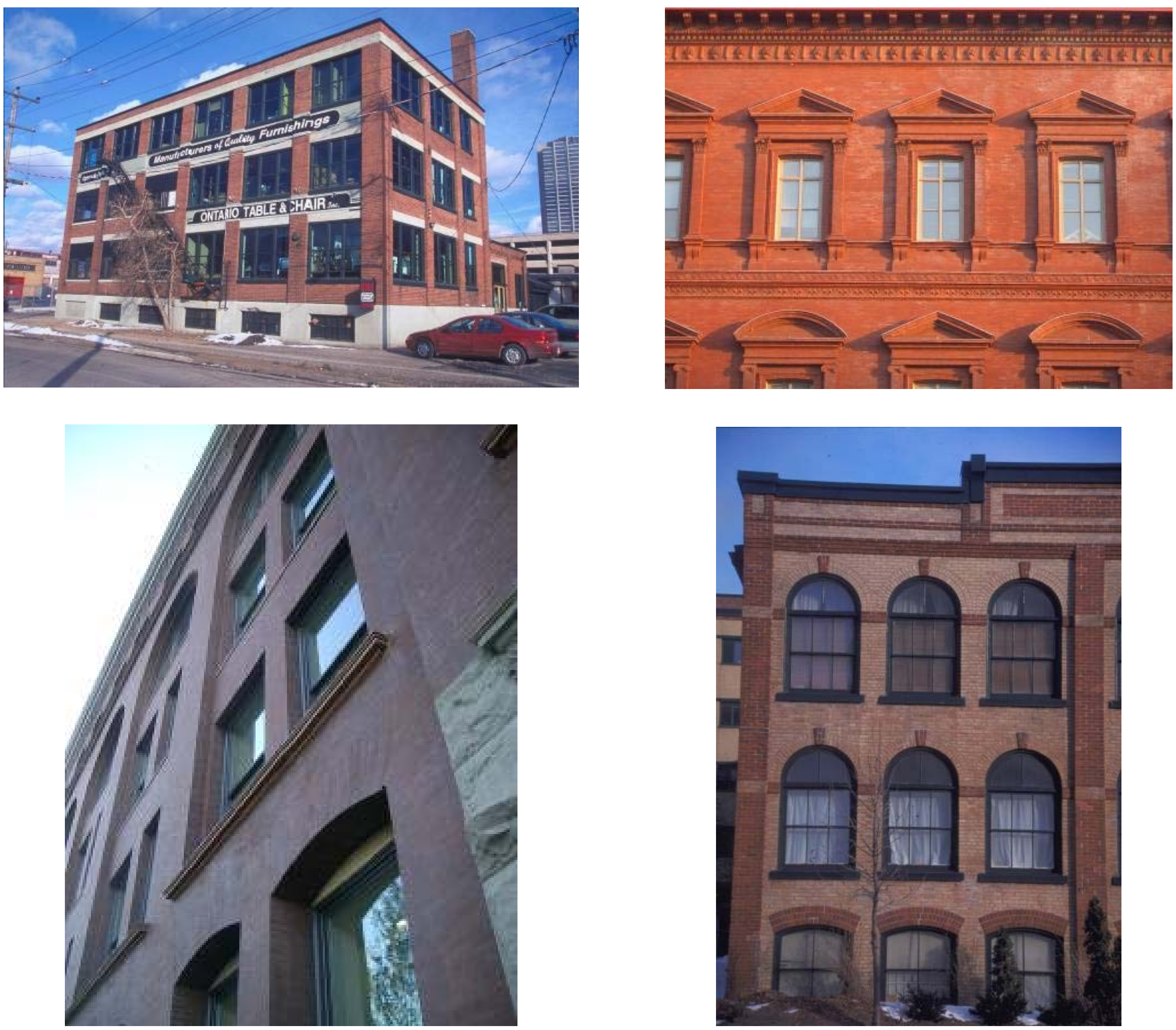

Figure 1: Historic mass masonry buildings

Interior retrofits of load-bearing masonry are often desired to preserve the exterior appearance. There are many possible interior insulation approaches that are, by and large, reasonably well understood. Adding insulation, increasing airtightness, replacing windows, and improving rain control constitute a normal retrofit package. Adding insulation to the walls of such masonry buildings in cold (and particularly cold and wet) climates may cause performance and durability problems, particularly rot and freeze-thaw damage. There are specific moisture control principles that must be followed for a successful interior insulation retrofit of a solid load-bearing masonry wall (Straube et al. 2012). Increasing the building airtightness as a result of the interior insulation retrofit can cause indoor air quality problems: mechanical ventilation, pollution source control, and combustion safety measures must be implemented to manage the risk

Numerous obstacles to more wide-scale deployment of interior retrofits include concerns about freeze-thaw damage caused by reduced outward heat flow and reduced inward drying, and the potential for decay of wood structural framing members (typically floor joists) that are embedded in mass assemblies. The problems and some case studies of interior retrofits are outlined by practitioners such as Gonçalves (2003), Maurenbrecher et al. (1998), Straube and Schumacher (2002, 2004), and Straube et al. 2012.

This Measure Guideline includes a review of decision criteria pertinent to retrofitting masonry walls from the interior and the possible risk of freeze-thaw damage. These criteria include cost and performance, durability, constructability, freeze-thaw degradation risk, air leakage performance and thermal performance. It also discusses fundamental building science and design principles for the use of interior insulation in masonry buildings, and construction detailing and procedures developed to provide understanding of how the various elements of the design are implemented.

This Measure Guideline is intended to support contractors implementing an interior insulation-based high performance enclosure retrofit for masonry buildings, as well as designers looking to design such retrofits. It may also be helpful to building owners wishing to learn more about strategies available for deep energy enclosure retrofit of masonry residential buildings on the interior. The document could also be used by owners to implement the retrofit strategy themselves, as it is a low-tech application and does not involve many safety measures.

2 Decision Making Criteria

This section discusses the major decision-making criteria once an interior retrofit has been decided on, after considering issues such as aesthetics, historic significance, improved comfort, and the lifespan of the project, which tend to dominate the decision-making process to determine the type of retrofit to be undertaken.

Cost and Performance

Cost and performance are intricately linked, and must be studied in combination to determine the best choice, per the decision-maker's goals and objectives. Installation costs for the retrofit solution described in this Measure Guideline can vary widely from estimates in the referred sources, depending on such factors as contractor experience, prevalent region practices, material costs, and the particular circumstances of the project. It is worth noting that the range is sometimes a factor of 5 to 10.

A number of suitable interior insulation options for the masonry building include XPS (extruded polystyrene) rigid insulation, 2 pound/cubic foot closed cell spray polyurethane foam (ccSPF) or a hybrid approach of ccSPF or XPS with fiberglass batt or cellulose insulation. These options can be compared in terms of the cost of materials and labor, constructability of the system, as well as the performance aspects of each option, to determine the best retrofit option. In many cases of insulation retrofits of load-bearing masonry buildings, the energy savings are not that important to the owner as much as increased thermal comfort, controlling rain penetration, and ensuring good indoor air quality.

The following options were considered and evaluated in terms of cost and performance for the wall retrofit; R-values are summarized in Table 1. Similar analysis could be done for equivalent options such as expanded polystyrene or polyisocyanurate rigid insulation.

