Chapter 5

Design & Construction

Introduction

More attention to design and construction is essential to meeting low thermal energy demand for buildings that meet Passive House or Net-Zero energy standards than is normally provided in current practice for large noncombustible multi-unit residential buildings (MURBs). Not only is a lot more insulation and thicker assemblies required, but the impact of thermal bridging at every junction between building components must be evaluated.

This chapter discusses the design principles for large MURBs to meet low thermal energy demand. Example construction details for steel-framed walls with a concrete structure are provided that satisfy these design requirements. The intent of these details are to highlight the concepts using methods and assemblies familiar to Canadian construction practice. The same principles apply to other types of construction, such as modular precast concrete panels. This chapter provides some examples where performance may differ to contrast some different challenges in alternative construction types.

Design Principles

Minimizing the impact of thermal bridges is a cornerstone to thermally efficient building envelopes. However, other design considerations are equally important to complying with the requirements of the building code and constructing a good building envelope. Design requirements, in no particular order, that must be met while chasing the holy grail of "Thermal Bridge Free" design (see sidebar) follow:

- Fire Protection and Combustibility
- Environmental Separation
- Structural Support
- Durability
- Constructability

Thermal Bridge Free Design is
a Passive House concept that is achieved when the sum of all linear and point thermal transmittances is equal or less than zero.

How can the impact be less than zero? Passive House uses outside dimensions for thermal transmittance calculations. Details such as parapets can have negative linear transmittances when using outside dimensions. See Chapter 2 for more explanation and the examples later in this chapter.

Components are also considered thermal bridge free in Passive House and not included in calculations when the following criteria are met.

$\Psi \leq 0.01$ W/ m K **$\chi/A \leq 0.01$ W/ m²K**

Requirements for high-rise residential buildings make goals for "Thermal Bridge Free" design not practical for many common types of construction and architectural designs. Nevertheless, low thermal energy demand can be achieved for large MURBs following familiar construction practices, with proven track records in meeting the challenges of Canadian climates, and have all the relevant testing completed to Canadian standards. Importing technology and systems from Europe is not necessary to meeting low thermal energy demand, irrespective of potentially easier paths to certification.

Many in industry are wondering how we will be building in the future when low thermal energy demand is a requirement. Feasible solutions derived from Canadian practice and current building code requirements are a focus of this guide.

The following sections outline how design selections, such as the type of insulation, cladding, glazing, as well as window detailing and insulation placement correspond to code requirements in the Canadian context for Part 3 noncombustible buildings. A consistent example assembly is used to illustrate the concepts presented in this section as illustrated by **Figure 5.1**.

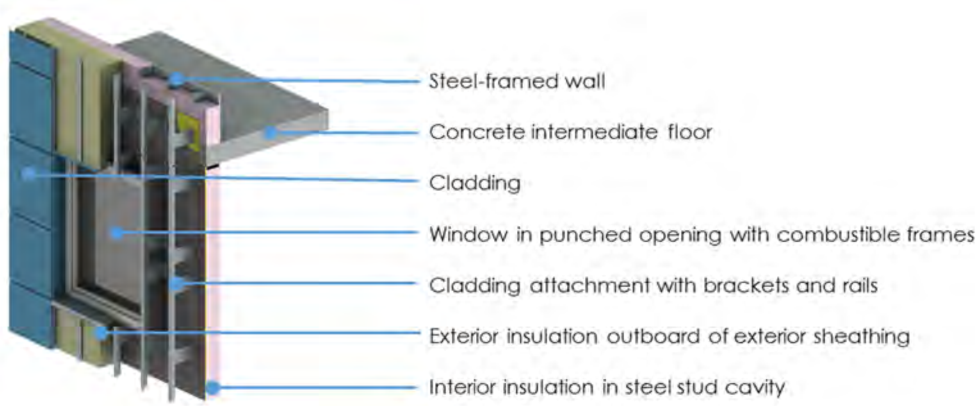


Figure 5.1: Example Window in a Punched Opening of a Steel-Framed Wall Assembly with Concrete Structure

FIRE PROTECTION AND COMBUSTIBILITY

Fire protection and combustibility requirements for high-rise residential buildings is a significant differentiator from being able to rely on past design examples for guidance and left wondering where to start when challenged with delivering a building that will have low thermal energy demand. The challenge is that many components relied upon to reduce thermal bridging and/or minimize wall thickness have combustible components. Examples of components are window frames, foam insulation, cladding attachments and thermal breaks.

NON-METALIC STRUCTURAL SUPPORTS, ATTACHMENTS AND THERMAL BREAKS

Many new systems and products have been developed that incorporate low thermal conductive combustible materials, such as plastic or fiberglass, to reduce thermal bridging. While plastic, fiberglass and other combustible materials can be manufactured with low flame spread and with limited risk of ignition, these combustible materials will ignite in the right conditions, can provide fuel for a fire, and raise questions about the potential loss of structural integrity during a fire.

This section gives an overview of the Building Code requirements for non-metallic supports, attachments and thermal breaks that are used in a structural capacity for non-combustible construction.

References to the National Building Code (NBC) are provided in the discussion[1] with applicability to broad range of products and components.

CAN NON-METALLIC COMPONENTS BE USED IN A NONCOMBUSTIBLE BUILDING?

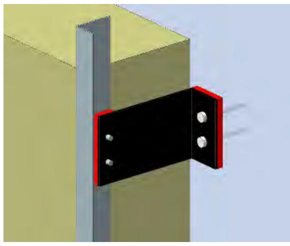
The short and simple answer is ….**YES**, by any of the following pathways. More information is provided in this section for the obstructed paths.

Clear Paths	**1**	The non-metallic **component** has passed either a. CAN/ULC-S114 (noncombustibility test) b. ULC-S135 (limited combustibility test)
	2	The **assembly** has passed CAN/ULC-134 "Fire Test of Exterior Wall Assemblies" and the building is sprinklered, if over three storeys in height.
Obstructed Paths	**3**	The non-metallic **components** are deemed similar to the "minor combustible components" listed in NBC 3.1.5.2.(1) and the local Authorities Having Jurisdiction (AHJ) agrees
	4	An alternative solution is provided for the project and is accepted by the local AHJ.

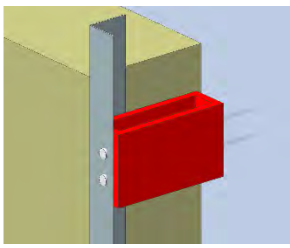
To help with connecting products to the concepts presented in this section, common non-metallic components are grouped together based on common characteristics, such as structural function and connection, potential contribution to fire growth and spread, and position within the assembly.

[1] Requirements of other Canadian jurisdictions might slightly differ, but the concepts generally apply regardless of the jurisdiction.

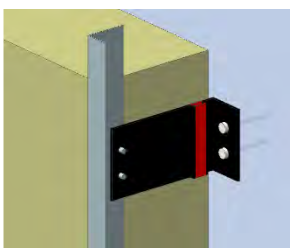
Types of Combustible Components for Supports, Attachments and Thermal Breaks



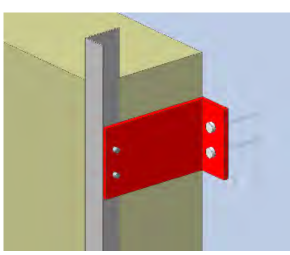
Type 1 - Shims: A combustible material functions as a shim, often 5 mm to 20mm (2/5 inches to 3/4 inches) in depth, where metal fasteners connect a metal structural component through to another component. The shims can be buried in the insulation at the sheathing, anywhere in the insulation to connect together two components of the support system, or between the cladding and cladding support system.



Type 2 - Thermal Spacers: The combustible material is larger than shims, is the full depth of the insulation, and functions as a rigid spacer for the connection of long metal fasteners through the insulation back to the structure. The outer rail or sub-girt is completely outboard of the thermal spacer for the metal fasteners to function as the primary structural attachment. This type of system also often requires plastic shims at the sheathing to plumb the cladding.



Type 3 - Glazing Type Thermal Breaks: Aluminum support brackets have plastic thermal breaks similar to thermally broken windows. The outer metal rail or sub-girt can partially penetrate the insulation or be entirely in the cavity behind the cladding, which may also have a plastic shim between the metal bracket and outer metal rail or sub-girt.



Type 4 - Combustible Brackets or Girts: The combustible material functions as the primary structural support to attach the cladding to the structure. Combustible brackets are either completely buried in the insulation or only exposed at the outer most surface depending on the type of the exterior outer metal rail or sub-girt. The exterior metal rail or sub-girt can partially penetrate the insulation or be entirely in the cavity behind the cladding. Combustible girts have the exterior flange exposed to the cladding cavity.

