Timber Curtainwall Research Report – Thermal Parametric Study | Project R-11605.001

Canada's Earth Tower, 7th and Pine, Vancouver, BC

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Acronyms & Symbols

A_T	Total product area (m^2)
IGDB	International Glazing Database
k	Thermal conductivity
NFRC	National Fenestration Rating Council
PH	Passive House
PHI	Passive House Institute (Germany)
PHIUS	Passive House Institute US
SHGC	Solar Heat Gain Coefficient
U_f	Frame, thermal transmittance ($W/m^2 \cdot K$)
U_g	Center-of-glass, thermal transmittance ($W/m^2 \cdot K$)
U_w	Overall, thermal transmittance ($W/m^2 \cdot K$)
VT	Visible Transmittance

1 Background

Across Canada, building energy codes are requiring higher performing building enclosure, with some jurisdictions going as far as requiring Passive House or near Passive House performance. At the same time, the mid- to high-rise construction market has seen an increased use of mass timber construction.

Many of the mass timber projects to date have made use of prefabricated wall and floor panels, with the membrane, insulation, and window installs completed in a factory prior to arriving on site. As the first wave of tall mass timber projects reach completion, several advantages have come to light, including:

→ Speed of construction: pre-fabrication of the floor, wall, and roof panels has allowed for rapid on-site construction and completion of the building envelope

→ Sustainability: compared to concrete, timber has a lower life-cycle CO_2 footprint and panelization has led to reduced waste. While life-cycle studies vary, one example of a life-cycle study completed by researchers at the Canadian Wood Council and the University of British Columbia estimated up to a 71% reduction in the contribution to global warming potential by switching from concrete to mass timber construction, (Robertson, Lam, & Cole, 2012).

→ Thermal performance: compared to conventional concrete and steel construction, timber allows for decreased thermal bridging at building interfaces and overall improvements to the effective building enclosure thermal performance.

Figure 1: Two examples of mass-timber projects completed in British Columbia. The newly constructed MEC Headquarters (Proscenium Architecture), and the 18-Storey UBC Brock Commons student residence (Acton Ostry Architects Inc.).

While pre-fabricated mass timber wall panels with punched windows have and are being used on several projects, design teams are already looking for ways to incorporate floor-to-ceiling glazing into their mass timber designs. This in turn has led to an increasing interest in the design and use of timber curtainwall products in the place of conventional aluminum systems. The objective of this research is to present a conceptual mass timber framed curtainwall design for use in high-rise applications.

As part of this research, RDH :

→ Performed an industry review of existing high-performance curtainwall products.

→ Performed a simulation based parametric analysis to evaluate the impact of individual curtainwall components on the overall product U-value.

→ Performed preliminary engineering of a timber curtainwall design concept.

More broadly, this research project aims to support Canada's transition to a wood-inclusive construction industry by,

→ Creating broader adoption and commercialization of wood-based products in construction of high-rise buildings through developing higher-performance curtainwall systems.

→ Creating a ready-to-use design capable of use by the growing number of mass timber Passive House projects across Canada.

→ Supporting Canada's transition to a more wood-inclusive construction industry by enabling wood to be used in a highly visible application as part of a high-performance glazing system.

2 Industry Review of High-Performance Curtainwall

RDH performed an industry review of existing high-performance curtainwall products to assess current curtainwall technologies and system performance levels. Both the Passive House Institute (PHI) certified product database and the National Fenestration Rating Council (NFRC) certified product directory were reviewed for high-performance (i.e., low U-value) curtainwall products. For the purpose of this study, only certified or labeled products with an overall U-value less than 1.0 W/m²·K (0.18 Btu/hr·ft²·°F) were considered. For context, this U-value target sits between the Passive House certification requirement of 0.80 W/m²·K and the prescriptive code requirement of 1.4 W/m²·K for the City of Vancouver. This target is also significantly lower than the U-values achieved by conventional double-glazed curtainwalls, which are typically greater than 1.8 W/m²·K.

At the time of writing, the number of products in each respective database with U-values < 1.0 W/m²·K were:

→ 43 curtainwall products (from 21 manufacturers) in the PHI certified component database

→ 11 curtainwall products (from 8 manufacturers) in the NFRC certified product directory

Because of the differences between the PHI and NFRC simulation methodologies (standard size, boundary conditions, etc.,), the two databases were not directly compared.

Passive House certified products

Figure 2.1 plots PH certified curtainwall products based on their overall U-value (U_W) versus their frame U-values (U_f). As one of the goals of this research study is to facilitate the development of timber framed curtainwalls, the products with timber framing are highlighted in blue.

Per the PHI certification requirements, the U_W-values include the following assumptions:

→ a standard product size of 1.2 m wide by 2.5 m tall

→ a center-of-glass U-value (U_g) of 0.7 W/(m²K), which is roughly equivalent to a triple-pane IGU with Argon fill and multiple low-e coatings

These standardized assumptions enable product comparisons from different manufacturers.

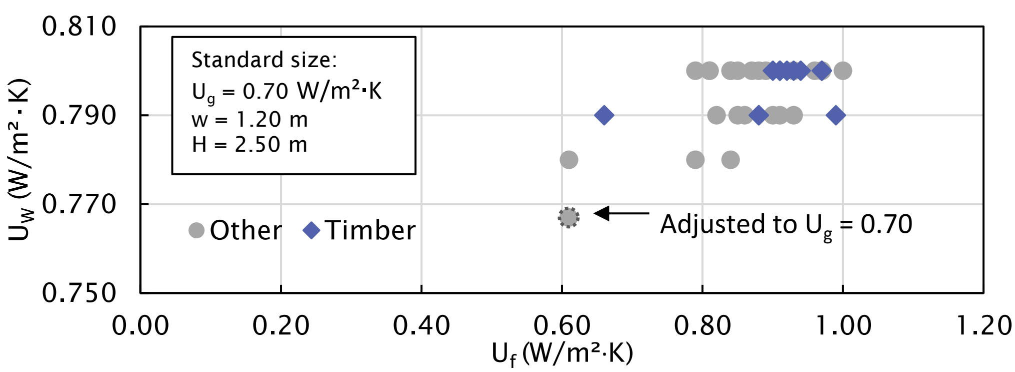


Figure 2.1 Passive House certified curtainwall product U-values versus frame U-values. Timber frames are highlighted in blue.

Three observations can be made from Figure 2.1:

→ The range in the U_W-values is very narrow, with all but one of the certified products between 0.78 and 0.80 W/(m²K). This is likely due to the PHI window certification criteria of a U_W ≤ 0.80 for the cool-temperate climate zone (i.e., Darmstadt, Germany or Vancouver, Canada).

→ The range in frame U-values is wider, with U_f values from 0.6 to 1.0 W/(m²K).

→ There is no clear distinction in window frame performance between the various window frame materials, with timber frames spanning almost the full range in U_f and U_W. The curtainwall with the lowest U_W in the PHI database uses fiberglass.

NFRC

Figure 2.2 plots NFRC certified products based on their U_W. Since the NFRC certification program does not report U_f values, the x-axis is simply the manufacturer. Timber framed curtainwall products are highlighted in blue.

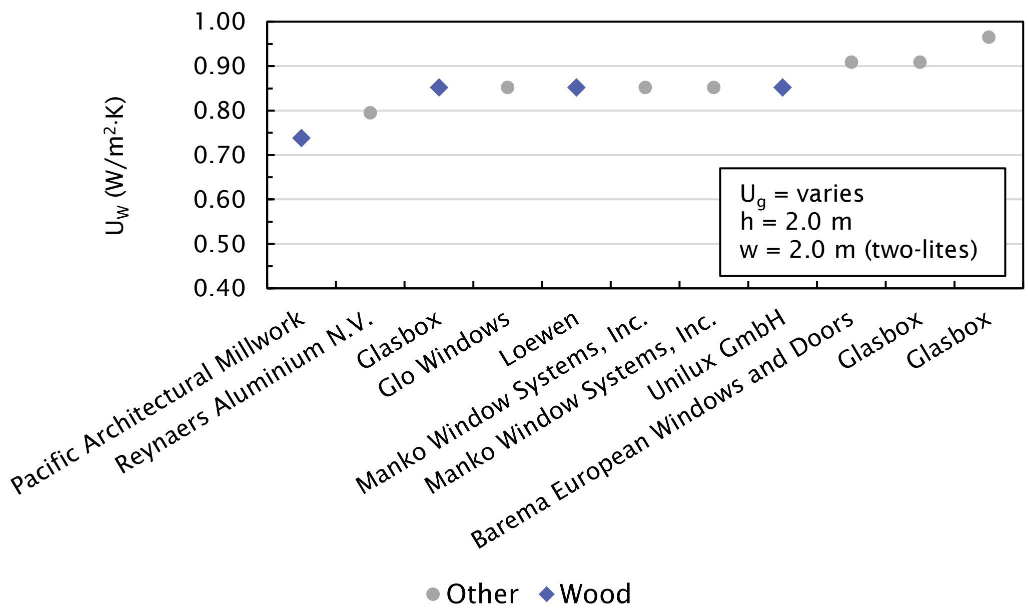


Figure 2.2: NFRC certified curtainwall U-values. Window U-values are based on a standard size of 2.0 m x 2.0 m and two lites (Equivalent to a 1.0 m wide by 2.0 m tall unit)

Two observations can be made from Figure 2.2,

→ Despite a wider range in U_w, the lowest U-value, 0.74 W/m²K, remains close to 0.8 W/m²K.

→ There is no clear distinction in window frame performance between the various window frame materials, with timber frames spanning almost the full range in U_W.

There are several differences between the PHI and NFRC certification programs. One of the differences is the standard size, with the NFRC standard size for curtainwall products being smaller than PHI (i.e., more frame to glass area). A second difference is that NFRC requires simulation of a specific IGU, whereas PHI certification assumes a standard U_g based on the climate zone in which certification is being sought. A third key difference is that NFRC simulations are conducted at -18 °C, compared to 0 °C (IGU) / -10 °C (window) according to PHI. The impact of all three of these differences is that NFRC simulations tend to result in higher U-values compared to similar PHI simulations. However, it is possible to simulate with a center-of-glass U-value less than 0.70 W/m²·K (or other reference glazing U_g values) when simulating according to NFRC and potentially calculate U_W-values lower than PHI.

