

Windows Installation Designs for Meeting Demanding Thermal Code Requirements

ABSTRACT

The building enclosure industry has been moving toward the use of exterior continuous insulation for decades now, and the thickness of the insulation required has been increasing. Thicker exterior insulation requires new design solutions for cladding attachments and penetration, such as window openings. Modern emerging building codes, such as the *National Energy Code for Buildings 2020* in Canada and ASHRAE 90.1-2022, *Energy Standard for Sites and Buildings Except Low-Rise Residential Buildings*, require that the considerable thermal bridging impact of window installation details be considered. Finally, the need to focus on the water and airtightness of window installations is now widespread, and new standards, such as CSA A440.6, *High Exposure Fenestration Installation*, provide requirements for demanding applications.

This paper reviews the design and construction challenges of window installation in walls with more than about 38 mm (1.5 in.) of continuous insulation. New products have become available that may help solve some of the challenges. The design process, technology, and techniques for ensuring water- and airtight installation while mitigating thermal bridging are presented, along with a range of thermal calculations and construction details to bring these solutions to life.

LEARNING OBJECTIVES

- » Explain how building codes are changing to require improved thermal performance by reducing thermal bridges.
- » Identify how the fundamental control layers maintain their continuity at the head and sill of typical windows.
- » Describe the limitations of common window buck solutions for window installation
- » Identify how some newly available thermally improved materials and products can be used to make window installation thermally efficient as well as air- and water-tight.

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The installation of windows in walls is a common enclosure design requirement and yet a common source of problems. The wide range of different types of walls, cladding, and windows results in a vast range of possible combinations. As a result, the design of the window-to-wall interface detail is commonly unique to each project. Adding to the design and construction challenges are the changing requirements for better insulation values and controlling (limiting) thermal bridging. Despite these realities, this paper proposes that there are standard design principles that can simplify and guide the design of these important details.

The design of a wall must of course be considered in the design of the window rough opening. Hence, the common features of wall assemblies will be briefly considered. An increasingly common approach to understanding building enclosure design is embodied in the "Perfect Wall."^{1,2} which identifies the enclosure control layers and an arrangement that meets most requirements. Although the relative position in the wall of the functional layers shown in **Figure 1** is the best for most applications, variations are common. For example, modern walls may have a water control layer outboard of the insulation, not use a vapor control layer, or routinely add insulation within hollow support frames made of steel and wood. However, despite variations, the layers identified must be present in any functional enclosure assembly and will need to be identified to allow for the design of a proper window installation.

In Canada, Part 5 of the National Building Code explicitly outlines the

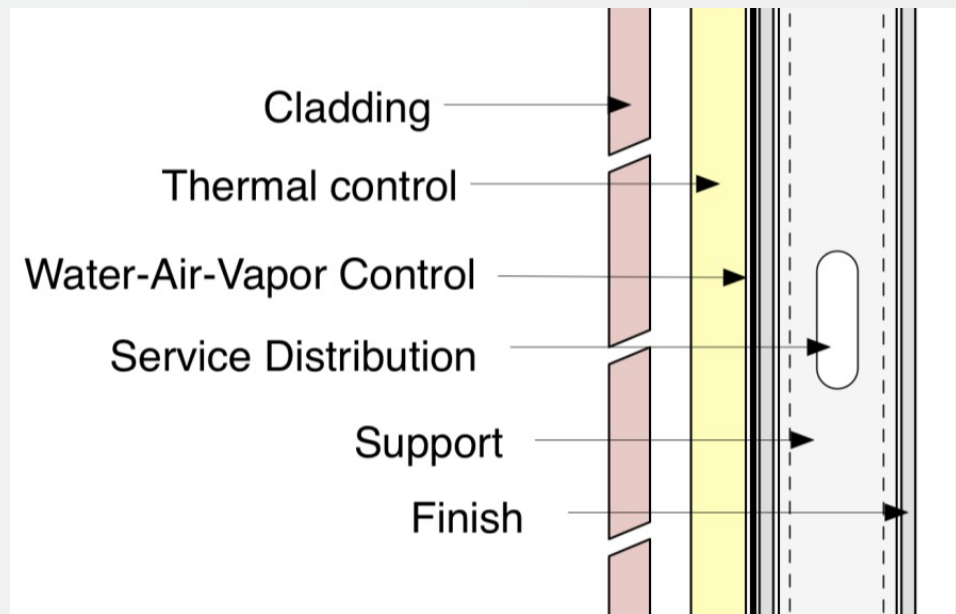


FIGURE 1. "Perfect Wall" enclosure design.

requirements for enclosures. Separate subsections describe thermal control (5.3), air control (5.4), vapor control (5.5), and water control (5.6).

