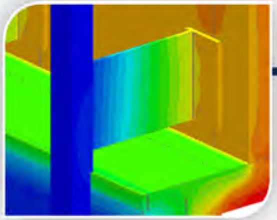


METHODOLOGIES FOR DETERMINING THERMAL TRANSMITTANCE

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.

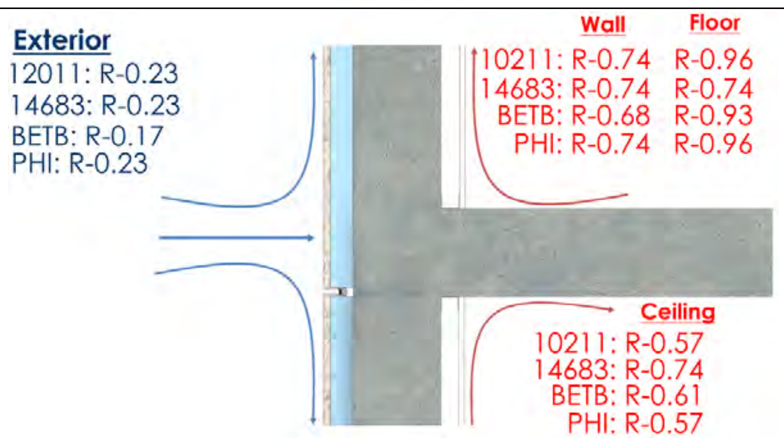
Table 2.1 provides a high level overview of the procedures and parameters that can impact thermal transmittance calculations. The procedure and parameters are categorized either as minor differences or potentially significant differences for the various methodologies discussed in this chapter.

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

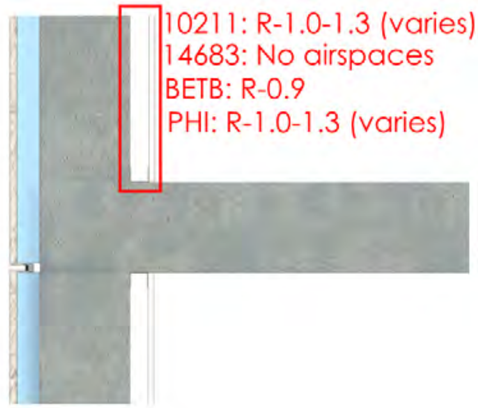
Minor Differences	Potential Significant Differences
Boundary conditions and airspaces	Window to wall interface
Interior vs exterior dimensions	Two-dimensional (2D) and geometry simplifications
Cut-off planes	Contact resistance
Slab-on-grade heat loss	Designs and details to minimize thermal bridging

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>

<table>
<tr><th colspan="2">Procedure or Parameter</th><th>Impact on Thermal Transmittance</th></tr>
<tr><td>Air Spaces</td><td>



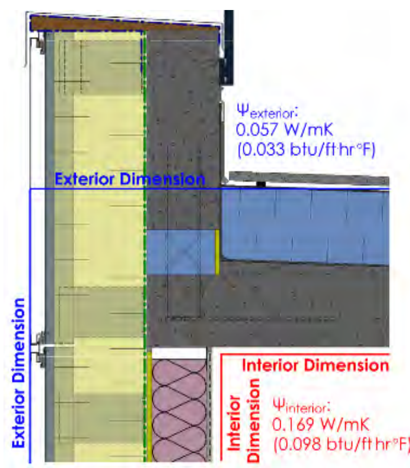
</td><td>Less than 2% impact on clear field U-value and linear transmittances for insulated assemblies > R-5 (RSI-0.88).</td></tr>
<tr><td>Interior vs Exterior Dimension Values</td><td>

10211 allows for either approach

14683 provides values for interior, exterior and midplane dimensions

BETB Guide provides values for interior dimensions

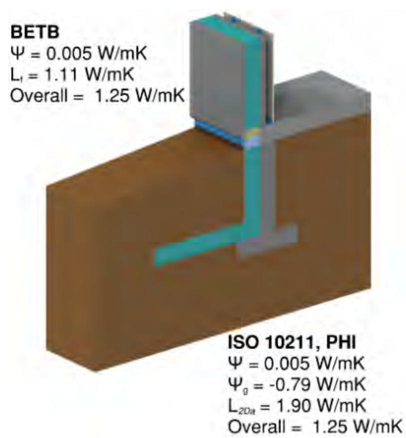
PHI uses exterior dimensions



</td><td>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.</td></tr>
<tr><td>Slab-on-Grade Values</td><td>