Red – combustible component	**Brown – Insulation**
Black – metal component	**Blue - Substrate**

PATHWAY 3 MINOR COMBUSTIBLE COMPONENTS

Pathway three is an obstructed path because NBC Article 3.1.5.2 allows interpretations to what is deemed "similar minor components" compared to a list of specific permitted combustible components.

There are a wide variety of interpretations of what is deemed "similar", but there are two commonalities from the listed of permitted components that lead to two criteria for judging what is deemed "similar minor components":

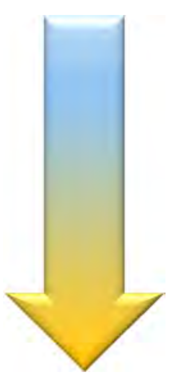
Criterion 1: The combustible component is limited in quantity of combustible material.

Criterion 2: Life safety is not compromised if the combustible component fails in a fire.

Criterion one is based on the intent statement explaining that certain combustible materials are permitted since "they are deemed to insignificantly contribute to fire growth and spread". The non-metallic components outlined in this section have a limited amount of combustible material and clearly meet Criterion one.

Criterion two is not explicitly stated in the code and is an interpretation based on the function of the listed minor combustible components. Criterion two is not satisfied for some non-metallic components and cannot be automatically considered "similar" minor combustible components. The likelihood that alternative compliance paths will be required increases as follows.

Minor Combustible Component



Not a Minor Combustible Component

Type 1 – Shims clearly complies with both criteria and is a minor combustible component.

Type 2 – Thermal Spacers meets Criterion one. An argument can be that Criterion two is met because the cladding may sag in a fire but will be held in place by the fasteners. However, there is a possibility that an Authority Having Jurisdiction (AHJ) will not accept this argument without testing.

Type 3 – Glazing Type Thermal Breaks meets Criterion one. Criterion two is not satisfied if the cladding weight is supported by this component. The same technology and risk exists for aluminum windows, where the glass and exterior frame will fall out if the thermal break was compromised by fire. There is a moderate probability that an AHJ will not consider this type of component to be a minor combustible component.

Type 4 – Combustible Brackets or Girts: meets Criterion one, but not Criterion two. There is a high probability that an AHJ will not consider this type of component to be a minor combustible component.

PATHWAY 4 ALTERNATIVE SOLUTIONS

Criterion two for Type 3 and 4 non-metallic components can be met if the fixed points in a cladding attachment system are metallic and support the full weight of the cladding and the non-metallic components resist wind loads and accommodate movement as shown in **Figure 5.2** below.

An Alternative Solution (also called a variance in some jurisdictions) is a potential path if all other paths are not feasible. Alternative Solutions are permitted under the NBC if it can be demonstrated that the same level of performance as NBC Division B is provided. An Alternative Solution is typically site and building specific. Path four is an obstructed path because there is no guarantee that the AHJ will accept this solution.

There are measures to reduce the risk of fire growth and spread, at and in the exterior wall assembly, to support an Alternative Solution. This is a potential option when all other pathways are not viable; for instance the assembly has NOT been tested to CAN/ULC-S134, the combustible components will not pass ULC-S114 or ULC-S135, and the AHJ will not consider the supports as minor combustible components.

The following combination of mitigating features may form the basis of an Alternative Solution to the criteria outlined in NBC Article 3.1.5.6:

- **Interior layer of gypsum board** reduces the risk of high heat exposure to cladding supports from an interior fire.
- **Noncombustible exterior cladding** reduces the risk of an exterior fire (i.e. barbeque, car, arson) propagating on the exterior surface and directly exposing combustible supports.
- **Exterior mineral wool insulation** surrounding all supports reduces the risk of direct flame exposure and radiant heat flux to the supports.
- Include **noncombustible attachment back to the structure** so that failure of the combustible element may lead to sagging, but the cladding will stay in-place during a fire.

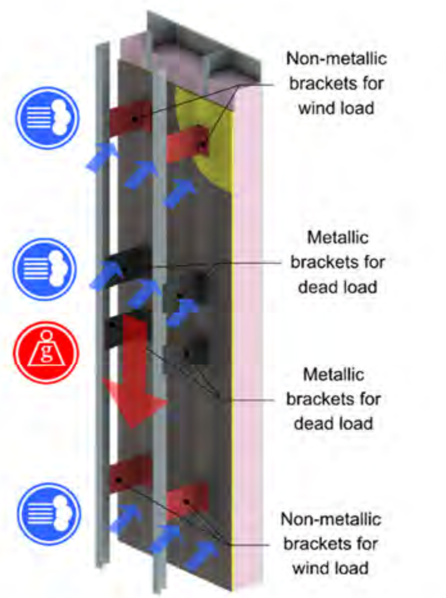


Figure 5.2: Cladding System with Metallic and Combustible Support Brackets

The Alternative Solution will outline how the wall assembly would be expected to pass the ULC-S134 exterior wall fire test if it was tested including the non-metallic cladding supports. The local AHJ may require submission of detailed cladding support documentation, structural failure analysis, and/or further quantitative analysis to show how insignificant the contribution of the supports to fire growth and spread.

COMBUSTIBLE WINDOW FRAMES

Combustible window sashes and frames, including vinyl and fiberglass, are permitted on noncombustible buildings provided the requirements of NBC Clause 3.1.5.4.(5) are met as outlined in **Figure 5.3**.

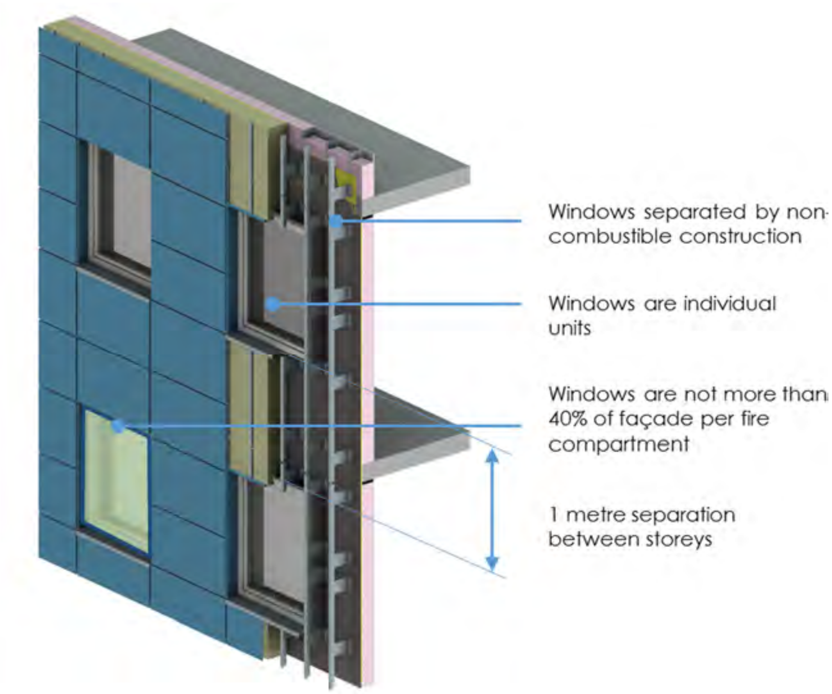


Figure 5.3: Combustible Window Frames in Noncombustible Construction

Design freedom is restricted by limitations on the size and spacing of combustible window frames and often leads to Alterative Solutions on projects. Some industry stakeholders are also proposing changes to the requirements for combustible window frames based on testing and analysis of both thermally broken aluminum and combustible window frames.

FOAM INSULATION

Overall wall thickness can be a challenge when designing low thermal energy buildings when viewed from conventional perspectives of constructability, cost and useable floor space if constrained. Foam insulation with lower conductivity per unit thickness (high

R/inch) can help reduce the overall wall thickness and is well-suited to incorporate into panelized systems as outlined in the construability section.

Foamed plastic insulation needs to be protected by a thermal barrier as outlined in NBC Article 3.1.5.15 for noncombustible construction. Thermal barrier requirements vary depending on flame–spread rating, if the building is sprinklered and building height.

Additional consideration in detailing might be required compared to conventional wall assemblies to protect thick layers of combustible insulation from adjacent spaces. For example, minimizing thermal bridging at window interfaces might expose foam insulation in a precast sandwich panel and require an additional thermal barrier at the window perimeter as shown in **Figure 5.4**.