Impact of frame material

An analysis of the PHI and NFRC certified products did not reveal a relationship between frame material and U-value. This finding was unexpected since low-conductivity frame materials such as wood can be 100 to 1000 times less thermally conductive than conventional metal framing materials such as steel and aluminum.

However, an analysis of existing curtainwall designs shows that high-performance curtainwalls thermally separate the framing system from the thermal control layer of the curtainwall. This is achieved through a combination of high-efficiency spacer bars, thick glazing gaskets, insulation, and other low-conductivity glazing accessories. As a result, the interior mullions have a reduced impact on the overall thermal performance of the curtainwall. These strategies are explored in more detail in Section 3.

Despite the relatively small impact of frame material on U_W, it is worth noting that the installed performance of timber frame products is expected to perform better than comparable products with more conductive framing elements. This is due to a potential reduction in thermal bridging at the curtainwall to opaque wall interface. However, as most curtainwall installations are floor-to-floor and consist of multiple connected lites, the installed performance is not considered any further in this report.

Comparison to conventional curtainwall

Conventional curtainwall systems used today comprise of a thermally broken aluminum frame with a double-glazed IGU with Argon fill and a low-e coating. The thermal break in these systems is typically not much wider than 6 mm and made of a rigid plastic (e.g., polyamide). Apart from the framing, the curtainwall accessory parts including anti-rotation blocks and glass carriers are commonly also made of aluminum. These systems typically achieve U-values in the range of 1.8 to 2.2 W/m²·K. Comparatively, the U-value of a conventional curtainwalls can be 150% higher than one of the high-performance curtainwall products analyzed above. Figure 2.3 provides an example of a conventional and high-performance curtainwall.

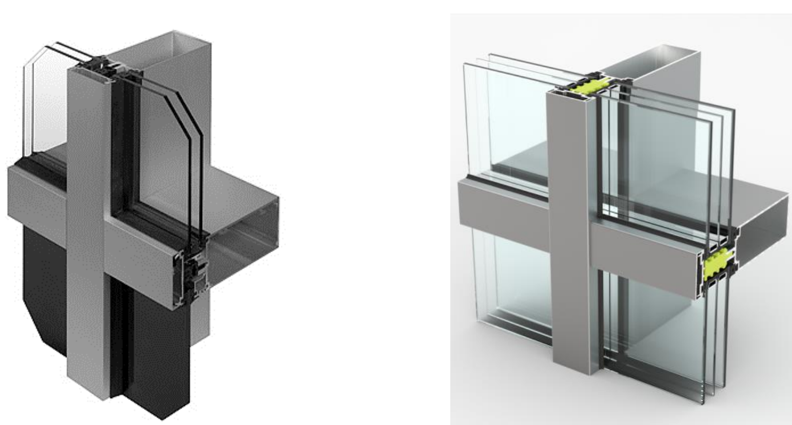


Figure 2.3: Kawneer 1600UT (left) and Kawneer AA 100 Q HI+ (right) illustrating conventional and high-performance curtainwall products (www.Kawneer.com)

Impact of curtainwall thermal performance on the effective R-value

Regardless of the certification program, it is clear from an analysis of the PHI and NFRC certified product databases that there are several existing curtainwall products which can achieve an overall thermal performance around 0.8 W/(m²K) or R_{IP}-7 ft²·°F·hr/Btu. While these high-performance curtainwall products represent a significant improvement over conventional double-glazed thermally broken aluminum systems commonly in use today, 2 W/m²·K or R_{IP}-3 ft²·°F·hr/Btu, the U-values still represent a weak point in the thermal envelope of a building enclosure. This is increasingly true as the opaque building enclosure increases in performance, with high-performance opaque wall systems used on low-energy buildings achieving 0.2 W/m²·K or R_{IP}-30 ft²·°F·hr/Btu or better. Figure 2.4 illustrates the relationship between opaque and transparent building enclosure performance, window-to-wall ratio (WWR), and effective thermal performance. It also clearly demonstrates that for buildings with more than 40% glazing, the only practical means of increasing the overall effective thermal performance of the above-grade vertical building enclosure is to improve the window performance.

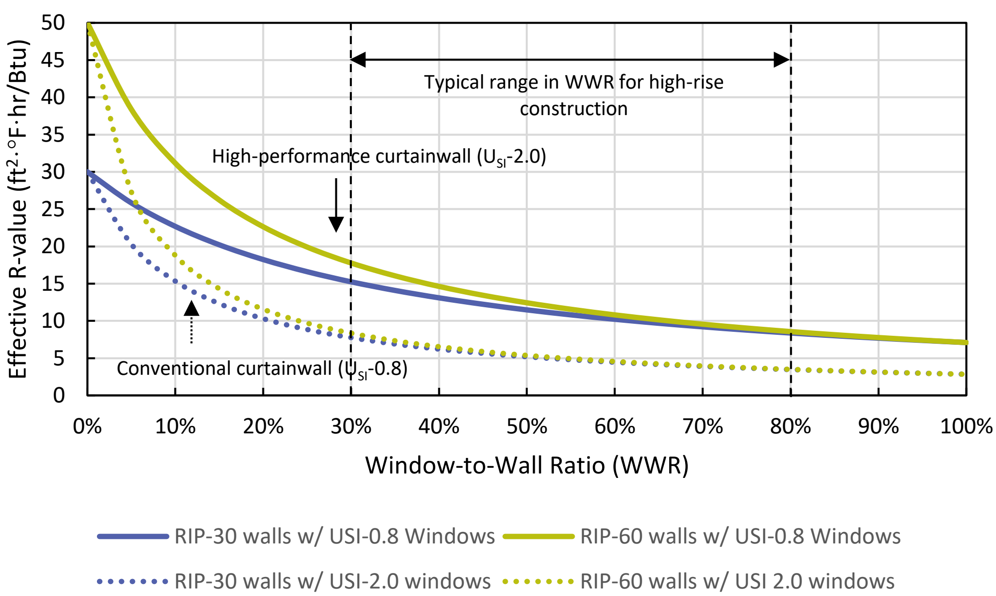


Figure 2.4: Effective R-value versus window-to-wall ratio (WWR) for R_{IP}-30 and R_{IP}-60 ft²·°F·hr/Btu walls, and U_{SI}-0.8 and U_{SI}-2.0 W/m²·K. windows.

3 Parametric Thermal Analysis of Timber Curtainwall Frames

This section of the report presents the results of a parametric thermal simulation study. The parametric study begins with a typical timber framed curtainwall product, with features commonly seen in high-performance curtainwall systems. The baseline model is then modified to investigate the impact of individual parameters on the overall thermal performance of the curtainwall (U_W). The studied parameters and their impact on U_W compared to the baseline case are summarized in Figure 3.1.

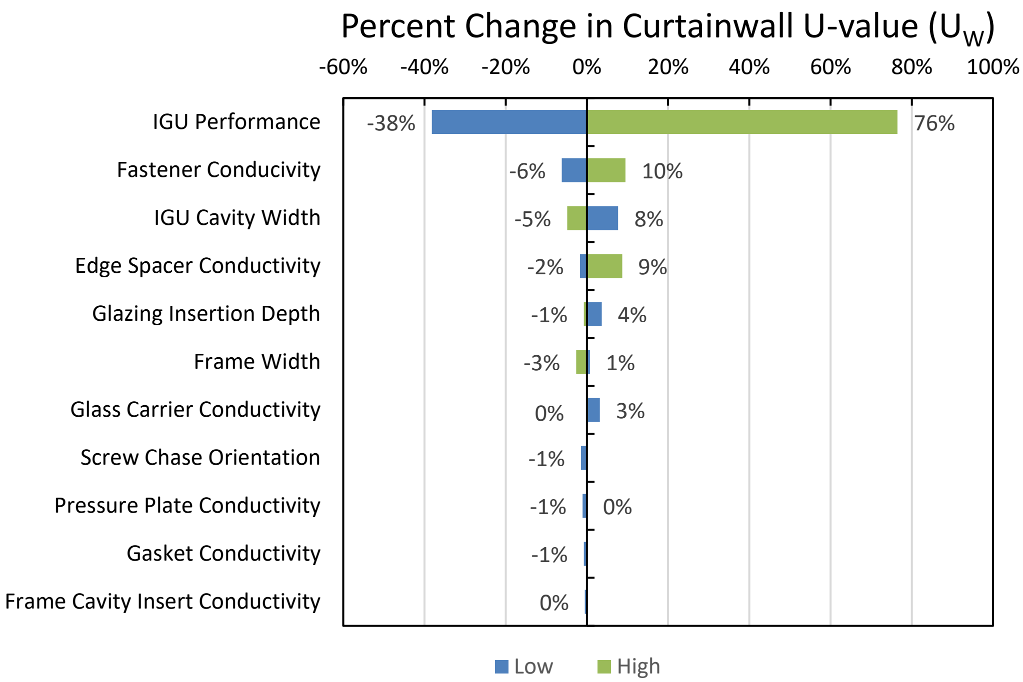


Figure 3.1 Curtainwall parameters and their impact on the overall curtainwall U-value.

As discussed later in this report, only a limited number of the assessed parameters are shown to have a significant impact on the overall thermal performance of the curtainwall.

3.1 Methodology

The baseline timber curtainwall frame is shown in Figure 3.2. The baseline was selected as an example of a high-performance timber framed curtainwall system.

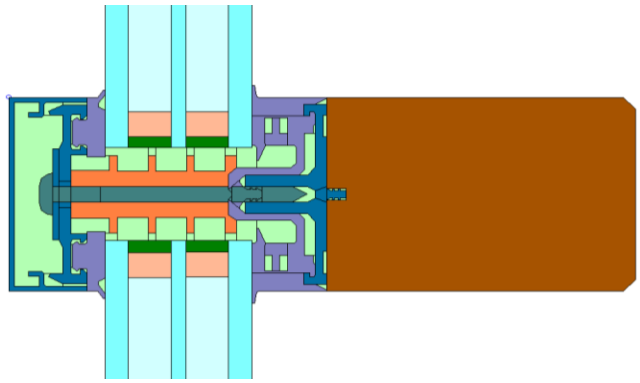


Figure 3.2 Baseline timber frame curtainwall system

RDH made the following assumptions throughout all the cases in the parametric study:

→ Frames are simulated according to the ISO 10077 (i.e., consistent with Passive House window simulations) with the following exceptions:

  → Intermittent fasteners are included according to the procedure described in the NFRC THERM/WINDOW Simulation Manual to permit an investigation of the impact of these components. For this reason, the U_f values noted in this report are higher than those typically noted on PHI certificates.