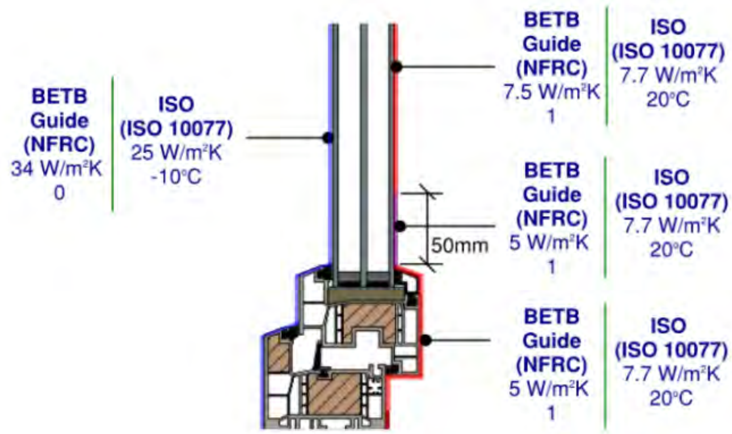
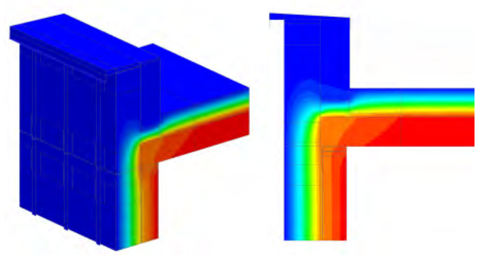
ISO 10211, PHI splits the thermal transmittance through the floor slab (L_{2Da}) and perimeter footing thermal transmittance (Ψ_g) as two separate values. The at-grade interface between the footing and wall is presented as a separate linear transmittance (Ψ).

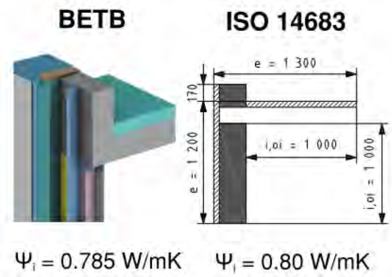


ISO 14683 provides Ψ values for the at-grade interface only.

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.

</td><td>No difference, except how values are presented and inputted into calculations.</td></tr>
</table>

	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**.

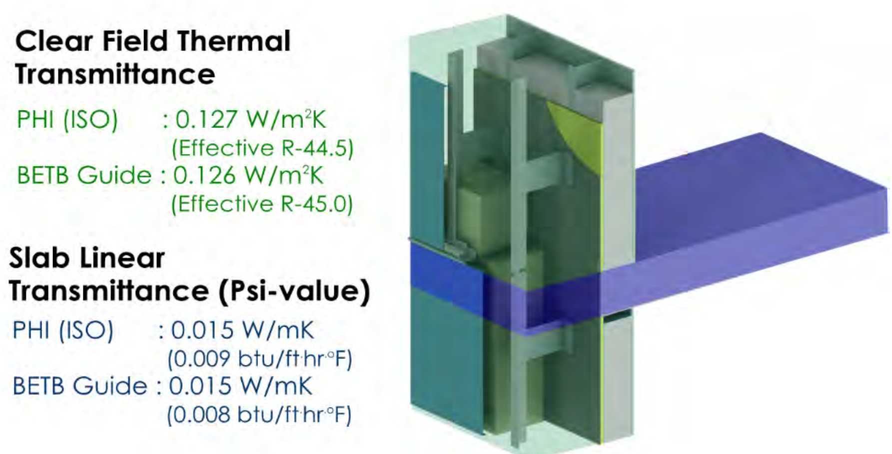


Figure 2.1: Example Differences in Thermal Transmittance due to Varying Boundary Conditions at an Intermediate Concrete Floor

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.