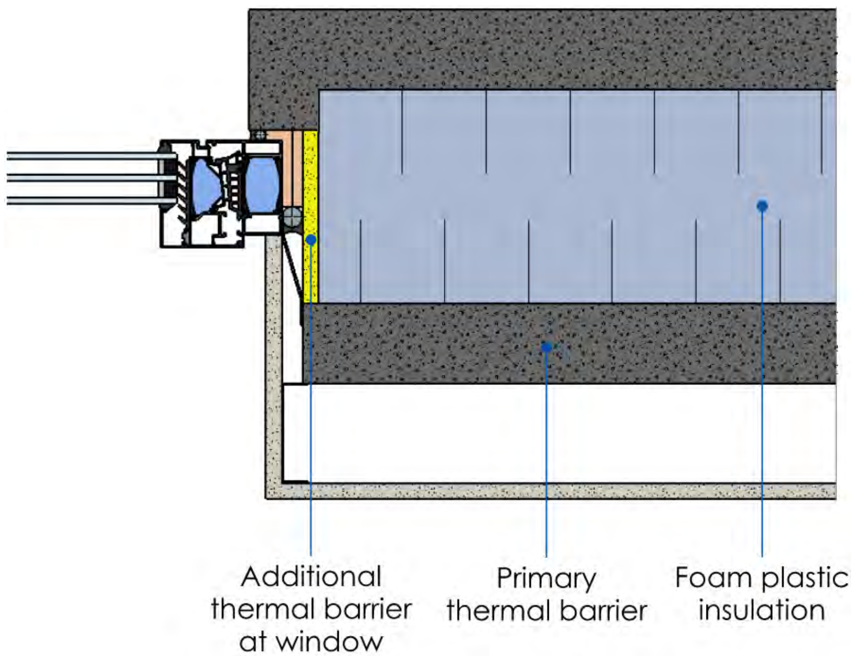
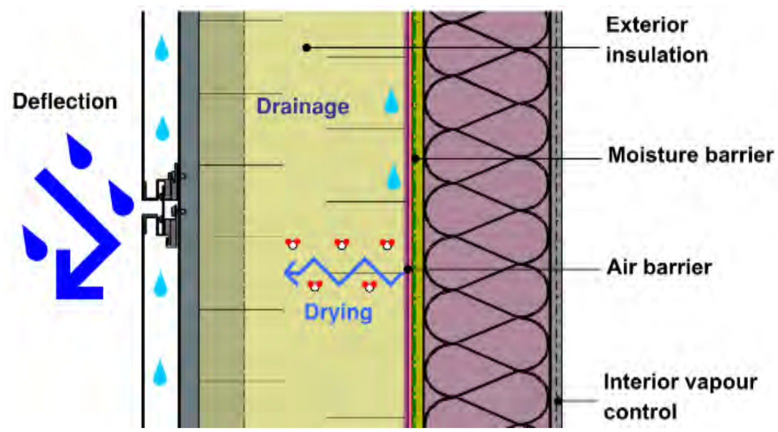


Figure 5.4: Thermal Barrier over Foam Plastic Insulation at Window Jamb in Precast Sandwich Wall Panel

The features leading to the need for additional protection in this detail are the insulation thickness, window positioning, over-insulating the window frame and maximizing the insulation at the window perimeter. Strategies to minimize thermal bridging at glazing interfaces is discussed in the example construction details later in this chapter.

ENVIRONMENTAL SEPARATION

Requirements for environmental separation for low thermal energy demand high-rise residential buildings are the same as for conventional practice with regard to the control of condensation, precipitation, vapour diffusion and sound transmission. The challenges are meeting the requirements for low thermal transmission and high levels of airtightness.



Control layers and environmental separation requirements that must be met are outlined in the adjacent figure and **Table 5.1** below.

Table 5.1: Control Layers and Environmental Separation Requirements

Rainwater Management	• Deflect rainwater at exterior surface • Capillary gap behind cladding to restrict moisture transfer across the wall • Drained cavity to drain moisture at the backside of the cladding
Moisture or Weather Resistive Barrier	• Membrane to resist water penetration • Secondary drainage plane
Air Barrier	• Continuous barrier • Low air permeance materials • Resist full wind pressure and transfer to the structure • Allowance for movement from cyclic thermal and moisture loads, interstory drift and structural deflection • Building envelope airtightness testing
Vapour Control	• Sufficiently low permeance • Positioned within the assembly to avoid moisture accumulation
Resistance to Heat Transfer	• Control the risk of condensation • Low thermal transmittance • Minimize thermal bridging • Occupant comfort

STRUCTURAL SUPPORT

Design teams require a holistic viewpoint and higher level of collaboration among disciplines to meet the challenge of low thermal energy demand. From a structural perspective these prerequisites present some challenges and may require a deviation from conventional practice. Some designs that are easy and efficient from a structural perspective are not feasible when thermal bridging is fully factored into decisions and low thermal energy demand is a requirement.

For example, interior insulated cast-in-place concrete walls that are preferred for residential high-rise construction in some markets, are not feasible for buildings required to meet a low thermal energy demand. Wall systems that maintain the continuity of the thermal insulation across the building structure are the only option. Examples include exterior insulated walls, precast concrete panels, or any wall system that is hung outboard of the structure with continuous insulation, such as insulated metal panels. These wall systems are not complicated from a structural design perspective but are not as easy as painting a concrete wall or column and adding some insulation inboard the wall structure.

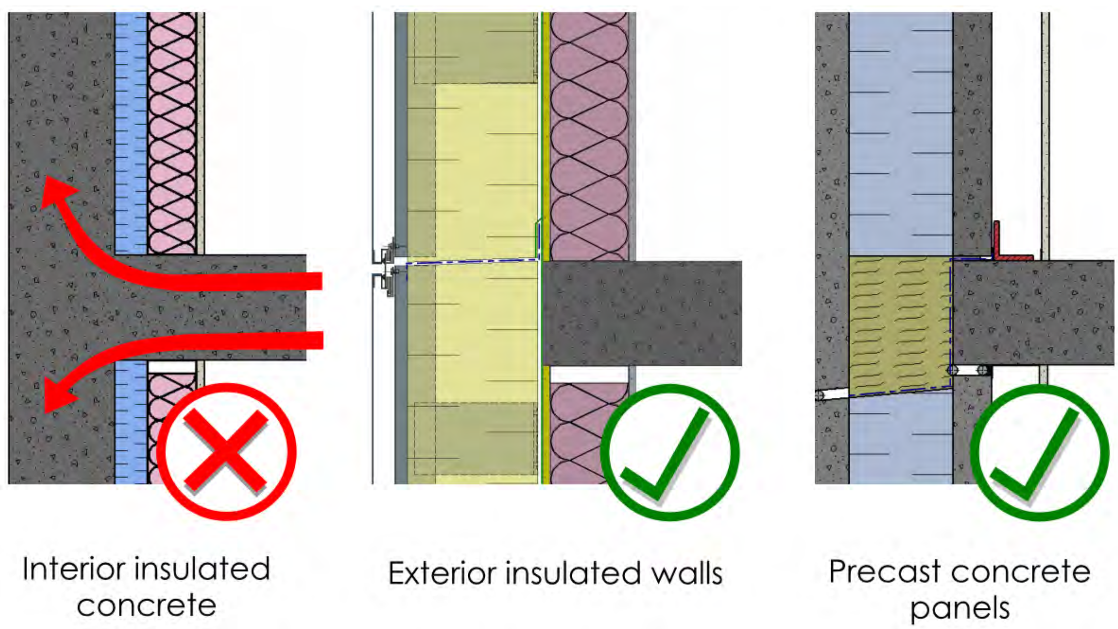


Figure 5.5: Examples Maintain the Continuity of the Thermal Insulation across the Building Structure

Challenges from a structural perspective for designing low thermal energy demand buildings are:

1. How to effectively introduce thermal breaks or insulation into joints and transfer loads to the structure where conventional practice depends on intimate contact.

2. Providing redundant supports for cladding systems with combustible components to address fire protection and combustibility concerns, while optimizing overall wall thickness and thermal performance.

3. Positioning windows and doors within the exterior insulation, outboard the back-up wall, to minimize thermal bridging

4. Accommodating more complicated point connections than compared to conventional practice for components that bypass the insulation, such as for balconies or overhangs.

DURABILITY

Assemblies and components must be designed with Canada's climate and construction practice in consideration for their expected service life. Material deterioration occurs when components are exposed to UV, wind, extreme temperature changes and moisture. Any forgiveness associated with higher energy flows does not exist for buildings with low thermal energy demand and more consideration is needed to assess the durability of components. In the past, there was enough energy transferred through the building envelope to compensate for some deficiencies or inadequate material choices to keep susceptible materials sufficiently warm and dry. For example, the corrosion resistance of components in a rain-screen cavity should be specified for a wet environment with extreme temperature fluctuations.

Standards such as CAN/CSA S478 – Guideline on Durability in Buildings and ISO 13823 provide recommendations to assist designers by providing a framework to determine durability targets and criteria for specifying durability requirements. The standards also provide advice on environmental and design factors that affect the durability of building components and materials. The goal of durable building design is to meet the intended design service life of the building. Components that are covered and cannot be easily maintained or accessed must last the life of the assembly.

Durability extends beyond design and selection of materials. Durability is also a function of construction, maintenance and operation of a building. Quality control and assurance activities should include design reviews, shop drawing reviews, mock-ups, field reviews, testing and verification.

