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THERMAL BRIDGING FACTORS FOR ENERGY EFFICIENCY MODELS

Main Category:	Mechanical Engineering
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MEC-139 EXAM PREVIEW

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Exam Preview:

1. Thermal bridging in building practice can usually be divided into two types: linear details that predominately exhibit three-dimensional heat flow and point details whose heat flow is primarily two-dimensional.
    a. True
    b. False
2. Using Table 2-2. Surface conductances for modeling windows and curtainwalls, what is the coefficient (W/m^2 K) for the interior center of glass?
    a. 5.0
    b. 7.5
    c. 34
    d. 45
3. According to the reference material, which of the following is NOT a performance metrics that are commonly evaluated in most assessments of thermal bridges?
    a. Condensation resistance
    b. Heat Flow
    c. Energy efficiency
    d. Comfort
4. According to the reference material, almost all enclosures must satisfy support, control, finish, and distribution functions. However, only the support and control functions are needed throughout the entire building.
    a. True
    b. False

5. In general, the physical function of separation required of the building enclosure may be further grouped into four sub-categories: Support, Control, Finish, and Distribution. Which of the following functions does drywall accomplish?
    a. Support
    b. Control
    c. Finish
    d. Distribution
6. A gap between a window or door and the rough opening is always required to accommodate construction tolerances and differential movement be-tween the enclosure and the window system. This gap, when combined with the hollow nature of many open aluminum and fiberglass window frame systems, can result in a void that is 2-3 in. (50-75 mm) wide and as deep as most of the window frame
    a. True
    b. False
7. Which of the following TB Mitigation strategies has the advantage of: much easier to achieve thermal continuity at floor slabs, partition walls, and other large and important TBs while minimizing disruption to the occupants?
    a. Thermal flanking
    b. Interrupt flow path
    c. Insulate on the interior
    d. Insulate on the exterior
8. According to the reference material, there are three broad categories of properties of insulation and materials. They can be highly conductive, moderately conductive, or insulating. Which of the following materials is moderately conductive?
    a. Wood
    b. Glass
    c. Stone
    d. Fiberglass
9. It is recommended that ventilation (with heat recovery if practical) be used to reduce the indoor RH to below 40% when outdoor temperatures are be-low 40 °F, and then to reduce the maximum RH by about 10% for every 20 °F drop in outdoor temperature.
    a. True
    b. False
10. Building pressurization should be provided by setting airflows during commissioning to develop no more than about _ Pa pressure or be managed dynamically with controls on the supply or exhaust fans.
    a. 3
    b. 5
    c. 8
    d. 10

Abstract

To meet energy reduction goals, this document investigates a number of heat transmittance factors for use in including the heat loss of thermal bridging in the energy analysis of buildings. This work provides practical guidelines for the mitigation and reduction of thermal bridge problems in existing and new facilities. A wide range of building types was investigated from which nine common types were identified, and a number of important thermal bridge details were chosen for each. A list of details was compiled, from which 30 were chosen for detailed analysis based on their significance.

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1 Introduction

1.1 Background

Approximately 25% of the Department of Defense's total energy use is consumed by buildings—over 577,000 buildings on more than 5300 sites. The U.S. Department of Defense (DoD) spent over $3.5 billion for energy for fixed installations in 2006. The Energy Independence and Security Act (EISA 2007), and Energy Policy Act (EPAct 2005) require the Army to dramatically reduce overall facility primary energy usage over the coming decades. The Army Energy Security Implementation Strategy (DA 2009) laid out the Department of the Army's strategy for large energy reductions. More recently, the Army published the "Army Vision for Net Zero," which states the ambitious goal of reaching Net Zero Energy at all fixed installations (ASA[IE&E] 2012).

This goal implicitly includes an enormous stock of existing buildings, and achieving this goal will require the implementation of building envelope performance requirements not yet seen in the Federal government. The building envelope represents an area of much needed improvement in these facilities. Guidance has already been published to encourage much more efficient building envelopes. However, that guidance does not address thermal bridging despite the fact that failure to mitigate it has been shown to represent losses of 8.45 kWh/m^2-year (2.68 kBtu/sq ft-year) to 12.6 kWh/m^2-a (3.99 kBtu/sq ft-a) in otherwise Zone H1A (Paris) high performing buildings (Citterio, Cocco, and Erhorn-Kluttig 2008).

A "thermal bridge" (TB) is a part of an envelope in which heat transfer is greater than would be expected in a wall made up of planar layers such as gypsum wallboard, insulation, sheathing, and cladding. TBs often result from the inclusion of materials of higher conductivity that "bridge" from inside to outside. Structural steel studs are a typical example; steel has a conductivity value three orders of magnitude higher than typical insulation materials (ASHRAE 2009a). Geometrical differences can also cause TBs, e.g., where increased surface area on either side causes a "fin effect," transferring more heat than a planar surface would. The concrete slab, being more conductive than the wall around it, further increases heat transfer.

TBs can be defined as localized areas of high heat flow through a building enclosure component (wall, roof, window) relative to the average heat flow through the component. They are usually caused by highly conductive elements penetrating the primary insulation layer, thereby allowing heat to "bridge" around the insulation. It has become increasingly apparent that TBs should be avoided in new construction and mitigated in existing construction because they can have a significant impact on whole building energy use, condensation, and comfort.

The impacts of TBs (Erhorn-Kluttig and Erhorn 2009) include:

- The total impact of TBs on heating energy required is significant. A study done in France found that it is possible to save 8.45 kWh/m^2-a (2.68 kBtu/sq ft-a) in heating energy by retrofitting a residential concrete building with TB mitigation. A German study found that, when compared to standard construction, a "double house" treatment of TBs can save 9.9-12.6 kWh/m^2-a (3.14-3.99 kBtu/sq ft-a) (Erhorn, Gierga and Erhorn-Kluttig 2002, Lahmidi and Leguillon Undated). In some cases, avoiding and mitigating TBs in the design can save more primary energy than installing solar hot water systems.
- The impact on cooling energy, the relative conductive contribution of which is much smaller, is less significant. However, the impact on cooling peak load is significant. A simulation study done in Greece found that, for typical Greek masonry construction, the calculated peak cooling load is 10% higher when TBs are considered (Theodosiou and Papadopoulous 2008).
- Where a European Union Member State's building code requires a default U-factor increase in buildings for which calculations do not explicitly address TBs, this value is usually found to be worse than if the thermal bridges had been explicitly calculated. That is, detailed calculation tends to predict a lower overall U-factor for a building than does the addition of a default increment. For instance, a study done in Poland, using an aerated concrete building, found that standard prediction methods lead to an additional 0.036 W/m^{2}K (0.0063 Btu/sq ft-°F-h), compared to the default of 0.05 W/m^{2}K (0.0088 Btu/sq ft-°F-h) for premium construction and 0.1 W/m^{2}K (0.018 Btu/sq ft-°F-h) for standard construction. Similarly, a study done in the Netherlands found a 3.75-11.25% improvement in their "Energy reduction value" when they use detailed calculation measures rather than the default TB penalty (Wojnar, Firlag and Panek 2009; Spiekman 2009).

The absolute impact of TBs has often been thought of as small relative to an envelope's overall losses, but this relative contribution has been increasing as buildings become more energy efficient. In fact, thermal bridging effects can be as high as a 30% of the total energy loss through the envelope (Theodosiou and Papadopoulos 2008) Singular TB will not necessarily create a considerable impact, but their superposition along the entire building certainly will. In the past, much attention was paid to improving the "clear wall" portion of the envelope – those planar areas that have regularly spaced structural components and that are free of windows, doors, etc. As additional insulation improvements in the clear wall show diminishing returns, mitigating TBs becomes the wiser investment. For example, a fenestration load for a blast-resistant window that is dominated by the thermal bridging of the frame and steel reinforced rough opening becomes increasingly worthwhile to consider.

1.2 Objectives

The overall objective of this project was to identify possible causes of TBs and to propose alternative treatments for them. The specific objective of this work was to generate a number of heat transmittance factors (Ψ and χ) for use in including thermal bridging heat loss in building energy analysis, and practical methods to implement those indices to predict and reduce overall building energy consumption.

1.3 Scope

Many small details and assumptions can yield small differences in the quantitative results. However, a high degree of precision is not needed because the quantitative inputs vary widely and because the end-use of the results is to inform decision-making. The inputs may not be well known because many of the dimensions of existing buildings are uncertain and variable, and because the property values of construction materials are influenced by moisture and age, etc., which makes them also highly variable. Since the results will be used to compare different design options, relative accuracy is more important than the absolute accuracy.

Note that, where the results of this work do not meet the needs of both the enhancement of whole building hourly energy analysis (the primary objective) and of a simplified steady-state analysis, the primary goal was given precedence.

Many methods of analysis, and assumptions made in heat transfer analysis can significantly affect the results of the analysis and on its later implementation by others. For this reason, this work summarized best practice in analysis and reporting of thermal bridging results. These results are largely in line with International Standards Organization (ISO) 10211, and were the basis of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) RP-1365 work (Lawton 2012).

1.4 Approach

This work investigated a wide range of building types from the provided drawing packages. Seven types of common buildings construction types were identified, and a number of important TB details were chosen for each. A list of 30 were chosen for detailed analysis based on their significance.

1.5 Mode of technology transfer

It is anticipated that the results of this analysis will be incorporated into a general "Thermal Bridge Catalog" and also to enhance whole building hourly energy analysis. When applied to a building energy analysis program, the results will also be useful in improving a simplified steady-state analysis, and to assess condensation risks and comfort.

2 The Effects of Thermal Bridging

2.1 Basic definitions

The effect of thermal bridging will be assessed through the use of differential heat loss coefficients that are added to the heat loss coefficient for an enclosure with no TB such that:

$$Q = (U_o \bullet A + H_{TB}) \bullet \Delta T \qquad (2\text{-}1)$$

where:

- Q = the rate of heat loss at a given time
- U_o = the heat loss coefficient for the enclosure component without considering TBs
- A = the area of the enclosure component
- H_{TB} = a factor to account for the additional heat loss caused by TBs (a heat transfer coefficient)
- ΔT = the temperature difference across the enclosure.

Thermal bridging in building practice can usually be divided into two types: linear details that predominately exhibit two-dimensional heat flow, and point details whose heat flow is primarily three-dimensional. Assigning the symbol Ψ to the transmittance of heat in two-dimensional details and the symbol χ to the transmittance of a point TB results in a heat loss equation that accounts for thermal bridging for a given building enclosure component:

$$Q = [U_o \bullet A + \Sigma(\Psi_i \bullet L_i) + \Sigma(\chi_j \bullet n_j)] \bullet \Delta T \qquad (2\text{-}2)$$

where:

- U_o = the "clear field" assembly heat transmittance
- A = the area of the assembly, including all details in the analysis area
- Ψ_i = the linear heat transmittance value of detail "i"
- L_i = the total length of the linear detail "i" in the analysis area
- χ_j = the point heat transmittance value of detail "j"
- n = the number of point TBs of type "j" in the analysis area.

Other factors, such as the existence of performance problems caused by thermal bridging, or the repair and renovation of enclosures for other reasons will change this assessment on specific projects. Oftentimes, solving or avoiding a comfort or condensation problem is sufficient reason to address a TB regardless of other factors.

In most building types, once clear wall TBs such as steel studs, floor slabs, and Z-girts are eliminated, the most significant TB conditions in terms of length, magnitude, and economic mitigation potential are window installation or "fitting" details. These also represent a commonly occurring junction quite often revisited for upgrade (to improve energy or blast resistance) or replacement.

For this reason special care was given to window detailing as a significant change can be made by following certain principals. Issues such as drainage and air sealing at these junctions are also crucial and will make a substantial difference to energy, comfort and durability. In building practice, thermal bridging can usually be divided into two types: linear details that predominately exhibit two-dimensional heat flow, and point details whose heat flow is primarily three-dimensional. To assess the effect of thermal bridging for a given building enclosure component, this work assigned the symbol Ψ to the transmittance of heat in two-dimensional details and the symbol χ to the transmittance of a point TB, and generated a number of Ψ and χ factors (heat transmittances) for use in including the heat loss of thermal bridging in the energy analysis of buildings.

Due to the generally limited magnitude of χ factors and the extra effort required for their calculation, most junctions are best accounted for with linear TB Ψ factors. However, point TBs or χ factors for elements such as steel point connections, balcony connections or steel columns may have a significant effect on energy use if often repeated in a building. Condensation may be an important issue at these points, depending on the magnitude of the χ factor, and may be a sufficient reason to take action to solve even if the problem occurs rarely in a building.

2.2 Calculation methodologies

As for most other work in this area, thermal mass (heat capacity) and temperature-dependent effects are ignored. In most cases, this is acceptable. However, dynamic effects can alter the actual heat flow for some situations (solid masonry, interactions with soil), and temperature-dependency can have a more than 10% impact.

Most modern computer-based finite element/finite volume simulation programs can accurately and repeatedly calculate steady-state, temperature-independent heat flows. The variations in results are mostly the result of the following important sets of assumptions:

1. Geometric definition of TBs
2. Definition of the Ψ and χ factors
3. Choice of thermal conductivity of materials
4. Choice of heat transfer coefficients at surfaces ("surface films") and in air-filled cavities and voids
5. Simplifications of construction geometry to model.

Assuming linearity and no thermal mass effects, models can be run at an exterior temperature of 0 °C and an interior temperature of 1 °C to automatically non-dimensionalize the results to what resembles a Temperature Index if desired.

Figure 2-1 shows an example of how the linear transmittance would be calculated for a projecting cantilevered slab edge penetrating through a wall.

In whole building energy modeling, heat flow through the enclosure depends on both the enclosure component U-values and their respective surface areas. Most energy modelers use the exterior elevations of the architectural drawings when extracting dimensions to be used for their models (Figure 2-2). In this approach, the exterior dimensions (including floor slab thicknesses) are entered. Therefore, the exterior dimensions of the buildings are used in energy modeling inputs as opposed to the interior space dimensions. This work reports the Ψ and χ transmittance values based on exterior dimensions.

Figure 2-1. Example process for calculating linear transmittances of a slab edge through a wall.

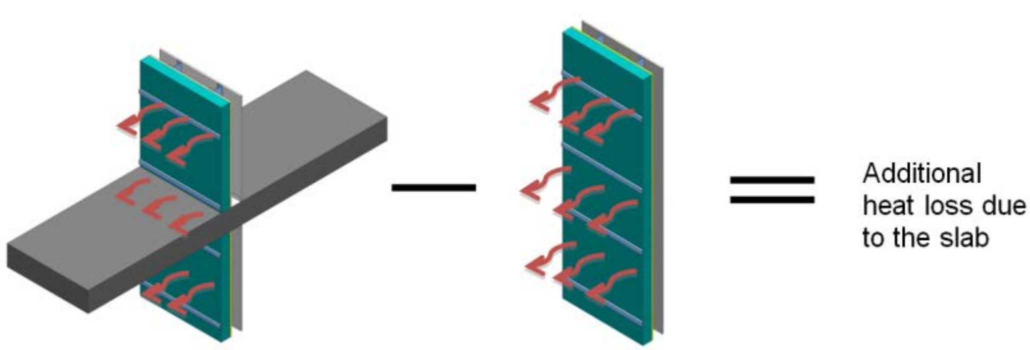
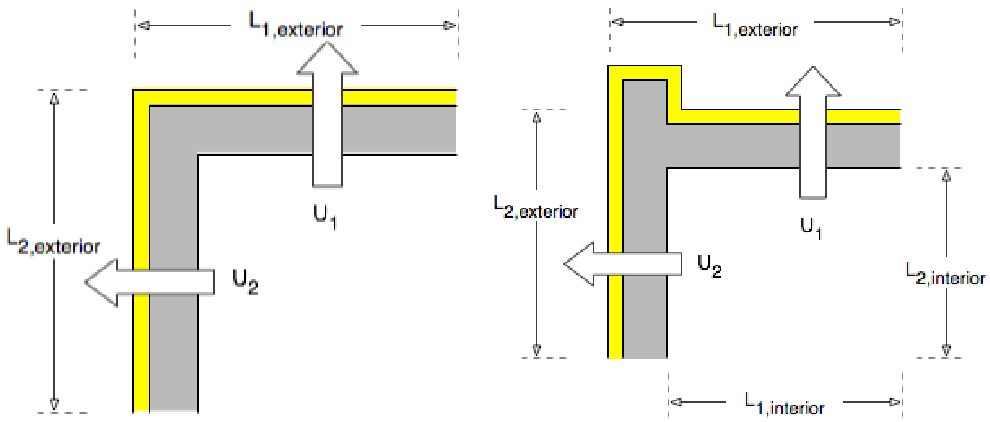


Figure 2-2. Example definitions of external dimensions for TB calculations.



The clear field U-value for a wall or roof component should include only the uniformly distributed TB effects of any typical square foot. *The linear transmittance should contain all the effects a detail has in changing the heat flow through a clear wall assembly. This includes any changes in framing, added materials like flashings or changes in exposure to the exterior*. This is done so that the area-based clear field and the linear dimension based details can be kept separate.

For example, the recurring steel studs in a steel stud assembly can be incorporated in the "clear wall" U-value for such a component. However, the top and bottom tracks at slabs and around window jambs should be included in the slab edge linear transmittance and window jamb, respectively. By not including the tracks in the clear field, the clear field U-value can remain constant, regardless of the height of the wall. If tracks were included in the clear field, a different clear field U-value would be needed for each different wall height.

For windows, the "clear wall" value is the center-of-glass U-value, and the psi-value can be defined as the entire effect of the window frames, connection detail to a specific wall, and spacer. However, in North American practice, the U-value for entire glazing products are usually provided, that is, the combined heat flow through the glazing, edge spacer, and frame. Hence, a psi-value is more usefully generated to simply illustrate the installation details of a glazing system, thereby accounting for the heat flow over and above the U-value for the glazing product.

The choice of thermal conductivity of materials is of course critical to the results. Although ASHRAE, The Chartered Institution of Building Services Engineers (CIBSE), National Institute of Standards and Technology (formerly National Bureau of Standards) (NIST) and others provide tables of thermal conductivity for many materials, slight variations in manufacture, moisture content, and age can make small differences in conductivity. Materials such as masonry and concrete have particularly large variations. Even steel, a common material that is important to thermal bridging, has a range of reported conductivity (k = 45 to 55 W/mK for carbon steel). Because of these variations, it is important that the values used in any analysis be well documented. It is recommended that material properties be taken at standard North American rating conditions of a mean of 24 °C (75 °F) as these are the most commonly available. Care should be taken to adjust European conductivities derived from testing at a mean temperature of 10 °C (50 °F).

The transfer across airspaces and from surfaces to the surrounding environment is complex. It is recommended that the thermal performance be simplified to simple lumped conductances/resistances as per standard practice. ASHRAE provides recommended values for surface transfer (summarized below in Table 2-1) intended for design conditions. The winter design condition will be used for most analysis, as it is the most extreme. In the case of average conditions, an exterior heat transfer coefficient of 17 or 20 W/m^2°C can be used.

The *ASHRAE Handbook* (ASHRAE 2009b, Ch 26, Table 3) provides a detailed table of numerous factors affecting heat transfer across airspaces. The value for heat transfer given for a mean temperature of 10 °C with a temperature difference of 16.7 °C is recommended for basic analysis. For more detailed work, enclosed air spaces within curtain wall and window framing can be calculated using ISO 10077 and ASHRAE recommendations (Table 2-2).

Table 2-1. Surface transfer coefficients.

Surface position*	Flow direction	Surface emittances	
Still air (e.g., interior)		$\varepsilon = 0.90$	$\varepsilon = 0.05$
Horizontal (i.e., ceilings and floors)	Upward Downward	9.3 6.1	4.3 1.3
Vertical (i.e., walls)	Horizontal	8.3	3.4
Moving air (e.g., exterior)			
6.7 m/s (winter design)	Any	34	34
3.4 m/s (summer)	Any	23	23
Average conditions	Any	17	16
*adapted from Table 1, Ch 26, ASHRAE Handbook of Fundamentals 2009.			

Table 2-2. Surface conductances for modeling windows and curtainwalls (adapted from ISO 10077, ASHRAE Handbook of Fundamentals 2009).

Detail	Description	Coefficient (W/m^2 K)
Exterior surfaces	Surface exposed to 15 mph (24 km/h) wind	34
Interior center of glass	Assuming interior mean radiant temperature of 21 °C and a 39 °C Delta T	7.5
Interior edge of glass	Reduced radiation and convection in edges or junction between two surfaces, applied to a distance of 30 mm from sight line	5.0
Horizontal frame surface	Reduced radiation and convection in edges or junction between two surfaces	5.0
Vertical frame surface	Aluminum frame exposed to indoor air and surfaces	7.5

Thermal transfer between materials in contact is normally assumed to be perfect. However, there is a small resistance to heat transfer because materials are never in perfect contact. This so-called “contact resistance” can be ignored when a low conductivity material is in contact with a low- or medium conductivity material, but may be important to include when metals contact medium conductivity materials. Based on computer model calibration with hot-box test result, it has been found that contact resistances between materials vary between 0.01 and 0.03 m^2 °C/W (Table 2-3). The ASHRAE Handbook suggests values of as high as RSI* 0.10 may occur, although the authors of this report have not found values this high in their experience.

Table 2-3. Summary of contact resistances.

Condition	Resistance (RSI)
Steel Flange at gypsum/wood Sheathing	0.030
Steel-to-concrete interface	0.010
Steel-to-steel interfaces	0.002
Insulation interfaces	0.010

The geometry of all models is a simplified version of reality. The use of 2D models implicitly acknowledges this. Even with 3D models, however, the level of detail required is difficult to prescribe. Does the typical radius of a steel stud corner (typically equal to twice the thickness of the steel), or a hot-rolled edge of a shelf angle need to be modeled, or can rectangular shapes be used? Masonry walls are essentially never flat, and contain mor-

* R-value [thermal resistance] Système International.

tar joints: do these joints need to be accounted for? Since there are few industry guidelines to rely on and, in most cases, the analyst's judgment must be used to assess the impact of geometric simplification.

The most common simplification might be to assume sharp rectangular corners on all concrete, masonry, and steel sections. Another simplification might be to assume that the mortar joints and voids in masonry can be included in an effective thermal conductivity of a masonry layer, i.e., the 2D and 3D heat flow effects in a hollow core masonry wall can be represented by a single thermal conductance divided by the nominal masonry layer thickness. However, the degree of simplification that is acceptable has not been well researched. It is recommended that the degree of simplification and its effect on results should be researched in future projects.

2.3 Targets for thermal bridging mitigation

Three performance metrics are commonly evaluated in most assessments of TBs:

1. Heat flow
2. Condensation resistance
3. Comfort.

Heat flow is the primary goal of this project. The TB values of psi and chi (Ψ and χ) are used to assess this goal. This method, which is quickly becoming the industry standard approach, is recommended.

For high performance buildings, it is recommended that that CERL target psi-values in the order of the U-values, per ASHRAE 189.1-2009.* That is, psi-values (in Btu/hr ft °F) of typical junctions could be considered "high performance" if they are less than the U-value(s) listed in Table 2-4.

Table 2-4. Maximum U-value (Btu/hr ft^2 °F) for Non-residential Walls (ASHRAE 189.1-2009).

	CZ1	CZ2	CZ3	CZ4	CZ5	CZ6	CZ7	CZ8
Mass	0.151	0.123	0.104	0.090	0.080	0.071	0.060	0.060
Metal	0.079	0.079	0.079	0.052	0.052	0.052	0.052	0.052
Steel	0.077	0.077	0.077	0.055	0.055	0.055	0.055	0.055
Wood	0.064	0.064	0.064	0.064	0.051	0.045	0.045	0.045

* This recommendation is an estimate based on engineering experience with existing building retrofits. Much more research is needed to define recommendation with better certainty.

Surface condensation resistance is especially important in heating climates. TBs will have low interior surface temperatures during cold weather. These cold surfaces naturally tend to be the first surfaces to experience condensation. One of the best metrics for assessing the condensation risk is the Temperature Index (TI) of a specific detail. The TI is defined by the coldest interior surface temperature (T_s) in a detail. Standards EN ISO 13788 and Canadian Standards Association (CSA) A440 both use this definition:

$$TI = (T_s - T_o)/(T_i - T_o) \quad (2\text{-}3)$$

Given the expected interior air temperature (T_i), interior dewpoint temperature (T_{dp}), and exterior air temperature (T_o) during cold weather for a particular building, the TI can be used to predict if condensation will occur by comparing the predicted surface temperature (T_s) to the dewpoint temperature. More specifically, condensation will occur for the chosen conditions if $T_{dp} > T_s$.

Comfort is more difficult to precisely measure and is the least critical metric for modern details. However, comfort may be an important driver for upgrading details in existing buildings. It can be approximated by an area-weighted interior surface temperature for a specified temperature difference, or normalized as an area-weighted TI. In special cases, a full mean radiant temperature analysis may be justified.

2.4 Using thermal bridging factors in energy models

Although assessing thermal bridging using individual factors allows better examination of those details, in many cases the interest is the impact of thermal bridging on overall building performance. To include the effects of thermal bridging transmittances in whole building energy modeling, the overall wall or roof assembly U-value inputs into the energy model should be modified by using the appropriate Ψ and χ factors. An equivalent of effective total U-value can be entered into computer energy models as:

$$U_{corr} = U_o + [\Sigma(\Psi_i \bullet L_i) + \Sigma(\chi_j \bullet n_j)]/A \quad (2\text{-}4)$$

where U_{corr} is the corrected U-value and all other terms have been previously defined.

If an energy model requires R-values rather than U-values, the surface transfer coefficients (“surface films”) that usually need to be subtracted as

R-values often do not include the film coefficients (whereas U-values often do). A corrected R-value can easily be calculated as:

$$R_{corr} = 1/U_{corr} - 1/h_o - 1/h_i \quad (2\text{-}5)$$

where:

h_o and h_i are the interior and exterior surface transfer coefficients, respectively.

ASHRAE and many other energy codes allow the use of a variety of energy simulation programs, most of which are capable of simulating the dynamic effect of thermal mass on annual energy use. Modeling thermal mass requires that the characteristics of opaque building enclosure assemblies be input by layers with information on thickness, conductance, thermal mass and the extent of framing and other TBs. Most programs have a data entry subroutine or "wizard" that calculates the effective U-value for a "clear field" enclosure assembly from such input. As such, they do not account for additional framing within the body of an assembly, and TBs that commonly occur at floor-wall and wall-roof intersections and around window, door, and Heating, Ventilating, and Air-Conditioning (HVAC) penetrations. These input routines do not usually allow for the direct entry of U-values reduced by thermal bridging effects, and so the data entry must be modified to properly account for thermal bridging.

The recommended approach to account for thermal bridging is to reduce the R-value of the layer with highest resistance and lowest thermal mass to account for thermal bridging. This is typically the insulation layer. The U-value of the layer can be adjusted by modifying the input thickness, thermal conductivity, thermal conductance, or framing factor until the U-value of the assembly matches the calculated corrected or effective U_{corr}-value that includes thermal bridging.

3 Building Enclosure Fundamentals

The building enclosure is defined as the physical component of a building that separates the interior from the exterior; it is an environmental separator. In practice, the building enclosure must provide the “skin” to the building, i.e., not just separation but also the visible façade. Unlike the superstructure or the service systems of buildings, the enclosure is always seen and is therefore of critical importance to owners, the occupants, and the public. The appearance and operation of the enclosure have a major influence on the interior environment and on factors such as comfort, energy efficiency, durability, and occupant productivity and satisfaction.

In general, the physical function of separation required of the building enclosure may be further grouped into three sub-categories:

1. **Support** functions, i.e., to support, resist, transfer and otherwise accommodate all the structural forms of loading imposed by the interior and exterior environments, by the enclosure, and by the building itself. The enclosure or portions of it can be an integral part of the building superstructure, usually by design, but sometimes not.
2. **Control** functions, i.e., to control, block, regulate and/or moderate all the loadings due to the separation of the interior and exterior environments. This largely means the flow of mass (air, moisture, etc.) and energy (heat, sound, fire, light, etc.).
3. **Finish** functions, i.e., to finish the surfaces at the interface of the enclosure with the interior and exterior environments. Each of the two interfaces must meet the relevant visual, aesthetic, wear and tear and other performance requirements.

A fourth building-related category of functions can also be imposed on the enclosure, namely:

4. **Distribution** functions, i.e., to distribute services or utilities such as power, communication, water in its various forms, gas, and conditioned air, to, from, and within the enclosure itself.

Almost all enclosures must satisfy support, control, finish, and distribution functions. However, only the support and control functions are needed throughout the entire building. Support and control functions must continue across every penetration, every interface, and every assembly. The lack of this required continuity is the cause of the vast majority of enclosure performance problems. The need for finish and distribution varies over the extent of the enclosure. It is rather unlikely to find an enclosure that requires a finish on the interior and exterior throughout the entire building. It is even more unlikely to find a building that imposes the distribution function on the enclosure over its entire surface.

The **support function** is of primary importance. Without structural integrity, the remaining functions are useless. However, the industry has reached a high level of understanding and accomplishment in this area. Support systems have evolved from massive elements pierced at a few locations, to efficient primary structural systems with lightweight framed infill and sheathing. The trend to lightweight enclosures is likely to continue as the demand for more resource-efficient buildings grows.

For physical performance, the most common required enclosure **control functions** include rain, air, heat, vapor, fire, and smoke, sound, light (including view, solar heat, and daylight), insects, particulates, and access. Again, as these functions are required throughout the entire building, continuity of these control functions, especially at penetrations and connections, is critical to a successful enclosure. The most important control function with respect to durability is rain control followed by airflow control, thermal control, and vapor control. The level of fire and sound control required varies with code requirements and owner requirements.

Unlike the control and support functions, which rely on continuity to achieve performance, the **finish function** is optional, and may not be needed in some areas. For example, the finish is often considered unimportant above suspended ceilings or in-service or industrial spaces. Exterior finish is often termed “cladding,” but this use of the term is imprecise, since cladding systems and materials often includes some control functions (such as ultraviolet [UV] control, solar control, impact resistance, etc.) while also providing the finish function.

The **service distribution function**, a building function often imposed on the enclosure, largely services the adjacent interior spaces and only needs to be met where there is a service or utility to be distributed. Large proportions of most enclosures do not need to fulfill this building function. The distribution function of the building however usually impacts the control-related functions. For example, service entrances penetrate the entire enclosure, and pipes, ducts and wires that run through insulated stud spaces can seriously reduce the performance of insulation installed here.

Confusion about the classification of the functional roles of enclosure components and materials is far too common. This confusion can cause serious performance and durability problems, for example:

- Vinyl wallpaper is often applied as a finish, but in fact fulfills the control-related function of vapor diffusion control and acts as a Class I vapor control layer. This unintentional control of diffusion can, and too often does, create serious mold problems in air-conditioned buildings.
- Drywall is often seen as fulfilling a finish function, but in fact, the paint is more often the finish and the drywall often serves as a control layer for fire, sound, and air flow. If a designer or builder stops the drywall above a suspended ceiling because a finish function is not needed here, the required fire, sound, and airflow control will be missing.
- A thick self-adhered bituminous membrane is often used to drainwater and control airflow in high performance assemblies. However, this membrane is also a very low permeance vapor control layer. Locating it on the outside of all or most of the insulation in a cold climate can lead to damaging cold weather condensation.

From a more practical point of view, it is useful to divide the functions of the enclosure into various sub-categories that may be assigned to actual products and sub-system assemblies. With respect to the control function, these are termed *control layers*. The most important and commonly defined enclosure control function layers are, in approximate order of importance:

1. Water/rain control layer (e.g., drainage plane and gap or waterproofing)
2. Airflow control layer (e.g., an air barrier system)
3. Thermal control layer (e.g., insulation, radiant barriers, etc.)
4. Vapor control layer (e.g., vapor retarder or vapor barrier as required).

Each control "layer" may be a single material, or a sub-assembly of materials that together provide the control desired. In many cases, two or more of the control functions are provided by a single material or layer. For example, a membrane may provide water and air control, or spray foam insulation may provide vapor, air, and thermal control.

Figure 3-1 shows an idealized enclosure with the four control layers labeled, along with cladding, support, and interior finish function layers. The water, air, and vapor control layers are shown as lines to indicate that they can, in reality, be quite thin (e.g., less than $^{1}/_{16}$ in. or 1 mm) and still perform their functions very well. The support and the thermal control layer are shown as thicker components, because in practice these layers need to be thicker (e.g., well over 1 in. or 25 mm) to perform their function. Depending on loads and spans, the vertical support structure will usually be in the range of 3 to 8 in. (75 to 200 mm). Depending on its properties, the climate, and building design, the thermal control layer will usually be 2 to 10 in. thick (50-250 mm).

Figure 3-2 depicts the special, but common and practical, case of an assembly that collapses the water, air, and vapor control layers into a single physical material (such as a peel-and-stick membrane), and provides an optional service distribution space and interior finish.

The key to high performance is that the four control layers be provided and that they be as continuous and unbroken as possible across penetrations and transitions. The design and construction team must be able to identify the materials/sub-assemblies that provide each of the four control functions. Once the control layers in each enclosure component (e.g., window, roof, wall) are identified or specified, continuity analysis is conducted by drawing a line for each control layer around the entire enclosure through all penetrations and transitions. Any interruption in a line is a defect that must be rectified.

Figure 3-1. Idealized enclosure showing the four primary control layers.

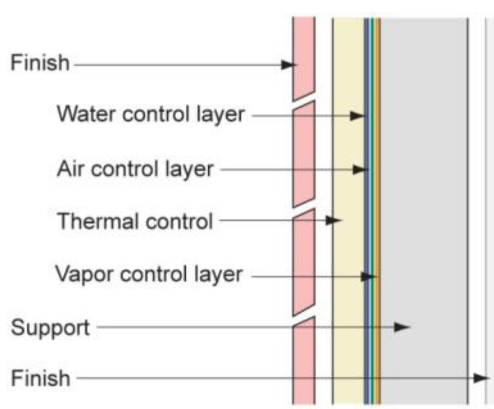
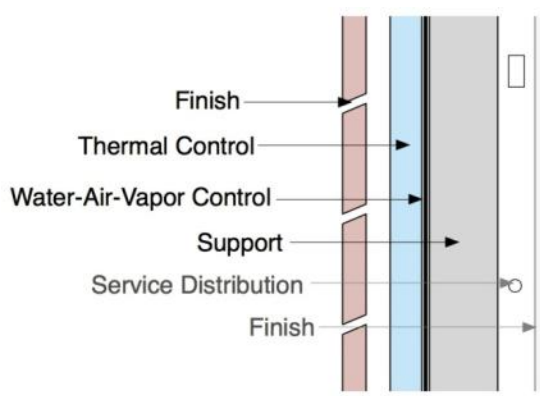


Figure 3-2. Idealized enclosure with service distribution and finishes.



Although control layers are commonly defined and labeled as such in modern enclosure designs, they are often more difficult to identify in existing and historic buildings. Older buildings used masonry as the primary water control layers (i.e., the storage or mass approach to rain control) and as the support function (Figure 3-3). Air flow control was often a layer of interior plaster or exterior stucco, although sufficiently thick and impermeable masonry could fulfill that role.

A masonry wall retrofit for improved thermal control often uses spray foam as both a thermal control layer and air control, and requires a new interior finish/fire control layer in the form of gypsum board on steel studs (Figure 3-4). Alternatively, a higher performance lower-moisture-risk retrofit that changes the exterior appearance could use an Exterior Insulation Finishing System (EIFS) on the exterior and empty steel studs on the interior (Figure 3-5). Labeling the control layers acts as a design quality control tool, and as a means of effective communication in construction documentation.

Figure 3-3. Existing solid masonry wall showing control layers.

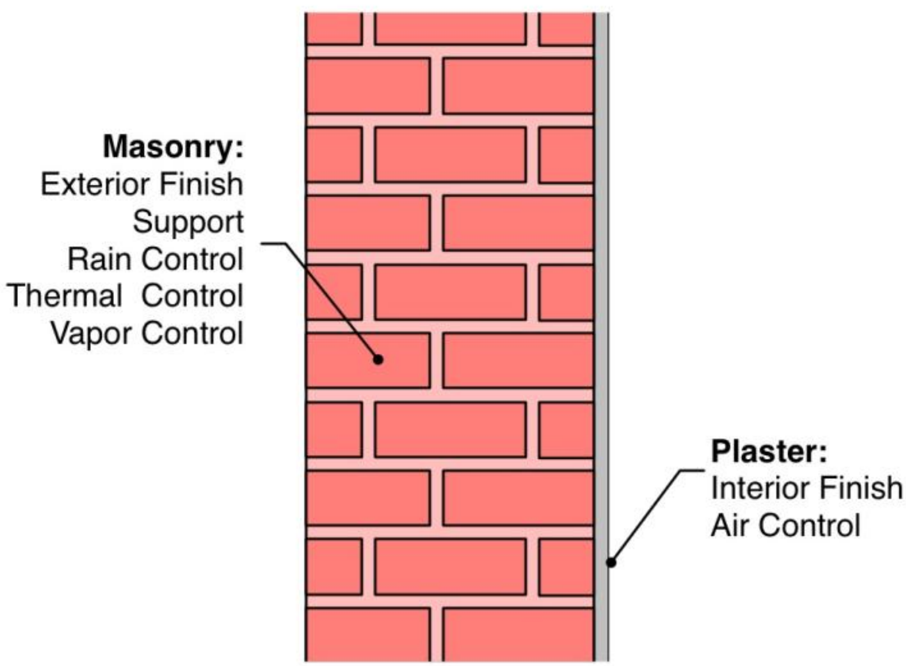


Figure 3-4. Interior retrofit of solid masonry wall showing control layers.