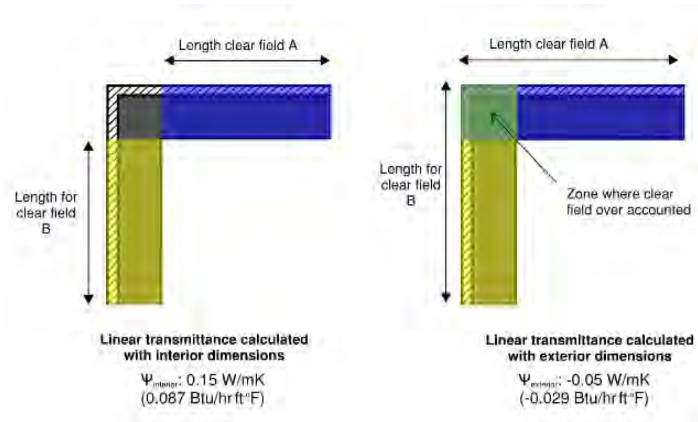
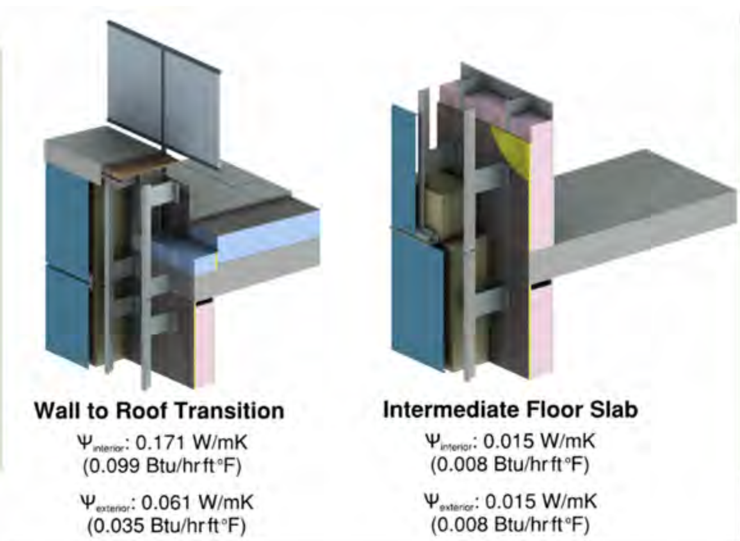


Figure 2.2: Interior versus Exterior Dimensions for Thermal Transmittance Calculations

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.

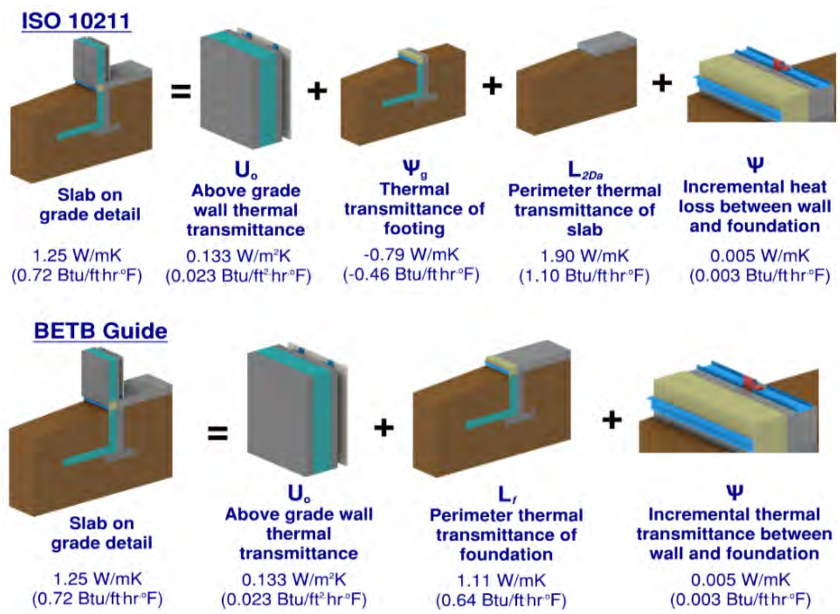
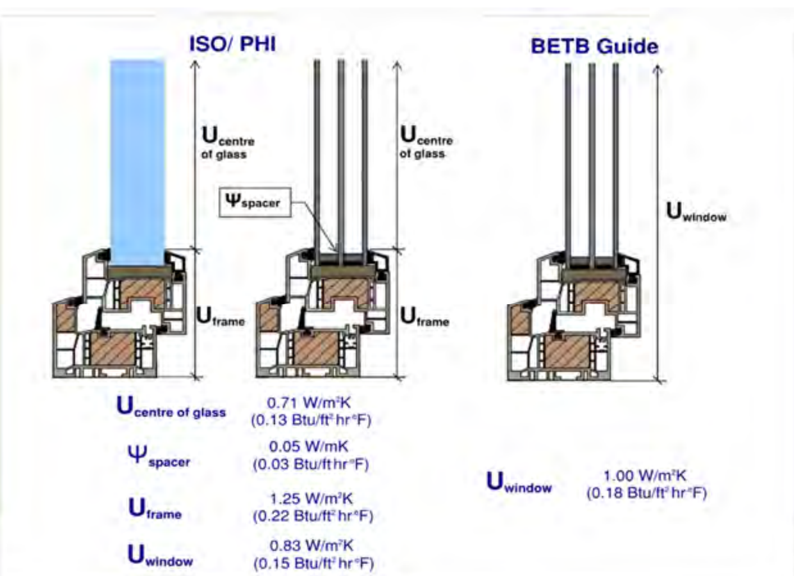


