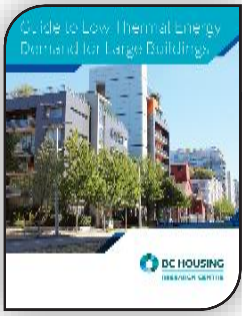
Guide to Low Thermal Energy Demand for Large Buildings

BC HOUSING
RESEARCH CENTRE

Acknowledgements

BC Housing gratefully acknowledges the invaluable support and funding contribution of Canada Mortgage and Housing Corporation (CMHC) and Natural Resources Canada (NRCan) through its Program of Energy Research and Development (PERD) in the production of this publication. This guide was prepared by Morrison Hershfield.



ABOUT THIS GUIDE

This publication was prepared by

Morrisonhershfield.com
April 2018

This guide aims to broaden the common understanding of how large buildings can meet higher levels of performance as required by Passive House, BC Energy Step Code, City of Vancouver Zero Emission Building Plan and City of Toronto Zero Emissions Building Framework. This guide has a focus on current Canadian code requirements, construction practice and tested systems.

Table of Contents

Table of Contents

Table of Contents

Table of Contents

Chapter 1

Overview

There is strong interest in Canada for the next generation of high performance energy standards – like Passive House or Net-Zero – to meet energy and emission goals. While the majority of Passive House and Net-Zero projects have been single family homes and low-rise buildings, there is momentum in industry to apply these standards to larger buildings. How to adapt these standards to large multi-unit residential buildings (MURBs) has not been widely studied nor are there many examples of completed buildings.

This guide aims to broaden the understanding of how high-rise residential buildings can meet the next generation of Net-Zero or Net-Zero ready standards that are applicable to Canadian climates and build upon current design requirements and construction practice in Canada. A new metric called **Low Thermal Energy Demand Intensity (TEDI)** is used in this document to discuss viable approaches to designing and constructing Net-Zero ready high-rise residential buildings. See the side bar for more explanation on the concept of TEDI that the next generation of energy codes and standards are adopting. Examples of how TEDI is being introduced in Canadian codes and standards follow later in this chapter.

Minimizing the impact of thermal bridging and ventilation heat recovery are critical to low TEDI buildings. Standard practice for high-rise residential buildings will continue to evolve to address both of these requirements. Moreover, standardization of thermal bridging calculations and testing for heat recovery ventilators (HRVs) in the context of Canadian high-rise residential buildings is not yet completed.

To help with the process of standardization and provide guidance to industry this document provides insight into:

- **Thermal Bridging Calculation Methodologies**, including the Building Envelope Thermal Bridging (BETB) Guide, ASHRAE-1365-RP, ISO 10211, ISO 14683 and Passive House Institute (PHI)
- **HRV Testing Protocols**, including PHI, the Home Ventilating Institute (HVI) and the Air-Conditioning, Heating and Refrigeration Institute (AHRI)

What is TEDI?

TEDI is a metric that represents the annual heating load per floor area of a building. This is the amount of heat needed to offset the heat loss through the building envelope and condition the ventilation air.

TEDI is derived from energy simulations. Any parameter that impacts the heating load is captured by TEDI, including exterior surface area, thermal transmittance of building envelope components, airtightness, solar radiation, internal gains, heat recovery and ventilation.

The TEDI concept has been applied by Passive House Institute and European jurisdictions to focus industry on minimizing heating load, dependence on large and complex mechanical systems, and increase occupant comfort in buildings.

- **TEDI in the Context of Whole Building Energy**, including a discussion on software implications
- **Design and Construction** requirements of low TEDI high-rise residential buildings applicable to Canadian climates and practice

Introduction of TEDI to Canadian Codes and Standards

Building codes are evolving to meet multiple objectives, including reducing energy consumption, reducing greenhouse gas emissions, increasing resiliency and passive survivability. The City of Toronto, City of Vancouver and the Province of British Columbia have included TEDI into policy, along with other metrics to meet one or all of these objectives. These forward thinking policy directives are Toronto's "Zero Emissions Building Framework", City of Vancouver's "Zero Emission Building Plan" and the Province of British Columbia through the "BC Energy Step Code".

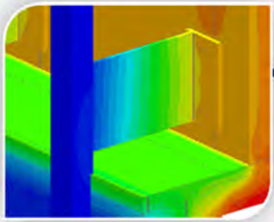
TEDI has attracted interest from policy makers in an effort to promote better building envelopes without being overly prescriptive on requirements. Under current energy codes like ASHRAE 90.1 (ASHRAE, 2007) or NECB (NRC, 2011), there is substantial room to trade-off mechanical and electrical efficiencies with lower performing envelopes. A metric like TEDI elevates the importance of the building envelope, which is viewed as one of the more robust energy saving measures in a building. Unlike mechanical and electrical systems, the building envelope is typically not prone to user or operator error, thereby more likely to realize its projected energy savings. Moreover, many components of the building envelope typically last the service life of the building, making its initial make-up and performance critical for the building's long-term performance. Finally, efficient building envelopes can provide additional benefits to energy and greenhouse gas emissions reductions, as shown in the "Zero Emissions Building Framework" (City of Toronto, 2017). The analysis done to support this policy showed how improved building envelopes can perform substantially better in power outages and maintain livable space temperatures, even under extended cold periods.

WELCOME TO CANADA, TEDI

BC Energy Step Code and City of Toronto Zero Emissions Building Framework requirements for TEDI for high-rise multi-unit residential buildings is outlined below. Both of these policies include additional requirements not covered in this document.

A **TEDI of 15 kWh/m²/year** is a net-zero ready or near net-zero building. The stated intent of some jurisdictions is that this level of performance will be met by all new buildings by 2032.

BC Energy Step Code		Toronto Zero Building Emissions Framework	
Step	TEDI Requirement (kWh/m²/year)	Tier	TEDI Requirement (kWh/m²/year)
1	None	1	70
2	45	2	50
3	30	3	30
4	15	4	15



Chapter 2

Methodologies for Determining Thermal Transmittance

Introduction

A key to meeting low thermal energy demand intensity (TEDI) for buildings is a holistic assessment of thermal bridging for thermal transmittance calculations. An awareness of how thermal transmittance is determined by various approaches is helpful when utilizing and comparing results from various sources. This section summarizes and contrasts methodologies for quantifying thermal transmittance for the opaque building envelope elements with reference to the following guideline documents and standards:

- **ISO Standard 10211**: 2007 (E) Thermal Bridges in building construction – Heat flows and surface temperature – *Detailed calculations* – Provides procedures for thermal transmittance calculations by numerical methods.
- **ISO Standard 14683**: 2007 (E) Thermal Bridges in building construction – Linear thermal transmittance – *Simplified methods and default values* – Provides simplified methods and default thermal transmittance values.
- **Building Envelope Thermal Bridging (BETB) Guide** and **ASHRAE-1365-RP** – Provides procedures for calculating thermal transmittances that combines North American conventions with the ISO 10211 methodology and some refinements to more accurately simulate steel-framed assemblies. The BETB Guide provides a catalogue of 3D construction details applicable to North America.
- **Passive House Institute Standard (PHI)** – References ISO 10211. Transmittance values are available on the PHI website for certified products that are mostly European.

The BETB Guide, ISO 14683, and PHI draw significantly from ISO 10211 in calculating thermal transmittance. Nevertheless, variations in the calculation procedures between these documents result in some differences in thermal transmittance. This chapter provides clarity as to what differences in methodology are insignificant and which variables that are significant to thermal transmittance. This information will provide insight for comparing details from different methodologies and sources objectively.

GLAZING THERMAL TRANSMITTANCE

The focus of this chapter is on thermal transmittance of ***opaque elements***. There are also differences between methodologies for ***transparent glazing assemblies*** (i.e. **ISO 10077** vs **NFRC-100**), which are not specifically addressed in this document. These differences are important to recognize when determining TEDI and peak heating loads within the whole building context. Some differences in calculating glazing performance is discussed in this chapter in the context of thermal bridging. For more information on comparisons between common window standards, see the *2014 International Window Standards Final Report from RDH and BC Housing.*

Comparions of Calculation Methodologies

Many of the differences in the ISO 10211, PHI or the BETB Guide methodologies result in minor impacts on thermal transmittance. A more significant source of variation of thermal transmittances is the level of detail accounted for in the model, which is not explicitly different between these documents.

ISO 14683 provides insight in Section 5 to the expected accuracy from various sources of thermal transmittance data, ranging from details that are directly simulated to default catalogues. Examples of how these ranges apply to the BETB Guide and calculation approaches outlined in the ASHRAE Handbook of Fundamentals is provided to offer insight to how the accuracy expectations apply in practice.

±5%	**Numerical simulations of specific details**. This accuracy is expected when using results in Appendix B of the **BETB Guide** for project details that exactly match the scenario and assumptions outlined in Appendix A.
±5-20%	**Generic details from a catalogue.** The range accounts for catalogue details that do not exactly match the detail being considered. This range of accuracy is expected when using the visual summary at the beginning of Appendix B in the **BETB Guide**.
±5-20%	**Manual calculations.** Examples are the parallel path or isothermal planes methods detailed in the **ASHRAE Handbook of Fundamentals**. Accuracy depends on the type of assembly.
+50%	**Default values**. An example is **ISO 14683** or the Tables in Section 4.2 of the **BETB Guide**. These represent simplified assemblies and/or an expected range based on a catalogue of details. Use these values when the results of more detailed calculations is not available and ballpark estimates are acceptable.

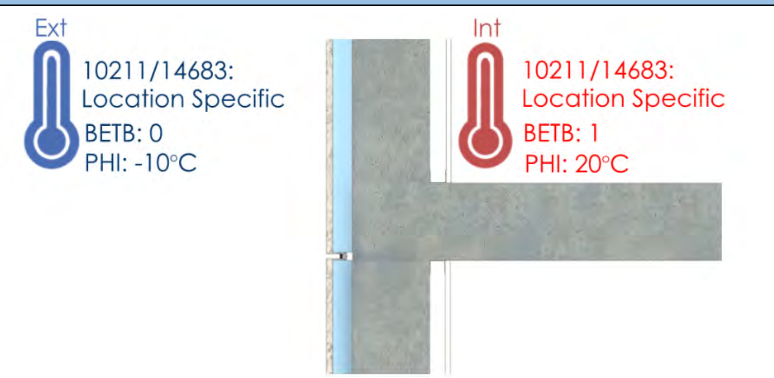
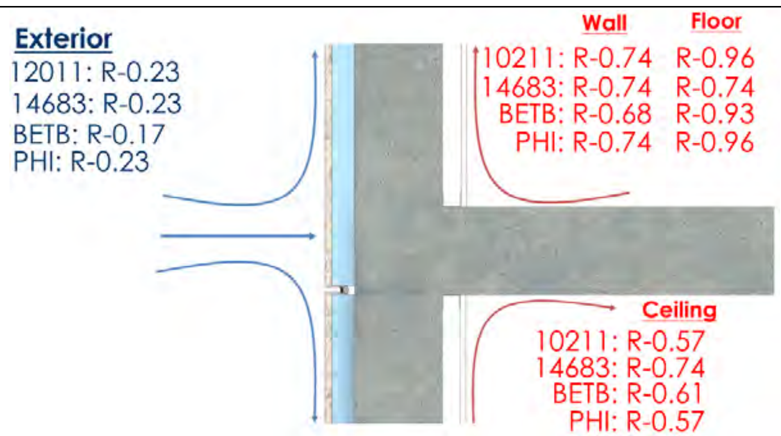
Table 2.1 provides a high level overview of the procedures and parameters that can impact thermal transmittance calculations. The procedure and parameters are categorized either as minor differences or potentially significant differences for the various methodologies discussed in this chapter.

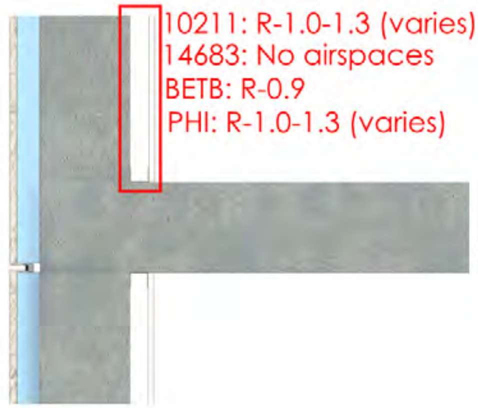
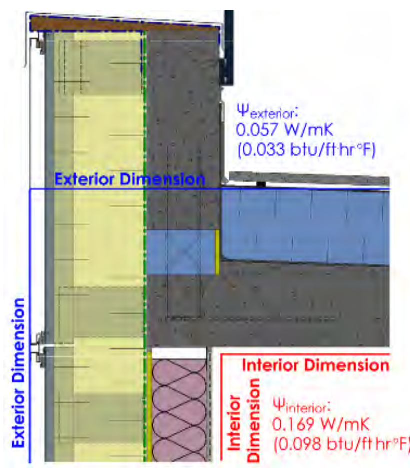
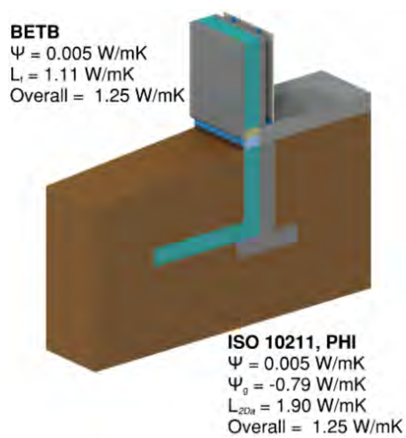
Table 2.1: Overview of Procedures and Parameters that Impact Thermal Transmittance

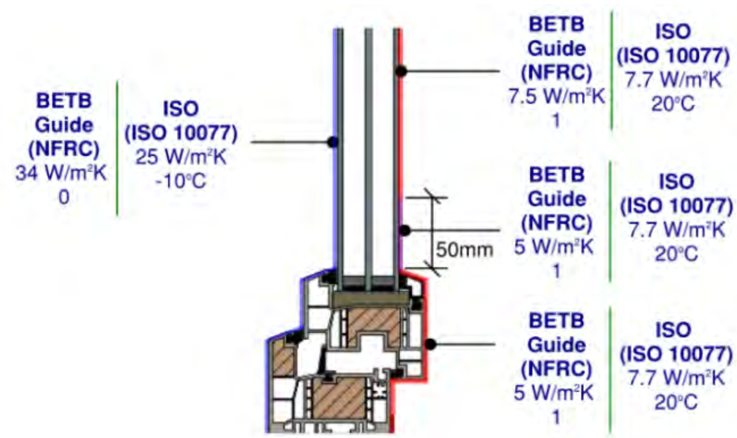
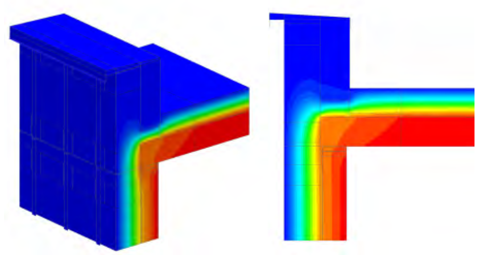
Minor Differences	Potential Significant Differences
Boundary conditions and airspaces	Window to wall interface
Interior vs exterior dimensions	Two-dimensional (2D) and geometry simplifications
Cut-off planes	Contact resistance
Slab-on-grade heat loss	Designs and details to minimize thermal bridging

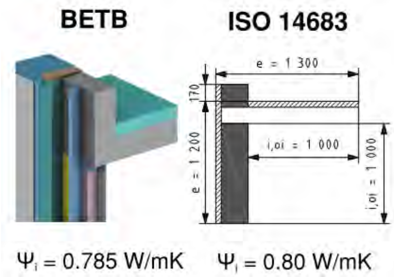
Table 2.2 provides more detail to how much and why there are differences in the thermal transmittance calculations. More detailed discussion and examples follow these tables. These sections provide insight to when thermal transmittance values from various sources are appropriate and comparable.

Table 2.2: Description Procedures and Parameters that Impact Thermal Transmittance

<table>
<tr><th colspan="2">Procedure or Parameter</th><th>Impact on Thermal Transmittance</th></tr>
<tr><td>Boundary Temperature</td><td>
</td><td>No impact for steady-state calculations when using constant material properties.</td></tr>
<tr><td>Air Films</td><td>
</td><td>Less than 2% impact on clear field U-value and linear transmittances for insulated assemblies > R-5 (RSI-0.88).</td></tr>
</table>

	Procedure or Parameter	Impact on Thermal Transmittance
Air Spaces		Less than 2% impact on clear field U-value and linear transmittances for insulated assemblies > R-5 (RSI-0.88).
Interior vs Exterior Dimension Values	**10211** allows for either approach **14683** provides values for interior, exterior and midplane dimensions **BETB Guide** provides values for interior dimensions **PHI** uses exterior dimensions 	No impact when following consistent conventions. If mismatched, thermal transmittance may be different depending on the construction and the quantity of the interface. Order of magnitude of 15% variation for low/mid-rise and 5% for high-rise construction is expected in the overall thermal transmittance.
Slab-on-Grade Values	**ISO 10211, PHI** splits the thermal transmittance through the floor slab (L_{2Da}) and perimeter footing thermal transmittance (Ψ_g) as two separate values. The at-grade interface between the footing and wall is presented as a separate linear transmittance (Ψ).  **ISO 14683** provides Ψ values for the at-grade interface only. **BETB Guide** provides combined heat loss of the slab and footing as one value (L_f) and provides a separate (Ψ) for the at-grade interface.	No difference, except how values are presented and inputted into calculations.

	Procedure or Parameter	Impact on Thermal Transmittance
Cut-off Planes	**ISO 10211** indicates cut-off planes for modelling to be at symmetry planes between repeating thermal bridges, or at least 1000 mm away from each thermal bridge. **ISO 14683, BETB Guide** and **PHI** generally conform to the rules in **ISO 10211**.	No impact between standards. Modelling closer cut off planes will result in differences for assemblies with strong lateral heat flow.
Glazing Transitions		Differences in glazing air film coefficients may lead to small differences to the window to wall interface Ψ-value. The impact may add up to be a significant factor in buildings with a large quantity of interfaces as outlined in Chapter 4.
2D or 3D Analysis	**ISO 10211** provides guidelines for 2D and 3D analysis. **ISO 14683** has Ψ-values from 2D analysis.  **BETB Guide** has thermal transmittance values from 3D analysis. **PHI** allows for use of both 2D and 3D models, but values are typically determined using 2D analysis in practice.	Impacts vary greatly depending on detail or system. Details with numerous lateral heat flow paths can result in ±60% variation in values between 2D and 3D models.
Geometric Simplifications	**ISO 10211** outlines acceptable simplifications for geometry and equivalent thermal conductivities. However, the standard states that a geometrical model with no simplifications shall have precedence. **BETB Guide** does not contain significant simplifications to the geometry and materials, since the thermal transmittance values were derived using 3D analysis.	Impacts vary depending on the level of simplification.

	Procedure or Parameter	Impact on Thermal Transmittance
Default Values	Default linear transmittance values from **ISO 14383** represent worst-case scenarios determined using 2D numerical analysis in accordance with **ISO 10211**.  These values cautiously overestimate the impact of thermal bridging and are intended to be used when more precise values are not available. **ISO 14383** default values are generally higher than the values found in the **BETB Guide**, except for assemblies with complex heat flow paths.	Significant differences in values, up to +20%, due to simplification. Can be used as initial conservative baseline if nothing else available. Use default values with caution for systems with metal framing.
Surface Temperatures	Surface temperatures in **ISO 10211**, **PHI** are expressed as temperature factors, f_{RSI} and in **BETB Guide** as temperature indices, T_i. **ISO 10211**, **PHI** allow for temperatures to be determined by 2D or 3D modelling. **BETB Guide** values are primarily from 3D analysis.	Differences are related to boundary conditions and film coefficients. The differences between 2D and 3D analysis may have significant impact for evaluating the risk of condensation.
Contact Resistance	The **BETB Guide** is based on research from **ASHRAE 1365-RP**. This work included validation to the reference cases in Annex A of **ISO 10211:2007 (E)** to demonstrate accuracy for well-defined problems. Simulations were also compared to the guarded hot-box measurements as part of **ASHRAE 1365-RP** and subsequent studies on cladding attachments and spandrels. The comparisons to lab measurements highlights the impact of natural phenomena, such as contact resistance, that is not explicitly covered by **ISO** and **PHI**.	Contact resistance, such as between steel studs and the sheathing, can result in a difference in thermal resistance in the order of magnitude of 5-20% depending on the assembly components.
Designs and Details to Minimize Thermal Bridging	The biggest impact to thermal transmittance is how thermal bridging is mitigated at interface details. Many of the assemblies covered by the **BETB Guide** are representative of conventional practice. Many details have linear transmittances greater than 0.5 W/m K. Mitigated scenarios are considered below 0.2 W/m K. **Passive House** has much higher expectations with regard to minimizing thermal bridging with a goal of 0.01 W/m K as outlined in the introduction to Chapter 5. For low TEDI buildings, mitigating thermal bridging to 0.1 W/m k is mediocre and exploring gains by improved details is a worthwhile exercise.	Examples of low TEDI details is provided in Chapter 5.

Boundary Conditions and Air Spaces

BOUNDARY TEMPERATURES

Thermal transmittance is calculated for a temperature difference across the assembly for all the methodologies. ISO 10211 does not dictate specific temperatures to use. PHI analysis is done at -10°C exterior and 20°C interior conditions. The BETB Guide uses a non-dimensional unit temperature.

ISO 10211, PHI and the BETB Guide generally use constant thermal properties and steady-state analysis. This allows the thermal transmittance values of highly insulated building envelope assemblies to be not climate or temperature specific. The temperature dependency of materials, such as found for some insulations, is generally not part of thermal transmittance calculations. Consequently, the simulated boundary temperatures do not have an impact on thermal transmittance (U-values, Ψ-values and χ-values).

BOUNDARY AIR FILMS

Air movement over the exterior and interior surfaces is a complex interaction of conduction, convection and radiation heat flow. All the methodologies use standardized film coefficients or heat transfer coefficients to estimate the heat flow at the boundary layer at the interior and exterior surface.

For PHI, air films for opaque surfaces are taken from ISO 6946. The values are RSI-0.04 for the exterior surfaces, based on a 5 m/s wind speed, and range from RSI-0.10 to 0.17 for interior surfaces depending on the surface orientation. For the BETB Guide, air films for opaque surfaces are taken from the ASHRAE Handbook of Fundamentals. The values are RSI-0.03, based on a 6.7 m/s wind speed, and range from RSI-0.10 to 0.16 for the interior surfaces.

These small differences in the air film resistances are minor (at *most* an R-0.2, RSI-0.03 difference) when compared to the rest of the insulated assembly resistance. Air film resistances have a greater impact on glazing assemblies due to the comparatively low overall thermal resistance of glazing. More discussion follows later in this chapter.

AIR SPACES

For ISO 10211, PHI and BETB Guide methodologies, still air spaces within the assembly are treated in two different approaches, depending on the size and location.

For planar airspaces, such as in uninsulated stud cavities, all the standards treat air spaces as a constant material by combining the effects of radiation, convection and conduction in the cavity into an equivalent thermal conductivity. The equivalent conductivity depends on cavity depth, direction of heat flow and temperature difference. ISO 10211 and PHI reference ISO 6946 which contains design values for air spaces that are irrespective of temperature difference, which result in an airspace resistance of up to R-1.3 (RSI-0.23). The BETB Guide references similar tabulated values for airspaces within the ASHRAE Handbook of Fundamentals, but are assumed to be R-0.9 (RSI-0.16) as a conservative approach so that the thermal transmittance is not dependent on temperature. This allows results to be applied to many climates without sacrificing accuracy.

For small ventilated or unventilated airspaces, like those within glazing frames, ISO 10211, PHI and the BETB Guide all follow ISO 10077-2. The conductivity of air is calculated based on correlations using the depth, width and emissivity across the airspace.

COMBINED IMPACT OF BOUNDARY CONDITIONS AND AIR SPACES

For highly *insulated assemblies*, air boundary conditions and air spaces contribute only a small portion to the overall thermal resistance in comparison to the rest of the assembly components. The variation in boundary temperatures, heat transfer coefficients (air films) and equivalent conductivities of air gaps, results in minor impacts in the clear field U-value and even smaller differences in linear transmittance of interface details. This is illustrated for an example intermediate floor in **Figure 2.1**.

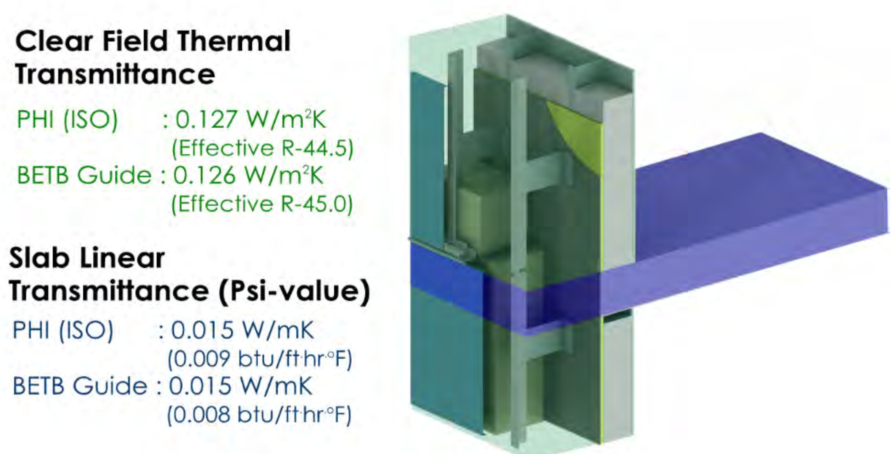


Figure 2.1: Example Differences in Thermal Transmittance due to Varying Boundary Conditions at an Intermediate Concrete Floor

Interior versus Exterior Dimensions

For details where the clear field assemblies meet at angles and have different interior and exterior surface areas, like corners and wall to roof interfaces, linear transmittances may appear to be significantly different from various sources. The difference can be simply due to differences in reporting conventions as shown in **Figure 2.2**.

The additional heat flow from a geometric thermal bridge, like corners, can be accounted for by adding the interface linear transmittance to the clear field transmittance using either the exterior or interior dimensions.

Linear transmittance based on exterior dimensions can be negative since the clear field area is over accounted for. Conversely, linear transmittance based on interior dimensions are positive and larger because less clear field area is not over estimated in the calculation. The overall heat flow will be the same either way, as long as the take-off for the clear field area matches the corresponding linear transmittance reporting convention.

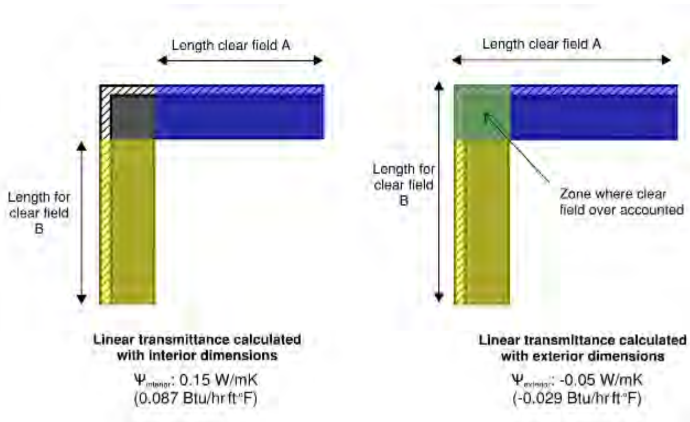
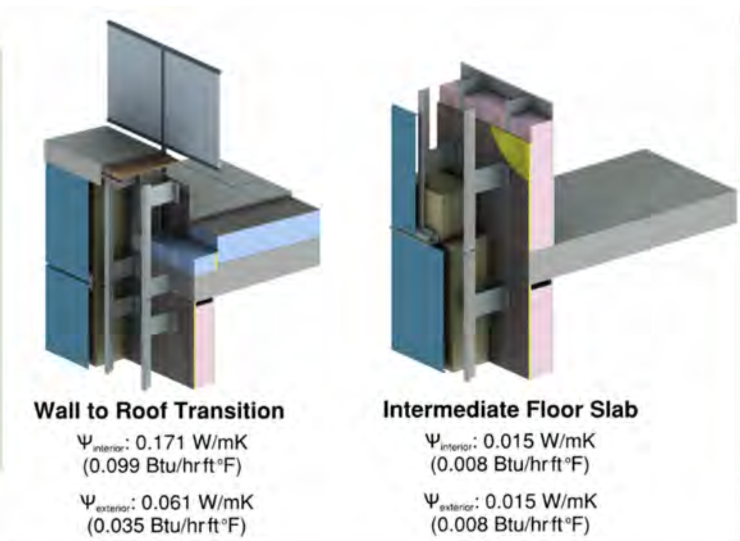


Figure 2.2: Interior versus Exterior Dimensions for Thermal Transmittance Calculations

ISO 10211, PHI and the BETB Guide allow for any of these approaches; however, the values presented in the BETB Guide catalogue are based on interior dimensions. This allows for the BETB database to have a single transmittance value and will lead to conservative estimates if conventions are mismatched in practice.



Single Plane Assemblies

The interior/exterior convention has no impact on the linear transmittance value for assemblies in a single plane, like the intermediate floor shown to the left. This is due to the fact that there is no difference in areas or lengths between inside and outside.

Slab-on-Grade Thermal Transmittance

Determination of thermal transmittance for slab-on-grade and foundation are the same in the BETB Guide and PHI as both follow ISO 10211. However, the methodologies deviate in how the values are reported. In all these methodologies, the thermal bridging elements from the footing are evaluated by steady-state calculations according to ISO 10211.

In ISO 10211 the incremental thermal transmittance between the above grade wall and footing is presented as a linear transmittance, Ψ. The thermal transmittance of the foundation below-grade is presented as separate thermal values for the slab L_{2Da} and footing Ψ_g as shown in **Figure 2.3**.

The BETB Guide provides the slab-on-grade to wall interface as a linear transmittance. The slab-on-grade and footing transmittance are included in a linear value, L_f. This perimeter transmittance is consistent with how energy simulation software model ground heat flow.

See **Figure 2.3** for how ground heat flow is determined for ISO 10211 and BETB Guide. Regardless of reporting conventions, the overall thermal transmittance of slab-on-grade are the same.