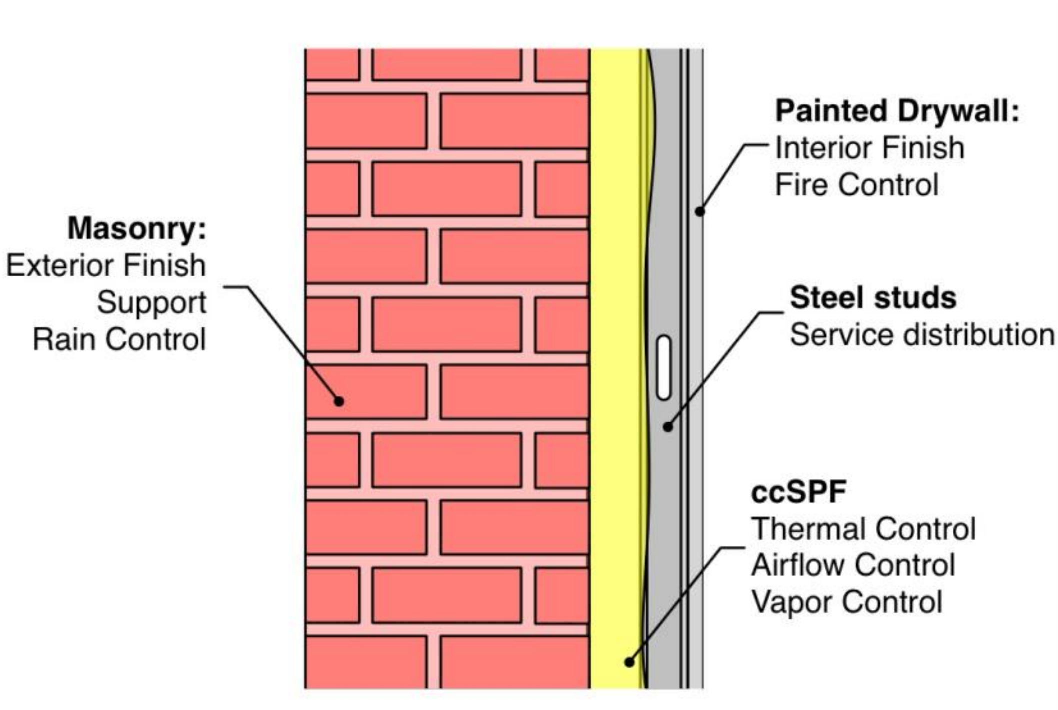
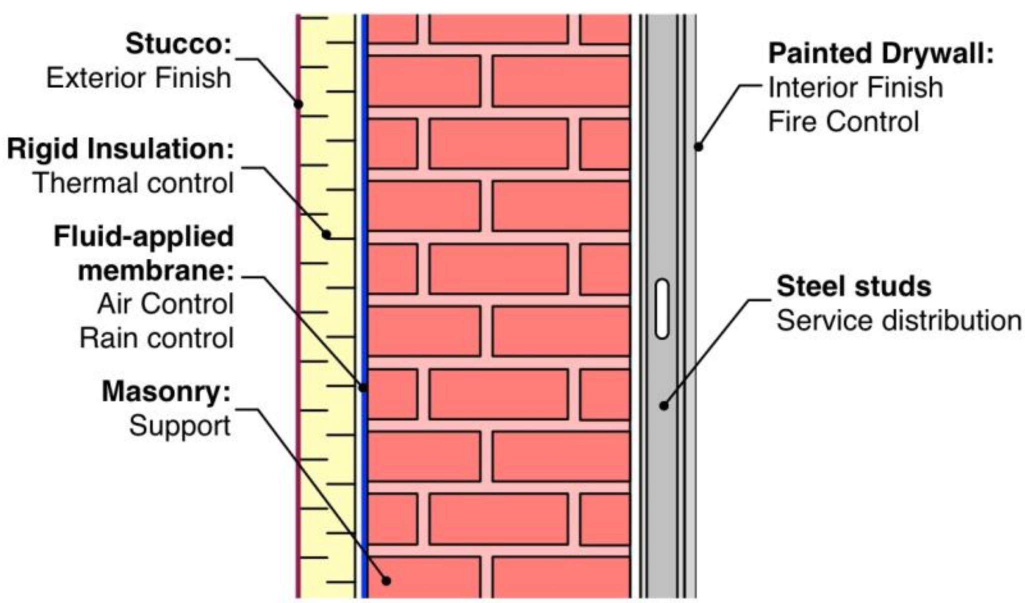


Figure 3-5. Exterior retrofit of solid masonry wall showing control layers.



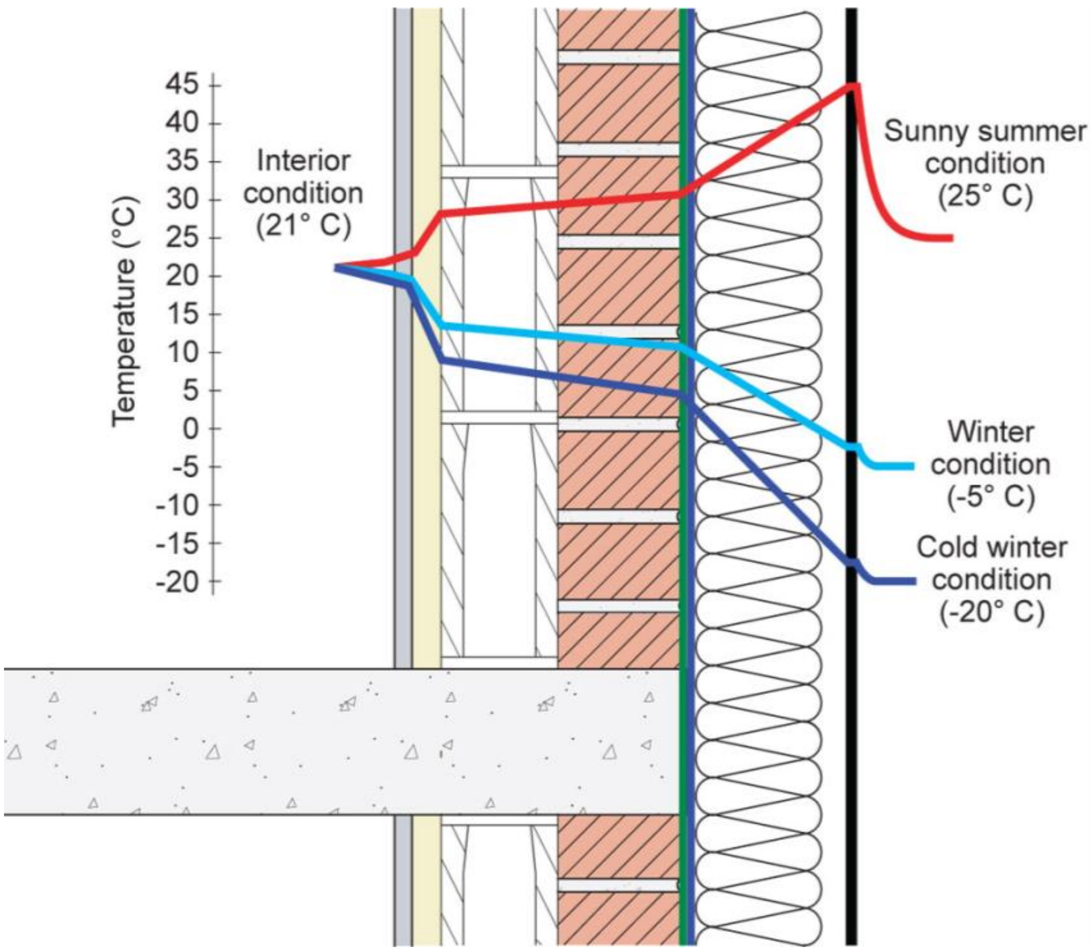
4 TB Mitigation Strategies

Three general approaches to reducing heat flow through TBs, all of which attempt to block the heat flow path are to: (1) insulate on the exterior, (2) insulate on the interior, or (3) block the flow path.

4.1 Insulate on exterior

Insulating on the exterior breaks the TB on the exterior of the structure by providing thermal insulation over the existing structure (Figure 4-1).

Figure 4-1. Exterior insulation retrofits maintain existing structure at stable temperatures.



4.1.1 Advantages

This approach has the major advantage in that it is *much easier to achieve thermal continuity at floor slabs, partition walls, and other large and im-*

portant TBs while minimizing disruption to the occupants. It is relatively simple to add air and water control to the exterior of the existing building at the same time as insulation, thereby maintaining the existing structure and enclosure at more stable temperatures and much drier conditions. Thus, *exterior insulation retrofits deliver the highest technical performance at the lowest technical risk of durability and moisture problems.*

4.1.2 Concerns and disadvantages

The major disadvantage to insulating on the exterior breaks is the need to reclad the building, potentially incurring extra costs and changing the appearance of the building. Other concerns relate to structural issues of attaching claddings, hand rails, sunshades, etc.; accommodating required setbacks from neighboring buildings; selecting the appropriate cladding (ensuring appropriate impact resistance, fire resistance, etc.); and dealing with trim details at windows, doors, and parapets. The insulation choice is often limited to products that can resist moisture, resist some wind, meet fire codes, etc. These choices tend to be foam plastics with some fire resistance and stonewool semi-rigid boards.

Detailing flashings and finishes at penetrations, especially windows, is a design challenge. It can be difficult to flash to the outside over larger gaps while avoiding the sagging of polymeric flashing membranes and the thermal bridging of metal flashing. It can be a challenge to ensure drainage from window openings. Windows, if left in place without treatment, often act as TBs, especially around their rough openings.

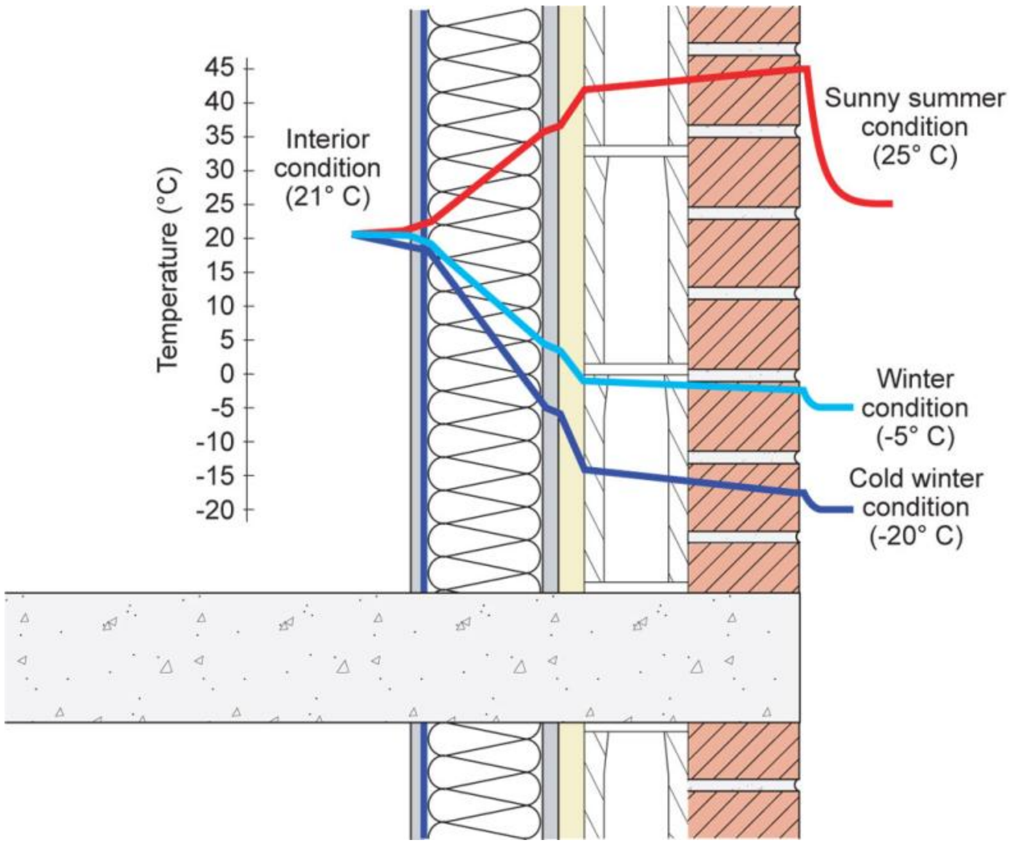
During construction, there is often less control of quality because of weather impacts, and access may be more difficult especially on tall multistory buildings.

In hot-humid climates (or during warm humid weather), inward air leakage may result in increased condensation on the existing structure (especially steel and gypsum) after insulating. In such situations, a water control layer is often required on the exterior of the existing assembly.

4.2 Insulate on interior

Insulating on the interior breaks the TB on the interior of the structure/ enclosure by adding insulation and thermal breaks (Figure 4-2).

Figure 4-2. Interior insulation reduces the interior temperature of the existing wall in cold weather.



4.2.1 Advantages

The primary advantages of this approach are that it allows the exterior appearance to remain the same, and it avoids the expense of new cladding. Work can be done room-by-room, which may assist sequencing (but often reduces productivity). Indoor work is protected from the weather (which can be a significant issue) and requires no access to the façade.

4.2.2 Concerns and disadvantages

The primary disadvantage to insulating on the interior breaks is that thermal continuity is difficult/impossible to achieve at floor slabs and partition walls, and at windows (if left in place).

Another concern is that, in cold climates when the existing structure and enclosure are closed off from the exterior conditions, interior insulation entails some risk of durability problems. In cold weather, this can result in air leakage condensation (if outward air leakage occurs), freeze-thaw damage of frost-susceptible materials (e.g., older masonry), and even corrosion, rot, and mold due to slower drying brought on by reduced heat flow from the interior.

Selection of interior insulation must consider fire performance (especially if the interior finish is not continuous above ceilings or at interior soffits), vapor resistance, air permeance, and moisture tolerance. After insulating, new interior finishes will be required with appropriate consideration of fire performance and impact resistance.

After insulating on the interior breaks, the exterior enclosure may still require expenditure for renewal and repair, as interior retrofits will not often resolve rain and air leaks through the existing enclosure. A last consideration is that the room-by-room approach used in interior work often limits the productivity of construction work, especially if rooms are small.

4.3 Interrupt flow path

Reducing heat flow into or out of a highly conductive pathway can become the “rate limiting step” that reduces the total flow through the bridge. This method usually applies only to materials with complex geometries or that are highly conductive, especially window frames, structural penetrations, etc. An understanding of the thermal “choke point” allows one to make better decisions about where to add thermal control.

Because heat flow often occurs as a series flow, the addition of thermal resistance near the outside of a TB will theoretically reduce the flow of heat as much as adding resistance near the inside. However, the location of the intervening insulation layer must be chosen with care to control the interior temperature. Figure 4-3 demonstrates the impact of locating a thermal break in line with the insulated glazing unit (IGU) during cold weather. Inside the thermal break (“choke” point), the frame is close to the interior temperature; outside the thermal break, the frame is cold and close to the exterior temperature.

Figure 4-4 shows an example of the impact of thermal break location where the thermal break in (notionally a conductive window frame with thermal insulation added) will behave differently depending on the choices made. For the same insulation value applied in all scenarios, A will have the coldest surface temperature.

Figure 4-3. A thermal break in an aluminum window frame provides an interruption to heat flow.

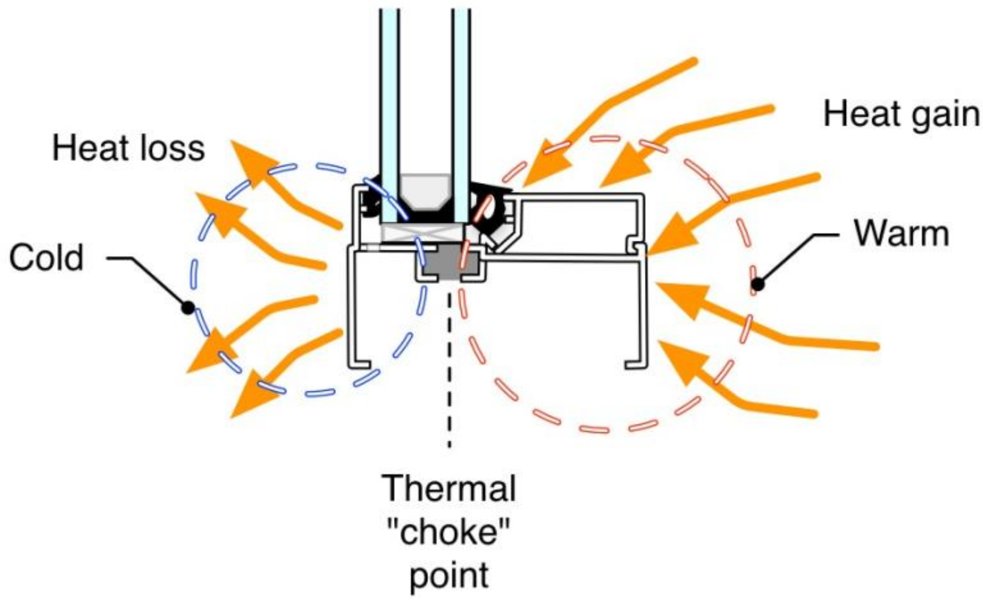
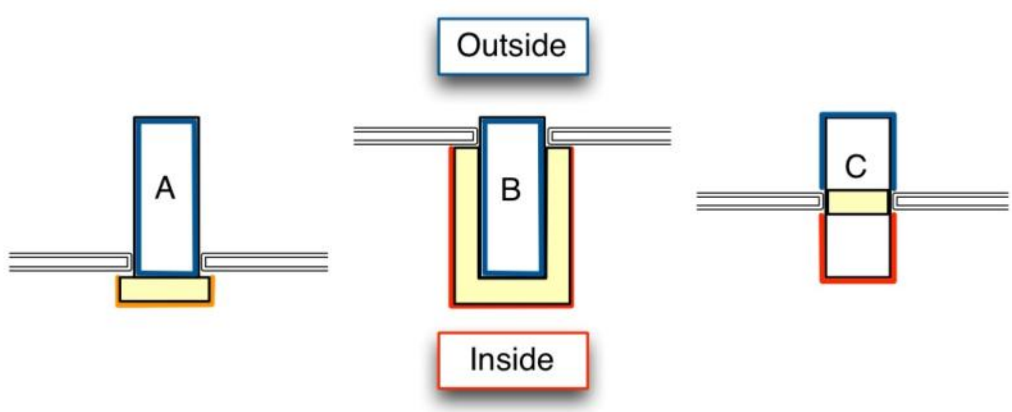


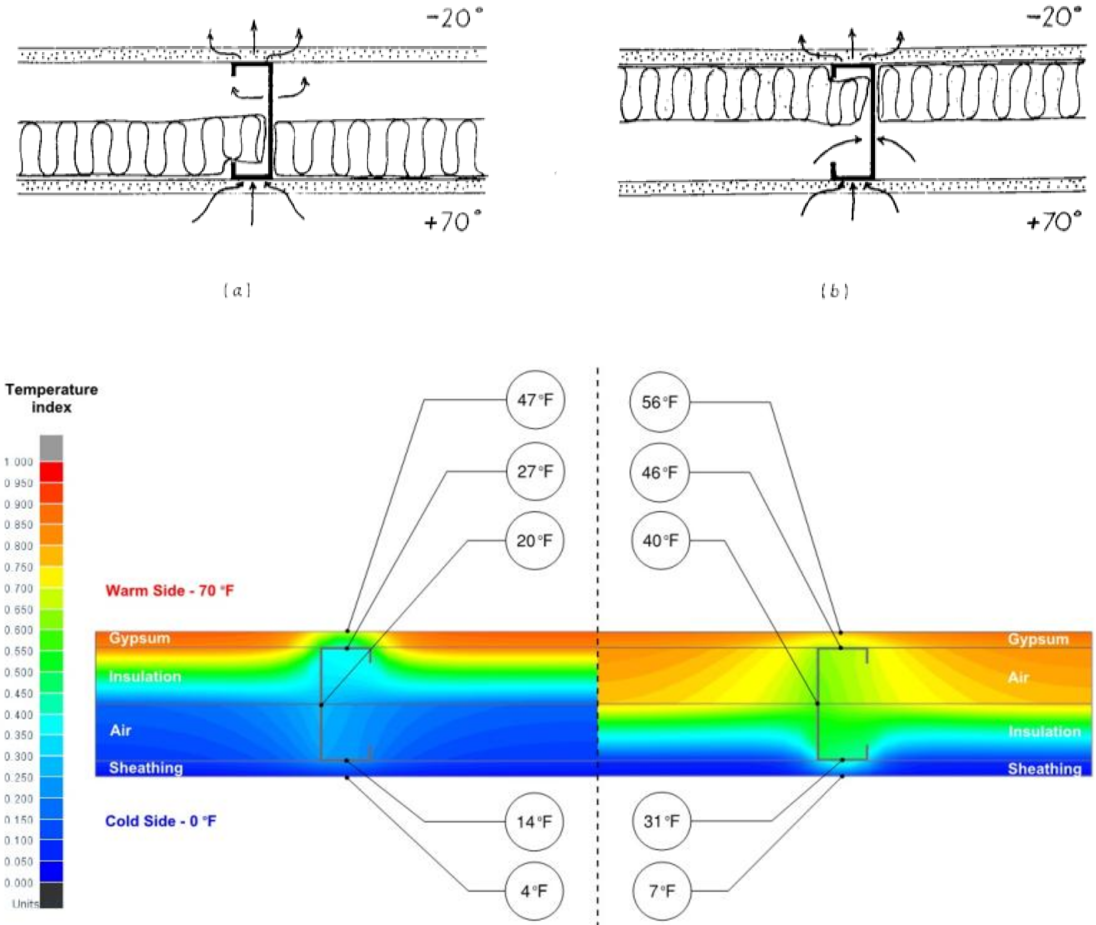
Figure 4-4. The location of the thermal resistance at a TB impacts interior surface temperature, condensation risk, and heat flow.



In Scenario A, there is a significant area exposed to the cold outside, relative to the small inside heat collection area. Hence the interior surface temperature may be low, but the insulation will work well to reduce heat flow, much better than in Scenario B (Figure 4-5).

Scenario B has a large insulated area that is exposed to a temperature drop, thereby increasing heat flow relative to A, maintaining the temperature of the frame at a relatively high (but still cold) level.

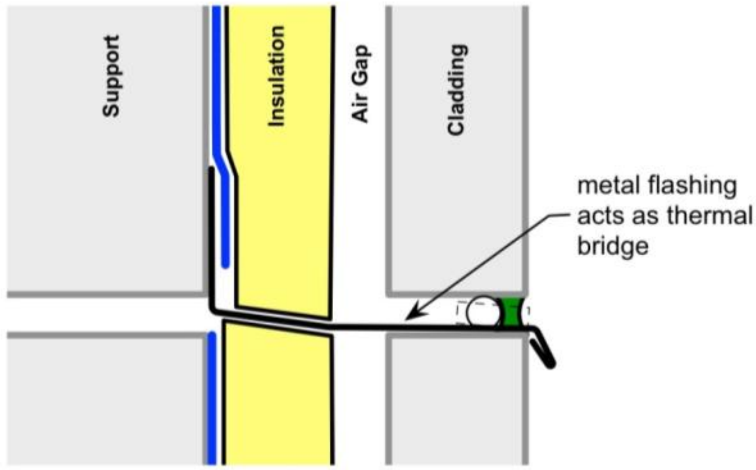
Figure 4-5. Locating insulation as in Scenario A results in lower interior surface temperatures because of higher heat loss area than heat collection area.

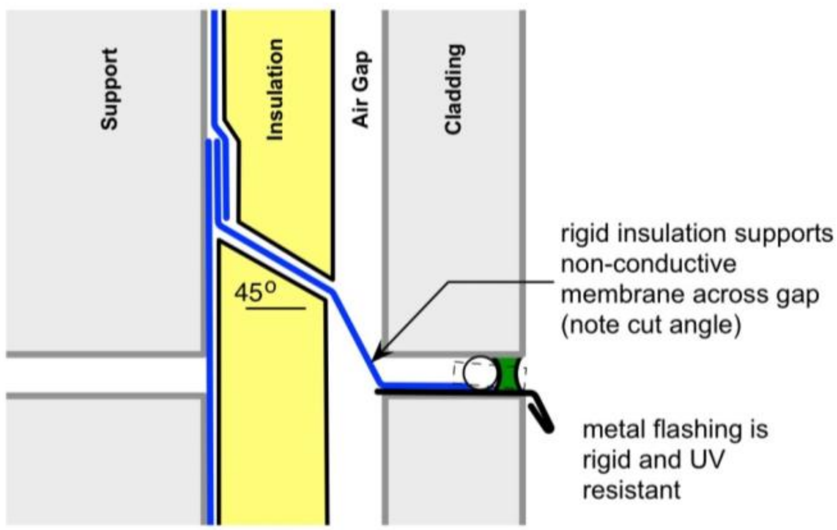


Scenario C does not have heat flow quite as small as A, but has surface temperatures that are quite high, i.e., warm. Also, note that Scenario B has a much larger risk of condensation if water vapor can pass through the inner surface and reach the large cold frame area.

Metal flashings that penetrate the insulation layer are another example of a TB that can be rectified. The easiest approach is the use metal flashing only to cross part of the insulation and take water to the exterior. Polymeric, self-adhered membranes are much less conductive and hence can be used to connect the water control layer on the face of the wall to the metal flashing. One should take care when taking this approach to ensure that the unsupported polymeric flashing does not sag and allow drainwater to become trapped within the wall (Figure 4-6). Metal flashings can be used to support membrane flashings across larger air gaps (i.e., over about 1 in.), but are not needed for small gaps if the geometry encourages outward flow.

Figure 4-6. Heat flow through metal flashings can be broken with careful use of membranes.





Thermal breaks in the form of plastic, wood, and rubber are commonly used to interrupt the heat flow path in windows and curtainwalls. It is important for these breaks to be aligned with the thermal resistance of the wall and with the thermal resistance of the IGU (i.e., the center of the IGU). Bypassing these thermal breaks with conductive elements such as steel lintels and aluminum receivers is common, but easy to avoid in design.

4.4 Thermally-broken structural connections

Thermal breaks with high strength, stiffness, and creep resistance are required in structural connections such as canopies, balconies, and sign connections, cladding attachments, brick ties, and window supports. This limits designers' choices. Another common method of creating a thermal choke point is to reduce the area of the thermally conductive element. For example, reducing the area of steel, aluminum, or concrete penetrations of the primary thermal control layers can be quite effective. However, in the case of metals, cross-sectional area reductions of 75 to 95% are often needed to reduce heat flow by even half. Fortunately, this is often easy to accomplish in structural design, as the use of steel knife-edge supports can provide this level of heat flow reduction.

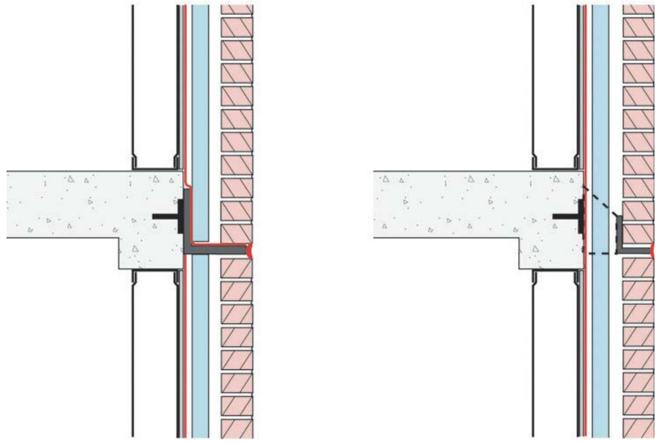
Figure 4-7 shows how this method might be used at a relieving angle. Such an approach also often improves the ability of the connection to be sealed against both air and water penetration. Combining a reduction in area of metal with the use of stainless steel (which has 1/3 the conductivity of carbon steel and less than 1/8 the conductivity of aluminum) can often yield usefully large reductions in heat flow.

Some beams that penetrate the enclosure can also be designed as propped cantilevers (e.g., at canopies or balconies) that allow for significant reductions in heat flow by reducing the steel area penetrating the insulation by the use of bolts in tension and shear (Figure 4-8) rather than hot-rolled sections. This solution performs well thermally if the bolts are made of stainless steel (which is 1/3 as conductive as carbon steel) and if the gap between beam ends is filled with insulation and (critically) is aligned with the insulation layer of the wall or roof. It can be quite beneficial to cover one or both ends of the connection to prevent the flow of heat into or out of the connection. It can be also important cover the ends of the bolts to reduce heat flow.

Wherever possible, a low conductivity thermal break, such as a pad of glass-reinforced nylon or fiberglass sheet, should be added to provide further thermal resistance where modeling shows it to be useful (Figure 4-9). These measures must be assessed to confirm they have sufficient structural strength and stiffness, and that they provide sufficient fire resistance.

To control condensation in cold climates, structural connections made of metal will often benefit from being insulated on the interior with an air- and vapor impermeable insulating layer such as closed-cell spray foam (an air and vapor resistant insulation). This layer prevents interior humid air from contacting surfaces below the dewpoint temperature of interior air even at the small areas that sometimes remain in a thermally-broken connection. Because vapor diffusion may also allow cold weather condensation, vapor impermeable insulation should be used.

Figure 4-7. Replacement of masonry veneer relieving angles with standoffs reduces the area of steel and hence the heat flow through this TB.



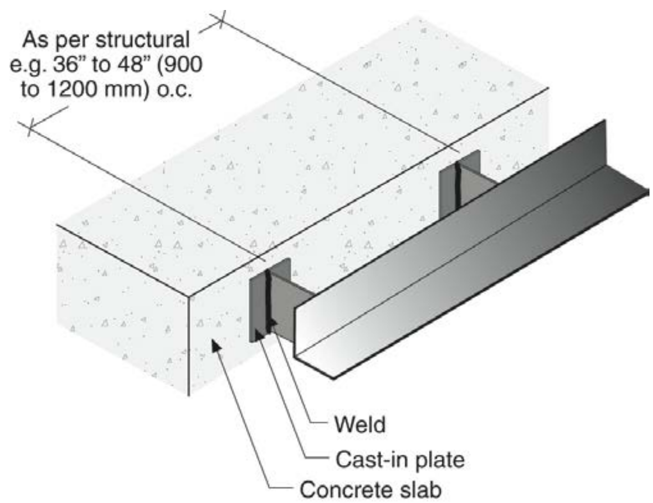


Figure 4-8. Thermally improved beam connection at the point where it penetrates the insulation layer in an enclosure.

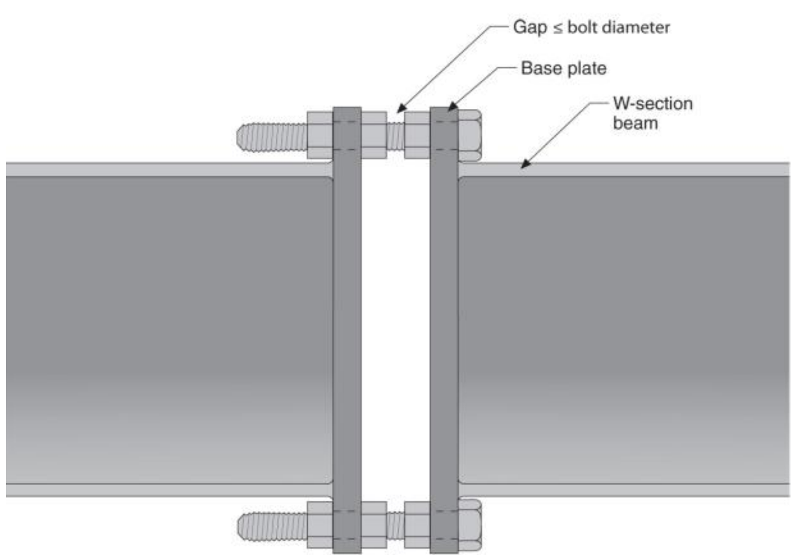
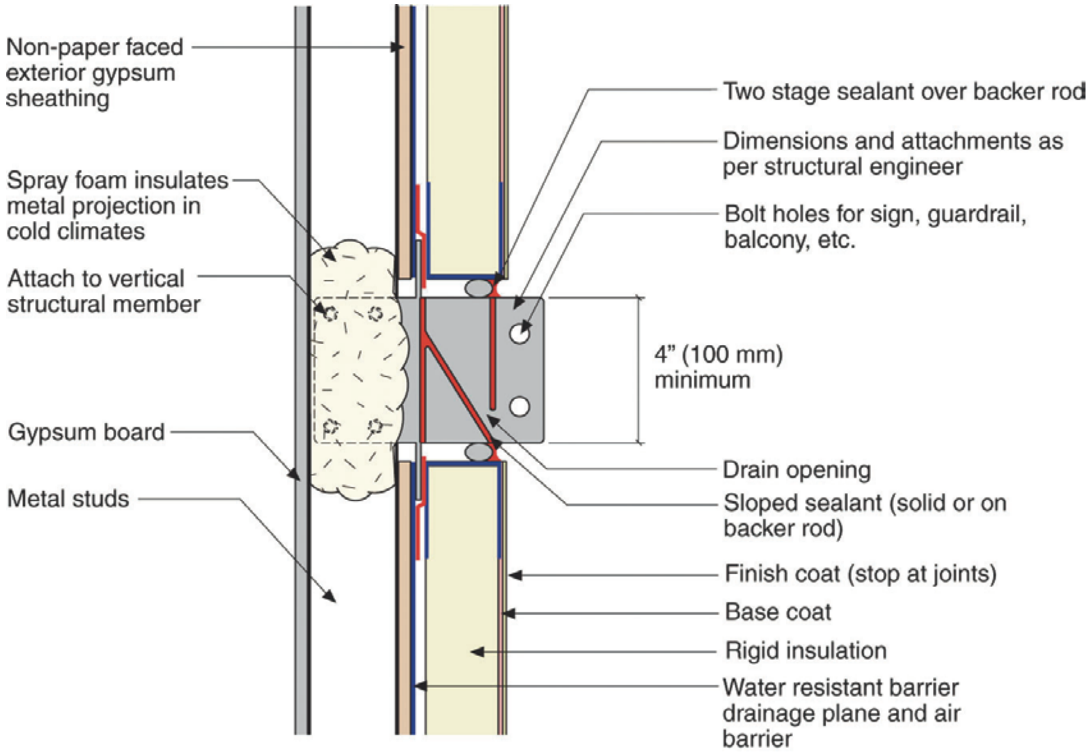


Figure 4-9. Insulation on the inside of structural connection penetrating insulation to control cold weather condensation.



4.5 Thermal flanking

In some scenarios, heat flow may bridge around insulation by traveling through conductive elements that are not perpendicular to the enclosure surface. The heat flow path is curved or "bent" in such TBs. This "thermal flanking" is an important problem to identify and rectify. Figure 4-10 shows an example of thermal flanking in a retrofit project that installed highly-insulating windows in a thick masonry wall. Figure 4-11 shows the use of thermal flanking around a thermal break in a curtainwall. Not dealing with the thermal flanking loss would significantly reduce the effectiveness of the window upgrade and potentially cause condensation problems during cold weather.

Figure 4-10. Thermal flanking around a new high performance window in a thick solid masonry wall.

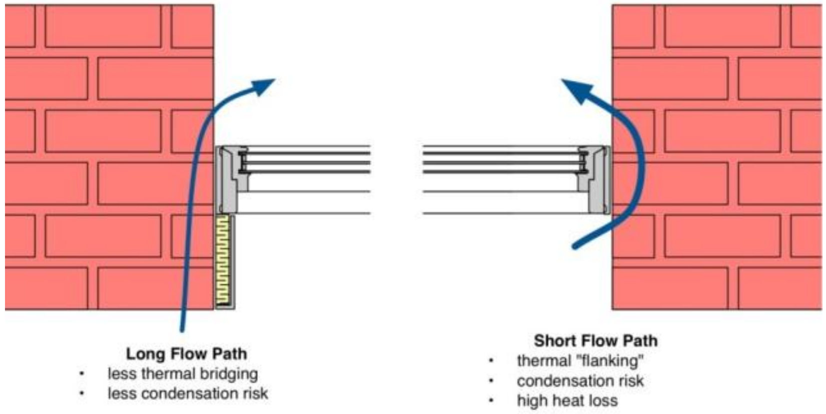
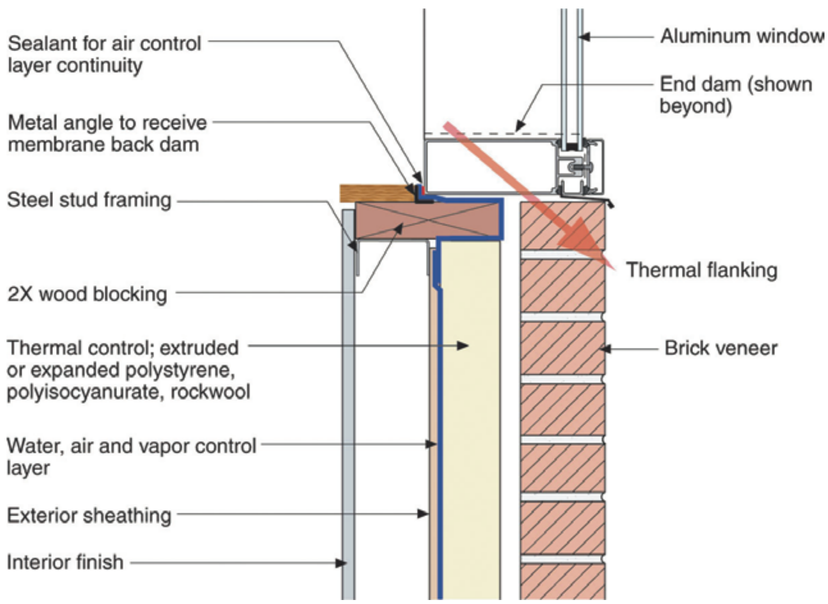


Figure 4-11. Thermal flanking around thermal break in a curtainwall.



4.6 Properties of insulation and materials

It is useful to understand the wide range of material conductivity that building materials have, so that TBs can be anticipated by inspection of the design drawings. Three broad categories are:

- Highly conductive (R-value less than about 0.1 per inch, k more than 1.5 W/mK): steel, aluminum, glass, concrete, metal flashing, brick, stone
- Moderately conductive (R-value of between about 0.1 and 2 per inch): wood, gypsum, dense polymers (nylon, polyvinyl chloride [PVC,] fiber-glass), sealants, rubber

- Insulating (R-values over 2 per inch, k<0.07 W/mK): extruded polystyrene (EPS), expanded polystyrene (XPS), polyisocyanurate (PIC), fiberglass, stone wool.

High strength materials (often used to perform support functions) almost always have high thermal conductivity. Low conductivity materials (i.e., insulations), almost always have low strength. However, some insulations have sufficient strength that they can be used to develop details that can reduce thermal bridging and also provide sufficient structural support for their purpose. For example, EPS can be readily specified with compressive strengths that range from 20 to 100 psi at 10% deformation. Wood, while not commonly considered an insulation material, can often be used in specific details to provide moderate insulation (R1/inch) and relatively high strength (allowable compressive strengths of 1000-3000 psi). Plywood, with a slightly lower R-value than wood, has an allowable compressive strength of about 200 psi, but higher bending strength than solid wood.