Figure 2.3: Approaches to Ground Heat Flow

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.

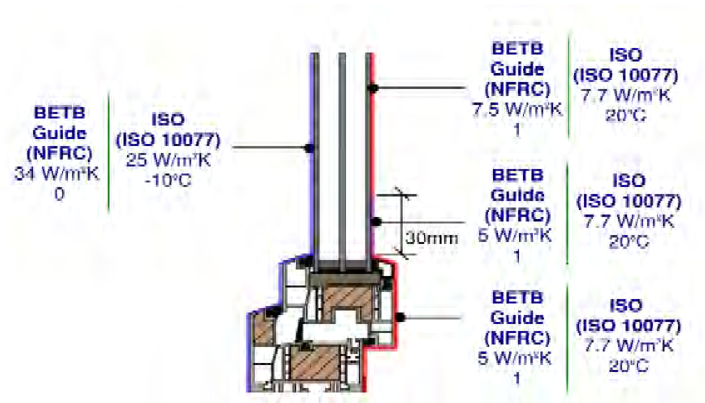
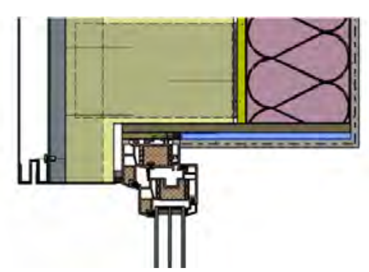


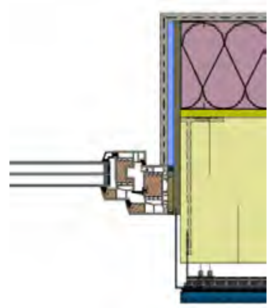
Figure 2.4: Glazing Air Films for PHI and BETB

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**.

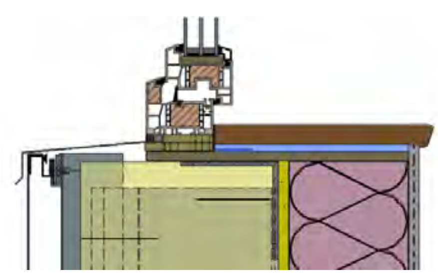
Table 2.3: Comparison of Window to Wall Interface Transmittances



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**.