  → Glass carriers are included as point transmittances (Χ-values) based on the published default values from the Passive House Institute (PHI, 2017).

→ U_W calculations assume a 1.2 m wide by 2.5 m tall product, with dimensions taken to the centerline of the mullions (glass to frame ratio of 93%). The standard product consists of a single lite with head, sill and left/right jambs, as shown in Figure 3.3.

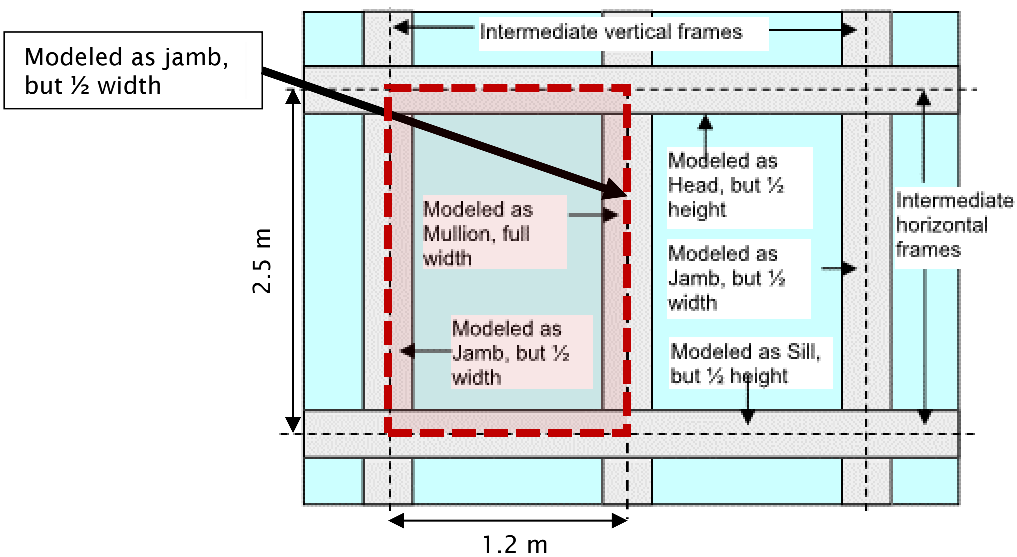


Figure 3.3 Illustration of the curtainwall configurations assumed for the U_W calculations.

Additionally, the baseline model assumes the following properties:

→ Framing: 50 mm timber (k = 0.13 W/m·K), with a glass-to-frame ratio of 94%

→ Pressure cap & plate: aluminum alloy (k = 160 W/m·K)

→ Glazing gaskets: silicone (5 mm wide exterior, 13.5 mm wide interior),

→ Frame cavity: includes a foam insulation insert (k = 0.05 W/m·K)

→ IGU: triple-pane with an overall thickness of 38 mm, and a U_{COG} = 0.70 W/m²·K

→ Spacer bar: SWISSSPACER Ultimate (box 2: 0.14 W/m·K)

→ Fasteners: Stainless-steel at 152 mm o.c.,

The baseline model's simulation results are presented in Table 1 below.

TABLE 1: BASELINE MODEL PERFORMANCE VALUE

Scenario	U_f W/m²·K	Ψ_g W/m·K	U_g W/m²·K	U_W W/m²·K
Baseline	1.98	0.034	0.70	0.86

A workshop was held in February 2019 to identify a list of curtainwall parameters that could be varied to impact curtainwall thermal performance. As a result of this workshop, a total of 12 parameters were selected to assess their impact on curtainwall performance:

(1) center-of-glass U-value

(2) fastener thermal conductivity (material & spacing)

(3) IGU cavity width

(4) spacer bar thermal conductivity

(5) glazing insertion depth

(6) frame width

(7) glass carrier thermal conductivity (material & spacing)

(8) screw spline orientation

(9) pressure plate thermal conductivity

(10) gasket thermal conductivity

(11) frame cavity insulation thermal conductivity.

(12) glass to frame ratio

The parameters are called out in Figure 3.4, and are explored in the following sub-sections.

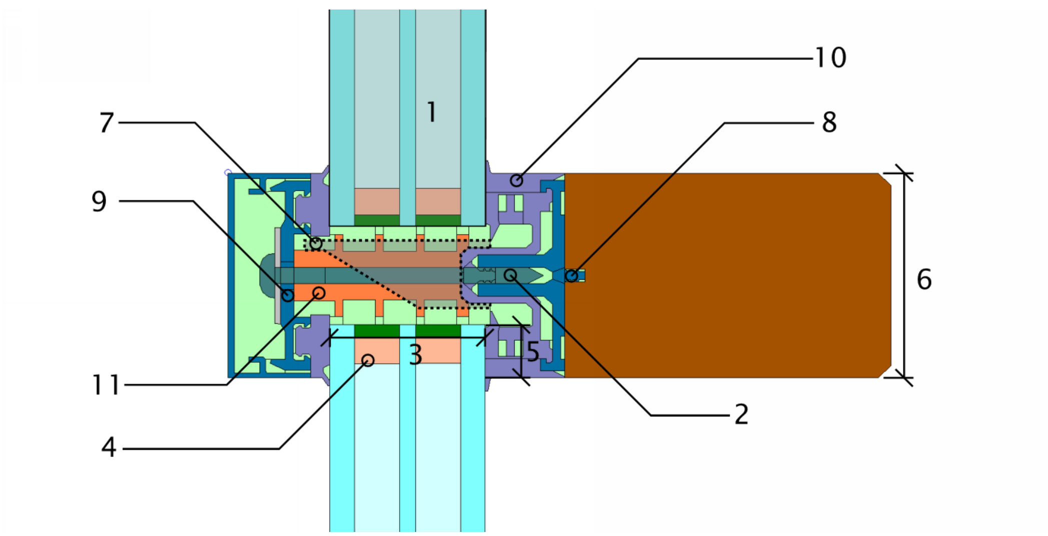


Figure 3.4 Parameters altered for curtainwall

For each of the investigated parameters, a high and a low case is examined to provide a range in the performance impact. This step-by-step approach allows for a relative measure of the importance of each parameter.

3.2 Center-of-Glass U-value (U_g)

The center-of-glass U-value (U_g) refers to clear field thermal performance of the IGU. For products with large glass-to-frame ratios (>90%) such as curtainwalls, U_g can have the single largest impact on the overall thermal performance of the window. This is due to the large glass area as well as the wide range in IGU performance.

The baseline U_g is 0.70 W/m²·K, which is representative of a high-performance triple-pane IGU with Argon fill and multiple low-e coatings. To isolate the impact of U_g on U_W, all other parameters were kept constant, with U_g adjusted mathematically in the calculation of U_W.

The lower bound (best-case) scenario is U_g = 0.35 W/m²·K, which is representative of hybrid vacuum glazing IGU consisting of a double-glazed vacuum IGU and a third pane of low-e coated glass sealed to the unit with a spacer bar and Argon fill. Compared to the baseline model, U_W decreases 38% to 0.53 W/m²·K.

The upper-bound (worst-case) scenario is a U_g = 1.40 W/m²·K, which is representative of an Argon filled double-glazed IGU, with one low-e coating. Compared to the baseline model, U_W increases 55% to 1.33 W/m²·K.

For comparative purposes, similar calculations were performed assuming a generic aluminum curtainwall frame. While the trend between U_W and U_g is the same, Figure 3.5 shows that for products with large glazing ratios, the center-of-glass performance can have a greater impact on U_W than the curtainwall system type.

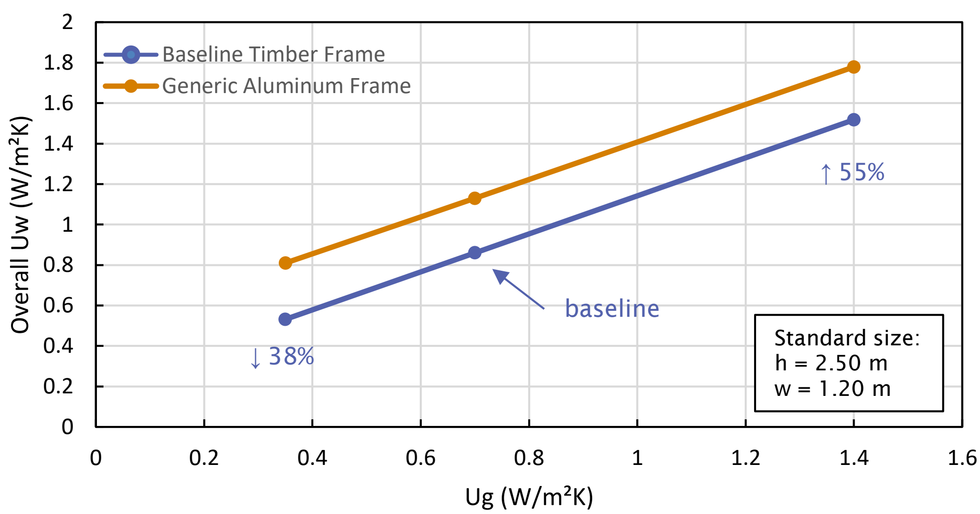


Figure 3.5 Impact of glazing thermal performance on overall window thermal performance.

TABLE 2: Worst, baseline, and best-case scenarios for variations in U_g			
Scenario	**Best**	**Baseline**	**Worst**
(U_g)	U_g **= 0.35**	U_g **= 0.70**	U_g **= 1.40**
U_W (W/m²·K)	0.53	0.86	1.52

3.3 Fastener Thermal Conductivity ($k_{fastener}$)

Fasteners are included in the simulations using the effective thermal conductivity method described in the NFRC THERM/WINDOW Simulation manual. Following this procedure, fasteners are drawn in the model and are assigned an effective thermal conductivity based on the conductivity and spacing of the fastener. The baseline model includes a 4 mm (dia.) stainless-steel (k = 17 W/m·K) fastener to attach the pressure plate back to the curtainwall frame (see Figure 3.5). The fastener spacing is held constant in this analysis at 152 mm (6") o.c.