- 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 disadvantage of using rigid sheet goods (such as XPS) compared to a monolithic material (such as spray foam) is the challenge of establishing a continuous air barrier, as it requires ensuring that the board is firmly in contact with the masonry without any gaps, as well as the implementation of the drawn details. The advantage, however, is that the installation can be performed by a homeowner, providing a significant cost savings.

Spraying 5" of ccSPF 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 therefore can be completed in a shorter amount of time. The drawback, however, is the cost of material and labor (Ueno et al. 2013). Also, ccSPF installations beyond 2”-3” thicknesses must be done in layers, further increasing the installation time and labor cost.

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 raises the R-value of the assembly. The fiberglass batt insulation is a more affordable product and can be installed by a homeowner; however, the ccSPF has a higher cost and the installation must be carried out by a professional.

BEopt economic analysis

In order to provide an economic analysis that is representative of a typical construction market, the BEopt analysis could be performed. BEopt, the Building America performance analysis tool, which features options for retrofit projects, is used to analyze the energy use and the cost effectiveness of the wall retrofit measures considered. More information can be found at https://beopt.nrel.gov.

Table 1 lists R-values and costs for the four compared exterior wall insulation options: 6” of XPS rigid insulation, 4” of XPS rigid insulation, 5” of ccSPF and 2” of ccSPF with fiberglass batt insulation. The cost values were obtained from RSMeans Reed Construction Data 2012 (Reed 2012), a cost-estimating tool, which provides the cost of materials, installation, and overhead and profit. The R-values listed in Table 1 were derived from earlier BEopt models (Christensen et al. 2006).

Table 1. Cost Values for Wall Retrofit Options

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

The cost optimized wall system based on 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. The 6” XPS with 2x4 stud wall is the one with best thermal performance (by a small margin); it also involves low-tech construction techniques (making it relatively easier to implement), and was thus chosen for discussion in this Measure Guide.

Durability

Solid load-bearing masonry assemblies are by their nature durable. However, the manner in which they manage moisture is quite different than modern, framed, multilayer assemblies. It is important to understand the difference in behavior to support decision-making during retrofits.

The primary concern with insulating older load bearing masonry buildings in cold climates is the possibility of causing freeze-thaw damage of the brickwork and decay in any embedded wood structure, both of which are caused by excess moisture content. Other durability concerns of interior insulation retrofits are that the assembly will reduce drying to the interior and the amount of energy flow through the wall (and thus the drying potential) will be minimized. An additional durability risk is that bulk water entry will not be as evident from interior inspection in the post-retrofit building.

Yet another concern is the rot/corrosion of embedded elements (e.g., wood joists or reinforcing steel). The worst issues with embedded joist durability are related to bulk water issues, such as excess deposition on the wall, cracks in the façade (allowing leakage), or proximity to grade (or worse, below grade conditions). If any of these issues are found in the site inspection, they must be addressed before considering an interior insulation retrofit.

A counteracting aspect of this issue with interior insulation retrofits is that although the assembly may have higher moisture content, it is also much colder during winter months, which slows the rate of both corrosion (chemical reactions) and rot (biological reactions) (Straube et al. 2012).

Constructability

The ease of construction might be a consideration depending on the specific requirement of the decision-maker. For larger projects with higher budgets, it might be possible to hire trained professionals to perform complicated jobs. But for smaller projects where the building owners wish to perform the retrofit themselves, it might be worthwhile to consider options that involve low-tech construction techniques and are easier to implement. Among the options listed in Table 1, the interior retrofit options consisting of XPS with stud wall are comparatively easier to implement and do not require trained professionals.

WUFI hygrothermal analysis

The WUFI hygrothermal computer simulation model could be 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.

Freeze-Thaw Degradation Risk

For existing mass masonry walls, a site assessment must be performed to examine the existing water management features of the building, and look for evidence of existing damage and/or water penetration. Existing problems will be exacerbated by interior insulation. The brick material properties may then be tested to ensure that the wall can be retrofitted without durability problems (Straube et al. 2012). This would involve material property testing (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. Further information on the testing procedures can be found in Straube et al. (2012).

The purpose of the brick analysis is to ensure that the addition of high levels of interior insulation does not present a risk of freeze-thaw damage to the mass masonry walls in the building. 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) (Ueno et al. 2013). Individual sample bricks are collected from the interior and exterior of the original building, followed by material property testing to assess freeze-thaw risk. Testing includes dry density, water absorption coefficient (A-value), free water saturation, vacuum saturation, and determination of critical degree of saturation (S_{crit}). S_{crit} which reflects a brick's resistance to freeze-thaw damage; relatively high S_{crit} values (~0.75-0.80), indicate good resistance to damage. The measured values are then used in WUFI simulations to predict the brick moisture content during freezing conditions for the existing and proposed retrofit wall assemblies under varying rain exposures.

Air Leakage Performance

It is highly risky to design a retrofit assembly that allows significant air leakage; therefore, the air leakage performance of the retrofit strategies must be evaluated before making a decision. 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. In general, it is assumed that air leakage across the enclosure has been essentially controlled using appropriate air sealing materials and techniques, such as taping the joints of the rigid insulation's innermost and outermost layers, and using interior spray foam insulation.

Thermal Performance

The decision on the thermal performance depends on the specific requirements of the project. For projects that need to meet stringent energy performance goals, a higher level of insulation must be provided.

Thermal insulation follows the law of diminishing returns: return on investment decreases with increasing insulation thickness. Given that the wall assemblies are being changed from uninsulated to insulated assemblies, it is likely that the initial inch or two of insulation should be highly cost effective. Optimization would be a function of insulation cost, climate zone, and energy costs.

3 Technical Description

Masonry Wall Interior Insulation Retrofit Assembly

The retrofit assembly consists of three 2" layers of rigid foam insulation (with staggered seams), adhered to the masonry and between layers with a single-component polyurethane adhesive. The innermost layer of rigid insulation (closest to the interior) has 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 installation of the interior finishes and to provide space for running services. (Figure 2)