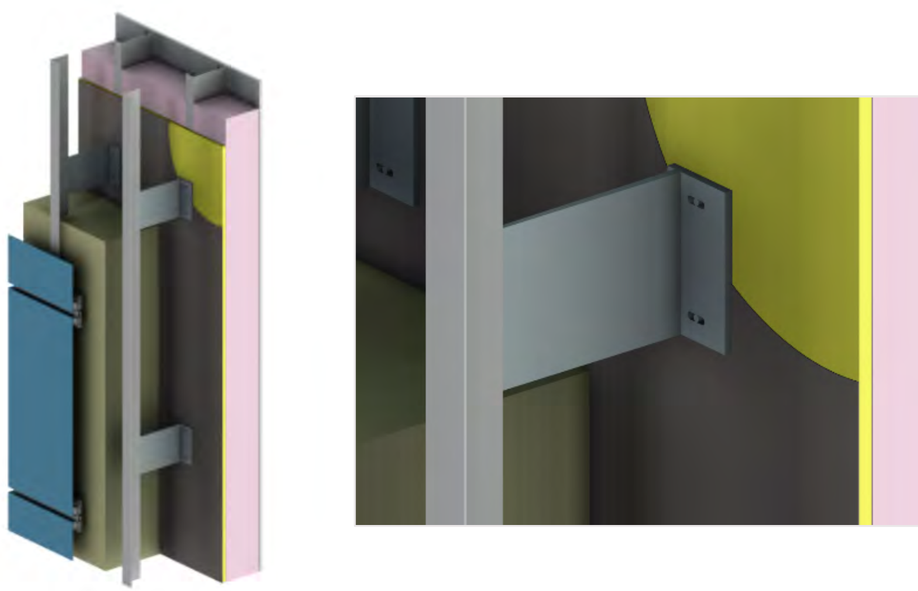
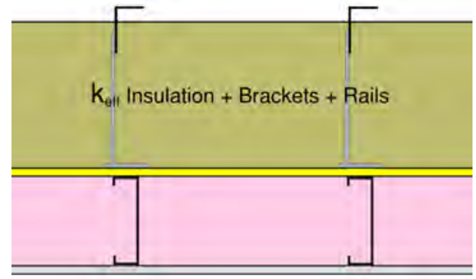
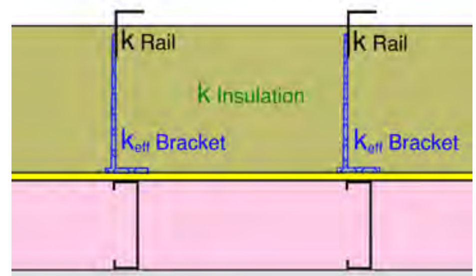
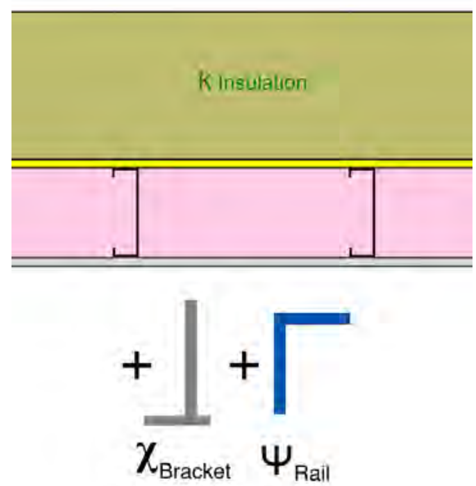


Figure 2.5: Example Bracket and Rail Cladding Attachment System

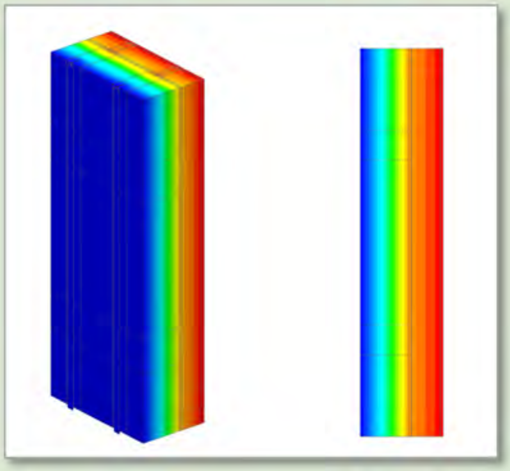
A single 2D section cannot fully represent the heat flow through the assembly for the intermittent bracket. The studs and rails are continuous and can be represented in a horizontal section. The brackets can be incorporated into 2D simulations as outlined by the following three approaches.

<table>
<tr>
<td>Approach 1: Averaged By Volume</td>
<td>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.</td>
<td>
</td>
</tr>
<tr>
<td>Approach 2: Effective Conductivity for Intermittent Components</td>
<td>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.</td>
<td>
</td>
</tr>
<tr>
<td>Approach 3: Linear and Point Transmittances</td>
<td>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.</td>
<td>
</td>
</tr>
</table>

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).