Different insulations have different characteristics that must be considered during design when specifying products. Different materials and different forms of product are available. The important characteristics, in approximate order of importance, that must be considered include:

1. *Physical strength*: Can it be fastened to a wall, or must it be installed between framing? Can it withstand roof foot traffic? Does it provide sufficient support for the cladding?
2. *Moisture resistance*: Can it be used outside the water control layer in walls, below grade, or above a roof membrane in a low-slope roof?
3. *Fire properties*: Can it be used in non-combustible buildings? What is its flame spread rating? What protection is required for use?
4. *Vapor permeance*: Is a vapor barrier, vapor retarder, or vapor open? Does the enclosure design require a certain level of permeance?
5. *Air permeance*: Is the insulation air permeable enough to act as part of an air barrier system? Can it resist wind washing convection losses, or does it have little to no resistance?
6. *Thermal conductivity*: What is the thermal resistance per unit thickness (e.g., R-value per inch)?
7. *Insect resistance*: What is its insect resistance if buried in contact with soil in termite zones?
8. *Cost*: What is the likely installed cost per unit of thermal resistance provided? Does this cost include other features such as air and vapor control?

Note that the R-value/inch (thermal conductivity) of insulation is actually a tertiary concern, and other characteristics often govern the selection.

Board insulation of EPS, XPS, and semi-rigid stone wool all have decades of successful use in below-grade and above-grade applications, including walls and roofs, when exposed to rain and soil moisture. Polyisocyanurate can be used in above-grade walls, even where exposed to moisture, provided the facers are inorganic (i.e., foil or glass fiber).*

Closed-cell spray foam insulation can be used in damp locations such as outside the water control layer, and below grade. Open-cell spray foam can be used on the interior of all enclosure types, including below-grade assemblies. Both products are capable of providing excellent airflow control, and conforming and adhering to rough surfaces, making them common choices for interior masonry retrofits. Like most plastics, they do not support mold growth.

Low-density fibrous batt and roll insulation of various mineral fibers (glass, rock, slag, etc.) is economical, but limited to interior applications where support is provided by framing or by a strong facer attached to the wall/roof. This form of insulation requires care during installation to prevent excess compression and voids.

Sprayed fiberglass, rockwool, or cellulose fibers can be used as insulation on the interior of enclosures when protected from wetting, and can conform and adhere to rough surfaces. Some products (especially cellulose) require framing to support them, but none of these products can provide air tightness or vapor diffusion resistance. Blown-in loose fill insulation can also be made of these materials, but can only be used on top of horizontal or gently sloping surfaces because of their very limited mechanical strength.

Less common products, such as foam glass, aerogel blankets, and vacuum insulated panels should be considered for special applications or to satisfy unique demands that can justify their higher cost, especially in small, targeted areas that can make use of their properties (i.e., high compressive strength and non-combustibility in the case of foam glass, and high R-value per inch in the case of aerogels and vacuum panels).

* Organic facers (kraft paper) are widely used in exposed membrane roofs as the membrane is deemed to be perfectly waterproof, but such facers will deteriorate and grow mold if wetted.

5 Retrofit Durability Concerns

The addition of insulation (or the removal/reduction of a TB) will always cause one side of the enclosure to become warmer and the other side colder than before. The colder side will of course be the outer portions of the enclosure in cold weather and the inner portions in warm weather. This has important ramifications for enclosure durability. If one side of the enclosure becomes colder, condensation is more likely to occur, to be more intense, and to occur more often than otherwise. Also, colder materials always dry more slowly than warmer materials. The temperature difference between a wetted material and its surrounding environment is a key determinant of its potential to dry.

This means that increasing the resistance to heat flow (either by adding insulation or breaking a TB) during the retrofit of a building enclosure will increase the risk of condensation, or will decrease the ability of an assembly to dry when wetted (by condensation, rain leaks, ground water), or often both. To manage these durability risks, a retrofit must reduce the risk by some means, or assess the risk to be sufficiently low.

Freeze-thaw deterioration of older masonry and terra cotta buildings is a significant risk in cold climates (climate Zone 5 and higher) if interior insulation retrofits are pursued. This risk can be managed by appropriately considering the wall's exposure to wetting, the freeze-thaw resistance of the materials, and the drying potential available.

Two sources of moisture damage are responsible for the majority of practical problems in retrofits: rain leakage and air leakage condensation. Both must be addressed in any enclosure retrofit and upgrade.

5.1 Air leakage condensation

Air leakage condensation is a serious potential damage mechanism in both cold weather and hot-humid weather. In most cases, *air leakage transports 10 to 100 times the quantity of water vapor than does diffusion.* Consequently, condensation due to diffusion is not commonly a serious problem. The addition of insulation in a thermal retrofit should, by definition, increase the temperature of materials on one side and reduce the temperature of materials on the other side of the insulation layer. This applies to walls with an added layer of insulation, or windows with a thermal break added, or a roof-wall junction with spray foam added. In cold weather, it is the layers outside the insulation that will get colder, and the layer inside the insulation that becomes warmer. In warm weather, the situation is reversed. In both cases, condensation becomes much more likely after a thermal retrofit because one layer is colder than before, and therefore condensation is both more likely to occur, and to occur at a higher intensity.

In cold weather, condensation can provide the water required to cause freeze-thaw action or allow corrosion or rot that damages the exterior layers of enclosures. In hot-humid weather, condensation can provide the moisture to damage interior finishes, to support mold growth, to corrode interior steel framing, and to wet fibrous insulation.

Outward air leakage through an enclosure is common, and often results in condensation on the back of sheathing and/or on the back of cladding (Figure 5-1). However, convective air loops, where air moves from the inside, through the enclosure, and back to the inside, can also cause condensation (Figure 5-2) in situations where little resistance to airflow is provided, i.e., when gaps and openings allow natural convection. Air leakage condensation within enclosures can be limited or eliminated by:

- eliminating the ability of water vapor to reach cold surfaces on which it might condense and cause damage
- ensuring that the temperature of surfaces at risk of condensation are kept above the dewpoint temperature of the source of air that might feed the condensation
- if the source of water vapor is interior air (the common case in cold weather), reducing the moisture content of the interior air by providing ventilation, dehumidification, or source control.

5.1.1 Air barriers

The first solution entails providing an air barrier to prevent air leakage. In short, this means ensuring there are no cracks, gaps, openings, or holes through which air can flow. A continuous series of materials must be assembled to cover the whole building enclosure, from the slab to the wall, wall through windows, and over the parapet onto the roof. An air barrier system must also be sufficiently stiff and strong to withstand the full design wind load and transfer it back to the enclosure support structure.

Figure 5-1. Cold weather air leakage condensation due to airfow through enclosure.

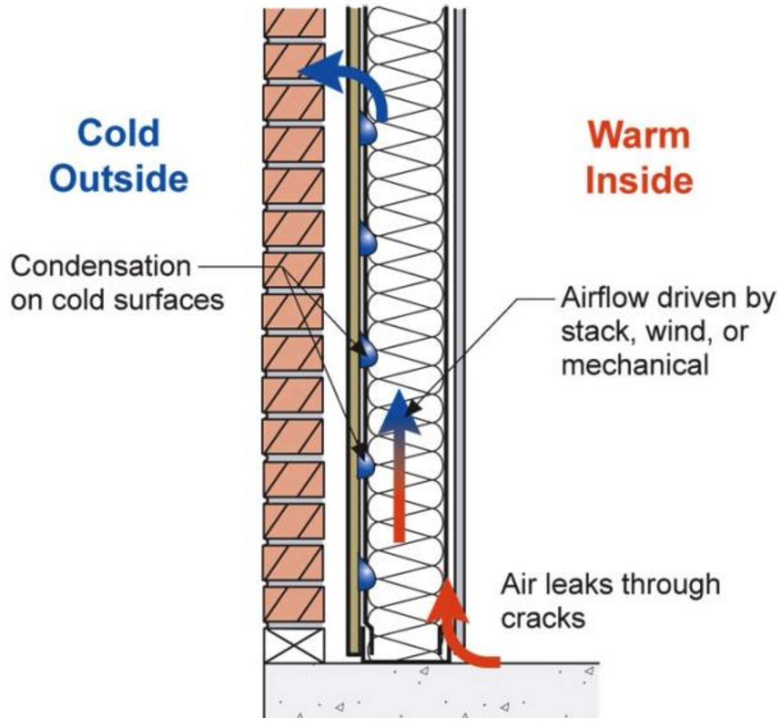
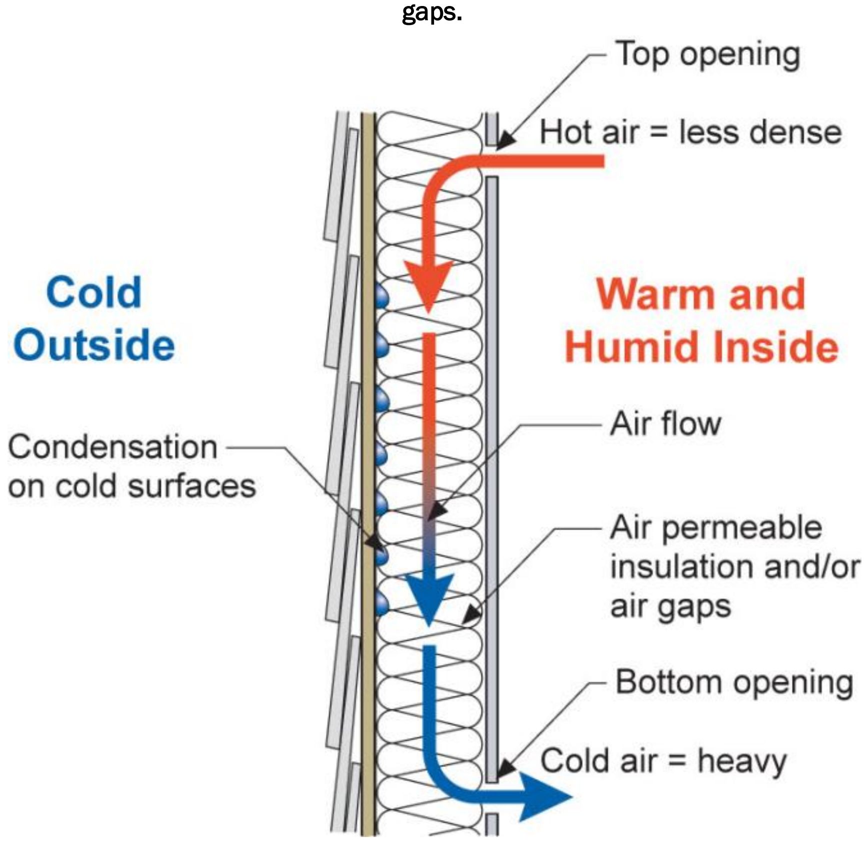


Figure 5-2. Convection can move air through highly porous insulation, but especially through gaps.



However, providing a near-perfect air barrier is not always sufficient. It is also necessary to reduce mechanical (HVAC) building pressurization/de-pressurization that can force air through even very small remaining openings. Because airtight buildings allow little air leakage, the standard HVAC practice of supplying a fixed volumetric rate of air supply that is higher than exhaust rate can result in very high pressures and obviate many of the goals of providing airtightness. Hence, building pressurization should be provided by setting airflows during commissioning to develop no more than about 5 Pa (0.02 in. w.c.) pressure or be managed dynamically with controls on the supply or exhaust fans.

5.1.2 Convection suppression

Even with no excess mechanical pressurization and a perfect air barrier system, air leakage condensation can occur due to natural convection. This is particularly relevant to interior thermal retrofits (see Figure 5-3) as the existing wall or roof may be sufficiently airtight. If care is not be taken to eliminate gaps between the insulation and existing walls or to reduce the air permeance of the interior linings (gypsum wallboard or equivalent), especially at complex floor penetrations, partitions walls, etc., convection loops will not be suppressed. All insulation types can be used to suppress insulation as long as no interconnected gaps exist around them. Even fibrous insulations resist convection if produced using modern fiber diameters and densities (higher densities and lower fiber diameters always decrease air permeance).

5.1.3 Insulation as condensation control

The second category of solutions requires the application of insulation to prevent condensation on moisture sensitive materials. For example, during cold weather, condensation on the sheathing of framed walls can be avoided by the use of exterior insulation strategies. Locating the insulation outboard of the sheathing and framing ensures that the materials remain much warmer so hence condensation will not occur (Figure 5-4).

Figure 5-3. Convection loops can easily occur between the insulation and the structure in an interior retrofit if a gap is left.

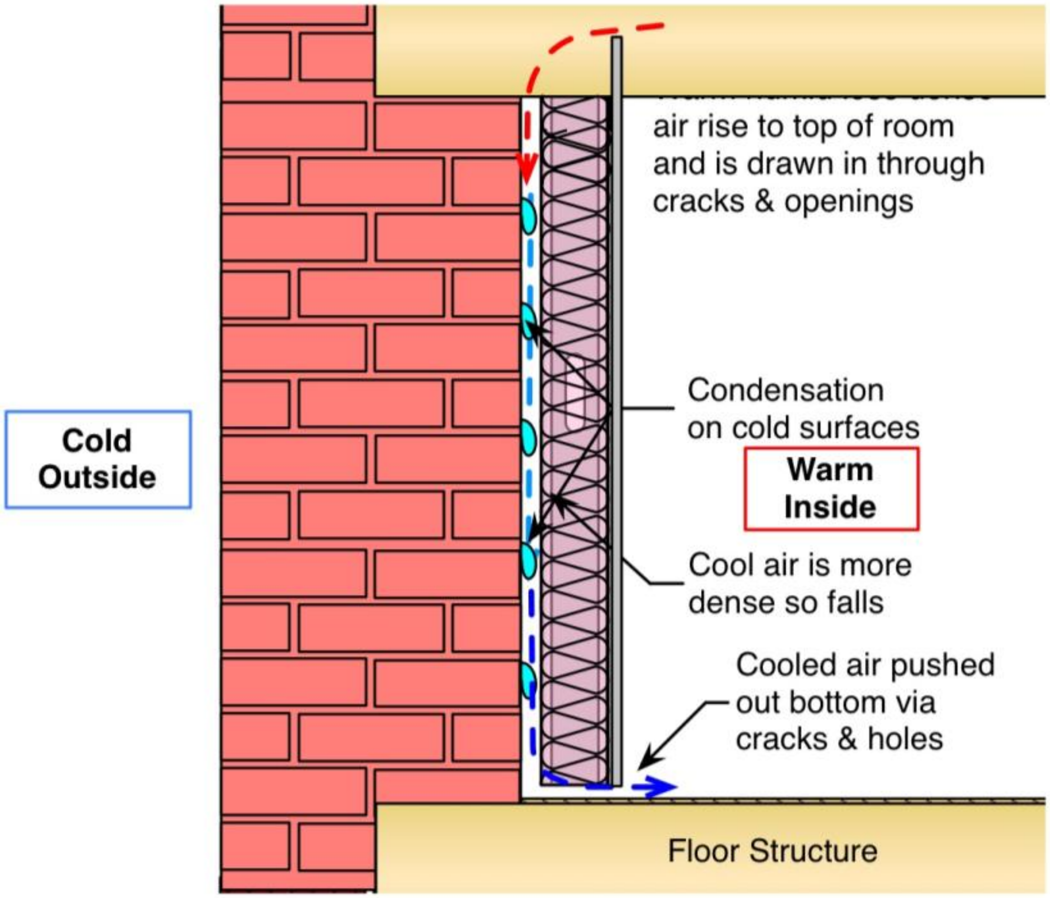
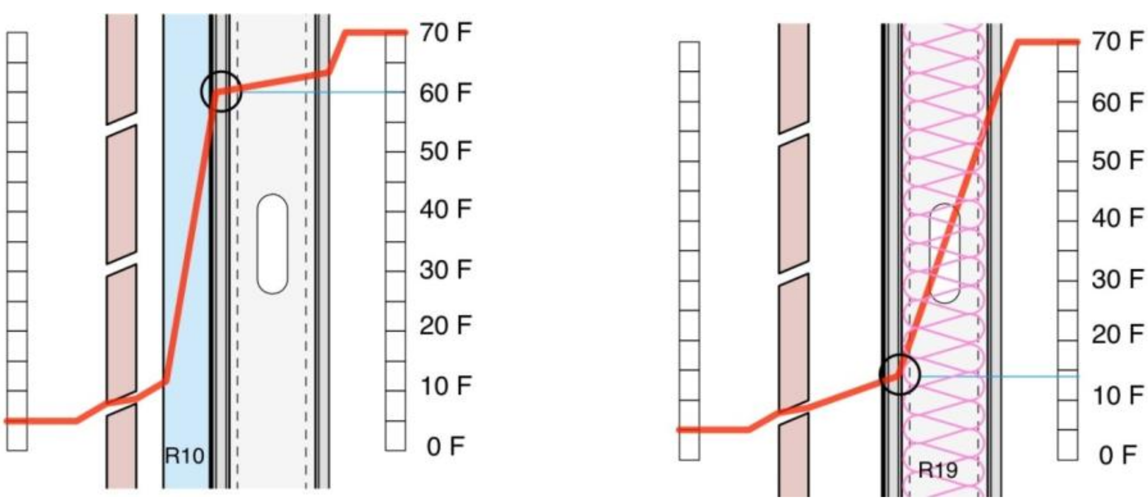


Figure 5-4. Insulating sheathing controls air leakage condensation by warming moisture sensitive surfaces.



5.1.4 Controlling interior relative humidity

Finally, the third category of solutions involves the control of indoor relative humidity (RH). If, during cold weather, the indoor RH is high, condensation is more likely to occur and to occur with greater intensity. Many retrofits, intentionally or accidentally, result in a reduction in building air leakage. This is a desirable outcome for many reasons. However, in highly occupied buildings, interior moisture generation can be sufficient to raise the interior humidity to damaging levels if a significant increase in airtightness is not simultaneously addressed by controlled ventilation.*

It is recommended that ventilation (with heat recovery if practical) be used to reduce the indoor RH to below 40% when outdoor temperatures are below 40 °F, and then to reduce the maximum RH by about 10% for every 20 °F drop in outdoor temperature (i.e., 30%@10 °F, 20% @ -10 °F, 15% @-20 °F). HRVs help with removing moisture in cold weather better than Energy Recovery Ventilation (ERV) systems.

5.2 Rain

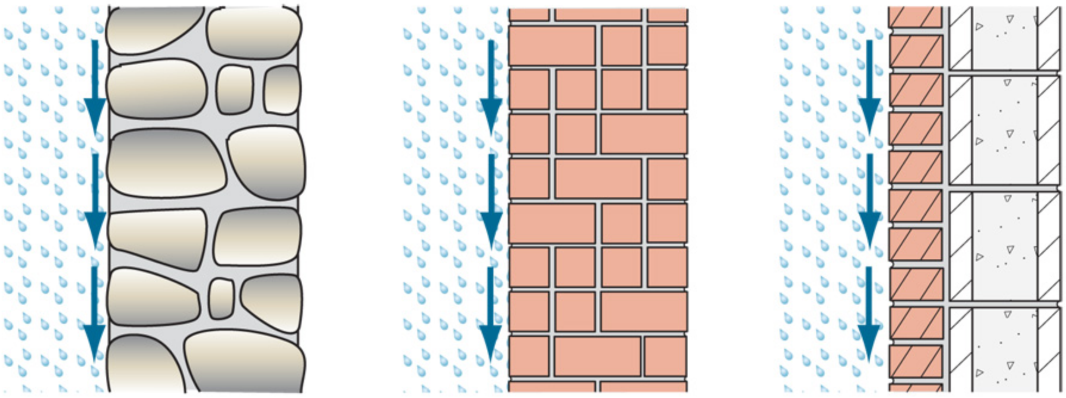
The control of rain penetration is critically important. Three broad strategies can be used to control rain penetration: storage, drainage, and exclusion.

5.2.1 Storage: Mass walls

Mass storage (Figure 5-5) is the oldest and the most common strategy for many institutional buildings more than 30 years old. This approach requires the use of an assembly of materials with enough storage mass and moisture tolerance to absorb all rainwater that is not drained or otherwise removed from the outer surface. In a functional mass or storage wall this moisture is eventually removed by evaporative drying from both the inside and outside before it reaches the inner surface of the wall as a liquid. Although enclosures employing this strategy might be best termed “moisture storage” systems, “mass” is often used because a large quantity of material is required to provide sufficient storage.

* The increased energy used for ventilation should always be less, often much less, than the energy used to condition air leakage. Increasing airtightness allows the ventilation to be provided when and where needed, unlike air leakage. Mechanical ventilation can employ heat recovery to dramatically reduce the energy cost of ventilation.

Figure 5-5. Mass (storage) enclosure assemblies.



The maximum quantity of rain that can be controlled is limited by the storage capacity available relative to drying conditions. Some examples of mass systems include solid multi-wythe brick masonry, brick over block walls (with no clear drainage cavity or drain openings) and single-wythe block masonry. Modern tilt-up and precast assemblies do absorb and store a small amount of rain, but are more usefully classified as perfect barrier assemblies.

5.2.2 Drainage: Drained systems

Drained (Figure 5-6) and screened enclosures assume some rainwater will penetrate the outer surface (hence the cladding "screens" rain) and remove this water by designing an assembly that provides drainage (i.e., a capillary breaking drainage plane, a drainage gap, flashing, and weep hole/drain). For most cladding systems, such as brick veneers, stucco, and the joints between cladding panels of clapboards, terra cotta, metal, or natural stone leak, this is the most practical and successful system of enclosure wall rain control. Even EIFS systems (which leak mostly at the joints and window penetrations) are now often designed as drained systems. Drained, or "rainscreen"* systems have five components (Figure 5-7):

1. Cladding, or rainscreen
2. One or more drainage gaps, or drainage spaces
3. One or more drainage planes, a capillary inactive material that acts as the water control layer together with the drainage gap
4. Flashing, which collects water flowing vertically on the drainage plane and directs it to the exterior
5. Weep holes or drain openings to allow water collected by flashing to exit.

* Note that the screen is much more than a rainscreen. It must also resist solar radiation, wind, snow, impact, flame spread, graffiti, etc.

Figure 5-6. Drained screened enclosure walls.

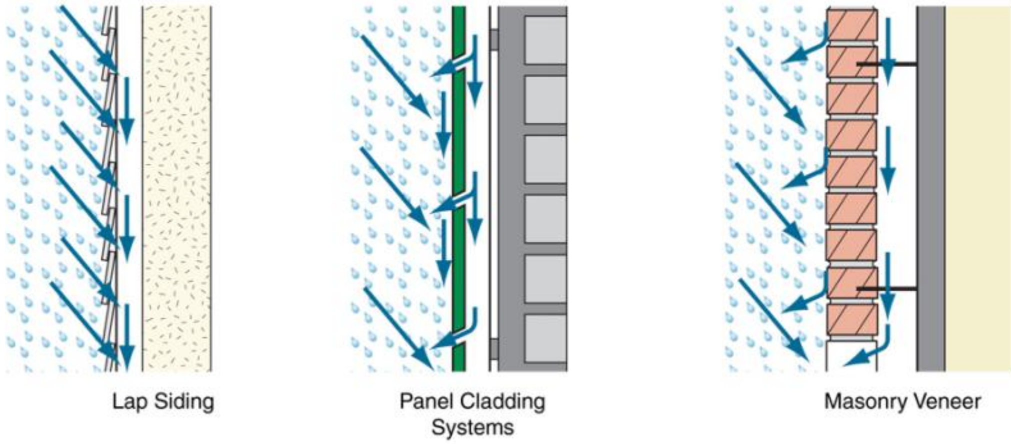
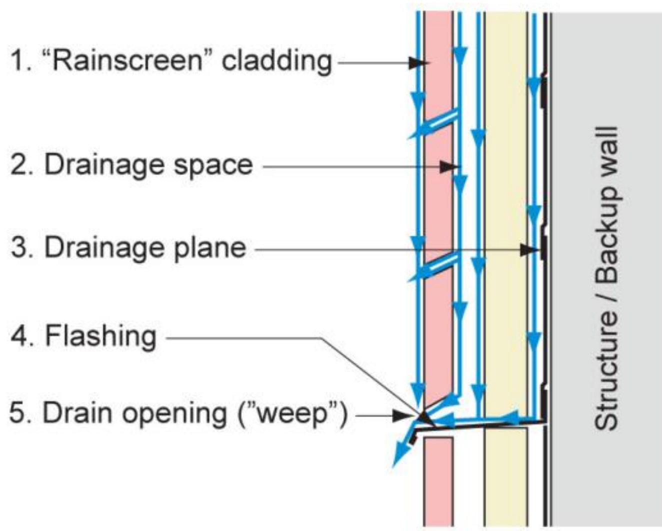


Figure 5-7. The five components of a drained system, sometimes called “rainscreen” systems.

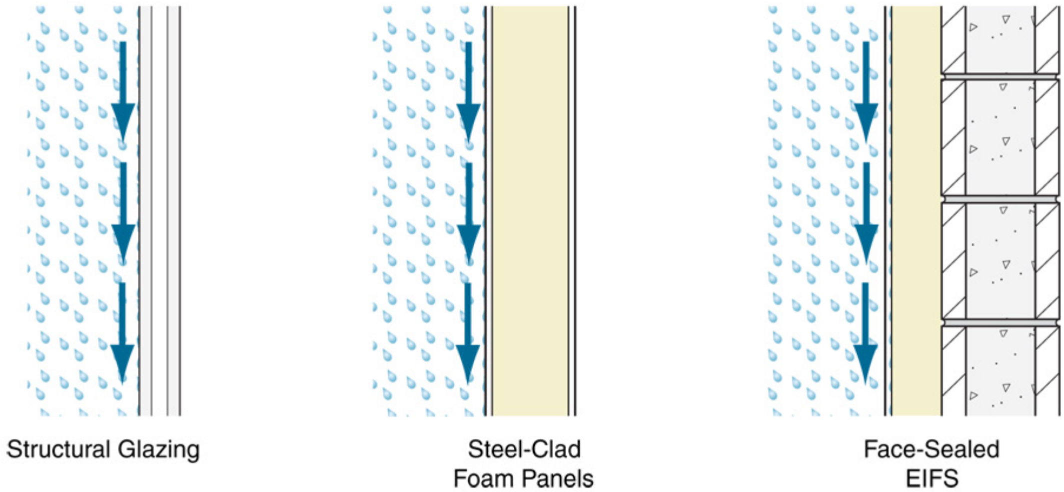


A drainage gap behind the cladding is easily provided in walls with exterior insulation; drained systems complement walls with continuous exterior insulation, especially exterior insulation retrofits.

5.2.3 Exclusion: Perfect barriers

Perfect barrier systems (Figure 5-8) stop, or exclude, all water penetration at a single plane. Such perfect control required the advent of modern materials. Some examples of perfect barrier walls are IGUs, low-slope membrane roofs, and some metal and glass curtain wall systems. Because it is difficult to build and maintain a perfect barrier, most walls are designed as, or perform as, imperfect barrier wall systems of either the mass type or the screened type.

Figure 5-8. Perfect barrier enclosures.



However, some, usually factory-built, systems provide wall elements that are practical perfect barriers. For example, architectural precast concrete can be considered watertight, as can glazing and roof membranes. The joints between perfect barrier elements should almost always be drained joints, in the form of two-stage sealant joints or similar. This is a critical requirement for functional precast concrete and glazing systems. Window frame joints, joints to rough openings, and joints between precast panels, should all be designed using the drained approach.

Perfect barriers may be face-sealed, i.e., the perfect barrier is at the exterior face or concealed barrier. This protects the barrier behind some layers. Face-sealed sealant joints (e.g., a single line of caulking) have a poor record of performance and cannot be recommended for controlling rain entry. In most cases, the use of “two-stage” drained joints should be used between perfect barrier elements.

5.2.4 Thermal insulation retrofits and rain penetration

Given that a thermal upgrade will require a reduction in wetting to balance the reduction in drying that results from reduced heat flow (either by insulating or reducing thermal bridging or increasing airtightness), upgraded rain penetration performance will often be required. This is most relevant around window and door penetrations: although a window installation that leaks slightly into an uninsulated wall may not cause problems if drying occurs after each leak, reducing the heat flow will reduce drying and thereby may cause a problem when none existed before. Hence, in most cases it is strongly recommended that windows and doors be installed in a drained rough opening during a thermal retrofit.

6 Special Conditions

6.1 Window/storefront installation

Four primary principles should be followed during the design of a retrofit window or storefront installation:

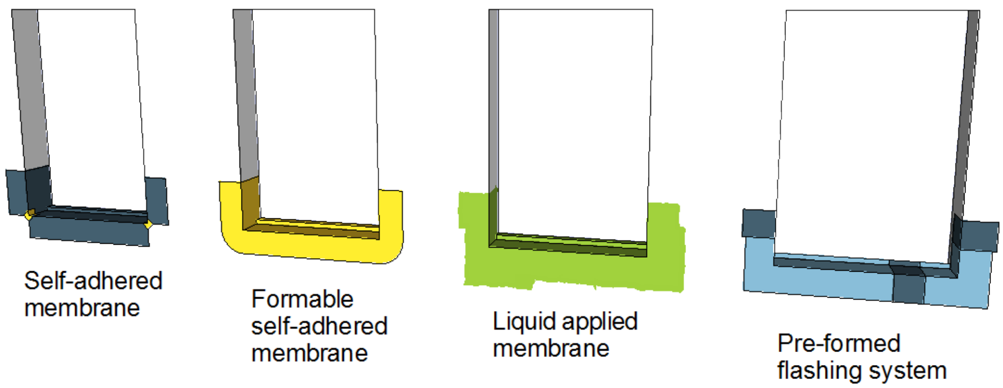
1. The rough opening should be waterproofed so that water can drain out of the space between the window frame and the rough opening.
2. The plane of primary thermal resistance of the window should align with the insulation in the wall to ensure continuity of thermal resistance. If there are design reasons to locate the window in a different location, the thermal control layer must be adjusted to suit.
3. The primary air barrier system of the wall should be sealed to the air barrier within the glazing product. The air barrier connection to the window must be to the interior of the drained space.
4. The gravity weight of the unit must be transferred to the enclosure structure at the sill, and the lateral wind and blast loads must be transferred at all sides.

6.1.1 Rain control

The most common serious in-service problems with window installation stem from rain penetration. To manage this, sub-sill flashing should always be required (Figure 6-1). This flashing should be waterproof (i.e., resist long-term exposure to standing water). In most cases, the material should also be vapor impermeable to resist standing water, and sufficiently abrasion resistant to survive the installation of the windows and doors (and their often sharp edges).

The jamb and head treatment does not require materials that are as resistant to water and water vapor as the sills because liquid water will not be standing in these locations. Hence, the jamb and head water (and air) control layers may be either vapor permeable or impermeable. In cold and wet/humid climates, the selection of vapor permeable membranes is recommended as their use significantly increases the drying potential of materials around the window opening (especially wood bucks).

Figure 6-1. Various methods of providing drainage at the sill of rough openings.



Critical features of sub-sill flashing include a raised vertical section at the back (called a "back dam") that is tall enough to allow for installation of sealant between it and the window (to provide both water control and air-flow control continuity). The upturn also ensures that water on the sill flashing will not move inward by gravity or along with airflow. The larger the dimension of the upturn, the better the performance, but dimensions of ⅜ in. (10 mm) are a practical minimum, and dams higher than about 1.5 in. (40 mm) provide little real benefit, but do cause practical installation and integration problems. The "end dams" are the waterproof ends of the flashing. The intersection of the back dam and end dam is often the most challenging corner detail to build in a waterproof manner.

6.1.2 Thermal control layer alignment

One often least-considered principle is that it is important to align the thermal control of the window with the thermal control layer of the wall to avoid thermal bridging and the potential for cold weather condensation and energy loss. In aluminum windows, the thermal break provides a clear indication of the thermal control layer. For fiberglass, vinyl, and wood windows, the thermal resistance of the frame is more uniform, and hence thermal control layer alignment is usually easier (as the frame is wider than the thermal break).

6.1.3 Window support

A common concern that arises in designing window installation details for walls with more than about 2 in. (50 mm) of continuous insulation is how to provide structural support for the weight of the window. Lateral loads, e.g., wind and blast pressures, which do not involve concerns of twisting and long-term creep movements, are easier to accommodate with fasteners that pass directly through the frame, or with angle supports on the interior face.

Claddings such as precast and masonry veneers can often support the outer edge of a window (Figure 6-2) especially in low-rise buildings. This approach cannot be used if the exterior cladding can move significantly differentially with respect to the backup.

An alternate, more general, approach provides good thermal continuity by supporting the window/ storefront with intermittent clips of metal or fiberglass (Figure 6-3). Fiberglass is sufficiently non-conductive that standard fiberglass angles (e.g., 3 x 3 x 1/4 in.) could be used over the entire width of the sill if desired (the water control layer could pass behind or over the front of the angle).

Figure 6-2. Drained, air-sealed, and thermally continuous window installation for a wall with exterior insulation retrofit.

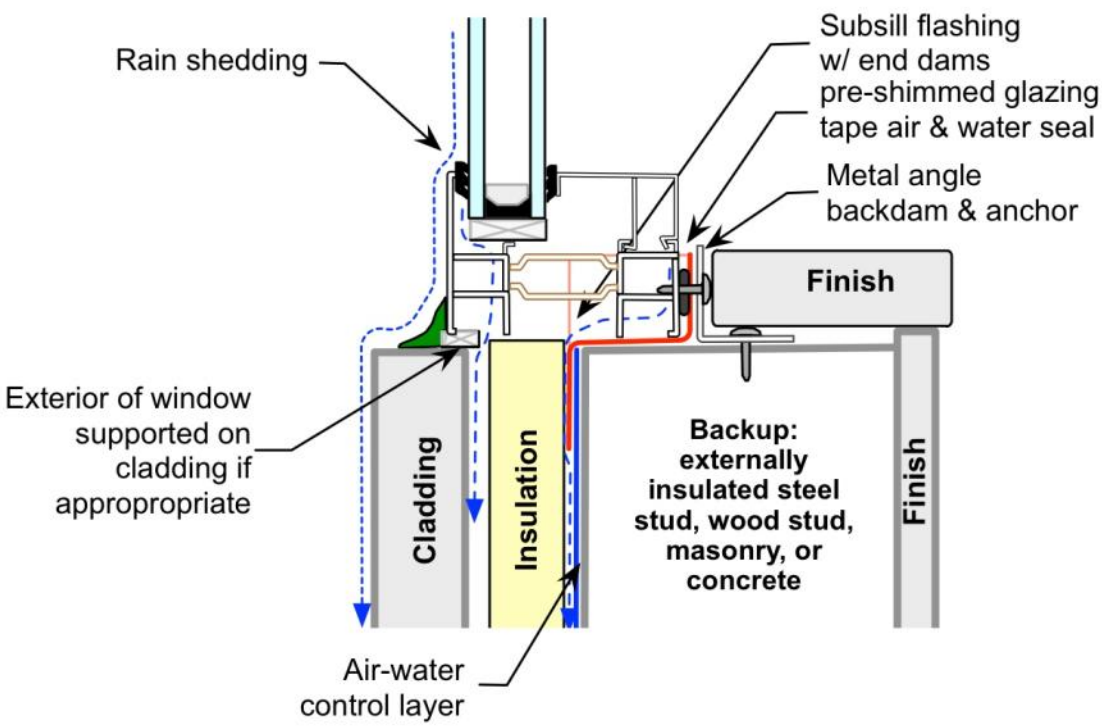
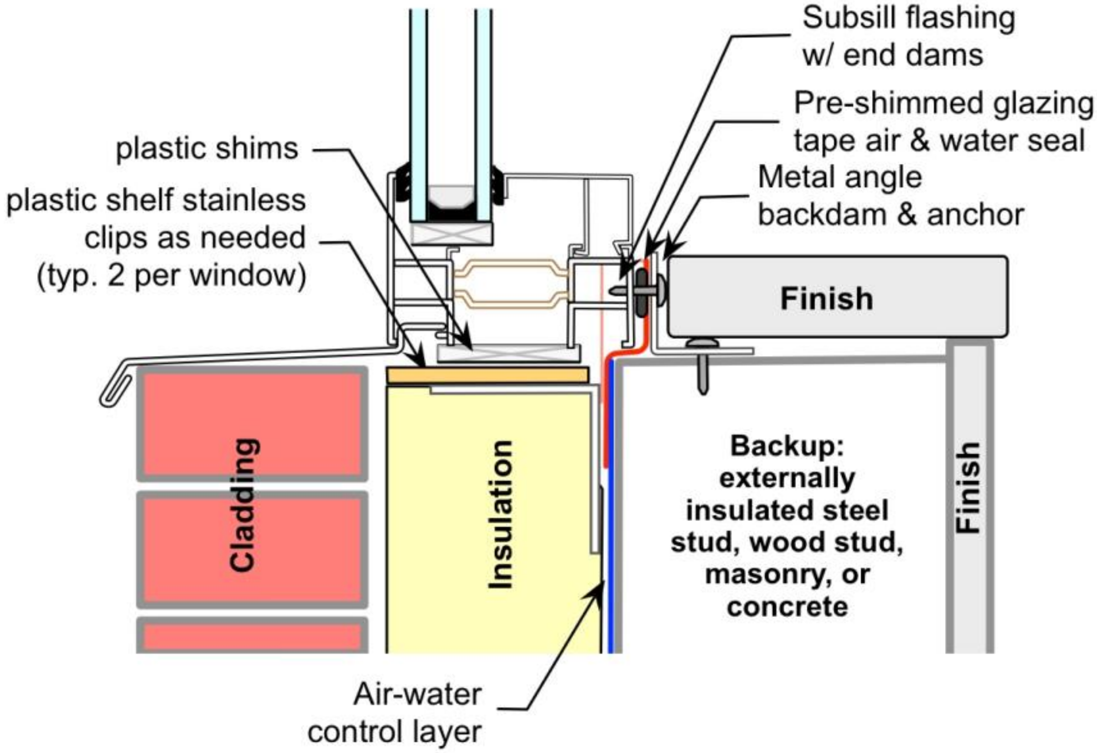


Figure 6-3. Window installation over wide cavity using clips to support weight of window.



The weight of an IGU is always supported within the window/curtainwall/storefront frame on rubber setting blocks. To support the outer portion of a window with a single light so that its thermal break is aligned with wall insulation, the support clips or window support should be installed below the IGU (Figure 6-4). Some systems (like most curtainwalls) have thermal breaks that are structurally capable of transferring torsion to the inner part of the frame. Such systems can be supported by interior angles and other interior fastening methods (Figure 6-5).

6.1.4 Window installation in mass walls

The same principles should be applied to masonry/concrete mass walls as to drained walls. However, for an interior insulation retrofit, the water control layer in such systems is the structure, and the interior insulation of a retrofit is often the air control layer.