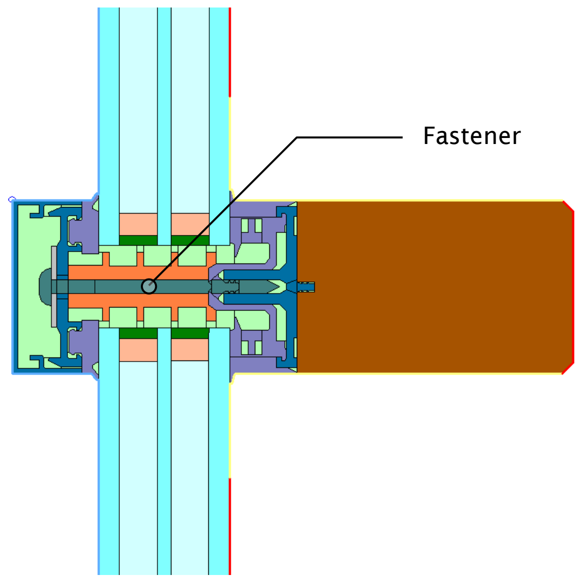


Figure 3.6 Fastener in curtainwall frame (jamb).

The lower-bound (best-case) scenario assumes a fastener with a thermal conductivity of 0.40 W/m·K, which is representative of a non-metal material such as fiberglass. Compared to the baseline, U_f decreases 55% to 0.90 W/m²·K. At the same time, the heat loss through the edge-of-glass, Ψ_g, increases 16% to 0.040 W/m·K, revealing that improvements to the frame can result in an increase in flanking losses at the frame to glass interface. The net result is a 6% decrease in U_W to 0.81 W/m²·K.

The upper-bound (worst-case) scenario assumes a fastener with a thermal conductivity of 62 W/m·K, which is representative of a galvanized steel fastener. Compared to the baseline, U_f increases 73% and Ψ_g decreases 7%. The net result is a 10% increase in U_W to 0.94 W/m²·K.

While galvanized-steel fasteners are readily available (worst-case), suitable non-metal fasteners are not. Design of such fasteners would likely require decreasing the space between fasteners and increasing the size of the fastening elements. Additionally, factors such as fire resistance would need to be considered, since many low conductivity materials are also combustible. A potentially more likely scenario would be a hybrid approach with stainless-steel primary fasteners and non-metal bolts as secondary supporting elements. Because of the lack of market availability, the results for the non-metal scenario are considered an optimistic and ultimate best-case scenario, with the baseline stainless-steel fasteners representing the practical best-case scenario for high-performance curtainwall systems today.

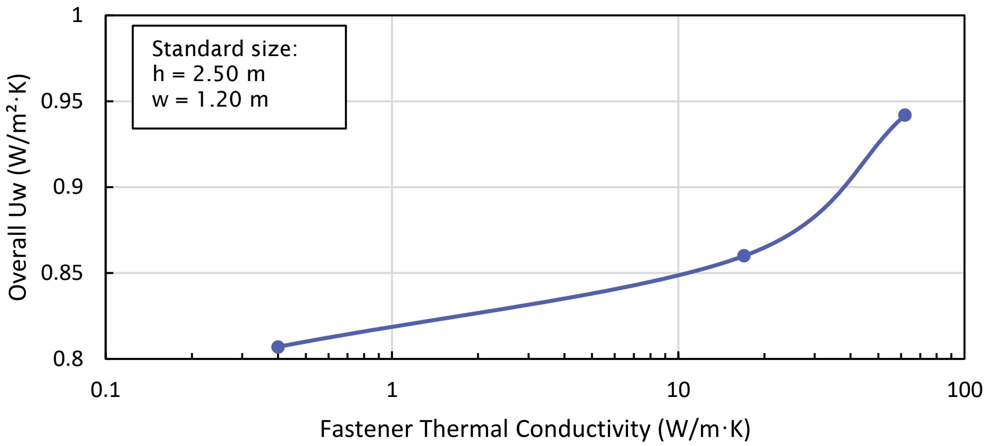


Figure 3.7 Impact of thermal conductivity of fastener on overall window thermal performance.

TABLE 3: Worst, baseline, and best-case scenarios for variations in $k_{fastener}$			
Scenario ($k_{fastener}$)	**Best**	**Baseline**	**Worst**
	$k_{fastener}$ **= 0.40**	$k_{fastener}$ **= 17**	$k_{fastener}$ **= 62**
U_W (W/m²·K)	0.81	0.86	0.94

3.4 IGU Cavity Width

Figure 3.2 shows variations in the IGU width. The baseline IGU width is 38 mm which represents the width of a triple pane IGU with two 11 mm air cavities, a 4 mm inner lite, and two 6 mm outer lites. By increasing the width of the IGU, the heat flow path at the glazing edge is increased, reducing the overall heat loss. While varying the IGU can also impact the center-of-glass U-value, to isolate the impact of IGU width on U_W, U_g was held constant at 0.70 W/m²·K. for each width.

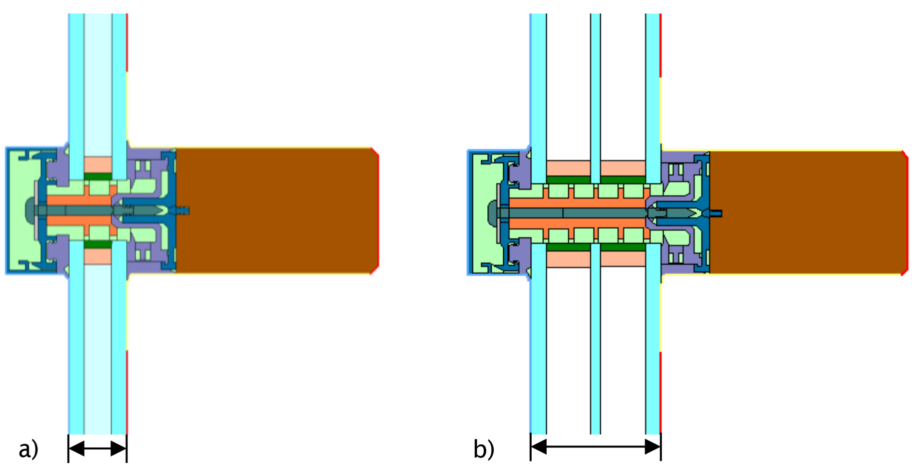


Figure 3.8 Curtainwall frame configuration with a a) 23 mm IGU cavity width and b) a 52 mm IGU cavity width

The lower-bound case (worst-case) scenario assumes a 23 mm wide IGU, which is representative of a double-glazed IGU. Compared to the baseline model, U_f increases 28% to 2.54 W/m²·K. Ψ_g also increases by 40% to 0.048 W/m·K due to the shorter heat flow path from the interior to the exterior. The overall effect was an increase in U_W of 8% to 0.93 W/m²·K.

The upper-bound (best-case) scenario assumes a 52 mm IGU width, which is representative of a thick triple-glazed or a quad-glazed IGU. Compared to the baseline model, U_f decreases 17% to 1.64 W/m²·K, and Ψ_g decreases 25% to 0.025 W/m·K. The overall effect was a decrease in U_W of 5% to 0.82 W/m²·.

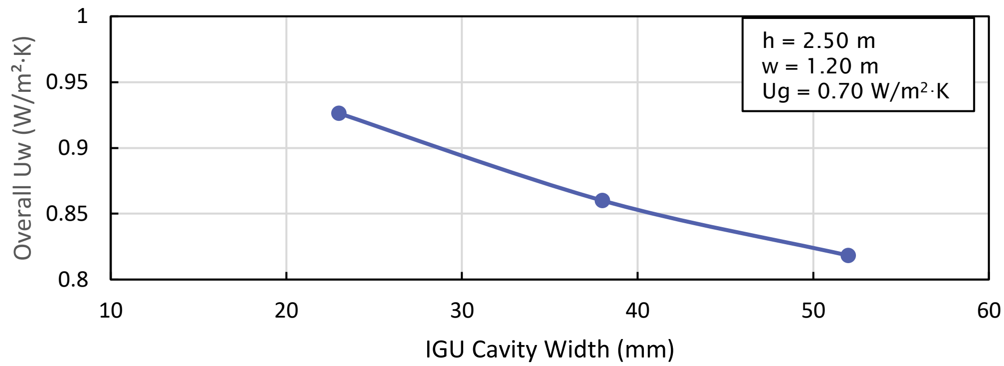


Figure 3.9 Impact of IGU cavity width on overall window thermal performance.

3.5 Edge Spacer Conductivity

High-performance IGU edge spacers are included in the simulations using the two-box model approach. According to this method, the spacer bar assembly (seal and edge spacer) is replaced by two homogenous materials; box 1 and box 2. Box 1 represents the secondary seal (i.e., sealant), while box 2 represents the edge spacer (see Figure 3.10). The baseline model assumes a thermal conductivity of 0.14 W/m·K for box 2, which represents a high-performance all-plastic edge spacer. To isolate the impact of the spacer bar (box 2), the thermal conductivity of box 1 is 0.40 W/m·K for all simulations.

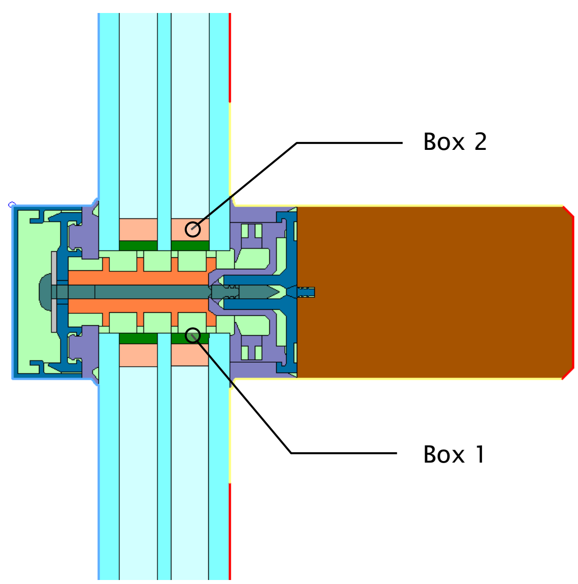


Figure 3.10 Baseline jamb profile with the edge spacer boxes (1 and 2) called-out.