A steel stud assembly with all the insulation outboard the exterior sheathing is more durable because the structure is kept warm and dry. They are straightforward to design because one membrane can provide the air, vapour, and moisture control, and manages water effectively via a drained cavity outboard of the insulation. The examples in this chapter present scenarios with and without batt insulation in the stud cavity. Nevertheless, even with the batt insulation in the stud cavity the ratio of outboard to inboard thermal resistance is such that the structure will be relatively warm or above freezing for exterior temperatures down to -40°C, except at the location of the metal brackets through the exterior insulation.

CONSTRUCTABILITY

Constructability is critical to realizing low thermal energy demand from a quality control and cost perspective in the context of high-rise residential development.

This guide provides examples of site-built details and assemblies that are common in current practice when high performance assemblies are required. These assemblies can be built using components that are readily available, have relevant Canadian testing, and supported by many trades, suppliers and manufacturers able to deliver these systems. Non-exclusive examples which will be discussed further in this section include site built exterior insulated wall assemblies, pre-fabricated paneled walls and precast sandwich panels.

SITE BUILT EXTERIOR INSULATED WALL ASSEMBLIES

The advantages of a site built exterior insulated wall assembly include:

1. Familiar construction practices in the Canadian market
2. A broad spectrum of façades are possible due to the extensive selection of available panels and cladding
3. Field review and testing can occur as the critical layers are constructed in a manner that enables easier resolution of construction issues
4. Quality control of the critical barriers is straightforward and performance targets can confidentially be met, particularity when continuity matters for hard targets such as airtightness

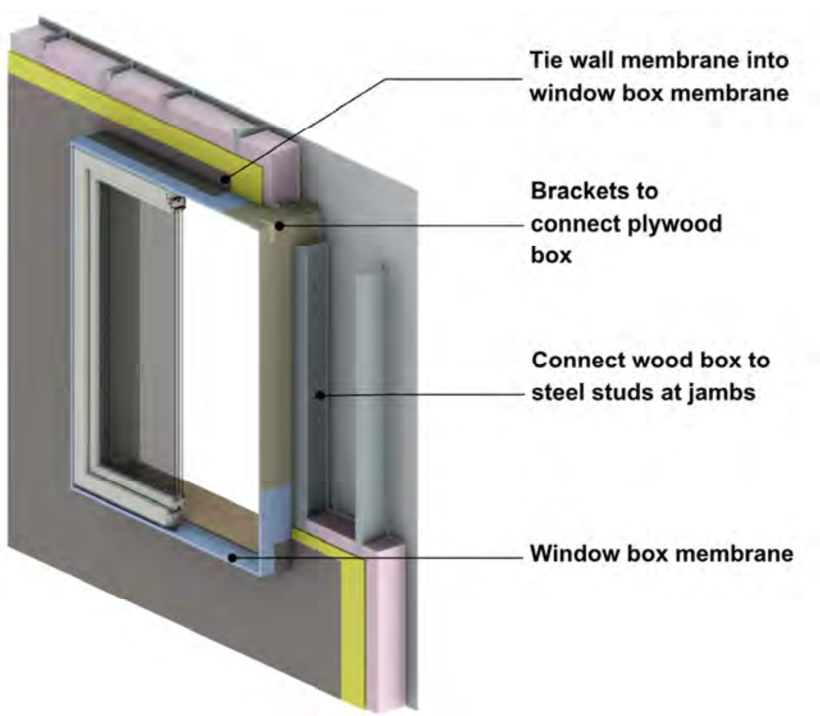


Figure 5.6: Detailing of Window with a Wood Box

The main disadvantage compared to other assemblies ubiquitous for high-rise residential construction, such as window-wall, is that a higher level of construction sequencing and exterior access is required during construction. The costs are more than compared to window-wall for high-rise construction, but the biggest cost differential is related to cladding choice, which is often driven by architecture.

There are challenges compared to conventional practice at some details when the objective is to fully minimize thermal bridging. For example, detailing the air and moisture barrier can be seen as more difficult at windows when a wood liner is used to position the window in the plane of the exterior insulation as shown in **Figure 5.6**. Wrapping a self-adhesive membrane around a wood liner can be a challenge, but there are alternative liquid applied membranes that will allow for easier application around wood liners. Some contractors could turn this challenge into an opportunity by pre-fabricating a wood box that is installed into the rough opening with the window and/or membranes pre-installed into the wood box.

PRE-FABRICATED PANELIZED WALLS

Some industry stakeholders are interested in developing or importing pre-fabricated panelized wall systems for Passive House or Net-Zero buildings.

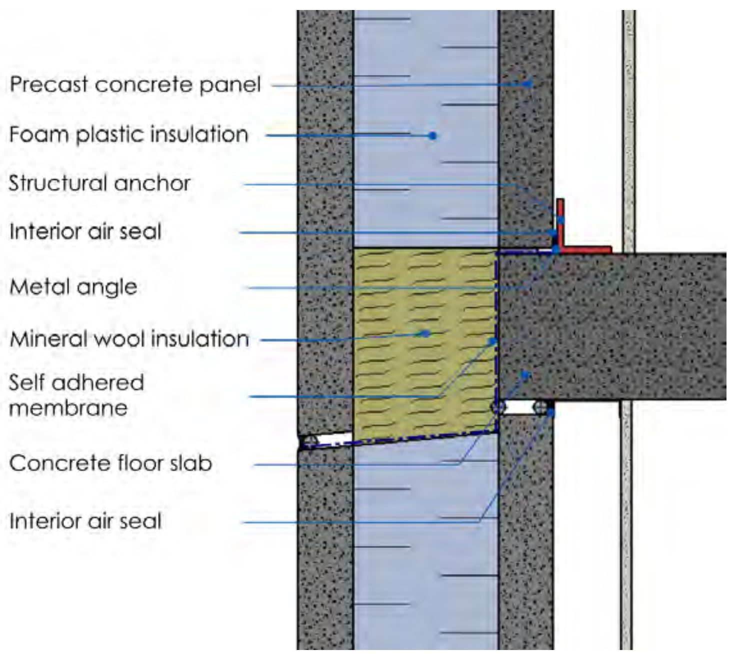


Figure 5.7: Example Precast Sandwich Panel with Enhanced Detailing

Some of this interest appears to be derived from the perception that panelized systems are needed to meet high levels of airtightness based on European experience and practice. The opposite has shown to be true in the Canadian context for some panelized or unitized systems because of the quantity and complexity of joints that do not sufficiently accommodate construction tolerances and movement.

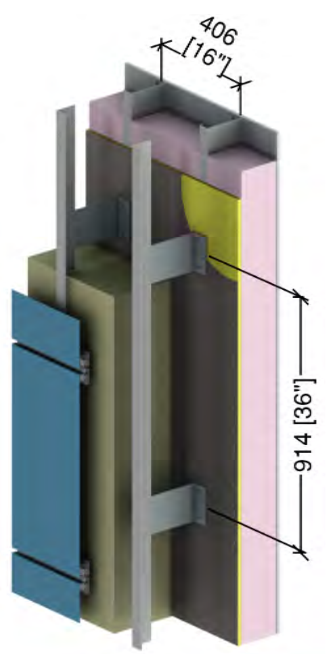
Nevertheless, panelized or unitized systems can result in better quality control of components, such as reduced cracking of concrete, and can speed up construction schedules when adequately designed and tested. Systems that speed up construction are ones that limit exterior access work to a bosun chair, such as applying sealants, and have durable finishes that can withstand the harsh conditions of construction. Panelized systems that require cranes can be disruptive to some construction practices where a crane is heavily used to form the concrete structure. Implications are additional cranes or other approaches to concrete forming will be required.

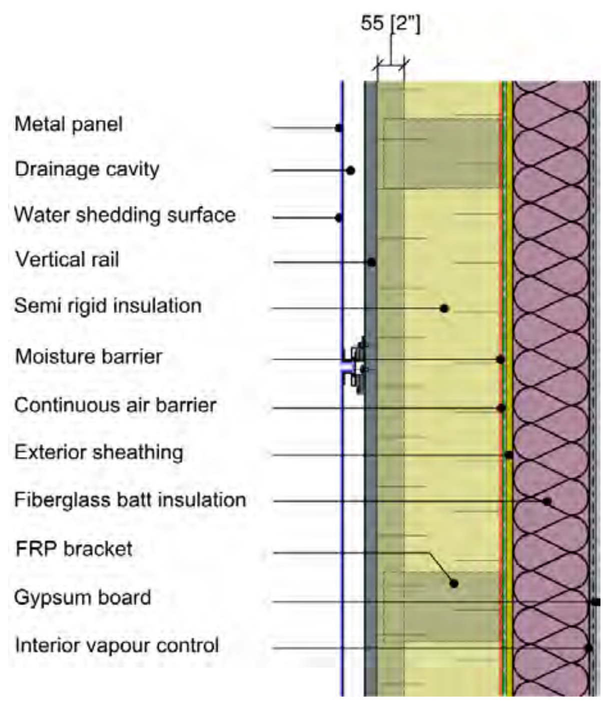
An example of a system that is well positioned in the Canadian market to meet the requirements of low thermal energy demand with the benefits of an accelerated construction schedule is a precast sandwich panel as illustrated in **Figure 5.7**. Enhanced detailing at intermediate floors, window interfaces, and the connectors is necessary to meet the higher design requirements, but can be realistically achieved. Moreover, there are local suppliers geared up to deliver these systems that have the engineering and testing to support panels with thick insulation layers and minimal thermal bridging.