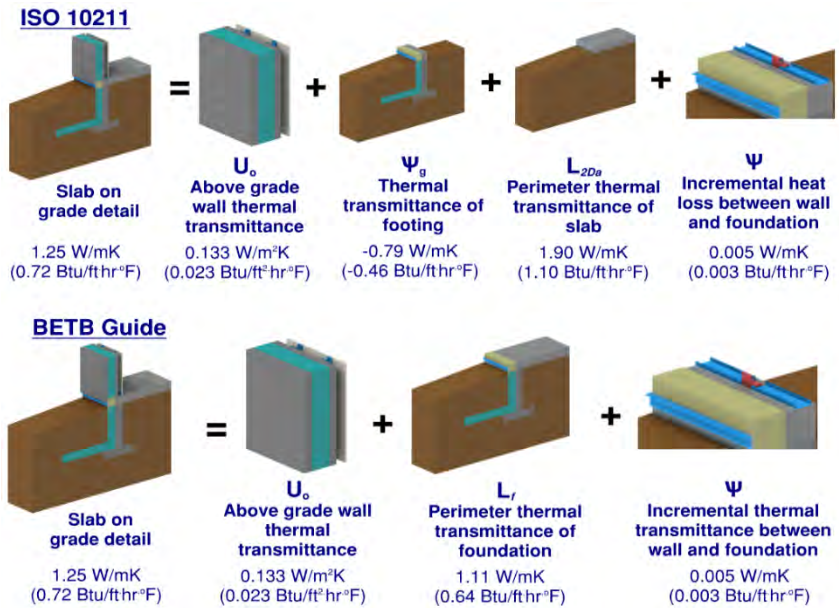
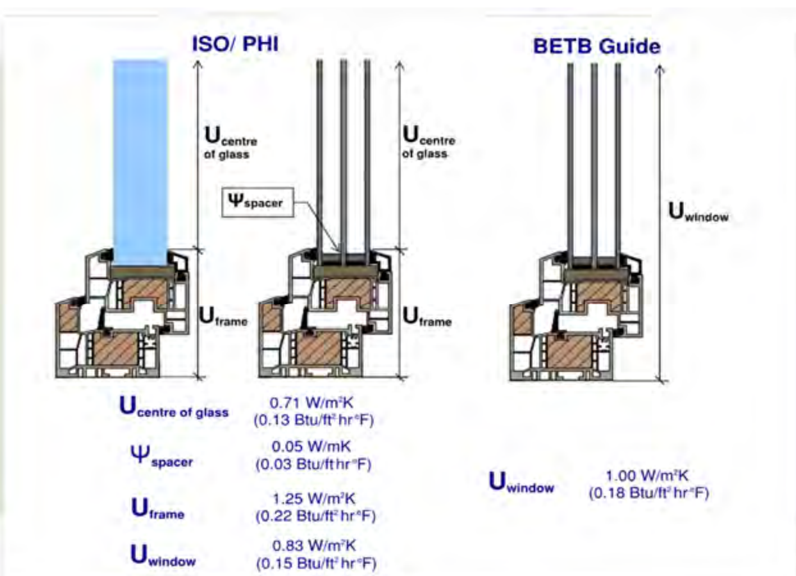


Figure 2.3: Approaches to Ground Heat Flow

Window to Wall Interfaces

The BETB Guide utilizes NFRC-100 assumptions for calculating glazing performance as part of calculating window to wall linear transmittances. To calculate $\Psi_{install}$, the entire window is modelled with the glass, spacer and frame to determine U_w. The same procedures as ISO 10211 are then followed to determine the interface Ψ-value.

PHI uses ISO 10077 to determine the glazing thermal transmittance and ISO 10211 to calculate the linear transmittance of the install detail. The glazing U-value (U_w) is calculated by combining the centre of glass U-value with the spacer and frame transmittances. Using ISO 10211, the glazing assembly is then subtracted from the window transition detail, along with the adjacent clear wall, to get the $\Psi_{install}$ of the transition.



Frame and Spacer

In **PHI**, the window transmittance is calculated using multiple sections to determine Ψ_{spacer} and U_{frame}. These values are calculated by comparing the window section with the spacer to an idealized window with a thermal block of the same U-value as the centre-of-glass. The **BETB Guide** does not determine these values separately and instead simulates the window section together.

Figure 2.4 outlines the boundary conditions and air films. PHI and ISO 10211 use the air films from ISO 10077 and the BETB Guide uses air films from NFRC-100. While not significant to the opaque elements, differences in boundary conditions and air cavities can have an impact on glazing thermal transmittance. Studies such as the International Window Standards study (RDH Building Science, 2014), have shown that triple glazing and low conductivity frames may have product U-values that differ by as much as 25% between PHI (ISO 10077) and NFRC-100. This can lead to some confusion if product U-values are compared side by side that are based on different methodologies.

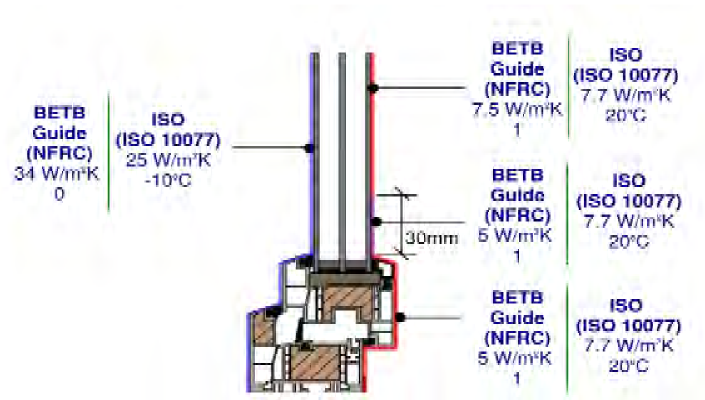
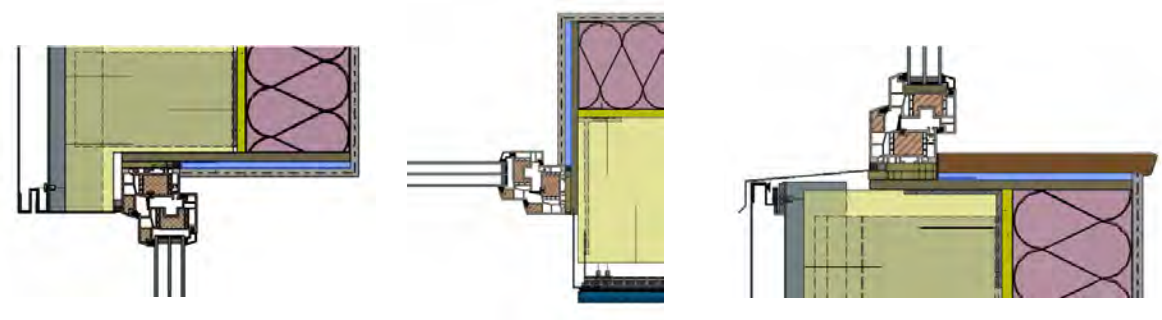


Figure 2.4: Glazing Air Films for PHI and BETB

Differences in assumed air film coefficients for glazing has a small impact on the linear transmittance ($\Psi_{install}$) of the window to wall interface. This small difference can add up to be significant over a large interface length for all the windows in a building. An example is presented for a vinyl window installed in a steel-framed wall for the head, jamb and sill sections below in **Table 2.3**.

Table 2.3: Comparison of Window to Wall Interface Transmittances



Head **Jamb** **Sill**

Approach	Linear Transmittance W/m K (BTU/ft hr°F)		
	Head	Jamb	Sill
BETB Guide	0.047 (0.027)	0.109 (0.063)	0.099 (0.057)
ISO 10077/10211	0.038 (0.022)	0.096 (0.055)	0.088 (0.051)

2D versus 3D Analysis

Differences between two-dimensional (2D) and three-dimensional (3D) analysis can be significant to thermal transmittance and surface temperature. This section outlines the impact on thermal transmittance and the following section outlines the impact on surface temperatures. The relative difference is dependent on how the wall, roof, or floor construction is simplified in a 2D model and if heat flow paths exist in multi-directions.

The approach to 2D analysis depends on the detail that is being evaluated and the following factors:

- **Type** of thermal bridge - linear or discrete points,
- If there are **multiple** thermal bridges, and
- If the thermal bridges are in **multi-directions**.

For example, a wall assembly with intermittent brackets and steel studs has two types of thermal bridges in one direction. A parapet with a concrete roof deck with the same wall assembly has additional thermal bridges (difference in interior and exterior surface areas and the concrete roof deck) and has heat flow in multi-directions.

DISCRETE THERMAL BRIDGES

An example of how discrete thermal bridges are included in 2D calculations follows for an intermittent cladding support bracket and a steel-framed wall. The intermittent cladding attachment system is shown in **Figure 2.5**.

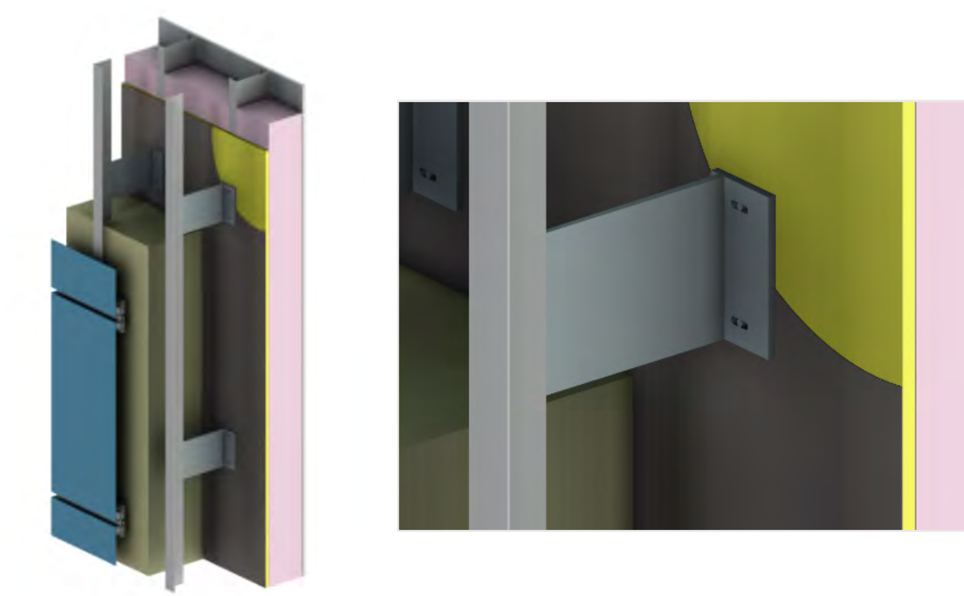
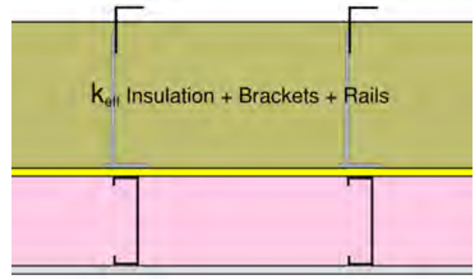
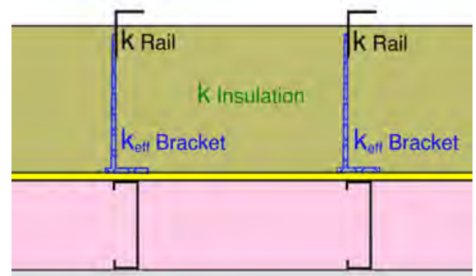
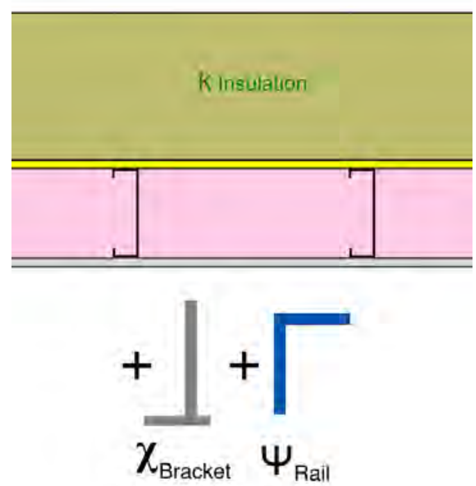


Figure 2.5: Example Bracket and Rail Cladding Attachment System

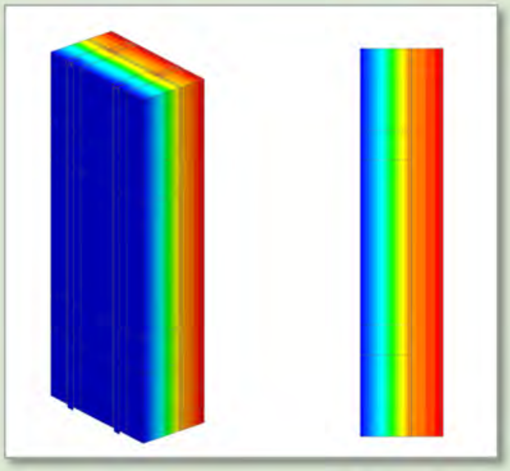
A single 2D section cannot fully represent the heat flow through the assembly for the intermittent bracket. The studs and rails are continuous and can be represented in a horizontal section. The brackets can be incorporated into 2D simulations as outlined by the following three approaches.

Approach 1: Averaged By Volume	An average conductivity is calculated for the exterior insulation and brackets based on the percent volume of the brackets, rails and insulation. A single homogenous block with an averaged conductivity is included in the 2D model. The steel studs are directly modelled.	
Approach 2: Effective Conductivity for Intermittent Components	An effective conductivity is determined for the intermittent brackets, based on area weighting of the bracket to insulation in the 3rd dimension. The rest of the section and components (rail, studs, insulation) are directly modelled with corresponding thermal conductivities.	
Approach 3: Linear and Point Transmittances	Linear and point transmittances are found for the rail and bracket using 2D sections. These linear and point transmittances are combined with the wall thermal transmittance with no brackets or rails in the exterior layer.	

Three-dimensional analysis allows components to be modelled directly where the actual heat flow paths are simulated. **Table 2.4** shows the differences in calculated thermal transmittances for the example assembly when the brackets are made of fibre-reinforced plastic (FRP) and aluminum.

Table 2.4: Comparison of Thermal Transmittance using 3D Analysis and Various 2D Approaches for an Exterior Insulated Steel Stud Assembly with Intermittent Brackets

Bracket Material	Approach	Thermal Transmittance W/m²K (BTU/ft²hr°F)	Effective R-value m²K/W (ft²hr°F/BTU)	Percent Difference Compared to 3D Analysis
	1D Nominal	**0.090 (0.016)**	**11.1 (62.8)**	**-**
FRP	**3D Analysis**	**0.118 (0.021)**	**8.5 (48.3)**	**-**
	2D – Approach 1	0.267 (0.047)	3.8 (21.3)	-56%
	2D – Approach 2	0.117 (0.021)	8.6 (48.6)	1%
	2D – Approach 3	0.116 (0.020)	8.7 (49.1)	2%
Aluminum	**3D Analysis**	**0.216 (0.038)**	**4.6 (26.3)**	**-**
	2D – Approach 1	0.390 (0.069)	2.6 (14.6)	-45%
	2D – Approach 2	0.368 (0.065)	2.7 (15.4)	-41%
	2D – Approach 3	0.159 (0.028)	6.3 (35.8)	36%



REPEATING THERMAL ANOMALIES

ISO 10211 provides a framework to allow repeating thermal bridges to be accounted for separately by linear or point transmittances or to be combined into the clear field U-value. **ISO 14683** does not address assemblies with repeating thermal bridges. The **BETB Guide** incorporates repeating thermal bridges directly into the clear wall U-value. **PHI** allows for both approaches; however, linear and point transmittances of components are often calculated to assess if the component is thermal bridge free (see Chapter 5 for more discussion).

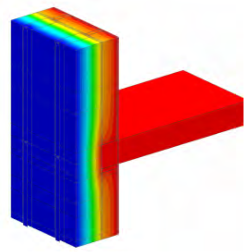
Caution is required when assessing point transmittances using theoretical spacing of components for systems with a combination of brackets and rails. The spacing of components varies significantly on projects and closely spaced components can influence the transmittance values of repeating thermal bridges.

LINEAR THERMAL BRIDGES AND INTERFACE DETAILS

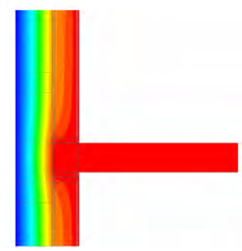
Calculating linear thermal transmittances using 2D analysis requires repeating thermal bridges parallel to the cross section of the interface detail to be simplified or ignored. For example, the cladding attachments and studs are parallel to the modelled cross section for the intermediate floor. This approach misses the impact of any lateral heat flow paths, such as heat flow from the floor, through the studs and out the cladding attachments. Comparisons between 2D and 3D analysis are shown in **Table 2.5**.

Table 2.5: Comparison of 3D and 2D Analysis for an Intermediate Floor and Parapet

Intermediate Floor

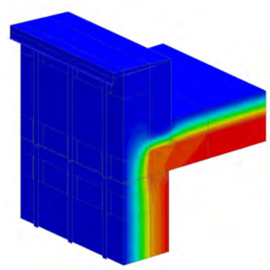


3D Analysis

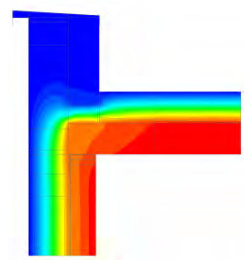


Simplified 2D Analysis

Parapet



3D Analysis



Simplified 2D Analysis

Detail	3D Analysis W/mK ((btu/ft·hr·°F)	Simplified 2D Analysis W/mK ((btu/ft·hr·°F)
Intermediate Floor	0.015 (0.008)	0.011 (0.006)
Parapet	0.061 (0.035)	0.051 (0.030)

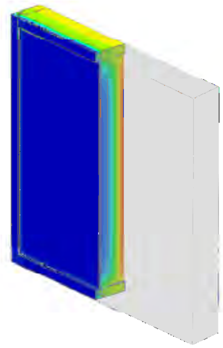
OPAQUE GLAZING SPANDRELS SYSTEMS

Insulated opaque glazing spandrels for curtain wall or window wall are examples where there is significant lateral heat flow through aluminum framing and metal back-pans that are not fully accounted for by 2D analysis. Insulated curtain wall spandrel assemblies evaluated in 2D according to NFRC-100 can overestimate the thermal performance by 20-33% compared to what is measured in hotbox tests (Norris et al, 2015).

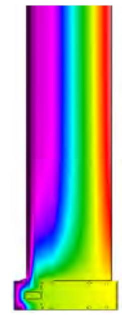
The NFRC-100 2D modelling approach can be modified to better account for edges, distances and other unique aspects of spandrel systems. However, modified NFRC-100 2D analysis still does not fully capture the complex heat flow paths of spandrel panels and can result in thermal transmittances 16 to 25% lower than measured by a guarded hotbox. A 3D spandrel model can directly capture the lateral heat flow and can provide results within 5% of measured guarded hotbox values. **Table 2.6** shows the results from one scenario of evaluated scenarios from the referenced paper.

Table 2.6: Comparison of 2D and 3D Analysis to Hotbox Measurements for a Highly Insulated Curtain Wall Spandrel

Hotbox Lab Measurement



3D Analysis



2D Analysis

Approach	Thermal Transmittance W/m^2K (BTU/ft^2hr^oF)	Effective R-value m^2K/W (ft^2hr^oF/BTU)	Percent Difference Compared to Hotbox Measurement
Hotbox Measurement	**0.87 (0.153)**	**1.2 (6.5)**	**-**
3D Analysis	0.87 (0.153)	1.2 (6.5)	0%
2D NFRC-100	0.63 (0.111)	1.6 (9.0)	32%
2D NFRC Modified	0.68 (0.120)	1.5 (8.3)	24%

SURFACE TEMPERATURES

Surface temperatures can assist in determining condensation risk and thermal comfort. The method in determining surface temperatures are similar in ISO 10211, PHI and the BETB Guide. Surface temperatures are expressed as temperature indices in the BETB Guide and temperature factors, f_{RSI} in ISO 10211 and PHI. Both values are ratios of the surface temperature relative to the interior and exterior temperatures. Differences in surface temperatures arise due to different assumptions for air films. For highly insulated assemblies, the difference in surface temperatures are minor. However, there is a much greater impact on surface temperatures for lower resistance assemblies, such as glazing, since air films account for a greater portion of the total thermal resistance.

Table 2.7 shows an example where the difference in surface temperatures (exterior temperature of -10°C and an interior temperature of 20°C) at the coldest location of a window to wall interface at the head-jamb corner. The temperature locations were taken at the edge of glass, 50 mm (2 inch) away from the sight edge. At this condition the framing is 7.4°C using assumptions outlined by PHI and 8.8°C using the film coefficients in the BETB Guide. This difference may seem minor, but may be significant for evaluating condensation risk.

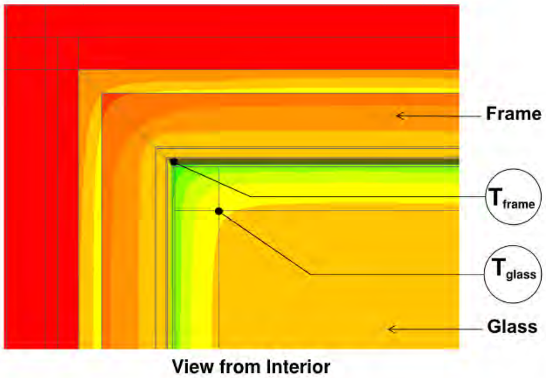


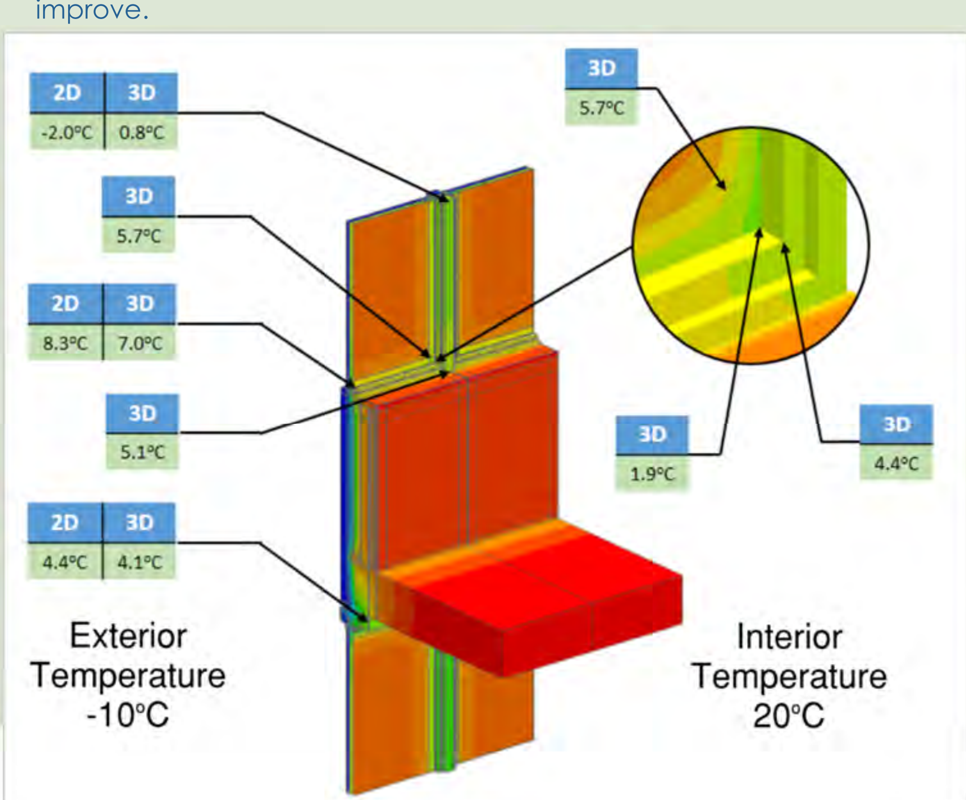
Table 2.7: Glazing Surface Temperatures for an Exterior Temperature of -10°C and Interior Temperature of 20°C

Location	BETB Guide		PHI and ISO Standards	
	Temp. Index	Surface Temp. (°C)	Temp. Factor	Surface Temp. (°C)
Glass	0.80	13.9	0.74	12.2
Frame	0.63	8.8	0.58	7.4

Surface temperatures evaluated following ISO 10211 air films are typically lower than temperatures from the BETB Guide and ASHRAE due to the different assumed air films.

Condensation Risk for Unitized Glazing Systems

Surface temperatures determined by 2D analysis can be significantly different than 3D analysis. 2D analysis calculates average temperatures at best, but the coldest temperature is what counts for evaluating the risk of condensation. All the necessary assumptions for 2D analysis can overshadow the required resolution to evaluate condensation risk. 3D analysis captures lateral heat flow and will often show different temperatures compared to 2D analysis. 3D analysis better reflects reality and has the advantage of being able to identify precise components to target and improve.



This comparison between 2D and 3D analysis for a window wall system shows how the vertical frames are colder for the 2D analysis but the horizontal frames are colder for the 3D analysis.

Detailed versus Simplified Geometry

Assumptions of how geometry is idealized in thermal models results in varying impacts on linear transmittance from minor to significant, depending on the complexity of the interface. An example of a complex window to wall interface as shown in **Figure 2.6** is outlined in this section where the differences between a simplified, intermediate, and detailed approach are significant. Examples of simple geometry without significant differences are outlined in the final section.

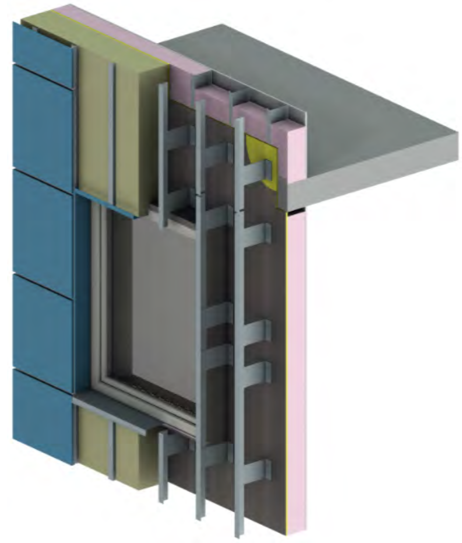


Figure 2.6: Window to Wall Interface

SIMPLIFIED APPROACH

With the simplified approach the head, sill, and jamb linear transmittances are calculated based on idealized geometry for a section modeled without studs and brackets as shown in **Figure 2.7**. An example of the simplified section is shown below. The simplified approach is frequently used when evaluating thermal bridging at window to wall interfaces with 2D finite element modelling programs such as THERM.

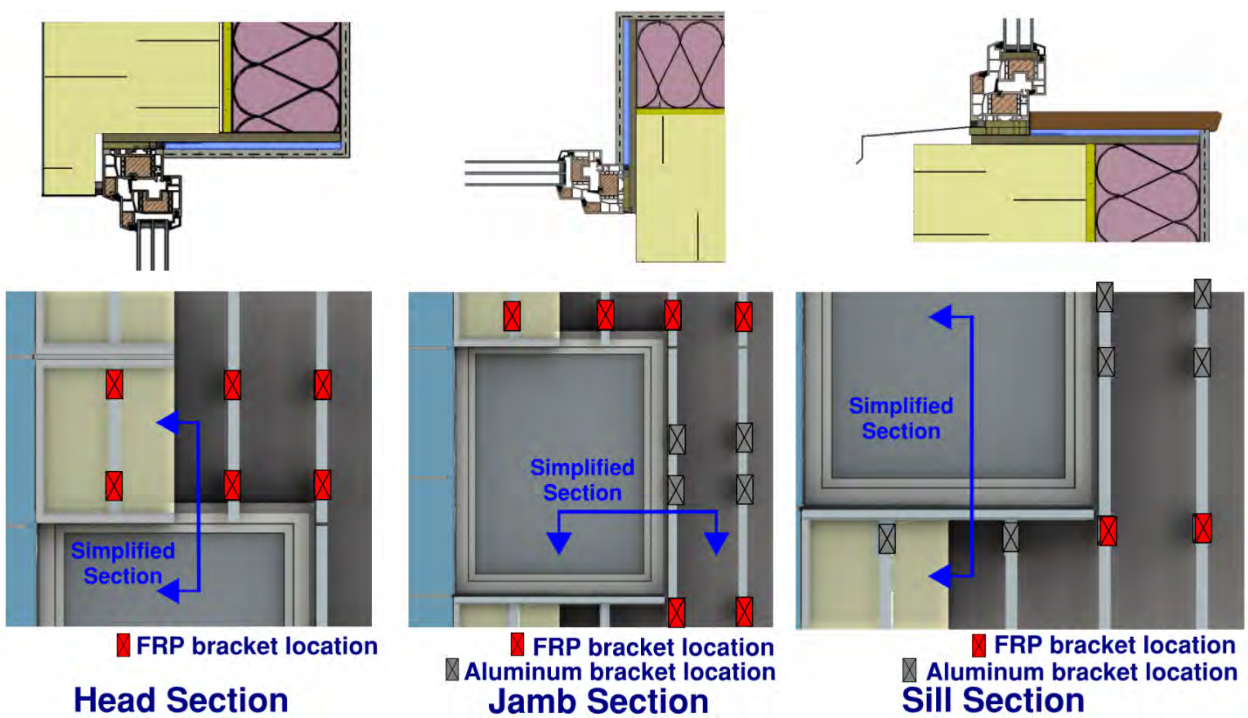


Figure 2.7: Modelled Sections Window to Wall Interfaces for the Simplified Approach

INTERMEDIATE APPROACH

Similar to the simplified approach, the head, sill and jamb linear transmittances are calculated using idealized geometry. However, the modelled sections now include the studs and brackets at the uniform spacing. For example, the width of the head and sill modelled sections are 406 mm (16 inches) wide based on the spacing of the steel studs and 457 mm (18 inches) high based on the 914 mm (36 inch) vertical spacing of the brackets. **Figure 2.8** shows these assumptions for the example window.

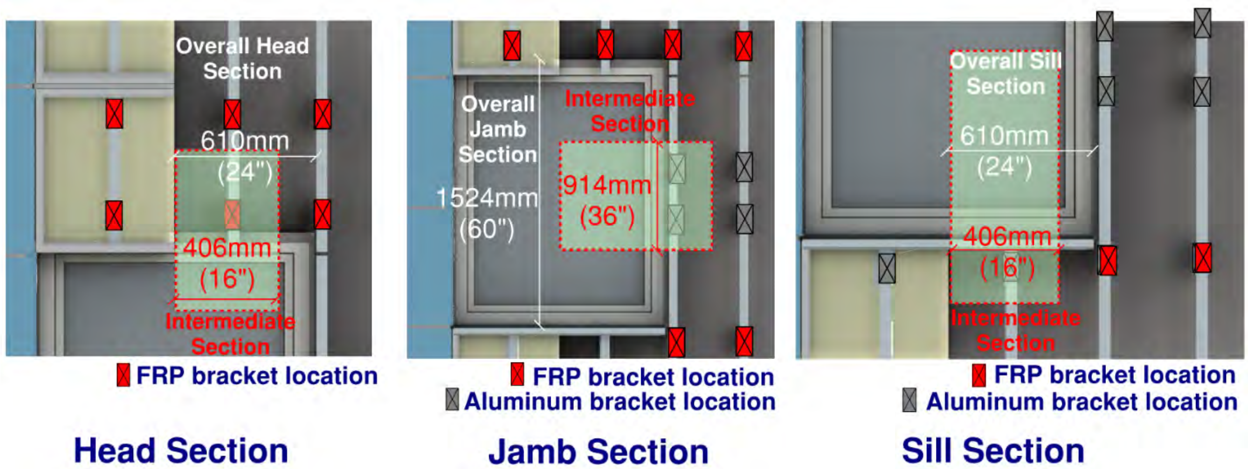


Figure 2.8: Modelled Sections Window to Wall Interfaces for the Intermediate Approach

The complication is that the impact of the studs and brackets can be overestimated once applied to the overall window to wall interface. The example window is 1219 mm (48 inches) wide and 1524 mm (60 inches) high. Essentially an extra stud and bracket is factored into the calculation when the head and sill linear transmittance are applied to a 1219 mm (48 inch) interface length. Similarly the impacts of the brackets are overestimated at the jamb when applied to a 1524 mm (60 inch) interface length for the jamb.

DETAILED APPROACH

The window to wall interface linear transmittance is determined using a 3D model of a specific geometry and window size. The drawback of this approach is that the window to wall linear transmittance is averaged over the entire interface, including the head, sill and jamb.

The intent of separating the head, sill and jamb linear transmittances is to allow the individual transmittances to be applied to any window size when there are significant differences between the details of the head, sill and/or jamb.