The lower-bound (best-case) scenario is a hypothetical value of 0.07 W/m·K. This value is selected as a 50% improvement over the baseline case, which is at the higher end of the options currently available. Compared to the baseline model, Ψ_g decreases 18% to 0.028 W/m·K, and U_W decreases 2% to 0.85 W/m²·K.

The upper-bound (worst-case) scenario assumes a box 2 thermal conductivity of 0.81 W/m·K, which is representative of a stainless-steel spacer. Compared to the baseline model, Ψ_g increases 92% to 0.065 W/m·K, and U_W increases 9% to 0.93 W/m²·K (see Figure 3.10).

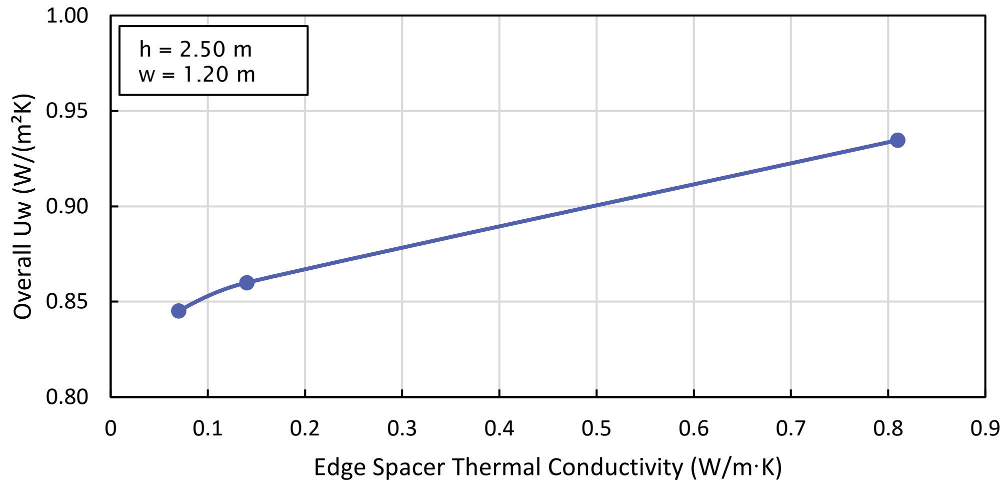


Figure 3.10 Impact of edge spacer thermal conductivity on overall window thermal performance.

3.6 Glazing Insertion Depth

The glazing insertion depth refers to the distance measured from the edge of the mullion to the edge of the IGU as shown in Figure 3.11. By inserting the IGU deeper into the frame, the edge spacer is protected, and the flanking losses are reduced. The glazing insertion depth is limited by the width of the frame and the need to accommodate movement in the system. The glazing insertion depth in the baseline model is 13 mm.

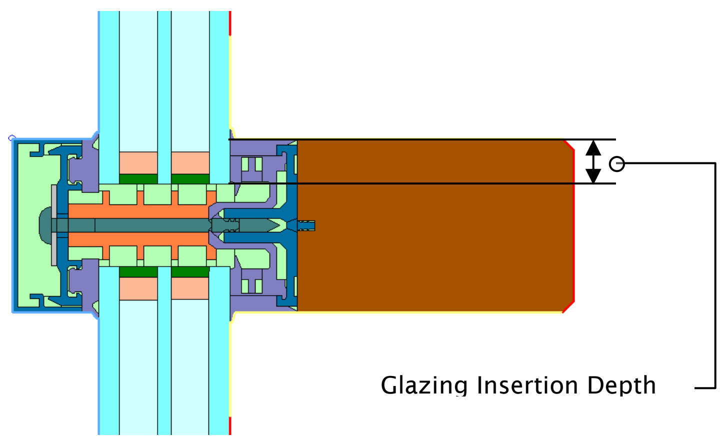


Figure 3.11 The baseline curtainwall frame shows glazing insertion depth.

The lower-bound (worst-case) scenario assumes a glazing insertion depth of 6 mm. This adjustment also results in an increase in the size of the frame cavity, see Figure 3.12. Compared to the baseline model, U_f increases 21% to 2.40 W/m²·K, and Ψ_g increases 8% to 0.037 W/m·K. The overall impact is an increase in U_W of 4% to 0.89 W/m²·K.

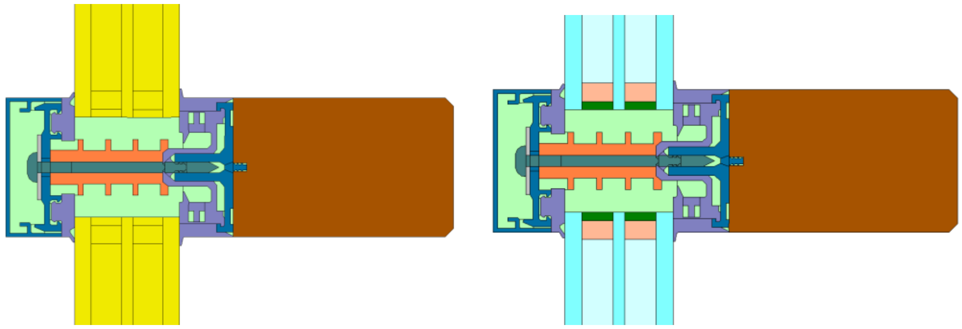


Figure 3.12 Curtainwall frame with a 6mm glazing insertion depth

The upper-bound (best-case) scenario assumes a glazing insertion depth of 19 mm. In this case the IGUs take up most of the frame cavity and compress the frame cavity insulation (refer to Figure 3.13). Compared to the baseline model, U_f decreases 2% to 1.95 W/m²·K and Ψ_g decreases 5% to 0.032 W/m·K. The overall impact is a decrease in U_W of 1% to 0.85 W/m²·K.

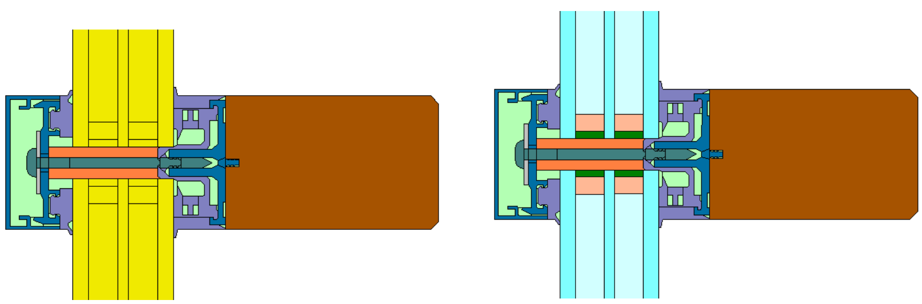


Figure 3.13 Curtainwall frame configuration with 19mm glazing insertion depth

Figure 3.14 plots U_W versus the glazing insertion depth.

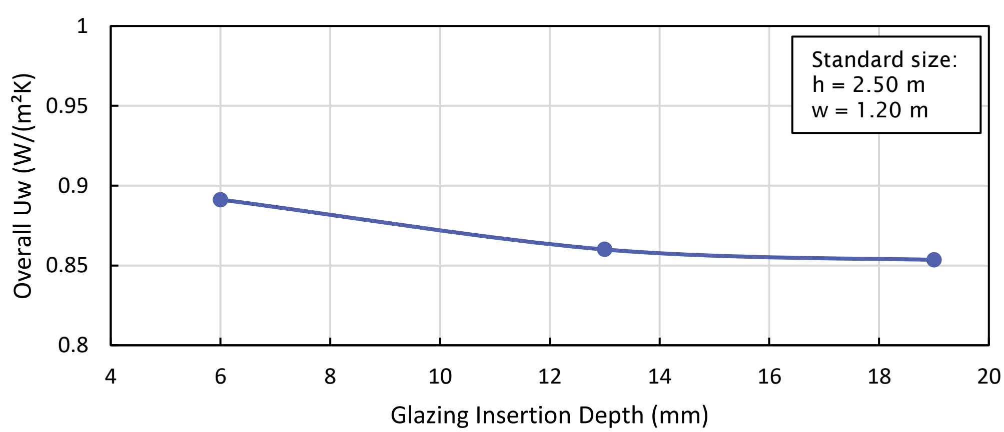


Figure 3.14 Impact of glazing insertion depth on overall window thermal performance.

3.7 Frame width

The width of the frame in the baseline model is 50 mm. By increasing the frame width, it is possible to increase the amount of insulation and spread the heat loss through the fasteners and other thermal bridges over a larger area. The net effect is often a decrease in the U-value of the frame. However, since the frame is larger, the glass to frame area decreases, which in turn may increase or decrease the U_w depending on the relative performance of the frame versus the IGU.

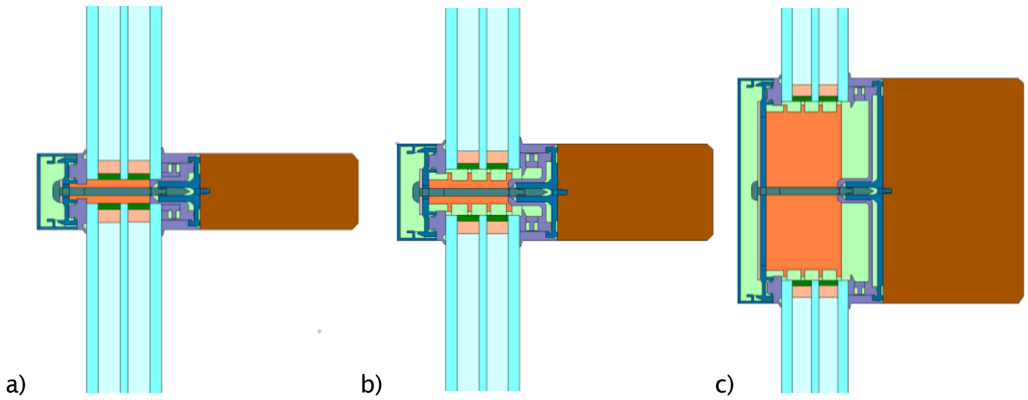


Figure 3.15 *Curtainwall frame with 38mm (a), 50mm (b) and 127mm (c) wide frame*

The lower-bound (worst-case) scenario assumes a frame width of 38 mm. Compared to the baseline model, U_f increases 24% to 2.45 W/m²·K. due to the reduced frame area and insulation. The overall impact on U_W is minor, with an increase of 1% to 0.87 W/m²·K.