Figure 6-4. Support clips below window frames should be located below IGU setting blocks.

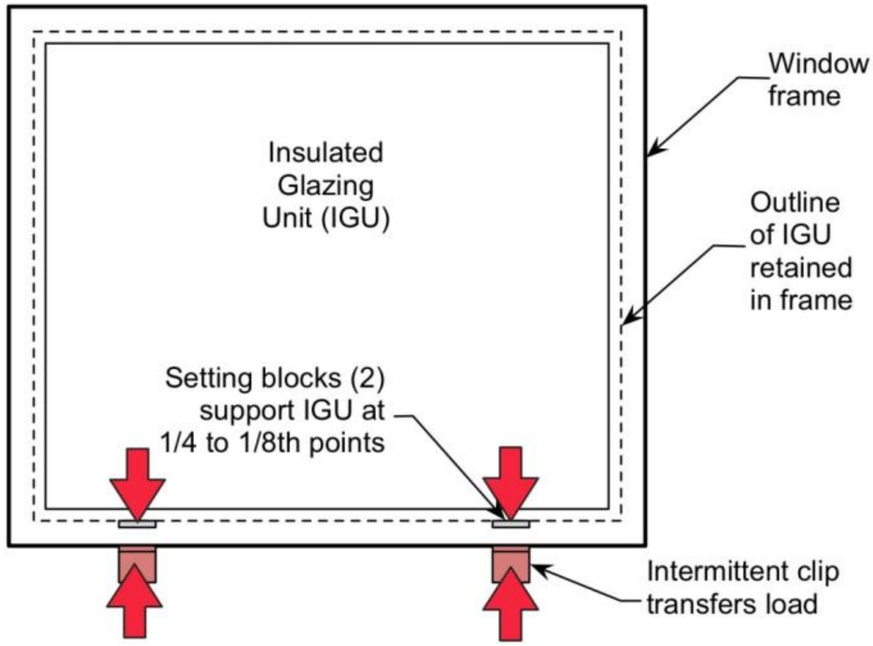
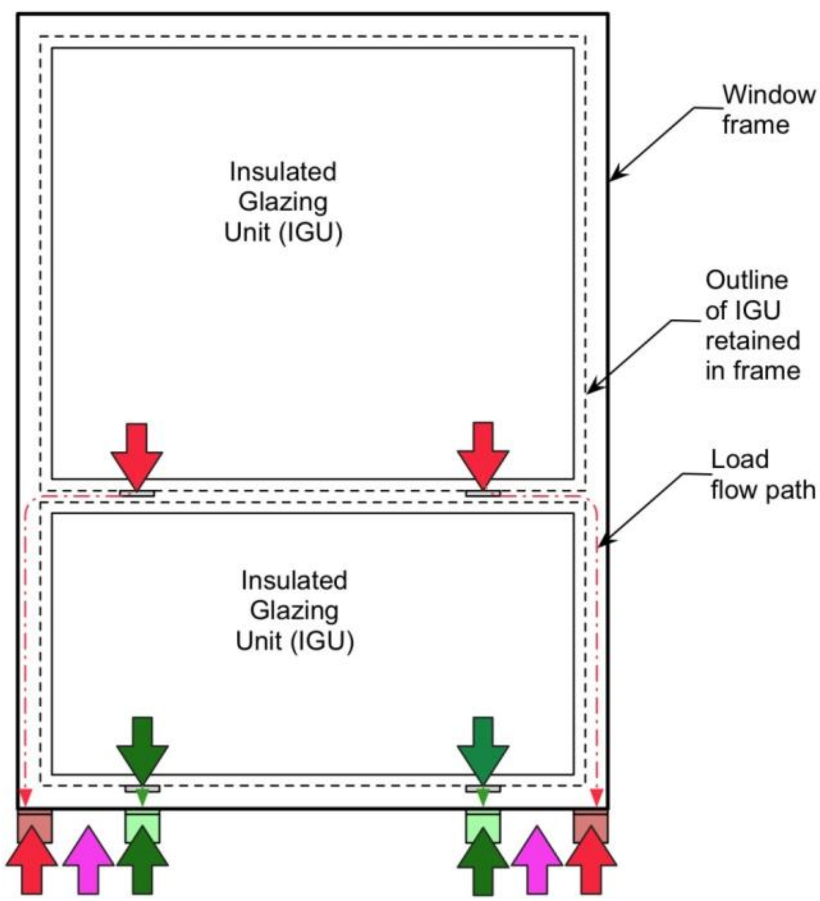


Figure 6-5. For windows with stacked lights, support clips must be provided below the frame jamb and the IGU setting blocks, or perhaps midway between both.



In a window retrofit, the interior insulation should be wrapped around to the exterior on all four sides. In practice, a layer of plywood is used over this insulation to provide a suitable working surface that allows water and air control layers to be attached, and to provide support for the window installation without violating the thermal control. The alignment of thermal and air control layers can be particularly challenging in the case of an interior retrofit of a mass or perfect barrier wall (such as tilt-up, load-bearing masonry) because the window is often installed far outboard of the interior insulation and air tightness layer added during the retrofit. Any successful solution will provide continuity of the air, water, and thermal control layers. Figures 6-6 and 6-7 provides a conceptual example of how this might be achieved.

Exterior insulation and overcladding can use more common installation details with or without wood bucks. The continuity of the water, air and thermal control layers is just as critical, but often easier to achieve (Figure 6-8).

Figure 6-6. Drained, air-sealed, and thermally continuous window installation for a load-bearing wall with interior insulation retrofit.

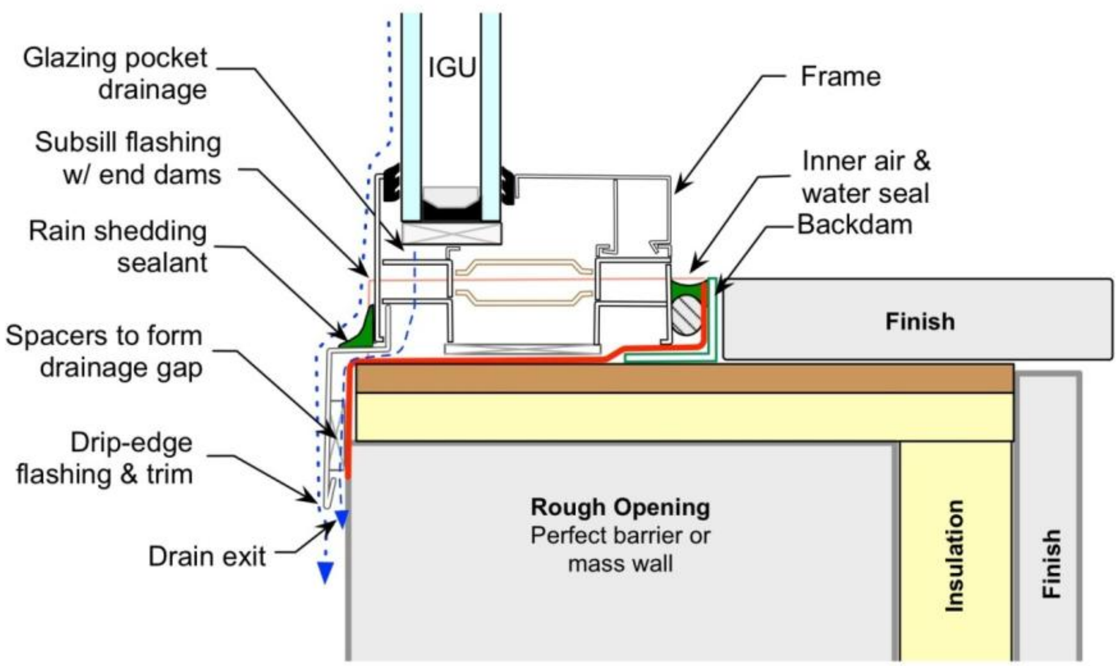


Figure 6-7. Plan detail at replacement window jamb of an interior insulation wall retrofit.

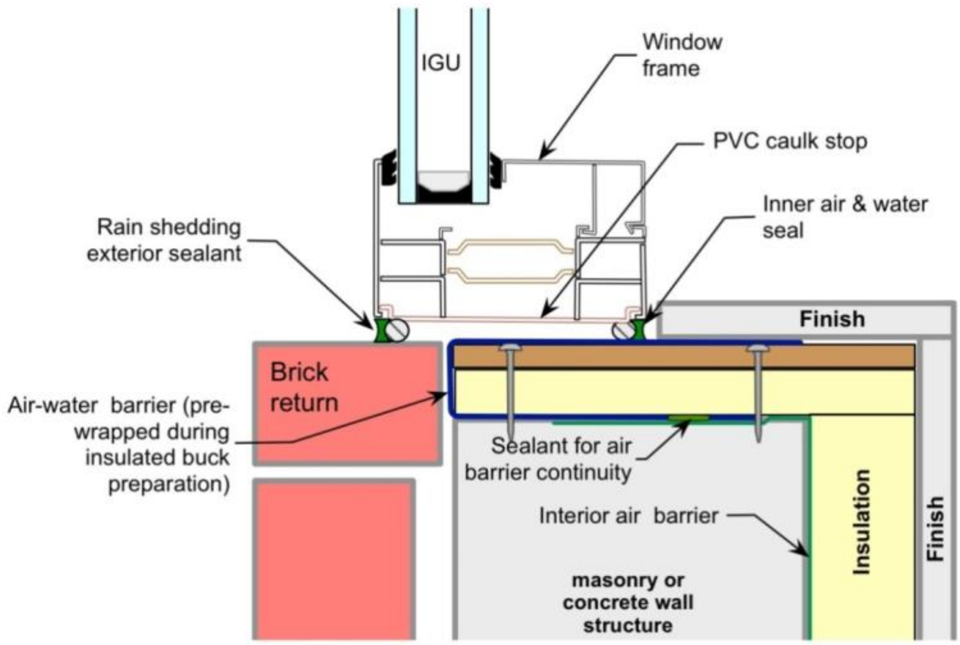
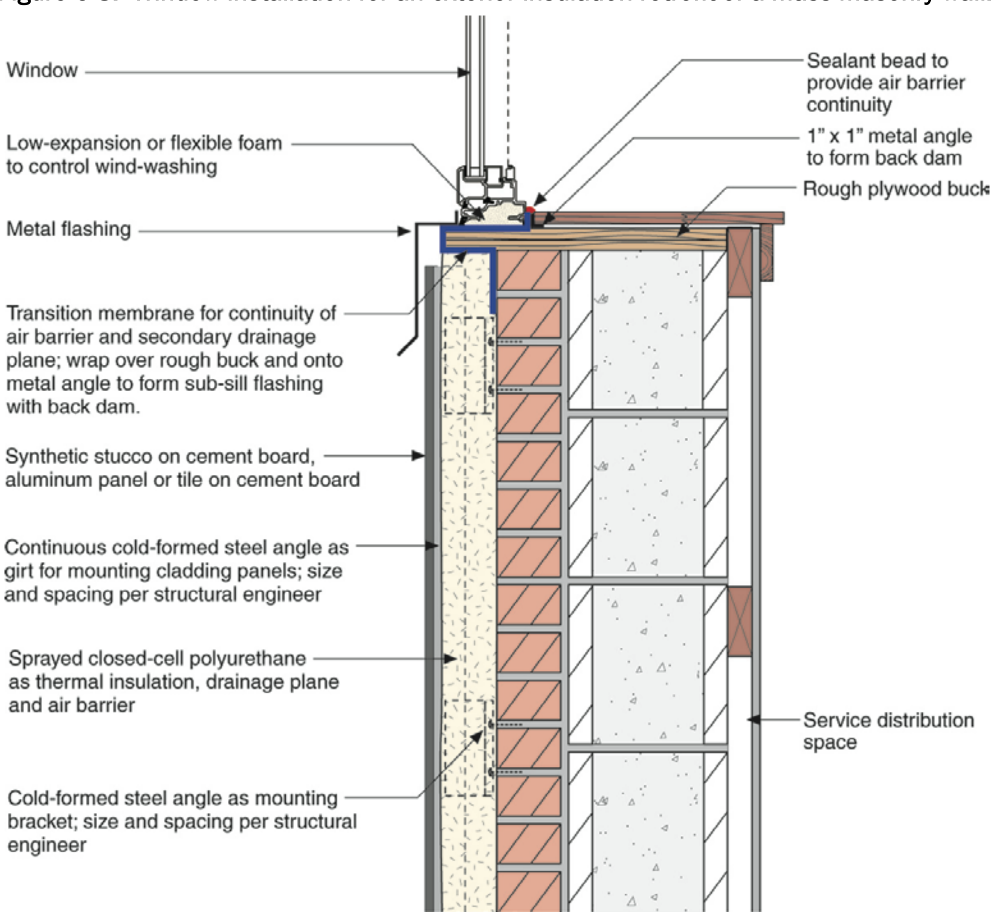


Figure 6-8. Window installation for an exterior insulation retrofit of a mass masonry wall.

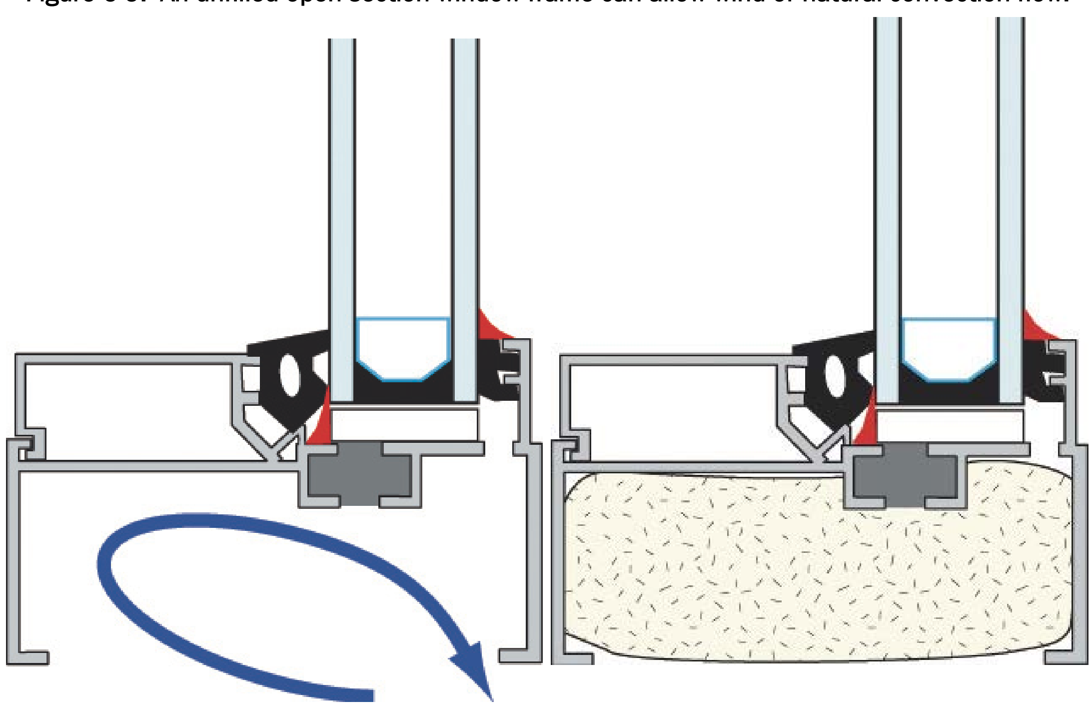


6.1.5 Gaps around windows and doors

A gap between a window or door and the rough opening is always required to accommodate construction tolerances and differential movement between the enclosure and the window system. This gap, when combined with the hollow nature of many open aluminum and fiberglass window frame systems, can result in a void that is 2-3 in. (50-75 mm) wide and as deep as most of the window frame (Figure 6-9). *This void should be at least partially filled to reduce the flow of air driven by natural convection and/or wind through these voids.*

Filling these voids can be partially achieved by factory-installed custom-shaped foam plastic or rigid stone sections. Such inserts do not provide much insulation in the traditional sense since heat mostly flows around the insert by conduction in the aluminum. Instead, they merely reduce convection and block radiation. The remaining gap between the frame and the rough opening also needs to be filled, either with low-density fibrous batt insulation (problematic because of quality control during installation), or via the use of a closed-cell backer rod and sealant on both the exterior and the interior (but with drain holes through the exterior). In some regions, it is also common to use low-expansion foam dispensed from cans to fill the void although this may sometimes be considered unacceptable at the sill (where drainage is required).

Figure 6-9. An unfilled open section window frame can allow wind or natural convection flow.



6.1.6 Curtainwall installation

Supporting a curtainwall in a rough opening is relatively easy, as the large tubes provide significantly greater strength and stiffness than open section window frames. Connecting the tube to the structure with standard F connectors will allow the glazing to project outwards and align with an exterior insulation layer. Section 4.5 includes for more information about thermal flanking.

In the case of a curtainwall installation, a drained opening is rarely needed. Instead, the water and air control layer of the wall should be connected to the inner shoulder of the curtainwall with a transition membrane. The thermal break in a curtainwall should be aligned with the insulation layer of the wall in which the system is installed just as for windows and storefronts (Figure 6-10).

At the head of the curtainwall, the air-water control layer will often be split into a rain-shedding layer that directs draining water to the flashing, and the primary air-water control layer that connects to the interior of the shoulder of the curtainwall (Figure 6-11).

Figure 6-10. Curtainwall installation detail at transition to exterior insulated wall.

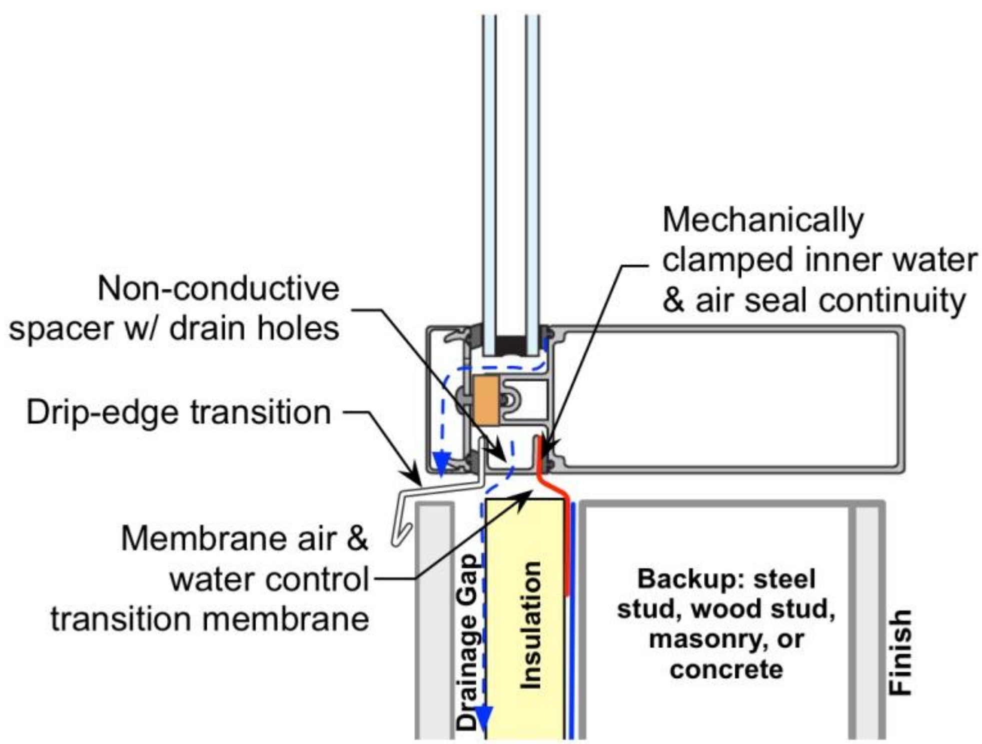
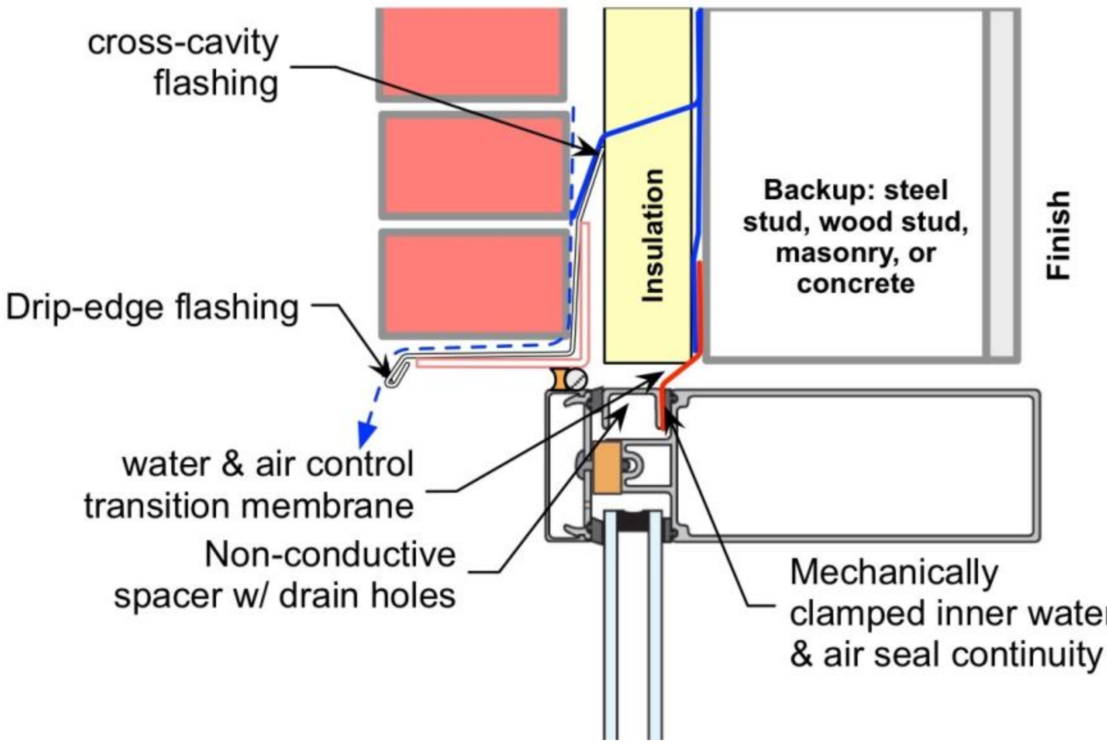


Figure 6-11. Curtainwall head detail showing continuity of the air and water control layers.



It is important in all window and curtainwall systems to provide drainage from the IGU pocket to the exterior. In the case of curtainwall systems, a spacer is often required where the system stops to fill the space that a symmetrical extrusion would assume would be filled by an IGU or thin spandrel panel material (such as glass or metal panels). This spacer should be made of some stiff non-conductive spacer (typically PVC sections; solid nylon; EPDM [hard ethylene propylene diene M-class, “rubber”], or even foam plastic), not of aluminum, which is a notable TB.

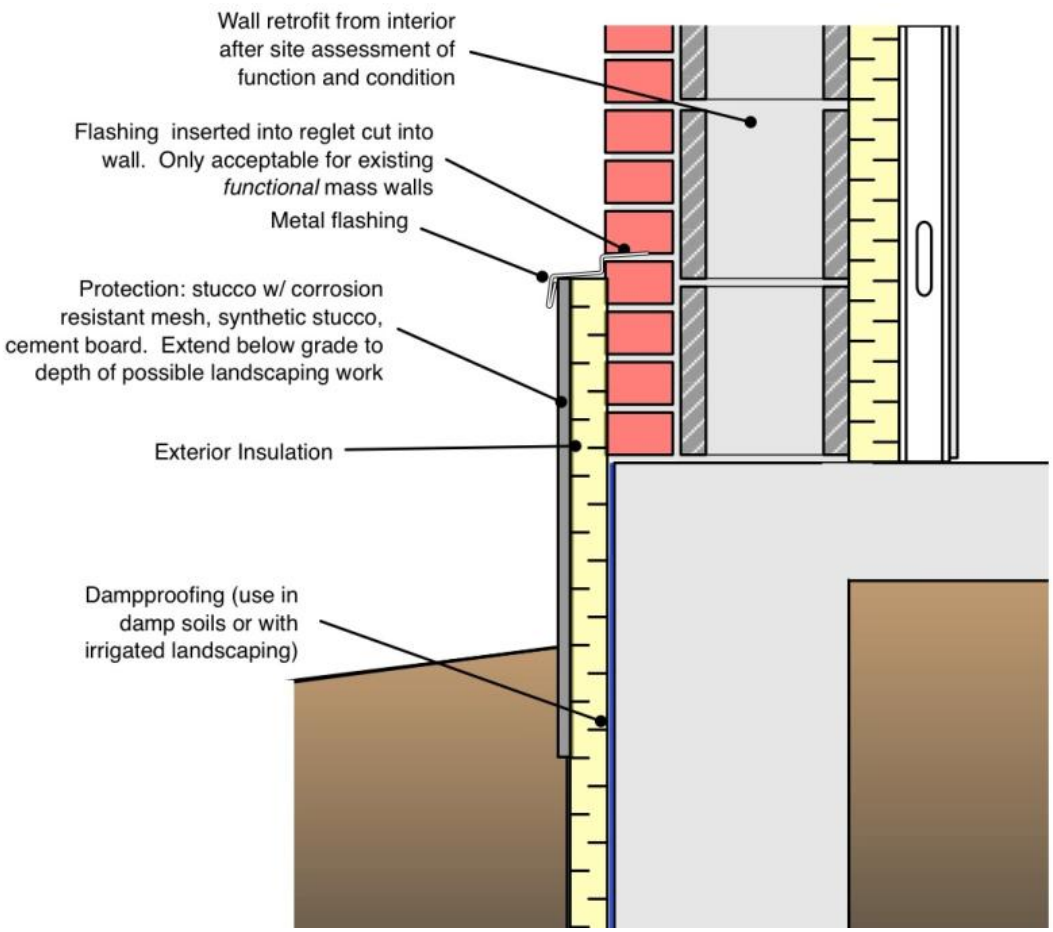
6.2 Exterior insulation below grade

Below-grade insulation can be XPS, EPS, or high-density stonewool/rockwool. However, in all cases this insulation requires protection from impact, and in the case of foam plastics, ultraviolet radiation. An aesthetically appealing finish is also often desired. This finish can be provided by cement-based stucco with corrosion-resistant reinforcing, by polymer-modified stucco reinforced with glass fiber, or by metal or PVC sheets.

The transition from exterior below-grade insulation to above-grade assemblies should typically be managed with a flashing transition to separate the two types of construction. This flashing will also usually serve as part of the rain control approach. If the rain control of the above-grade system (see Section 5.2) is a drained system (common in exterior retrofit), the flashing should return back to the drainage plane. If the rain control strategy for the above-grade assembly is a perfect barrier or a mass system, the flashing may be connected to these rain control assemblies. In face-sealed systems (e.g., precast or tilt-up concrete), this connection can be accomplished with a pressure-bar and sealant, or a reglet cut into the concrete. In a mass system (e.g., multi-wythe masonry, adobe), the flashing should be inserted into a reglet cut deeply into the mass layer (Figure 6-12). In no case should flashing be attached to the face of the cladding in a drained system.

Termite resistance will often need to be considered in warmer climates with sufficient exposure. Foam insulation can act as a protected pathway for termite access, and hence appropriate flashing and termiticides should be employed.

Figure 6-12. Example of exterior insulation below-grade transition.



7 Building Sections

A wide range of building types from the provided drawing packages was investigated. This chapter identifies seven types of common buildings types, and lists 30 different thermal bridge scenarios. Each detail is supplemented with notes that give further information about practical limitations or applications of that detail and that direct the reader to specific sections of the report for more information. The 30 building sections chosen for detailed analysis are:

1. Concrete Masonry Unit (CMU) or Concrete wall with interior insulation
   a. At grade (stem wall)
   b. At suspended slab (w/steel stud or exposed block)
   c. At parapet with concrete roof
   d. Parapet with steel roof deck and steel joist
   e. Window jamb
   f. Window head
   g. Window sill
   h. Blast-resistant window jamb
   i. Door jambs to CMU
   j. Thru slab projection (shade or balcony)
2. CMU or concrete wall with exterior insulation
   a. Roof parapet with concrete roof
   b. Parapet with steel roof deck and joists
   c. At grade transition wall
   d. Window jamb
   e. Window head
   f. Window sill
   g. Blast-resistant window jamb
   h. Blast-resistant window head
   i. Suspended slab at shelf angle
3. Steel stud wall with interior and exterior insulation
   a. Roof parapet with steel frame
   b. Window jamb
   c. Window head
   d. Window sill
   e. Steel tube blast-resistant curtainwall
   f. Steel beam penetration

4. Steel building with Insulated Metal Panel
    a. Eave Detail
5. Precast sandwich panel
    a. Steel roof joists bearing on inner wythe
6. Important Clearwall Details
    a. Six -inch steel studs @16-in. o.c. with brick ties
    b. Concrete wall with interior steel stud assembly
7. Historical Details w/interior insulation
    a. Window sill in solid brick masonry

These details are presented in the following pages.

7.1 1a CMU or concrete wall with interior insulation: At grade stem wall

Figure 7-1. At grade stem wall: As found and corrected.

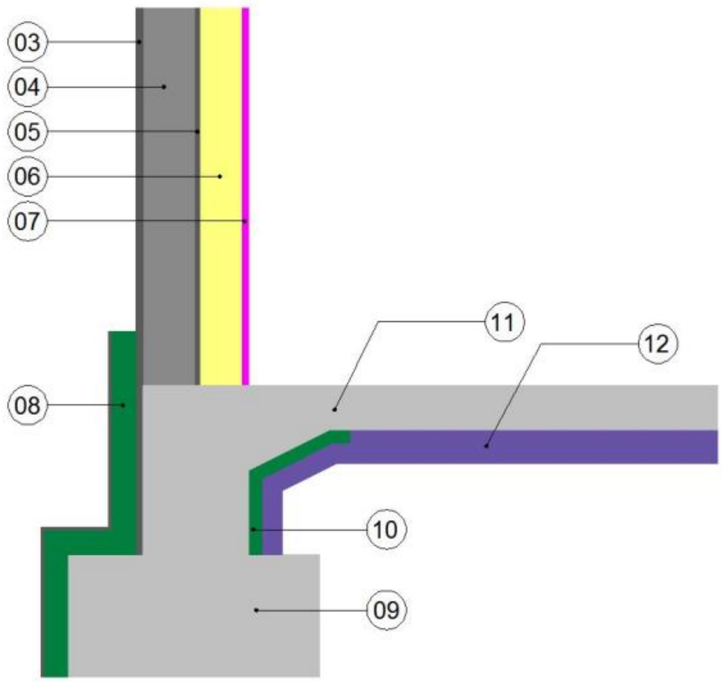


Table 7-1. Modeling values: At grade transition.

ID	Component	Thickness in. (mm)	Conductivity Btu/ft·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)
1	Interior Film (Wall)	—	—	R-0.74 (0.13 RSI)	—
2	Interior Film (Floor)	—	—	R-0.97 (0.17 RSI)	—
3	External Stucco	1 (25)	0.8089 (1.4)	R-0.10 (0.018 RSI)	115(1850)
4	CMU	7⅝ (194)	0.069 (1.2)	R-0.916 (0.161 RSI)	130 (2100)
5	Interior Plaster	3/4 (19)	0.8089 (1.4)	R-0.08 (0.014 RSI)	115(1850)
6	Insulation Bay with Steel Studs	6 1/8 (156)	0.0584 (0.10)	R-8.7 (1.539 RSI)	-
7	Gypsum Board	1/2 (13)	0.092 (0.16)	R-0.5 (0.08 RSI)	50 (800)
8/x/y	Exterior XPS Insulation	3 ½ (89)	0.017 (0.029)	R-17.2 (3 RSI)	1.8 (28)
9	Reinforced 30MPa concrete	—	1.04 (2.4)	—	150 (2400)
10	Existing XPS Insulation	2 (51)	0.017 (0.029)	—	1.8 (28)
11	Reinforced 30MPa concrete	6.5 (165)	1.04 (2.4)	R-0.39 (0.069 RSI)	150 (2400)
12	Crushed Stone	5 (127)	0.9245 (1.6)	R-0.45 (0.079 RSI)	125(2000)
14	Exterior Film (Wall)	—	—	R-0.23 (0.04 RSI)	—
15	Exterior Film (Floor) Temp 50 °F (10 °C)	—	—	R-0.00 (0.00 RSI)	—

Table 7-2. Thermal performance: At grade transition.

Condition	Clear Wall R-Value (W/m²K)	Linear Transmittance (Ψ) Btu/hr ft°F (W/mK)
Wall Clear Field	R-10.3 (0.552)	—
Floor Clear Field	R-0.84 (6.749)	—
As-Built Slab (no exterior or interior insulation)	—	-0.359 (-0.622)
Retrofit with...		
12-in. exterior	—	-0.452 (-0.782)
12-in. exterior (x) and 12-in. exterior (y)	—	-0.471 (-0.815)
18-in. exterior (x) and 12-in. exterior (y)	—	-0.507 (-0.877)
24-in. exterior (x) and 12-in. exterior (y)	—	-0.535 (-0.926)

Notes:

This detail is difficult to retrofit. The most practical, and yet expensive, approach is to excavate to the footing and insulate from the exterior. The above-grade wall is assumed to exist as drawn.

Although shown as CMU, the wall's support function could be easily filled by a precast, tilt-up, site-cast concrete with almost no impact on thermal performance. More relevant is the rainwater control strategy (Section 5.2). In existing walls, the CMU wall tends to perform as a mass wall (Section 5.2.1) and cannot be insulated on the interior if there is experience that the wall leaks (i.e., exposure leads to high driving rain deposition that overwhelms the storage capacity). Concrete walls tend to act as perfect barrier systems (i.e., the absorption rate is so low that the storage capacity cannot be used) and thus rain control failures at joints and cracks need to be solved (by creating drained joints or perfect barrier seals) before insulating (Section 5.2.3).

The most practical air control layer (Section 5.1) in this wall system is often to seal the CMU with a liquid coating on the inside (usually vapor permeable) whereas concrete is sufficiently airtight that it only needs to be sealed at joints and cracks. However, this location of the air barrier requires convection loops to be controlled by high-density fibrous or foam insulation with joints sealed (Section 5.1.2). An alternate approach is to use interior gypsum board as the air barrier, but this requires significantly more care as all the penetrations such as floor slabs, partition walls, and services, need to be made airtight, which can be difficult in practice.

The interior insulation can be of any type, provided the fire protection requirements are met (Section 4.6) and convection loops are dealt with. The additional exterior insulation must be appropriate for exterior use, and protected against impact with an aesthetically acceptable cover (Section 6.2). The rain control of the transition of below-grade exterior insulation to above-grade assembly must be carefully considered (Section 6.2, Figure 6-12)

The thermal performance of this detail can be further increased by increasing the thickness of the insulation and covering more (or all) of the exterior (see Section 4.1), and by adding a skirt around the perimeter to reduce losses to the soil.

7.2 1b CMU or concrete wall with interior insulation: Suspended slab (steel stud or exposed block)

Figure 7-2. Suspended slab.

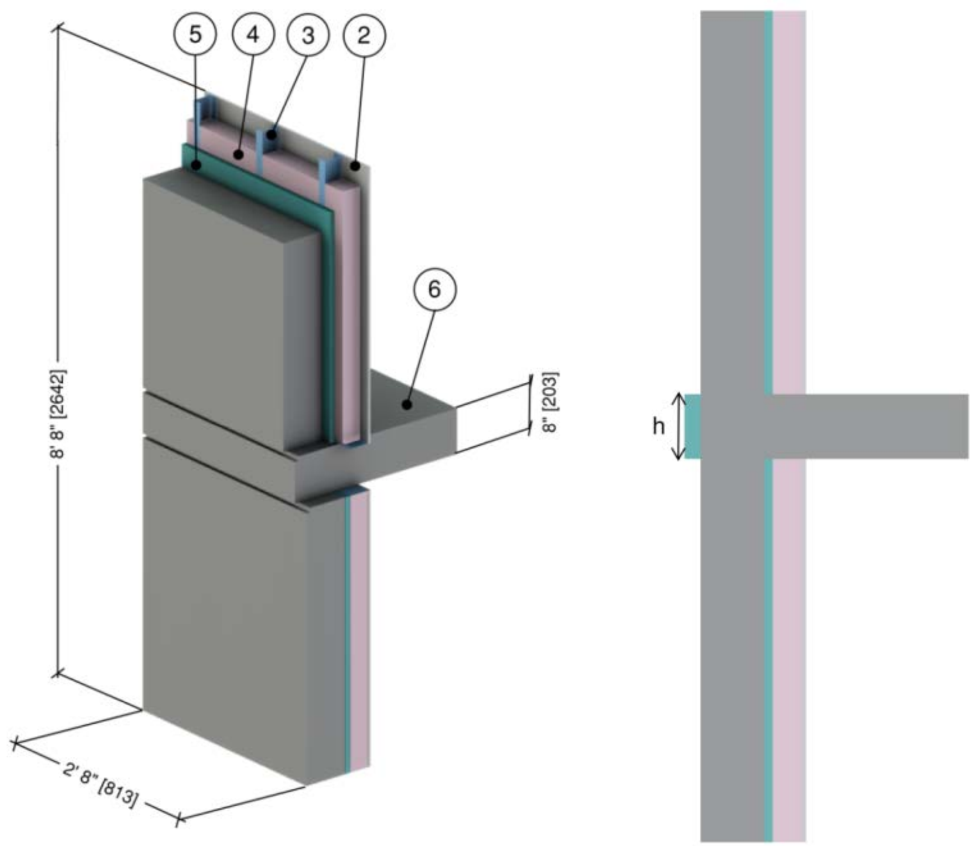


Table 7-3. Modeling values: Suspended slab.

ID	Component	Thickness in. inch (mm)	Conductivity Btu/ft·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)
1	Interior Film (right side)[1]	—	—	R-0.6 (0.11 RSI) to R-0.9 (0.16 RSI)	—
2	Gypsum Board	1/2 (13)	0.092 (0.16)	R-0.5 (0.08 RSI)	50 (800)
3	3 5/8-in. Steel Studs with Top and Bottom Tracks	18 Gauge	35.825 (62)	—	489 (7830)
4	Batt Insulation in Stud Cavity	3 ⅝ (92)	0.024 (0.042)	R-12 (2.1 RSI)	0.9 (14)
5	Continuous Insulation	1 (25)	—	R-5 (0.88 RSI)	1.8 (28)
6	Concrete Wall/Floor Slab	8 (203)	1.04 (1.8)	—	140 (2250)
h	Exterior insulation	2 (51)	0.017 (0.029)	R-10 (1.75 RSI)	1.8 (28)
7	Exterior Film (left side)[1]	—	—	R-0.2 (0.03 RSI)	—

Table 7-4. Thermal performance: Suspended slab with R-Value of R-15.