Table 2.8 summarizes the difference between the simplified, intermediate and detailed approaches for the steel-framed wall shown in **Figure 2.6.** An interior insulated poured-in-place concrete wall with insulation uninterrupted by metal framing is included for comparison using data from detail 6.3.11 of the BETB Guide (Version 1.2, 2016). The difference between all three approaches is significant for the steel-framed wall with complex framing, but minor for the concrete wall because there is not significant thermal bridges through the insulation layer at the window to wall interface.

Table 2.8: Window to Wall Linear Transmittance for Detailed and Simplified Approaches

Assembly and Approach		Linear Transmittance W/m K (BTU/ft hr°F)			
		Head	Jamb	Sill	Entire Interface
Steel-Framed	Simplified	0.039 (0.022)	0.044 (0.025)	0.024 (0.014)	0.038 (0.022)
	Intermediate	0.047 (0.027)	0.109 (0.063)	0.081 (0.047)	0.087 (0.050)
	Detailed	N/A	N/A	N/A	0.041 (0.024)
Concrete	Simplified	0.139 (0.080)	0.088 (0.051)	-0.040 (-0.023)	0.067 (0.039)
	Intermediate	Does not apply because there is no multidirectional framing			
	Detailed	N/A	N/A	N/A	0.066 (0.038)

When are 2D Simplifications Adequate?

Default linear transmittance values from ISO 14383 are intended to represent worst-case scenarios determined by 2D numerical modelling in accordance with ISO 10211. In general the ISO 14383 default values are higher than the values found in the BETB Guide. However, there are cases where 3D values contained in the BETB Guide are higher than the default values for assemblies with strong lateral heat flow paths and discrete thermal bridges, such as is the case with steel studs and cladding sub-framing.

The scenarios that the ISO 14383 default values are good approximations are for concrete structures with single insulation layers, simple interface details and thermal bridges that can be captured by a single section. Examples where ISO 14383 default values closely match the BETB Guide details are illustrated in **Figure 2.9**.

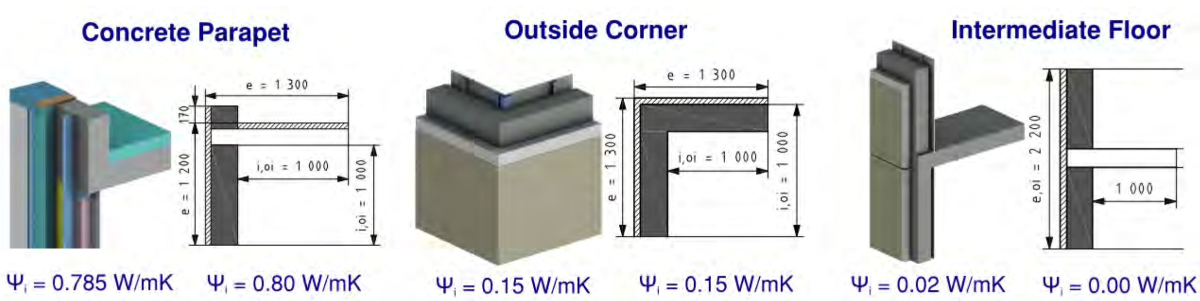
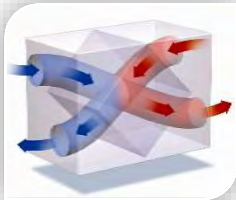


Figure 2.9: Comparison of Interior Transmittance Values (Ψi) Between BETB Guide 3D Analysis and ISO 14683 Default Values



Chapter 3

HEAT RECOVERY VENTILATORS

Introduction

All buildings must be ventilated as required by the applicable building code. There are many ways in which a multi-unit residential building (MURB) can be ventilated, but for buildings attempting to achieve low thermal energy demand intensity (TEDI), heat recovery on ventilation air is essential. For MURBs, this is often through individual suite energy or heat recovery ventilators (ERV/HRV), however, central or floor by floor ventilation systems with heat recovery are also possible. HRVs are self-contained ventilation systems designed to provide outdoor air to spaces, but also to temper that air via heat exchanger, which transfers heat from outgoing exhaust air to the incoming outdoor air. Figure 3.1 shows a diagram of a typical HRV. Energy recovery ventilators (ERVs) are similar, but they also recover latent energy from exhaust air, as well as managing humidity.

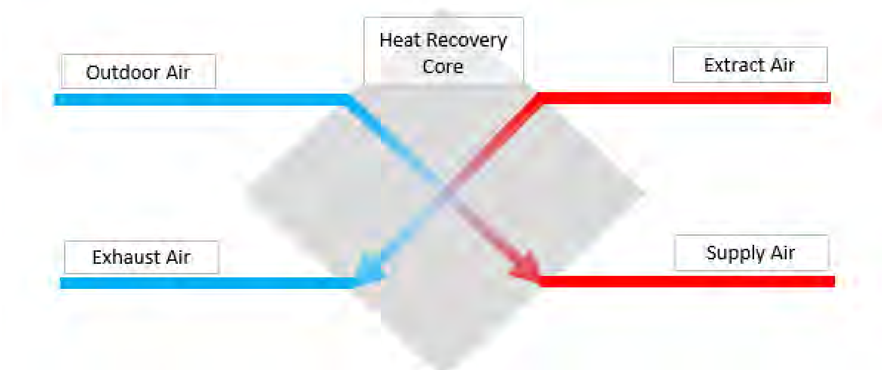


Figure 3.1: Typical HRV Schematic

HRVs directly reduce a suite or building's overall heating energy demand due to the tempering of incoming air. They also consume energy due to the fans (typically two), which are built-in and serve as drivers of supply and exhaust flows. Additional energy consumption by HRVs includes the potential requirement for preheat coils to prevent frost from building up within the unit. Preheat may be required when outdoor conditions are below the manufacturer's recommended operating limits of the unit. However, the overall net effect is a reduction in energy consumption because the savings in heating energy is typically significantly higher than the losses due to fans and auxiliary coils.

This section provides a brief overview of HRV rating methods and direction on how to properly represent HRVs in whole building energy modelling software depending on its rating method and software capabilities, with the goal of representing their benefit as accurately as possible.

Overview of Standards

The selection of an HRV for a design requires understanding of the requirements of the project as well as various key characteristics of the units under consideration. Various standards and certifications have developed out of a need to be able to compare HRVs in a fair way. There are various certifications and testing methodologies available, but the following are the main standards referenced in North America:

- ANSI/AHRI Standard 1060-2014: Performance Rating of Air-to-Air Exchangers for Energy Recovery Ventilation Equipment
    - AHRI is typically used for commercial units with flows from 50 to 5,000 cfm.
    - This standard can be used to rate stand-alone cores such as heat pipes or self-contained units like HRVs.
- CAN-CSA C439-2014: Standard Laboratory Methods of Test for Rating the Performance of Heat/Energy Recovery Ventilators
    - The CSA standard is the main rating methodology in North America serving as a basis for both EnergyStar and the HVI rating systems.
    - This standard can be applied to packaged units only, but the standard applies to units of any size.
- Home Ventilation Institute (HVI) Publication 920: Product Performance Certification Procedure Including Verification and Challenge
    - Uses CSA C439 as a basis for its methodology.
    - Applies to packaged products intended for residential occupancy only.
- EnergyStar
    - Uses CSA C439 as a basis for its methodology.
    - Applies to packaged units up to 500 cfm.
    - Introduces some additional requirements such as minimum efficiency and fan power limits.
- Passive House
    - Proprietary methodology developed for use in the Passive House program.
    - Includes additional requirements such as minimum efficiency, fan power limits, supply air temperature limits and bypass requirements.
    - Metrics measure drop-off in air temperature leaving the unit, instead of uplift in air temperature leaving the unit. All of the other standards use uplift.

KEY METRICS

When comparing the standards, it is important to understand that there are differences in terminology for the key metrics involved. The terms *efficiency* and *effectiveness* are used throughout these standards. Both are an attempt to measure the *useful* heat transfer provided by the HRV as a fraction of the theoretical maximum energy that can be extracted. The higher the efficiency, the more energy is recovered and used to temper incoming air. The differences arise in what is included in the theoretical maximum energy that can be extracted and what is considered useful heat. Table 3.1 summarizes the differences between how the terms are used in each standard. HVI's Sensible Recovery Efficiency (SRE) and Passive House's efficiency are the metrics most applicable to energy modelling and are referenced later in this chapter.

Table 3.1: Summary and Comparison of Key Metrics

Metric	HVI/CSA	PH	AHRI
Theoretical Energy Available	Difference in temperature between air extracted from space and incoming outdoor air.		
Effectiveness	Includes air leakage, cross contamination and fan power. (Apparent Sensible Recovery Effectiveness: ASRE)	n/a	Includes air leakage, cross contamination and fan power. Fan power is not accounted for in stand-alone cores.
Net Effectiveness	n/a	n/a	Removes effects of cross contamination, but still includes fans, if present.
Effectiveness (Low Temperature Rating)	Includes air leakage, cross contamination, fan power and defrost/bypass effects.	n/a	n/a
Efficiency	Removes effects of air leakage, cross contamination, defrost and supply fan power. (Sensible Recovery Efficiency: SRE)	Includes air leakage, cross contamination and fan power.	n/a

The metrics are derived from measurements taken at particular temperatures and flows. It is important to use the metric measured at the flow closest to the design flow rate of the HRV being modelled. For example, HVI often provides efficiency values for a range of flows, in contrast to Passive House efficiencies, which are always provided at a specific flow rate. For a multi-speed unit, this would be a calculated flow rate, depending on the minimum and maximum flows. This calculated value is not directly an average, so this can make comparisons between Passive House and other ratings difficult for multi-speed units. See the Passive House documentation for details (PHI, 2009).

The largest difference between Sensible Recovery Efficiency (SRE) and Apparent Sensible Recovery Effectiveness (ASRE) (from Table 3.1) is the inclusion of supply fan heat effects, leakage and cross contamination. A comparison of the differences between SRE and ASRE for several hundred HRVs from the HVI product database is shown in Figure 3.2. There is a strong relationship between SRE/ASRE difference and fan power, as would be expected.

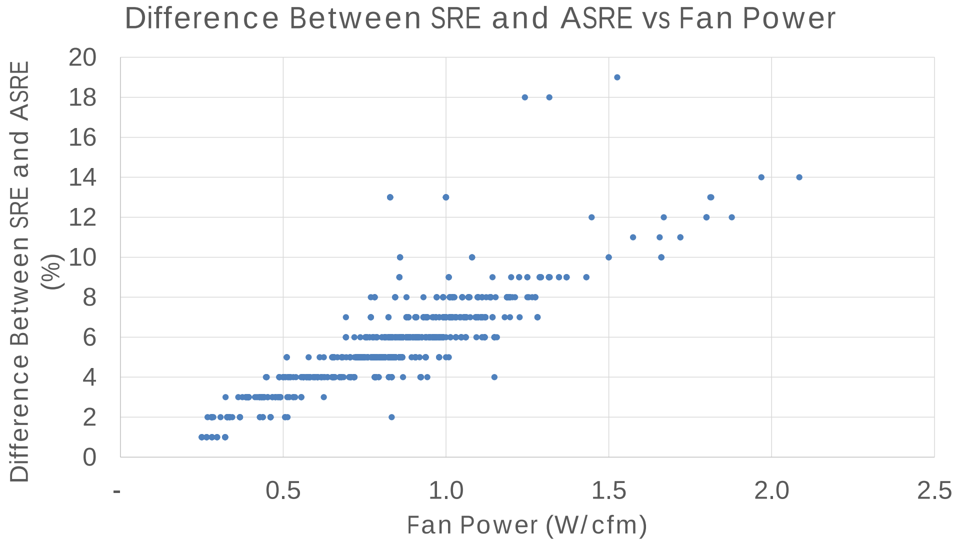


Figure 3.2: Effects of Fan Power on SRE vs ASRE

Third Party Methodologies

Methodologies for interpreting HRV ratings and modelling HRVs vary. Moreover, additional requirements related to HRVs that are not directly related to a particular HRV rating methodology may also be required in projects. For example, the supply air temperature for Passive House is not allowed to drop below certain comfort limits. There is also a requirement that HRV effectiveness be de-rated by 12% if the unit is not an officially certified Passive House HRV.

The Passive House Institute of the US (PHIUS) studied HRV ratings in the context of Passive House in the report "PHIUS Technical Committee ERV/HRV Modeling Protocols" (PHIUS, 2015). The intent was to find a more equitable representation of HVI rated HRVs for the North American industry. The report recommends to manually adjust for fan power using HVI rated conditions for efficiency (not effectiveness). This means that the effects of leakage and cross contamination are not accounted for and the effect of fan heat is approximated. This is generally a good approach, but the PHIUS method is specifically designed to recreate a Passive House rating for use in the Passive House software only.

While the above methods may not be ideal representations of HRVs in actual operation, they are required to support specific methodologies like Passive House, and are to be used in conjunction with specific tools that support these methodologies and associated assumptions.

Recommended Methodology

There are various methodologies and standards with different terminology and focus. This can lead to significant confusion and controversy relating to which one is "best". Fundamentally, all of the examined standards provide useful information when used with understanding of its context and when trying to answer the question "How will this HRV impact my building's energy consumption?" The primary goal, when trying to answer this question, is to accurately model the energy impacts of the HRV on the design. In order to do this, all of the energy-related impacts should be represented.

At first, it may appear that the ASRE is the most desirable metric because it includes as many "real world" effects as possible. There are several problems with this approach. Leakage of air into the HRV and transfer of heat through the HRV casing affect the temperature of air being provided to the space, however, they occur at the expense of additional load on the space itself. This leads to no overall net savings in heating energy so it is not appropriate to include this in a metric designed to help assess overall energy consumption. Cross contamination between supply and exhaust flows does lead to a net reduction in energy consumption because the air would otherwise leave the building and be lost. However, allowing "credit" for this in a metric endorses energy savings at the cost of air quality.

> ### CONTEXT IS KEY
>
> The various rating methodologies differ in their intent, context and assumptions, so it is a challenge to use them for fair comparisons between HRVs. However, they all provide metrics useful for judging real-world annual energy use when used in their intended way. Fundamentally, the different methodologies are all "correct" for their given contexts. The key is to use them appropriately.

The recommended approach is to use the SRE for energy modelling exercises. However, this is not without issues because supply fan power is not included in the SRE. Fan power directly offsets heating load, at the cost of Energy Use Intensity (EUI), which is a real and necessary impact that should be accounted for in an energy model. Fan power should be modelled directly, if possible, or the SRE can be adjusted to account for fan power. A description of the potential adjustment is included later in this chapter.

When comparing HRVs, it is important to understand if a particular metric gives "credit" for one effect or another (poorly performing fans, leakage, etc.), but when judging its impact on a building, what matters most is that the metric is used correctly in the tool. The challenge is that different energy modelling tools make different basic assumptions and have different defaults, which can make accurately using the available metrics a challenge. Several key points should be understood:

1. Energy modelling software will either assume a location for the fans in a heat recovery device or start with a default fan arrangement. These assumptions and/or defaults may not match the actual fan placement of the HRV in question. The energy modeller must understand these differences and adjust for them if necessary.

2. The impacts of defrost and other control methods, such as summer bypass, will not already be accounted for by default in an energy model, so the energy modeller must implement these effects separately. Modelling controls separately is desirable because they can vary between projects even with identical HRVs. The details of how this is done depends on the software.

3. When modelling a heat recovery system using an hourly simulation program such as EnergyPlus or eQuest, the energy modeller must determine if an adjustment to efficiency is required. The flow charts in Figure 3.3 and Figure 3.4 provide a more detailed description of this process, but the modeller must do one of the following:

    - Ensure that modelled fan placement matches the HRV's design,

    - Adjust the effects of fan heat on the airstream of the modelled HRV to match the effects of the fans in the actual HRVs, and

    - Adjust the efficiency up or down appropriately so that when/if the energy model adds fan heat, the overall efficiency matches the HRV's rated efficiency.

4. Use the efficiency metric measured at the design flow rate of the HRV, if available.

5. Fan power is not included in an AHRI rating for a stand-alone core regardless of the use of effectiveness or efficiency.

6. HVI/CSA's effectiveness and low temperature rating efficiency are similar in that they both take into account defrost cycling time. These values should not be used directly because defrost and its effect on heat recovery is modelled explicitly elsewhere through bypass controls, pre-heat coils or other software-dependent approaches.

The following flow charts (Figure 3.3 and Figure 3.4) demonstrate the recommended approach to HRV modelling when HVI/CSA and AHRI metrics are available. These flow charts apply to projects pursuing conventional high performance building targets. If a project is pursuing Passive House certification, then the Passive House metrics and methodology must be used.

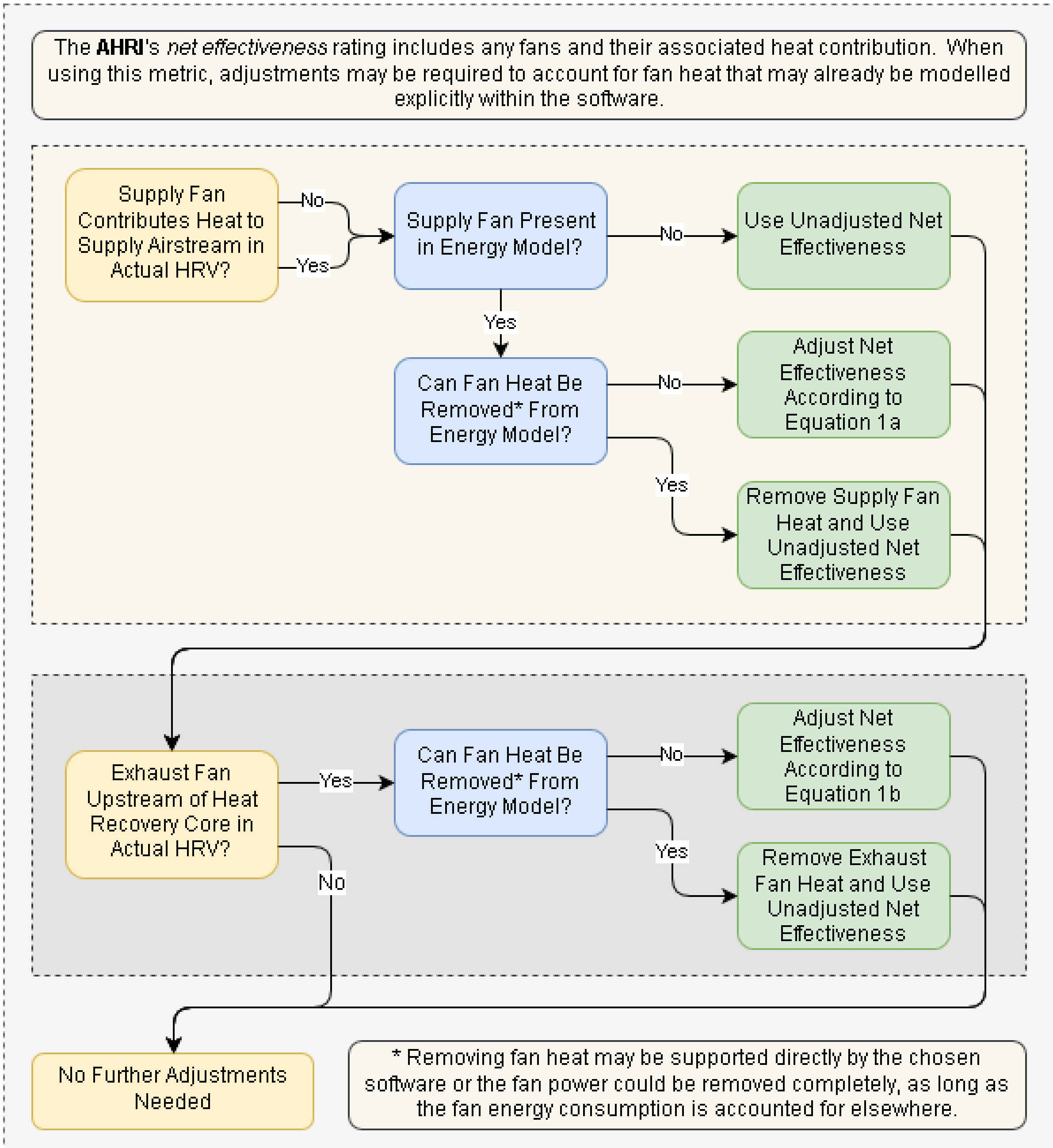


Figure 3.3: HRV Modelling Flow Chart (AHRI)

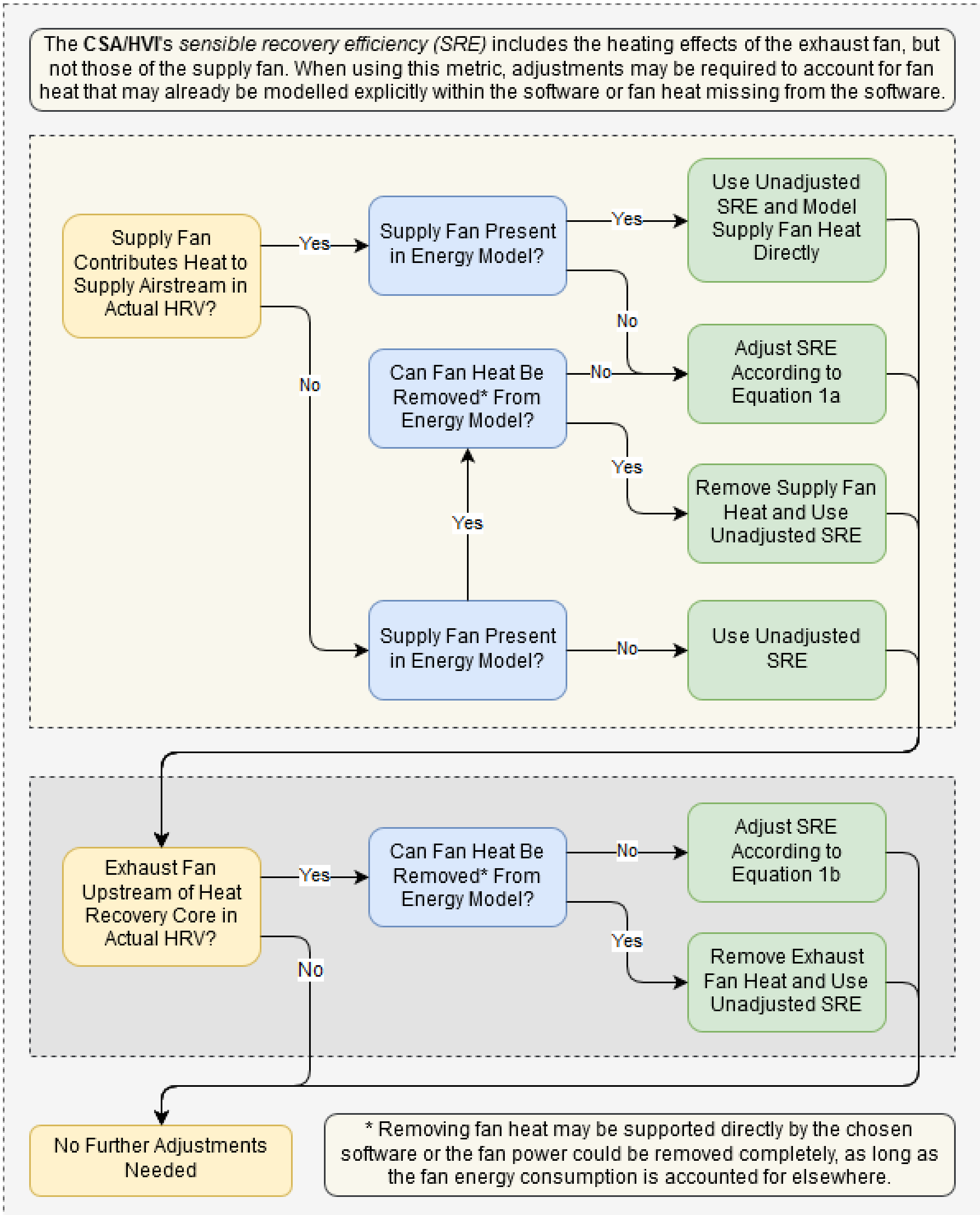


Figure 3.4: HRV Modelling Flow Chart (CSA/HVI)

The following equation can be used to adjust the rated efficiency. The constants shown here are the combinations of conversions of units and the rated difference in temperatures required by the methodology in question. More details about the derivation of these formulas can be found in Appendix B.

$$\varepsilon_{Adjusted} = \varepsilon_{Rated} \pm A_{SF} - A_{EF} \qquad \text{(Equation 1)}$$

Where A_{SF} is the adjustment for the supply fan and A_{EF} is the adjustment for the exhaust fan. A_{SF} will be positive in cases when the energy modeller is trying to add the effects of fan heat and negative when trying to remove the effects of fan heat. In order to decide, the energy modeller must understand the software being used and whether fan heat is already accounted for in the energy model. The end goal is to account for fan heat fairly, in the appropriate place and only once. A_{EF} will always be negative or zero because the metric being adjusted will already include the effects of the exhaust fan.

$$A_{SF} = \pm \frac{\left(\frac{W_{SF}}{cfm}\right)}{12.5497 + \left(\frac{W_{EF}}{cfm}\right)} \qquad \text{(Equation 1a)}$$

$$A_{EF} = 0.07968 \times \varepsilon_{rated} \times \left(\frac{W_{EF}}{cfm}\right) \qquad \text{(Equation 1b)}$$

W_{SF} *and* W_{EF} = *Rated power consumption of the supply and exhaust fans respectively.*

cfm = *Rated flow rate of unit in cubic feet per minute*

ε_{rated} = *Rated efficiency as a fraction (SRE for CSA/HVI) or net effectiveness (AHRI)*

The fan powers in the equations above should be considered zero if the fan motor is not in the same airstream as the fan itself. If one motor serves two fans, the entire fan power should be allocated to the appropriate airstream. There is a small difference between calculating the effects of the supply and return fans individually or together. However, this difference is small, and decreases as fan power decreases, so is not considered here.

Adjusting efficiency using Equation 1 brings the SRE metric closer to the ASRE metric. The remaining differences are primarily due to leakage and cross contamination. Figure 3.5 shows the differences between the adjusted SRE and ASRE versus unadjusted SRE for several hundred HRVs from the HVI database. Most HRVs have 2-4% difference after adjustment. The more efficient units differ by at most 2%. Several outliers are present. These represent HRVs with particularly inefficient fans or HRVs where the fan arrangement is not typical.

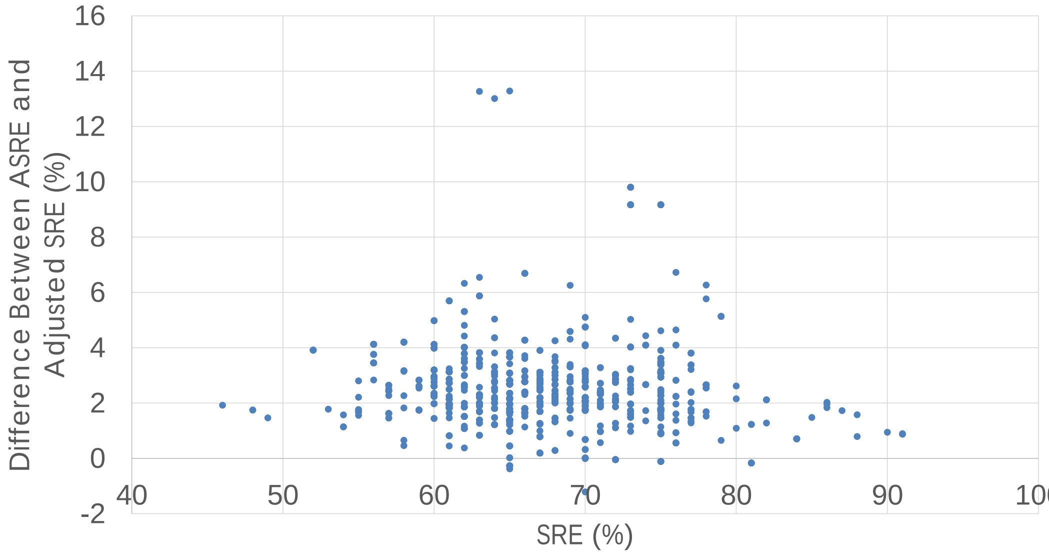


Figure 3.5: Difference between Adjusted SRE and ASRE versus SRE

The primary differences between metrics are due to fans, leakage and cross contamination. Fan heat is accounted for in the energy model or adjusted using Equation 1, air leakage from the room into the HRV will not affect energy use in reality and cross contamination is energy savings at the expense of air quality.

Fans

A key difference between the standards is the assumption of when/if fan energy is "useful". In the Passive House method, all fan heat (supply and exhaust) is assumed to contribute to offsetting heating loads. This may or may not be appropriate for a given project. In the other methodologies, the supply fan contributes to heating during heating season, but applies a penalty during cooling season. Also, if the exhaust fan is upstream of the heat recovery core, its impact will be included in the effectiveness, while if it is downstream it will not.

In all methodologies that include fan power, inefficient fans can inflate the results. Passive House is the only method to also limit fan power as a requirement to meeting the standard. Passive House requires that HRVs not exceed 0.45 Wh/m^3 (~0.26 W/cfm) at the tested flow rate. By limiting fan power, Passive House reduces the heating effects of low-efficiency fans. In any methodology, the fan power must be considered due to its effect on overall energy consumption.

Defrost

Defrost strategies can play an important role in a heat recovery system for Canadian climates. All heat recovery devices have a low limit on their operating temperatures, meaning they will automatically shut off or take some action to prevent damage due to frost or low temperatures. The minimum operating temperature differs between units, with higher efficiency units typically having lower minimums. The defrost strategy can significantly impact thermal energy demand in a building because the measures taken to mitigate frost will often reduce heat recovery effectiveness or temporarily disable heat recovery completely. The following are common strategies for frost control in HRVs:

- Bypass: Internal or external to the HRV, a bypass system will allow outdoor air to be supplied without it passing through the heat recovery core. This ensures that ventilation air is provided, but provides no heat recovery. This method will put all ventilation air heating load directly onto the mechanical system and could also lead to comfort issues when cold air is introduced directly into the heated space.

- Recirculation: Exhaust air is recirculated as supply air, warming the heat recovery core and reducing frost. The disadvantage to this method is that there is no ventilation air during recirculation mode. This is a simple method, but there is no heat recovery during recirculation and some codes do not allow ventilation to be stopped in this way.

- Exhaust Only: Using this method involves stopping the flow of outdoor air through the heat recovery core, but continuing to exhaust air from the building. This allows the core to warm up without cold outdoor air entering, but means there is no ventilation during this period. It also leads to an imbalance of air pressures within the building, which is undesirable.

- Outdoor Air Preheat: Incoming outdoor air is preheated to ensure the air is always above the minimum operating temperature of the HRV. This allows heat recovery and ventilation at all times, but introduces additional heating energy for the preheat coil. This is the optimal method of defrost because the amount of additional heating energy will likely be lower than the amount of heat recovery gained.

It is generally recommended that ventilation is provided continuously for MURBs, therefore, the outdoor air preheat method is generally recommended. Some jurisdictions allow certain exceptions to this and/or include additional requirements. Nevertheless, the energy required to preheat the incoming air is important to consider. Table 3.2 shows the penalty a building will incur due to preheating the outdoor air up to the low limit of an HRV for typical MURB ventilation rates. When comparing HRVs of similar efficiency, the unit with the lower temperature limit will result in a lower TEDI due to less preheat. It is clear that the penalties can be significant in colder climates so design teams should carefully consider the temperature rating of the project's HRVs.

It is important to understand that ensuring constant ventilation may result in a penalty, but will also ensure that the heat recovery device is available at all times because it would otherwise be bypassed. This can lead to an overall net reduction in TEDI even after the preheat penalty, depending on the efficiency of the HRV and the climates.