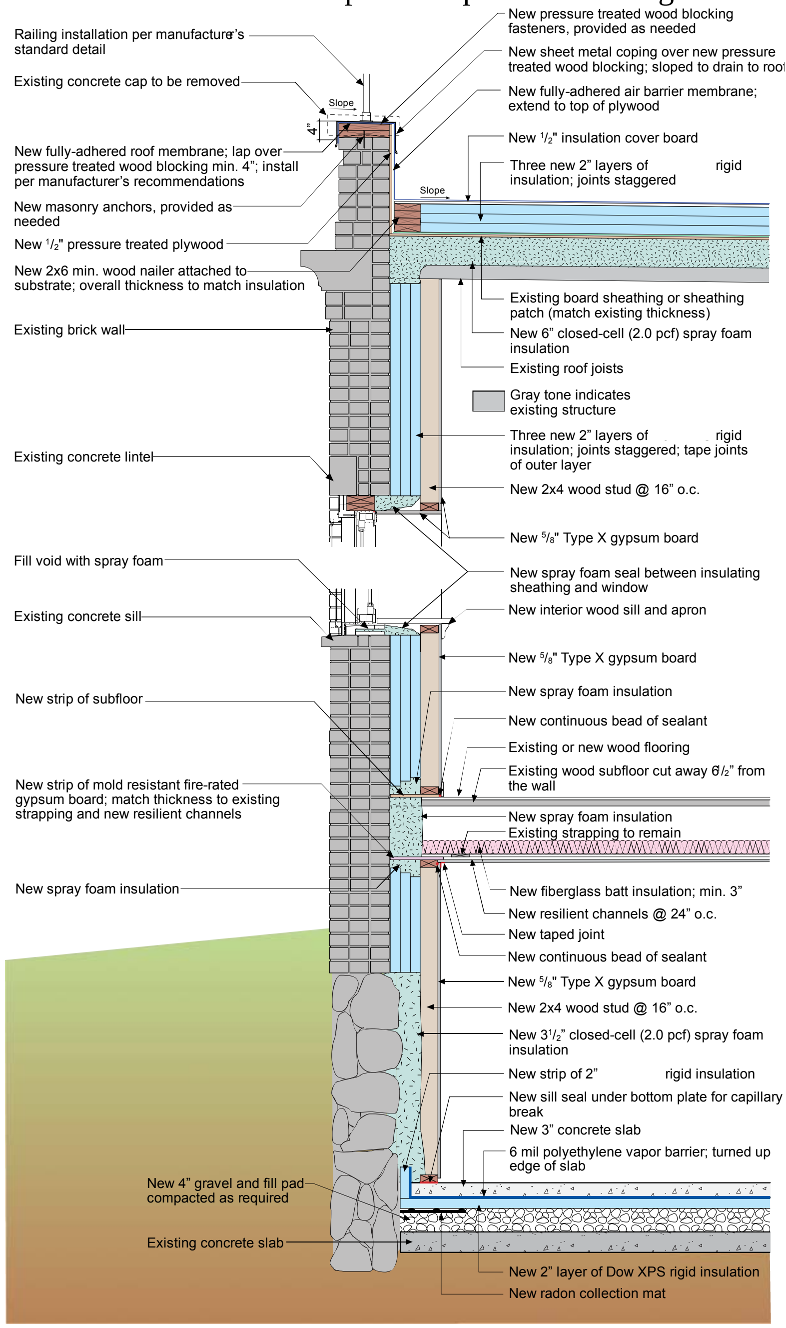

Figure 2: Bearing Masonry Interior Insulation Retrofit Approach

System Interaction

If an interior retrofit improves both the insulation value and airtightness, numerous risks must be assessed. Both improvements may reduce the durability of the masonry, because the masonry will be colder for longer periods of time than before, and will have less drying capacity, both because it is colder and also because the interior layers added by the retrofit will restrict vapor diffusion. The colder post-retrofit masonry will also make air leakage condensation much more likely in cold weather. The retrofit solution outlined in this Measure Guide includes robust air control measures in addition to high R-value thermal performance. The performance of the bearing masonry interior insulation retrofit solution relative to critical control functions is described below.

Water Control

Controlling bulk water entry into the wall when executing interior retrofits is of vital importance, especially as water leakage will no longer be visible from inside until damage occurs to interior finishes. If rain control cannot be addressed and upgraded, interior insulation should not be implemented (Straube et al. 2012).

In most walls, a water control layer protects the structure. Water control layers are water repellent materials (building paper, housewrap, sheet membranes, liquid applied coatings, or taped and sealed rigid insulation boards) that are located behind the cladding and are designed and constructed to drain water that passes through the cladding. They are interconnected with flashings, window and door openings, and other penetrations of the building enclosure to provide drainage of water to the exterior of the building. The materials that form the water control layer, in this case the innermost rigid insulation board behind the masonry wall, overlap each other shingle fashion or are sealed so that water drains down and out of the wall (see Figure 4). The water control layer is often referred to as the “drainage plane” or “water resistant barrier” or “water control layer”.

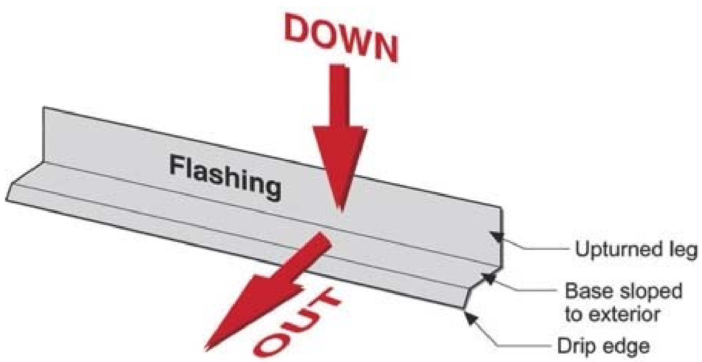

Figure 3: The "down" and "out" approach to flashing

The manner in which load-bearing masonry wall manages water is quite different than modern, framed, multilayer assemblies. These mass masonry walls absorb and safely store water during precipitation, and later dry during more advantageous conditions. Solid masonry walls may contain many hollow spaces or voids (Figure 3), which act as capillary breaks, and may allow water to accumulate or concentrate, as they are invariably not intentionally drained. Guidance for key details and conditions to address are covered in Straube et al. 2012.

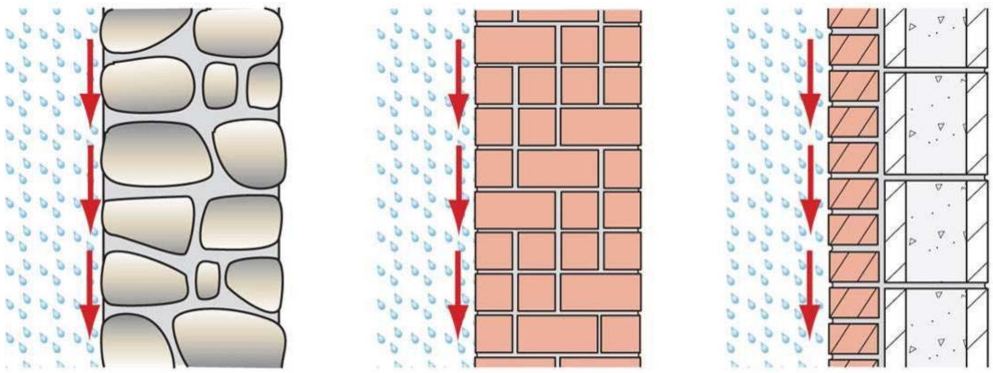

Figure 4: Examples of mass masonry walls and rain control

In order for the water control layer to be effective, all windows must be installed in a pan flashed and drained opening, with the jambs and head of the frame taped or sealed to the wall water control layer. Flashings are the most under-rated building enclosure component and arguably the most important. Drainage and shedding are accomplished by a sloped sill detail with end dams, and a sufficient drip edge beyond the wall below.

Air Control

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 2005).

Load-bearing masonry walls pose a condensation risk at the masonry-to-insulation interface. Air leakage could bypass imperfectly installed air barriers, resulting in condensation problems. This condensation-based wetting would occur in a layer this is cold enough to precipitate condensation, and often would drop below freezing. To avoid this problem, excellent airtightness on the interior is essential.