Condition	Clear Wall R-Value (W/m²K)	Linear Transmittance (Ψ) Btu/hr ft°F (W/mK)
Wall Clear Field	R-15 (2.64 RSI)	–
As-Built Slab (no exterior insulation)	—	0.494 (0.855)
Retrofit with...		
8-in. (h) external insulation	—	0.457 (0.79)
18-in. (h) external insulation	—	0.388 (0.671)
36-in. (h) external insulation	—	0.275 (0.476)

Table 7-5. Thermal performance: Suspended slab with R-Value of R-7.7.

Condition	Clear Wall R-Value (W/m²K)	Linear Transmittance (Ψ) Btu/hr ft°F (W/mK)
Wall Clear Field	R-7.7 (1.36 RSI)	—
As-Built Slab (no exterior insulation)	—	0.486 (0.841)
Retrofit with...		
8-in. (h) external insulation	—	0.423 (0.731)
18-in. (h) external insulation	—	0.326 (0.564)
36-in. (h) external insulation	—	0.152 (0.262)

Notes:

This detail is difficult to retrofit effectively. Ideally, the entire exterior would be insulated, but an 18- to 36-in. wide strip of insulation is reasonably effective. Exterior insulation would also be required at partition walls and parapets. It is difficult to do this retrofit from the interior as both the floor and ceiling would need to be insulated.

Although shown as concrete, the wall's support function could be easily filled by a precast, tilt-up, or CMU with almost no impact on thermal performance. It is assumed the wall is functional before the retrofit is applied.

There are few risks to this detail. However, a steeply-sloped, durable top edge and drip-edge at the bottom of the projecting insulation band is important to avoid the collection of rain and melt water.

The thermal performance can be further increased by increasing the thickness of the insulation and covering more (or all) of the exterior (see Section 4.1). The primary improvement is gained by increasing "h" and the entire wall should ideally be covered with exterior insulation (Section 4.1) to achieve high performance

7.3 1c CMU or concrete wall with interior insulation: At parapet with concrete roof

Figure 7-3. Parapet with concrete roof.

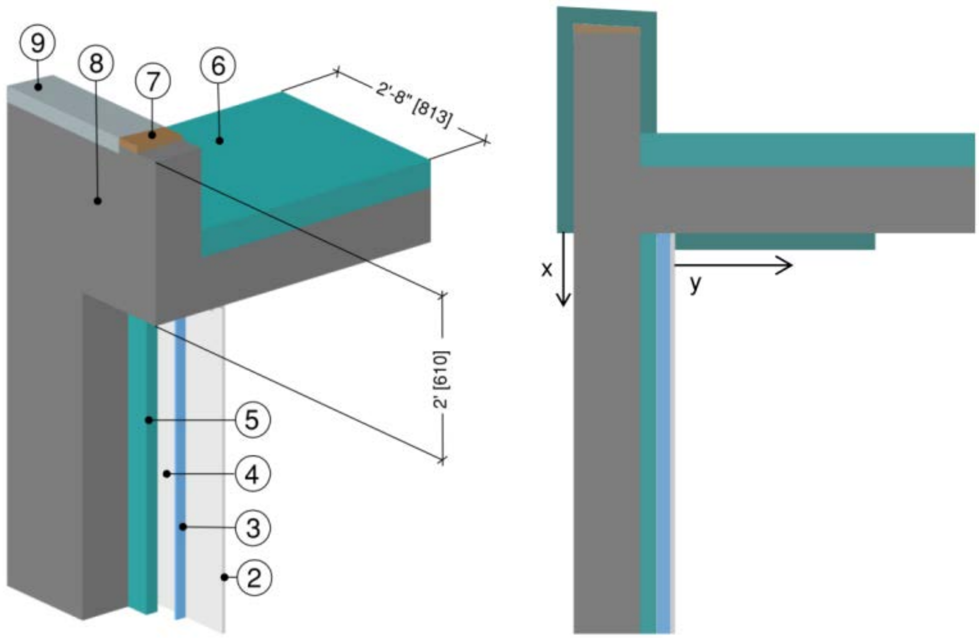


Table 7-6. Modeling values: Parapet with concrete roof.

ID	Component	Thickness in. (mm)	Conductivity Btu/ft·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)
1	Interior Film (right side)[1]	–	–	R-0.6 (0.11 RSI) to R-0.7 (0.12 RSI)	–
2	Gypsum Board	1/2 (13)	0.092 (0.16)	R-0.5 (0.08 RSI)	50 (800)
3	1 5/8-in. Steel Studs with Top Tracks	20 gauge	35.825 (62)	–	489 (7830)
4	Air in Stud Cavity	1⅝ (42)	–	R-0.9 (0.16 RSI)	0.075 (1.2)
5	Interior Insulation	2 (50)	–	R-10 (1.76 RSI)	1.8 (28)
6	Roof Insulation	4 (102)	–	R-20 (3.5 RSI)	1.8 (28)
7	Wood Blocking	⅝ (16)	0.052 (0.09)	R-1 (0.18 RSI)	27.8 (445)
8	Concrete Slab and Parapet	8 (203)	1.04 (1.8)	–	140 (2250)
9	Metal cap flashing/ finish roof material is incorporated into exterior heat transfer coefficient				
x	Exterior Insulation	2 (51)	0.017 (0.029)	R-10 (1.75 RSI)	1.8 (28)
y	Interior Insulation	2 (51)	0.017 (0.029)	R-10 (1.75 RSI)	1.8 (28)
10	Exterior Film (left side)[1]	–	–	R-0.2 (0.03 RSI)	–

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation

Table 7-7. Thermal performance: Parapet with concrete roof with R-Value of R-13.5.

Condition	Clear Wall R-Value (W/m²K)	Linear Transmittance (Ψ) Btu/hr ft°F (W/mK)
Wall Clear Field	R-13.5 (2.37 RSI)	–
Roof Clear Field	R-21.4 (3.77 RSI)	–
As-Built Slab (no exterior or interior insulation)	–	0.6 (1.038)
Retrofit with...		
0-in. exterior (x) and 12-in. interior (y)	–	0.227 (0.393)
12-in. exterior (x) and 12-in. interior (y)	–	0.174 (0.301)
0-in. exterior (x) and 24-in. interior (y)	–	0.161 (0.279)
12-in. exterior (x) and 24-in. interior (y)	–	0.122 (0.211)
12-in. exterior (x) and 0-in. interior (y)	–	0.271 (0.469)
no exterior and 12-in. interior (y)	–	0.268 (0.464)
no exterior and 24-in. interior (y)	–	0.192 (0.333)

Table 7-8. Thermal performance: Parapet with concrete roof with R-Value of R-2.79.

Condition	Clear Wall R-Value (W/m²K)	Linear Transmittance (Ψ) Btu/hr ft°F (W/mK)
Wall Clear Field	2.79 (0.49)	–
Roof Clear Field	21.41 (3.77)	–
As-Built Slab (no exterior or interior insulation)	–	0.451 (0.78)
Retrofit with...		
0-in. exterior (x) and 12-in. interior (y)	–	0.159 (0.275)
12-in. exterior (x) and 12-in. interior (y)	–	–
0-in. exterior (x) and 24-in. interior (y)	–	0.094 (0.163)
12-in. exterior (x) and 24-in. interior (y)	–	–
12-in. exterior (x) and 0-in. interior (y)	–	0.081 (0.14)
no exterior and 12-in. interior (y)	–	0.229) (0.397)
no exterior and 24-in. interior (y)	–	0.147 (0.254)

Notes:

This detail can often be retrofit during reroofing with relative ease. However, to reduce heat flow by more than one third, interior insulation would also need to be applied for at least 24 in. along the interior ceiling, which necessitates access to the interior.

Although shown as concrete, the wall's support function could be easily filled by a precast, tilt-up, or concrete CMU with almost no impact on thermal performance. It is assumed the wall is functional before the retrofit is applied.

There are few risks to this detail. The interior insulation must be protected from fire if made of foam. If the interior foam does not have intrinsic will air and vapor resistance, it must be provided. The interior foam must also be pressured tight to the substrate to prevent convective loops (Section 5.1.2).

The thermal performance can be further increased by increasing the thickness of the insulation and covering more (or all) of the exterior (see Section 4.1). The primary improvement is gained by increasing "h" and the entire wall should ideally be covered with exterior insulation (Section 4.1) to achieve high performance

Applying insulation over the entire exterior is the most practical way to reach very high performance levels.

7.4 1d CMU or concrete wall with interior insulation: Parapet with steel roof reck and steel joist

Figure 7-4. Parapet with steel roof deck and joists.

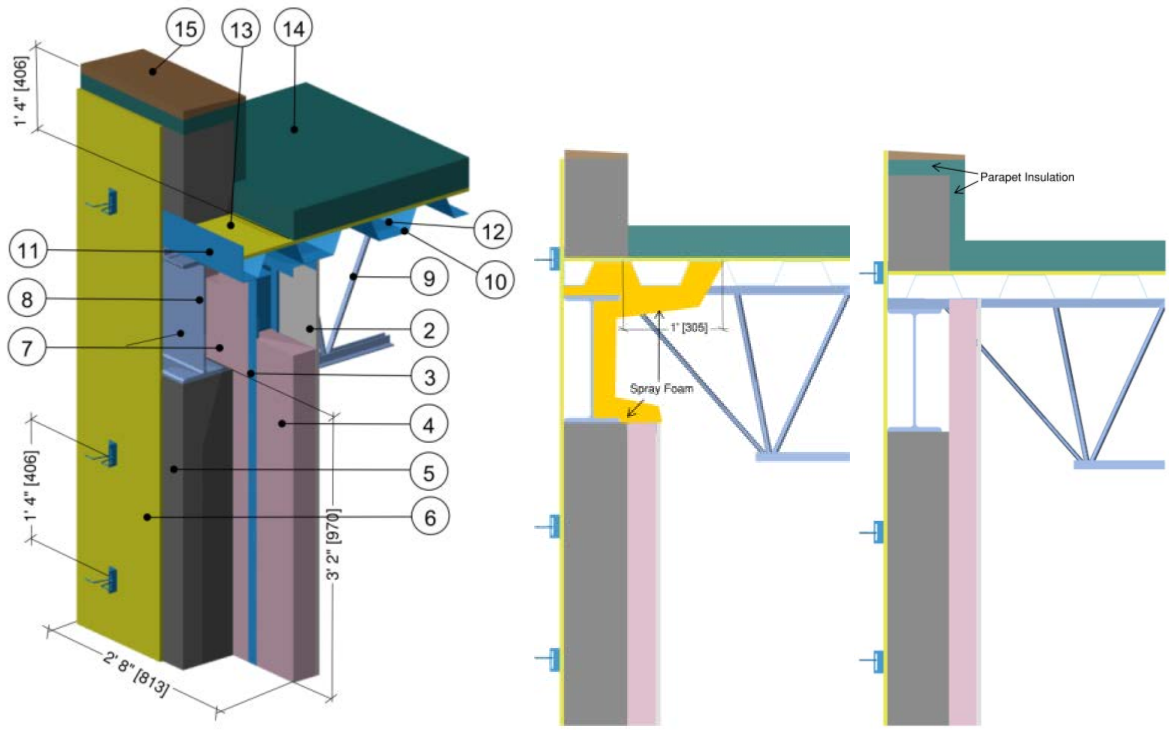


Table 7-9. Modeling values: Parapet with steel roof deck and joists.

ID	Component	Thickness in. (mm)	Conductivity Btu/ft·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)
1	Interior Film (right side)[1]	–	–	R-0.7 (0.12 RSI) to R-0.9 (0.16 RSI)	–
2	Gypsum Board	1/2 (13)	0.092 (0.16)	R-0.5 (0.08 RSI)	50 (800)
3	3 5/8-in. x 1 5/8-in. Steel Studs	18 Gauge	35.825 (62)	–	489 (7830)
4	Fiberglass Batt Insulation	3⅝ (92)	0.024 (0.042)	R-12 (2.1 RSI)	0.9 (14)
5	CMU Block Wall	8 (203)	0.603 (1.044)	R-1.1 (0.19 RSI)	140 (2550)
6	Exterior Sheathing	½ (13)	0.092 (0.16)	R-0.5 (0.09 RSI)	50 (800)
7	Beam Air Cavities	–	–	R-0.9 (0.16 RSI)	–
8	Steel Beam (W410)	–	28.891 (50)	–	489 (7830)
9	Open Web Steel Joist	–	28.891 (50)	–	489 (7830)
10	Steel Deck	–	28.891 (50)	–	489 (7830)
11	Shelf Angle	–	35.825 (62)	–	489 (7830)
12	Roof Air Cavity	3 (76)	–	R-0.9 (0.16 RSI)	–
13	Gypsum Overlay Board	½ (13)	0.092 (0.16)	R-0.5 (0.08 RSI)	50 (800)
14	Exterior Insulation, Roof	4 (102)	–	R-20 (3.5 RSI)	1.8 (28)
15	Wood Blocking	⅝ (16)	0.052 (0.09)	R-1 (0.18 RSI)	27.8 (445)
16	Metal cap flashing/ finish roof material is incorporated into exterior heat transfer coefficient				

ID	Component	Thickness in. (mm)	Conductivity Btu/ft·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)
	Interior Spray Foam	—	—	R-10 (1.75 RSI)	1.8 (28)
	Exterior Insulation, Parapet	2 (51)	0.017 (0.029)	R-10 (1.75 RSI)	1.8 (28)
17	Exterior Film (left side)[1]	—	—	R-0.2 (0.03 RSI)	—
[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation					

Table 7-10. Thermal performance: Parapet with steel roof deck and joists.

Condition	Clear Wall R-Value (W/m²K)	Linear Transmittance (Ψ) Btu/hr ft°F (W/mK)
Wall Clear Field	R-8.9 (1.57 RSI)	—
Roof Clear Field	R-21.4 (3.77 RSI)	—
As-Built Slab, full stud height	—	0.574 (0.994)
As-Built Slab, low stud height		1.314 (2.274)
Retrofit with...		
R10 Parapet Insulation, full stud height	—	0.548 (0.948)
R10 Spray Foam, low stud height	—	0.461 (0.798)

Notes:

This detail is relatively simple to execute. To increase performance the insulation should be extended from the top of the parapet to down the face to below the I-beam to the exterior.

The spray foam should be closed cell to control with vapor diffusion condensation in climate Zones 5 and higher.

7.5 1e CMU or concrete wall with interior insulation: Window jamb (1)

Figure 7-5. Window jamb – as found.

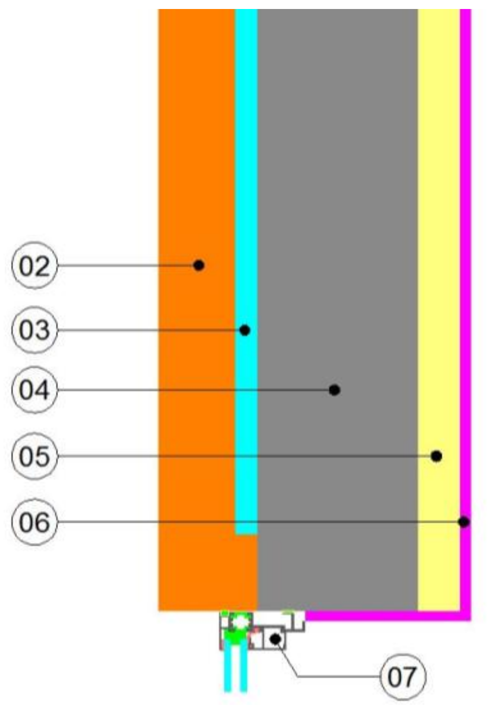


Table 7-11. Modeling values: Window jamb— as found.

ID	Component	Thickness in. (mm)	Conductivity Btu/ft·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)
1	Interior Film	–	–	R-0.74 (0.13 RSI)	–
2	Brick	3⅝ (92)	0.578 (1)	R-0.523 (0.092 RSI)	110 (1800)
3	Air Cavity	1 (25)	0.070 (0.122)	R-1.185 (0.209 RSI)	–
4	CMU	7⅝ (194)	0.069 (1.2)	R-0.916 (0.161 RSI)	130 (2100)
5	Interior Insulation	2 (51)	0.0139 (0.024)	R-12 (2.11 RSI)	2 (32)
6	Gypsum Board	½ (13)	0.092 (0.16)	R-0.5 (0.08 RSI)	50 (800)
7	5500 ISOWEB WINDOW	–	–	–	–
8	Exterior Film	–	–	R-0.23 (0.04 RSI)	–

Table 7-12. Thermal performance: Window jamb— as found.

Condition	Clear Wall R-Value (W/m²K)	Linear Transmittance (Ψ) Btu/hr ft°F (W/mK)
Wall Clear Field	R-16 (0.351)	–
As-Built Fitting Situation	–	0.308 (0.533)

7.6 1e CMU or concrete wall with interior insulation: Window jamb (2)

Figure 7-6. Window jamb – improved.

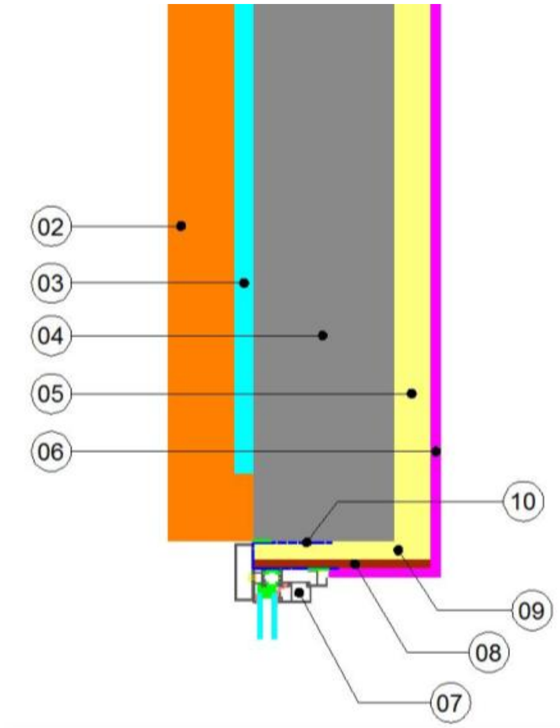


Table 7-13. Modeling values: Window jamb - improved.

ID	Component	Thickness in. (mm)	Conductivity Btu/ft·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)
1	Interior Film	–	–	R-0.74 (0.13 RSI)	–
2	Brick	3⅝ (92)	0.578 (1)	R-0.523 (0.092 RSI)	110 (1800)
3	Air Cavity	1 (25)	0.070 (0.122)	R-1.185 (0.209 RSI)	–
4	CMU	7⅝ (194)	0.069 (1.2)	R-0.916 (0.161 RSI)	130 (2100)
5	Interior Insulation	2 (51)	0.0139 (0.024)	R-12 (2.11 RSI)	2 (32)
6	Gypsum Board	½ (13)	0.092 (0.16)	R-0.5 (0.08 RSI)	50 (800)
7	5500 ISOWEB WINDOW	–	–	–	–
8	Plywood	¾ (19)	0.058 (0.1)	–	40 (600)
9	Interior Insulation	1 (25)	0.0139 (0.024)	–	2 (32)
10	Air - Water Control Layer	–	–	–	–
11	Exterior Film	–	–	R-0.23 (0.04 RSI)	–

Table 7-14. Thermal performance: Window jamb - improved.

Condition	Clear Wall R-Value (W/m²K)	Linear Transmittance (Ψ) Btu/hr ft°F (W/mK)
Wall Clear Field	R-16 (0.351)	–
Proposed Fitting Situation	–	0.079 (0.136)

Notes:

Window details are often critical for the success of an insulation retrofit. This detail shows the impact for a high performance window inserted into an internally retrofit masonry wall. By wrapping even a thin layer of insulation into the rough opening, heat flow can be reduced by a factor of four. If windows are replaced, this is a relatively easy detail to achieve, but requires careful coordination between the window section and the insulated jambs to ensure complete closure from the exterior. Section 6.1.2 and Figure 6-7 provide more information about this type of condition.

Although shown as concrete, the wall's support function could be easily filled by a precast, tilt-up, or concrete CMU with almost no impact on thermal performance. It is assumed the wall is functional before the retrofit is applied.

The primary concerns in applying this detail is achieving continuity of the air-water control layers while providing support for the window install (see Section 6.1). Every window section is likely to have a slightly different solution, but all will have clear water and air control layers identified and made continuous. Designers will also need to complete the exterior closure to ensure that the insulation and the air-water control layers are not visible and are protected from sun and direct rain impingement.

The thermal performance can be further increased by increasing the thickness of the insulation, especially at the window rough opening return, although thicker insulation here will reduce the size of the window opening. The primary improvement is gained by increasing "h" and the entire wall should ideally be covered with exterior insulation (Section 4.1) to achieve high performance

7.7 1f CMU or concrete wall with interior insulation: Window head (1)

Figure 7-7. Window head – as found.

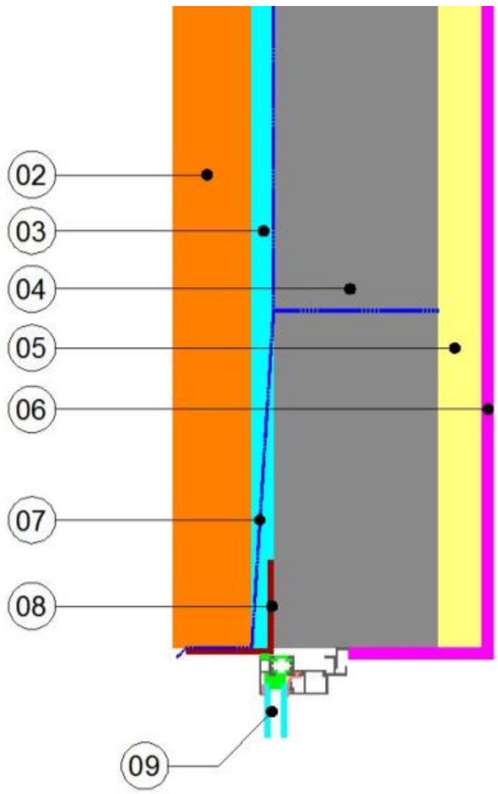


Table 7-15. Modeling values: Window head — as found.

ID	Component	Thickness in. (mm)	Conductivity Btu/ft·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)
1	Interior Film	–	–	R-0.74 (0.13 RSI)	–
2	Brick	3⅝ (92)	0.578 (1)	R-0.523 (0.092 RSI)	110 (1800)
3	Air Cavity	1 (25)	0.070 (0.122)	R-1.185 (0.209 RSI)	–
4	CMU	7⅝ (194)	0.069 (1.2)	R-0.916 (0.161 RSI)	130 (2100)
5	Interior Insulation	2 (51)	0.0139 (0.024)	R-12 (2.11 RSI)	2 (32)
6	Gypsum Board	½ (13)	0.092 (0.16)	R-0.5 (0.08 RSI)	50 (800)
7	Air/Water Control Layer	–	–	–	–
8	Steel Lintel	–	27.7 (48)	–	450(7700)
9	5500 ISOWEB WINDOW	–	–	–	–
10	Exterior Film	–	–	R-0.23 (0.04 RSI)	–

Table 7-16. Thermal performance: Window head — as found.

Condition	Clear Wall R-Value (W/m²K)	Linear Transmittance (Ψ) Btu/hr ft°F (W/mK)
Wall Clear Field	R-16 (0.351)	–
As-Built Fitting Situation	–	0.315 (0.546)

7.8 1f CMU or concrete wall with interior insulation: Window head (2)

Figure 7-8. Window head – corrected.

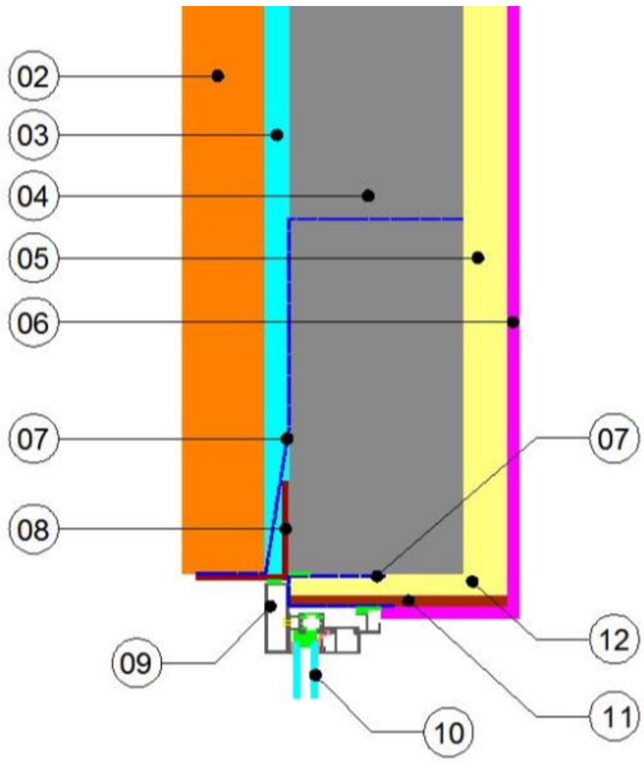


Table 7-17. Modeling values: Window head — corrected.

ID	Component	Thickness in. (mm)	Conductivity Btu/ft·hr·˚F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)
1	Interior Film	—	—	R-0.74 (0.13 RSI)	—
2	Brick	3⅝ (92)	0.578 (1)	R-0.523 (0.092 RSI)	110 (1800)
3	Air Cavity	1 (25)	0.070 (0.122)	R-1.185 (0.209 RSI)	—
4	CMU	7⅝ (194)	0.069 (1.2)	R-0.916 (0.161 RSI)	130 (2100)
5	Interior Insulation	2 (51)	0.0139 (0.024)	R-12 (2.11 RSI)	2 (32)
6	Gypsum Board	½ (13)	0.092 (0.16)	R-0.5 (0.08 RSI)	50 (800)
7	Air-Water Control Layer	—	—	—	—
8	Steel Lintel	—	27.7 (48)	—	450(7700)
9	Standard Snap On Trim	2 (51)	85.5 (160)	—	—
10	5500 ISOWEB WINDOW	—	—	—	—
11	Plywood	¾ (19)	0.058 (0.1)	—	38 (600)
12	Interior Insulation	1 (25)	0.0139 (0.024)	—	2 (32)
13	Exterior Film	—	—	R-0.23 (0.04 RSI)	—

Table 7-18. Thermal performance: Window head — corrected.

Condition	Clear Wall R-Value (W/m^2K)	Linear Transmittance (Ψ) Btu/hr ft°F (W/mK)
Wall Clear Field	R-16 (0.351)	—
Proposed Fitting Situation	—	0.086 (0.149)

Notes:

This detail is similar to the jamb detail in 1e). Section 6.1.2 and Figure 6-7 provide more information about the thermal performance of this type of condition.

It is critical that the head flashing direct draining water outward at this location, and it is also necessary to main airtightness here. (See Sections 5.1.1, 6.1.2, and 6.1.5).

7.9 1g CMU or concrete wall with interior insulation: Window sill (1)

Figure 7-9. Window sill – corrected.

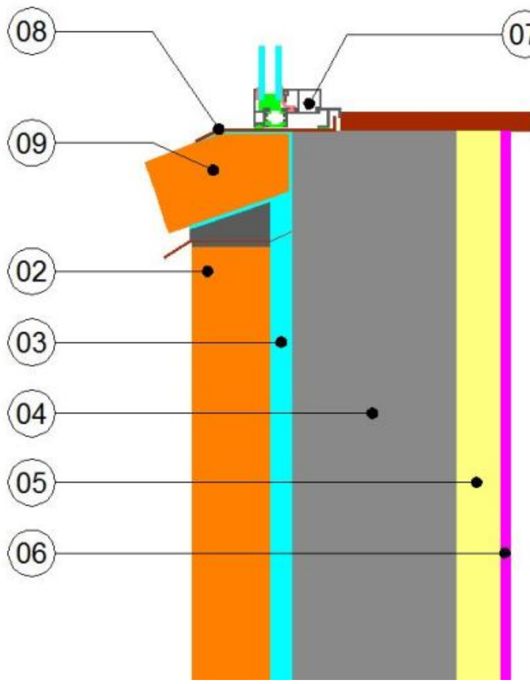


Table 7-19. Modeling values: Window sill — corrected.

ID	Component	Thickness in. (mm)	Conductivity Btu/ft·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)
1	Interior Film	—	—	R-0.74 (0.13 RSI)	—
2	Brick	3⅝ (92)	0.578 (1)	R-0.523 (0.092 RSI)	110 (1800)
3	Air Cavity	1 (25)	0.070 (0.122)	R-1.185 (0.209 RSI)	—
4	CMU	7⅝ (194)	0.069 (1.2)	R-0.916 (0.161 RSI)	130 (2100)
5	Interior Insulation	2 (51)	0.0139 (0.024)	R-12 (2.11 RSI)	2 (32)
6	Gypsum Board	1/2 (13)	0.092 (0.16)	R-0.5 (0.08 RSI)	50 (800)
7	5500 ISOWEB WINDOW	—	—	—	—
8	Aluminum Sill Flashing	12 Gauge	86 (160)	—	
9	Brick Sill	3⅝ (92)	0.578 (1)	—	110 (1800)
10	Exterior Film	—	—	R-0.23 (0.04 RSI)	—

Table 7-20. Thermal performance: Window sill — corrected.

Condition	Clear Wall R-Value (W/m²K)	Linear Transmittance (Ψ) Btu/hr ft °F (W/mK)
Wall Clear Field	R-16 (0.351)	—
As-Built Fitting Situation	—	0.322 (0.558)

7.10 1g CMU or concrete wall with interior insulation: Window sill (2)

Figure 7-10. Window sill – corrected.

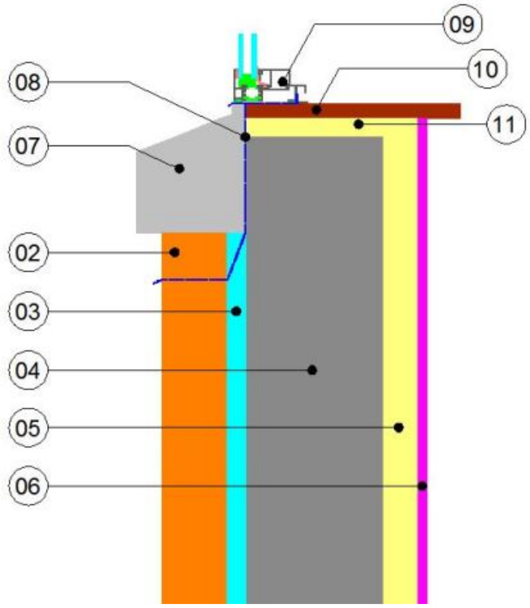


Table 7-21. Modeling values: Window sill — corrected.

ID	Component	Thickness in. (mm)	Conductivity Btu/ft·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)
1	Interior Film	—	—	R-0.74 (0.13 RSI)	—
2	Brick	3⅝ (92)	0.578 (1)	R-0.523 (0.092 RSI)	110 (1800)
3	Air Cavity	1 (25)	0.070 (0.122)	R-1.185 (0.209 RSI)	—
4	CMU	7⅝ (194)	0.069 (1.2)	R-0.916 (0.161 RSI)	130 (2100)
5	Interior Insulation	2 (51)	0.0139 (0.024)	R-12 (2.11 RSI)	2 (32)
6	Gypsum Board	½ (13)	0.092 (0.16)	R-0.5 (0.08 RSI)	50 (800)
7	Concrete Sill	—	1.4 (2.4)	—	110 (1800)
8	Air-Water Control Layer	—	—	—	—
9	5500 ISOWEB WINDOW	—	—	—	—
10	Plywood	¾ (19)	0.058 (0.1)	—	40 (600)
11	Rigid Insulation	1 (25)	0.0139 (0.024)	—	2 (32)
12	Exterior Film	—	—	R-0.23 (0.04 RSI)	—

Table 7-22. Thermal performance: Window sill — corrected.

Condition	Clear Wall R-Value (W/m²K)	Linear Transmittance (Ψ) Btu/hr ft°F (W/mK)
Wall Clear Field	R-16 (0.351)	—
Proposed Fitting Situation	—	0.088 (0.152)

Notes:

This solution for a window opening is similar to that shown in detail 1e) and f). The support function can again be provided by using either poured concrete; precast, tilt-up, brick masonry; or CMU construction.

It is critical that the water control layer wrap under the window and direct any incidental rainwater that may penetrate the rough opening, or window itself, outward to the exterior (or to the drainage cavity if present). At the back dam (see Section 6.1), air tightness also needs to be maintained. Empty frames should be filled to control air movement (Section 6.1.5).

7.11 1h CMU or concrete wall with interior insulation: Blast-resistant window jamb (1)

Figure 7-11. Blast-resistant jamb – as found.

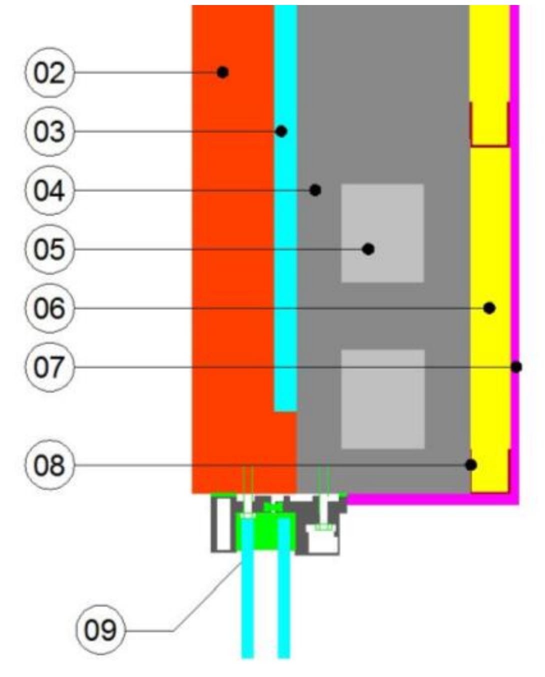


Table 7-23. Modeling values: Blast-resistant jamb — as found.

ID	Component	Thickness in. (mm)	Conductivity Btu/ft·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)
1	Interior Film	—	—	R-0.74 (0.13 RSI)	—
2	Brick	3⅝ (92)	0.578 (1)	R-0.523 (0.092 RSI)	110 (1800)
3	Air Cavity	1 (25)	0.070 (0.122)	R-1.185 (0.209 RSI)	—
4	CMU	7⅝ (194)	0.069 (1.2)	R-0.916 (0.161 RSI)	130 (2100)
5	Grout Fill		0.092 (1.6)	—	125 (2000)
6	Insulation	—	0.021 (0.036)	—	0.8 (13)
7	Gypsum Board	½ (13)	0.092 (0.16)	R-0.5 (0.08 RSI)	50 (800)
8	Steel Studs	—	27.7 (48)	—	480(7700)
9	625BL Armortex Window 42psi	—	—	—	—
10	Exterior Film	—	—	R-0.23 (0.04 RSI)	—

Table 7-24. Thermal performance: Blast-resistant jamb — as found.

Condition	Clear Wall R-Value (W/m²K)	Linear Transmittance (Ψ) Btu/hr ft°F (W/mK)
Wall Clear Field	R-6 (0.947)	—
As-Built Fitting Situation	—	0.235 (0.406)

7.12 1h CMU or concrete wall with interior insulation: Blast-resistant window jamb (2)

Figure 7-12. Blast-resistant jamb – corrected.

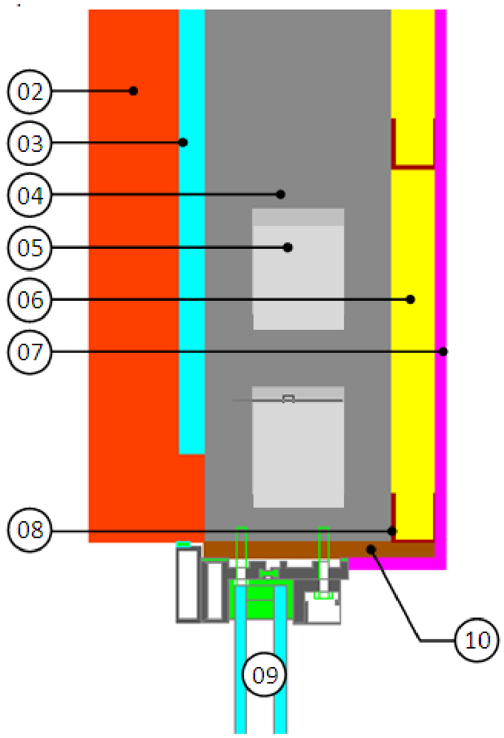


Table 7-25. Modeling values: Blast-resistant jamb — corrected.

ID	Component	Thickness in. (mm)	Conductivity Btu/ft·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)
1	Interior Film	—	—	R-0.74 (0.13 RSI)	—
2	Brick	3⅝ (92)	0.578 (1)	R-0.523 (0.092 RSI)	110 (1800)
3	Air Cavity	1 (25)	0.070 (0.122)	R-1.185 (0.209 RSI)	—
4	CMU	7⅝ (194)	0.069 (1.2)	R-0.916 (0.161 RSI)	130 (2100)
5	Grout Fill		0.092 (1.6)	—	125(2000)
6	Insulation	—	0.021 (0.036)	—	1 (16)
7	Gypsum Board	½ (13)	0.092 (0.16)	R-0.5 (0.08 RSI)	50 (800)
8	Steel Studs	—	27.7 (48)	—	480(7700)
9	625BL Armortex Window 42psi	—	—	—	—
10	Wood buck	—	0.006 (0.10)	—	32 (510)
11	Exterior Film	—	—	R-0.23 (0.04 RSI)	—

Table 7-26. Thermal performance: Blast-resistant jamb — corrected.

Condition	Clear Wall R-Value (W/m²K)	Linear Transmittance (Ψ) Btu/hr ft°F (W/mK)
Wall Clear Field	R-6 (0.947)	—
Proposed Fitting Situation	—	0.110 (0.192)

Notes:

This detail is easy to achieve if the window or door is being replaced during a blast-resistant retrofit.

Although shown as CMU, the support function could be provided by concrete or masonry.

To transfer the high blast loads from the door frame to the structure, solid wood can be used. The insulation level provided by the wood is modest, but can make a very significant reduction in thermal bridging. Alternative solutions could include the use of insulation at the jamb and widely spaced metal clips (see Section 4.4). The performance of the detail could be increased by using thicker layers of insulation.