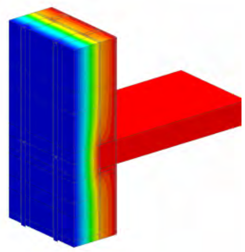
Caution is required when assessing point transmittances using theoretical spacing of components for systems with a combination of brackets and rails. The spacing of components varies significantly on projects and closely spaced components can influence the transmittance values of repeating thermal bridges.

LINEAR THERMAL BRIDGES AND INTERFACE DETAILS

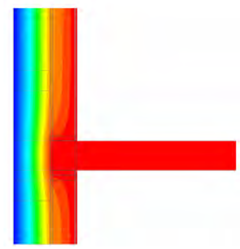
Calculating linear thermal transmittances using 2D analysis requires repeating thermal bridges parallel to the cross section of the interface detail to be simplified or ignored. For example, the cladding attachments and studs are parallel to the modelled cross section for the intermediate floor. This 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

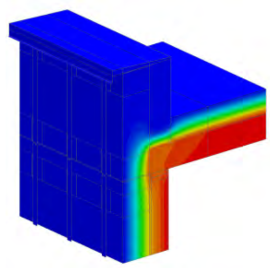


3D Analysis

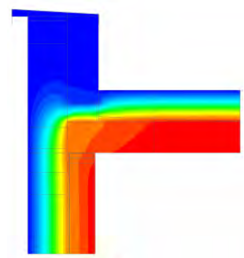


Simplified 2D Analysis

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)

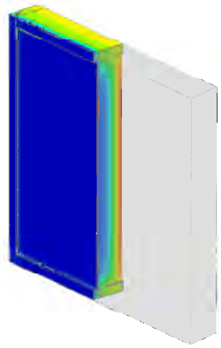
OPAQUE GLAZING SPANDRELS SYSTEMS

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/m²K (BTU/ft²hr°F)	Effective R-value m²K/W (ft²hr°F/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.

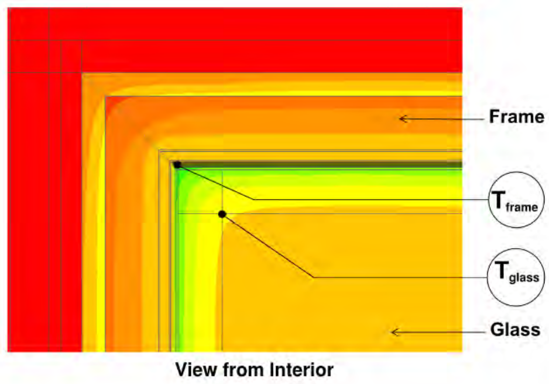


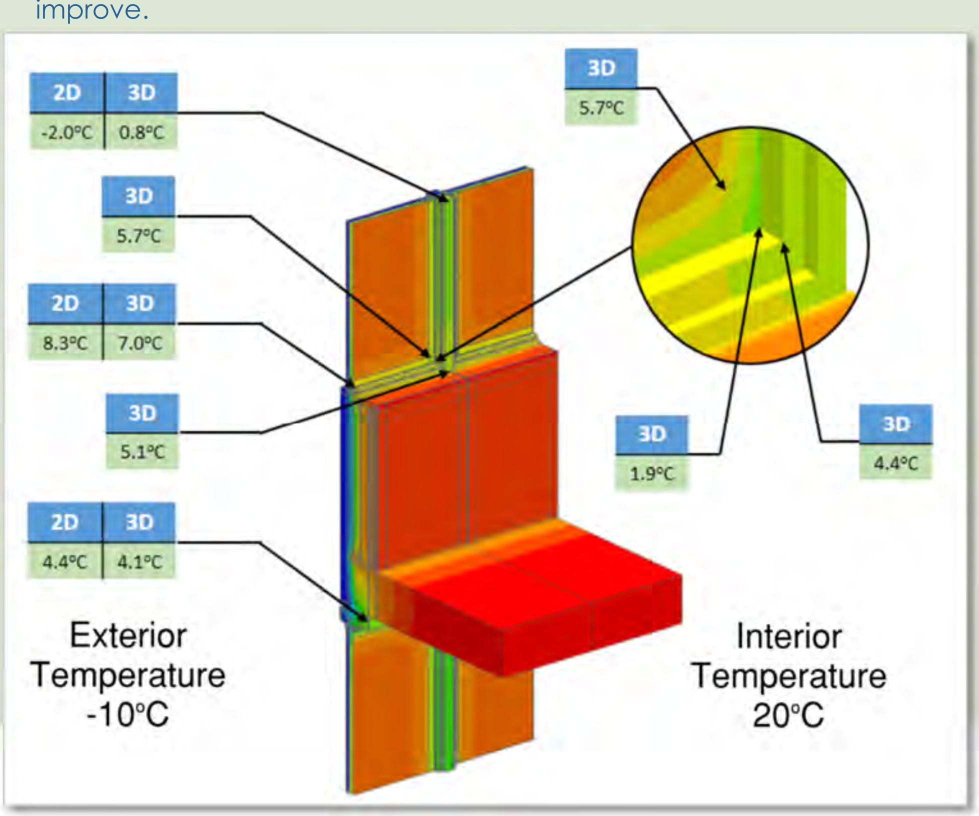
Table 2.7: Glazing Surface Temperatures for an Exterior Temperature of -10°C and Interior Temperature of 20°C