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. In case of interior retrofits using rigid board insulation, an interior air barrier in the form of taped and sealed joints is required to prevent interior air from contacting the cold masonry. Given the construction quality sensitivity of this taped system, air leakage (blower door) testing prior to interior finishes (gypsum board) would be a prudent step. Material compatibility must be ensured before selection of air flow retarder system component.

Exterior Wall and Wall-to-Window Air Barrier

The construction of the masonry walls to be retrofitted could include both multi-wythe solid brick walls, and exterior brick with a hollow clay block infill/backup wall, as shown in Figure 5. These photos show conditions after demolition of the interior furring, lath, and plaster (Ueno et al. 2013).

Figure 5: 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 6, left). In addition, the hollow clay blocks provide a major interconnected airflow network laterally across the wall (Figure 6, right).

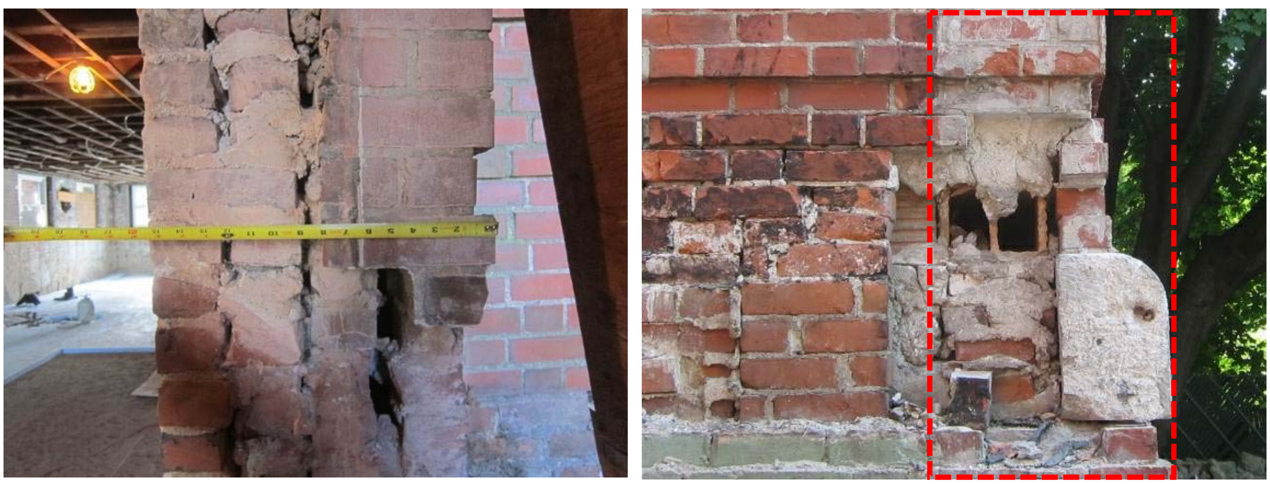

Figure 6: Wall section at solid brick (left) and at hollow clay block infill (right) conditions

The retrofit strategy decribed in this Measure Guide uses 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 performanceand durability, as it avoids wintertime air leakage condensation at the insulation-masonry interface (Straube et al. 2012).

The innermost layer of the rigid foam insulation forms the air barrier at the exterior walls; the seams are taped at the innermost layers. 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 7), air barrier continuity needs to be achieved from the rigid 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. Closed cell spray foam is used to connect the rigid foam board at difficult transitions (to window openings, portions of uneven surface brick, and the joist/floor areas).

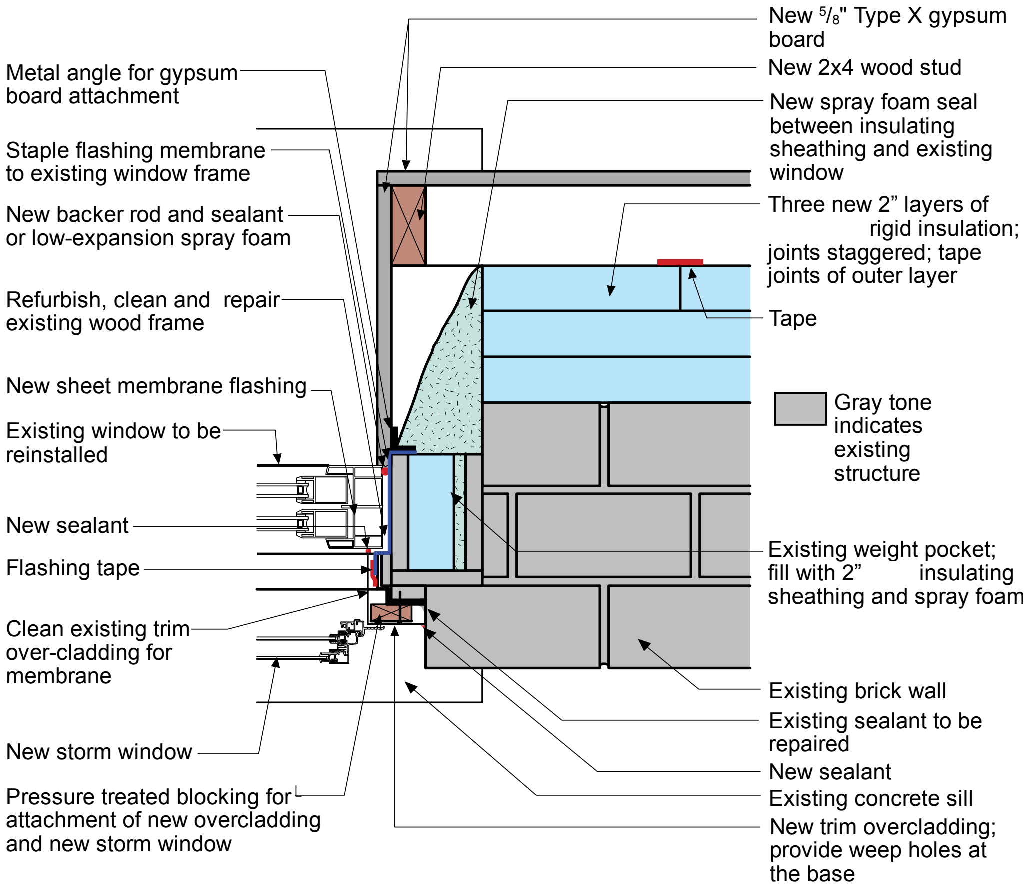

Figure 7: Window jamb retrofit detail, showing spray foam "fillet"

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

Wall-to-Roof Air Barrier

Continuity of the air barrier at the wall-to-roof interface is critical to prevent interior air leakage into the roof assembly. Figure 8 shows the air barrier connection from the wall to the retrofitted flat roof assembly (with a masonry parapet). The connection is made via ccSPF, which "caps" the edge of the rigid insulation at the wall and connects it to the underside of the roof deck and the masonry parapet.

On the top side of the roof, 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; therefore, the assembly could be modified.