The scenarios discussed in this chapter and the next chapter assume that an HRV is rated for operating conditions matching the typical outdoor temperature of the given climate, so that preheat is not required. If the unit had a lower limit than this, the penalties in Table 3.2 would apply to these scenarios as well.

Table 3.2: TEDI Penalty Due to Preheat Coil by Climate Zone

Preheat Coil Setpoint (°C) (HRV Low Limit Rating)	Preheat Coil TEDI Penalty (kWh/m²) by Climate Zone			
	4	5	6	7a
0	0.2	3.9	7.7	14.1
-5	0	1.6	4.0	9.1
-10	0	0.5	2.0	5.6
-15	0	0.1	0.9	3.1
-20	0	0	0.4	1.4
-25	0	0	0.1	0.5

Regardless of the method, the energy impacts of defrost must be included in energy models. The approach varies depending on the software, so the energy modeller must understand the design defrost strategy and how to implement this in the software being used on a project.

HRV Standards in Context

For most projects, there will be no choice in which standard to use. Requirements are imposed by the authority having jurisdiction or by the building rating system being used.

In a design with low thermal demand, the assumptions around which metric to use, and the resulting impact on overall building energy use and TEDI, may not be significant. Table 3.3 summarizes the effects of modelling HRVs in climate zone 7A using various rating methodologies. The "Max Difference" column shows the maximum difference in TEDI resulting from modelling the HRV for the various methodologies. The Passive House rating, the HVI ASRE rating and Adjusted SRE were modelled in EnergyPlus. Some of the units examined have both Passive House and HVI ratings available.

The differences between the ratings are small and consequently the differences in TEDI are also small. As the efficiency of the units increases and the fan power decreases, potential differences between standards are marginalized for low TEDI buildings.

Table 3.3: Summary of Impact on TEDI of Various Standards

HRV	PH Rating (%)	HVI ASRE Rating (%)	HVI SRE Rating Adjusted using Equation 1 (%)	Total Fan Power (Watts/cfm)	Max Difference in TEDI (kWh/m²) For Climate Zone 7A
1	92	90	88	0.52	1.71
2	84	88	87	0.39	1.74
3	-	83	79	0.88	1.77
4	-	81	76	0.77	2.22
5	-	64	60	1.01	1.86

Chapter 4

Whole Building Context

Introduction

A primary focus of this guide is to illustrate how to meet the challenges of low energy demand intensity (TEDI) for high-rise multi-unit residential buildings (MURBs) by understanding and mitigating the impact of thermal bridges at interface details, such as the wall to roof, wall to window and intermediate floor intersections. Other components that are important to reducing thermal loads are supported by available products (e.g. triple-glazed windows, HRVs) and better understood by current resources (e.g. "Illustrated Guide: Achieving Airtight Buildings" (RDH, 2017)). This chapter aims to put the thermal transmittance of the opaque building envelope in context with these other key parameters and identify design strategies that must be employed to achieve a low TEDI for high-rise residential buildings.

TEDI alone does not provide a complete representation of overall building energy consumption. Overall energy use, often presented as energy per building area or energy use intensity (EUI) encompasses the effects of all building systems, such as lighting, heating and domestic hot water. Many of these building systems interact with each other, with some loads impacting TEDI, but are not part of a low thermal demand strategy. For example, lighting and equipment add heat to a space and lower TEDI, but should be minimized to reduce overall EUI. Achieving both a low TEDI and EUI is important to achieve multiple high performance objectives, including lower energy use and cost, reduction of greenhouse gas emissions and improved thermal comfort. Various standards now have separate requirements for TEDI and EUI to manage this balance. For examples, see the City of Vancouver's "Zero Emissions Building Plan" (City of Vancouver, 2016), the City of Toronto's "Toronto Green Standard" (City of Toronto, 2017), "BC Energy Step Code" (Province of BC, 2017) and Passive House (Passive House Institute, 2016)). For the purposes of this chapter, many of these variables not directly linked to low thermal energy demand strategies (i.e. lighting, plug loads, operating schedules, etc.) are fixed, in line with industry standard "energy modelling guidelines" (City of Vancouver, 2017) referenced by "BC Energy Step Code" (Province of BC, 2017).

TEDI – One of Many

A building with low TEDI is only one of many performance criteria that are needed for low energy buildings. When TEDI is drastically reduced, loads other than heating become much more significant. Other loads, such as internal gains, can also impact TEDI. More people and lights, for example, reduce a building's TEDI. To avoid optimizing TEDI at the expense of other building systems, TEDI, when referenced in codes, is usually accompanied by rules around internal gains and/or EUI requirements.

As discussed in Chapter 1, the most well-known standards that currently employ a TEDI requirement include the "Zero Emissions Building Plan and Framework" in the cities of Vancouver and Toronto respectively (City of Vancouver, 2016) (City of Toronto, 2017), and the "BC Energy Step Code" (Province of BC, 2017). For high-rise residential buildings, the most stringent TEDI requirements have a maximum TEDI of 15 kWh/m^2/year, a limit generally representing net-zero ready or near net-zero ready buildings.

Figure 4.1 shows a sample end-use breakdown for a low energy building in Climate Zone 6 with a TEDI of 16.0 kWh/m^2 and an EUI of 85.9 kWh/m^2. This example building has a 100% efficient heating system (e.g. electric baseboard heating), 0.284 W/m^{2}K overall thermal transmittance of the walls (Effective R-20), triple-glazed windows, increased airtightness and premium HRVs. Less than a quarter of the building's energy use is related to space and ventilation heating for this example. The space heating is affected by several parameters as broken out in the graphs, including window, wall, ventilation and infiltration losses.

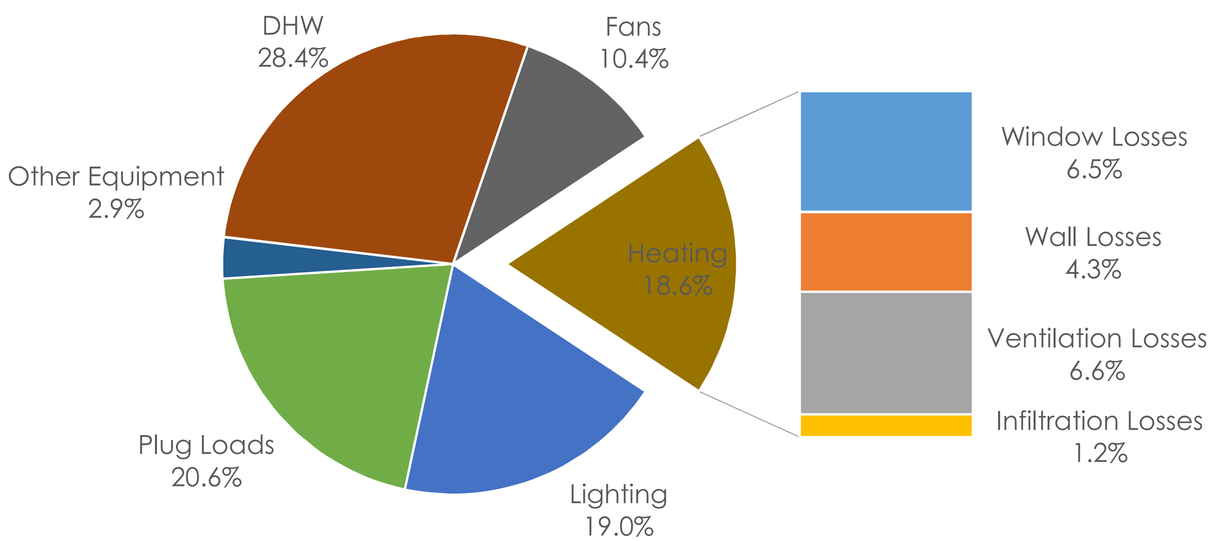


Figure 4.1: End-use Breakdown for a Low Energy MURB in Climate Zone 6

Figure 4.2 shows a sample breakdown of the heat gains and losses of a high-rise MURB with low thermal demand. Ventilation and windows have the highest heat losses, but also can provide the highest heat gains through the use of heat recovery and solar energy, respectively.

The breakdown shown in **Figure 4.2** depends on the building design, with the balance of the loads being affected by the heating balance point, climate and building envelope design. An important observation is that the internal gains from occupant-controlled sources are almost as large as the heat recovery component of the gains. As the loads in low TEDI buildings are reduced, these occupant-related gains become dominant. These internal gains are typically fixed to comply with codes and standards, but there is more of an incentive to reduce these loads when their share becomes relatively larger for low TEDI buildings. When reductions to internal gains can be realized, the need for better performing building envelopes becomes even more critical.

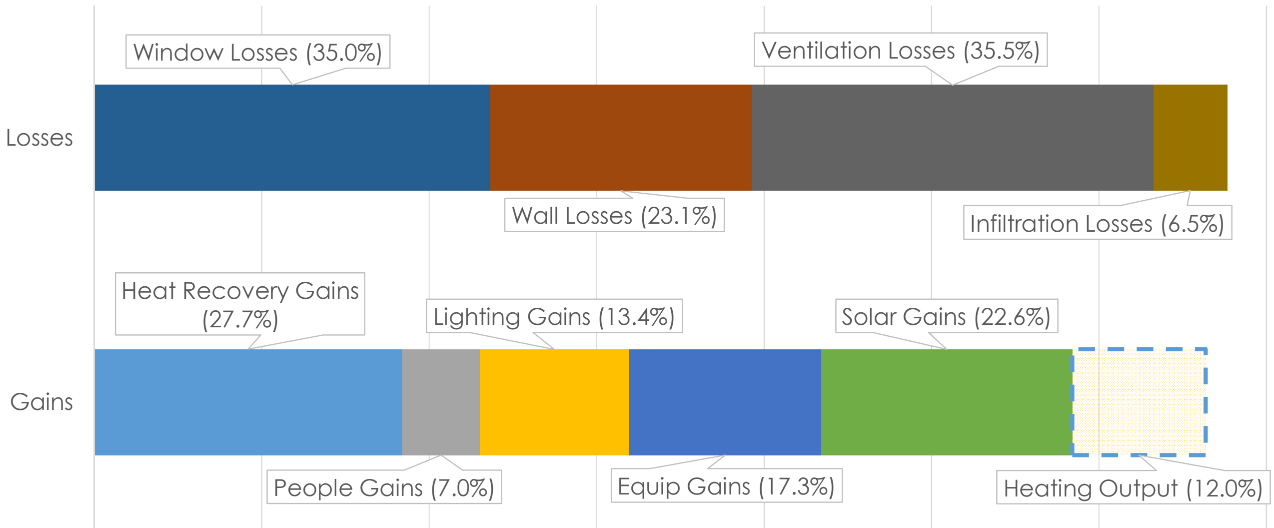


Figure 4.2: Example Breakdown of Heating Load Components

Characteristics of Low Energy Buildings

Achieving a low energy building requires making a significant number of design decisions, many of which are interrelated. A large number of design options, based on an archetype MURB (see BuildingPathfinder.com for details (OGBS, 2017)), were simulated to identify which combinations of options could meet the required performance targets. An interactive data visualization tool was used to visually represent the impact of combinations of design options on specified metrics, in this case TEDI. A screenshot of the tool is shown in **Figure 4.3**, where each line represents one simulation, and each axis represents a parameter in the simulation or an output from it. The location where the lines cross the axes corresponds to the value of that parameter or output for the given simulation.

A range of the major design parameters that govern TEDI were simulated to understand relative impacts and interactions between parameters. These parameters are discussed in more detail later in this chapter and include:

- Internal Gains
- Building Shape
- Opaque Envelope
- Glazing
- Overheating
- Air Infiltration
- Ventilation (See Chapter 3)

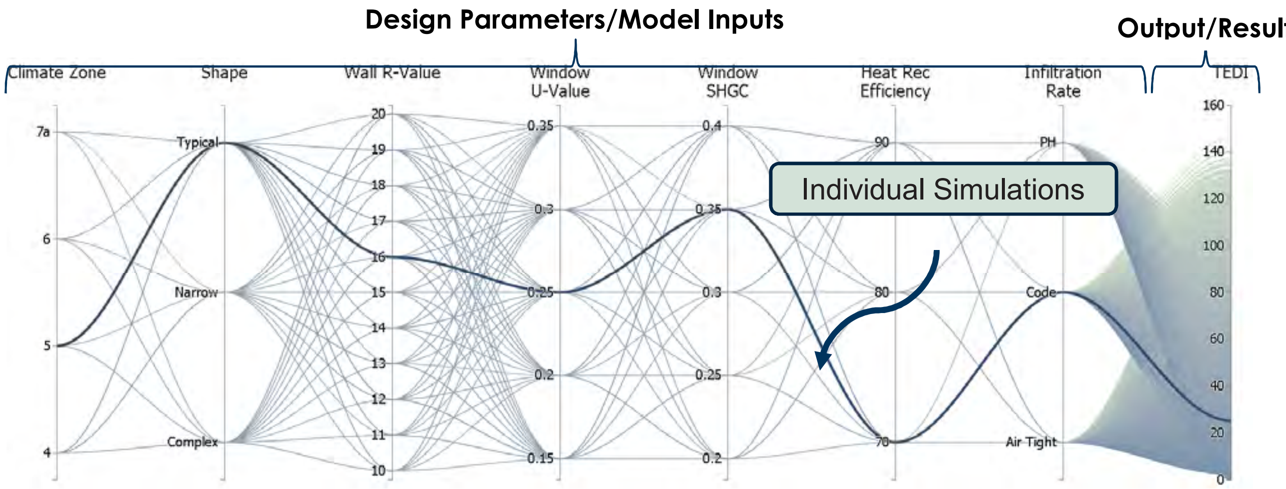


Figure 4.3: Example of Visualization of Simulation Results

INTERNAL GAINS

The term internal gains refers to the heat released by people, lighting and equipment in a building. Internal gains, when coincident with heating loads, can directly offset a building's thermal energy demand. Therefore, it is important to understand and account for these loads properly during the design process and evaluation of energy-use.

Occupant, equipment and lighting loads and schedules are typically assumptions defined by standards. Assumptions can vary significantly between standards and methodologies. The Passive House methodology, for example, uses a highly detailed adjustment factor to calculate the portion of internal energy consumption that contributes to offsetting heating loads. Standards such as “ASHRAE Standard 90.1-2007: Energy Standard for Buildings except Low-Rise Residential Buildings” (ASHRAE, 2007) and National Energy Code of Canada for Buildings (NECB) (NRC, 2011) assume virtually all internal energy use offsets heating loads directly. These two different approaches can make a significant difference on the building’s thermal demand, so a project’s goals must be clearly defined when evaluating TEDI.

KEY ASSUMPTIONS

Internal gains are important, but are often prescribed by specific code or standard. Assumptions must be appropriate for the project and to support the required outcome (e.g. BC Energy Step Code Compliance).

Specific loads and schedules often come from accepted third parties like NECB or ASHRAE. There are also City of Vancouver, City of Toronto and BC Step Code energy modelling guidelines (City of Vancouver, 2017) (City of Toronto, 2017), which prescribe the loads and schedules. These guidelines generally agree with other published data such as the report “Energy Consumption and Conservation in Mid- and High-Rise Multi-Unit Residential Buildings in British Columbia” (RDH, 2012).

An example of the impact of internal gains is demonstrated when comparing the assumptions used by Passive House and those from the City of Vancouver's "Energy Modelling Guidelines" (City of Vancouver, 2017) used by the "BC Energy Step Code" (Province of BC, 2017). The same building was modelled both ways and, after controlling for other factors, the results revealed different heating loads due to the differing assumptions for internal gains. Passive House significantly discounts peak internal gains (reducing their effect) to approximate variable internal gains that follow a schedule.

For an example building with low thermal demand, the annual heating load calculated using City of Vancouver's "Energy Modelling Guidelines" (City of Vancouver, 2017) for internal gains and associated schedules resulted in a TEDI that was approximately 8 kWh/m^2 lower than the same building using internal gains following the Passive House methodology. Since the impact is significant, assumptions for internal heat gain have to match the project objectives, be well understood by the energy modeller and be well documented for the rest of the project team.

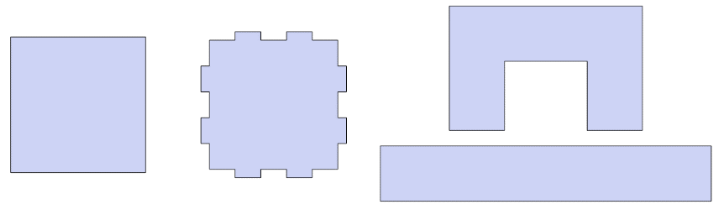
BUILDING SHAPE

A building's vertical surface area to floor area ratio (VFAR) is a significant influential factor on the heating energy use of a building, especially when the TEDI target is normalized for floor area. This metric is similar to a more common metric of surface area to volume ratio. However, for high-rise MURBs, the majority of heat loss occurs in the vertical surface areas due to the relative high percentage surface area compared to total exposed surfaces and due to the difficulty of effectively insulating vertical assemblies that also meet the other design requirements as outlined in Chapter 5. As such, VFAR has a more direct relationship with TEDI than surface area to volume ratio and has been used as the primary shape metric for consideration.

Complex and/or narrow shapes have more vertical surface area per floor area, leading to greater heat losses per unit floor area. Complex shapes with significant articulation have about 40% more vertical surface area per floor area than simple shapes like a square, while narrow shapes have about 80% more. **Table 4.1** demonstrates a selection of building shapes and their associated VFAR. Very small or narrow buildings will likely require improved envelope systems to compensate for higher vertical surface areas. A single family detached home typically has a VFAR between 1.2 and 1.5, while a high-rise MURB has a VFAR in the range of 0.5 to 0.65. The floor plates in **Table 4.1** are 600 m^2 and the TEDI values are for Climate Zone 6. When all other design elements are kept constant, TEDI increases as VFAR increases.

A building's shape can also impact the building envelope thermal transmittance because complex architecture often increases both the complexity and quantity of interfaces that lead to thermal bridging.

Table 4.1: VFAR for Example Building Shapes and Floor Plate Sizes



	Square	Articulated	Narrow
VFAR	0.49	0.59	0.7
TEDI (kWh/m^2)	15.1	20.3	26.1

THERMAL TRANSMITTANCE OF THE OPAQUE BUILDING ENVELOPE

A building envelope with low thermal transmittances or highly effective R-values is critical to achieving low thermal energy demand. This is achieved by well insulated assemblies and minimizing thermal bridging. Thermal bridging is best minimized and avoided early in the design process by evaluating the impact using default values founds in catalogues, such as the Building Envelope Thermal Bridging (BETB) Guide or ISO 14683. Assumptions can then be revisited and refined with project specific values as the design evolves and the other design requirements become more tangible.

Table 4.2 and **Table 4.3** shows the difference in overall wall thermal transmittance or effective R-value between a conventional and a low TEDI building using the MURB archetype building from the BETB Guide (Morrison Hershfield, 2016) for quantity takeoffs. The baseline case has an effective R-6.2 for the opaque wall compared to the low TEDI scenario of R-27.0 using details outlined in Chapter 5. The improvement is due to the combined improvement in the details and more insulation. This examples illustrates the potential for optimization on projects with a broad range of possibilities to mitigate thermal bridging. See Chapter 6 for more examples that highlight the impact of using the details presented in Chapter 5.

TIGHTLY COUPLED DESIGN PARAMETERS

Building envelope thermal transmittance and building shape are tightly coupled, each influencing the other. These characteristics should be considered early in the design as they can have a large impact on TEDI.

Table 4.2: Wall Thermal Transmittance for Conventional Assemblies and Details

Detail	Area or Length	Transmittance Value	Heat Flow (W/K)	Percent of Total Heat Flow (%)
Steel Stud Wall	5903 m^2	0.35 W/m^2K	2066	36.7%
Balcony Slab at Door	226 m^2	4.72 W/m^2K	1068	18.9%
Parapet at Wall	55 m	0.78 W/m K	43	0.8%
Parapet at Glazing	73 m	0.98 W/m K	72	1.3%
Intermediate Floor at Wall	616 m	0.20 W/m K	123	2.2%
Intermediate Floor at Balcony	778 m	1.06 W/m K	825	14.6%
Intermediate Floor at Glazing	1536 m	0.20 W/m K	307	5.5%
Window to Wall	5559 m	0.20 W/m K	1112	19.7%
Interior Wall Separation	988 m	0.20 W/m K	20	0.4%
		Overall Thermal Transmittance (W/m^2 K)		**0.92**
		Effective R-Value (hr·ft^2·F/BTU)		**6.2**

Table 4.3: Wall Thermal Transmittance for Low TEDI Assemblies and Details

Detail	Area or Length	Transmittance Value	Heat Flow (W/K)	Percent of Total Heat Flow (%)
Wall with FRP Brackets	6129 m^2	0.142 W/m^2K	870	67.4%
Delta U for Aluminum Brackets	6129 m^2	0.041 W/m^2K	251	19.5%
Wall to Roof	128 m	0.171 W/m K	22	1.7%
Intermediate Floor	2930 m	0.003 W/m K	10	0.8%
Window to Wall	5559 m	0.024 W/m K	133	10.3%
Interior Wall Separation	988 m	0.003 W/m K	3	0.3%
		Overall Thermal Transmittance (W/m^2 K)		**0.21**
		Effective R-Value (hr·ft^2·F/BTU)		**27.0**

GLAZING

Window to wall ratio is the percent of the total above grade wall surface area that is made up of windows. Glazing generally has higher thermal transmittance (U-value) than walls, but glazing also admits solar radiation that can offset heating loads. Accordingly, wall and glazing performance should generally not be compared directly in terms of U-value but rather assessed independently in the context of whole building energy use.

The interface quantity and arrangement of glazing can significantly influence the impact of thermal bridging at the window to wall interface. Typically, a balance of both window area and window shape should be considered when trying to achieve low TEDI. **Figure 4.4** illustrates four generic orientations and glazing layouts that lead to different outcomes for thermal transmittance due to the quantity of the window to wall interface.

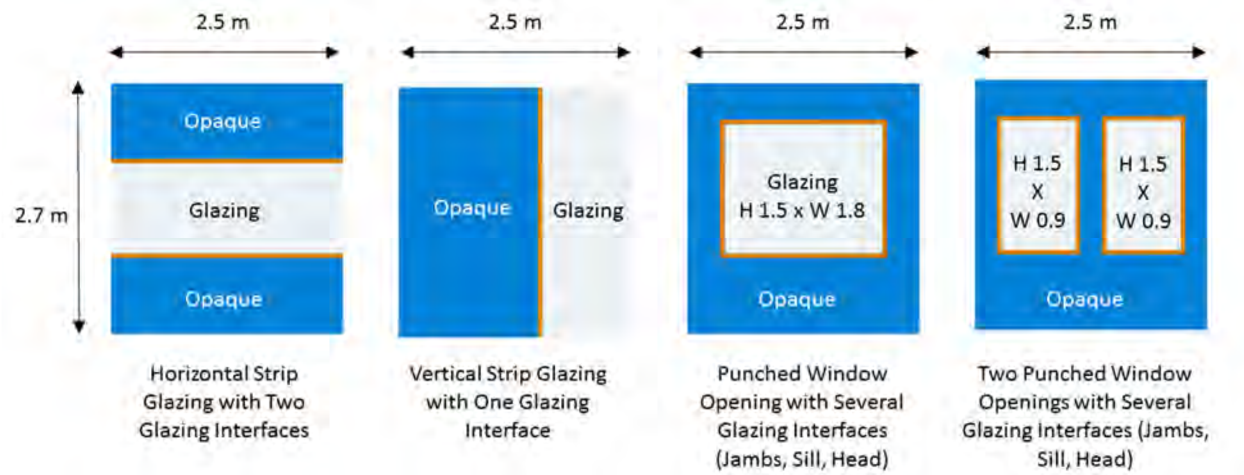


Figure 4.4: Example Window Orientations and Layouts

Table 4.4 summarizes the impact of glazing orientation and layout on the thermal transmittance for wall assembly with an effective R-value of R-16. Each scenario results in a different thermal transmittance depending on the window to wall interface length. This example assumes that each scenario has the same assemblies, same detailing, and same wall and glazing areas.

Table 4.4: Effects of Window Arrangement on Thermal Transmittance

	Horizontal Strip Glazing	Vertical Strip Glazing	Punched Window Opening	Two Punched Window Openings
Interface Length (m)	5	2.7	6.6	9.6
U-value (W/m² K)	**0.566**	**0.467**	**0.617**	**0.733**
Effective R-Value	10.2	12.2	9.2	7.8

Although details were kept the same for this comparison, the interface details typically are not identical for different glazing orientations and layouts. For example, the details for a window in a punched opening are typically different than for a curtain wall in a vertical orientation. Moreover, the jamb versus sill or head details can be quite different in terms of thermal bridging for a window in a punched opening. These differences can accentuate the differences presented in the table above because minimizing thermal bridging at the window to wall interface can be a challenge for windows for low TEDI buildings. See Chapter 5 for examples and more discussion.

The quantity and quality of glazing framing components also affects the window performance and thermal bridging at the window to wall. More framing can increase TEDI by increasing the window thermal transmittance and a fair assumption is that the overall airtightness will be decreased. Framing materials and components can affect thermal bridging because of how easily heat can transfer laterally through the window frames to the adjacent wall assembly and bypass the thermal insulation through structural framing.

WINDOW HEAT BALANCE

The balance between solar heat gain coefficient (SHGC) and thermal transmittance (U-value) for a window is a critical design consideration. The concept of the heat balance of windows can help in understanding this balance. Each window installed in a building will increase TEDI, relative to U-value, but decrease TEDI relative to the SHGC. When the gain is greater than the loss the window has a positive heat balance, otherwise it is a net loss to the building and considered to have a negative heat balance. Shading is also a factor in the heat balance of a window, because an ineffective shading strategy can block too much solar gain, which can lead to a net-negative window.

Table 4.5 and **Table 4.6** show how the window SHGC and U-value for different orientations will have positive or negative contribution to TEDI depending on the solar gains. The example is for a high-rise MURB with wall thermal transmittance of 0.35 W/m^2K (approximately R-16 effective R-value), R-30 roofs and 50% window to wall ratio.

Table 4.5: Net Contribution of Windows on TEDI for High-Rise MURB for Climate Zone 4

Orientation	Net Contribution of Windows on TEDI (kWh/m^2)	
	U-0.15 and SHGC 0.25	U-0.45 and SHGC 0.4
South	0.2	-1.7
East	-0.3	-3.6
North	-0.4	-3.9
West	-0.3	-2.9
Overall	-0.8	-12.1

Table 4.6: Net Contribution of Windows on TEDI for High-Rise MURB for Climate Zone 6

Orientation	Net Contribution of Windows on TEDI (kWh/m^2)	
	U-0.15 and SHGC 0.25	U-0.45 and SHGC 0.4
South	0.1	-3.3
East	-1.1	-6.1
North	-1.4	-7.0
West	-1.0	-5.8
Overall	-3.4	-22.3

Other design requirements, such as daylighting and views, typically constrain the placement and amount of windows per orientation. As a result, similar window areas and arrangements are typically provided on each façade orientation for high-rise construction. With TEDI becoming a more important design criteria, however, there are opportunities to optimize window placement, U-value and SHGC for low TEDI buildings, while balancing overall impacts on EUI.

COOLING LOADS AND OVERHEATING

Various measures for reducing TEDI may reduce building heating energy consumption, but can negatively affect cooling loads. In buildings without cooling, overheating is also a concern. This means there are both overall energy use (EUI) and thermal comfort issues (overheating) that must be considered when designing to low TEDI targets. Various passive cooling measures are typically required to manage overheating, with the most critical being shading and windows of appropriate size and number for natural ventilation. Other measures to counter increased cooling load or overheating, while preserving low TEDI include:

- Careful balance between SHGC and window U-values
- Bypassing heat recovery cores in the summer to provide outdoor air without tempering
- Air or water economizers to reduce cooling energy consumption, after cooling loads are reduced by the measures outlined above
- Night-time pre-cooling can limit cooling loads for the next day

A recent study for the City of Vancouver titled "Passive Cooling Measures for Multi-Unit Residential Buildings" (Morrison Hershfield, 2017) showed that bypassing heat recovery in the summer, proper design of shading reduced and openings for natural ventilation were effective in reducing overheating. **Table 4.7** and **Figure 4.5** use data from the report mentioned above to demonstrate some likely overheating solutions and their impact on potential overheated hours.

Table 4.7: Summary of Solutions to Overheating and Related Impacts

Cumulative Scenario (Each Includes the Previous)	Potential Overheated Hours	Reduction in Overheated Hours
None	1940	-
Natural Ventilation	315	1625
Balcony Shading	200	115
Reduced SHGC	110	90
Movable Exterior Screens	40	70
HRV Bypass	10	30

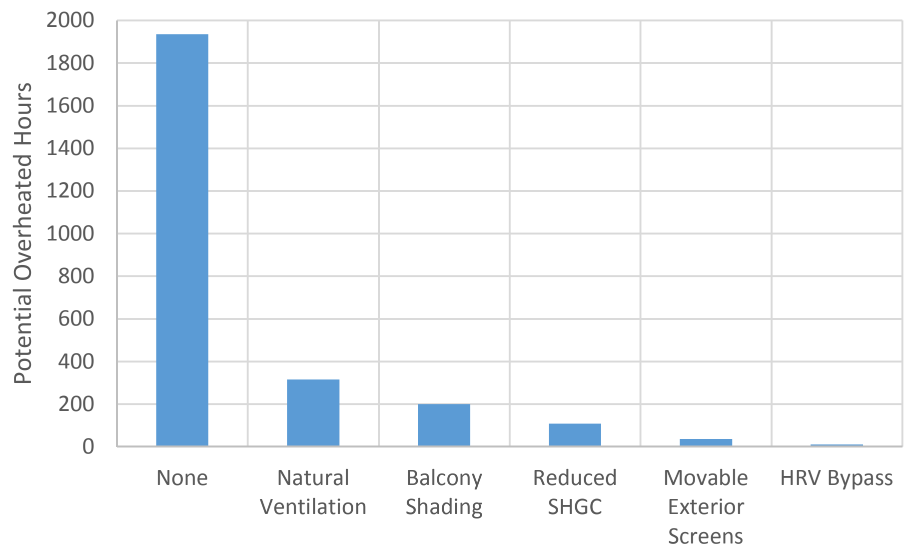


Figure 4.5: Cumulative Effects of Measures to Reduce Overheating

AIR INFILTRATION

Air infiltration significantly affects TEDI and is proportionally related to climate. Accurately accounting for infiltration can thus be a challenge that warrants concentrated effort to reflect "as built" reality. Several methodologies are available, including the ASHRAE Handbook – Fundamentals (ASHRAE, 2017). Reducing air infiltration in practice requires careful consideration to air-barrier requirements as outlined in Chapter 5 and testing to verify the level of airtightness. High levels of airtightness can significantly reduce TEDI as shown in **Figure 4.6**. The figure shows the impact on TEDI of Code (2.0 L/s/m^2 @ 75 Pa), Airtight (0.8 L/s/m^2 @ 75 Pa) and Passive House (0.08 L/s/m^2 @ 75 Pa) infiltration rates.