Providing continuity of the air barrier system and managing convection are important issues for this detail (Sections 5.1.1 and 5.1.2).

The primary risk is in the existing condition: gypsum wallboard that is uninsulated can often be damaged by condensation at these jamb locations in cold weather. The wood or insulation at the jamb in the proposed corrected detail must be protected from the exterior by a water and air control membrane.

7.13 1i CMU or concrete wall with interior insulation: Door jambs to CMU (1)

Figure 7-13. Door jamb to CMU – as found.

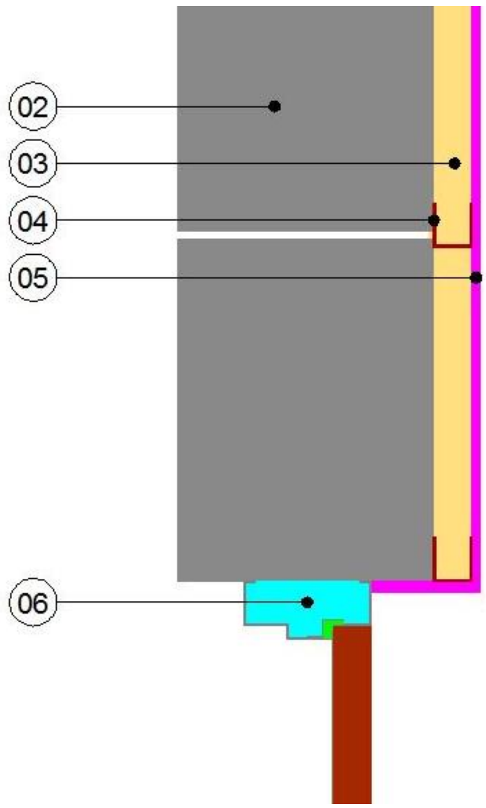


Table 7-27. Modeling values: Door jamb to CMU — as found.

ID	Component	Thickness in. (mm)	Conductivity Btu/ft·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)
1	Interior Film	—	—	R-0.74 (0.13 RSI)	—
2	CMU	7⅝ (194)	0.069 (1.2)	R-0.916 (0.161 RSI)	130 (2100)
3	Rockwool	2 (51)	0.021 (0.036)	R-6.26 (1.103 RSI)	2 (32)
4	Steel Studs	—	27.7 (48)	—	450(7700)
5	Gypsum Board	½ (13)	0.092 (0.16)	R-0.5 (0.08 RSI)	50 (800)
6	Hollow Metal Door	—	—	—	—
7	Exterior Film	—	—	R-0.23 (0.04 RSI)	—

Table 7-28. Thermal performance: Door jamb to CMU — as found.

Condition	Clear Wall R-Value (W/m²K)	Linear Transmittance (Ψ) Btu/hr ft°F (W/mK)
Wall Clear Field	R-5.39 (0.950)	—
As-Built Fitting Situation	—	0.113 (0.196)

7.14 1i CMU or concrete wall with interior insulation: Door jambs to CMU (2)

Figure 7-14. Door jamb to CMU – corrected.

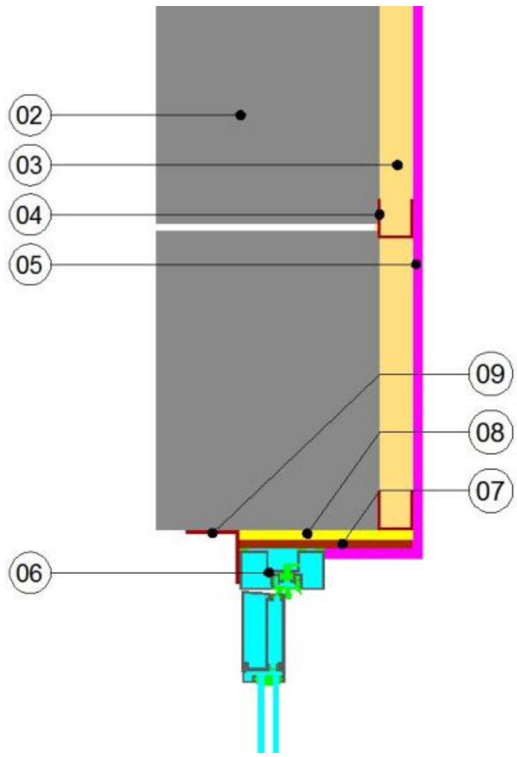


Table 7-29. Modeling values: Door jamb to CMU — corrected.

ID	Component	Thickness in. (mm)	Conductivity Btu/ft·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)
1	Interior Film	—	—	R-0.74 (0.13 RSI)	—
2	CMU	7⅝ (194)	0.069 (1.2)	R-0.916 (0.161 RSI)	130 (2100)
3	Rockwool	2 (51)	0.021 (0.036)	R-6.26 (1.103 RSI)	2 (32)
4	Steel Studs	—	27.7 (48)	—	450(7700)
5	Gypsum Board	½ (13)	0.092 (0.16)	R-0.5 (0.08 RSI)	50 (800)
6	Kawneer AA®250/425 Blast R Door	—	—	—	—
7	Timber Sheeting	—	0.006 (0.10)	—	32 (510)
8	Perimeter Insulation	—	0.021 (0.036)	—	2 (32)
9	Snap on Trim/Steel Support Angle	—	27.7 (48)	—	450(7700)
10	Exterior Film	—	—	R-0.23 (0.04 RSI)	—

Table 7-30. Thermal performance: Door jamb to CMU — corrected.

Condition	Clear Wall R-Value (W/m²K)	Linear Transmittance (Ψ) Btu/hr ft °F (W/mK)
Wall Clear Field	R-5.39 (0.950)	—
As-Built Fitting Situation	—	0.103 (0.178)

Notes:

Although shown as poured concrete, the support structure could be CMU or brick masonry.

Thermally-broken hollow metal door frames are not commonly available nor of high performance. A thermally-broken aluminum storefront could be considered.

The losses from a standard steel door are extremely high and will incur more heat losses and related problems than the TB at its edge. Due to the nature of thermal bridging, the psi-value will always be very odd if there are one or two uninsulated components or non-thermally-broken elements. The relevance of thermal bridging is more important when analyzing an insulated element or structure. Thus the psi-value for the "as found" TB could be misinterpreted as being acceptable. The reality is that the heat flow at the intersection is actually very high, but the heat flow right across the door surface is also very high.

These two examples, a situation with a thermally-broken frame and glass and another with a reasonable TB correction, were selected for this reason.

To improve the thermal performance, the thickness of the opening perimeter insulation can be improved, and a better insulated door fitted (metal clad wood, fiberglass, etc.).

Providing continuity of the air barrier system and managing convection are important issues for this detail (Sections 5.1.1 and 5.1.2).

7.15 1j CMU or Concrete wall with interior insulation: Thru slab projection (shade or balcony)

Figure 7-15. Through slab projection.

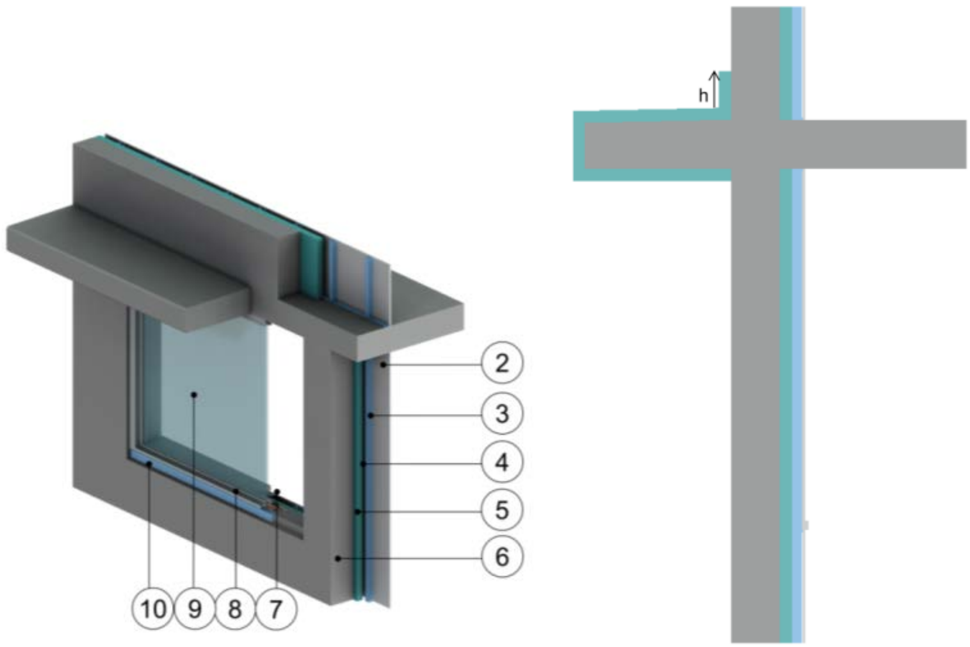


Table 7-31. Modeling values: Through slab projection.

ID	Component	Thickness in. (mm)	Conductivity Btu/ft·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)
1	Interior Film (right side)1	–	–	R-0.6 (0.11 RSI) to R-1.1 (0.20 RSI)	–
2	Gypsum Board	½ (13)	0.092 (0.16)	R-0.5 (0.08 RSI)	50 (800)
3	1 5/8-in. x 1 5/8-in. Steel Studs with Top and Bottom Tracks	18 Gauge	35.825 (62)	–	489 (7830)
4	Air in Stud Cavity	1⅝ (41)	–	R-0.9 (RSI-0.16)	0.075 (1.2)
5	Continuous Rigid Insulation	3 (76)	–	R-15 (2.6 RSI)	1.8 (28)
6	Concrete Wall/ Projected Floor Slab	8 (203)	1.04 (1.8)	–	140 (2250)
7	Metal sheet connected to studs	18 Gauge	35.825 (62)	–	489 (7830)
8	Wood Sill	1¼ (30)	0.052 (0.09)	–	31 (500)
9	5 ft (1.5m) x 6 ft (1.8m) Aluminum window: double glazed and thermally-broken, U = 0.35 Btu/hr·ft²oF (2.0 W/m²K)				
10	Aluminum Flashing	16 Gauge	127.12 (220)	–	0.21 (900)
h	Exterior Insulation	2 (51)	0.017 (0.029)	R-10 (1.75 RSI)	1.8 (28)
11	Exterior Film (left side)1	–	–	R-0.2 (0.03 RSI)	–

1 Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation

2 The thermal conductivity of air spaces within framing was found using ISO 100077-2

Table 7-32. Thermal performance: Through slab projection.

Condition	Clear Wall R-Value (W/m²K)	Linear Transmittance (Ψ) Btu/hr ft°F (W/mK)
Wall Clear Field	R-17.5 (3.08 RSI)	–
As-Built Slab Projection (no exterior insulation)	–	0.539 (0.932)
Retrofit with…		
Insulation on slab only	–	0.454 (0.786)
Insulation on slab and 6-in. (h) above	–	0.405 (0.701)
Insulation on slab and 12-in. (h) above	–	0.366 (0.634)

Notes:

This type of detail reflects both balcony projections and cast-in-place shading over windows. The floor is concrete, but the wall could be load-bearing CMU or brick masonry.

The addition of insulation reduces the size of the TB, but not significantly. To improve performance increasing the thickness will do little, and only extending the coverage to all or most of the exterior surface. In practice, it may be easier to remove the projection.

The primary risk to deal with in the retrofit is the potential for damage to the insulation on the top horizontal projection. This must be sloped and protected with some type of roofing membrane.

7.16 2a CMU or Concrete wall with exterior insulation: Roof parapet with concrete roof

Figure 7-16. Concrete wall with exterior insulation.

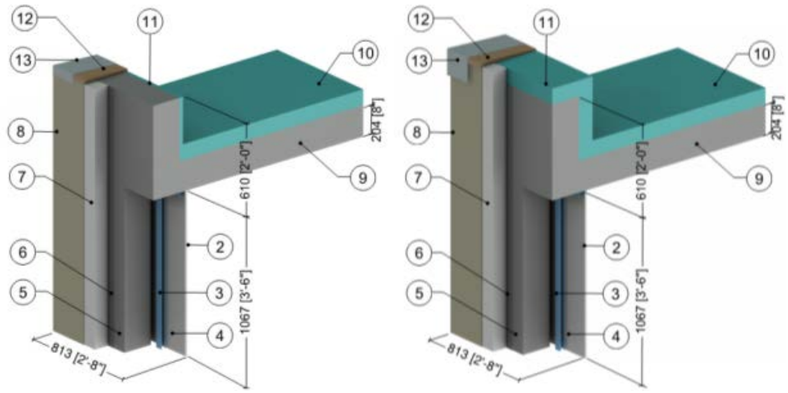


Table 7-33. Modeling values: Concrete wall with exterior insulation.

ID	Component	Thickness in. (mm)	Conductivity Btu/ft·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)
1	Interior Films (right side)1	–	–	R-0.6 (0.11 RSI) to R-0.7 (0.12 RSI)	–
2	Gypsum Board	½ (13)	0.092 (0.16)	R-0.5 (0.08 RSI)	50 (800)
3	1 5/8-in. x 1 5/8-in. Steel Studs (16-in. o.c.) with Top Tracks	18 Gauge	35.825 (62)	–	489 (7830)
4	Air in Stud Cavity	1⅝ (41)	–	R-0.9 (0.16 RSI)	0.075 (1.2)
5	Concrete Wall	8 (203)	1.04 (1.8)	–	140 (2250)
6	Water Resistive Barrier Adhesive	–	–	–	–
7	Insulation Board	4 (100)	0.023 (0.039)	R-15 (2.64 RSI)	1 (16)
8	Lamina	⅛ (4)	0.52 (0.9)	R-0.04 (0.01 RSI)	120 (1922)
9	Concrete Slab and Parapet	8 (203)	1.04 (1.8)	–	140 (2250)
10	Roof Insulation	4 (100)	–	R-20 (3.5 RSI)	1.8 (28)
11	Parapet Insulation	1 (25)	–	R-5 (0.88 RSI)	1.8 (28)
	Parapet Insulation – Fully Insulated	3 (76)	–	R-15 (2.64 RSI)	1.8 (28)
12	Wood Blocking	⅝ (16)	0.052 (0.09)	R-1 (0.18 RSI)	27.8 (445)
13	Flashing and roof finish material are incorporated into exterior heat transfer coefficient				
14	Exterior Film (left side)[1]	–	–	R-0.2 (0.03 RSI) to R-0.7 (0.12 RSI)	–
[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation					

Table 7-34. Thermal performance: Concrete wall with exterior insulation.

Condition	Clear Wall R-Value (W/m²K)	Linear Transmittance (Ψ) Btu/hr ft°F (W/mK)
Wall Clear Field	R-17.6 (3.10 RSI)	–
Roof Clear Field	R-21.9 (3.86 RSI)	–
As-Built Parapet	–	0.231 (0.400)
Retrofit with…		
Fully Insulated Parapet	–	0.125 (0.217)

7.17 2b CMU or Concrete wall with exterior insulation: Parapet with steel roof deck and joists

Figure 7-17. Parapet with steel roof deck and joists.

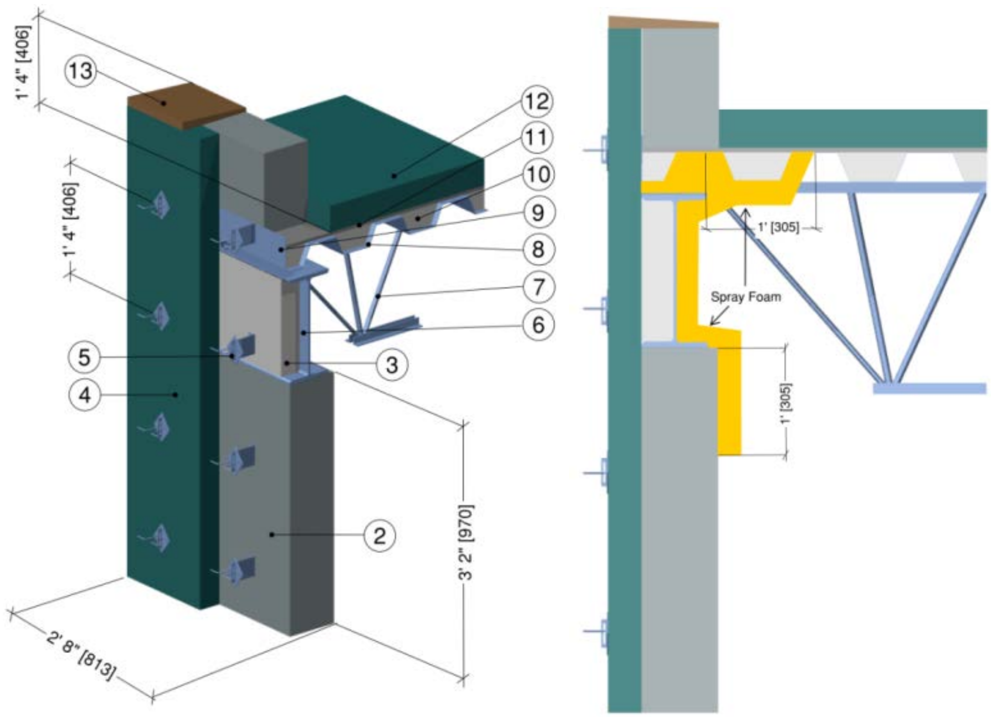


Table 7-35. Modeling values: Parapet with steel roof deck and joists.

ID	Component	Thickness in. (mm)	Conductivity Btu/ft·hr·°F (W/m K)	Nominal Resistance $hr \cdot ft^2 \cdot °F/Btu$ (m^2K/W)	Density lb/ft^3 (kg/m^3)
1	Interior Film (right side)[1]	–	–	R-0.7 (0.12 RSI) to R-0.9 (0.16 RSI)	–
2	CMU Block Wall	8 (203)	0.603 (1.044)	R-1.1 (0.19 RSI)	140 (2550)
3	Air Cavity	3⅜ (85)	–	R-0.9 (0.16 RSI)	
4	Exterior Insulation, Wall	2 (51)	0.017 (0.029)	R-10 (1.75 RSI)	1.8 (28)
5	Masonry Ties @ 16-in. (406 mm) o.c.	14 gauge	28.891 (50)	–	489 (7830)
6	Steel Beam (W410)	–	28.891 (50)	–	489 (7830)
7	Open Web Steel Joist	–	28.891 (50)	–	489 (7830)
8	Steel Deck	–	28.891 (50)	–	489 (7830)
9	Shelf Angle	–	35.825 (62)	–	489 (7830)
10	Roof Air Cavity	3 (76)	–	R-0.9 (0.16 RSI)	
11	Gypsum Overlay Board	½ (13)	0.092 (0.16)	R-0.5 (0.08 RSI)	50 (800)
12	Exterior Insulation, Roof	4 (102)	–	R-20 (3.5 RSI)	1.8 (28)
13	Wood Blocking	⅝ (16)	0.052 (0.09)	R-1 (0.18 RSI)	27.8 (445)
14	Metal cap flashing/ finish roof material is incorporated into exterior heat transfer coefficient				
	Interior Spray Foam	–	–	R-10 (1.75 RSI)	1.8 (28)
15	Exterior Film (left side)[1]	–	–	R-0.2 (0.03 RSI)	–
[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation					

Table 7-36. Thermal performance: Parapet with steel roof deck and joists.

Condition	Clear Wall R-Value (W/m^2K)	Linear Transmittance (Ψ) Btu/hr ft°F (W/mK)
Wall Clear Field	R-11.7 (2.00 RSI)	—
Roof Clear Field	R-21.4 (3.77 RSI)	—
As-Built Slab	—	0.318 (0.55)
Retrofit with...		
R10 Spray Foam	—	0.121 (0.209)

Notes:

This is easy to accomplish in both new and retrofit construction.

The wall could be load-bearing concrete, brick masonry, or CMU (shown in Figure 7-17).

The addition of insulation reduces the size of the TB, but not significantly. It can be improved by adding insulation all around the parapet, including the top.

The primary risk to deal is the fire protection of the spray foam. The spray foam should be closed cell to control with vapor diffusion condensation in climate Zones 5 and higher.

7.18 2c CMU or concrete wall with exterior insulation: At grade transition wall

Figure 7-18. At grade transition.

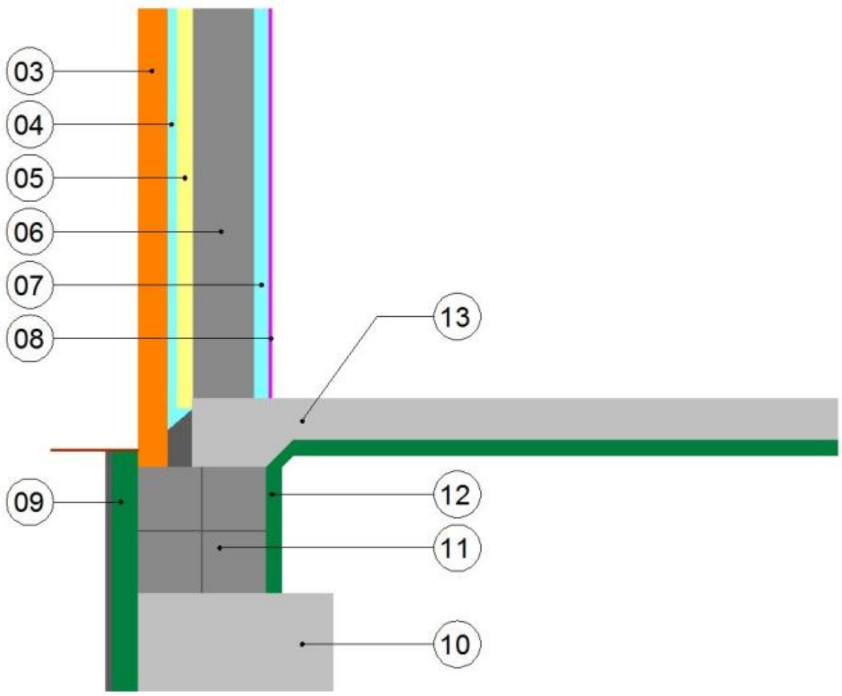


Table 7-37. Modeling values: At grade transition.

ID	Component	Thickness in. (mm)	Conductivity Btu/ft·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)
1	Interior Film (Wall)	—	—	R-0.74 (0.13 RSI)	—
2	Interior Film (Floor)	—	—	R-0.97 (0.17 RSI)	—
3	Brick	3⅝ (92)	0.578 (1)	R-0.523 (0.092 RSI)	110 (1800)
4	Air Cavity	1 (25)	0.1384 (0.2395)	R-0.602 (0.106 RSI)	—
5	Rigid Insulation	2 (51)	0.014 (0.024)	R-12 (2.117 RSI)	2 (32)
6	CMU	7⅝ (194)	0.069 (1.2)	R-0.916 (0.161 RSI)	130 (2100)
7	Air Layer with Steel Studs	1¾ (45)	0.222 (0.384)	R-0.672 (0.118 RSI)	—
8	Gypsum Board	½ (13)	0.092 (0.16)	R-0.5 (0.08 RSI)	50 (800)
9	Exterior XPS Insulation	2 (51)	0.017 (0.029)	R-10 (1.75 RSI)	1.8 (28)
10	Reinforced 30MPa concrete	—	1.04 (2.4)	—	150 (2400)
11	CMU	—	0.069 (1.2)	—	—
12	Slab XPS Insulation	2 (51)	0.017 (0.029)	R-10 (1.75 RSI)	1.8 (28)
13	Reinforced 30MPa concrete	5 (127)	1.04 (0.401)	R-0.174 (0.053 RSI)	150 (2400)
14	Exterior Film (Wall)	—	—	R-0.23 (0.04 RSI)	—
15	Exterior Film (Floor) Temp 50F 10C	—	—	R-0.00 (0.00 RSI)	—

Table 7-38. Thermal performance: At grade transition.

Condition	Clear Wall R-Value (W/m²K)	Linear Transmittance (Ψ) Btu/hr ft°F (W/mK)
Wall Clear Field	R-16.5 (0.344)	–
Floor Clear Field	R-11.21 (0.506)	–
As-Built Slab (no exterior or interior insulation)	–	0.323 (0.559)
Retrofit with...		
12-in. exterior	–	0.261 (0.452)
18-in. exterior (x)	–	0.203 (0.351)
24-in. exterior (x)	–	0.161 (0.279)
30-in. exterior (x)	–	0.138 (0.239)

Notes:

The wall system shown is a brick veneer, which is presumed to be a drained system. As such, the retrofit must be sure not to cover the drain holes or the drainage needs to be redirected somehow (perhaps in a drainage mat behind the additional exterior insulation.

The structure of the wall could be concrete or even steel studs with exterior insulation with similar behavior.

The insulation must be protected above grade from sun and physical attack (Section 6.2). The insulation choice must be made carefully to ensure it meets the requirements of below-grade use (Section 6.2).

Increasing the thickness of the insulation will do little to improve the performance relative to extending the insulation further upward along the wall.

7.19 2d CMU or concrete wall with exterior insulation: Window jamb (1)

Figure 7-19. Window jamb – as found.

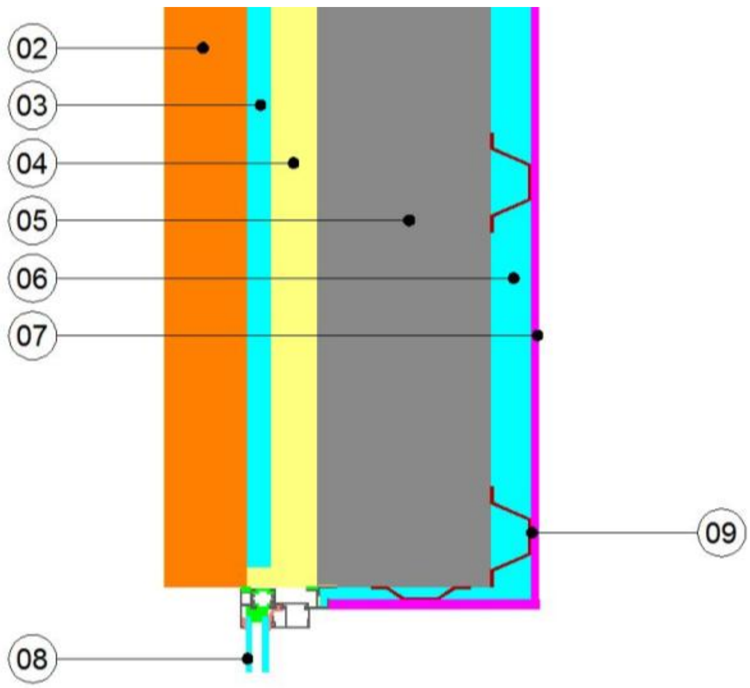


Table 7-39. Modeling values: Window jamb — as found.

ID	Component	Thickness in. (mm)	Conductivity Btu/ft·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)
1	Interior Film	—	—	R-0.74 (0.13 RSI)	—
2	Brick	3⅝ (92)	0.578 (1)	R-0.523 (0.092 RSI)	110 (1800)
3	Air Cavity	1 (25)	0.070 (0.122)	R-1.185 (0.209 RSI)	—
4	Insulation	2 (51)	0.0139 (0.024)	R-11.99 (2.112 RSI)	2 (32)
5	CMU	7⅝ (194)	0.069 (1.2)	R-0.916 (0.161 RSI)	130 (2100)
6	Air Layer with Steel Studs	1 ¾ (44)	0.2219 (0.384)	R-0.66 (0.116 RSI)	—
7	Gypsum Board	½ (13)	0.092 (0.16)	R-0.5 (0.08 RSI)	50 (800)
8	5500 ISOWEB WINDOW	—	—	—	—
9	Steel Studs	—	27.7 (48)	—	—
11	Exterior Film	—	—	R-0.23 (0.04 RSI)	—

Table 7-40. Thermal performance: Window jamb — as found.

Condition	Clear Wall R-Value (W/m²K)	Linear Transmittance (Ψ) Btu/hr ft °F (W/mK)
Wall Clear Field	R-15.7 (0.369)	—
As-Built Fitting Situation	—	0.012 (0.021)

7.20 2d CMU or concrete wall with exterior insulation: Window jamb (2)

Figure 7-20. Window jamb – corrected.

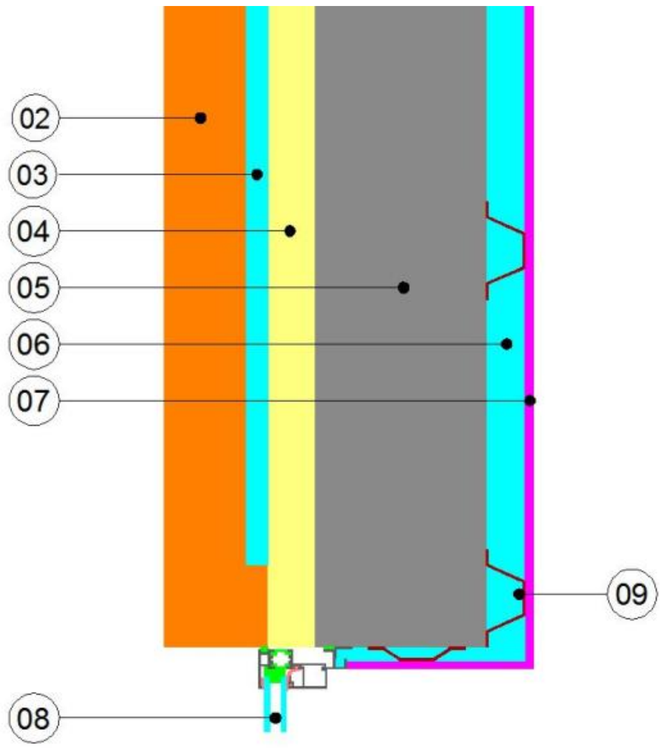


Table 7-41. Modeling values: Window jamb — corrected.

ID	Component	Thickness in. (mm)	Conductivity Btu/ft·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)
1	Interior Film	–	–	R-0.74 (0.13 RSI)	–
2	Brick	3⅝ (92)	0.578 (1)	R-0.523 (0.092 RSI)	110 (1800)
3	Air Cavity	1 (25)	0.070 (0.122)	R-1.185 (0.209 RSI)	–
4	Insulation	2 (51)	0.0139 (0.024)	R-11.99 (2.112 RSI)	2 (32)
5	CMU	7⅝ (194)	0.069 (1.2)	R-0.916 (0.161 RSI)	130 (2100)
6	Air Layer with Steel Studs	1 ¾ (44)	0.2219 (0.384)	R-0.66 (0.116 RSI)	–
7	Gypsum Board	½ (13)	0.092 (0.16)	R-0.5 (0.08 RSI)	50 (800)
8	5500 ISOWEB WINDOW	–	–	–	–
9	Steel Studs	–	27.7 (48)	–	–
11	Exterior Film	–	–	R-0.23 (0.04 RSI)	–

Table 7-42. Thermal performance: Window jamb — corrected.

Condition	Clear Wall R-Value (W/m²K)	Linear Transmittance (Ψ) Btu/hr ft°F (W/mK)
Wall Clear Field	R-15.7 (0.369)	–
Proposed Fitting Situation	–	0.009 (0.015)

Notes:

Although shown as CMU, the structure of the wall could be concrete or load-bearing masonry.

The key strategy shown here, and a very effective one, is to align the window's thermal break with that of the wall. This is primarily a design issue, and it is difficult to improve upon a psi-value of 0.009. This is easy to achieve in new design, or in a retrofit where the brick is removed, the CMU is insulated and the windows replaced.

To ensure good performance it is critical that sealant be shown and installed to provide air barrier continuity (Sections 6.1 and 5.1) and that proper rainwater management is used (Section 6.1.1).

7.21 2e CMU or concrete wall with exterior insulation: Window head (1)

Figure 7-21. Window head – as found.

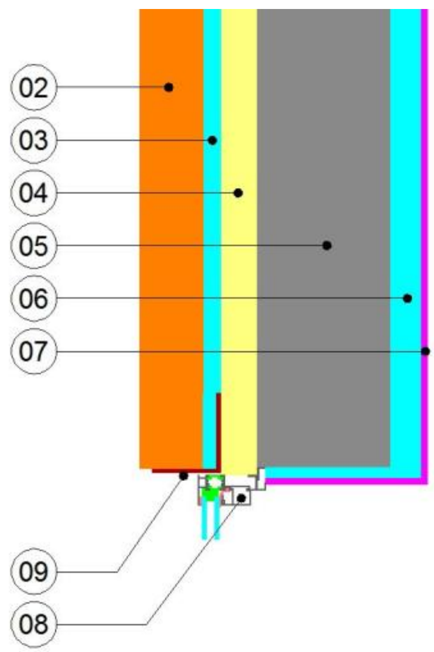


Table 7-43. Modeling values: Window head — as found.

ID	Component	Thickness in. (mm)	Conductivity Btu/ft·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)
1	Interior Film	—	—	R-0.74 (0.13 RSI)	—
2	Brick	3⅝ (92)	0.578 (1)	R-0.523 (0.092 RSI)	110 (1800)
3	Air Cavity	1 (25)	0.070 (0.122)	R-1.185 (0.209 RSI)	—
4	Insulation	2 (51)	0.0139 (0.024)	R-11.99 (2.112 RSI)	2 (32)
5	CMU	7⅝ (194)	0.069 (1.2)	R-0.916 (0.161 RSI)	130 (2100)
6	Air Layer with Steel Studs	1¾ (44)	0.2219 (0.384)	R-0.66 (0.116 RSI)	—
7	Gypsum Board	½ (13)	0.092 (0.16)	R-0.5 (0.08 RSI)	50 (800)
8	5500 ISOWEB WINDOW	—	—	—	—
9	Steel Lintel	¼ (6.4)	27.7 (48)	—	—
11	Exterior Film	—	—	R-0.23 (0.04 RSI)	—

Table 7-44. Thermal performance: Window head — as found.

Condition	Clear Wall R-Value (W/m²K)	Linear Transmittance (Ψ) Btu/hr ft°F (W/mK)
Wall Clear Field	R-15.7 (0.369)	—
As-Built Fitting Situation	—	0.044 (0.076)

7.22 2e CMU or concrete wall with exterior insulation: Window head (2)

Figure 7-22. Window head – corrected.

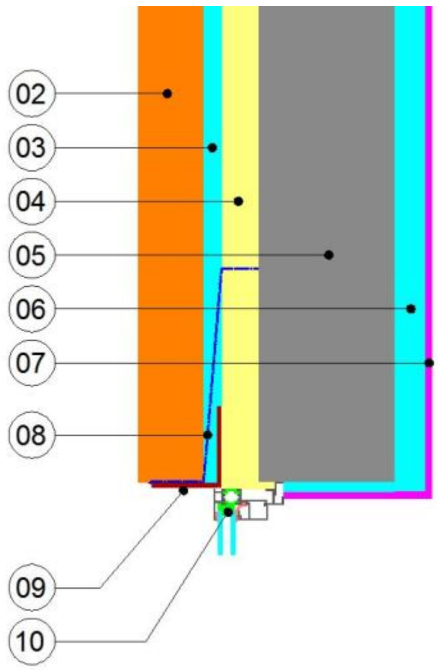


Table 7-45. Modeling values: Window head — corrected.

ID	Component	Thickness in. (mm)	Conductivity Btu/ft·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)
1	Interior Film	—	—	R-0.74 (0.13 RSI)	—
2	Brick	3⅝ (92)	0.578 (1)	R-0.523 (0.092 RSI)	110 (1800)
3	Air Cavity	1 (25)	0.070 (0.122)	R-1.185 (0.209 RSI)	—
4	Insulation	2 (51)	0.0139 (0.024)	R-11.99 (2.112 RSI)	2 (32)
5	CMU	7⅝ (194)	0.069 (1.2)	R-0.916 (0.161 RSI)	130 (2100)
6	Air Layer with Steel Studs	1¾ (44)	0.2219 (0.384)	R-0.66 (0.116 RSI)	—
7	Gypsum Board	½ (13)	0.092 (0.16)	R-0.5 (0.08 RSI)	50 (800)
8	Water Control Layer	—	—	—	—
9	Steel Lintel	¼ (6.4)	27.7 (48)	—	450(7700)
10	5500 ISOWEB WINDOW	—	—	—	—
11	Exterior Film	—	—	R-0.23 (0.04 RSI)	—

Table 7-46. Thermal performance: Window head — corrected.

Condition	Clear Wall R-Value (W/m²K)	Linear Transmittance (Ψ) Btu/hr ft °F (W/mK)
Wall Clear Field	R-15.7 (0.369)	—
Proposed Fitting Situation	—	0.006 (0.010)

Notes:

Although shown as CMU, poured concrete or masonry could be used.

The TB in this detail is the inset loose lintel that bypasses the thermal break of the window. Pulling the lintel forward breaks the TB. Although the heat loss is not large (psi-value of 0.044), it is easy to significantly reduce to near zero (psi-value of 0.006) and difficult to improve noticeably beyond this.

The primary challenge is to work out details for a specific project related to proper structural attachment (Section 6.1.3) and to finish the aesthetics on the exterior. Although rain control and air control remain important, the same strategies used in the as-found condition can be used in the corrected condition.

7.23 2f CMU or concrete wall with exterior insulation: Window sill (1)

Figure 7-23. Window sill – as found.

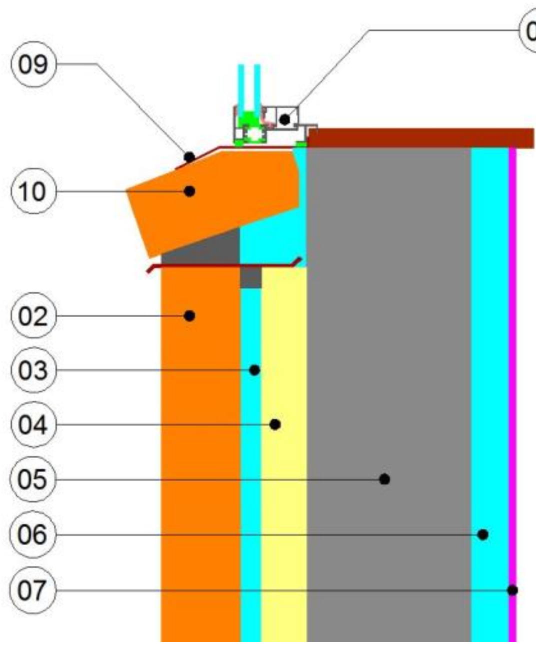


Table 7-47. Modeling values: Window sill — as found.