The upper-bound (best-case) scenario assumes a frame width of 127 mm. Compared to the baseline model, U_f decreases 44% to 1.11 W/m²·K. The overall impact on U_W is a decrease of 3% to 0.84 W/m²·K.

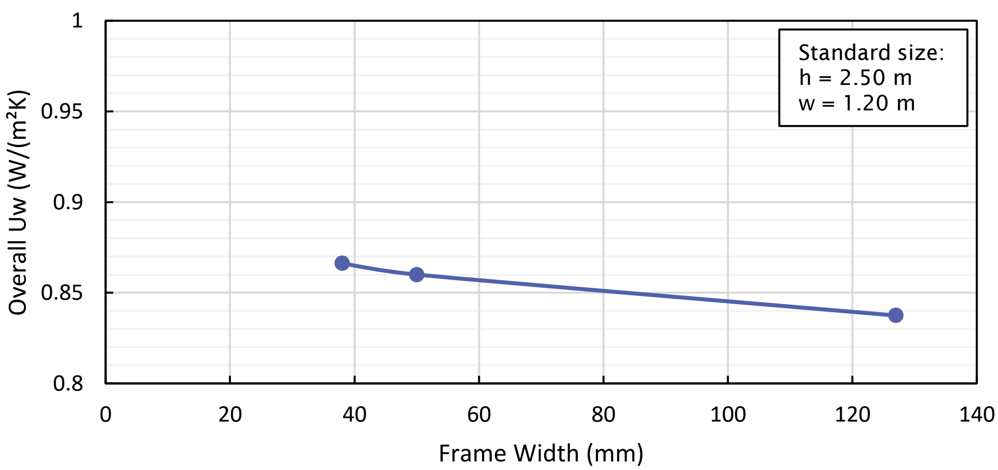


Figure 3.16 Impact of frame width on overall window thermal performance.

These results agree with an analysis of existing high-performance curtainwall systems which showed that wider frames tend to lead to have a lower overall U-value.

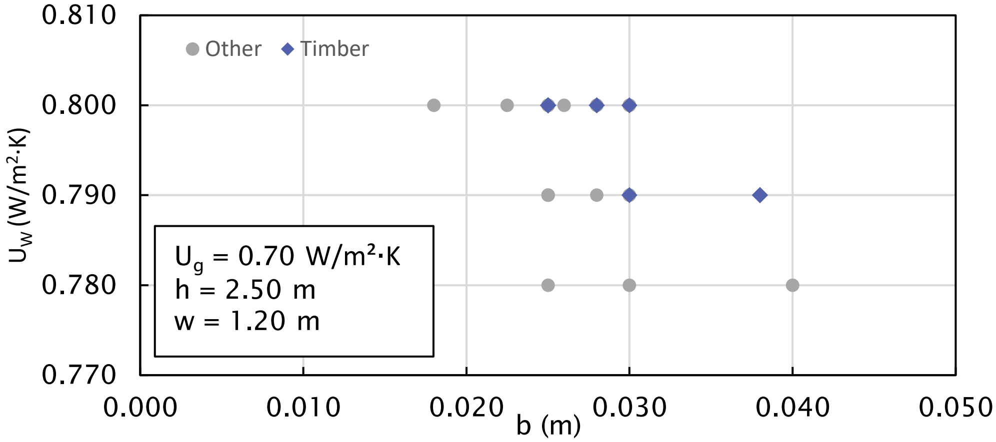
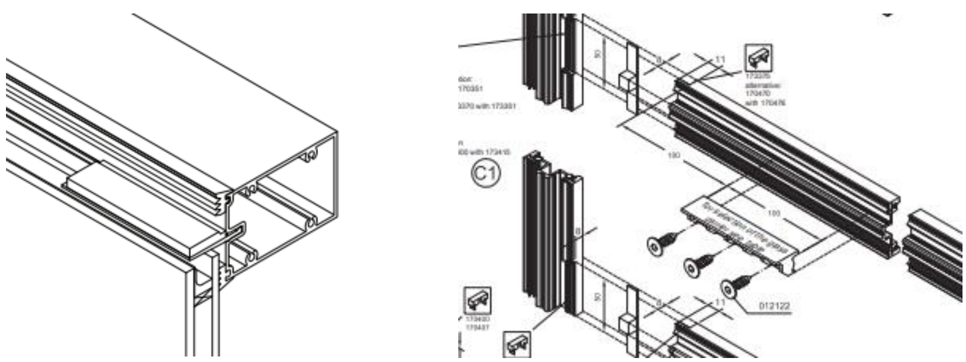


Figure 3.17 Passive House certified curtainwall U-values versus certified frame U-values. Results are based on a PHI standard size of 1.2 m x 2.5 m and a center-of-glass U-value of 0.70 W/m²·K. Wood frames are highlighted in blue.

Based on the analysis above at standard PHI size of 1.2 m x 2.5 m, wider frames tend to lead to a lower U_W. However, this slight improvement in U-value should be weighed against a decrease in the relative glass area and subsequent reductions in the solar heat gains.

3.8 Low Conductivity Glass Carriers

Curtainwall systems require dead load support of the IGU. A common strategy is to provide an intermittent clip, also known as a glass carrier, which attaches to the curtainwall frame and extends to the outer lite of glass to transfer the dead load. In a conventional curtainwall system, the glass carrier is often made of aluminum, resulting in a thermal bridge passing from the mullion to the outer lite of glass. In contrast, high-performance curtainwall systems typically employ non-metal glass carriers, which can significantly reduce the thermal bridging at this location.



Conventional	**High-Performance**
Aluminum Glass Carrier and Setting Block	Non-Metal Glass Carrier

Figure 3.18 Conventional and High-Performance IGU dead load support solutions.

Because of their intermittency, heat flow through glass carriers is often expressed as a point thermal transmittance (χ-value). The baseline scenario includes two non-metal glass carriers, each with a χ=0.003 W/K.

The lower-bound (best-case) scenario is a window that does not require a glass carrier. This option was included to assess the opportunity for improvements. Compared to the baseline model, U_W decreases less than 1%, which suggests that there is little benefit in thermally improving existing glass carrier technology.

The upper-bound (worst-case) scenario is a window with a conventional aluminum glass carrier, χ=0.04 W/K. Compared to the baseline model, U_W increases 3% to 0.89 W/m²·K.

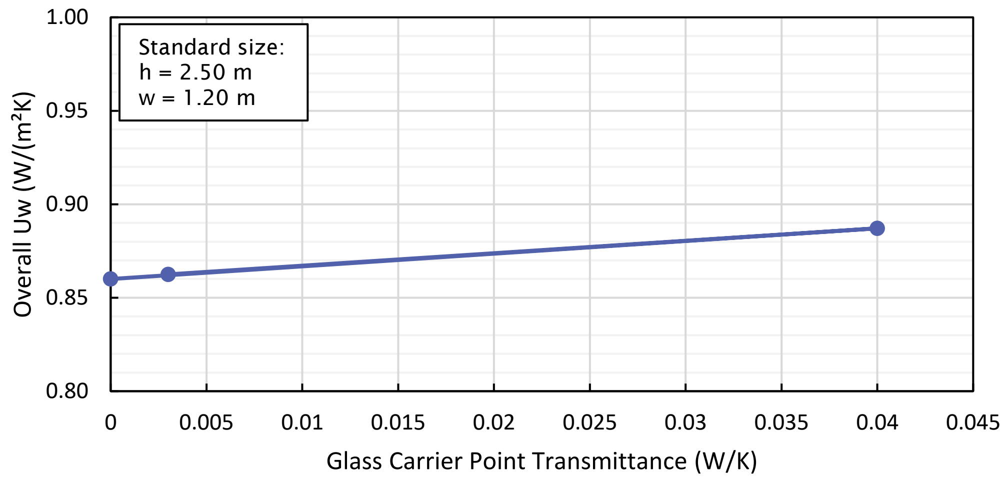


Figure 3.19 Impact of glazing shelf conductivity on overall window thermal performance.

3.9 Screw Chase

In the baseline model, the aluminum screw chase is provided to receive the pressure plate fastener. In high-performance curtainwall systems, the screw chase is often held back such that the aluminum nose does not extend beyond the IGU. This design feature is common since it reduces the amount of metal by-passing the thermal resistance of the IGU. However, the amount of aluminum in the frame cavity can be further reduced by flipping the screw chase around to point inwards towards the frame while still receiving the fastener (refer to Figure 3.20). The screw chase in the baseline model faces the exterior. Only one other option (facing the interior) is examined.

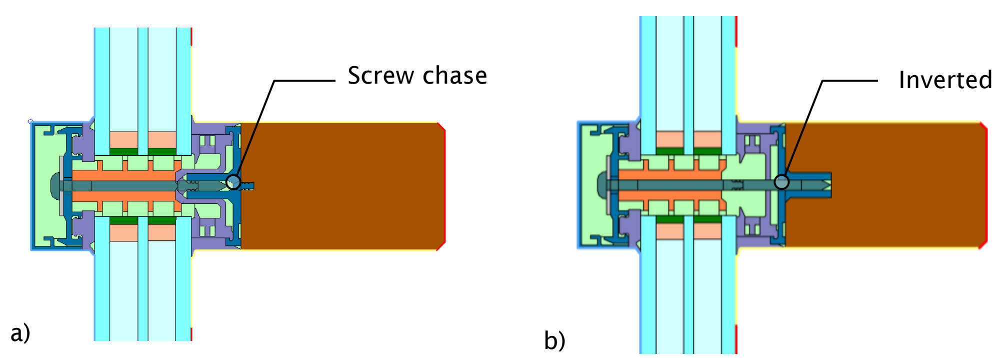


Figure 3.20 *Curtainwall frame with a) an exterior face screw chase and b) an interior facing reserved screw chase*

Compared to the baseline model, inverting the screw chase drops U_f by 13% to 1.73 W/m²·K. Overall the impact on U_W is a decrease of only 1% to 0.85 W/m²·K.