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.

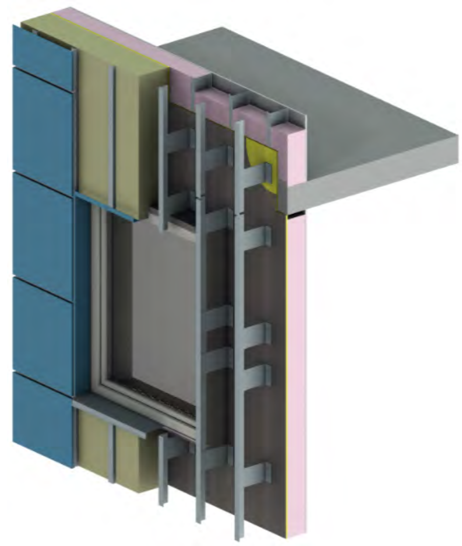


Figure 2.6: Window to Wall Interface

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.

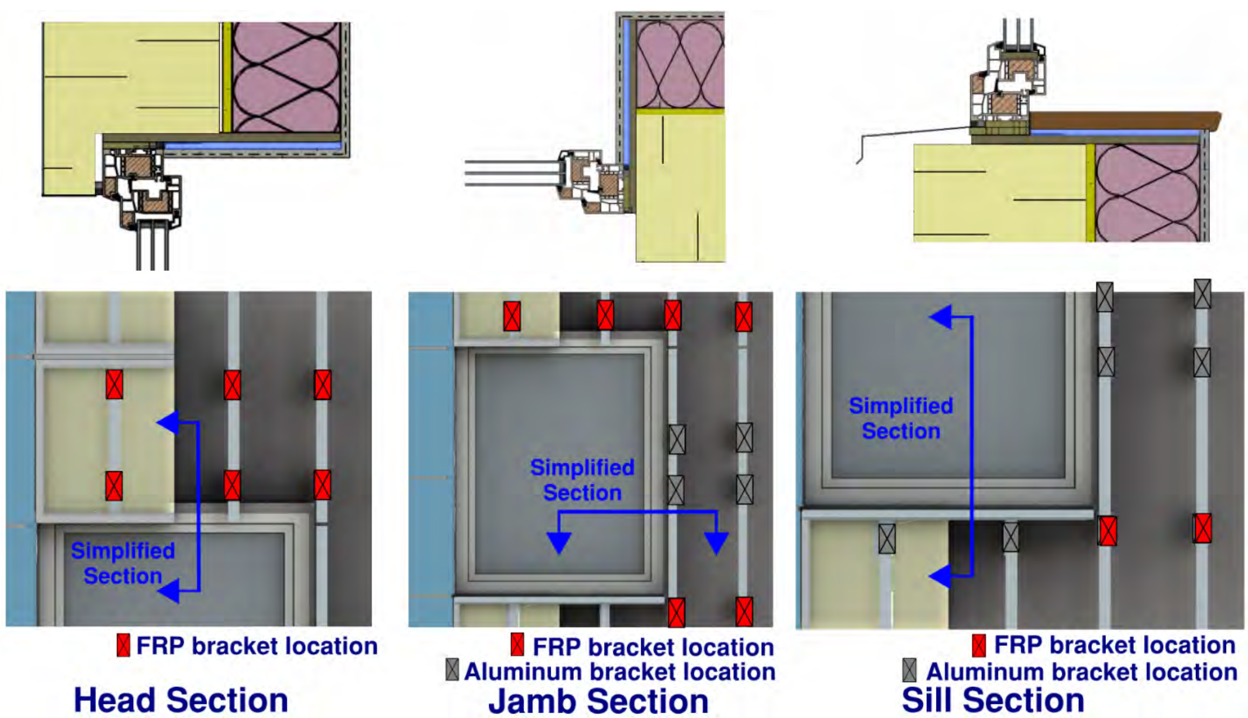


Figure 2.7: Modelled Sections Window to Wall Interfaces for the Simplified Approach

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.