ID	Component	Thickness in. (mm)	Conductivity Btu/ft·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)
1	Interior Film	—	—	R-0.74 (0.13 RSI)	—
2	Brick	3⅝ (92)	0.578 (1)	R-0.523 (0.092 RSI)	110 (1800)
3	Air Cavity	1 (25)	0.070 (0.122)	R-1.185 (0.209 RSI)	—
4	Insulation	2 (51)	0.0139 (0.024)	R-11.99 (2.112 RSI)	2 (32)
5	CMU	7⅝ (194)	0.069 (1.2)	R-0.916 (0.161 RSI)	130 (2100)
6	Air Layer with Steel Studs	1¾ (44)	0.2219 (0.384)	R-0.66 (0.116 RSI)	—
7	Gypsum Board	½ (13)	0.092 (0.16)	R-0.5 (0.08 RSI)	50 (800)
8	5500 ISOWEB WINDOW	—	—	—	—
9	Aluminum Sill Flashing	12 Gauge	160	—	175(2800)
10	Brick Sill	3⅝ (92)	0.578 (1)	—	110 (1800)
11	Exterior Film	—	—	R-0.23 (0.04 RSI)	—

Table 7-48. Thermal performance: Window sill — as found.

Condition	Clear Wall R-Value (W/m²K)	Linear Transmittance (Ψ) Btu/hr ft °F (W/mK)
Wall Clear Field	R-15.7 (0.369)	—
As-Built Fitting Situation	—	0.445 (0.771)

7.24 2f CMU or concrete wall with exterior insulation: Window sill (2)

Figure 7-24. Window sill – corrected.

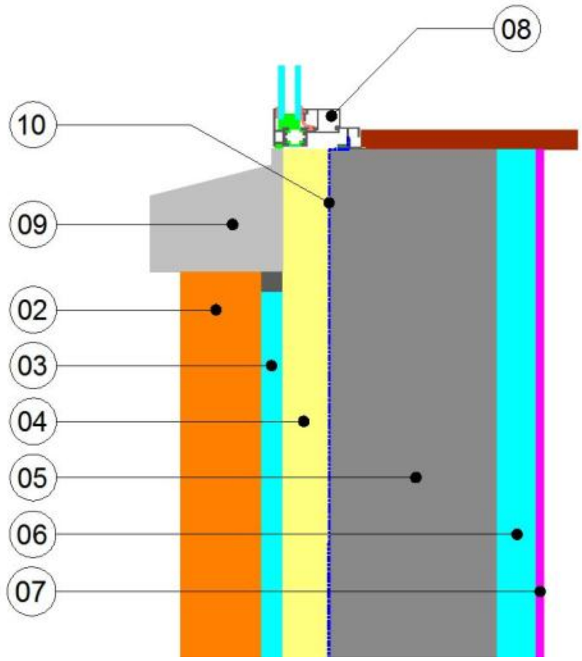


Table 7-49. Modeling values: Window sill — corrected.

ID	Component	Thickness in. (mm)	Conductivity Btu/ft·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)
1	Interior Film	—	—	R-0.74 (0.13 RSI)	—
2	Brick	3⅝ (92)	0.578 (1)	R-0.523 (0.092 RSI)	110 (1800)
3	Air Cavity	1 (25)	0.070 (0.122)	R-1.185 (0.209 RSI)	—
4	Insulation	2 (51)	0.0139 (0.024)	R-11.99 (2.112 RSI)	2 (32)
5	CMU	7⅝ (194)	0.069 (1.2)	R-0.916 (0.161 RSI)	130 (2100)
6	Air Layer with Steel Studs	1¾ (44)	0.2219 (0.384)	R-0.66 (0.116 RSI)	—
7	Gypsum Board	½ (13)	0.092 (0.16)	R-0.5 (0.08 RSI)	50 (800)
8	5500 ISOWEB WINDOW	—	—	—	—
9	Concrete Sill	—	1.4 (2.4)	—	110 (1800)
10	Air-Water Control Layer	—	—	—	—
11	Exterior Film	—	—	R-0.23 (0.04 RSI)	—

Table 7-50. Thermal performance: Window sill — corrected.

Condition	Clear Wall R-Value (W/m²K)	Linear Transmittance (Ψ) Btu/hr ft°F (W/mK)
Wall Clear Field	R-15.7 (0.369)	—
Proposed Fitting Situation	—	0.017 (0.030)

Notes:

This detail shows the significant thermal bridging possible at the sill through a conductive brick sill. A concrete or stone sill will be even more conductive.

During a window replacement, these sills can be removed, and the insulation made continuous and aligned with the window thermal break. This offers the chance to improve both window airtightness and rain control performance (Section 6.1).

The performance of the correct version can be improved only slightly from psi-value of 0.017 by using thicker insulation and tweaking the details of the window sill attachment to the window and the alignment of the thermal break.

Key to the success of this detail is ensuring good structural attachment of the window (Section 6.1.3) and alignment of the window TB.

7.25 2g CMU or concrete wall with exterior insulation: Blast resistant window jamb (1)

Figure 7-25. Blast-resistant window jamb – as found.

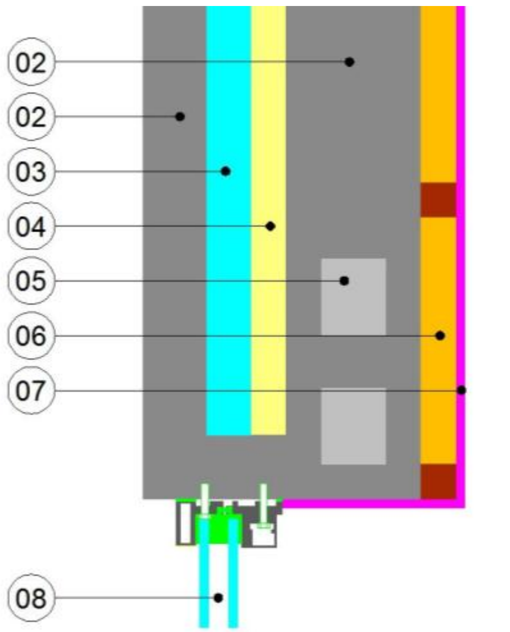


Table 7-51. Modeling values: Blast-resistant window jamb — as found.

ID	Component	Thickness in. (mm)	Conductivity Btu/ft·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)
1	Interior Film	—	—	R-0.74 (0.13 RSI)	—
2	CMU	7⅝ (194)	0.069 (1.2)	R-0.916 (0.161 RSI)	130 (2100)
3	Air Cavity	2.5 (64)	0.1489 (0.258)	R-1.4 (0.246 RSI)	—
4	Insulation	2 (51)	0.0139 (0.024)	R-11.99 (2.112 RSI)	2 (32)
5	Grout	—	0.092 (0.16)	—	130(2100)
6	Rockwool	2 (51)	0.021 (0.036)	R-6.26 (1.103 RSI)	4(64)
7	Gypsum Board	½ (13)	0.092 (0.16)	R-0.5 (0.08 RSI)	50 (800)
8	625BL Armortex Window 42psi	—	—	—	—
9	Exterior Film	—	—	R-0.23 (0.04 RSI)	—

Table 7-52. Thermal performance: Blast-resistant window jamb — as found.

Condition	Clear Wall R-Value (W/m²K)	Linear Transmittance (Ψ) Btu/hr ft °F (W/mK)
Wall Clear Field	R-21.4 (0.265)	—
As-Built Fitting Situation	—	0.260 (0.450)

7.26 2g CMU or concrete wall with exterior insulation: Blast resistant window jamb (2)

Figure 7-26. Blast-resistant window jamb – corrected.

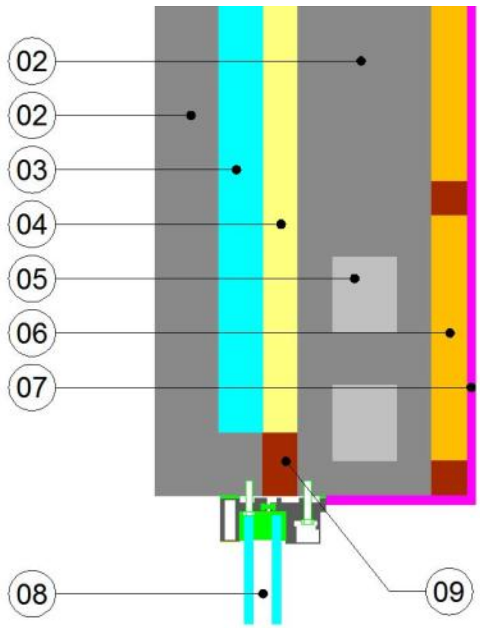


Table 7-53. Modeling values: Blast-resistant window jamb — corrected.

ID	Componente	Thickness in. (mm)	Conductivity Btu/ft·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)
1	Interior Film	—	—	R-0.74 (0.13 RSI)	—
2	CMU	7⅝ (194)	0.069 (1.2)	R-0.916 (0.161 RSI)	130 (2100)
3	Air Cavity	2.5 (64)	0.1489 (0.258)	R-1.4 (0.246 RSI)	—
4	Insulation	2 (51)	0.0139 (0.024)	R-11.99 (2.112 RSI)	2 (32)
5	Grout	—	0.092 (0.16)	—	130(2100)
6	Mineral Wool with Wood Framing	2 (51)	0.021 (0.036)	R-6.26 (1.103 RSI)	4 (64)
7	Gypsum Board	½ (13)	0.092 (0.16)	R-0.5 (0.08 RSI)	50 (800)
8	625BL Armortex Window 42psi	—	—	—	—
9	Timber Break	—	0.006 (0.10)	—	32 (510)
10	Exterior Film	—	—	R-0.23 (0.04 RSI)	—

Table 7-54. Thermal performance: Blast-resistant window jamb — corrected.

Condition	Clear Wall R-Value (W/m²K)	Linear Transmittance (Ψ) Btu/hr ft °F (W/mK)
Wall Clear Field	R-21.4 (0.265)	—
Proposed Fitting Situation	—	0.106 (0.183)

7.27 2h CMU or concrete wall with exterior insulation: Blast resistant window head (1)

Figure 7-27. Blast-resistant window head – existing.

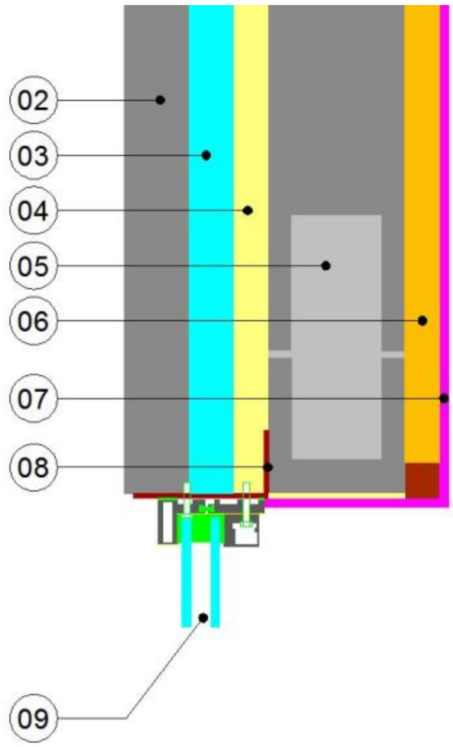


Table 7-55. Modeling values: Blast-resistant window head — existing.

ID	Component	Thickness in. (mm)	Conductivity Btu/ft·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)
1	Interior Film	—	—	R-0.74 (0.13 RSI)	—
2	CMU	7⅝ (194)	0.069 (1.2)	R-0.916 (0.161 RSI)	130 (2100)
3	Air Cavity	2.5 (64)	0.1489 (0.258)	R-1.4 (0.246 RSI)	—
4	Insulation	2 (51)	0.0139 (0.024)	R-11.99 (2.112 RSI)	2 (32)
5	Grout	—	0.092 (0.16)	—	130(2100)
6	Mineral Wool with Wood Framing	2 (51)	0.0266 (0.046)	R-6.26 (1.103 RSI)	4 (64)
7	Gypsum Board	½ (13)	0.092 (0.16)	R-0.5 (0.08 RSI)	50 (800)
8	Steel Lintel	—	27.7 (48)	—	480(7800)
9	625BL Armortex Window 42psi	—	—	—	—
10	Exterior Film	—	—	R-0.23 (0.04 RSI)	—

Table 7-56. Thermal performance: Blast-resistant window head — existing.

Condition	Clear Wall R-Value (W/m²K)	Linear Transmittance (Ψ) Btu/hr ft°F (W/mK)
Wall Clear Field	R-21.4 (0.265)	—
As-Built Fitting Situation	—	0.403 (0.697)

7.28 2h CMU or concrete wall with exterior insulation: Blast resistant window head (2)

Figure 7-28. Blast-resistant window head – corrected.

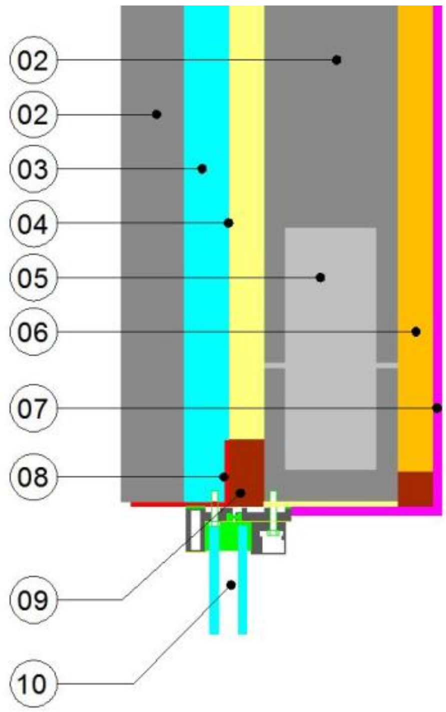


Table 7-57. Modeling values: Blast-resistant window head — corrected.

ID	Component	Thickness in. (mm)	Conductivity Btu/ft·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)
1	Interior Film	—	—	R-0.74 (0.13 RSI)	—
2	CMU	7⅝ (194)	0.069 (1.2)	R-0.916 (0.161 RSI)	130 (2100)
3	Air Cavity	2.5 (64)	0.1489 (0.258)	R-1.4 (0.246 RSI)	—
4	Insulation	2 (51)	0.0139 (0.024)	R-11.99 (2.112 RSI)	2(32)
5	Grout	—	0.092 (0.16)	—	130(2100)
6	Mineral Wool with Wood Framing	2 (51)	0.0266 (0.046)	R-6.26 (1.103 RSI)	4(64)
7	Gypsum Board	½ (13)	0.092 (0.16)	R-0.5 (0.08 RSI)	50 (800)
8	Steel Lintel	—	27.7 (48)/0 .058 (0.1)	—	480(7800)
9	Timber Break	—	0.006 (0.10)	—	32 (510)
10	625BL Armortex Window 42psi	—	—	—	—
11	Exterior Film	—	—	R-0.23 (0.04 RSI)	—

Table 7-58. Thermal performance: Blast-resistant window head — corrected.

Condition	Clear Wall R-Value (W/m²K)	Linear Transmittance (Ψ) Btu/hr ft°F (W/mK)
Wall Clear Field	R-21.4 (0.265)	—
Proposed Fitting Situation	—	0.189 (0.327)

Notes:

This detail shows the significant thermal bridging possible if structural steel components of a blast-resistant window installation are allowed to penetrate through the primary insulation layers. In this case, a structural thermal break (Section 4.4) is provided by using wood blocking to transfer compressive loads, and stainless steel bolts to transfer the tension loads.

The structure could be concrete or masonry.

For this detail to perform in a durable manner, the wood blocking would need to be protected from excessive rainwater wetting by a properly lapped water resistant barrier, preferably fully-adhered sheets or fluid applied. To allow drying of the wood blocking in wet or cold climates, the membrane should also be vapor permeable.

To improve the performance further, a higher performance structural break (for example, high strength 500 psi capable polyurethane, or 300 psi capable foamglass) or thicker block of wood laminated to high strength insulation could be considered.

7.29 2i CMU or concrete wall with exterior insulation: Suspended slab at shelf angle

Figure 7-29. Slab edge with shelf angle.

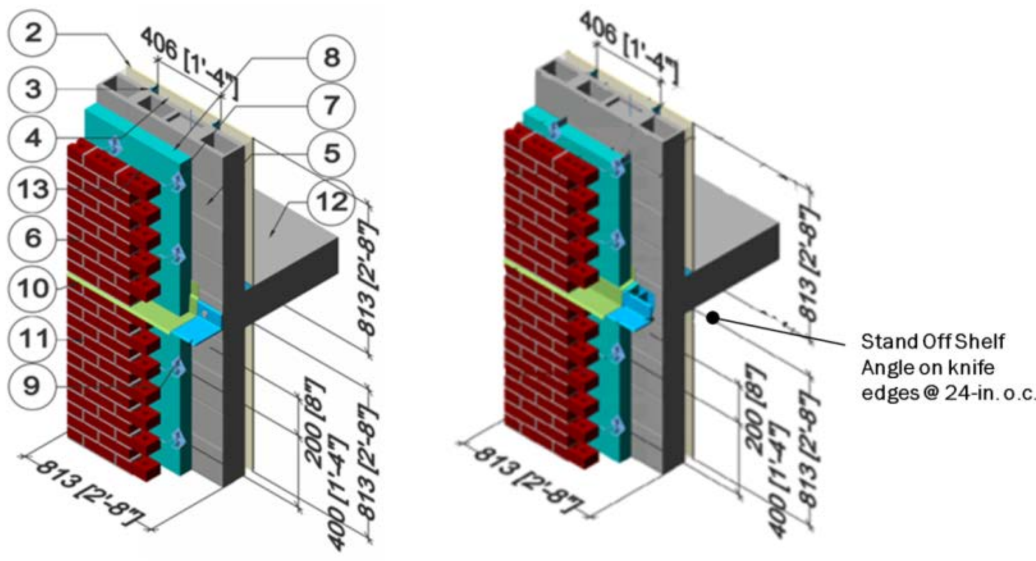


Table 7-59. Modeling values: Slab edge with shelf angle.

ID	Component	Thickness in. (mm)	Conductivity Btu·in/ft²·hr·oF (W/m K)	Nominal Resistance hr·ft²·oF/Btu (m²K/W)	Density lb/ft3 (kg/m3)
1	Interior Film (right side)[1]	—	—	R-0.6 (0.11 RSI) to R-0.9 (0.16 RSI)	—
2	Gypsum Board	½ (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)
3	1 5/8-in. Steel Studs with Metal Tracks	20 gauge	430 (62)	—	489 (7830)
4	Air in Stud Cavity	1⅝ (41)	—	R-0.9 (0.16 RSI)	0.075 (1.2)
5	Standard Concrete Block	7⅝ (190)	3.5 (0.5)	—	119 (1900)
6	Cement Mortar	—	3.5 (0.5)	—	113 (1800)
7	Masonry Ties @ 16-in. (406) o.c.	14 gauge	347 (50)	—	489 (7830)
8	Insulation	Varies	—	R-10 (1.76 RSI)	1.8 (28)
9	Shelf Angle	3/8 (10)	347 (50)	—	489 (7830)
10	Flashing-steel	20 gauge	347 (50)	—	489 (7830)
11	Brick Veneer	3⅝ (92)	5.4 (0.78)	—	120 (1920)
12	Concrete Slab	8 (203)	12.5 (1.8)	—	140 (2250)
13	Air Gap	1 (25)	—	R-0.9 (0.16 RSI)	0.075 (1.2)
14	Exterior Film (left side)[1]	—	—	R-0.2 (0.03 RSI)	—

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation

Table 7-60. Thermal performance: Slab edge with shelf angle.

Condition	Clear Wall R-Value (W/m²K)	Linear Transmittance (Ψ) Btu/hr ft°F (W/mK)
Wall Clear Field	R-14.2 (2.50)	–
As-Built Slab, Continuous Shelf Angle	–	0.258 (0.446)
Retrofit with...		
Standoff Shelf Angle	–	0.186 (0.322)

Notes:

This detail blunts the TB of the relieving or shelf angle often used in brick veneer construction by reducing the area of steel passing through the insulation (Section 4.4). Significant further reductions could be made by spacing the standoffs further apart (often a 48-in. o.c. is found to be sufficient structurally) and replacing the standoff with stainless steel rather than carbon steel. Avoiding the use of shelf angles by designing the brick veneer to be load bearing is often practical for buildings under five or six stories in height (differential movement becomes more and more important as the veneer height increases).

The 20-gauge steel flashing still acts as a TB- replacing with thermally non-conductive polymer or thinner stainless improves the performance.

7.30 3a Steel stud wall with interior & exterior insulation: Roof parapet with steel frame

Figure 7-30. Parapet with steel roof deck and joists.

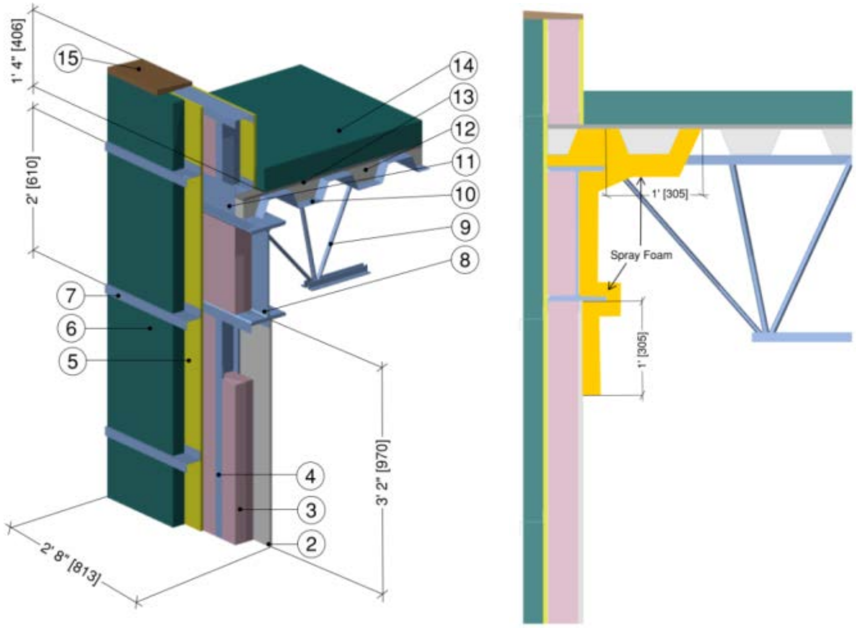


Table 7-61. Modeling values: Parapet with steel roof deck and joists.

ID	Component	Thickness in. (mm)	Conductivity Btu/ft·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)
1	Interior Film (right side)[1]	–	–	R-0.7 (0.12 RSI) to R-0.9 (0.16 RSI)	–
2	Gypsum Board	½ (13)	0.092 (0.16)	R-0.5 (0.08 RSI)	50 (800)
3	Fiberglass Batt Insulation	3⅝ (90)	0.024 (0.042)	R-12 (2.1 RSI)	0.9 (14)
4	3 5/8-in. x 1 5/8-in. Steel Studs with Metal Tracks	18 gauge	35.825 (62)	–	489 (7830)
5	Exterior Sheathing	½ (13)	0.092 (0.16)	R-0.5 (0.08 RSI)	50 (800)
6	Exterior Insulation, Wall	2 (51)	0.017 (0.029)	R-10 (1.75 RSI)	1.8 (28)
7	Horizontal Z-girts w/ 2 ½ in. Flange	18 gauge	35.825 (62)	–	489 (7830)
8	Steel Beam (W410)	–	28.891 (50)	–	489 (7830)
9	Open Web Steel Joist	–	28.891 (50)	–	489 (7830)
10	Steel Deck	–	28.891 (50)	–	489 (7830)
11	Shelf Angle	–	35.825 (62)	–	489 (7830)
12	Roof Air Cavity	3 (76)	–	R-0.9 (0.16 RSI)	
13	Gypsum Overlay Board	½ (13)	0.092 (0.16)	R-0.5 (0.08 RSI)	50 (800)
14	Exterior Insulation, Roof	4 (102)	–	R-20 (3.5 RSI)	1.8 (28)
15	Wood Blocking	⅝ (16)	0.052 (0.09)	R-1 (0.18 RSI)	27.8 (445)
16	Metal cap flashing/ finish roof material is incorporated into exterior heat transfer coefficient				
	Interior Spray Foam	–	–	R-10 (1.75 RSI)	1.8 (28)
17	Exterior Film (left side)[1]	–	–	R-0.2 (0.03 RSI)	–

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation

Table 7-62. Thermal performance: Parapet with steel roof deck and joists.

Condition	Clear Wall R-Value (W/m²K)	Linear Transmittance (Ψ) Btu/hr ft°F (W/mK)
Wall Clear Field, No Exterior Insulation	R-8.7 (1.54 RSI)	—
Wall Clear Field, R10 Exterior Insulation	R-16.3 (2.87 RSI)	—
Roof Clear Field	R-21.4 (3.77 RSI)	—
As-Built Slab, No Exterior Insulation	—	0.624 (1.08)
As-Built Slab, R10 Exterior Insulation	—	0.237 (0.411)
Retrofit with…		
R10 Spray Foam, No Exterior Insulation	—	0.123 (0.212)
R10 Spray Foam, R10 Exterior Insulation	—	0.095 (0.165)

Notes:

One improvement could be to add insulation around both faces and the top of the parapet.

7.31 3b Steel stud wall with interior & exterior insulation: Window jamb (1)

Figure 7-31. Window jamb – as found.

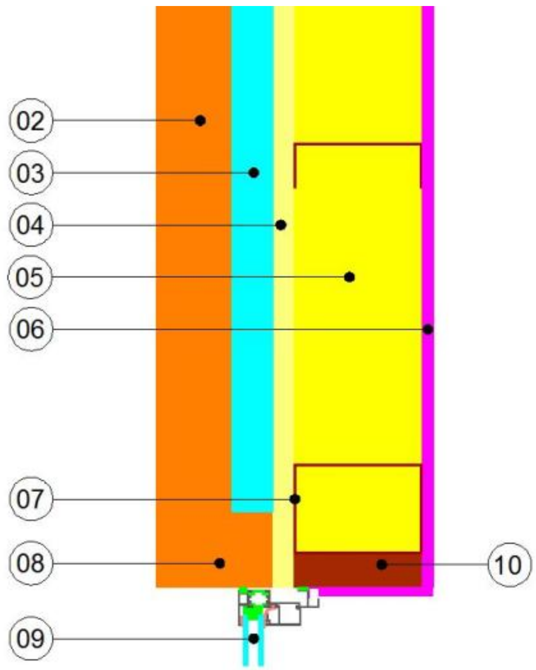


Table 7-63. Modeling values: Window jamb — as found.

ID	Component	Thickness in. (mm)	Conductivity Btu/ft·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)
1	Interior Film	—	—	R-0.74 (0.13 RSI)	—
2	Brick	3⅝ (92)	0.578 (1)	R-0.523 (0.092 RSI)	110 (1800)
3	Air Cavity	2 (51)	0.132 (0.23)	R-1.261 (0.222 RSI)	—
4	Insulation	1 (25)	0.0139 (0.024)	R-6 (1.055 RSI)	2 (32)
5	Rockwool	6⅜ (162)	0.0208 (0.036)	—	4 (64)
6	Gypsum Board	½ (13)	0.092 (0.16)	R-0.5 (0.08 RSI)	50 (800)
7	Steel Studs	—	27.7 (48)	—	480(7800)
8	Steel Lintel	—	27.7 (48)	—	480(7800)
9	5500 ISOWEB WINDOW	—	—	—	—
10	Wood Buck	—	0.006 (0.10)	—	30(450)
11	Exterior Film	—	—	R-0.23 (0.04 RSI)	—

Table 7-64. Thermal performance: Window jamb — as found.

Condition	Clear Wall R-Value (W/m²K)	Linear Transmittance (Ψ) Btu/hr ft°F (W/mK)
Wall Clear Field	R-22.6 (0.251)	—
Incorrect Fitting Situation	—	0.110 (0.191)

7.32 3b Steel stud wall with interior & exterior insulation: Window jamb (2)

Figure 7-32. Window jamb – corrected.

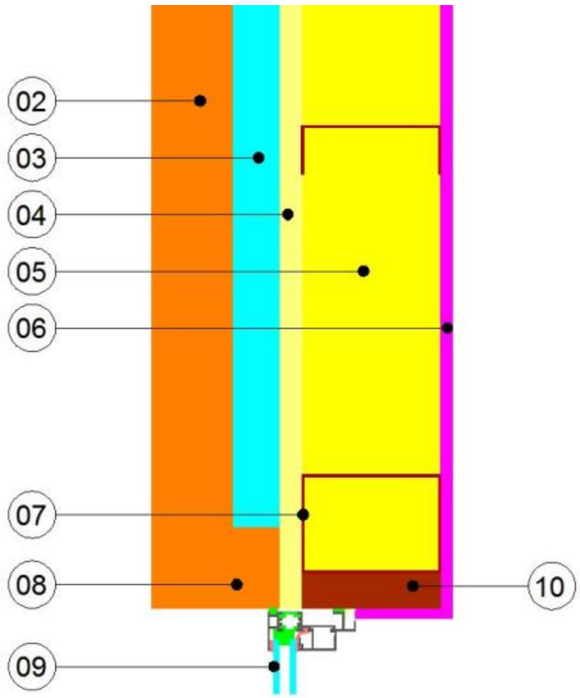


Table 7-65. Modeling values: Window jamb — corrected.

ID	Component	Thickness in. (mm)	Conductivity Btu/ft·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)
1	Interior Film	–	–	R-0.74 (0.13 RSI)	–
2	Brick	3⅝ (92)	0.578 (1)	R-0.523 (0.092 RSI)	110 (1800)
3	Air Cavity	2 (51)	0.132 (0.23)	R-1.261 (0.222 RSI)	–
4	Insulation	1 (25)	0.0139 (0.024)	R-6 (1.055 RSI)	2 (32)
5	Rockwool	6⅜ (162)	0.0208 (0.036)	–	2 (32)
6	Gypsum Board	½ (13)	0.092 (0.16)	R-0.5 (0.08 RSI)	50 (800)
7	Steel Studs	–	27.7 (48)	–	480(7800)
8	Steel Lintel	–	27.7 (48)	–	480(7800)
9	5500 ISOWEB WINDOW	–	–	–	–
10	Wood Buck	–	0.006 (0.10)	–	30(450)
11	Exterior Film	–	–	R-0.23 (0.04 RSI)	–

Table 7-66. Thermal performance: Window jamb — corrected.

Condition	Clear Wall R-Value (W/m²K)	Linear Transmittance (Ψ) Btu/hr ft°F (W/mK)
Wall Clear Field	R-22.6 (0.251)	–
Correct Fitting Situation	–	0.056 (0.097)

7.33 3c Steel stud wall with interior & exterior insulation: Window head (1)

Figure 7-33. Window head – as found.

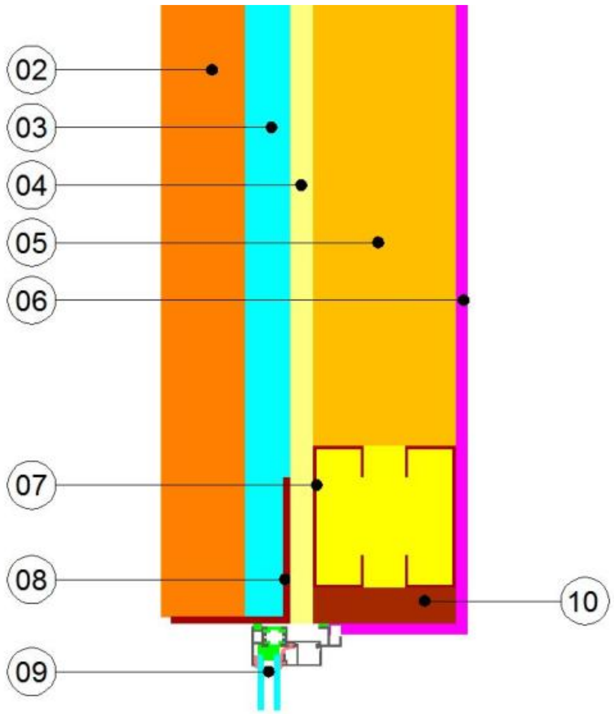


Table 7-67. Modeling values Window head — as found: Window head — as found.

ID	Component	Thickness in. (mm)	Conductivity Btu/ft·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)
1	Interior Film	—	—	R-0.74 (0.13 RSI)	—
2	Brick	3⅝ (92)	0.578 (1)	R-0.523 (0.092 RSI)	110 (1800)
3	Air Cavity	2 (51)	0.132 (0.23)	R-1.261 (0.222 RSI)	—
4	Insulation	1 (25)	0.0139 (0.024)	R-6 (1.055 RSI)	2(32)
5	Rockwool with Steel Studs	6⅜ (162)	0.0370 (0.064)	R-14.36 (2.53 RSI)	2(32)
6	Gypsum Board	½ (13)	0.092 (0.16)	R-0.5 (0.08 RSI)	50 (800)
7	Steel Studs	—	27.7 (48)	—	480(7800)
8	Steel Lintel	—	27.7 (48)	—	480(7800)
9	5500 ISOWEB WINDOW	—	—	—	—
10	Timber Buck	—	0.006 (0.10)	—	30(450)
11	Exterior Film	—	—	R-0.23 (0.04 RSI)	—

Table 7-68. Thermal performance: Window head — as found.

Condition	Clear Wall R-Value (W/m²K)	Linear Transmittance (Ψ) Btu/hr ft°F (W/mK)
Wall Clear Field	R-22.6 (0.251)	—
Incorrect Fitting Situation	—	0.143 (0.247)

7.34 3c Steel stud wall with interior & exterior insulation: Window head (2)

Figure 7-34. Window head – corrected.

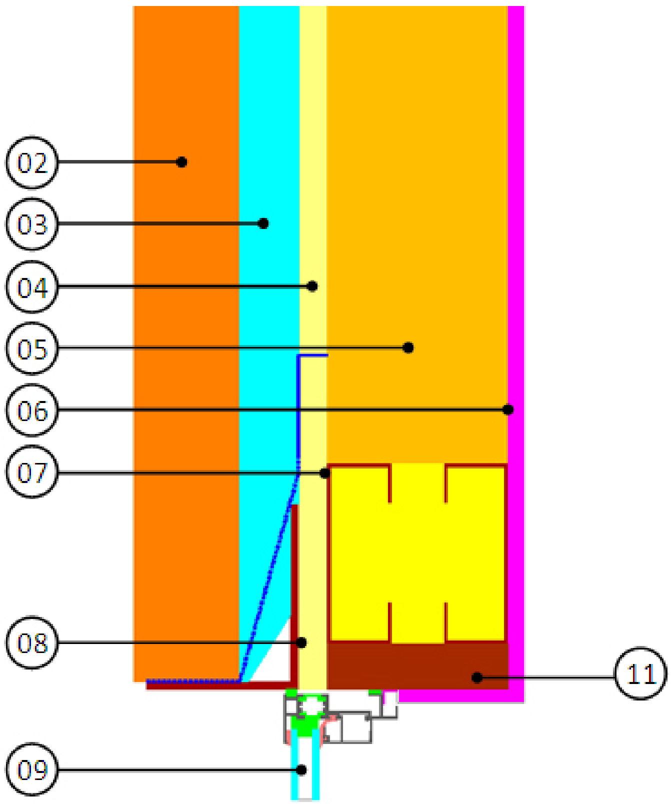


Table 7-69. Modeling values: Window head — corrected.

ID	Component	Thickness in. (mm)	Conductivity Btu/ft·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)
1	Interior Film	—	—	R-0.74 (0.13 RSI)	—
2	Brick	3⅝ (92)	0.578 (1)	R-0.523 (0.092 RSI)	110 (1800)
3	Air Cavity	2 (51)	0.132 (0.23)	R-1.261 (0.222 RSI)	—
4	Insulation	1 (25)	0.0139 (0.024)	R-6 (1.055 RSI)	2(32)
5	Mineral Wool with Steel Studs	6⅜ (162)	0.0370 (0.064)	R-14.36 (2.53 RSI)	2(32)
6	Gypsum Board	½ (13)	0.092 (0.16)	R-0.5 (0.08 RSI)	50 (800)
7	Steel Studs	—	27.7 (48)	—	480(7800)
8	Steel Lintel	—	27.7 (48)	—	480(7800)
9	5500 ISOWEB WINDOW	—	—	—	—
10	Water/Air Control Barrier	—	—	—	—
11	Timber Buck	—	0.006 (0.10)	—	30(450)
12	Exterior Film	—	—	R-0.23 (0.04 RSI)	—

Table 7-70. Thermal performance: Window head — corrected.

Condition	Clear Wall R-Value (W/m²K)	Linear Transmittance (Ψ) Btu/hr ft°F (W/mK)
Wall Clear Field	R-22.6 (0.251)	—
Correct Fitting Situation	—	0.044 (0.077)

Notes:

The TB in this detail is the inset loose lintel that bypasses the thermal break of the window. Pulling the lintel forward breaks the TB.

7.35 3d Steel stud wall with interior & exterior insulation: Window sill (1)

Figure 7-35. Window sill – as found.

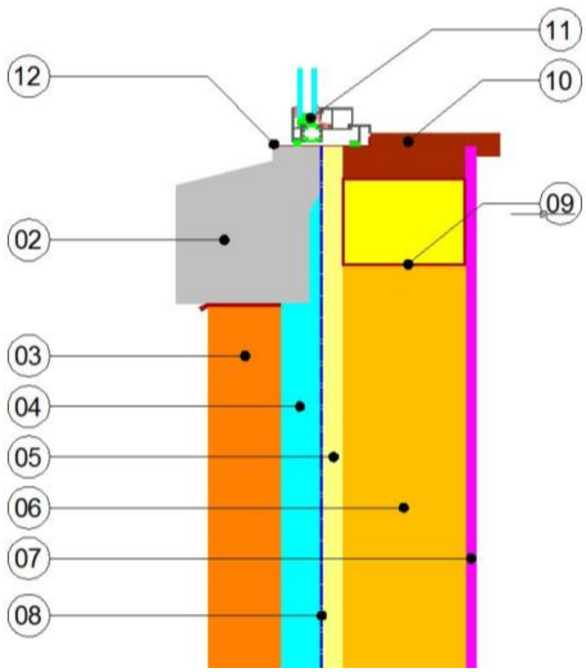


Table 7-71. Modeling values: Window sill — as found.