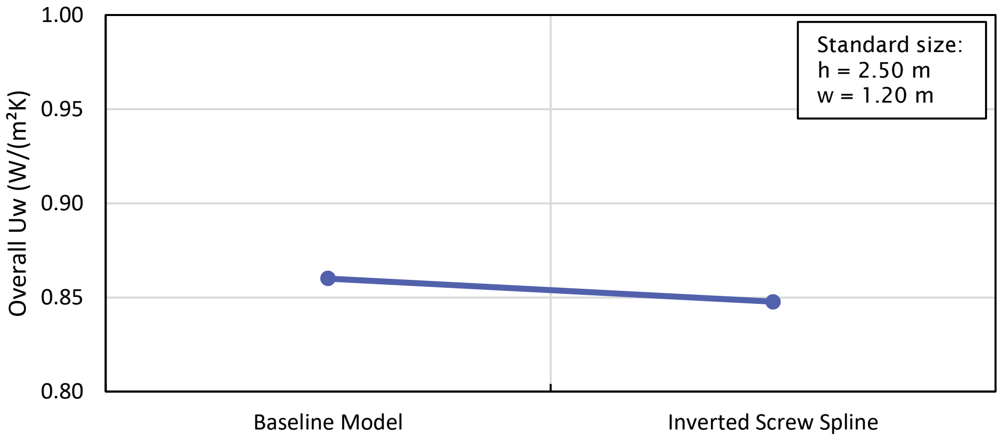


Figure 3.21 Impact of screw chase orientation on the overall window thermal performance.

3.10 Pressure Plate Thermal Conductivity

The pressure plate is located on the exterior side of curtainwall frame and is attached to the frame with fasteners (see Figure 3.22). The pressure plate in the baseline (and worst-case) scenario is assumed to be made of an aluminum alloy with a thermal conductivity of 160 W/m·K.

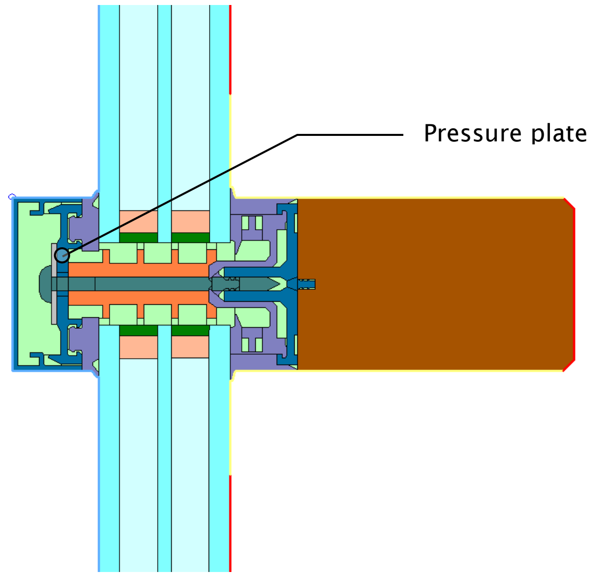


Figure 3.22 Baseline curtainwall frame with the pressure plate called out

The lower-bound (best-case) pressure plate thermal conductivity is 0.4 W/m·K, which is representative of fiberglass. Compared to the baseline model, U_f decreases 9% to 1.80 W/m²·K. The overall effect of the fiberglass pressure plate is a 1% decrease in U_W to 0.85 W/m²·K.

3.11 Gasket Thermal Conductivity

The conductivity of both the interior and exterior gaskets in the baseline model are 0.35 W/m·K, which is representative of silicone, which is a common gasket material. While there are many other considerations when selecting appropriate gaskets for a window product including durability and compatibility, the lower-bound (best-case) thermal scenario assumes flexible PVC gaskets with a thermal conductivity of 0.14 W/m·K.

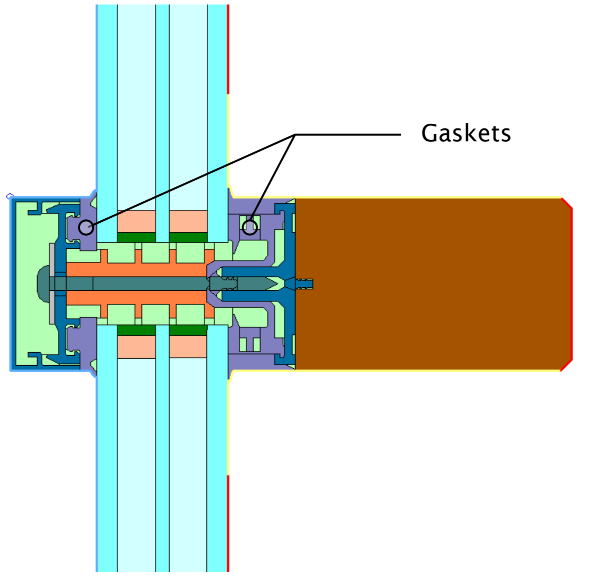


Figure 3.23 Gaskets in curtainwall frame.

Compared to the baseline model, U_f decreases 4% to 1.90 W/m²·K, and Ψ_g decreases 1% to 0.034 W/m·K. Overall, the simulated U_W decreases 1% to 0.85 W/m²·K.

3.12 Frame Cavity Insert Conductivity

The frame cavity insert refers to the thermal insulation inserted in the middle of the frame cavity (see Figure 3.24). The thermal conductivity in the baseline model is 0.05 W/m·K, which is representative of a polyurethane foam.

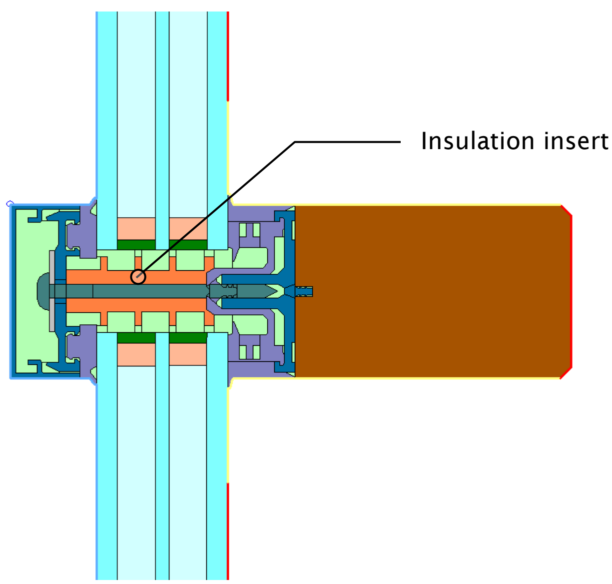


Figure 3.24 Frame cavity insert in curtainwall frame.

The lower-bound (best-case) scenario is an insert with a thermal conductivity of 0.014 W/m·K, which is representative of aerogel insulation. Compared to the baseline model, U_f decreases 5% to 1. 89 W/m²·K. At the same time, Ψ_g increases 2%, due to increased flanking losses at the glass to frame perimeter. Overall, U_W changed less than 1%.

3.13 Glass to Frame Ratio

In addition to the product design factors identified in the preceding sections, it is important to recognize the importance of the size on the actual installed performance of the fenestration system. The standard size used for labeling (NFRC) or certification (PHI) of curtainwall products typically results in a glass to frame ratio close to 90%. However, architectural layout, structural, and aesthetic requirements will often result in product sizes which differ from the standard size. Figure 3.25 illustrates the importance of large glass to frame ratios in terms of the overall thermal performance of the window.

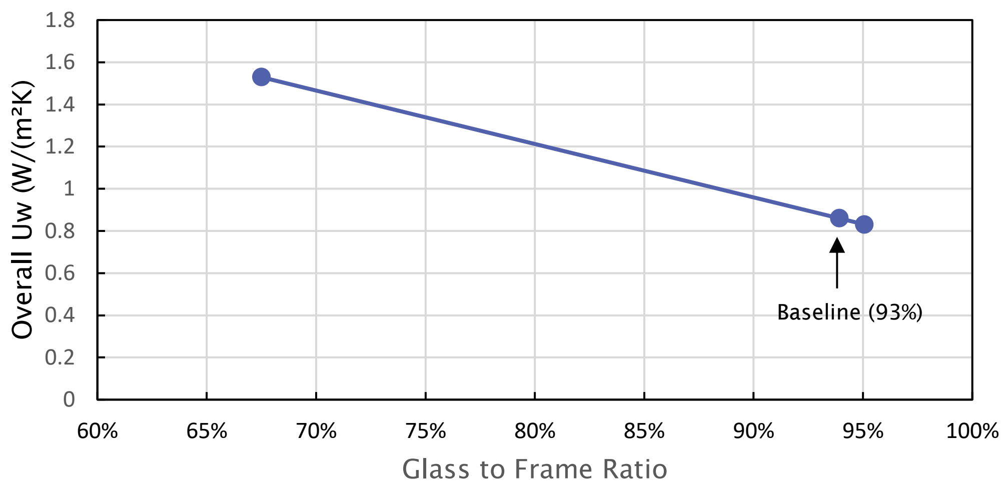


Figure 3.25 Impact of glass to frame ratio on the overall window thermal performance.

The lower-bound (worst-case) scenario assumes a product that is 200 mm wide and 500 mm tall and a glass to frame ratio of 68%. Compared to the baseline model, U_W increases 78%.

The upper-bound (best-case) scenario assumes a product that is 1,500 mm wide and 3,000 mm tall, and a glass to frame ratio of 95%. Compared to the baseline model, U_W decreases 4%.