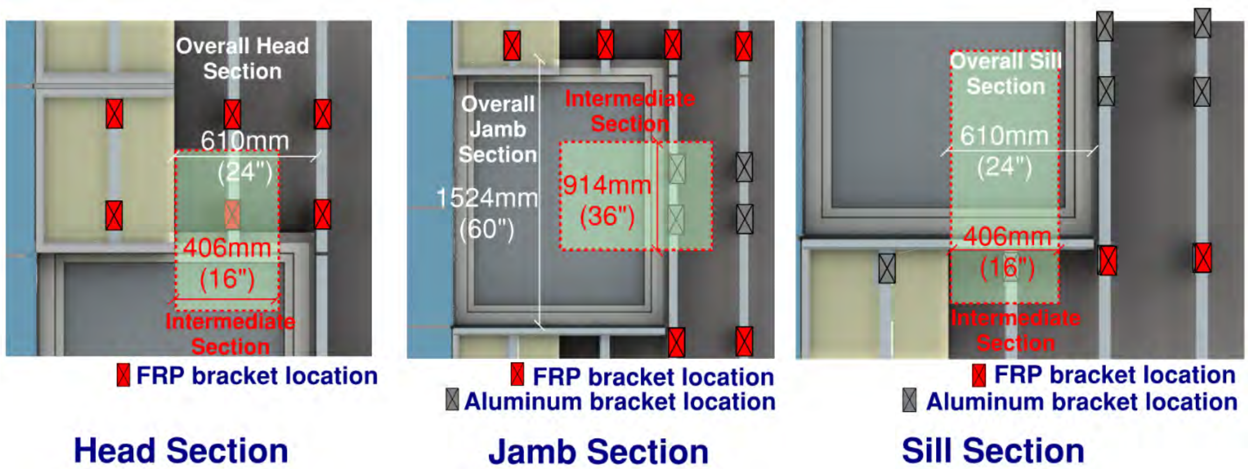


Figure 2.8: Modelled Sections Window to Wall Interfaces for the Intermediate Approach

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**.

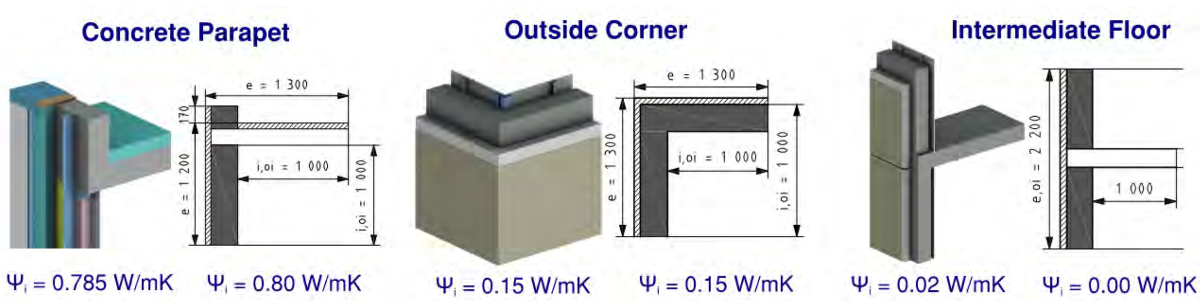


Figure 2.9: Comparison of Interior Transmittance Values (Ψ_i) Between BETB Guide 3D Analysis and ISO 14683 Default Values