The window, as part of the enclosure, must have all the same control layers. Like enclosure walls, windows may include additional functions, such as sound control, fire resistance, and impact resistance to respond to specific project requirements.

As society has demanded better energy efficiency and comfort, higher thermal performance has been required of enclosures. The building enclosure industry has been moving to the use of exterior continuous insulation for decades now and the thickness of the exterior insulation required has been increasing. Thicker thermal breaks and thicker insulated glazing units (that is, triple glazing) are the result of these same trends.

The framing component of vision framing can take on a bewildering array of shapes and numerous materials. However, for larger commercial and multi-unit residential buildings, shapes can be usefully categorized into four generic types: flanged, storefront, curtainwall, and solid (**Figure 2**). The locations of the control layers are not well identified for most window frame types, and this creates challenges for designing connections to the control and support layers of the surrounding walls.

Thicker exterior insulation requires new thermally efficient design solutions for cladding attachments and wall penetrations such as window openings. Modern emerging building codes, such as the *National Energy Code for Buildings 2020*³ in Canada and ASHRAE 90.1-2022, *Energy Standard for Sites and Buildings Except Low-Rise Residential*

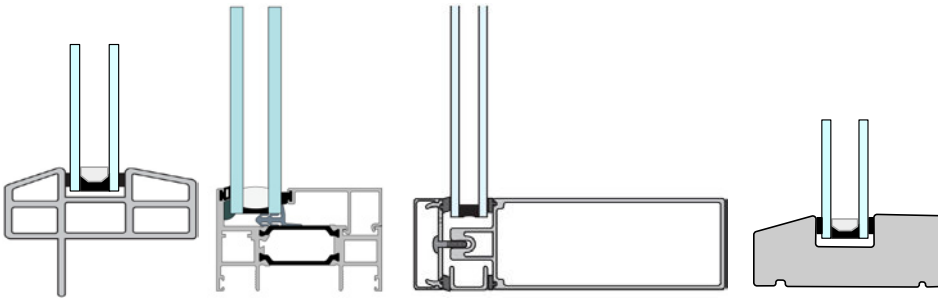


FIGURE 2. Four common categories of frame shape: flanged, storefront, curtainwall, and solid.

Buildings,⁴ require that the considerable thermal bridging impact of window installation details be considered.

The most critical function a window installation design must meet is that of structural support: if the window is not properly attached to a sufficiently strong enclosure support, failure will result in danger to life and safety. The primary life safety risk involves not in failing to resist the gravity load (which could cause the window to sag downward in its opening) but in the window falling outward (especially when that outward force is due to a human body). Design, construction, and inspection must always consider this structural function. Structural engineers specializing in window installation routinely provide designs to meet this need.

The remainder of this paper will focus on the air, water, and thermal control functions.

RAIN PENETRATION AND AIRTIGHTNESS

The second most important function of a window installation is to control rainwater penetration. This is a remarkably common defect observed routinely in practice. Windows and doors are routinely tested, in the laboratory, using standards such as ASTM E331⁵ since its introduction in the 1970s. Despite the widespread testing of window products for water penetration resistance, the poor control of rain penetration at windows has been well documented over the last 50 years, with surprisingly modern descriptions provided by Herbert,⁶ Scott,⁷ and Lies and Faith.⁸ Modern research has

increased over the last 25 years with dozens of published papers, such as RDH Building Engineering,⁹ Hardman and Katsaros,¹⁰ Lacasse,¹¹ and entire symposia subsequently devoted to the topic.^{12,13}

The need to focus on the water and airtightness of window installations is now widely accepted. ASTM E2112, *Standard Practice for Installation of Exterior Windows, Doors and Skylights*,¹⁴ has long guided installation. New standards, such as CSA A440.6, *High Exposure Fenestration Installation*,¹⁵ provide requirements for more demanding applications. The introduction to ASTM E2112-18 states, "Rainwater leakage has been the leading reason for dissatisfaction of building owners with performance of fenestration installations." This standard

explicitly only deals with walls that are drained (the term "drainage walls" is used) and face sealed (the term "surface barrier" is used) and does not directly address mass walls (the third rain control category) nor concealed perfect barriers (a type of perfect barrier rain control that does not place the barrier on the surface). More significantly, this widely used standard does not directly address airtightness or thermal continuity. Appropriate for its low-rise residential focus, most of the guidance provided relates to flanged windows. It is the authors' experience that in practice the ASTM E2112 standard does not provide sufficient guidance for designers of commercial non-flanged windows, and walls with exterior continuous insulation.