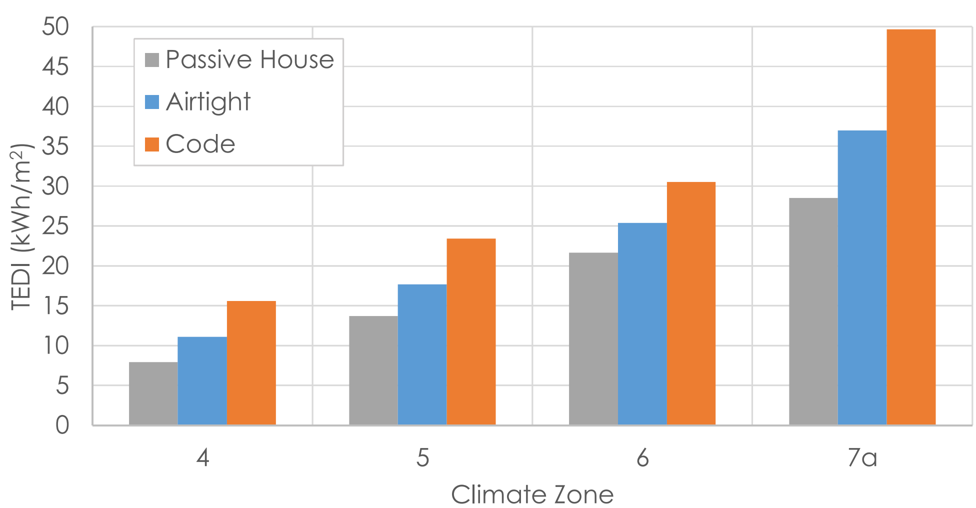


Figure 4.6: Impact of Air Infiltration on TEDI

VENTILATION

Ventilation and heat recovery play a strong role in a low TEDI building, but the relative impact is reduced with increasing effectiveness of heat recovery. **Figure 4.7** illustrates the impact of heat recovery effectiveness on the ventilation component of TEDI for different climates. All other building parameters are the same for this comparison. The impact of heat recovery effectiveness is reduced for warmer climates, but remains a critical consideration to meet low TEDI for targets of 15 kWh/m^2 regardless of climate. Additionally, once a premium efficiency HRV (85% or greater) is used, the ventilation load is small regardless of the climate.

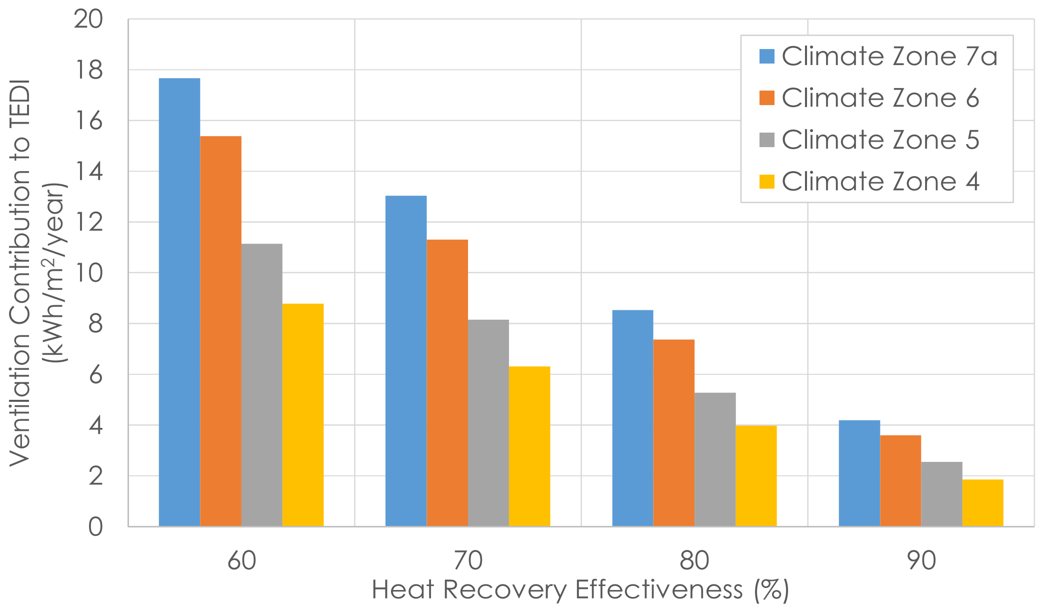


Figure 4.7: Impact of HRV Effectiveness on Ventilation Component of TEDI

The benefits of premium HRVs are clear from a TEDI perspective, but technologies that allow HRVs to achieve higher efficiencies are also bigger units. A 70% efficient unit can be approximately 57 cm x 55 cm x 26 cm (22 in x 21 in x 10 in) in comparison to a premium 90% efficient unit that can be approximately 70 cm x 84 cm x 57 cm (28 in x 34 in x 23 in). This larger size can have implications on where an HRV can be placed in a suite.

KEYS TO A LOW THERMAL DEMAND MURB

High efficiency heat recovery ventilators, high R-value walls, triple-glazing and decreased air infiltration are key characteristics of low thermal demand MURBs.

Paths to Low Energy Buildings

There are many possible combinations using the strategies presented in this chapter to achieve a low TEDI. **Figure 4.8** demonstrates over 275 possible options that meet a TEDI target of 15 kWh/m^2 for Climate Zone 6. The particular path that a project takes depends on a variety of factors, such as the building envelope systems, climate and site restrictions. The output metric is TEDI (kWh/m^2/year) and the design criteria (inputs) examined here include:

- **Climate Zone:** NBC Zones 4, 5, 6 and 7a
- **Shape**: Baseline (VFAR 0.5), complex (VFAR 0.7) and narrow (VFAR 0.9)
- **Wall Thermal Transmittance**: presented as effective R-values from R-10 to R-20 (hr ft² °F/BTU) for the opaque elements and including all thermal bridging
- **Window Thermal Transmittance**: U-values from 0.15 to 0.35 (BTU/ hr ft² °F), representing premium triple-glazed to good double-glazed windows
- **Window Solar Heat Gain Coefficient**: SHGC from 0.2 to 0.4
- **Heat Recovery Effectiveness**: 70, 80 or 90% effectiveness, representing good to premium HRVs
- **Infiltration**: Code (2 L/s/m^2 @ 75 Pa), Airtight (0.8 L/s/m^2 @ 75 Pa) and Passive House (0.6 ACH @ 50 Pa or approximately 0.08 L/s/m^2 @ 75 Pa)

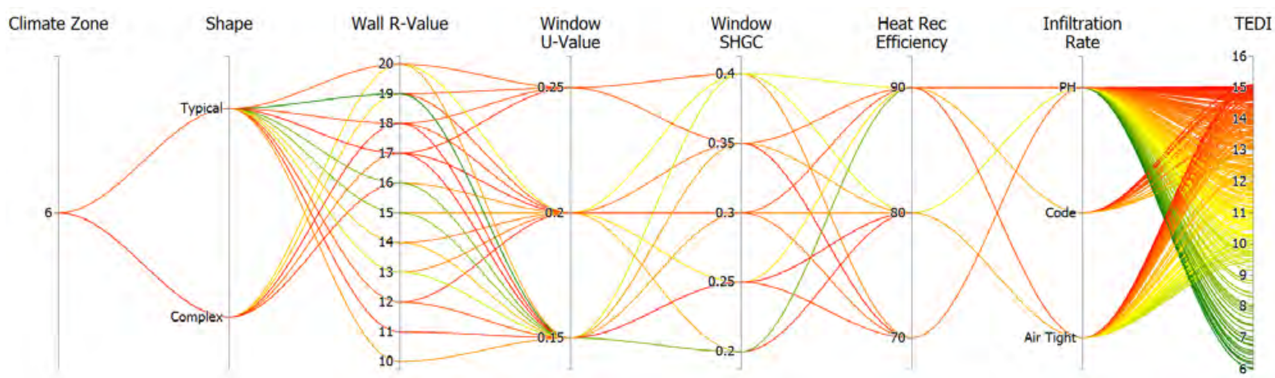


Figure 4.8: Various Paths to Low Energy Buildings in Climate Zone 6

Figures 4.9 to 4.12 illustrate designs that will lead to low energy buildings for four major NEBC Climate Zones for cities such as Victoria, BC (Zone 4), Kamloops, BC (Zone 5), Ottawa, Ontario (Zone 6) and Edmonton, Alberta (Zone 7a). The design options are not exhaustive, but illustrate the likely measures needed to achieve a TEDI below 15 kWh/m^2. All options include window to wall ratio of 40% and loads are simulated in accordance with the City of Vancouver's "Energy Modelling Guidelines" (City of Vancouver, 2017).

CLIMATE ZONE 4 DESIGN MEASURES

Climate Zone 4 is the easiest climate in Canada to achieve a low TEDI. Various paths are possible, including options that would not require a significant deviation from current practice for wall assemblies and glazing when high performance HRVs are provided. The examples shown in **Figure 4.9**, which meet a TEDI target of 15 kWh/m^2, include:

Orange Line	Double-glazed windows (0.35 U-value) are feasible when the following is provided: • Window SHGC of 0.4 • A highly insulated wall with mitigated thermal bridging (R-20) • High efficiency HRV (80%) • Improved airtightness (0.8 L/s/m^2 @ 75 Pa)
Green Line	Wall assemblies with moderate levels of insulation and mitigated thermal bridging (R-15) are feasible when the following is provided: • Triple-glazed windows (0.25 U-value and 0.3 SHGC) • High efficiency HRV (80%) • Improved airtightness (0.8 L/s/m^2 @ 75 Pa)
Blue Line	Wall assemblies that are not a stretch from current practice (R-10) are feasible when the following is provided: • Premium triple-glazed windows (0.15 U-value) • Medium efficiency HRV (70%) • Improved airtightness (0.8 L/s/m^2 @ 75 Pa)

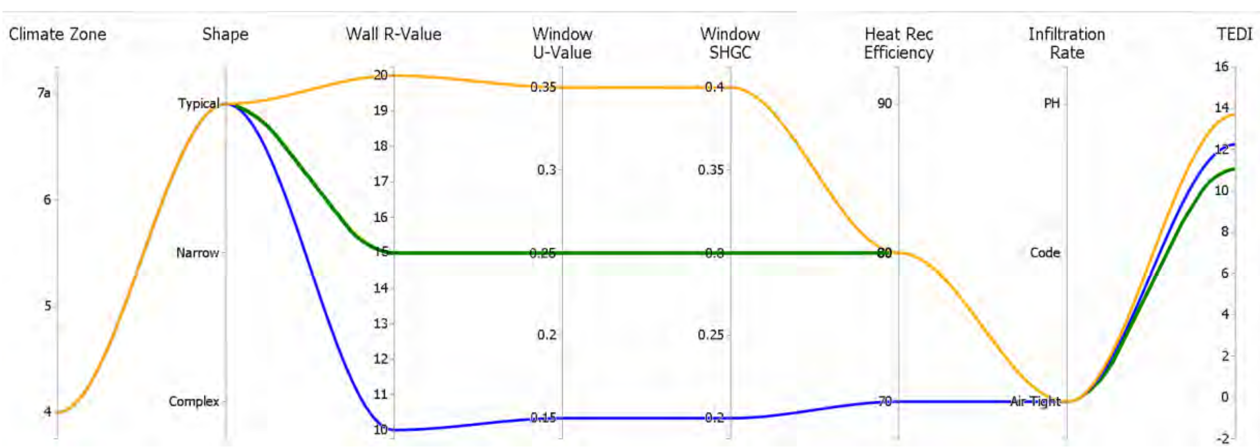


Figure 4.9: Example Paths to Low Energy Buildings in Climate Zone 4

CLIMATE ZONE 5 DESIGN MEASURES

There are fewer potential solutions for achieving a TEDI of 15 kWh/m² in Climate Zone 5 but it is still achievable. Most options available in this zone require a building shape with a VFAR less than 0.5. Complex or narrow shapes have limited options. Very few options are available without mid-to-higher performance HRVs. The examples shown in **Figure 4.10**, which meet a TEDI target of 15 kWh/m², include:

Orange Line	High quality double-glazed windows (0.3 U-value) are feasible when the following is provided: • Window SHGC of 0.3 • A highly insulated wall with mitigated thermal bridging (R-20) • Premium efficiency HRV (90%) • Passive House level of airtightness (0.08 L/s/m² @ 75 Pa)
Green Line	Wall assemblies with moderate levels of insulation and mitigated thermal bridging (R-15) are feasible when the following is provided: • Triple-glazed windows (0.25 U-value and 0.3 SHGC) • Premium efficiency HRV (90%) • Improved airtightness (0.8 L/s/m² @ 75 Pa)
Blue Line	Wall assemblies that are not a stretch from current practice (R-10) are feasible when the following is provided: • Premium triple-glazed windows (0.15 U-value) • Premium efficiency HRV (90%) • Improved airtightness (0.8 L/s/m² @ 75 Pa)

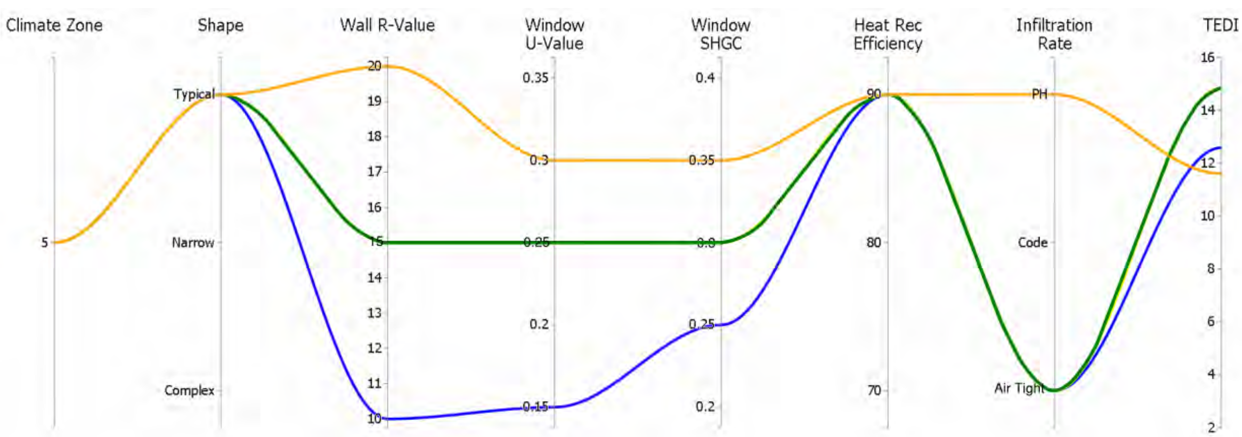


Figure 4.10: Example Paths to Low Energy Buildings in Climate Zone 5

CLIMATE ZONE 6 DESIGN MEASURES

The options for achieving a TEDI of 15 kWh/m^2 in Zone 6 are constrained, but a low TEDI is still achievable. Very few paths include complex or narrow building shapes. The examples shown in **Figure 4.11**, which meet a TEDI target of 15 kWh/m^2, include:

Orange Line	Standard triple-glazed windows (0.25 U-value) are feasible when the following is provided: • Window SHGC of 0.35 • A highly insulated wall with mitigated thermal bridging (R-20) • Premium efficiency HRV (90%) • Passive House level of airtightness (0.08 L/s/m^2 @ 75 Pa)
Green Line	Wall assemblies with moderate levels of insulation and mitigated thermal bridging (R-15) are feasible when the following is provided: • High quality triple-glazed windows (0.2 U-value and 0.3 SHGC) • Premium efficiency HRV (90%) • Passive House level of airtightness (0.08 L/s/m^2 @ 75 Pa)
Blue Line	Wall assemblies that are not a stretch from current practice (R-10) are feasible when the following is provided: • Premium triple-glazed windows (0.15 U-value and 0.35 SHGC) • Premium efficiency HRV (90%) • Passive House level of airtightness (0.08 L/s/m^2 @ 75 Pa)

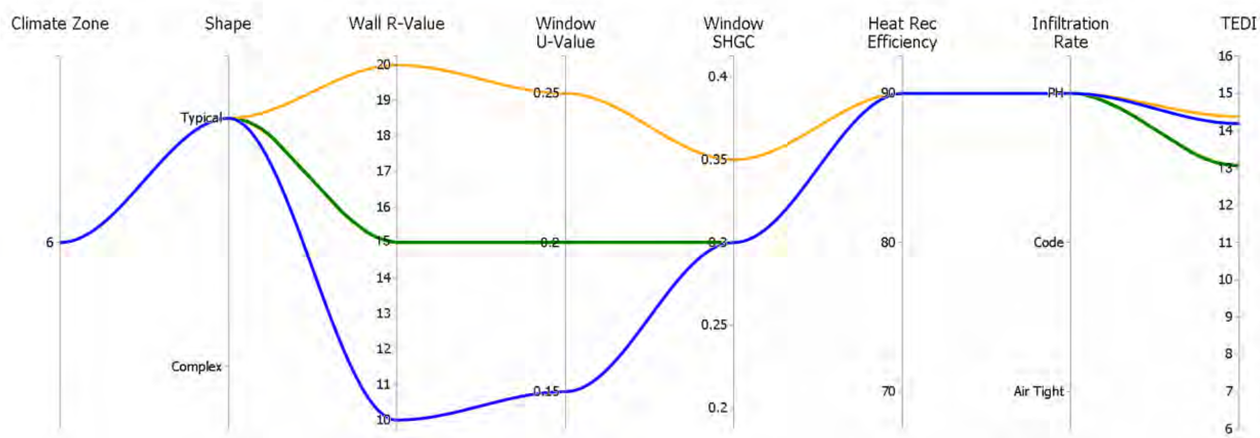


Figure 4.11: Example Paths to Low Energy Buildings in Climate Zone 6

CLIMATE ZONE 7A DESIGN MEASURES

There are significant challenges in achieving a low TEDI for Climate Zone 7a. A design needs to incorporate all of the high performance elements mentioned in this section, in addition to premium efficiency heat recovery and Passive House levels of airtightness. Premium quality triple-glazed windows with moderate SHGC are required. Wall R-values greater than the R-20 shown here are possible (up to R-40 was examined) and may reduce the pressure on other design elements, such as SHGC, but the other previously mentioned requirements remain. The examples shown in **Figure 4.12**, which meet low energy building requirements include:

Orange Line	High quality triple-glazed windows (0.2 U-value) are feasible when the following is provided: • Window SHGC of 0.35 • A highly insulated wall with mitigated thermal bridging (R-20) • Premium efficiency HRV (90%) • Passive House level of airtightness (0.08 L/s/m² @ 75 Pa)
Green Line	Wall assemblies with moderate levels of insulation and mitigated thermal bridging (R-15) are feasible when the following is provided: • Premium triple-glazed windows (0.15 U-value and 0.3 SHGC) • Premium efficiency HRV (90%) • Passive House level of airtightness (0.08 L/s/m² @ 75 Pa)
Blue Line	Wall assemblies that are not a stretch from current practice (R-10) are feasible when the following is provided: • Premium triple-glazed windows (0.15 U-value and 0.35 SHGC) • Premium efficiency HRV (90%) • Passive House level of airtightness (0.08 L/s/m² @ 75 Pa)

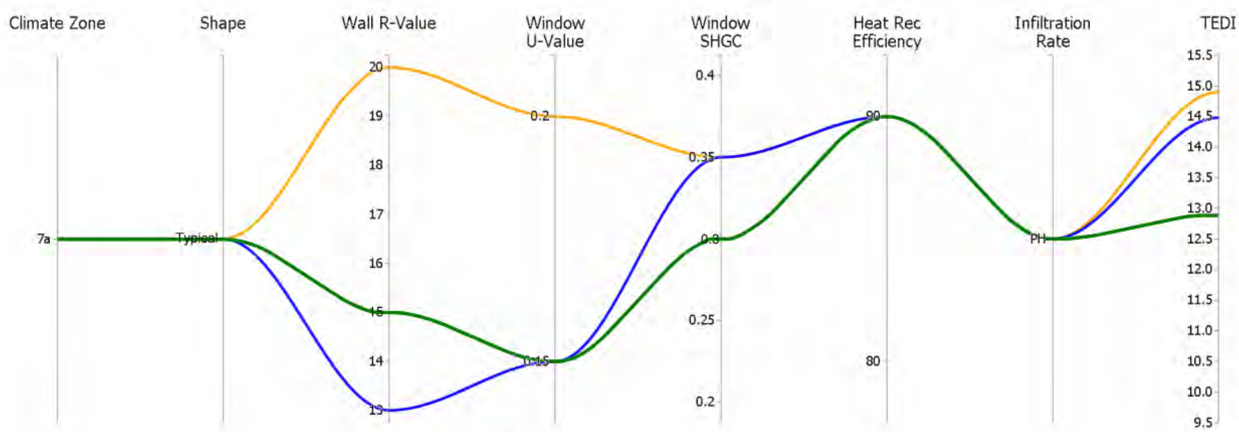


Figure 4.12: Example Paths to Low Energy Buildings in Climate Zone 7a

Table 4.8 below summarizes the example paths to low energy buildings described above. Visit BuildingPathfinder.com to explore more options for meeting low TEDI using the same archetype buildings and methodology presented in this chapter.

Table 4.8: Summary of Example Paths to Low Energy Buildings

NBC Climate Zone	Shape	Wall R-Value (hr ft² °F)/BTU	Window U-Value BTU/(hr ft² °F)	Window SHGC	Heat Rec Efficiency %	Infiltration Rate	TEDI kWh/m²
4	Typical	20	0.35	0.4	80	Airtight	14
4	Typical	15	0.25	0.3	80	Airtight	11
4	Typical	10	0.15	0.2	70	Airtight	12
5	Typical	20	0.3	0.35	90	PH	12
5	Typical	15	0.25	0.3	90	Airtight	15
5	Typical	10	0.15	0.25	90	Airtight	13
6	Typical	20	0.25	0.35	90	PH	14
6	Typical	15	0.2	0.3	90	PH	13
6	Typical	10	0.15	0.3	90	PH	14
7a	Typical	20	0.2	0.35	90	PH	15
7a	Typical	15	0.15	0.3	90	PH	13
7a	Typical	10	0.15	0.35	90	PH	15

CORRIDOR PRESSURIZATION

The above paths assume ventilation rates are strictly code-compliant. However, it is common industry practice to provide additional ventilation through corridor pressurization. The degree of additional air provided and whether there is heat recovery on this air will significantly affect the additional thermal energy demand added to the building. A high-rise MURB in Vancouver with 20 cfm/suite of additional ventilation could see approximately 9 kWh/m² of additional TEDI. This makes reaching a target of 15 kWh/m² significantly more difficult so the design team will need to carefully consider the implications of utilizing corridor pressurization.

COST

The recent "BC Energy Step Code Metrics Research Report" (Integral Group et al, 2017) studied the cost premium of achieving various levels of the new BC Step Code. This code has absolute targets for EUI and TEDI for which the highest step is equivalent to a net-zero ready building. The report found that the low thermal demand targets could be met in most cases with a cost premium of no more than 4%.

Software Tools

Various components affecting building energy consumption have been discussed in previous sections, such as internal gains, domestic hot water (DHW) and envelope-related characteristics. Ventilation was addressed in Chapter 3, but heating and cooling systems also require careful consideration when overall energy use reduction is a goal. Complex heating systems are not required for high-rise MURBs, but they are becoming more common as design teams strive to meet current energy standards. These systems, such as central plants, heat pumps and variable refrigerant systems, require more advanced understanding of engineering principles and usually more advanced software tools (EnergyPlus, IES, etc.) as well.

The degree of complexity of the tool used will depend on the degree of complexity of the building in question. These tools must at a minimum, have the capability to assess the impact and interactions between equipment loads, occupancy, lighting, schedules, outdoor temperatures, envelope, equipment part-load performance and ventilation rates, and must do so within short time-steps, preferably hourly or more frequently. One example to consider is dynamic shading (e.g. operable shading or dynamic glass) that has the ability to allow or block solar gains based on solar exposure and/or user input. The amount of solar radiation entering the building would be highly dependent on the position of the shading device, which can change several times throughout the day. Only an hourly simulation could capture this constantly changing variable and its impact on the heat balance within a building.

DYNAMIC SIMULATIONS AND COMPLEX MECHANICAL SYSTEMS

Understand the tools available and the types of mechanical, ventilation and other systems that they can simulate. When more complex HVAC systems are being considered and/or when design intent varies from a given tool's "default" assumptions or capabilities, it will likely be necessary to use a fully dynamic, hourly simulation software.

Passive House is referenced several times in this report due to its key low thermal energy demand requirement. Passive House certification requires using the PHPP spreadsheet based tool to assess the thermal energy and overall energy criteria specified by Passive House. PHPP and Passive House methodologies were studied as part of this report and the basic first-principles applied are common to other energy analysis tools such as envelope losses, accounting for solar gains, and accounting for occupant and equipment loads. However, PHPP uses various adjustment factors and correlations to estimate variances in schedules, daily temperature swings, occupant behavior and other factors. These assumptions may hold true for certain applications for which the tool was originally designed, but it is difficult to assess how well they would hold for larger, more complex buildings, where these adjustments and correlations start to deviate from "typical" to project specific assumptions.

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**.

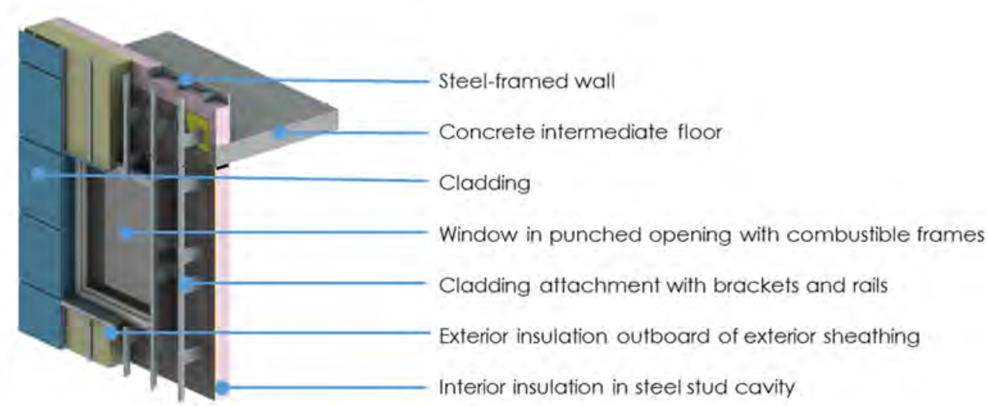


Figure 5.1: Example Window in a Punched Opening of a Steel-Framed Wall Assembly with Concrete Structure

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?

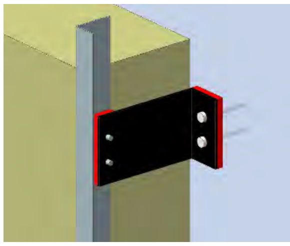
The short and simple answer is ….**YES**, by any of the following pathways. More information is provided in this section for the obstructed paths.

Clear Paths	1	The non-metallic **component** has passed either a. CAN/ULC-S114 (noncombustibility test) b. ULC-S135 (limited combustibility test)
Clear Paths	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
Obstructed Paths	4	An alternative solution is provided for the project and is accepted by the local AHJ.

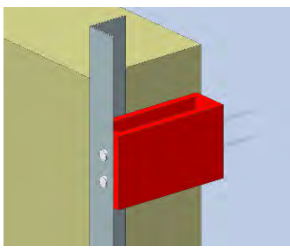
To help with connecting products to the concepts presented in this section, common non-metallic components are grouped together based on common characteristics, such as structural function and connection, potential contribution to fire growth and spread, and position within the assembly.

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

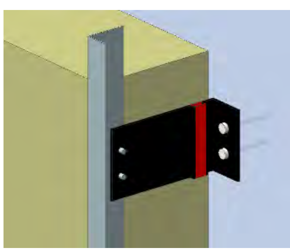
Types of Combustible Components for Supports, Attachments and Thermal Breaks



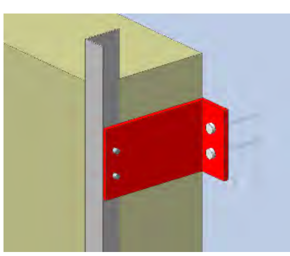
Type 1 - Shims: A combustible material functions as a shim, often 5 mm to 20mm (2/5 inches to 3/4 inches) in depth, where metal fasteners connect a metal structural component through to another component. The shims can be buried in the insulation at the sheathing, anywhere in the insulation to connect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

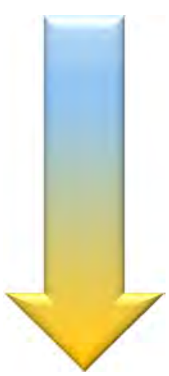
Criterion 1: The combustible component is limited in quantity of combustible material.

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.

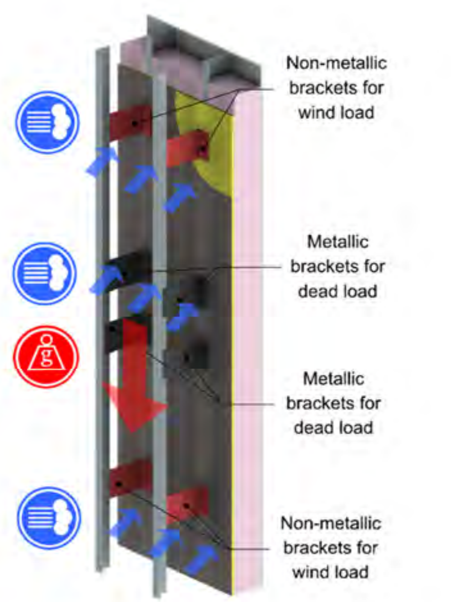


Figure 5.2: Cladding System with Metallic and Combustible Support Brackets

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**.

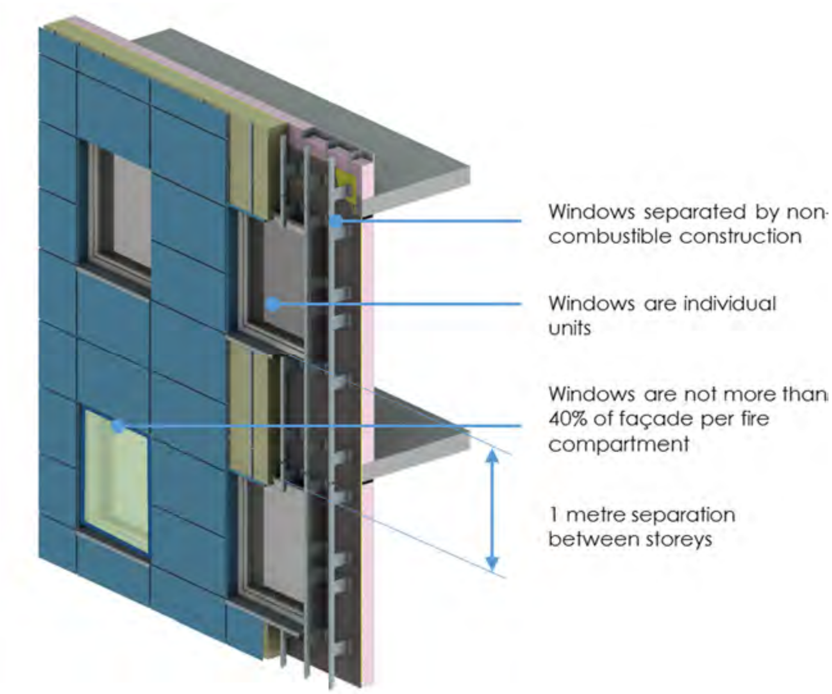


Figure 5.3: Combustible Window Frames in Noncombustible Construction

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**.