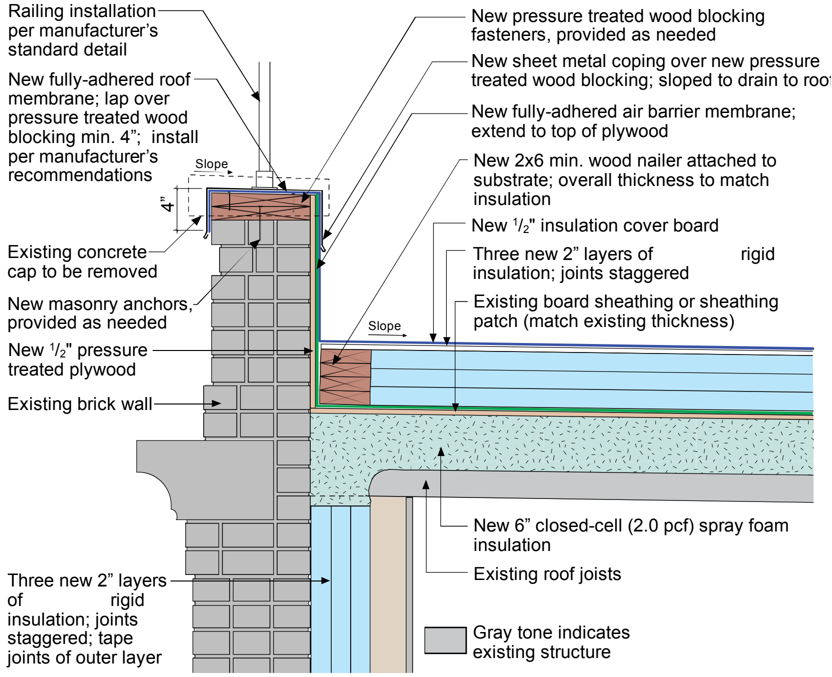

Figure 8: Flat roof retrofit detail at parapet

Above-Grade-to-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 (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.

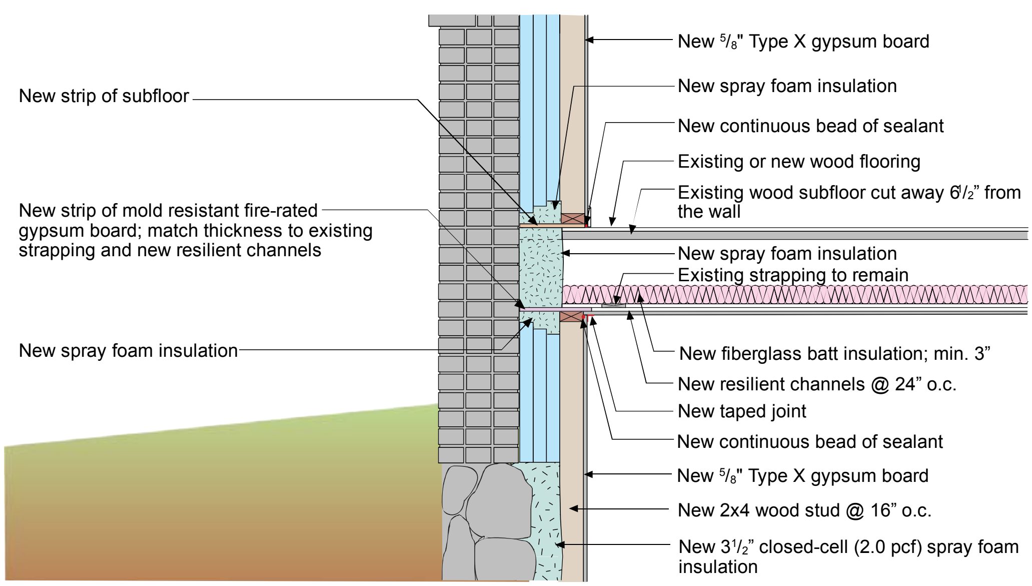

Figure 9: Above-grade wall to below-grade wall transition

Compartmentalization between Units

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 2005). However, creating effective compartmentalization between units 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.

To create effective compartmentalization between units, it is important to account for constructability (including sequencing) and fire resistance ratings requirements, which will guide the detailing of those complicated areas.

Figure 10 shows the detail of 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). In this detail, the floor joists run perpendicular to the exterior wall.

The interior-to-exterior air barrier is "passed" from the layers of rigid foam, through ccSPF insulation and fire resistance elements, to the rigid foam on the floor above (Ueno et al. 2013). 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.

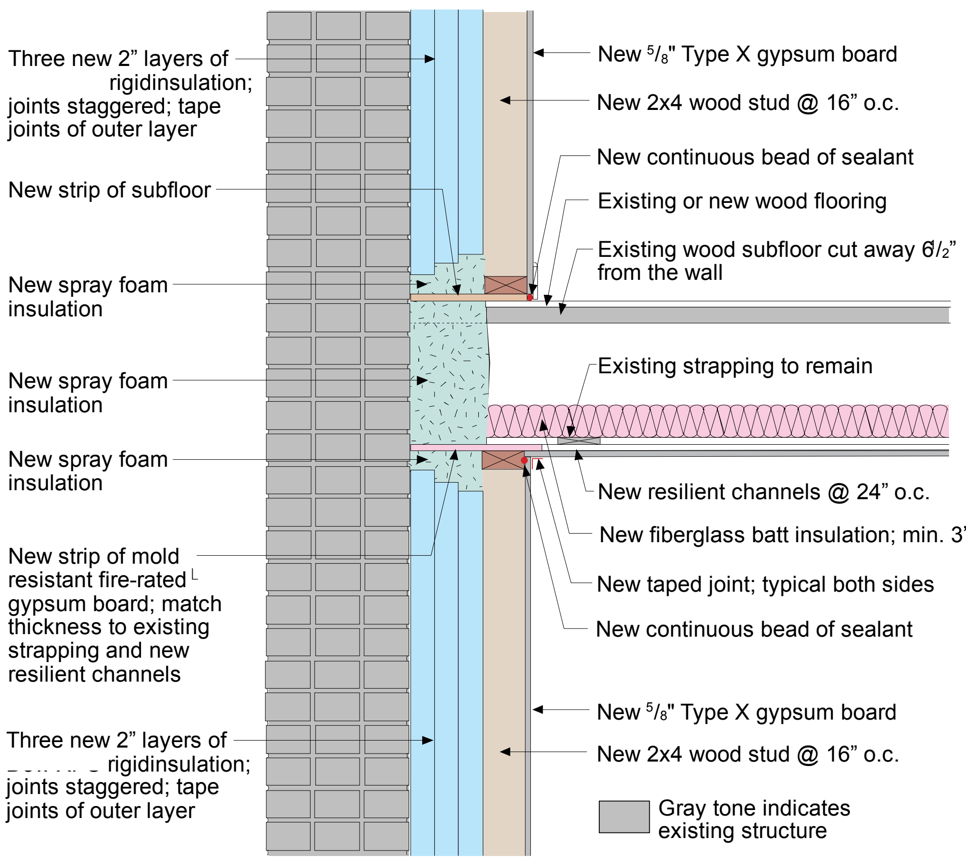

Figure 10: Unit-to-unit floor/ceiling assembly at exterior wall

Figure 11 shows the detail for a demising (unit-to-unit) wall intersecting the exterior wall. It is conceptually similar to the floor-ceiling intersection detail shown in Figure 10, with the "strip" of mold-resistant gypsum board where it is hidden within the exterior wall assembly, to provide continuous fire resistance up to the masonry wall. Again, spray foam is used to connect the exterior wall air barrier (rigid foam board) 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.