Example Low Thermal Transmittance Details

Low thermal transmittance assemblies or highly effective R-values are achieved by high levels of insulation and minimizing thermal bridging. The assemblies and details presented in this chapter follow the design principles presented earlier in the chapter.

The clear wall assembly included in all the details is a 2x6 steel stud wall assembly with 250 mm (10 inches) of semi-rigid mineral wool insulation (R-42) outboard of the exterior sheathing. The cladding is a composite metal panel system that is attached back to the steel studs with a bracket and rail sub-framing system. The brackets are combination of aluminum and fibre reinforced plastic (FRP) spaced at 910 mm (36 inches) o.c. vertically and 400 mm (16 inches) o.c. horizontally. The aluminum brackets are fixed points located between floors that are designed to support the cladding dead load. The control layers are identified in the graphics below.





Two scenarios were evaluated, with and without R-19 fiberglass batt insulation in the stud cavity. The results for the clear field wall assembly are presented in **Table 5.2**.

Table 5.2: Clear Field Wall Assembly Thermal Transmittance

Scenario	**Exterior Insulation Nominal R-value** hr·ft^{2}·°F/Btu (m^2K/W)	**Assembly R-value** hr·ft^{2}·°F/Btu (m^2K/W)	**Assembly U-value** Btu/ hr·ft^{2}·°F (W/m^2K)
Air in stud cavity	42.0 (7.40)	40.0 (7.04)	0.025 (0.142)
R-19 (3.35 RSI) insulation in stud cavity	42.0 (7.40)	48.3 (8.51)	0.021(0.118)

The clear field assembly does not include the impact of the aluminum bracket. The incremental additional heat loss for the aluminum brackets are provided as point transmittances (χ) since the spacing of the fixed brackets varies depending on the floor to floor height.

Table 5.3: Aluminum Bracket Point Transmittance Between Intermediate Floors

	Scenario	**Point Transmittance per Bracket** χ Btu/hr·ft·°F (W/K)	**Thermal Bridge Free?** ($\chi/A < 0.01$ W/m^2K)
	Air in stud cavity	0.013 (0.026)	Yes, for tributary areas > 28 ft^2 (2.6 m^2)
	R-19 (3.35 RSI) insulation in stud cavity	0.024 (0.045)	Yes, for tributary areas > 48 ft^2 (4.5 m^2)

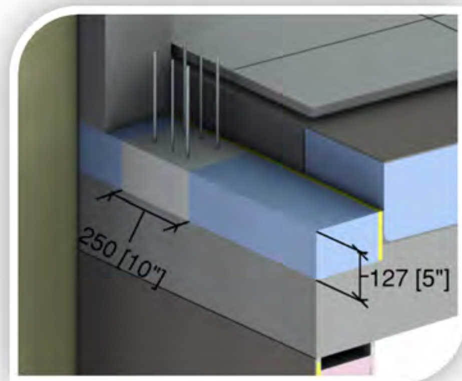
The example details include:

- Wall to roof interface (Detail 1)
- Intermediate floor (Detail 2)
- At-grade to below-grade parking garage interface (Detail 3)
- Window to wall interface (Detail 4)
- Door with intermittently attached balcony interface (Detail 5)

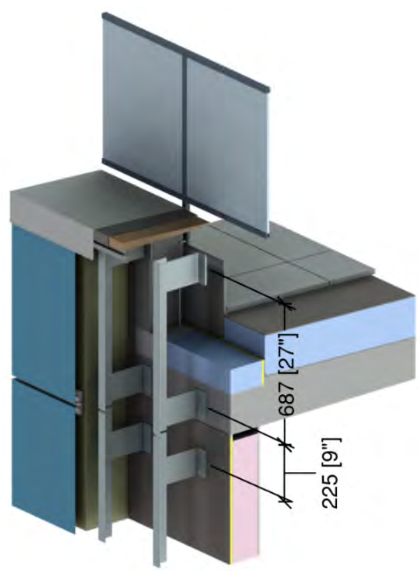
The thermal transmittance values presented in this chapter are based on BETB Guide methodology and linear transmittances are calculated based on interior and exterior dimensions.

DETAIL 1: WALL TO ROOF INTERFACE

The roof assembly is a protected membrane or inverted roof on a concrete deck with 200 mm (8 inches) or R-40 rigid foam insulation. The wall assembly is outlined at the beginning of this section.



The concrete parapet has a structural thermal break that allows 127 mm (5 inches) of rigid insulation to carry through to the wall insulation. Railing loads are transferred to the structure through the concrete parapet and thermal break modules with stainless steel reinforcing spaced at 1220 mm (4 feet) o.c. The aluminum bracket is located above the insulation so that the impact of the bracket is minimized.



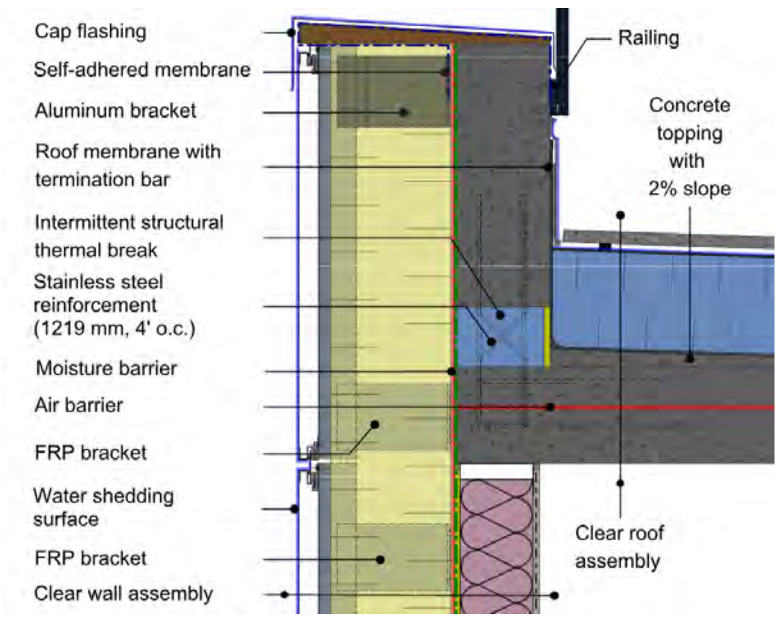


Table 5.4: Wall to Roof Interface Linear Transmittance

Scenario		$\Psi_{parapet}$ Btu/hr·ft·°F (W/mK)		Thermal Bridge Free? (Ψ< 0.01 W/mK)
		Inside Dimensions	Outside Dimensions	
Uninsulated stud cavity	Sloped deck	0.099 (0.171)	0.030 (0.051)	No
	With concrete topping	0.108 (0.187)	0.039 (0.067)	No
R-19 (3.35 RSI) insulation in stud cavity	Sloped deck	0.099 (0.171)	0.035 (0.061)	No
	With concrete topping	0.108 (0.186)	0.044 (0.076)	No

DETAIL 2: INTERMEDIATE FLOOR

The intermediate floor interface includes exterior insulation installed over a concrete floor slab edge with self-adhered membrane applied to the insulation for through wall flashing in lieu of metal flashing. The insulation at the slab edge should be rigid to adhere to and support the membrane. Movement is accommodated at the intermediate floor with double nested steel tracks, sliding point brackets and cladding, and the rails end at this location.