The airtightness of windows themselves is also tested (often using ASTM E283¹⁶), and windows are often rated for airtightness performance. However, the installation often results in air leakage around the window in the field. This air leakage is reported less often in the literature as a serious problem but can nonetheless result in durability impacts and increased heat flows.

In the authors' opinion, window frames and their rough openings should be assumed to allow rain penetration sometimes (often because of material

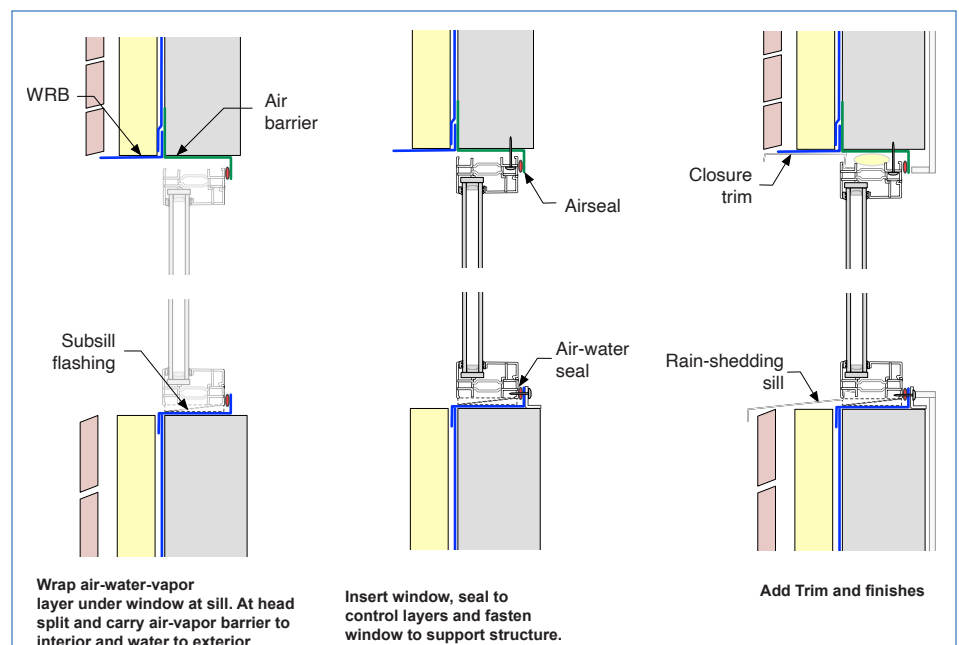


FIGURE 3. Generic punched window installation sequence.