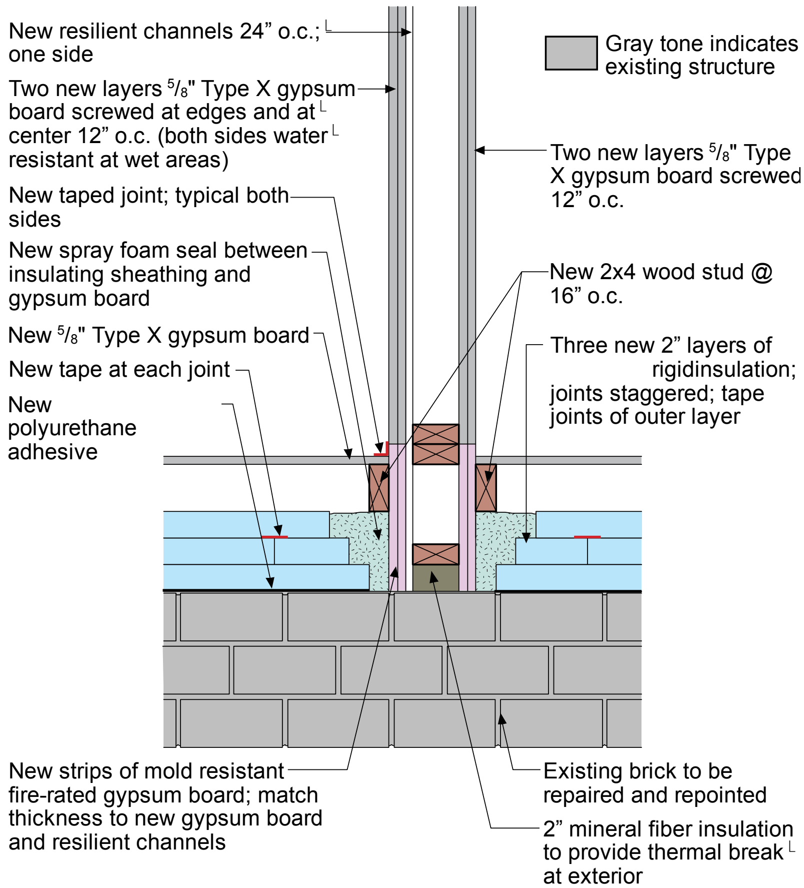

Figure 11: Rated partition intersection with exterior wall

Vapor Control

The fundamental principle of a vapor control layer is to keep water vapor out of an assembly and to also let water vapor out if it gets in. In this regard, the vapor control layer is in reality more of a vapor control "strategy" that uses materials with specific vapor control properties strategically within the assembly. It can get complicated because sometimes the best strategies to keep water vapor out also trap water vapor in.

Mass masonry walls manage moisture in a different way than modern, drained assemblies. Therefore, the balance of moisture (into and out of the wall) is strongly affected by interior insulation as the wall becomes colder. The assembly has reduced drying (because the energy flow through the wall has been reduced), and less drying to the interior (due to the addition of vapor-impermeable layers on the interior). In addition, moisture flow caused by air leakage into the interface between the masonry and the insulation can result in condensation problems; therefore, excellent airtightness is critical. The primary concern with insulating older load bearing masonry buildings in cold climates is the possibility of freeze-thaw damage of the brickwork and decay in any embedded wood structure. Both concerns are related to excess moisture content (Straube et al. 2012).

As discussed under "Cost and Performance," one insulation option is a "hybrid" approach, using ccSPF or XPS in combination with fiberglass batt or cellulose insulation. This is also known as "flash and batt" (Maines 2011). One potential problem, though, is cold-weather condensation at the interface between the air impermeable (foam) and air permeable (fiberglass/cellulose) insulation. The 2009 IRC and 2012 IRC (ICC 2009a, 2012a) provide guidance for assemblies that will control condensation for Climate Zones 5, 6, 7, 8 and Marine 4, in §R702.7.1, as shown in Table 2. The exterior insulation (e.g., insulating sheathing/spray foam insulation) raises the temperature of the condensing surface, thus reducing condensation risks. The percentage of the total insulation that is exterior insulation is shown in the table. These percentages can be used to calculate R-value ratios for the two insulation materials, in "hybrid" walls.

Table 2. Thermal resistance values to control condensation using exterior insulating sheathing, for climate zones 5, 6, 7, 8 and marine 4 from (2009 IRC and 2012 IRC).

Climate Zone	Minimum R-Value (2x4)	Minimum R-Value (2x6)	% Exterior Insulation (±)
4C	2.5	3.75	16%
5	5	7.5	28%
6	7.5	11.25	37%
7/8	10	15	44%

Thermal Control

The function of the thermal control layer is to control the flow of heat from both the inside to the outside and from the outside to the inside. As with the other control layers, the most important factor for the thermal control layer is its continuity.

CODE REQUIREMENTS FOR THERMAL INSULATION ARE FOUND IN SECTION 402 OF THE 2009 IECC AND R402 OF THE 2012 IECC.

Table 3 provides the minimum framed wall thermal resistance (R-value) requirements specified in the 2009 IECC (ICC 2009b) and the 2012 IECC (ICC 2012b) based on climate zone.

Table 3. Recommended Minimum R-Value for Wall Enclosures

	Framed Wall Minimum R-Value	
Climate Zone	**2009 IECC**	**2012 IECC**
1	13	13
2	13	13
3	13	20 or 13+5
4 except Marine	13	20 or 13+5
5 and Marine 4	20 or 13+5	20 or 13+5
6	20 or 13+5	20 + 5 or 13 + 10
7 and 8	21	20 + 5 or 13 + 10

Climate Zones and Building Environments

Buildings should be suited to their environment. Building enclosures should be designed for a specific hygrothermal region (Figure 13), rain exposure zone (Figure 14) and interior climate.

For most residential buildings, interiors are assumed to be conditioned to around 70°F in the winter and 75°F in the summer. Relative humidity should be limited to 35 percent (no higher) during the coldest month in winter and 65 percent (no higher) in the summer.

These conditions also form the basis for the requirements delineated in the model building codes. The model building codes climate zones referenced in the 2009 IECC (ICC 2009b) and the 2012 IECC (ICC 2012b) are shown in Figure 12.