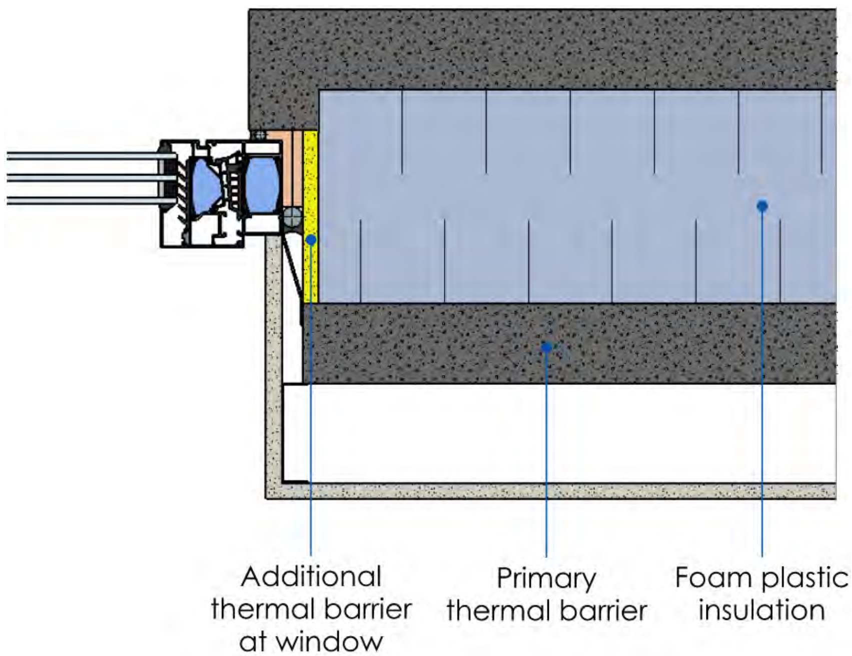
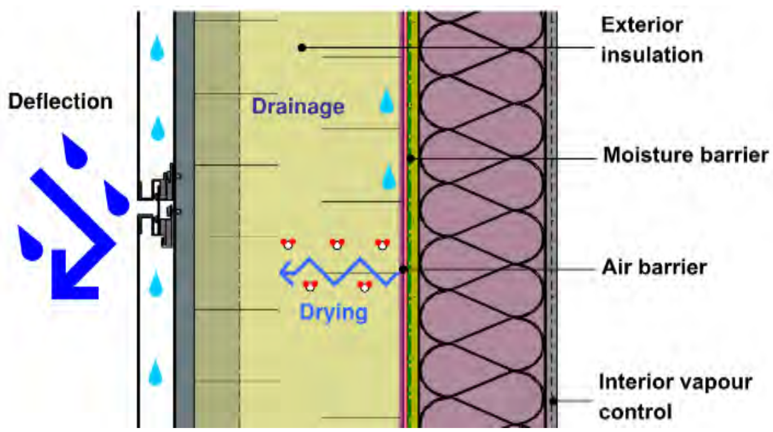


Figure 5.4: Thermal Barrier over Foam Plastic Insulation at Window Jamb in Precast Sandwich Wall Panel

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.

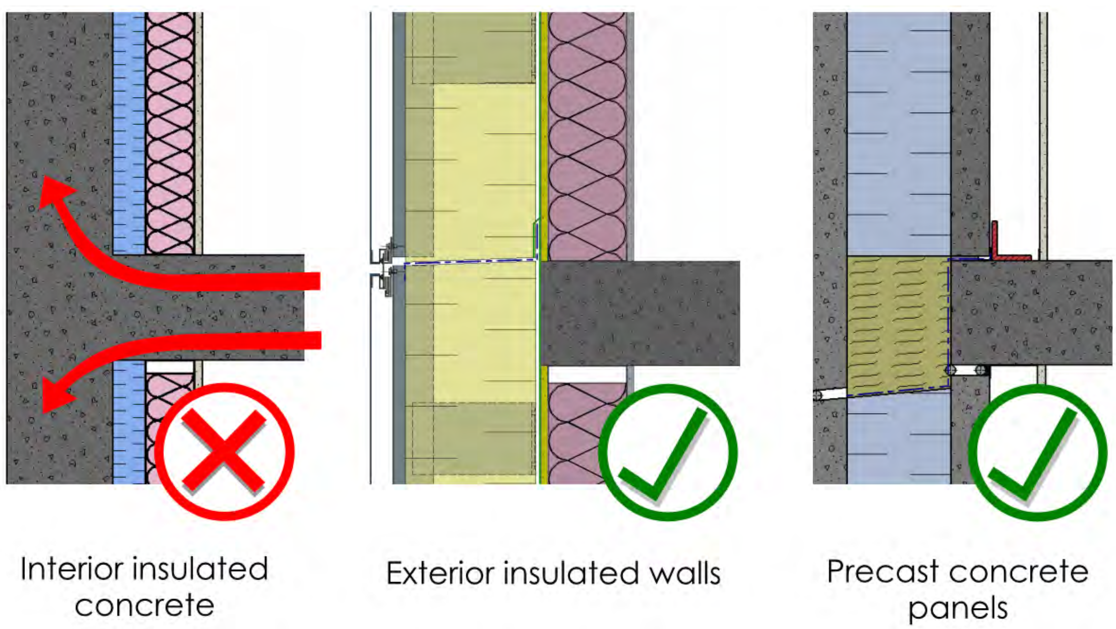


Figure 5.5: Examples Maintain the Continuity of the Thermal Insulation across the Building Structure

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

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

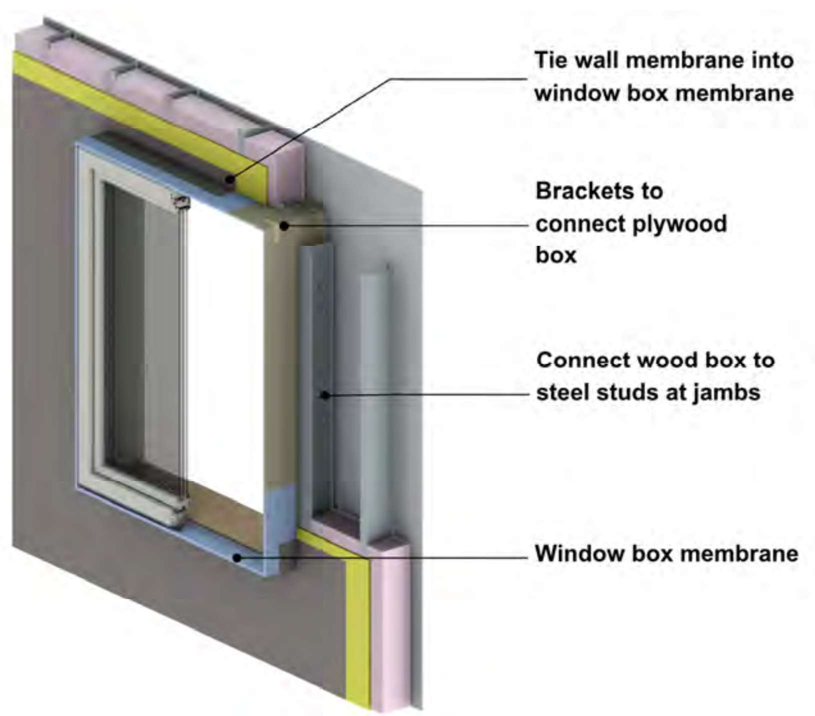


Figure 5.6: Detailing of Window with a Wood Box

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.

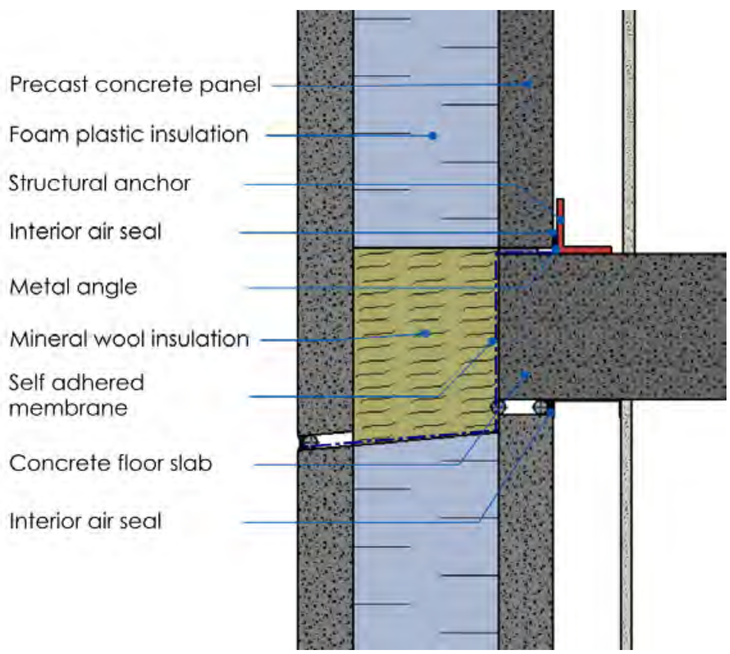


Figure 5.7: Example Precast Sandwich Panel with Enhanced Detailing

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.

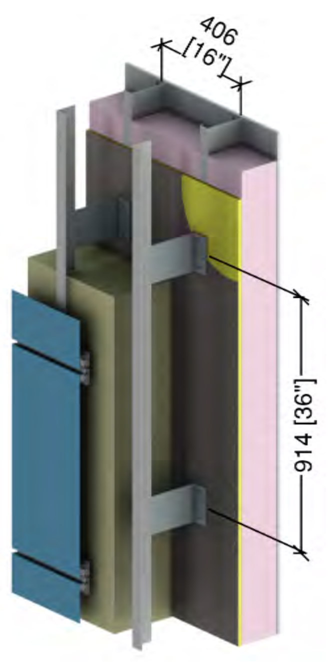
Nevertheless, panelized or unitized systems can result in better quality control of components, such as reduced cracking of concrete, and can speed up construction schedules when adequately designed and tested. Systems that speed up construction are ones that limit exterior access work to a bosun chair, 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.

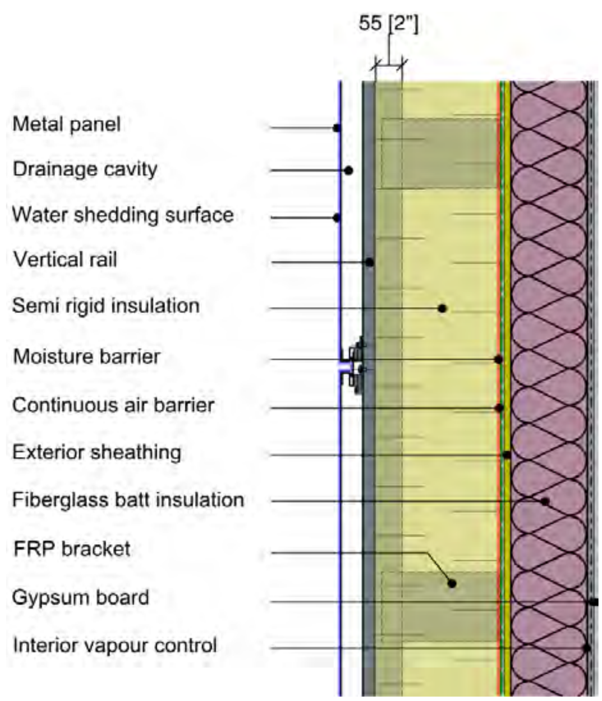
An example of a system that is well positioned in the Canadian market to meet the requirements of low thermal energy demand with the benefits of an accelerated construction schedule is a precast sandwich panel as illustrated in **Figure 5.7**. Enhanced detailing at intermediate floors, window interfaces, 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^{2}K/W)	Assembly R-value hr·ft^2·°F/Btu (m^{2}K/W)	Assembly U-value Btu/ hr·ft^2·°F (W/m^{2}K)
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? (χ/A < 0.01 W/m^{2}K)
	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)

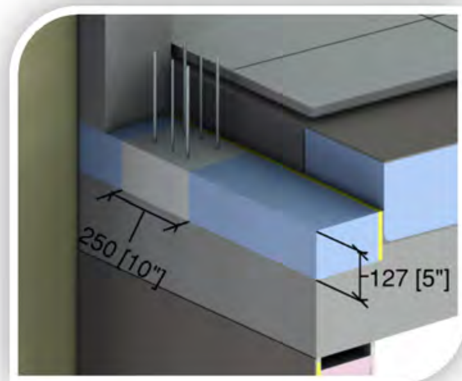
The example details include:

- 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)

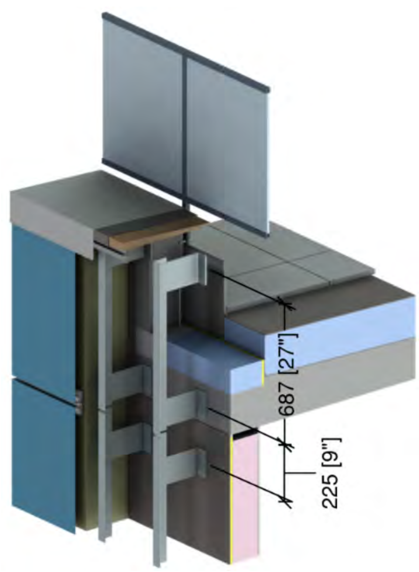
The thermal transmittance values presented in this chapter are based on BETB Guide methodology and linear transmittances are calculated based on interior and exterior dimensions.

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.



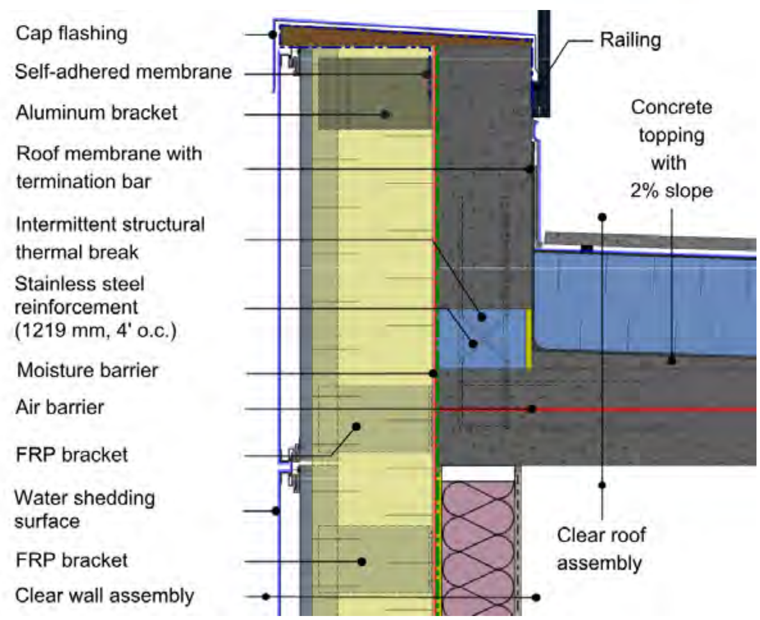


Table 5.4: Wall to Roof Interface Linear Transmittance

Scenario		$\Psi_{parapet}$ Btu/hr·ft·°F (W/mK) Inside Dimensions	$\Psi_{parapet}$ Btu/hr·ft·°F (W/mK) Outside Dimensions	Thermal Bridge Free? (Ψ< 0.01 W/mK)
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.

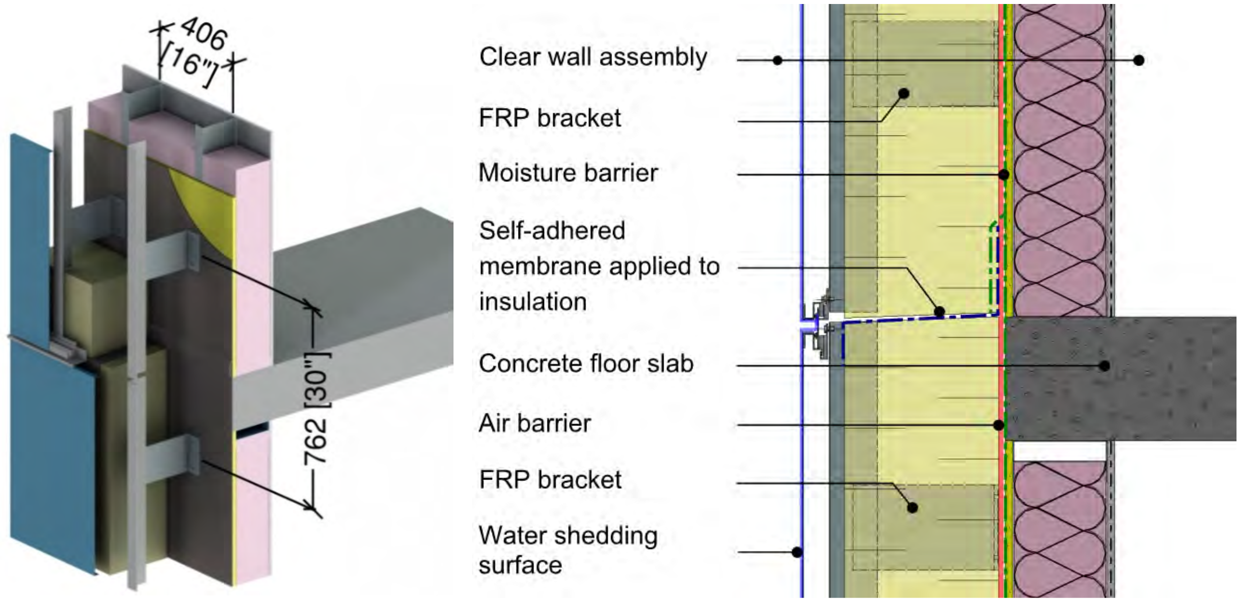


Table 5.5: Intermediate Floor Linear Transmittance

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.

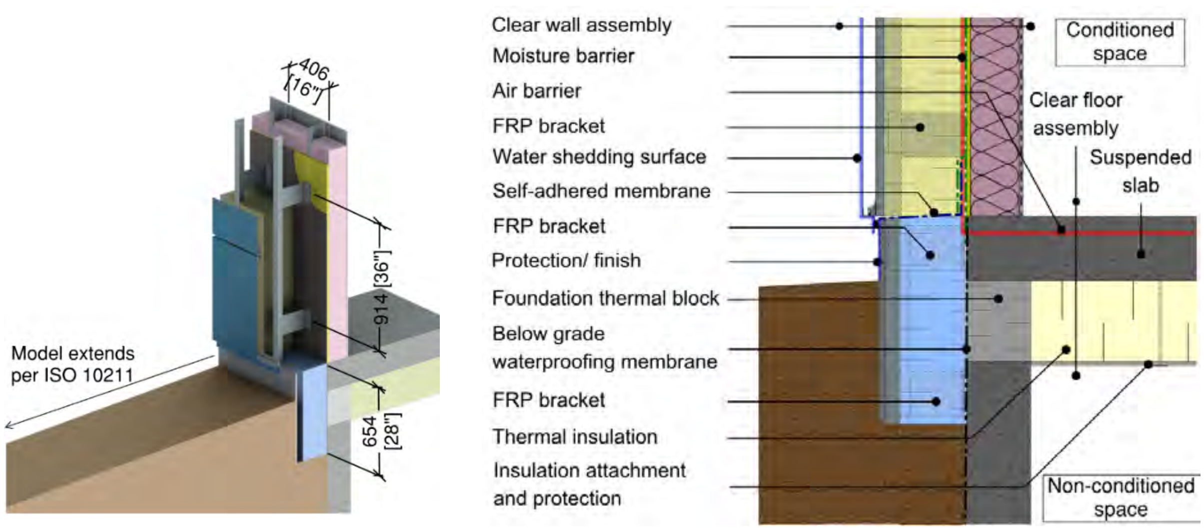


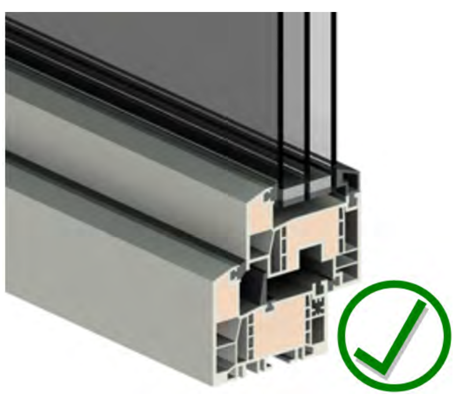
Table 5.6: At- Grade Transition to Parking Garage Linear Transmittance

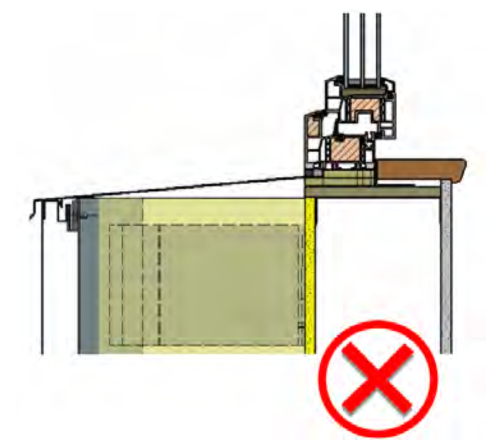
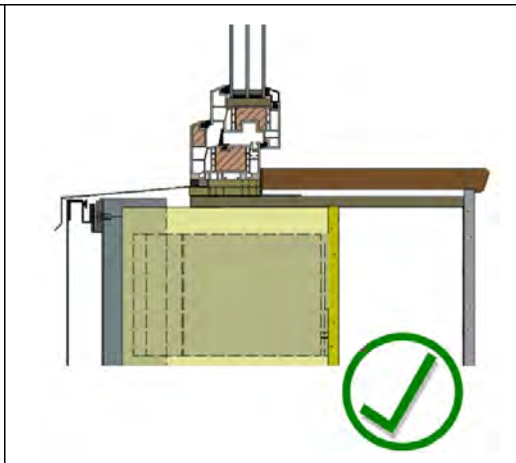
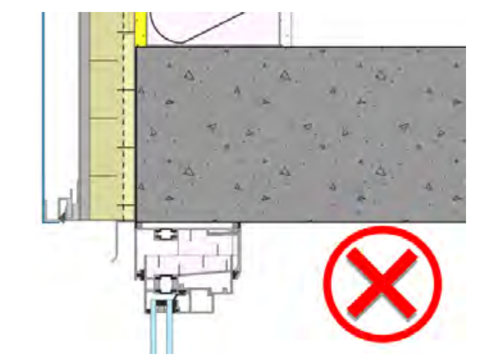
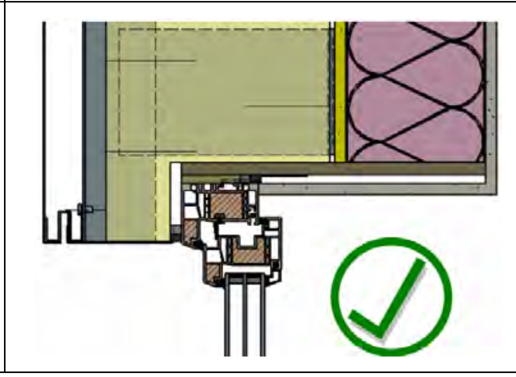
Scenario	$\Psi_{base\ of\ wall}$ Btu/hr·ft·°F (W/mK)		Thermal Bridge Free? (Ψ< 0.01 W/mK)
	Inside Dimensions	Outside Dimensions	
Uninsulated stud cavity	0.058 (0.101)	-0.009 (-0.016)	Yes, when evaluated with exterior dimensions
R-19 (3.35 RSI) insulation in stud cavity	0.059 (0.102)	-0.015 (-0.026)	Yes,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

Minimize the window perimeter and frame length by maximizing the size of glass per opening	 2' x 5' (0.6 m x 1.5 m) 4' x 5' (1.2 m x 1.5 m) Area: 30ft² (2.7m²), Interface Length: 32' (9.6m)	 6' x 5' (1.8 m x 1.5 m) Area: 30ft² (2.7m²), Interface Length: 22' (6.6m)
Use glazing systems that have large thermal breaks and insulation in the glazing framed cavities		

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.

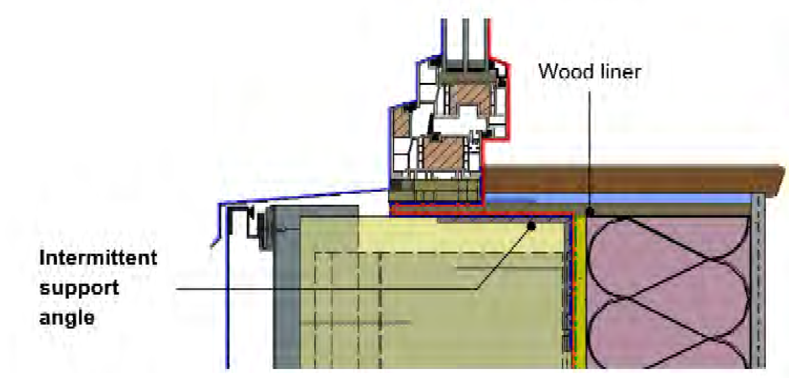
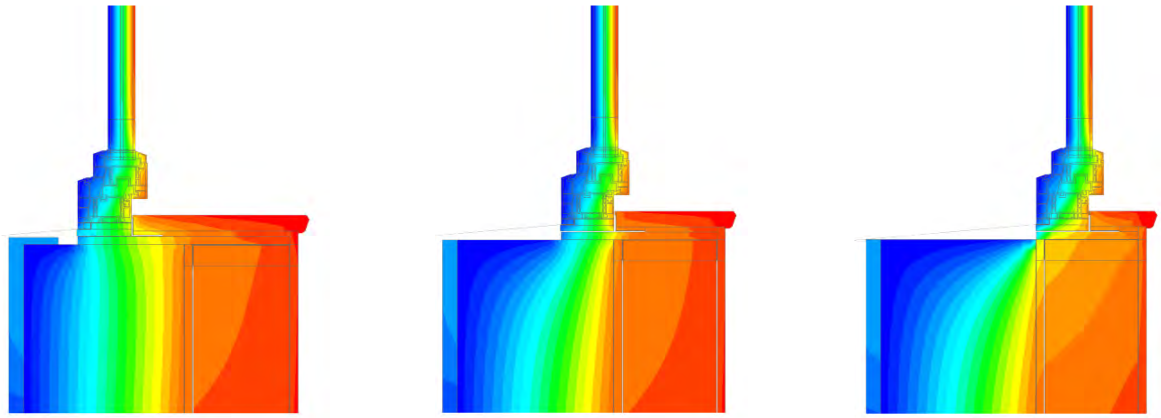


Figure 5.8: Support Angle below Window and Wood Liner

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

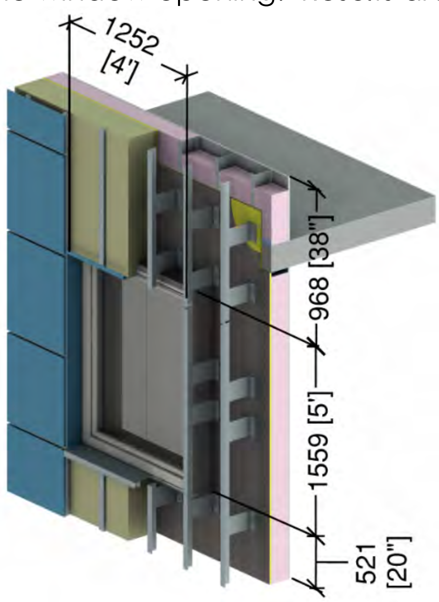
$\Psi_{install}$: 0.116 W/mK (0.067 Btu/hr·ft·°F)

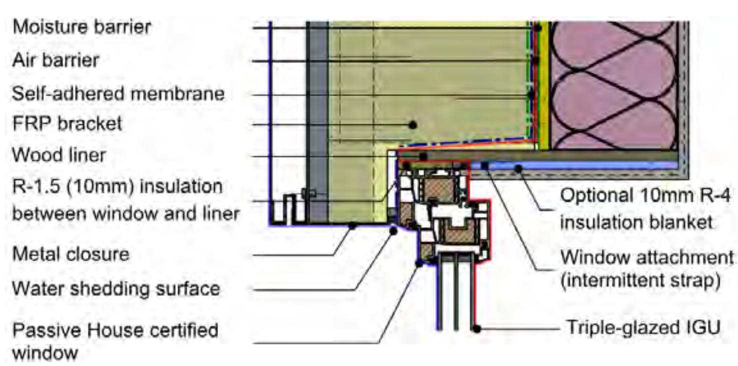
Window aligned with steel framing, air in stud cavity

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

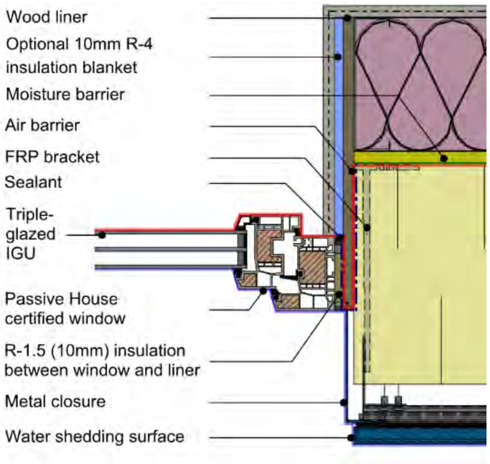
Figure 5.9: Impact of Window Positioning on Linear Transmittance

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**.

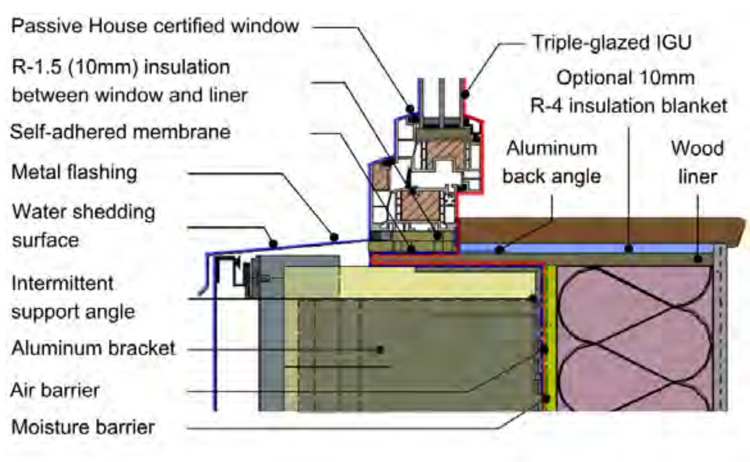




Head



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

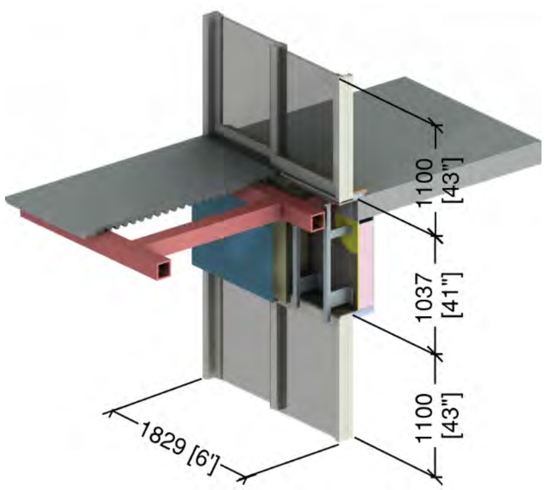
Table 5.8: Window to Wall Linear Transmittance with R-19 in Stud Cavity

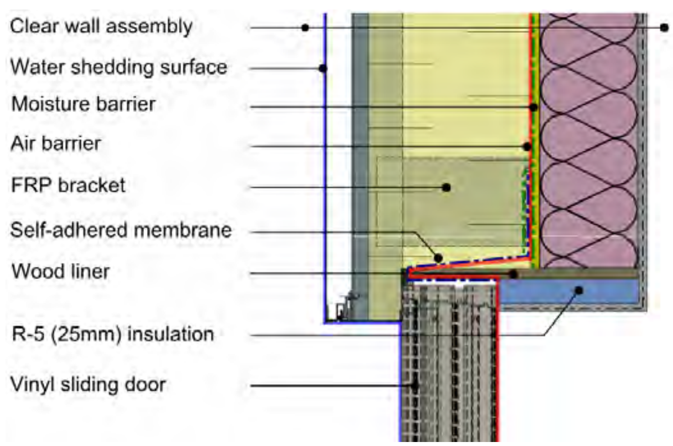
Scenario		Ψ Sill Btu/hr·ft·°F (W/mK)	Ψ Jamb Btu/hr·ft·°F (W/mK)	Ψ Head Btu/hr·ft·°F (W/mK)	Ψ Total Btu/hr·ft·°F (W/mK)	Thermal Bridge Free? (Ψ< 0.01 W/mK)
Sill Angle	R-4 Blanket					
Yes	No	0.057 (0.099)	0.063 (0.109)	0.027 (0.047)	0.026 (0.046)	No
	Yes	0.049 (0.084)	0.039 (0.067)	0.021 (0.036)	0.020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

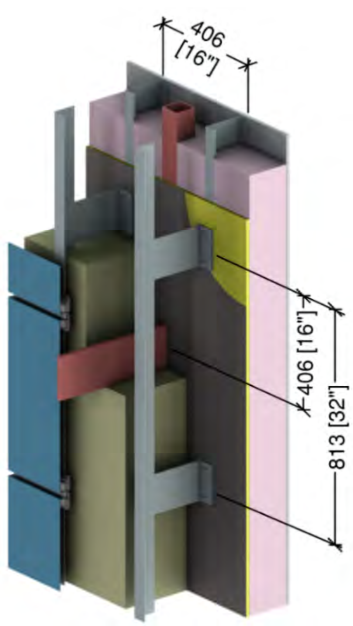
DETAIL 5: DOOR WITH INTERMITTENTLY ATTACHED BALCONY INTERFACE

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.