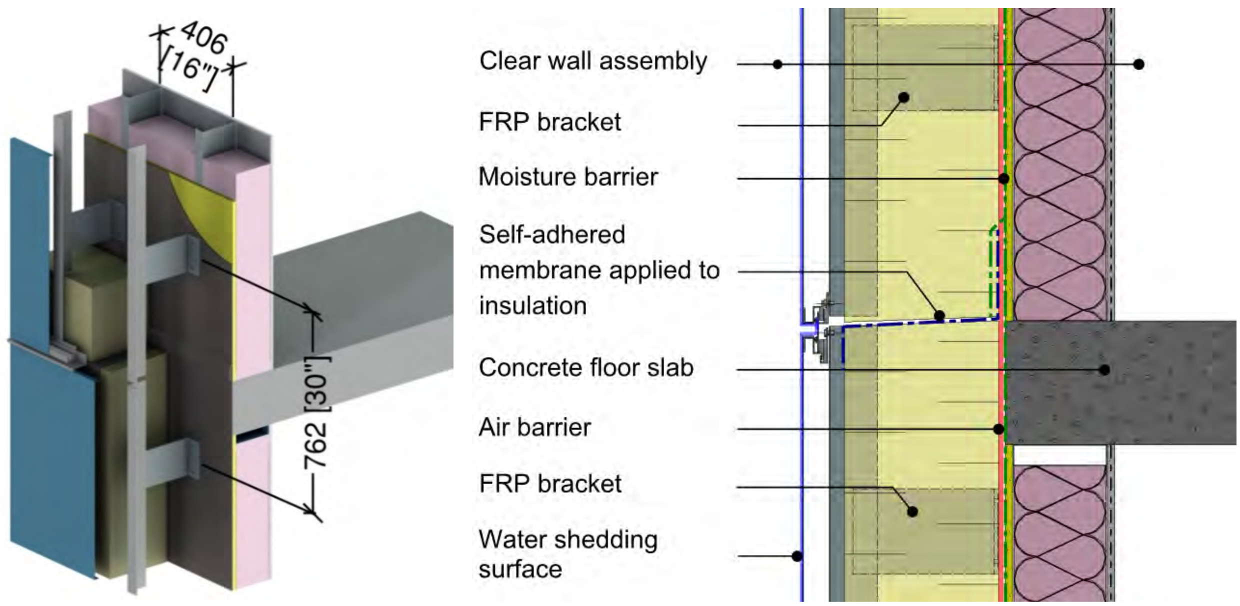


Table 5.5: Intermediate Floor Linear Transmittance

Scenario	Ψ_{floor} Btu/hr·ft·°F (W/mK)	Thermal Bridge Free? (Ψ< 0.01 W/mK)
Uninsulated stud cavity	0.002 (0.003)	Yes
R-19 (3.35 RSI) insulation in stud cavity	0.008 (0.015)	Close

DETAIL 3: AT-GRADE TO BELOW-GRADE PARKING GARAGE INTERFACE

The at-grade detail has rigid insulation that extends from the wall insulation to below-grade to connect insulation installed to the underside of a suspended floor separating the conditioned space from a below-grade parking garage. The floor is insulated with 250 mm (10 inches) or R-40 rigid insulation that is supported by hangers and protected by gypsum. The wall and floor insulation are connected by a thermal break. This detail requires the primary structural loads from the building to be transferred by other elements. A structural beam needs to be located near this detail so that the thermal break only supports the weight of the floor slab for the respective tributary area. Drainage at the base of the wall is provided by self-adhered membrane similar to the intermediate floors.

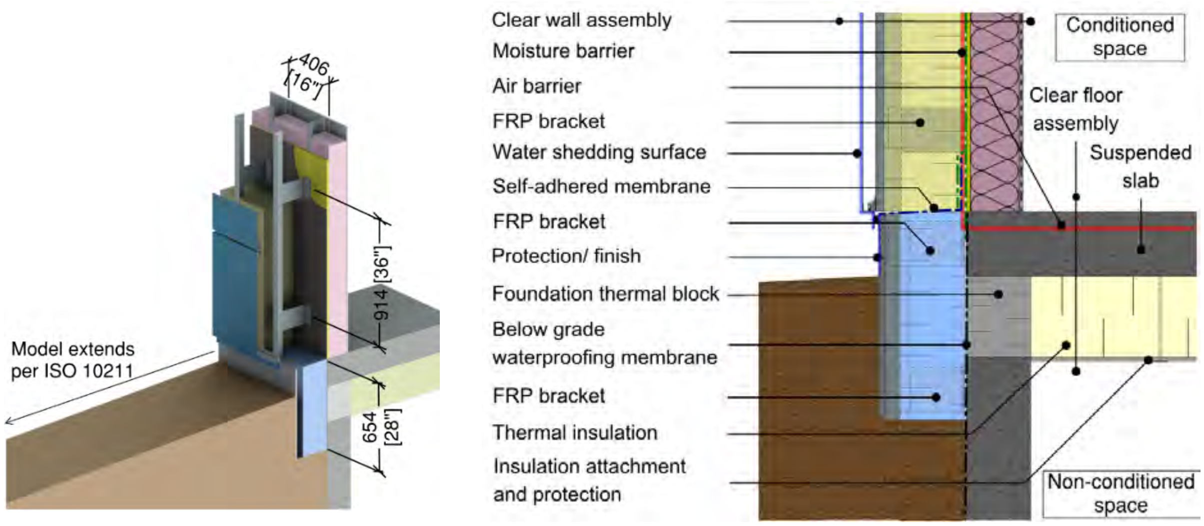


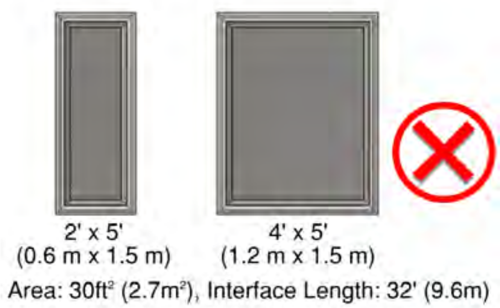
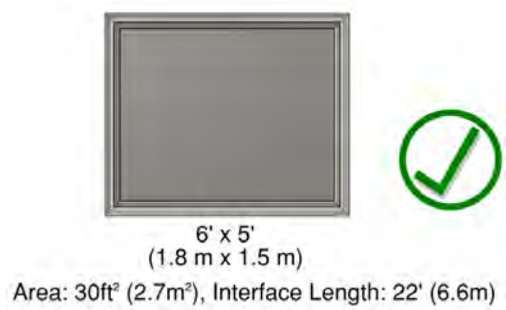
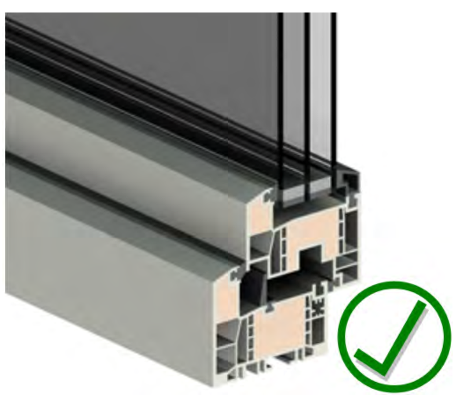
Table 5.6: At- Grade Transition to Parking Garage Linear Transmittance

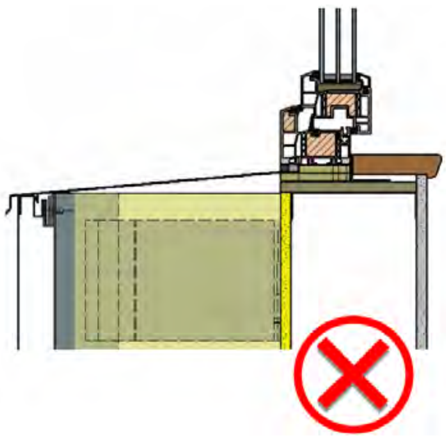
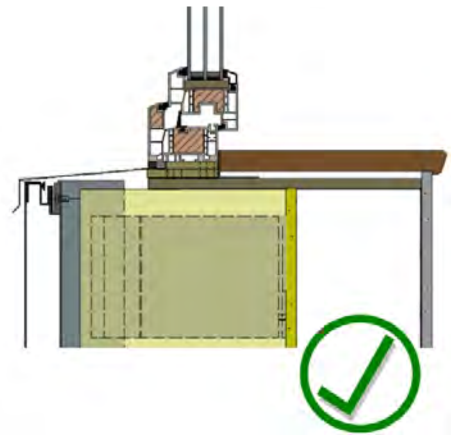
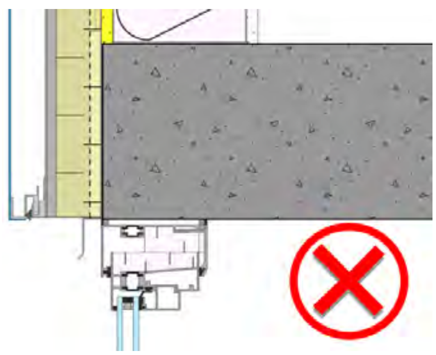
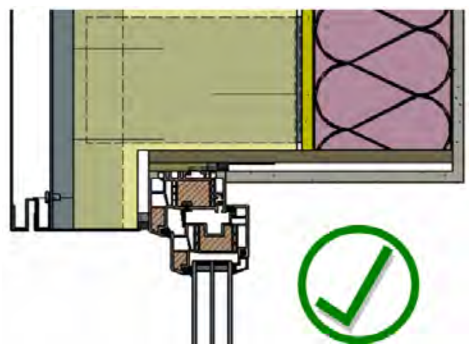
Scenario	$\Psi_{base\ of\ wall}$ Btu/hr·ft·°F (W/mK)		Thermal Bridge Free? (Ψ< 0.01 W/mK)
	Inside Dimensions	Outside Dimensions	
Uninsulated stud cavity	0.058 (0.101)	-0.009 (-0.016)	Yes, when evaluated with exterior dimensions
R-19 (3.35 RSI) insulation in stud cavity	0.059 (0.102)	-0.015 (-0.026)	Yes, when evaluated with exterior dimensions

DETAIL 4: WINDOW TO WALL INTERFACE

The window to wall interface is the most challenging detail to minimize thermal bridging and has the biggest impact for noncombustible residential buildings. Even small improvements can have a big impact when the quantity of this interface is factored into the overall thermal transmittance. PHI guidelines include guidance and principles to minimizing the impact of thermal bridging at window to wall interfaces. However, these principles deviate from current practice for noncombustible buildings and some design optimization is required to satisfy all the requirements, while mitigating thermal bridging.