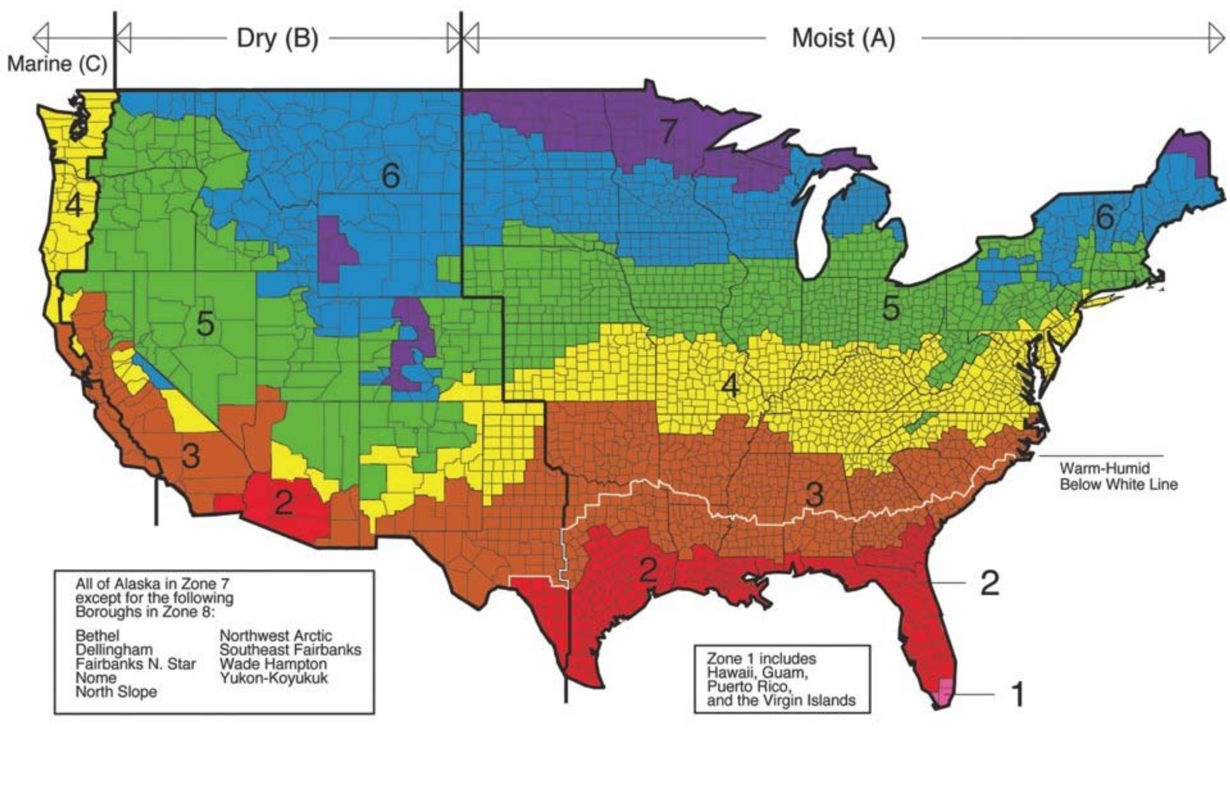

Figure 12: Department of Energy/ICC climate zones

Figure 13: Hygrothermal map (Lstiburek, Joseph. (2006a). Builder's Guide to Cold Climates. Westford, MA: Building Science Press)

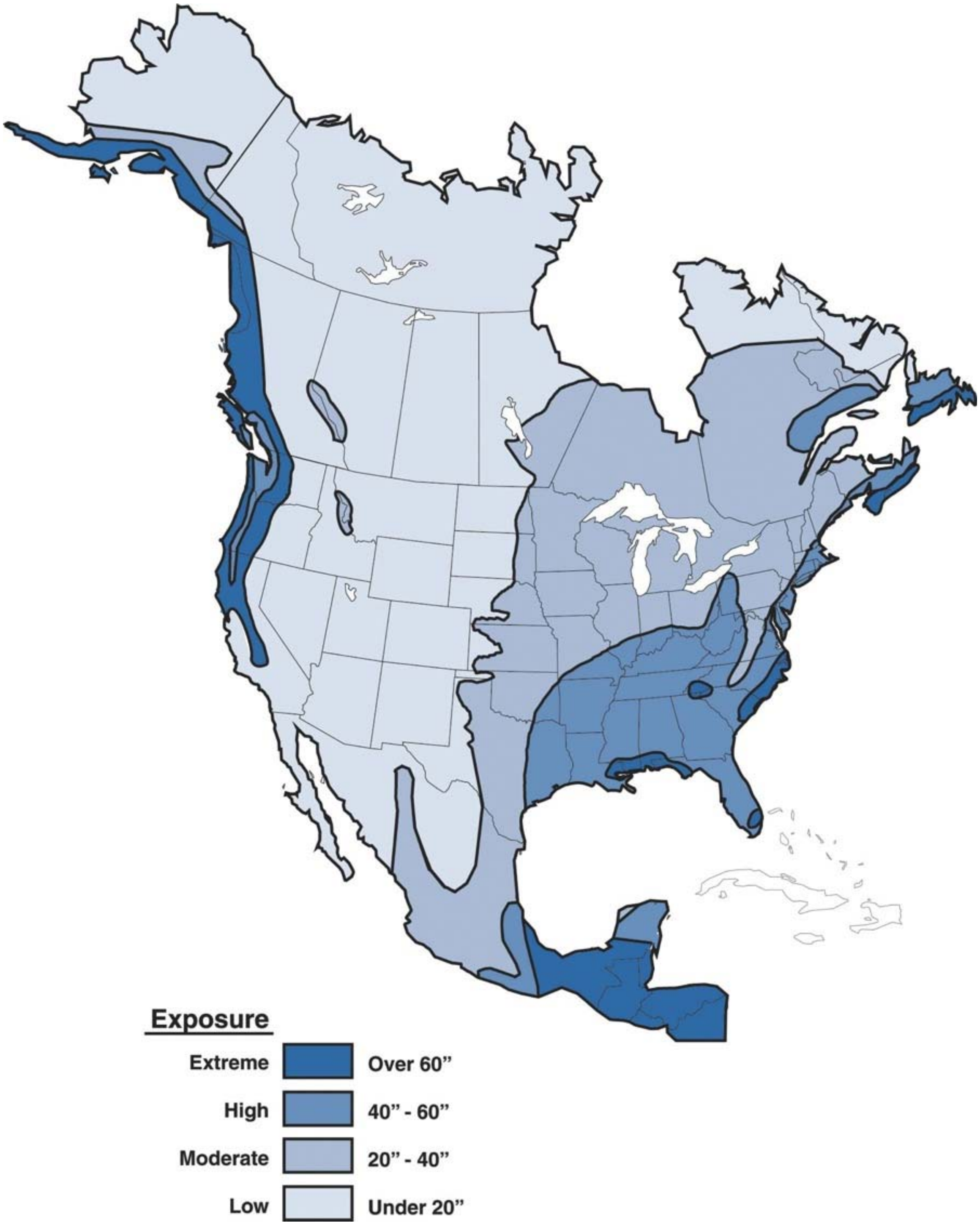

Figure 14: Rainfall map (Lstiburek, Joseph. (2006b). Water Management Guide. Westford, MA: Building Science Press)

4 Measure Implementation

Scope of Work

A. Remove any interior furring, lath and plaster.
B. Remove windows and doors as needed to allow flashing of openings and air control transitions into openings.
C. Install rigid foam board with staggered joints by applying adhesive bead, and tape the seams of the innermost board to act as an air control layer.
D. Re-install windows and doors or install new windows and doors in properly flashed openings.
E. In multifamily construction, install fire separation gypsum board and caulk the interior layer of rigid insulation to the face of the strip.
F. Seal all transitions including wall-to-window, wall-to-roof, wall-to-floor and joist ends using spray foam for air barrier continuity and to avoid thermal bridging.
G. Install framing inboard of the insulation.
H. Install interior gypsum board.

Climate Specific Factors

The building enclosures should be designed for a specific hygrothermal region and will be dependent on the design goals for the project. The assemblies should follow the minimum requirements based on the current adopted building code and energy code, respectively, for the project.