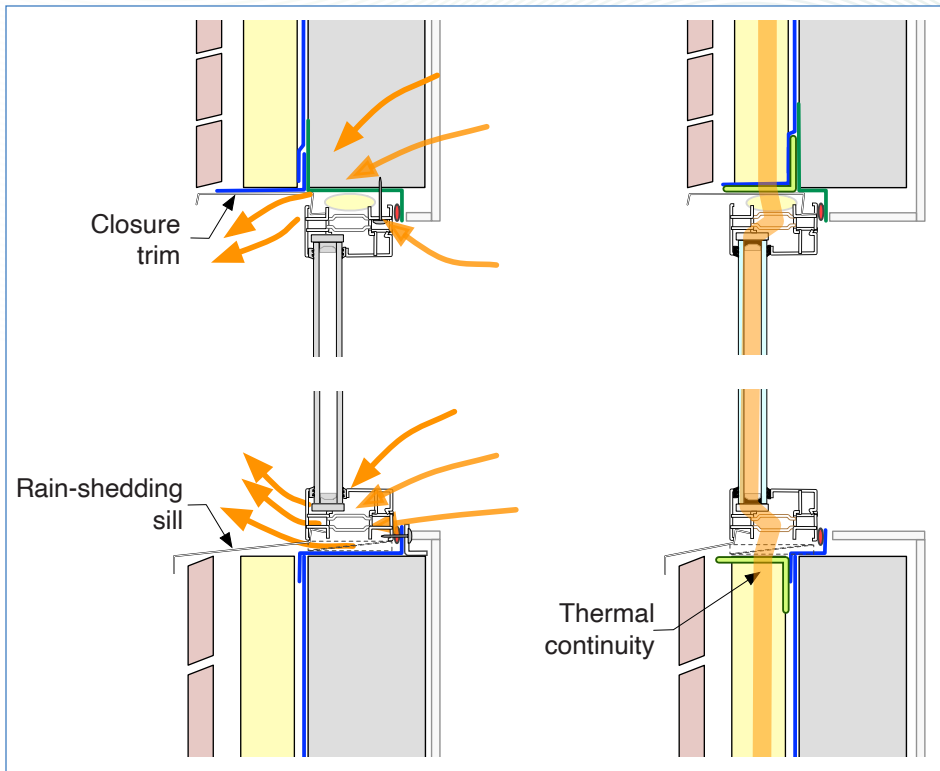


FIGURE 4. Thermal flanking can be avoided by ensuring alignment of thermal insulation.

deterioration over time or because of workmanship issues) and under some conditions (for example, hurricane-force-wind-driven rain). This leads to the recommendation that all rough openings should have water-resistant barriers applied and, most importantly, that drainage of the rough opening be provided and gross air leakage be blocked.

The purpose of any enclosure detail design between two distinct enclosure components is to connect the control layers of the two components, the interior and exterior finishes, and the structural components in a buildable and durable manner. When windows are connected to walls, it is recommended that the air control connection to windows be undertaken at the inside face of windows, and at the inner shoulder of the glazing rabbet for curtainwalls. For water control, the recommendation is to shed water to the exterior of unit frame at the head. At the sill, the water control should connect to the inside face of windows (or the inner shoulder of the glazing rabbet for curtainwalls).

The recommended approach to designing a window installation is shown in **Figure 3**. The air-water (and often vapor) control layer is wrapped under the window or door at the sill and raised upward and sealed to the inside of the frame for air barrier continuity. At the head, the water control is directed to the exterior and the air barrier is connected to the interior of the frame. Trims and finishes that are explicitly not

part of air, water, or thermal control are then added.

An inner air seal is provided around the entire perimeter, ensuring that air leakage is managed. While not always required, an upturned interior angle (or equivalent detail) is shown at the sill. Although this seal can be formed by the application of a backer rod and sealant in the rough opening, many window extrusion profiles (especially aluminum storefront sections of the type shown in **Fig. 3**) do not provide sufficient horizontal area for sealant adhesion. Sealing to the vertical inner surface is almost always possible and provides more than 1/2 in. of contact area for adhesion. An additional benefit of the upturn is that the air-water seal is not exposed to water that may accumulate on the rough opening sill: when exposed to air pressure, it will act across the inner seal and best practice is to limit water access to the air seal to limit air-pressure-driven water leakage.

MANAGING THERMAL BRIDGING

The installation of windows can locally increase heat flow. This is the definition of a thermal bridge. Building codes, such as NECB 2020¹⁷ and ASHRAE 90.1-2022,⁴ require the size of this thermal bridge to be estimated. Describing the methodology used to calculate and report thermal bridging is beyond the scope of this paper, but can be found in the codes and the standards they reference (for example, ISO 14683¹⁸ and

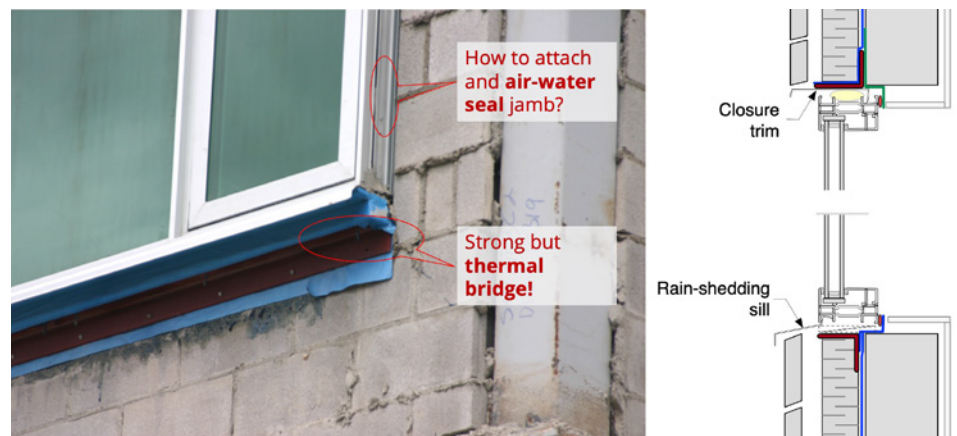


FIGURE 5. Steel angles provide structural support that allow windows to project outward, but impose significant thermal bridging.