Guidelines to minimizing thermal bridging at the window to wall interface follows.

<table>
<tr>
<td>Minimize the window perimeter and frame length by maximizing the size of glass per opening</td>
<td>
</td>
<td>
</td>
</tr>
<tr>
<td>Use glazing systems that have large thermal breaks and insulation in the glazing framed cavities</td>
<td></td>
<td></td>
</tr>
</table>

Place the window as close to the centre of insulation layer as feasible		
Over insulate the frames and minimize metal flashing and closures		

Additional support may be required at windows and doors to position over the exterior insulation for structural or fire protection purposes as shown in **Figure 5.8**. In this configuration, the wood at the sill may take the weight of the window but the structural loads are transferred to the steel studs at the jamb and the straps at the jamb and head that hold the window in place.

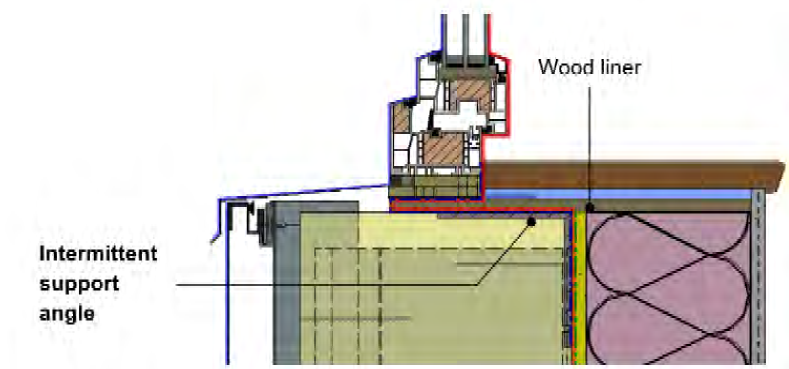
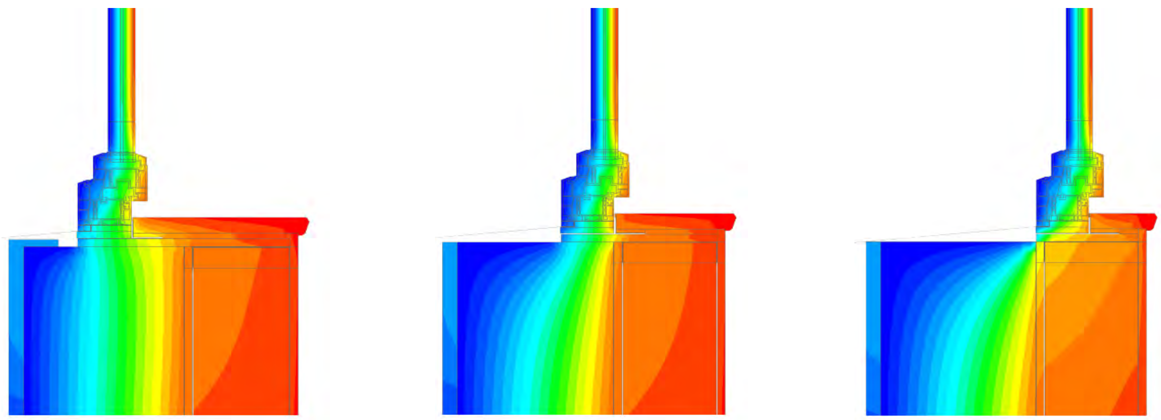


Figure 5.8: Support Angle below Window and Wood Liner

The window to wall interface presented in this chapter features a tilt and turn operable Passive House certified vinyl window with triple-glazing. The windows are positioned in the middle of the exterior insulation to minimize heat loss through thermal bridging as a base case scenario. The impact of window positioning is illustrated in **Figure 5.9**.



Window aligned with insulation, without support angle, air in stud cavity

$\Psi_{install}$: 0.062 W/mK (0.036 Btu/hr.ft·°F)

Window aligned with edge of insulation, without support angle, air in stud cavity

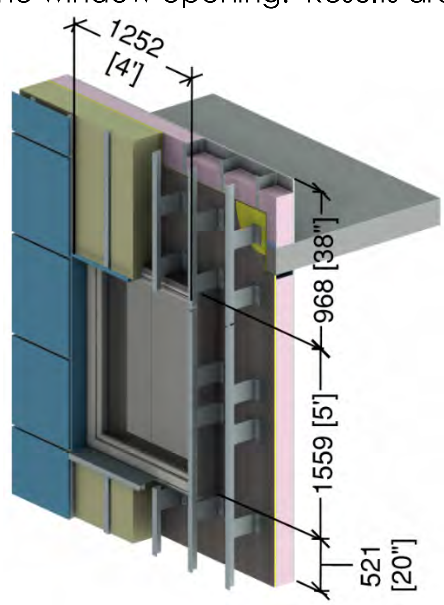
$\Psi_{install}$: 0.116 W/mK (0.067 Btu/hr·ft·°F)

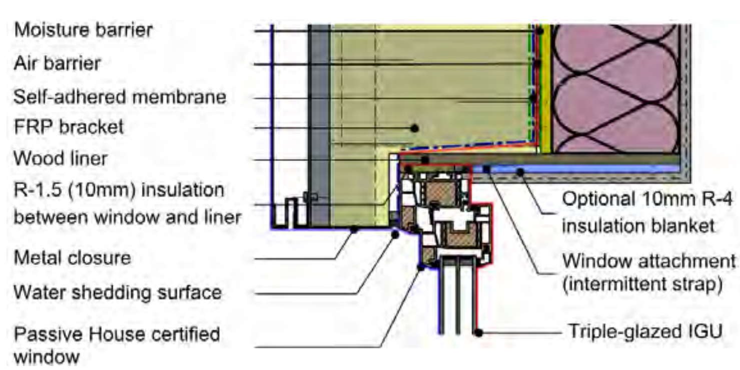
Window aligned with steel framing, air in stud cavity

$\Psi_{install}$: 0.164 W/mK (0.095 Btu/hr·ft·°F)

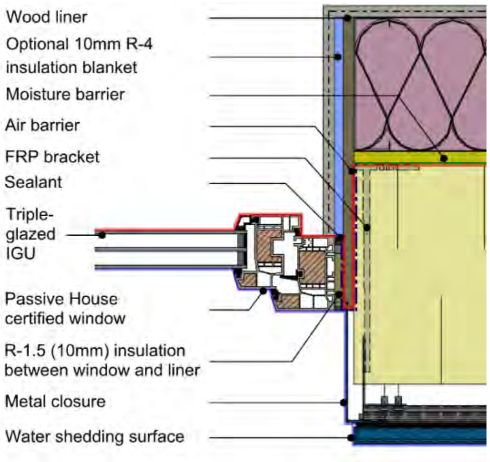
Figure 5.9: Impact of Window Positioning on Linear Transmittance

The following figures shows how the design requirements presented at the beginning of this chapter can be met and how to minimize thermal bridging as much as possible for the interface of glazing with a conductive cladding such as composite metal panels. For example, the window head is over insulated because drainage is not restricted, but the sill details have sloped metal flashing. Four scenarios were evaluated including with and without batt insulation in the stud cavity and with and without R-4 aerogel blanket around the window opening. Results are shown in **Table 5.7** and **Table 5.8**.