ID	Component	Thickness in. (mm)	Conductivity Btu/ft·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)
1	Interior Film	–	–	R-0.74 (0.13 RSI)	–
2	Concrete Sill	–	1.4 (2.4)	–	150(2400)
3	Brick	3⅝ (92)	0.578 (1)	R-0.523 (0.092 RSI)	110 (1800)
4	Air Cavity	2 (51)	0.132 (0.23)	R-1.261 (0.222 RSI)	–
5	Insulation	1 (25)	0.0139 (0.024)	R-6 (1.055 RSI)	2(32)
6	Mineral Wool with Steel Studs	6⅜ (162)	0.0370 (0.064)	R-14.36 (2.53 RSI)	2(32)
7	Gypsum Board	½ (13)	0.092 (0.16)	R-0.5 (0.08 RSI)	50 (800)
8	Air-Water Control Layer	–	–	–	–
9	Steel Studs	–	27.7 (48)	–	480(7800)
10	Timber	–	0.006 (0.10)	–	30(450)
11	5500 ISOWEB WINDOW	–	–	–	–
12	Aluminum Sill Pan	–	92.45 (160)	–	175(2800)
13	Exterior Film	–	–	R-0.23 (0.04 RSI)	–

Figure 7-36. Thermal performance: Window sill – as found.

Condition	Clear Wall R-Value (W/m²K)	Linear Transmittance (Ψ) Btu/hr ft°F (W/mK)
Wall Clear Field	R-22.6 (0.251)	–
Incorrect Fitting Situation	–	0.278 (0.481)

7.36 3d Steel stud wall with interior & exterior insulation: Window sill (2)

Figure 7-37. Window sill – corrected.

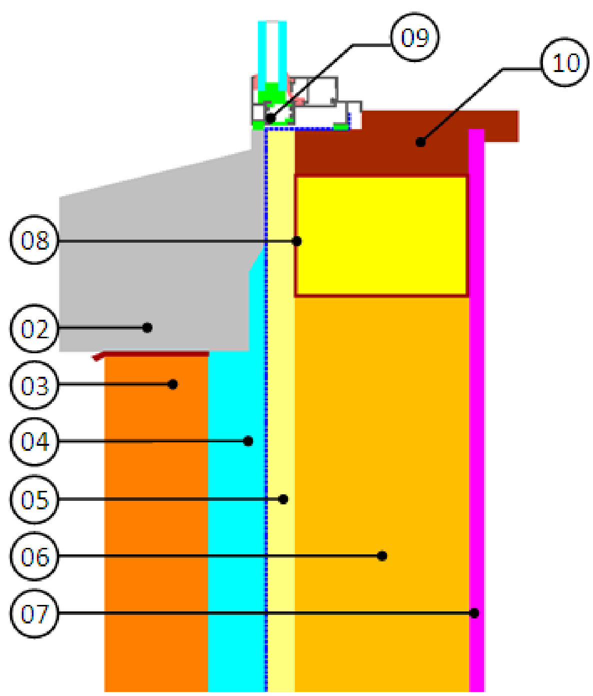


Table 7-72. Modeling values: Window sill — corrected.

ID	Component	Thickness in. (mm)	Conductivity Btu/ft·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)
1	Interior Film	—	—	R-0.74 (0.13 RSI)	—
2	Concrete Sill	—	1.4 (2.4)	—	150(2400)
3	Brick	3⅝ (92)	0.578 (1)	R-0.523 (0.092 RSI)	110 (1800)
4	Air Cavity	2 (51)	0.132 (0.23)	R-1.261 (0.222 RSI)	—
5	Insulation	1 (25)	0.0139 (0.024)	R-6 (1.055 RSI)	2(32)
6	Rockwool with Steel Studs	6⅜ (162)	0.0370 (0.064)	R-14.36 (2.53 RSI)	2(32)
7	Gypsum Board	½ (13)	0.092 (0.16)	R-0.5 (0.08 RSI)	50 (800)
8	Steel Studs	—	27.7 (48)	—	480(7800)
9	5500 ISOWEB WINDOW	—	—	—	—
10	Timber	—	0.006 (0.10)	—	30(450)
12	Exterior Film	—	—	R-0.23 (0.04 RSI)	—

Table 7-73. Thermal performance: Window sill — corrected.

Condition	Clear Wall R-Value (W/m²K)	Linear Transmittance (Ψ) Btu/hr ft°F (W/mK)
Wall Clear Field	R-22.6 (0.251)	—
Correct Fitting Situation	—	0.057 (0.098)

7.37 3e Steel stud wall with interior & exterior insulation: Steel tube blast resistant curtainwall

Figure 7-38. Steel frame blast resistance curtain wall.

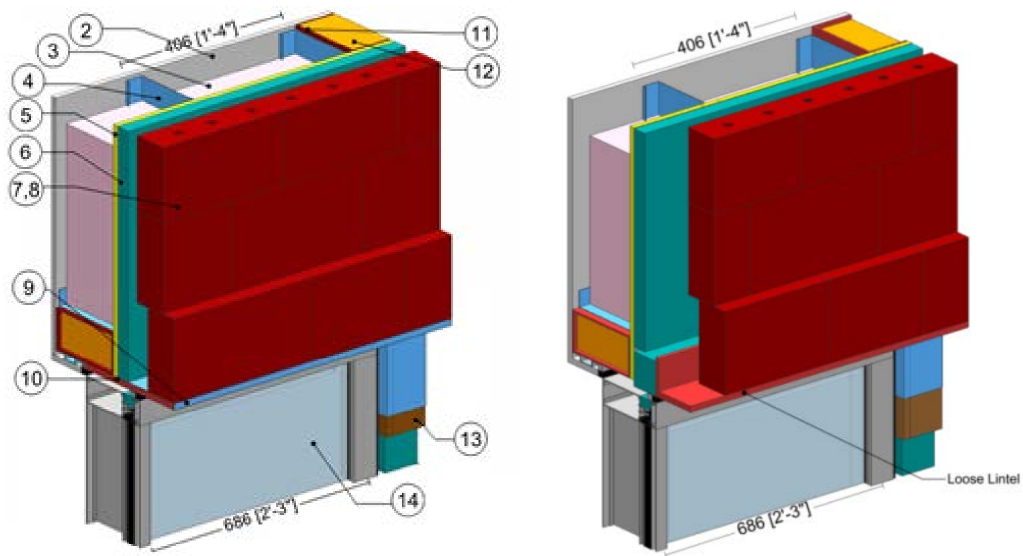


Table 7-74. Modeling values: Steel frame blast resistance curtain wall.

ID	Component	Thickness in. (mm)	Conductivity Btu/ft·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)
1	Interior Film (right side)[1]	–	–	R-0.7 (0.12 RSI) to R-0.9 (0.16 RSI)	–
2	Gypsum Board	½ (13)	0.092 (0.16)	R-0.5 (0.08 RSI)	50 (800)
3	Fiberglass Batt Insulation	8 (90)	0.024 (0.042)	R-25 (4.4 RSI)	0.9 (14)
4	8-in. x 1 5/8-in. Steel Studs with Metal Tracks	18 gauge	35.825 (62)	–	489 (7830)
5	Exterior Sheathing	½ (13)	0.092 (0.16)	R-0.5 (0.08 RSI)	50 (800)
6	Exterior Insulation, Wall	1½ (38)	0.017 (0.029)	R-7.5 (1.32 RSI)	1.8 (28)
7	Brick Ties	14 gauge	28.891 (50)	–	489 (7830)
8	Brick Veneer	3⅝ (92)	0.451 (0.78)		
9	Steel Flashing	18 gauge	35.825 (62)	–	489 (7830)
10	Continuous Steel Lintel	⅜ (10)	28.891 (50)	–	489 (7830)
11	HSS Post	⅜ (10)	28.891 (50)	–	489 (7830)
12	Interior Spray Foam	8 (203)	–	R-40 (7.0 RSI)	1.8 (28)
13	Wood Blocking	1 (25)	0.052 (0.09)	–	27.8 (445)
14	Conventional Curtain Wall System with Double Glazed IGU, U_{COG} = 0.32 Btu/ft²·hr·°F (1.81 W/m²K)				
15	Exterior Film (left side)[1]	–	–	R-0.2 (0.03 RSI)	–
[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation					

Table 7-75. Thermal performance: Steel frame blast resistance curtain wall.

Condition	Clear Wall R-Value (W/m²K)	Linear Transmittance (Ψ) Btu/hr ft°F (W/mK)
Wall Clear Field, Split Insulation	R-20.1 (3.54 RSI)	–
As-Built Window Head, Full Lintel	–	0.395 (0.684)
Retrofit with…		
Window Head, Loose Lintel	–	0.076 (0.131)

Notes:

Although blast anchors are typically rather large pieces of conductive steel or aluminum, they do not increase heat flow significantly as long as they remain on the inside of the thermal break. Metal components, such as lintels, that bridge the insulation layer can have a larger impact and should be avoided where possible.

This detail shows the benefit of using loose lintels over the window rather than a penetrating metal plate. Loose lintels are also better able to accommodate differential movement between the brick and the support structure.

7.38 3f Steel stud wall with interior & exterior insulation: Steel beam penetration

Figure 7-39. At steel beam penetration.

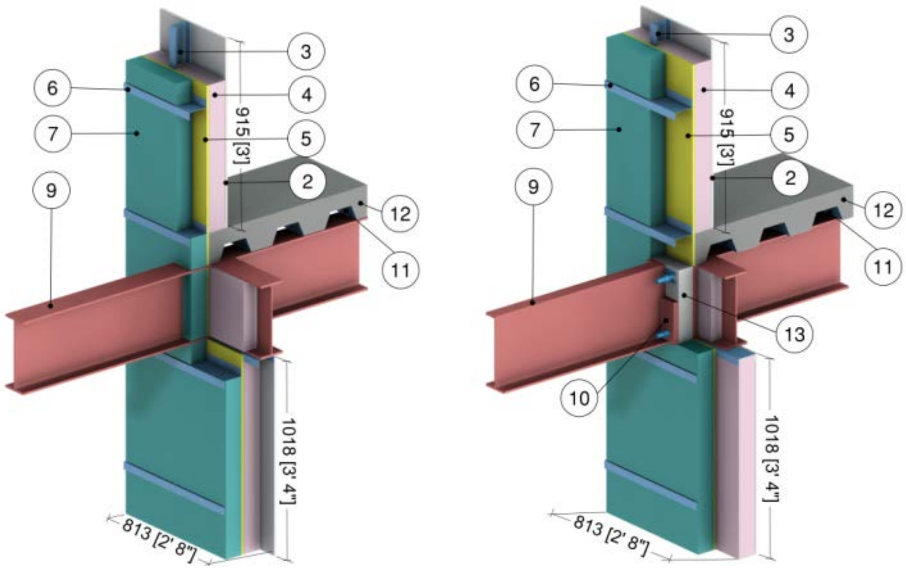


Table 7-76. Modeling values: At steel beam penetration.

ID	Component	Thickness in. inch (mm)	Conductivity Btu/ft·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)
1	Interior Film (right side)[1]	–		R-0.6 (0.11 RSI) to R-0.9 (0.16 RSI)	
2	Gypsum Board	½ (13)	0.092 (0.16)	R-0.5 (0.08 RSI)	50 (800)
3	3 5/8-in. x 1 5/8-in. Steel Studs with Top and Bottom Tracks	18 Gauge	35.825 (62)	–	489 (7830)
4	Fiberglass Batt Insulation	3⅝ (92)	0.024 (0.042)	R-12 (2.1 RSI)	0.9 (14)
5	Exterior Sheathing	½ (13)	0.092 (0.16)	R-0.5 (0.08 RSI)	50 (800)
6	Horizontal Z-girts with 1 ½ in. Flange	18 Gauge	430 (62)		489 (7830)
7	Exterior Insulation	3⅛ (80)	0.2 (0.029)	R-15.7 (2.77 RSI)	1.8 (28)
8	Metal Cladding with ½ in. vented airspace incorporated into exterior heat transfer coefficient				
9	Steel Beam W14x26 (W360x39)	–	347 (50)	–	489 (7830)
10	Steel Bearing Plates	$1\,^3/_{16}$ (30)	347 (50)	–	489 (7830)
11	Steel Deck	$^1/_{16}$ (1.6)	347 (50)	–	489 (7830)
12	Concrete Topping	6 (152)	6.3 (0.9)	–	120 (1920)
13	Isokorb type S modules	3 ⅛ (80)			
14	Exterior Film (left side)[1]	–		R-0.2 (0.03 RSI)	

Table 7-77. Thermal performance: At steel beam penetration.

Condition	Clear Wall R-Value (W/m²K)	χ Btu/hr °F (W/°K)
Continuous Beam	R-17 (3.04)	1.73 (0.92)
With Schoeck Isokorb Type S	R-17 (3.04)	0.91 (0.48)

Notes:

The specific steel section shown is a moderately large one. The heat flow varies little for reasonable ranges in size and thickness of steel.

In many penetrations, the water control and air control also need to be addressed. These control layers are usually not provided by proprietary thermal breaks and will require additional design.

This could be further improved by avoiding the avoiding the use of a large penetrating structural steel element. However, as this is a rather large beam, it is unlikely that there would be many penetrations in a large building. Section 4.4 describes more effective remediation methods.

The primary reason to apply the solution shown could be to solve a condensation problem by reducing the local heat loss on the interior. High interior humidity buildings in cold climates are sensitive to otherwise modest TBs.

7.39 4a Steel building with insulated metal panel: Eave detail

Figure 7-40. Parapet with steel roof deck and joist.

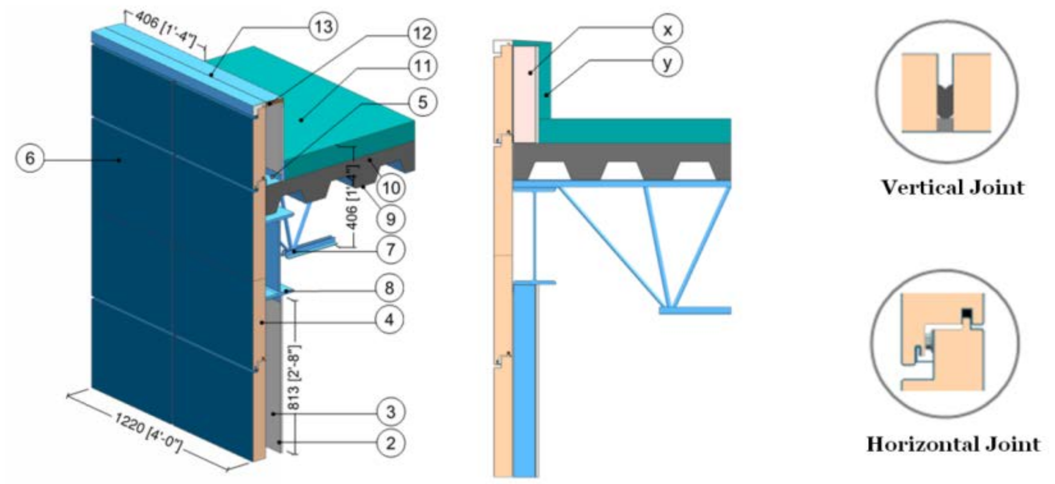


Table 7-78. Modeling values: Parapet with steel roof deck and joist.

ID	Component	Thickness in. (mm)	Conductivity Btu/ft·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)
1	Interior Film (right side)[1]	–	–	R-0.7 (0.12 RSI) to R-0.9 (0.16 RSI)	–
2	Gypsum Board	½ (13)	0.092 (0.16)	R-0.5 (0.08 RSI)	50 (800)
3	Air Gap in Stud Cavity	3⅝ (92)	–	R-0.9 (0.16 RSI)	0.075 (1.2)
4	Polyiso Insulation	3 (76.2)	0.143 (0.02)	R-21.0 (3.70)	1.8 (28)
5	Steel Studs (3 5/8-in. x 1 5/8-in.) @ 16-in. o.c. with Track	18 gauge	430 (62)	–	489 (7830)
6	Steel Facer Skin	24 gauge	430 (62)	–	489 (7830)
7	Open Web Steel Joist	–	314 (45)	–	489 (7830)
8	Steel Beam (W410)	–	314 (45)	–	489 (7830)
9	Steel Deck	$^{1}/_{16}$ (1.6)-	314 (45)	–	489 (7830)
10	Concrete Topping	6 (152)	6 (0.9)	–	120 (1920)
11	Roof Insulation	4 (102)	–	R-20 (3.5 RSI)	1.8 (28)
12	Wood Block	⅝ (16)	0.6 (0.09)	R-1 (0.18 RSI)	27.8 (445)
13	Flashing and roof finish material is incorporated into exterior heat transfer coefficient				
x	Batt Insulation in stud cavity	3⅝ (143)	0.025 (0.044)	R-12 (2.11 RSI)	0.9 (14)
Y	Roof Insulation around parapet	2 (50)	–	R-10 (1.76)	1.8 (28)
14	Exterior Film (left side)[1]	–	–	R-0.2 (0.03 RSI)	–

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation

Table 7-79. Thermal performance: Parapet with steel roof deck and joist.

Condition	Clear Wall R-Value (W/m²K)	Linear Transmittance (Ψ) Btu/hr ft°F (W/mK)
Wall Clear Field	R-19.5 (3.43)	—
Roof Clear Field	R-21.0 (3.69 RSI)	—
As-Built Slab, no extra batt or roof insulation	—	0.272 (0.470)
Retrofit with...		
Batt Insulation in parapet stud cavity (x)	—	0.215 (0.373)
Roof Insulation around parapet (y)		0.169 (0.293)

Notes:

Metal panels are well-insulated in their body, but their highly conductive skins can result if thermal flanking and thermal bridging if care is not taken in detailing.

The joints usually have steel passing through at least some of the insulation, and this can result in a non-trivial loss in thermal resistance, as can metal flashings.

Insulating the back of parapets made of metal panels can result in some reduction at this common detail.

7.40 5a Precast sandwich panel: Steel roof joists bearing on inner wythe

Figure 7-41. Parapet with steel roof deck and joists.

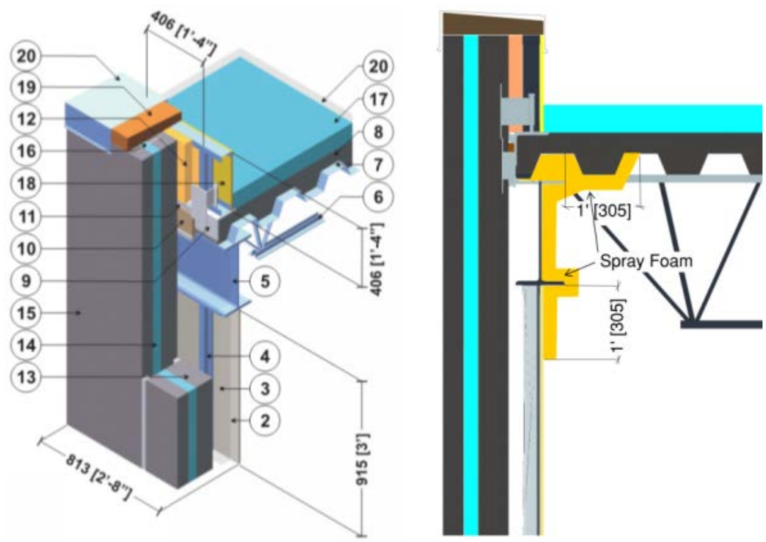


Table 7-80. Modeling values: Parapet with steel roof deck and joists.

ID	Component	Thickness in. (mm)	Conductivity Btu/ft·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)
1	Interior Film (right side)1	—	—	R-0.6 (0.11 RSI) to R-0.7 (0.12 RSI)	—
2	Gypsum Board	½ (13)	0.092 (0.16)	R-0.5 (0.08 RSI)	50 (800)
3	Air in Stud Cavity	5⅝ (143)	—	R-0.9 (0.16 RSI)	0.075 (1.2)
4	3 5/8-in. Steel Studs with Top and Bottom Tracks	18 gauge	35.825 (62)	—	489 (7830)
5	Steel Beam (W410)	—	28.891 (50)	—	489 (7830)
6	Open Web Steel Joist (550C)	—	28.891 (50)	—	489 (7830)
7	Steel Deck	$^{1}/_{16}$ (1.6)	28.891 (50)	—	489 (7830)
8	Concrete Topping	6 (152)	0.52 (0.9)	—	120 (1920)
9	Gravity and Slot Anchors at Slab	—	28.891 (50)	—	489 (7830)
10	Semi-Rigid Insulation	1 (25)	0.023 (0.04)	—	4.5 (72)
11	Silicone Sealant	½ (13)	0.202 (0.35)	—	—
12	Spray Foam Insulation	2 (51)	0.014 (0.025)	—	2.8 (39)
13	Precast Sandwich Panel, Interior Concrete Panel	4 (102)	1.04 (1.8)	—	140 (2250)
14	Precast Sandwich Panel, Insulation	2 (51)	—	R-10 (1.8 RSI)	1.8 (28)
15	Precast Sandwich Panel, Exterior Concrete Panel	4 (102)	1.04 (1.8)	—	140 (2250)
16	Precast Sandwich Panel, Structural Ties @ 24-in. (610) o.c.	16 gauge	35.825 (62)	—	489 (7830)
17	Roof Insulation	4 (102)	—	R-20 (3.5 RSI)	1.8 (28)
18	Exterior Sheathing	½ (13)	0.092 (0.16)	R-0.5 (0.08 RSI)	50 (800)

ID	Component	Thickness in. (mm)	Conductivity Btu/ft·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)
19	Wood Blocking	⅝ (16)	0.052 (0.09)	R-1 (0.18 RSI)	27.8 (445)
20	Flashing and roof finish material are incorporated into exterior heat transfer coefficient				
	Interior Spray Foam	—	—	R-10 (1.75 RSI)	1.8 (28)
21	Exterior Film (left side)[1]	—	—	R-0.2 (0.03 RSI)	—
[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation					

Table 7-81. Thermal performance: Parapet with steel roof deck and joists.

Condition	Clear Wall R-Value (W/m²K)	Linear Transmittance (Ψ) Btu/hr ft°F (W/mK)
Wall Clear Field	R-13.1 (2.30 RSI)	—
Roof Clear Field	R-21.2 (3.74 RSI)	—
Sandwich Panel Joint	—	0.026 (0.046)
As-Built Slab	—	0.375 (0.650)
Retrofit with…		
R10 Spray Foam	—	0.142 (0.246)

7.41 6a Important clearwall details: Six-inch steel studs at 16-in. o.c. with brick ties

Figure 7-42. Interior or stud cavity insulation.

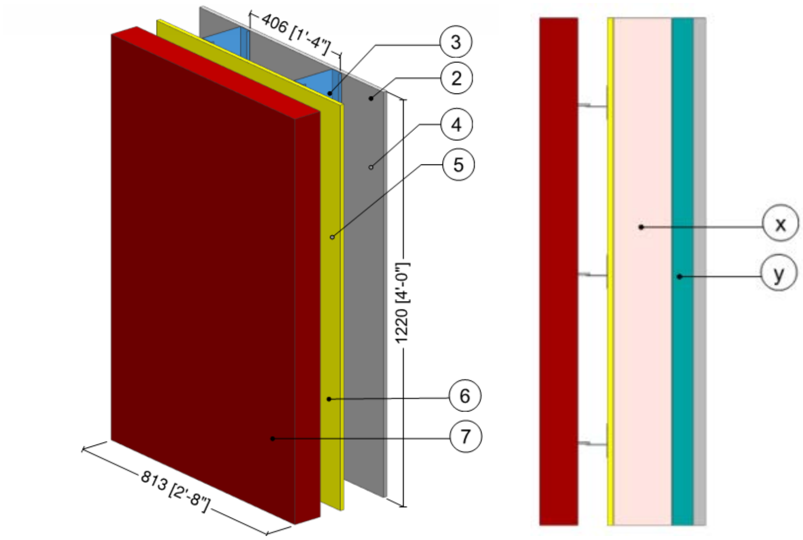


Table 7-82. Modeling values: Interior or stud cavity insulation.

ID	Component	Thickness in. (mm)	Conductivity Btu/ft·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)
1	Interior Film (right side)[1]	–	–	R-0.6 (0.11 RSI) to R-0.7 (0.12 RSI)	–
2	Gypsum Board	½ (13)	0.092 (0.16)	R-0.5 (0.08 RSI)	50 (800)
3	5 5/8-in. Steel Studs	18 gauge	35.825 (62)	–	489 (7830)
4	Air Gap in Stud Cavity	5⅝ (143)	–	R-0.9 (0.16 RSI)	0.075 (1.2)
5	Exterior Sheathing	½ (13)	0.092 (0.16)	R-0.5 (0.08 RSI)	50 (800)
6	Air Gap	1¼ (32)	–	R-0.9 (0.16 RSI)	0.075 (1.2)
7	Brick Veneer	3⅝ (92)	0.451 (0.78)	–	120 (1920)
x	Batt Insulation in Stud Cavity	5⅝ (143)	0.02 (.034)	R-21 (3.70)	0.9 (14)
y	Mineral Fiber Insulation	2 (51)	0.017 (0.029)	R-8.4 (1.48 RSI)	1.8 (28)
8	Exterior Film (left side)[1]	–	–	R-0.2 (0.03 RSI)	–

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation

Table 7-83. Thermal performance: Interior or stud cavity insulation.

Condition	Clear Wall R-Value (W/m²K)	Linear Transmittance (Ψ) Btu/hr ft°F (W/mK)
Wall Clear Field	R-4.3 (0.76)	–
Retrofit with...		
Batt Insulation in Stud Cavity (x)	R-12.7 (2.24)	–
Mineral Fiber Insulation (y)	R-13.3 (2.34)	–
Batt Insulation in Stud Cavity (x) and Mineral Fiber Insulation (y)	R-23.7 (4.18)	–

7.42 6b Important clearwall details: Concrete wall with interior steel stud assembly

Figure 7-43. Concrete wall with interior steel stud assembly.

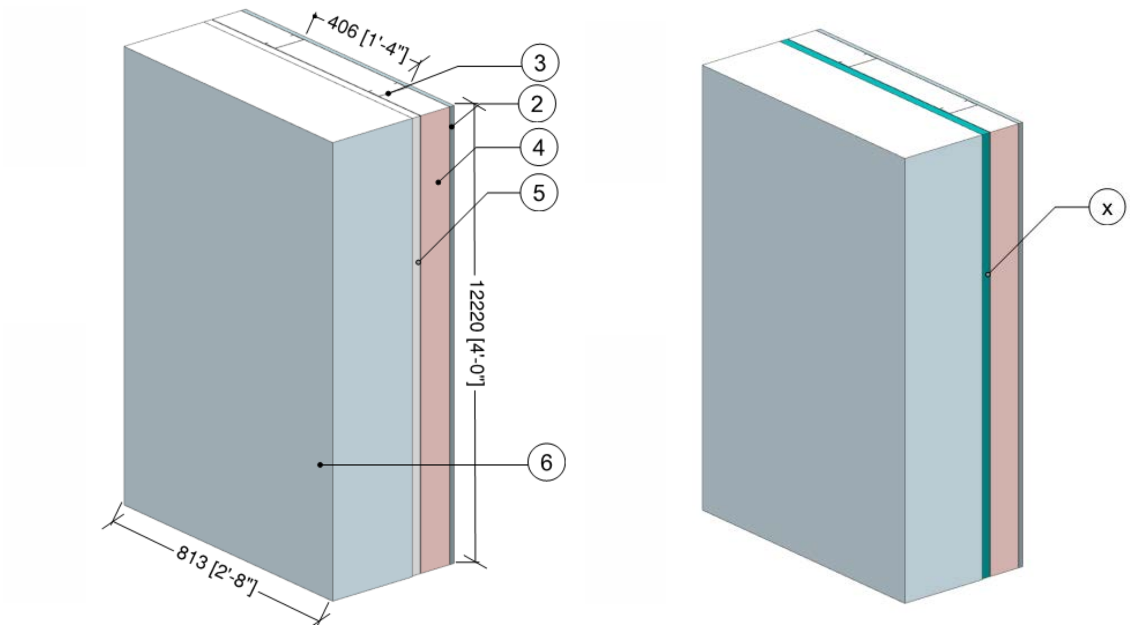


Table 7-84. Modeling values: Concrete wall with interior steel stud assembly.

ID	Component	Thickness in. (mm)	Conductivity Btu/ft·hr·°F (W/m K)	Nominal Resistance hr·ft^2·°F/Btu (m^2K/W)	Density lb/ft^3 (kg/m^3)
1	Interior Film (right side)[1]	–	–	R-0.6 (0.11 RSI) to R-0.7 (0.12 RSI)	–
2	Gypsum Board	½ (13)	0.092 (0.16)	R-0.5 (0.08 RSI)	50 (800)
3	3 5/8-in. Steel Studs	18 gauge	35.825 (62)	–	489 (7830)
4	Batt Insulation in Stud Cavity	3⅝ (143)	0.025 (0.044)	R-12 (2.11 RSI)	0.9 (14)
5	Air Gap	1 (25)	–	R-0.9 (0.16 RSI)	0.075 (1.2)
x	Spray Foam Insulation	1 (25)	0.014 (0.024)	R-6 (1.06 RSI)	0.35 (1470)
6	Concrete	10 (254)	1.04 (1.8)	–	0.20 (850)
8	Exterior Film (left side)[1]	–	–	R-0.2 (0.03 RSI)	–

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation

Table 7-85. Thermal performance: Concrete wall with interior steel stud assembly.

Condition	Clear Wall R-Value (W/m²K)	Linear Transmittance (Ψ) Btu/hr ft°F (W/mK)
Wall Clear Field	R-9.5 (1.67)	—
Retrofit with:		
1-in. spray foam insulation	R-15.8 (2.78)	—

Notes:

Adding R6 to the exterior of the steel stud inner faming results in an improvement of about R6 to the clear wall, but this insulation will be bypassed at floors and load-bearing partitions.

7.43 7a Historical details with interior insulation: Window sill in solid brick masonry (1)

Figure 7-44. Window sill – as found.

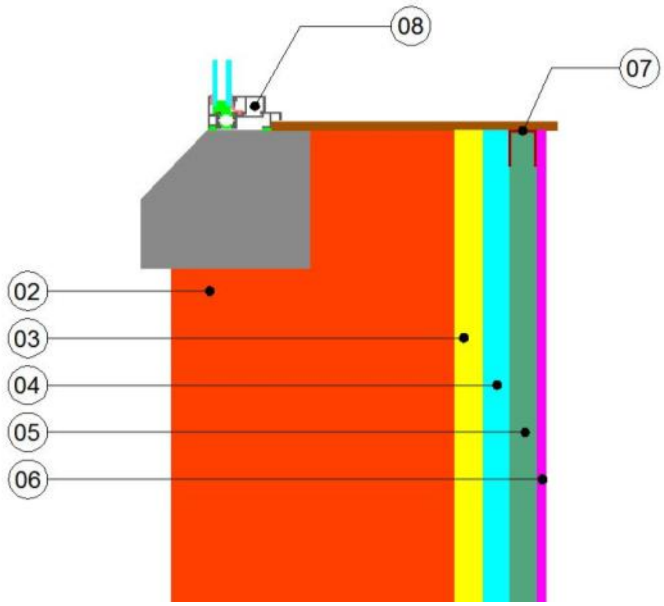


Table 7-86. Modeling values: Window sill — as found.

ID	Component	Thickness in. (mm)	Conductivity Btu/ft·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)
1	Interior Film	—	—	R-0.74 (0.13 RSI)	—
2	Brick	15⅝ (397)	0.5778 (1)	R-2.25 (0.397 RSI)	110 (1800)
3	Spray Foam	2 (51)	0.0139 (0.024)	R-12 (02.11 RSI)	2(32)
4	Air Gap	1½ (38)	0.1192 (0.206)	R-1 (0.185 RSI)	
5	Air Gap with Vertical Steel Studs	1½ (38)	0.806 (1.395)	R-0.16 (0.027 RSI)	
6	Gypsum Board	½ (13)	0.092 (0.16)	R-0.5 (0.08 RSI)	50 (800)
7	Steel Top and Bottom Track	—	27.7 (48)	—	480(7800)
8	5500 ISOWEB WINDOW	—	—	—	—
9	Exterior Film (Wall)	—	—	R-0.23 (0.04 RSI)	—

Table 7-87. Thermal performance: Window sill — as found.

Condition	Clear Wall R-Value (W/m²K)	Linear Transmittance (Ψ) Btu/hr ft°F (W/mK)
Wall Clear Field	R-16.9 (0.336)	—
As-Built Fitting Situation	—	0.466 (0.806)

Notes:

Beware rotting ends of joist and F/T of masonry at in cold climates, especially at grade (splash zone) and wherever rainwater is concentrated.

7.44 7a Historical details with interior insulation: Window sill in solid brick masonry (1)

Figure 7-45. Window sill – corrected.

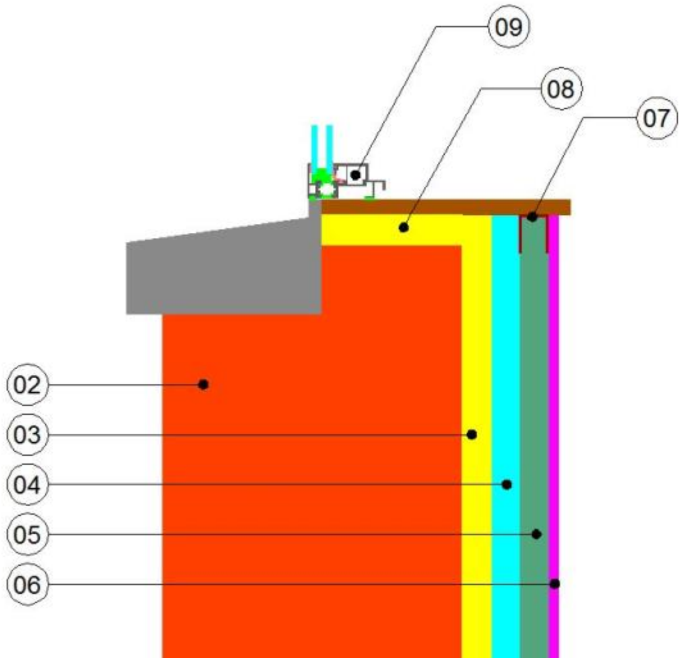


Table 7-88. Modeling values: Window sill — corrected.

ID	Component	Thickness in. (mm)	Conductivity Btu/ft·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)
1	Interior Film	–	–	R-0.74 (0.13 RSI)	–
2	Brick	15⅝ (397)	0.5778 (1)	R-2.25 (0.397 RSI)	110 (1800)
3	Spray Foam	2 (51)	0.0139 (0.024)	R-12 (02.11 RSI)	2(32)
4	Air Gap	1½ (38)	0.1192 (0.206)	R-1 (0.185 RSI)	
5	Air Gap with Vertical Steel Studs	1½ (38)	0.806 (1.395)	R-0.16 (0.027 RSI)	
6	Gypsum Board	½ (13)	0.092 (0.16)	R-0.5 (0.08 RSI)	50 (800)
7	Steel Top and Bottom Track	–	27.7 (48)	–	480(7800)
8	Spray Foam	1.5 (38)	0.0139 (0.024)	–	
9	5500 ISOWEB WINDOW	–	–	–	–
10	Exterior Film (Wall)	–	–	R-0.23 (0.04 RSI)	–

Table 7-89. Thermal performance: Window sill — corrected.

Condition	Clear Wall R-Value (W/m²K)	Linear Transmittance (Ψ) Btu/hr ft°F (W/mK)
Wall Clear Field	R-16.9 (0.336)	–
Proposed Fitting Situation	–	0.099 (0.171)

Notes:

This is an easy detail to implement whenever new windows are part of an interior insulation retrofit. The improvement in performance is very large and significant.

Although shown as brick masonry the wall could be concrete, or CMU.

The wood buck provided support to the window opening without compromising the thermal performance.

The principles of window installation in Section 6.1 should be followed.

The thermal performance can be further improved by specifying thicker insulation layers and thinner wood blocking. Insulation the exterior of the rough window opening, behind the precast sill, will also improve performance.

8 Conclusion and Recommendations

8.1 Conclusion

This work investigated a wide range of building types from which a number of Ψ and χ factors (heat transmittances) were generated for use in including the heat loss of thermal bridging in the energy analysis of buildings. Also, this work explored practical alternatives to implement thermal bridge mitigation in existing and new Army buildings.

Seven types of common buildings types were identified, and a number of important TB details were chosen for each. A list of 30 were chosen for detailed analysis based on their significance.

8.2 Recommendations

It is recommended that the importance or significance of thermal bridging be ranked according to:

1. The length of the condition in a specific building type
2. How common the condition in this building type is
3. The magnitude of the TB (psi-factor)
4. How common the building type is in the inventory
5. The potential for economical mitigation of the TB.

It is also recommended that the library of thermal bridge construction details, begun in this work, be expanded to include typical thermal bridges in a complete range of Army construction types.

Acronyms and Abbreviations

Term	Definition
ANSI	American National Standards Institute
ASA(ALT)	Office of the Assistant Secretary of the Army for Acquisition, Logistics, and Technology
ASA(IE&E)	Assistant Secretary of the Army for Installations, Energy and Environment
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
CEERD	US Army Corps of Engineers, Engineer Research and Development Center
CERL	Construction Engineering Research Laboratory
CIBSE	The Chartered Institution of Building Services Engineers
CMU	Concrete Masonry Unit
CRREL	Cold Regions Research and Engineering Laboratory
CSA	Canadian Standards Association
DA	Department of the Army
DoD	U.S. Department of Defense
EIFS	Exterior Insulation Finishing System
EISA	US Energy Independence and Security Act of 2007
EPDM	ethylene propylene diene M-class (rubber)
EPS	Extruded Polystyrene
ERDC	Engineer Research and Development Center
ERDC-CERL	Engineer Research and Development Center, Construction Engineering Research Laboratory
ERV	Energy Recovery Ventilation
F/T	Freeze/Thaw Cycle
HQUSACE	Headquarters, US Army Corps of Engineers
HRV	heat recovery ventilator
HSS	Hydraulic Steel Structures
HVAC	Heating, Ventilating, and Air-Conditioning
ID	Identification
IGU	Insulated Glazing Unit
ISO	International Standards Organization
NIST	National Institute of Standards and Technology
NSN	National Supply Number
OMB	Office of Management and Budget
OWSJ	Open Webbed Steel Joists
PIC	Polyisocyanurate
PVC	polyvinyl chloride
RH	Relative Humidity
RSI	R-value [thermal resistance] Système International
SAR	Same as Report

Term	Definition
SF	Standard Form
SS	Steel Stud
TB	Thermal Bridge
TI	Temperature Index
TR	Technical Report
URL	Universal Resource Locator
UV	Ultraviolet
WWW	World Wide Web
XPS	Expanded Polystyrene

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