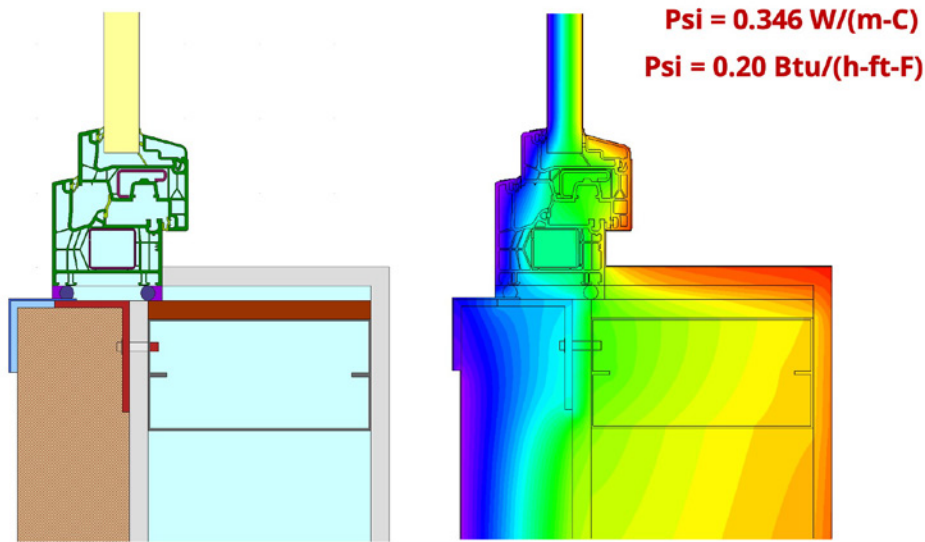


FIGURE 6. Thermal bridging calculation results for linear thermal bridging of steel window support angle.

However, the thermal continuity is lacking: that is, the thermal break in the window is not aligned with the thermal control layer. Thermal flanking can, in theory, be overcome by aligning the thermal break of the window with the thermal insulation layer(s) of the wall assembly (**Figure 4**). In modern wall assemblies with exterior continuous insulation, aligning the thermal breaks within aluminum window frames requires different solutions to ensure structural support.

A significant number of zero-energy and other low-energy buildings have been built with thick layers of exterior insulation for over 25 years. Hence, numerous techniques and details have been tried and tested on many jobsites. The earliest options developed were wood “bucks,” essentially sawn timber or engineered lumber frames that project outward from the face of the wall into the insulated cavity and provide support. This approach largely solves the thermal bridging issues, but the use of wood has significant limitations. Wood moisture movement routinely results in challenges during construction caused by warping and cupping. Before the window can be installed, the air-water membrane from the wall must be wrapped first outward and then inward, resulting in complex

CSA Z5010²⁵). In short, however, the increased heat flow caused by thermal bridging can be reported as an additional heat loss coefficient per length of sill, jamb, and head. The standard symbol used to describe linear thermal bridges is the Greek letter psi (Ψ), with units of $W/(m \cdot K)$ or $Btu/(h \cdot ft \cdot F)$.

Research into the window-wall interface for North American building assemblies has been somewhat sparse, but several good references

exist.^{19–21} Increased heat flow around a window installation, often labeled as thermal flanking,² has more than just energy implications. Cold-weather condensation due to poor thermal control at window perimeters is an important problem that requires consideration (see, for example, Maref et al.²²).

The generic approach to detailing shown in the previous section manages air and water tightness very well.