Field Inspection

Identify and address risks to occupants or the building that could be aggravated by the work. Verify safe working conditions. Determine whether the building has more urgent problems that must be addressed. Determine the feasibility of the retrofit solution and of options.
Inspect and assess the building for:

- Structural integrity of masonry wall,
- Presence of hazardous materials (e.g. lead, radon, asbestos)
- Rainwater, groundwater or plumbing water leaks,
- Rot or decay in wood members connected to masonry wall, and
- Insect/pest damage/activity.

Deficiencies or hazards must be remediated prior to the project or remediation must be incorporated into the scope of the project.

Identify any atmospherically vented (or naturally aspirated) combustion appliances in the home. With the exception of gas stoves and cooktops, combustion appliances – including fireplaces – should be direct-vented or direct exhaust-vented equipment. Atmospherically vented appliances must be replaced or reconfigured to direct-vented or direct exhaust-vented operation prior to the project or as part of the project scope.

Verify that all kitchen and bathroom exhausts are vented to the exterior of the building. Source control ventilation deficiencies must be corrected either prior to or as part of the project.

If the home lacks a ventilation system meeting the requirements of The 2012 International Residential Code (2012 IRC, ICC 2012a), Section M1507.3, a ventilation system meeting this requirement must be installed either prior to or as part of the project.

Implementation Risks

Construction and renovation work entails inherent risks to workers. All applicable safety procedures must be followed. Although the retrofit solution described in this Measure Guide does not involve high risks owing to its low-tech nature, it does involve use of adhesives and cutting foam. Therefore, it is recommended that all workers handling or cutting material:

1. Wear protective clothing and avoid exposed skin.
2. Wear goggles or similar enclosed eye protection.
3. Wear gloves.
4. Avoid spraying foam on areas not intended to be spray-foamed.

Installation Procedure

A. Remove any interior furring, lath and plaster

The interior of masonry walls may be finished with plaster, often gypsum or lime-cement based, and sometimes installed over furring strips and/or lath. In some cases, a layer of bitumen is applied between the interior finish and the masonry. Remove any existing interior furring, lath and plaster to expose the brick structure from the interior for retrofit since they could be moisture sensitive (like gypsum), or form a void that can create unintentional air leakage (such as furring and lath). Clean the brick to allow for reasonable adhesion of insulation (spray foam or rigid board). Make sure that the building is suitable for retrofit with a site assessment; possibly consider collecting brick samples for laboratory assessment of freeze-thaw degradation risk.

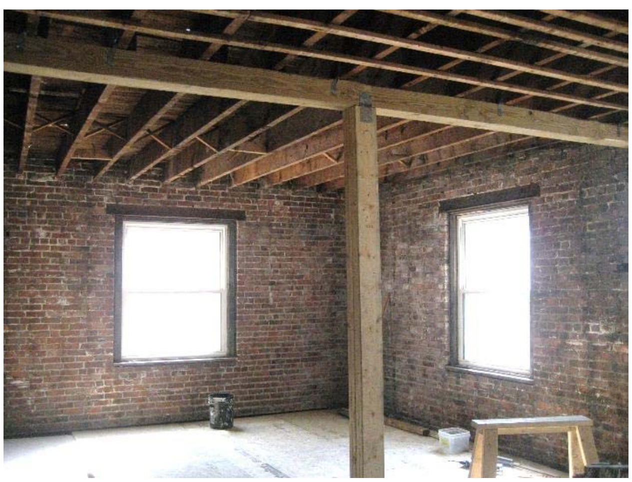

Figure 15: Interior furring, lath and plaster removed

B. Remove windows and doors as needed to allow flashing of openings and air control transitions into openings

Remove all existing windows and doors to allow flashing of openings and air control transitions into openings.

Figure 16: Removal of existing window (left) and window removed (right)

C. Install rigid foam board with staggered joints by applying adhesive bead, and tape the seams

Apply the adhesive bead on the rigid board insulation 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. A small-scale mockup could be built in case unskilled or low-skilled labor is used for construction execution to provide with a visual example of the retrofit assembly geometries.

Single-component polyurethane adhesive is shown below; an alternate product is construction adhesive that is compatible with foam (i.e., will not dissolve polystyrene). The construction adhesive option, however, has limited gap-filling properties, and will give worse performance than urethane foam (adhesion and air sealing) on uneven substrates.

Figure 17: Mockup (left); Use of polyurethane adhesive (right)

Make careful cuts around windows, doors and other wall openings while installating the rigid foam insulation and tape the seams of the innermost insulation layer. The rigid foam seams should be sealed with tape typically used for sealing housewrap or rigid foam seams (commonly referred to as “construction tape” or “sheathing tape”). Most of these tapes are polypropylene films with an acrylic adhesive.

Figure 18: Installation of foam on masonry (left); Multiple layers of insulation (right)

D. Re-install windows and doors or install new windows and doors in properly flashed openings

Refurbish, clean and repair existing window and door frames. Flash the openings properly. Re-install the existing windows and doors or install new ones.

Figure 19: Openings properly flashed (left); Window re-installed (right)

E. Install fire separation gypsum board and caulk the interior layer of rigid insulation to the face of the strip

In multifamily construction, 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, place a strip of fire separation gypsum board at the perimeter during wall construction, before the field of the ceiling is built. 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. Note that four layers of foam are used; the additional layer is a strip of foam filling the web of the steel lintel over the window. It is recommended to use non-paper faced gypsum board for the fire separation strip as it is in direct contact with the masonry.

Figure 20: Floor/ceiling fire separation gypsum board (left); Conditions after interior framing (right)

F. Seal all transitions including wall-to-window, wall-to-roof, wall-to-floor and joist ends using spray foam for air barrier continuity and to avoid thermal bridging

Carefully cut the wall rigid foam board around the windows and use ccSPF to seal the wall to window transition.

Figure 21: Rigid wall insulation around window (left) and infill with spray foam (right)

To achieve the air barrier connection between the above-grade wall and sloping roof, leave the wall rigid foam board clear of the roof and connect the wall air barrier to the roof spray foam air barrier with ccSPF.

Figure 22: Rigid wall insulation left clear of roof (left) and infill with spray foam (right)

At the joist ends, adhere scraps of rigid foam insulation with polyurethane adhesive between the joists first and then fill the rest of the cavity with spray foam insulation. Alternately, this can be simply done with spray foam insulation; foam scrap was used here for cost reasons. Note that there is a generous space at the perimeter of each block, which allows effective air sealing with a spray foam kit.

The floor detail consists of a strip of floor sheathing at the perimeter. Caulk the space between the subfloor and the rigid board insulation.

Figure 23: Rim joist foam blocks (left); air seal between rigid foam and floor (right)

G. Install framing inboard of the insulation

Install the framing inboard of the insulation. 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.

Figure 24: Framing installed inboard of insulation

H. Install interior gypsum board

Install the interior wall and ceiling gypsum board. Tie the strip of the fire separation gypsum board to the ceiling gypsum board, which provides unit-to-unit separation.

Figure 25: Gypsum Board installed

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About this Report

This report was prepared with the cooperation of the U.S. Department of Energy's Building America Program.

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