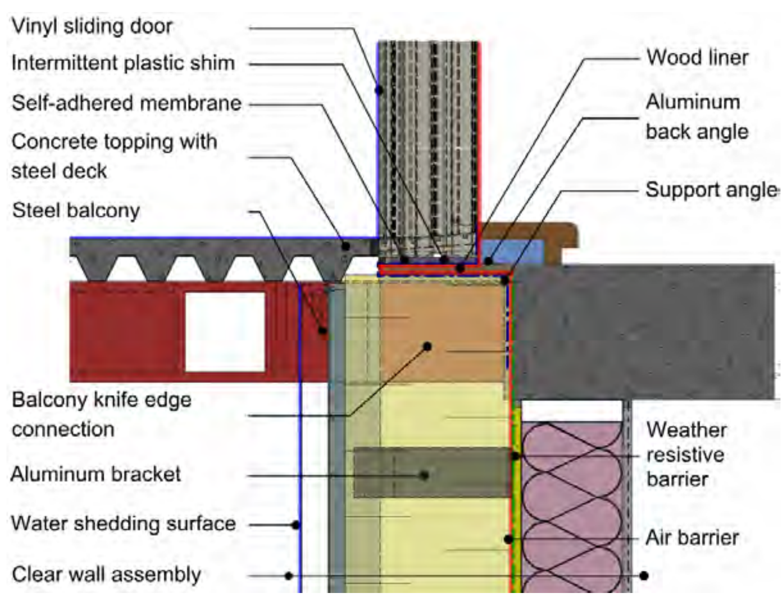




Door



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

Chapter 6

FUTURE HORIZONS

The Guide to Low Thermal Energy Demand Intensity (TEDI) for Large Buildings, or abbreviated to The Low TEDI Guide, is an initial attempt to provide insight into how high-rise residential buildings can meet low TEDI targets in Canada. There is no doubt that more examples will help practitioners efficiently and effectively optimize designs to meet low TEDI targets. For example, more analysis can be done to show how thermal bridging can be minimized for other construction types and details, such as for pre-cast concrete sandwich panels, as well as how the same principles can be applied to other non-combustible building type. Nevertheless, the concepts outlined in The Low TEDI Guide apply broadly and provide a starting point for a playbook on the integrated design of low TEDI buildings. The common understanding of what is needed and expected is likely the most challenging hurdle that a design team will face when presented with the opportunity to deliver a low TEDI Multi-unit Residential Buildings (MURB).

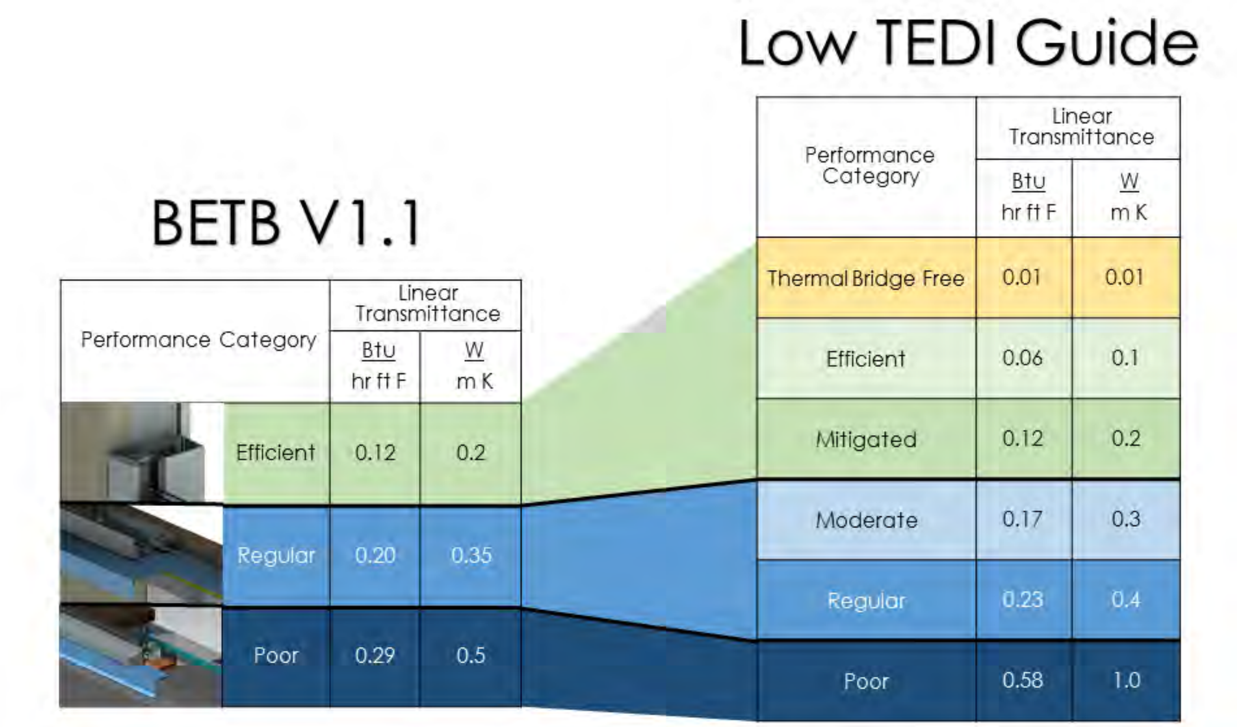
This final chapter summarizes the highlights of the Low TEDI Guide so that practitioners can start to implement these principles in practice, and provides examples of the impact of utilizing the concepts presented in Chapter 5.

Thermal Transmittances

An awareness of how thermal transmittance is determined by various approaches is helpful when using and comparing results from various sources. The key guidance from Chapter 2 are:

1. The window to wall interface demands the greatest attention for thermal transmittance calculations because of the potential variation in values and impact on the overall thermal transmittance.
2. Two-dimensional simplifications are sufficient for moderately conductive structures with simple heat flow paths, such as concrete structures with single insulation layers.
3. Three-dimensional analysis is recommended for thermal analysis of assemblies with highly conductive and complex heat flow paths, such as intermittent cladding attachments, metal framing intersections with multidirectional conductive heat flow paths, and for evaluating the risk of condensation at interface details.
4. Assumptions for air spaces and boundary conditions do not have a significant impact on opaque thermal transmittances. Thermal values from various sources with slight variations in assumptions are generally comparable for low TEDI buildings, except at the window to wall interface.
5. The biggest impact to realizing low thermal transmittance is the quality of the details and design teams aggressively minimizing thermal bridging.

Meeting low TEDI targets is difficult to achieve without higher thermal quality details as outlined in Chapter 5 and the examples at the end of this chapter. Using a detail that is categorized as "efficient" by the BETB Guide based on conventional practice will make meeting low TEDI targets difficult. Accordingly, adjusted performance categories are needed for low TEDI buildings to reflect higher expectations for linear transmittances. Figure 6.1 outlines the necessary refinements to the BETB performance categories to reflect the expectations of low TEDI buildings.



BETB V1.1

Performance Category	Linear Transmittance Btu / hr ft F	Linear Transmittance W / m K
Efficient	0.12	0.2
Regular	0.20	0.35
Poor	0.29	0.5

Low TEDI Guide

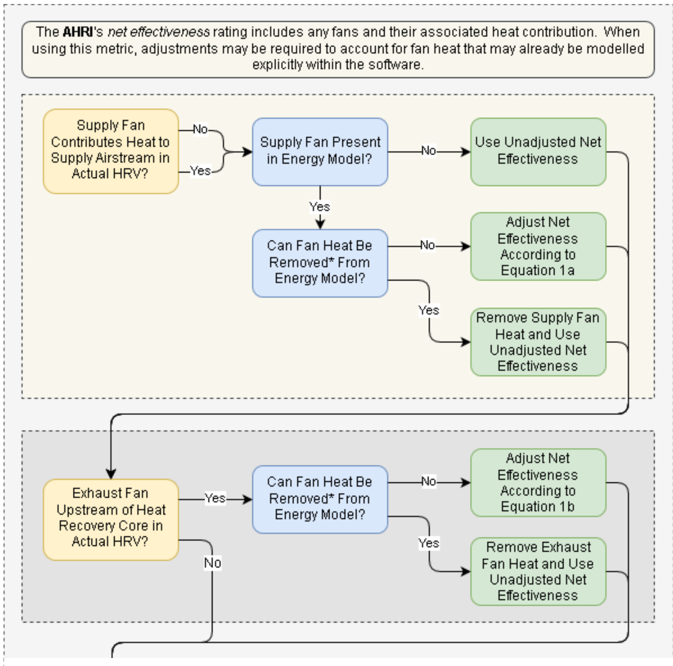
Performance Category	Linear Transmittance Btu / hr ft F	Linear Transmittance W / m K
Thermal Bridge Free	0.01	0.01
Efficient	0.06	0.1
Mitigated	0.12	0.2
Moderate	0.17	0.3
Regular	0.23	0.4
Poor	0.58	1.0

Figure 6.1: Refined Performance Categories for Low TEDI Expectations

Heat Recovery Ventilators (HRV) Protocols

Chapter 3 outlines how HRVs are critical to achieving low TEDI buildings and how focusing too much on protocol differences is not productive to realizing low TEDI buildings.

There is often no choice as to which standard to use, due to available data or project requirements, and a capable energy modeller is able to accurately model the energy-related impact using data derived from any of the protocols summarized by this Guide. However, an energy modeller needs to fully understand the objectives and context of the various standards.



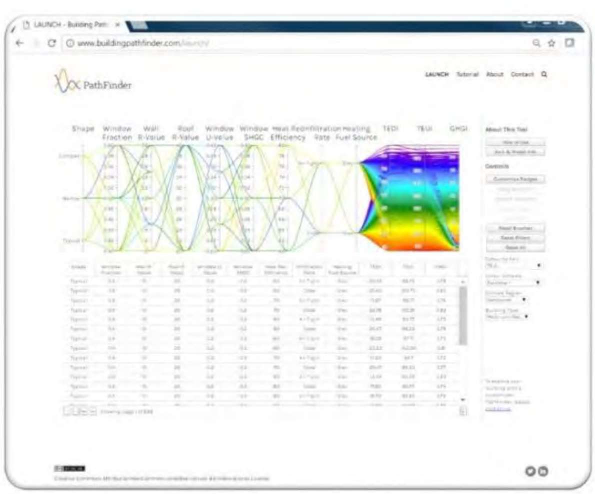
Chapter 4 has flow-charts that outline how to adjust fan power and model HRVs for various available metrics

The main difference between standards is the treatment of fan power. An energy modeller needs to understand the available metrics and energy modeling software so that the fan power efficiency can be adjusted appropriately, if required.

When available, the HVI standard is the easiest to use because it is the most commonly understood and can be directly simulated in commonly used software for whole building energy analysis of MURBs.

TEDI in the Context of Whole Building Energy

TEDI alone does not provide a complete representation of overall building energy consumption and EUI cannot be overlooked. Other building energy loads become increasingly important as TEDI is decreased. Capable software and engineering understanding is critical to capturing how energy use is impacted by the interaction of the various heating load components.



There are many paths to achieve a low TEDI building. Nevertheless, there are common requirements, such as minimized thermal bridging, highly insulated walls, high performance glazing, airtight assemblies, and HRVs. Chapter 4 provides some highlights and considerations per climate zone. Visit BuildingPathfinder.com to visually explore a wider range of design options to achieve low TEDI and EUI targets.

The Low TEDI Guide and BuildingPathfinder can help practitioners set expectations for performance levels of the building envelope and HRVs early in the design process and confirm by project specific calculations as the building design starts to take form.

Design and Construction

Chapter 5 discusses the design principles for large MURBs to meet Low TEDI Buildings. Requirements for Fire Protection and Combustibility, Environmental Separation, Structural Support, Durability, and Constructability are outlined using example details that minimize thermal bridging using methods and assemblies familiar to Canadian construction practice. Thermal transmittance values are provided with and without batt insulation in the stud cavity.

A fundamental question that will be asked during the early days of designing low TEDI MURBs will be how thick the walls need to be to meet the new targets. This will be more challenging to answer than in the past as the ultimate wall thickness is dependent on not only insulation effectiveness for the clear field assembly but also on the quantity and quality of interfaces between building components. The following examples highlight how this question can be answered, putting low TEDI transmittances into perspective, and highlight utilization of the values presented in Chapter 5.

The MURB presented in the examples has the following baseline characteristics:

- Based on the BETB Guide High-rise MURB architype
- 40 storey building with identical layouts and footprint on each floor
- Concrete structure with steel-framed infill per Chapter 5 assembly and details
- 30% glazing with 1.8 m x 1.5 m (6'x5') windows (windows varied in example 3)

EXAMPLE 1 – EXPECTATIONS FOR INTERFACE DETAILS

Essentially the expectations for linear transmittances should be an order of magnitude higher for low TEDI buildings than conventional practice if minimizing wall thickness is a consideration. For example, Figure 6.2 shows how a target of 0.28 W/m^{2}K (R-20 effective) for the opaque wall can be met for various combinations of transmittances and the impact on wall thickness. Only the window to wall (glazing) interface and clear field transmittances were varied for this example. All the other transmittances are constant using values from Chapter 5. This example does not include the impact of balconies, which is outlined in the following example.

The 0.28 W/m^{2}K target can only be met for the "Efficient Glazing Interface" scenario with a 492 mm (19.5 inch) thick wall and R-19 cavity insulation within the 6 inch steel studs. The window to wall interface linear transmittance for the "Efficient Glazing Interface" scenario is 0.1 W/m K. In comparison, this target can be met with a 16.5mm (14.5 inch) thick wall with R-19 cavity insulation or a 16.5 inch (416 mm) thick wall for a fully exterior insulated wall using any of the scenarios for Detail 4 in Chapter 5 (0.024 W/m K for the uninsulated stud cavity and 0.046 W/m K for the R-19 scenarios).

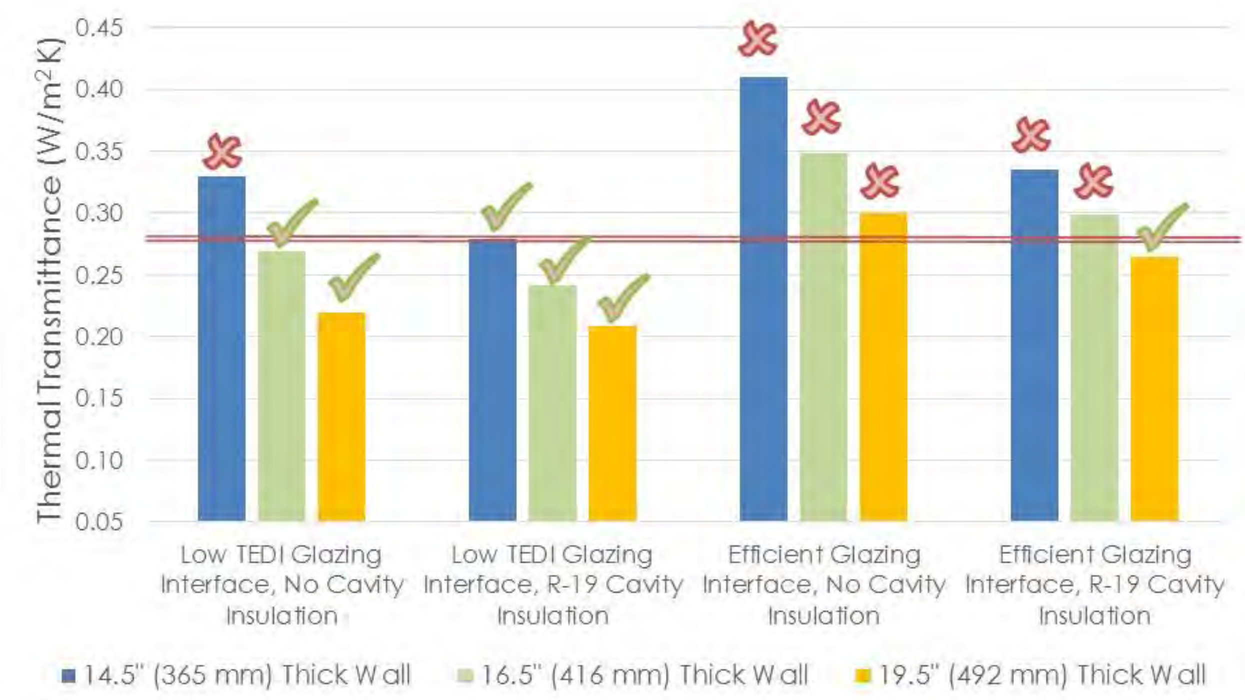


Figure 6.2: Impact of Window to Wall (Glazing) Interface Transmittance on Wall Thickness for a Target of 0.28 W/m²K (R-20 effective)[1]

For this example there is no rational wall thickness (i.e. greater than 1 m) that meets the 0.28 W/m²K target for a window to wall interface linear transmittance of 0.2 W/m K, which is the upper end of the "Efficient" Category in the BETB Guide Version 1.1 (2016) based on conventional practice. Recognition of this reality is part of the reason why the transmittance expectations for interface details needs to be refined for low TEDI buildings as outlined at the beginning of this chapter.

EXAMPLE 2 – IMPACT OF BALCONIES

Components such as balconies add thermal bridging that must be compensated for by thicker walls for fixed thermal transmittance targets. Accounting for thermal bridging related to intermittently attached balconies[2] is slightly more complicated than required for conventional cantilevered concrete balconies. The beam connection to intermediate floor and cable support are accounted for separately in the overall thermal transmittance calculation. Also, point transmittances are accounted for on a number of components basis, which takes more consideration for quantity take-offs than required for a linear value.

[1] The target is met when the thermal transmittance is below the red bar shown on the chart

[2] Values presented in Detail 5 in Chapter 5

A comparison between an intermittently attached and a cantilevered concrete balcony is presented in Figure 6.3 and Table 6.1. This example not only highlights the impact of balconies on the overall thermal transmittance but also shows how the transmittances values for Detail 5 can be incorporated into overall thermal transmittance calculations.

For the cantilevered concrete balcony scenario, the concrete slab bypasses the thermal insulation and the interface length is the width of the balcony. The beam and cable penetrations for the intermittently attached balcony are outlined in Figure 6.3.

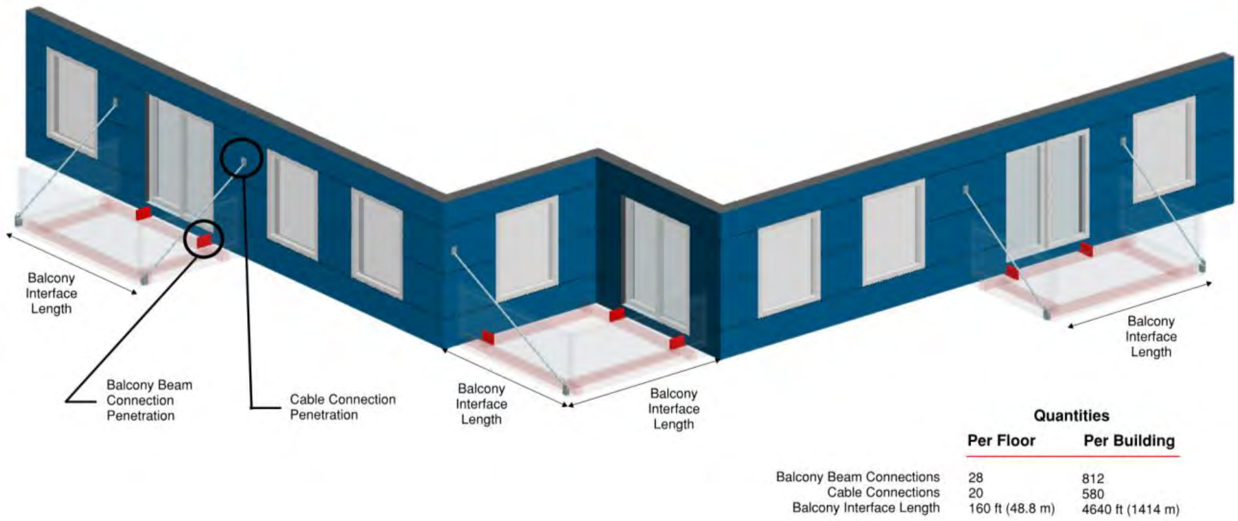


Figure 6.3: Balcony Layout and Quantities for a Floor for Example Thermal Transmittance Calculation (25% of floor shown)

Table 6.1: Comparison of the Impact of Intermittently Attached to Cantilevered Concrete Balconies for Low TEDI Glazing Interfaces and R-19 Cavity Insulation Scenarios

Scenario	Detail	Quantity	Transmittance Value	Heat Flow (W/K)	% Total Heat Flow	Overall Transmittance
Intermittently Attached Balcony	Clear Field	7087 m²	0.142 W/m²K	1004	56%	0.254 W/m²K (R-22 Effective)
	Beam Connection	812	0.271W/K	220	12%	
	Cable Connection	580	0.147 W/K	85	5%	
	Other Interfaces	-	-	488	27%	
Cantilevered Concrete Balcony	Clear Field	7087 m²	0.142 W/m²K	1004	36%	0.390 W/m²K (R-15 Effective)
	Balcony	1414 m	0.9 W/m K	1273	46%	
	Other Interfaces	-	-	488	18%	

The 0.28 W/m²K target can only be met with intermittently attached balconies using the low TEDI details with a 492 mm (19.5 inch) thick wall and R-19 cavity insulation as seen in Figure 6.4. The exterior insulation will need to be upwards of 330 mm (13 inches) thick or 572 mm (20.5 inches) total wall thickness for the "efficient glazing interface" scenario with R-19 cavity insulation to meet the 0.28 W/m²K target.

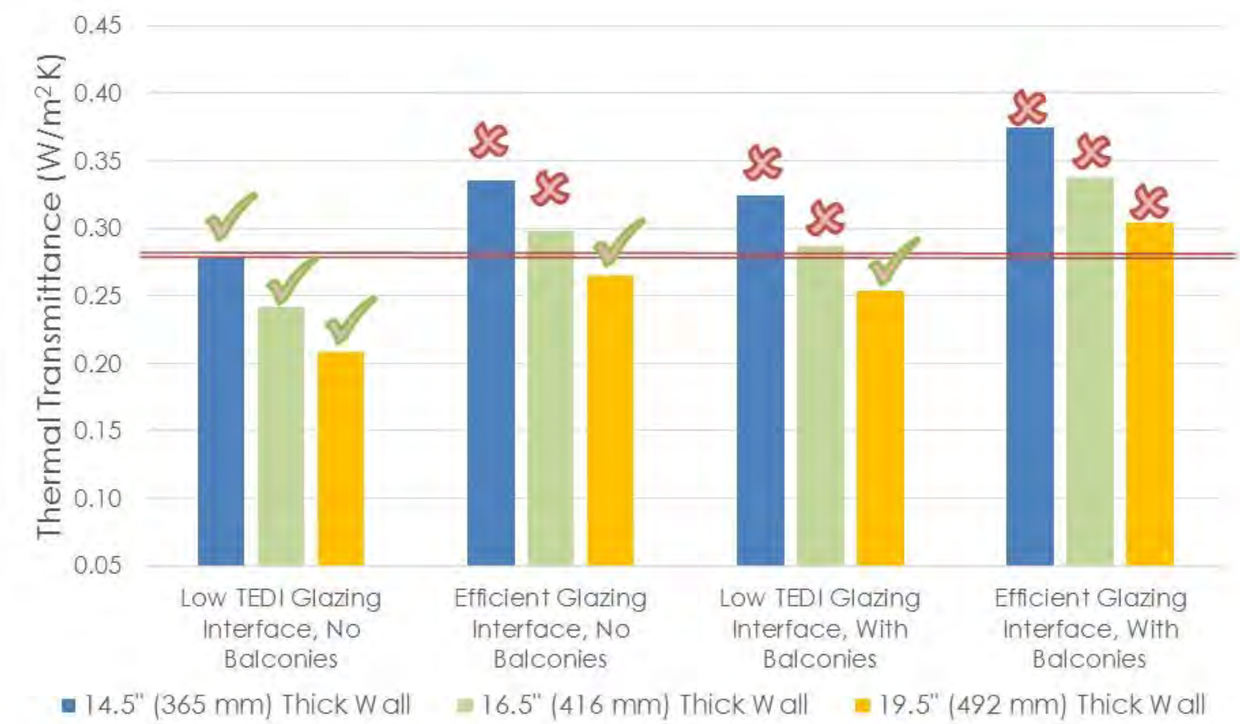


Figure 6.4: Impact of Balconies on Wall Thickness for a Target of 0.28 W/m²K (R-20 effective) for Low TEDI Glazing Interfaces and R-19 Cavity Insulation Scenarios

EXAMPLE 3 – IMPACT OF GLAZING SIZE

Minimizing the window perimeter and frame length by maximizing the size of glass per opening was introduced in Chapter 5 and is illustrated in the graphics above. Figure 6.5 outlines the impact of glazing size on thermal transmittance and overall wall thickness for a fixed glazing ratio of 30%. The only difference between the two scenarios is the difference in interface length for one window versus two smaller windows. All the scenarios have R-19 cavity insulation.

Similar to the impact of balconies, meeting the 0.28 W/m^{2}K target for the opaque walls is a challenge for the "efficient glazing interface" scenarios and the wall will need to be slightly thicker for the low TEDI glazing scenarios. Moreover, there are opportunities to refine and optimize opaque targets on projects in conjunction to the window thermal transmittances as outlined in Chapter 4 using whole building energy analysis.

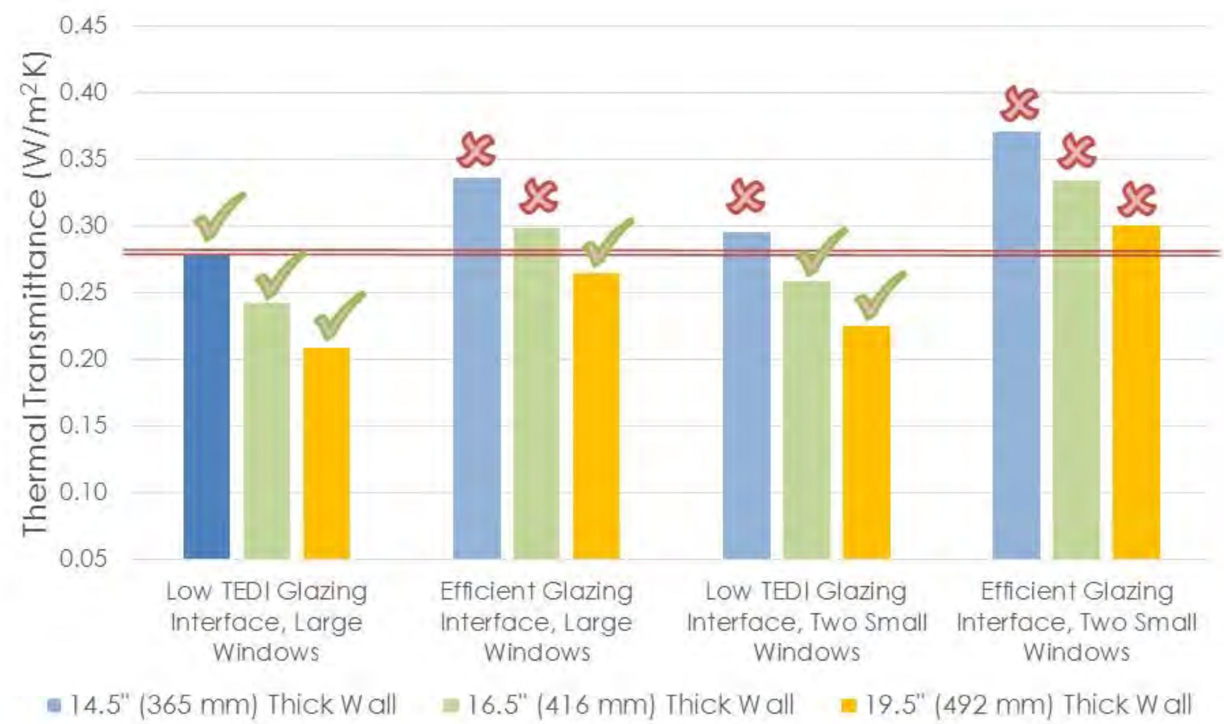


Figure 6.5: Impact of Window Size for a Fixed Glazing Ratio on Wall Thickness for a Target of 0.28 W/m^{2}K (R-20 effective)

References

ANSI/AHRI Standard 1060-2014. *Performance Rating of Air-to-Air Exchangers for Energy Recovery Ventilation Equipment*. Arlington, VA.

ANSI/NFRC 100-2014. *Procedure for Determining Fenestration Product U-Factors.* National Fenestration Rating Council, Inc. Greenbelt, MD.

ASHRAE. 2017. *ASHRAE Handbook—Fundamentals*. American Society of Heating, Refrigerating and Air-conditioning Engineers, Inc. Atlanta, Georgia.

ASHRAE. 2007. *ANSI/ASHRAE/IESNA Standard 90.1-2007, Energy Standard for Buildings except Low-Rise Residential Buildings*. American Society of Heating, Refrigerating and Air-conditioning Engineers, Inc. Atlanta, Georgia.

CAN/ULC-S114-2005. *Standard Method of Test for Determination of Non-combustibility in Building Materials*. Ottawa, Ontario.

CAN/ULC-S134-1992. *Standard Method of Fire Test of Exterior Wall Assemblies*. Ottawa, Ontario.

CAN/ULC-S135-2004. *Standard Method of Test for Determination of Degrees of Combustibility of Building Materials Using an Oxygen Consumption Calorimeter (Cone Calorimeter)*. Ottawa, Ontario.

CAN/CSA-C439-2009 (R2014). *Standard Laboratory Methods of Test for Rating the Performance of Heat/Energy Recovery Ventilators*. Ottawa, Ontario.

CAN/CSA-S478-1995 (R2007). *Guideline on Durability in Buildings*. Toronto, Ontario.

City of Toronto. 2017. *Toronto Green Standard.* Toronto, Ontario.