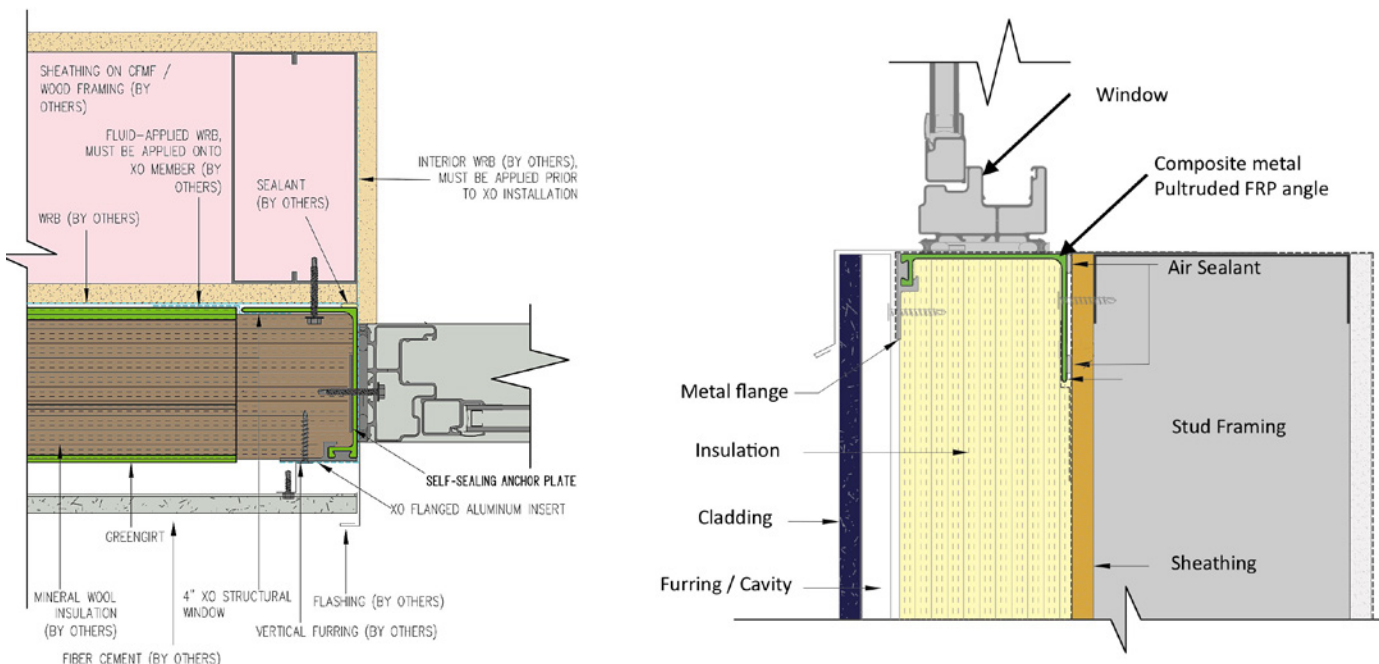


FIGURE 7. Example composite metal hybrid FRP angle window sill installation (Advanced Architectural Products, 2024).

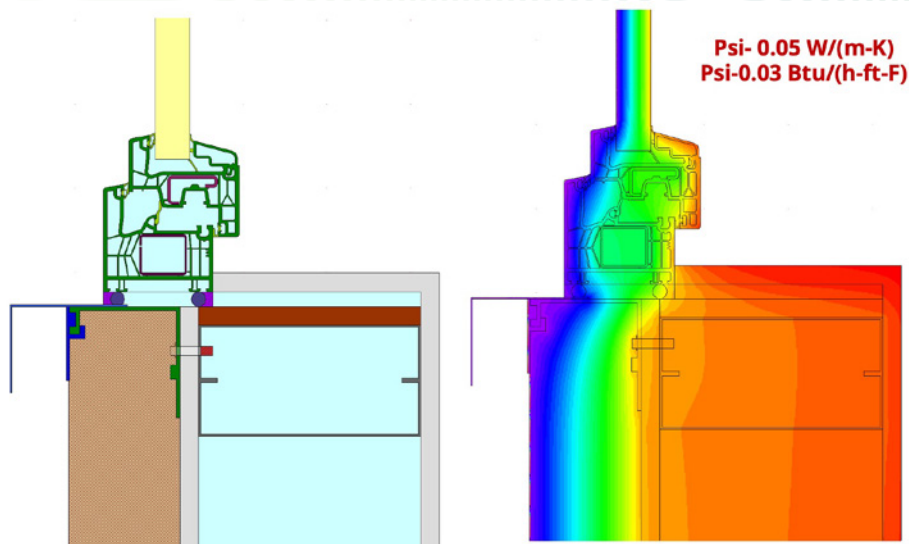


FIGURE 8. Thermal bridging calculation results for window sill installation using a composite FRP metal hybrid angle.

area would be $24 \times 0.30 = 7.2 \text{ Btu}/(\text{h}\cdot^\circ\text{F})$ and through the 20 feet of perimeter would be $20 \times 0.2 = 4 \text{ Btu}/(\text{h}\cdot^\circ\text{F})$. Thus, the total heat flow rises from 7.2 to 11.2, an increase of over 50%. Another perspective is that the additional heat flow caused by this window installation is equal to the heat loss through 60 square feet of R-15 opaque wall.