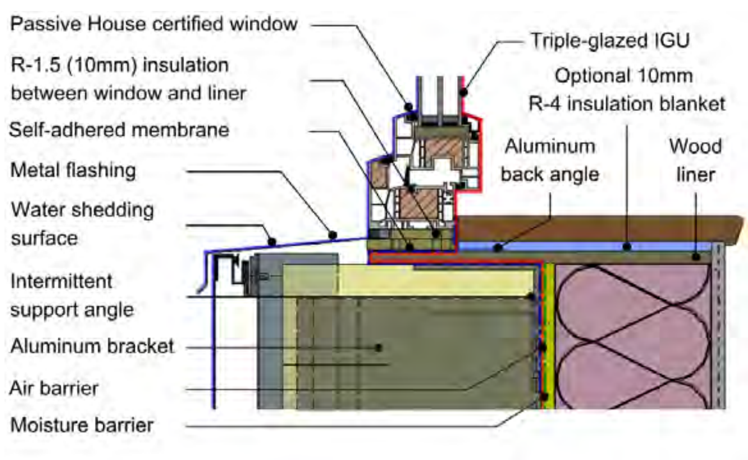




Head



Jamb



Sill

Table 5.7: Window to Wall Linear Transmittance with Uninsulated Stud Cavity

Scenario		Ψ Sill[1] Btu/hr·ft·°F (W/mK)	Ψ Jamb Btu/hr·ft·°F (W/mK)	Ψ Head Btu/hr·ft·°F (W/mK)	Ψ Total[2] Btu/hr·ft·°F (W/mK)	Thermal Bridge Free? (Ψ< 0.01 W/mK)
Sill Angle	R-4 Blanket					
Yes	No	0.048 (0.083)	0.050 (0.087)	0.020 (0.034)	0.014 (0.024)	No
	Yes	0.044 (0.075)	0.031 (0.053)	0.014 (0.024)	0.009 (0.016)	Close
No	No	0.036 (0.062)	0.050 (0.087)	0.020 (0.034)	0.011 (0.019)	No
	Yes	0.030 (0.052)	0.031 (0.053)	0.014 (0.024)	0.006 (0.010)	Yes

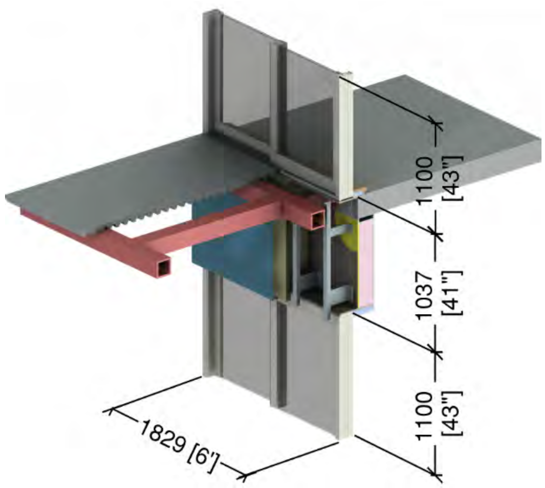
Table 5.8: Window to Wall Linear Transmittance with R-19 in Stud Cavity

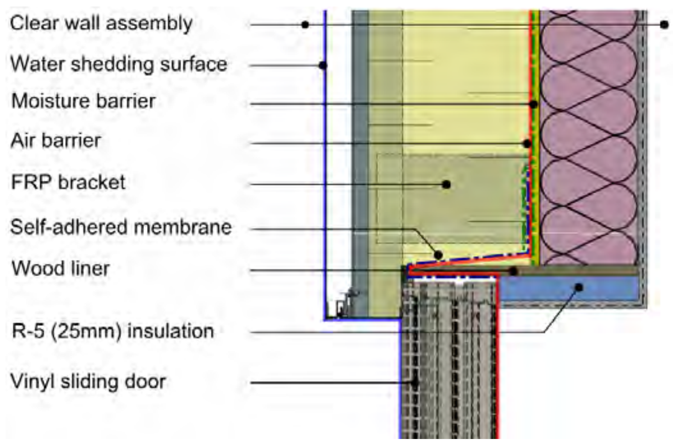
Scenario		Ψ Sill Btu/hr·ft·°F (W/mK)	Ψ Jamb Btu/hr·ft·°F (W/mK)	Ψ Head Btu/hr·ft·°F (W/mK)	Ψ Total Btu/hr·ft·°F (W/mK)	Thermal Bridge Free? (Ψ< 0.01 W/mK)
Sill Angle	R-4 Blanket					
Yes	No	0.057 (0.099)	0.063 (0.109)	0.027 (0.047)	0.026 (0.046)	No
	Yes	0.049 (0.084)	0.039 (0.067)	0.021 (0.036)	0.020 (0.035)	No
No	No	0.047 (0.081)	0.063 (0.109)	0.027 (0.047)	0.024 (0.041)	No
	Yes	0.040 (0.069)	0.039 (0.067)	0.021 (0.036)	0.018 (0.030)	No

[1] Transmittances do not include the impact of the aluminum brackets. The separate head, sill, and jamb transmittances were derived using the intermediate approach outlined in Chapter 2.
[2] Total linear transmittances are derived using the detailed approach outlined in Chapter 2.

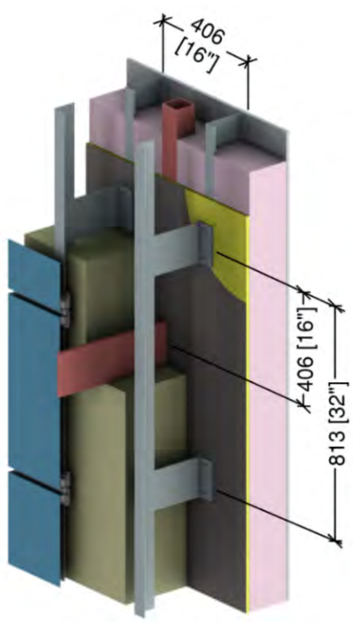
DETAIL 5: DOOR WITH INTERMITTENTLY ATTACHED BALCONY INTERFACE

The balcony detail is a steel balcony supported by an intermittent knife edge attachment bolted to the slab and tie back cables connected to the walls. This type of construction minimizes thermal bridging by reducing the amount of components penetrating through the insulation and permits the floor edge to be insulated. The vinyl sliding door is positioned in the middle of the exterior insulation similar to the window to wall interface.

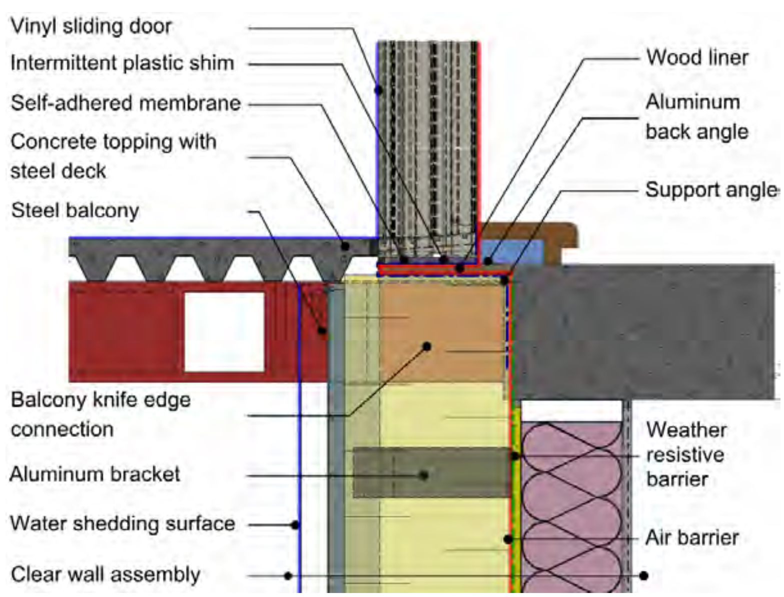




Door



Cable Support Connection



Balcony Door Sill

Table 5.9: Door with Intermittently Attached Balcony Thermal Transmittances

Scenario	Door Interface			Beam Connection to Floor	
	Ψdoor sill[1] Btu/hr·ft·°F (W/mK)	**Ψdoor head** Btu/hr·ft·°F (W/mK)	**Thermal Bridge Free?** (Ψ< 0.01 W/mK)	**χknife edge** Btu/hr·°F (W/K)	**Thermal Bridge Free?** (χ/A< 0.01 W/m²K)
Uninsulated Stud Cavity	0.024 (0.042)	0.044 (0.076)	No	0.048 (0.271)	No
R-19 (3.35 RSI) Insulation in stud cavity	0.035 (0.061)	0.041 (0.071)	No	0.046 (0.261)	No

Table 5.10: Cable Connection to Wall Thermal Transmittances

Scenario	**Ψcolumn**[1] Btu/hr·ft·°F (W/mK)	**Thermal Bridge Free?** (Ψ< 0.01 W/mK)	**χknife edge** Btu/hr·°F (W/K)	**Thermal Bridge Free?** (χ/A < 0.01 W/m²K)
Uninsulated Stud Cavity	0.000 (0.000)	Yes	0.026 (0.147)	No
R-19 (3.35 RSI) Insulation in stud cavity	0.001 (0.001)	Yes	0.012 (0.071)	No

[1] Linear transmittance values do not include the effect of the knife edge connection