City of Toronto. 2017. *Zero Emissions Framework.* Toronto, Ontario.

City of Vancouver. 2016. *Zero Emissions Building Plan.* Vancouver, BC.

City of Vancouver. 2017. *Energy Modelling Guidelines.* Vancouver, BC.

Home Ventilation Institute (HVI) Publication 920. 2009. HVI Product Performance Certification Procedure Including Verification and Challenge. Wauconda, IL.

Integral Group, Morrison Hershfield, E3 Eco Group. 2017. *Energy Step Code – 2017 Metrics Research Full Report.* BC Housing. Burnaby, BC. https://www.bchousing.org/research-centre/library/residential-design-construction

ISO 10077-2:2003 (E). *Thermal performance of windows, doors and shutters – Calculation of thermal transmittance – Part 2: Numerical method for frames.* Geneva, Switzerland.

ISO 10211:2007 (E). *Thermal bridges in building construction – Heat flows and surface temperatures – Detailed calculations.* Geneva, Switzerland.

ISO 13823:2008. *General principles on the design of structures for durability.* Geneva, Switzerland.

ISO 14683:2007. *Thermal Bridges in Building Construction - Linear Thermal Transmittance - Simplified Methods and Default Values.* Geneva, Switzerland.

ISO 6949:2007. *Building Components and Building Elements - Thermal Resistance and Thermal Transmittance - Calculation Method.* Geneva, Switzerland.

Morrison Hershfield Limited. 2016. *Building Envelope Thermal Bridging Guide.* BC Hydro. Vancouver, BC. www.bchydro.com/thermalguide

Morrison Hershfield Limited. 2017. Passive Cooling Measures for Multi-Unit Residential Buildings. Final Report. Vancouver, BC.

National Research Council of Canada. 2015. National Building Code of Canada 2015. Ottawa, Ontario.

National Research Council of Canada. 2011. *National Energy Code of Canada for Buildings.* Second Edition. Ottawa, Ontario.

Norris, N., Carbary, L. D., Yee, S., Roppel, P., & Ciantar, P. 2015. "The Reality of Quanitfying Curtain Wall SPandrel Thermal Performance: 2D, 3D and Hotbox Testing". Proceedings of 4th BEST Confernce *Building Enclosure Science and Technology (Best 4).* Kanas City, Missouri.

OGBS. 2017. *Building Pathfinder.* http://www.buildingpathfinder.com/

Passive House Institute (PHI). 2009. Requirements and testing procedures for energetic and acoustical assessment of Passive House ventilation systems > 600 m^3/h for Certification as "Passive House suitable component". Darmstadt, Germany. http://www.passivehouse.com/

Passive House Institute (PHI). 2016. *Criteria for the Passive House, EnergPHit and PHI Low Energy Building Standard. Version 9f* Darmstadt, Germany. http://www.passivehouse.com/

Passive House Institute US (PHIUS). 2015. *PHIUS Technical Committee ERV/HRV Modeling Protocols.* PHIUS Tech Corner. Chicago, IL. www.phius.org

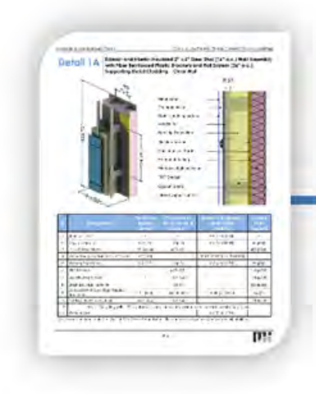
Province of British Columbia. 2017. *BC Energy Step Code.* Victoria, BC.

RDH Building Engineering Ltd. 2012. *Energy Consumption and Conservation in Mid- and High-Rise Multi-Unit Residential Buildings in British Columbia.* Vancouver, BC. https://www.bchousing.org/research-centre/library/building-science-reports

RDH Building Engineering Ltd. 2014. *International Window Standards – Final Report.* Vancouver, BC https://www.bchousing.org/research-centre/library/building-science-reports

RDH Building Science Inc. 2017. *Illustrated Guide: Achieving Airtight Buildings.* BC Housing. Burnaby, BC. https://www.bchousing.org/research-centre/library/residential-design-construction

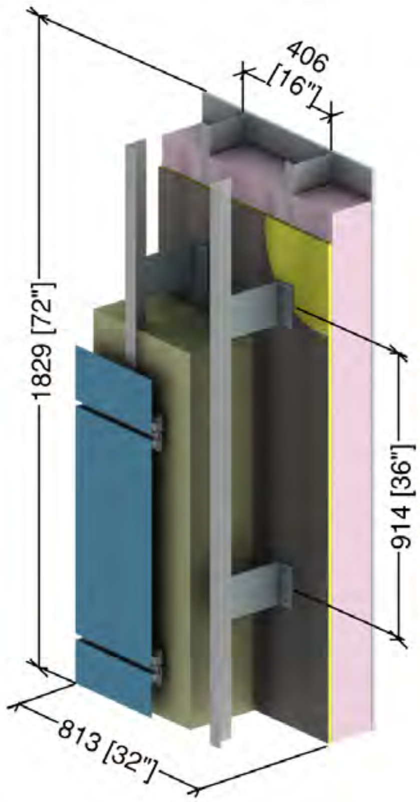
Roppel, P., Lawton, M. 2011. Thermal Performance of Building Envelope Details for Mid- and High-Rise Buildings. *ASHRAE Research Project 1365-RP Final Report*. American Society of Heating, Refrigerating and Air-conditioning Engineers, Inc. Atlanta, Georgia.

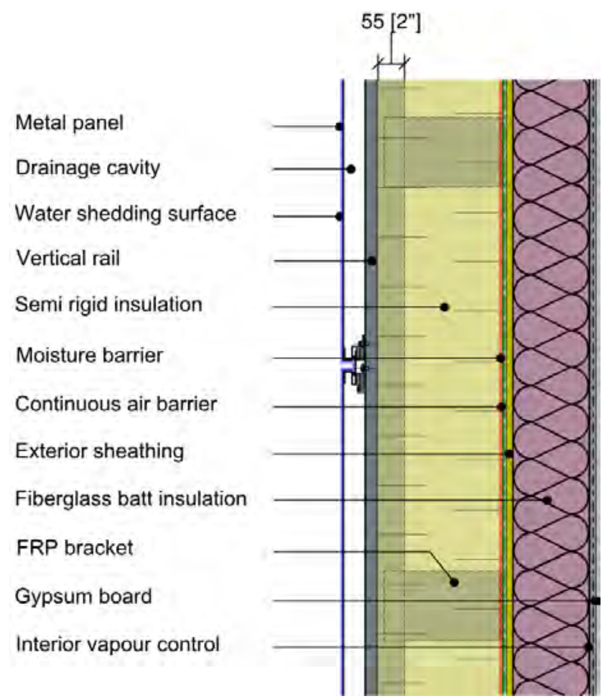


Appendix A

MATERIAL DATA SHEETS

Detail A | Clear Wall

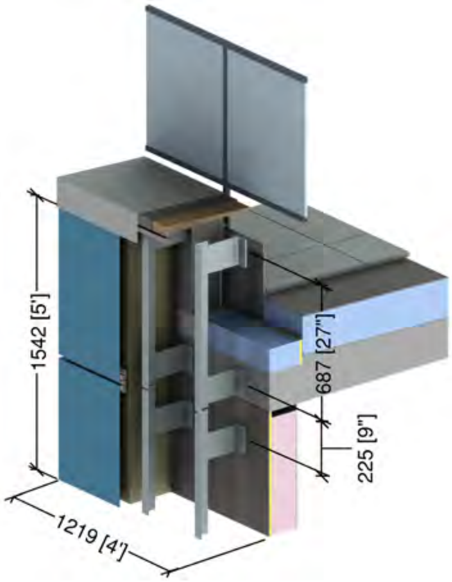


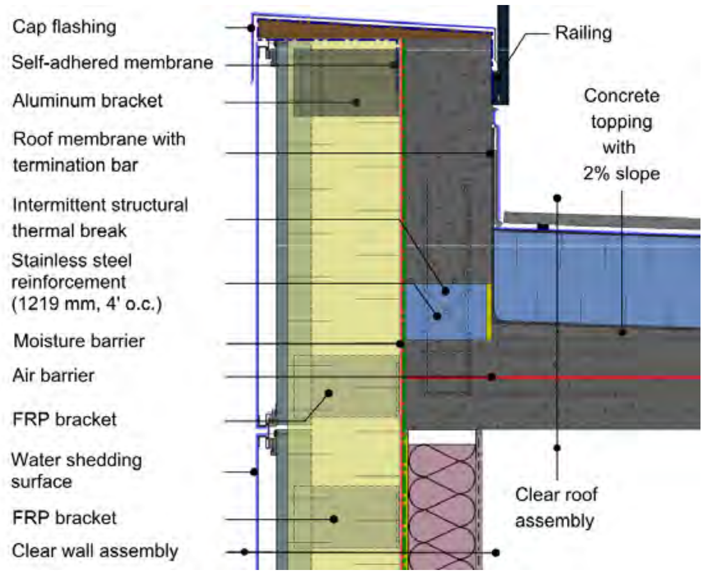


ID	Component	Thickness Inches (mm)	Conductivity Btu·in / ft²·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)
1	Interior Films[1]	-	-	R-0.7 (0.12 RSI)	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)
3	2" x 6" Steel Studs	18 Gauge	430 (62)	-	489 (7830)
4	Air or Fiberglass Batt in Stud Cavity	6" (152)	-	R-0.9, R-19 (0.16, 3.35 RSI)	-
5	Exterior Sheathing	1/2" (13)	1.1 (0.16)	R-0.6 (0.10 RSI)	50 (800)
6	FRP Bracket	-	4.85 (0.7)	-	110 (1760)
7	Aluminum Bracket	-	1109 (160)	-	171 (2739)
8	Stainless Steel Fastener	-	118 (17)	-	500 (8000)
9	Mineral Wool Semi Rigid Exterior Insulation	10" (254)	0.24 (0.034)	R-42 (7.40 RSI)	4.5 (72)
10	Vertical Aluminum L-Rail	0.09" (2.2)	1109 (160)	-	171 (2739)
11	Metal Cladding with 1/2" vented airspace incorporated into exterior heat transfer coefficient				
12	Exterior Film[1]	-	-	R-0.7 (0.12 RSI)	-

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

Detail 1 | Wall to Roof Interface

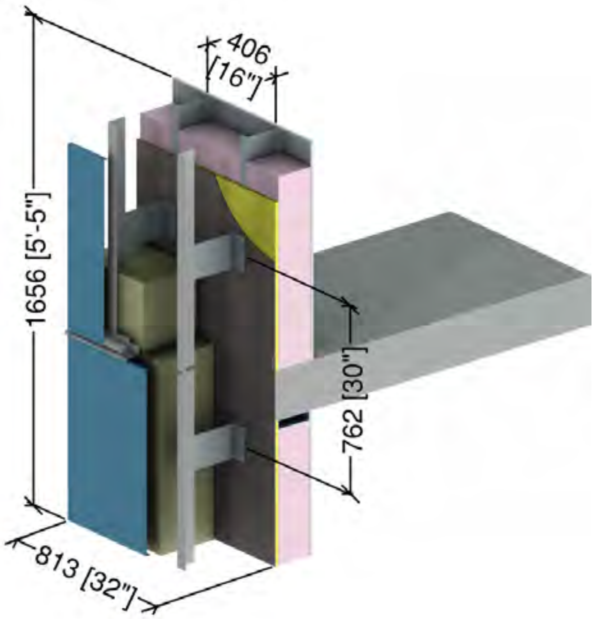


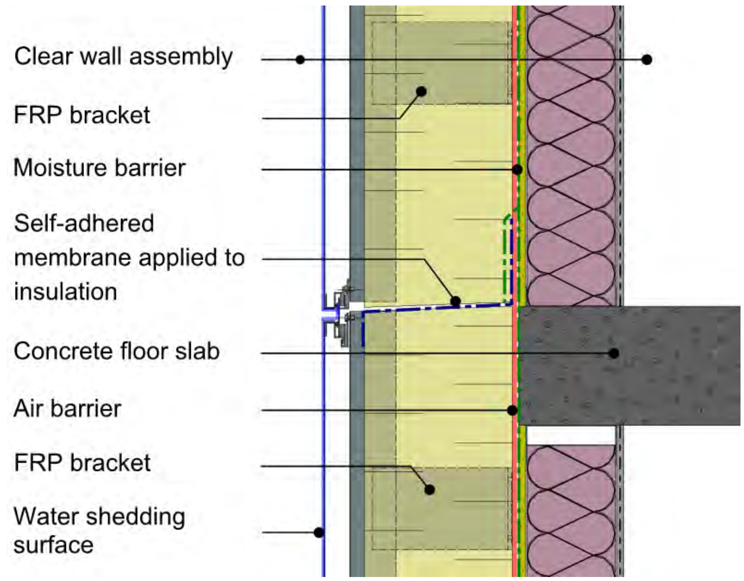


ID	Component	Thickness Inches (mm)	Conductivity Btu·in/ft²·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)
1	Interior Film[1]	-	-	R-0.6 (0.11 RSI) to R-0.7 (0.12 RSI)	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)
3	2" x 6" Steel Studs with Top Track	18 Gauge	430 (62)	-	489 (7830)
4	Air or Fiberglass Batt in Stud Cavity	6" (152)	-	R-0.9, R-19 (0.16, 3.35 RSI)	-
5	Exterior Sheathing	1/2" (13)	1.1 (0.16)	R-0.6 (0.10 RSI)	50 (800)
6	FRP Bracket	-	4.85 (0.7)	-	110 (1760)
7	Aluminum Bracket	-	1109 (160)	-	171 (2739)
8	Semi Rigid Exterior Insulation	10" (254)	0.24 (0.034)	R-42 (7.40 RSI)	4.5 (72)
9	Vertical Aluminum L-Rail	0.09" (2.2)	1109 (160)	-	171 (2739)
10	Metal Cladding with 1/2" vented airspace incorporated into exterior heat transfer coefficient				
11	Concrete Slab and Parapet	8" (203)	12.5 (1.8)	-	140 (2250)
12	Stainless Steel Rebar	-	118 (17)	-	48.1 (7700)
13	Polystyrene Foam Insulation	5" (127)	0.22 (0.031)	R-22 (3.87 RSI)	66 (1060)
14	Wood Blocking	5/8" (16)	0.69 (0.10)	R-1.0 (0.18 RSI)	31 (500)
15	Aluminum Cap Flashing	18 Gauge	1109 (160)	-	171 (2739)
16	Rigid Roof Insulation	8" (203)	0.20 (0.029)	R-40 (7.04 RSI)	1.8 (28)
17	Flashing & roof finish material are incorporated into exterior heat transfer coefficient				
18	Exterior Film[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

Detail 2 | Intermediate Floor Intersection

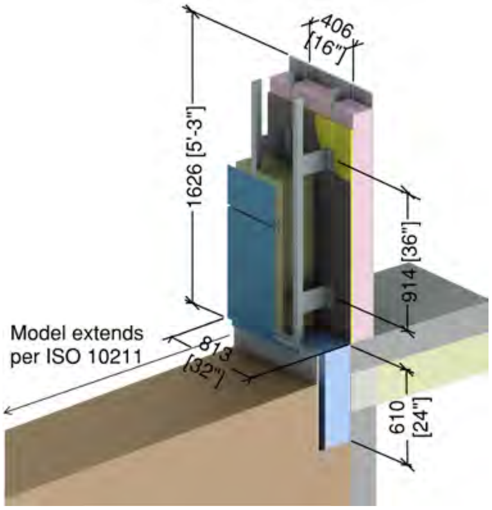


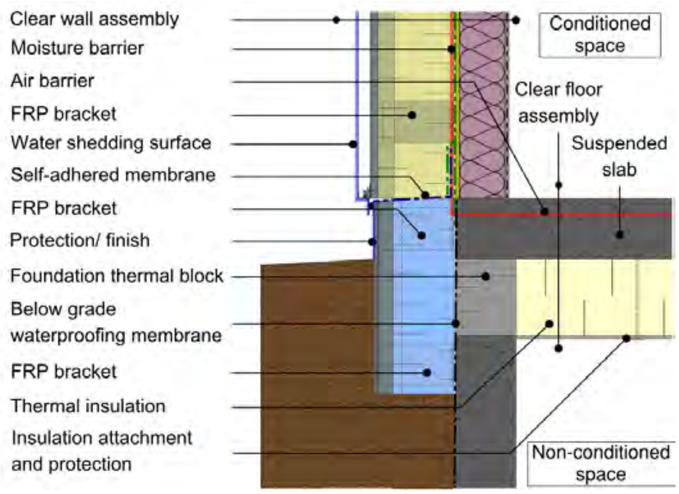


ID	Component	Thickness Inches (mm)	Conductivity Btu·in/ft²·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)
1	Interior Films[1]	-	-	R-0.6 (0.11 RSI) to R-0.9 (0.16 RSI)	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.09 RSI)	50 (800)
3	2" x 6" Steel Studs with Tracks	18 Gauge	430 (62)	-	489 (7830)
4	Air or Fiberglass Batt in Stud Cavity	6" (152)	-	R-0.9, R-19 (0.16, 3.35 RSI)	-
5	Exterior Sheathing	1/2" (13)	1.1 (0.16)	R-0.6 (0.10 RSI)	50 (800)
6	FRP Bracket	-	4.85 (0.7)	-	110 (1760)
7	Mineral Wool Semi Rigid Exterior Insulation	10" (254)	0.24 (0.034)	R-42 (7.40 RSI)	4.5 (72)
8	Vertical Aluminum L-Rail	0.09" (2.2)	1109 (160)	-	171 (2739)
9	Concrete Slab	8" (203)	12.5 (1.8)	-	140 (2250)
10	Metal Cladding with 1/2" vented airspace incorporated into exterior heat transfer coefficient				
11	Exterior Film[1]	-	-	R-0.7 (0.12 RSI)	-

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

Detail 3 | At-Grade to Below-Grade Parking Garage Interface

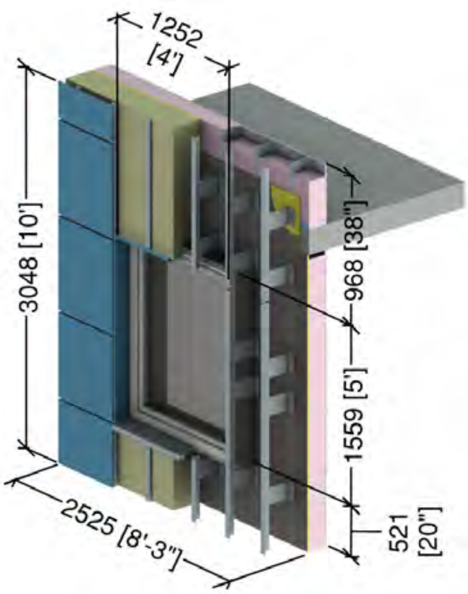


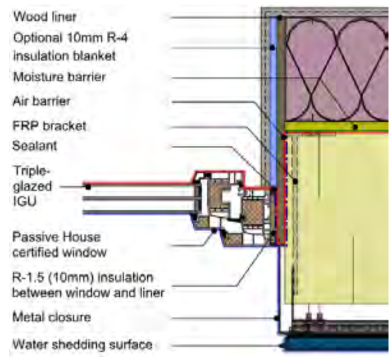


ID	Component	Thickness Inches (mm)	Conductivity Btu·in/ft²·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)
1	Interior Film[1]	-	-	R-0.7 (0.12 RSI) to R-0.9 (0.16 RSI)	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)
3	2" x 6" Steel Studs with Tracks	18 Gauge	430 (62)	-	489 (7830)
4	Air or Fiberglass Batt in Stud Cavity	6" (152)	-	R-0.9, R-19 (0.16, 3.35 RSI)	-
5	Exterior Sheathing	1/2" (13)	1.1 (0.16)	R-0.6 (0.10 RSI)	50 (800)
6	FRP Bracket	-	4.85 (0.7)	-	110 (1760)
7	Semi Rigid Exterior Insulation	10" (254)	0.24 (0.034)	R-42 (7.40 RSI)	4.5 (72)
8	Vertical Aluminum L-Rail	0.09" (2.2)	1109 (160)	-	171 (2739)
9	Metal Cladding with 1/2" vented airspace incorporated into exterior heat transfer coefficient				
10	Aluminum Flashing	18 Gauge	1109 (160)	-	171 (2739)
11	Concrete Foundation	8" (203)	12.5 (1.8)	-	140 (2250)
12	Foundation Thermal Block	8" (203)	0.20 (0.029)	R-40 (7.04 RSI)	1.8 (28)
13	Slab Insulation	10" (254)	0.24 (0.034)	R-42 (7.40 RSI)	4.5 (72)
14	Gypsum Thermal Protection Board	1/2" (13)	1.1 (0.16)	R-0.6 (0.10 RSI)	50 (800)
15	Below Grade Rigid Insulation	8" (203)	0.20 (0.029)	R-40 (7.04 RSI)	1.8 (28)
16	Cement Protection Board	1/2" (13)	12.5 (1.8)	-	140 (2250)
17	Soil	-	15.6 (2.25)	-	-
18	Exterior Film[1]	-	-	R-0.2 (0.03 RSI) to R-0.7 (0.12 RSI)	-

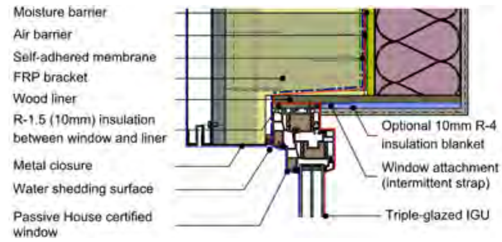
[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation

Detail 4 | Window to Wall Interface

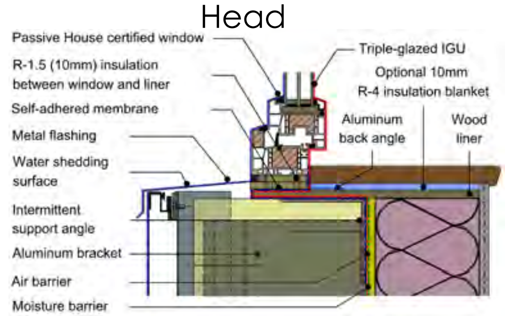




Jamb



Head

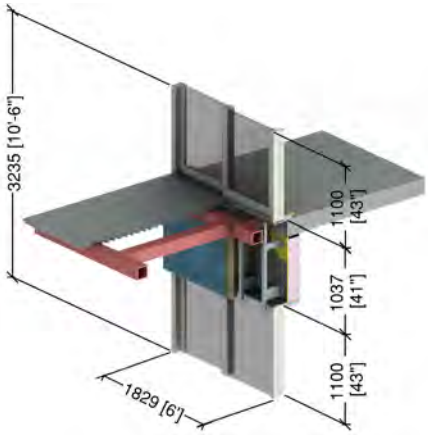


Sill

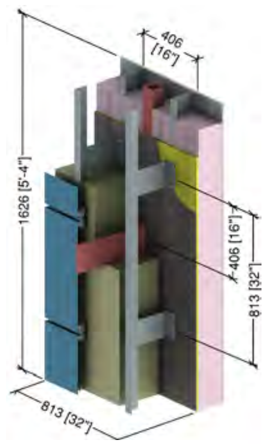
ID	Component	Thickness Inches (mm)	Conductivity Btu·in/ft²·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)
1	Interior Film[1]	-	-	R-0.6 (0.11 RSI) to R-1.1 (0.20 RSI)	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)
3	2" x 6" Steel Studs with Tracks	18 Gauge	430 (62)	-	489 (7830)
4	Air or Fiberglass Batt in Stud Cavity	6" (152)	-	R-0.9, R-19 (0.16, 3.35 RSI)	-
5	Exterior Sheathing	1/2" (13)	1.1 (0.16)	R-0.6 (0.10 RSI)	50 (800)
6	FRP Bracket	-	4.85 (0.7)	-	110 (1760)
7	Aluminum Bracket	-	1109 (160)	-	171 (2739)
8	Semi Rigid Exterior Insulation	10" (254)	0.24 (0.034)	R-42 (7.40 RSI)	4.5 (72)
9	Vertical Aluminum L-Rail	0.09" (2.2)	1109 (160)	-	171 (2739)
10	Metal Cladding with 1/2" vented airspace incorporated into exterior heat transfer coefficient				
11	5' (1.5m) x 4' (1.2m) Vinyl window: thermally broke, triple glazed IGU[2] U_{IGU} = 0.13 BTU/hr·ft²·°F (0.72 W/m²K)				
12	Aerogel Insulation Blanket	3/8" (10)	0.10 (0.014)	R-4.1 (0.71 RSI)	12.5 (200)
13	Wood Liner	1/2" (13)	0.69 (0.10)	R-1.0 (0.18 RSI)	31 (500)
14	Concrete Slab	8" (203)	12.5 (1.8)	-	140 (2250)
15	Aluminum Flashing	18 Gauge	1109 (160)	-	171 (2739)
16	Exterior Film[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 was found using ISO 100077-2

Detail 5 | Door with Intermittently Attached Balcony Interface



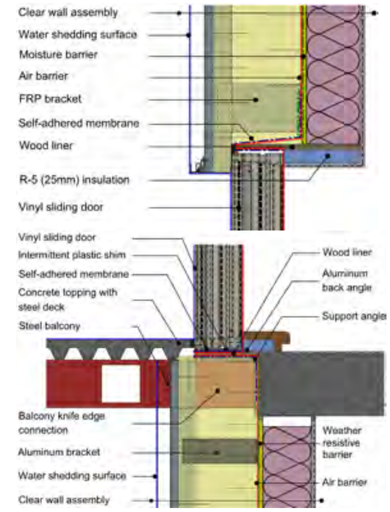
Metal Balcony connection



Cable support connection

Door

Balcony Door Sill



ID	Component	Thickness Inches (mm)	Conductivity Btu·in/ft²·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)
1	Interior Film[1]	-	-	R-0.6 (0.11 RSI) to R-1.1 (0.20 RSI)	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)
3	2" x 6" Steel Studs with Tracks	18 Gauge	430 (62)	-	489 (7830)
4	Air or Fiberglass Batt in Stud Cavity	6" (152)	-	R-0.9, R-19 (0.16, 3.35 RSI)	-
5	Exterior Sheathing	1/2" (13)	1.1 (0.16)	R-0.6 (0.10 RSI)	50 (800)
6	FRP Bracket	-	4.85 (0.7)	-	110 (1760)
7	Aluminum Bracket	-	1109 (160)	-	171 (2739)
8	Mineral Wool Semi Rigid Exterior Insulation	10" (254)	0.24 (0.034)	R-42 (7.40 RSI)	4.5 (72)
9	Vertical Aluminum L-Rail	0.09" (2.2)	1109 (160)	-	171 (2739)
10	Metal Cladding with 1/2" vented airspace incorporated into exterior heat transfer coefficient				
11	Concrete Slab	8" (203)	12.5 (1.8)	-	140 (2250)
12	Wood Liner	1/2" (13)	0.69 (0.10)	R-1.0 (0.18 RSI)	31 (500)
13	Steel Support Angle	1/2" (13)	430 (62)	-	489 (7830)
14	Steel Balcony Framing	5/8" (16)	430 (62)	-	489 (7830)
15	Concrete Balcony Topping	2.5" (64)	12.5 (1.8)	-	140 (2250)
16	Aluminum Back Angle	0.09" (2.2)	1109 (160)	-	171 (2739)
17	Thermally broken vinyl sliding door[2], triple glazed IGU U_{IGU} = 0.13 BTU/hr·ft^2·°F (0.72 W/m^{2}K)				
18	Steel Column and Knife Edge	5/8" (16)	430 (62)	-	489 (7830)
19	Exterior Film[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
[2] The thermal conductivity of air spaces was found using ISO 100077-2

$$\Delta T_{SF} = \frac{W_{SF}}{\dot{m}C_p}$$

Appendix B

HRV Correction Derivations

Adjusted HRV Efficiency

The equivalent efficiency is calculated such that after fan heat is added or removed by the energy modelling program, the same set of temperatures will result at rated conditions as those seen in the HVI or other testing.

The temperatures, powers and flows used here are at rated conditions and should be available from the documentation provided by the testing authority (HVI, AHRI, etc). The equations used to derive the equations for heat recovery adjustment are as follows:

The adjustments all start with the equation for efficiency from CSA/HVI:

$$\varepsilon_{Rated}(SRE) = \frac{\Delta T_{2-1}}{\Delta T_{3-1} + \Delta T_{EF}} \qquad \text{(Equation B.1)}$$

Several terms are not shown here because they will be zero or are specifically removed to avoid credit for undesirable affects. See HRV chapter for more background. The desired adjustment is applied to give the following, now including supply fan heat:

$$\varepsilon_{Rated} = \frac{\Delta T_{2-1} + \Delta T_{SF}}{\Delta T_{3-1} + \Delta T_{EF}} - Correction$$

Rearranging, we get:

$$Correction = \frac{\Delta T_{2-1} + \Delta T_{SF}}{\Delta T_{3-1} + \Delta T_{EF}} - \varepsilon_{Rated}$$

This simplifies to:

$$Correction = \frac{\Delta T_{SF}}{\Delta T_{3-1} + \Delta T_{EF}}$$

Then, given the following, we can derive a version relating the correction to fan power:

$$W_{Fan} = \frac{1.08 \times cfm \times \Delta T}{3.41214}$$

Where:

$W_{Fan} = Total\ rated\ power\ of\ supply\ or\ exhaust\ fan\ at\ rated\ conditions$

$\Delta T = Temperature\ rise\ of\ airstream\ assuming\ all\ fan\ energy\ to\ the\ airstream$

The other values are conversion factors. We arrive at:

$$Correction = \frac{\left(\frac{W_{SF}}{cfm}\right)}{12.5497 + \left(\frac{W_{EF}}{cfm}\right)} \qquad \text{(Equation B.2)}$$

The other corrections are derived in a similar manner starting with exhaust fan corrected using:

$$\varepsilon_{Rated} = \frac{\Delta T_{2-1}}{\Delta T_{3-1}} - Correction$$

Leading to:

$$Correction = \frac{\Delta T_{2-1}}{\Delta T_{3-1}} - \varepsilon_{Rated}$$

$$Correction = \varepsilon_{Rated} \times \left(\frac{W_{EF}}{cfm}\right) \times 0.07968$$ (Equation B.3)

Equations for simultaneously adding supply fan and removing exhaust fans may not be required, and provide similar results, but are as follows:

$$\varepsilon_{Rated} = \frac{\Delta T_{2-1} + \Delta T_{SF}}{\Delta T_{3-1}} - Correction$$

$$Correction = \frac{\Delta T_{2-1} + \Delta T_{SF}}{\Delta T_{3-1}} - \varepsilon_{Rated}$$

Leading to:

$$Correction = 0.07968 \times \left(\varepsilon_{Rated} \times \left(\frac{W_{EF}}{cfm}\right) + \left(\frac{W_{SF}}{cfm}\right)\right)$$ (Equation B.4)

Correction for simultaneously removing supply fan and exhaust fan are as follows:

$$\varepsilon_{Rated} = \frac{\Delta T_{2-1} - \Delta T_{SF}}{\Delta T_{3-1}} - Correction$$

$$Correction = \frac{\Delta T_{2-1} - \Delta T_{SF}}{\Delta T_{3-1}} - \varepsilon_{Rated}$$

Leading to:

$$Correction = 0.07968 \times \left(\varepsilon_{Rated} \times \left(\frac{W_{EF}}{cfm}\right) - \left(\frac{W_{SF}}{cfm}\right)\right)$$ (Equation B.5)