The limitations of the wood and steel angles have led to the development of alternative products. Polymer-based angles offer promise, as they are moisture-resistant and have inherently low thermal conductivity. However, polyvinyl chloride, used in many window frames, is not stiff or strong enough without large hollow sections, which complicate detailing, attachment, and installation. Pultruded fiberglass-reinforced plastics (FRPs) are also used in window frames and have much higher strength and stiffness. These offer promise, but have challenges associated with attachment: typical self-drilling screws and bolt holes have limited pullout strength due to cracking, fatigue, and temperature effects.

A pultruded FRP angle (sometimes used in a hybrid with metal) has recently been developed with sufficient strength and stiffness specifically for window installation (**Figure 7**). The thermal performance of this relatively slender and low-conductivity angle is very good. Thermal calculations using the same window and wall as before show almost seven times less thermal bridging than the steel angle design (**Figure 8**). Special aluminum inserts can be slid along the extrusion to significantly increase the load-carrying capacity at the sill for large and heavy units. These inserts increase the heat loss as point thermal bridges but are not usually required for common residential windows sizes and always cause less impact than a continuous steel angle.

The use of moisture-tolerant polymers allows the angle to be easily integrated with the air- and water-control strategy. In many scenarios, the easiest approach is to apply the air and water barriers as shown in **Figure 3**, and then apply the angles outboard of the membranes, followed by installation of the window and trim (left side of **Figure 9**) or

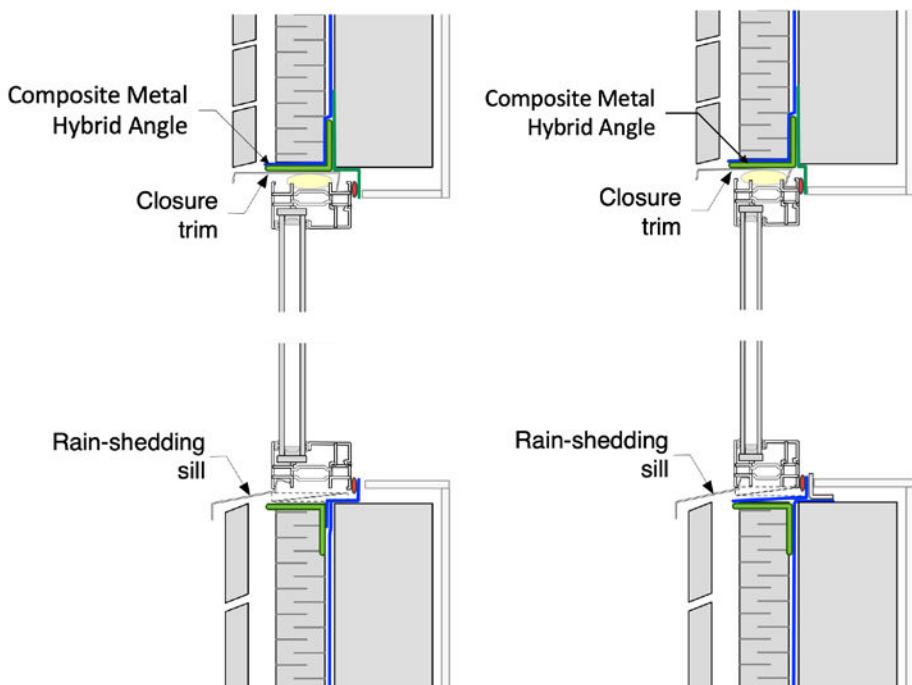


FIGURE 9. Integrating an air-water membrane with non-conductive structural angle.

membrane geometry, especially at the critical sill-to-jamb connection.

Alternative designs have used steel angles to support windows in alignment with the exterior insulation layer (**Figure 5**). These angles are dimensionally stable and strong, and, depending on their treatment and exposure, may not need to be protected with wrapped membranes. However, the thermal performance of these angles is very poor.

Figure 6 shows the results of a thermal analysis of a high-performance vinyl window in an externally insulated steel stud wall system. The thermal bridging due to the installation is predicted to be $0.20 \text{ Btu} / (\text{h}\cdot\text{ft}\cdot^\circ\text{F})$. The significance of this scale of impact can be appreciated by applying this calculation to a typical 4-foot-wide by 6-foot-tall high-performance commercial window with a U-value of $0.30 \text{ Btu}/(\text{h}\cdot\text{ft}^2\cdot^\circ\text{F})$. The heat flow through the 24-square-foot window

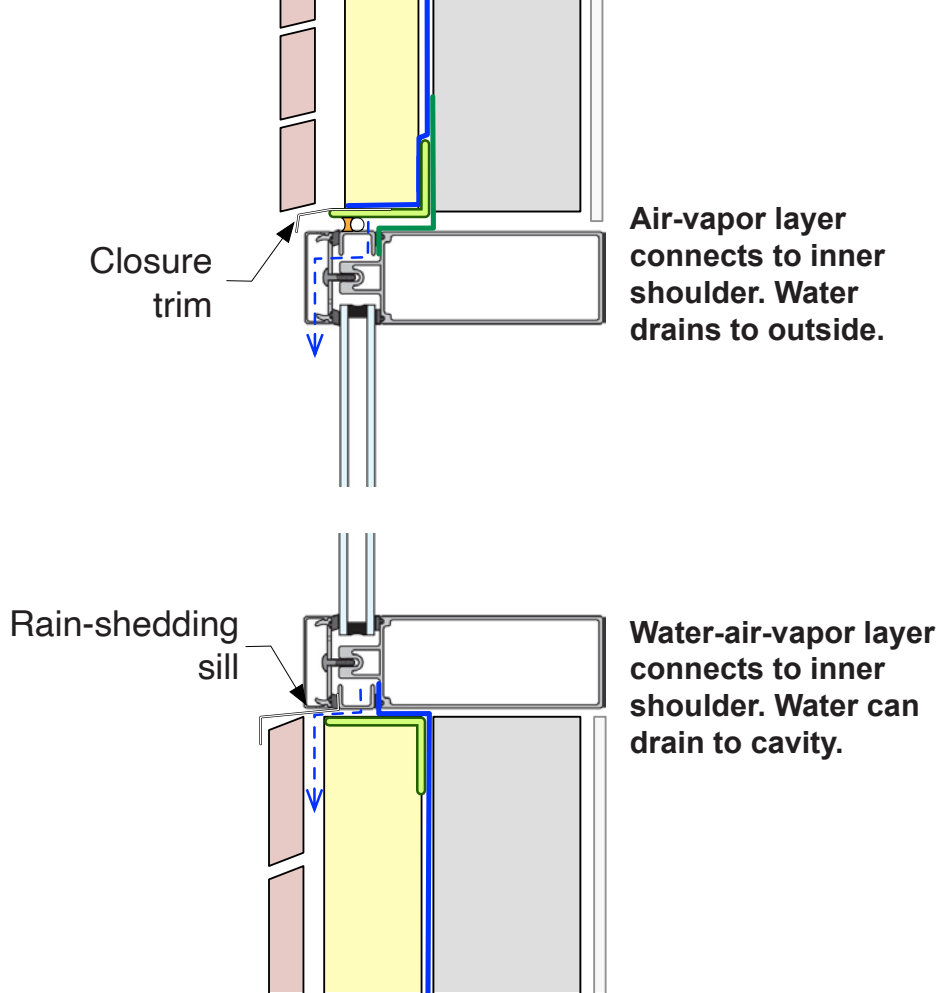


FIGURE 10. Generic curtainwall air-water-thermal integration with non-conductive structural angle.

integrated with a curtainwall **Fig. 10**. Alternatively, membranes can be added on top of the angle, provided the connection to the wall air-water barrier

is ensured.

Although most of the previous discussion has considered commercial

storefront-type windows, the recommended installation design can be applied to curtainwall-type framing as well. In the case of curtainwalls, the air-water barrier is connected to the inner glazing shoulder at the sill, and the water barrier is split to the exterior at the heads and jambs.

CONCLUSION

The installation of windows is a very important enclosure design detail that has become more challenging in light of changing thermal performance expectations and codes. Even without the need for more exterior continuous insulation, rain penetration at windows is a serious practical concern that must be addressed.

This paper has presented a series of recommendations for the generic design of window installations that meet the requirements of effective air and water penetration control. The impact of thermal flanking has been shown with the aid of representative calculations.

Finally, it was shown that the use of fiber-reinforced polymer angles can be a simple, powerful means of solving the combined challenge of air, water, and thermal control at punched window installations in modern wall assemblies with high levels of exterior continuous insulation.

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