4 Discussion

The parametric thermal study described in part 3 of this report provides valuable insight into the relative importance of curtainwall design variables with respect to overall thermal performance. Based on this analysis, the key variables have been narrowed down to:

- → Center-of-glass U-value
- → Fastener conductivity & spacing
- → IGU width
- → Edge spacer performance
- → Glass to Frame Ratio

These variables translate into the following design recommendations:

- → Select glazing with a low center-of-glass U-value. This parameter has the single largest impact on the overall product performance and is also anticipated to have the largest opportunity for future improvements.
  - → Triple-glazed IGUs U-values less than or equal to 0.70 W/m²·K are readily available and should be considered the default for high-performance curtainwall systems.
  - → For higher levels of thermal performance, heavier gas fills (Krypton, Xenon) and quad-glazed IGUs may be considered. Use of interior low-e coatings should be specified with care as they can result in lower interior surface temperatures.
  - → With appropriate due diligence, advanced glazing technologies such as vacuum glazing and suspended films may also be considered to achieve the highest levels of thermal performance.
- → Design for large window sizes. Second only to the center-of-glass U-value, the product size can have a significant impact on the actual installed performance.
  - → Glass to frame ratios ≥ 90% should be maintained where possible by other project limitations including structural loads and architectural layouts.
- → Specify low conductivity fasteners, and optimize fastener spacing based on the project’s structural requirements.
  - → Stainless-steel fasteners should be considered the default for high-performance curtainwall systems.
  - → With appropriate due diligence, opportunities to increase fastener spacing and to alternate with low-conductivity fastening elements could be considered.
- → Collaborate with IGU manufacturers to optimize gap width.
  - → Gap widths ≥ 12 mm should be considered the default for high-performance glazing (except for vacuum glazing, and suspended films).
  - → While increasing the gap width was shown to improve overall thermal performance, it is important to note that the center-of-glass U-value is a function of gap width. The gap width should be optimized to minimize the center-of-glass U-value.

→ Specify high performance edge spacers.

 → Dual seal stainless-steel edge spacers should be considered the minimum in terms of thermal performance for high-performance curtainwalls.

 → Dual seal all-plastic edge spacers may be considered for higher levels of thermal performance.

 → When considering the specification of different edge spacers, ensuring that the IGUs are designed and tested in accordance with applicable standards such as ASTM E 2190 *Standard Specification for Insulating Glass Unit Performance and Evaluation* is recommended.

4.1 Combined Scenario

Applying these recommendations, RDH simulated a combined curtainwall scenario that included the following changes from the baseline model:

→ Center-of-glass U-value (#1): 0.53 W/m²·K (decreased from 0.70 W/m²·K)

→ Fasteners (#2): Stainless-steel fasteners 200 mm o.c. (increased from 150 mm)

→ Glass to frame ratio (#12): 95% by increasing the size to 1,500 mm wide x 3,000 mm tall

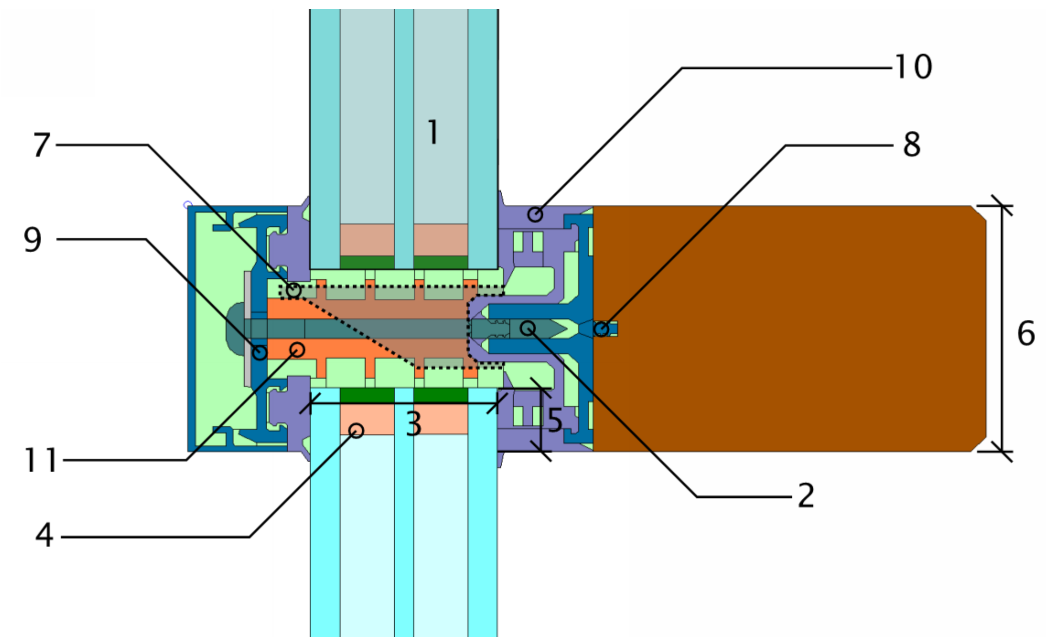


Figure 4.1 Detail drawing of the combined frame section

TABLE 4: BASELINE MODEL PERFORMANCE VALUE						
Scenario	**Width** (mm)	**Height** (mm)	U_f W/m²·K	Ψ_g W/m·K	U_g W/m²·K	U_W W/m²·K
Baseline	1,200	2,500	1.98	0.034	0.70	0.86
Improved	1,500	3,000	1.76	0.038	0.53	0.67

Figure 4.2 shows the colour isotherms and frame temperatures

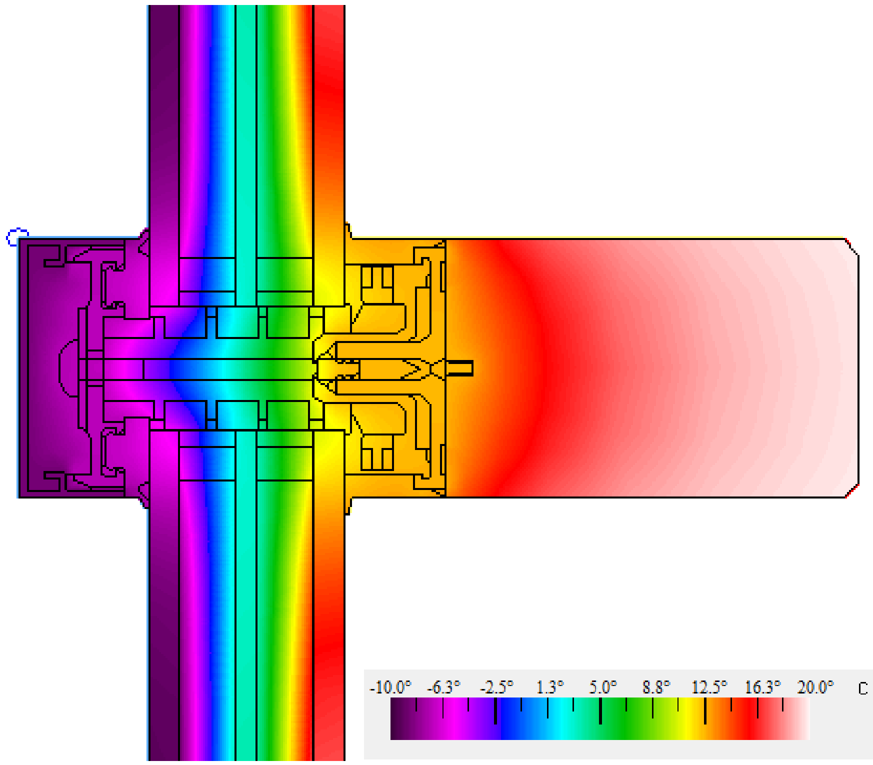


Figure 4.2 Colour isotherms of the frame section

4.2 Impact on building enclosure thermal performance

While this research report focused on the thermal performance of curtainwall products, it is important to recall the impact that curtainwall performance has on the overall thermal performance of the building. Figure 4.3 places this analysis back into the context of the overall effective R-value (combined walls and windows). Two scenarios are plotted, one for an R_{IP}-40 wall with high-performance curtainwall (blue), and a second for an R_{IP}-80 wall (green). The shaded areas represent the anticipated range in high-performance curtainwall performance (U_{SI}-0.70 to 1.0 W/m²·K), with the solid line representing a U_{SI}-0.80 curtainwall system.

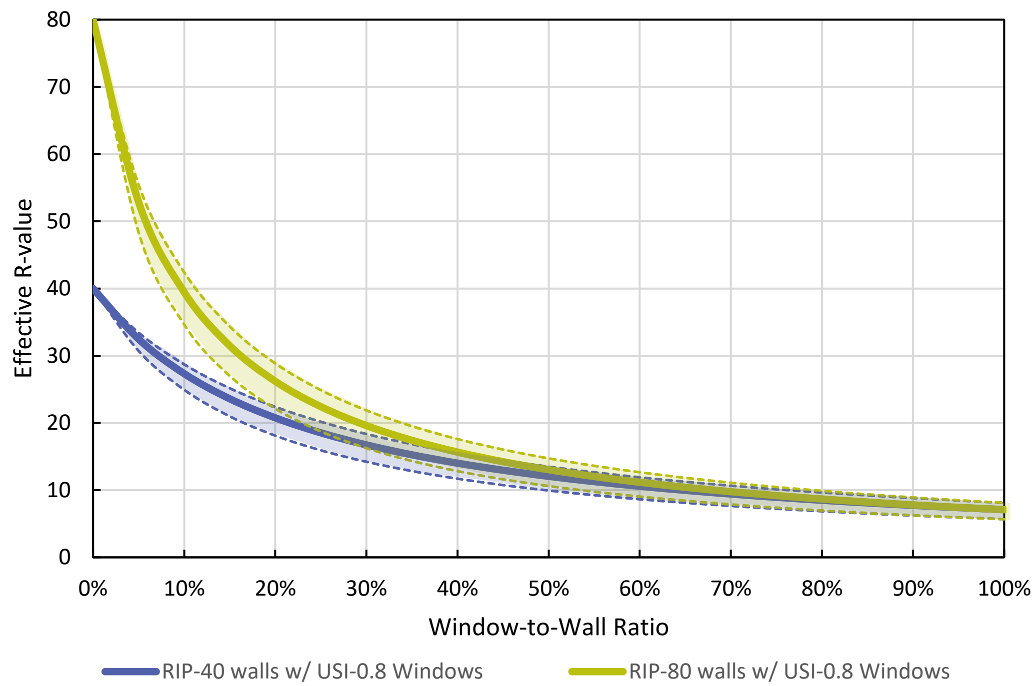


Figure 4.3 Effective R-value versus window-to-wall ratio (WWR) for an R_{IP}-40 and an R_{IP}-80 $ft^2·°F·hr/Btu$ wall, and U_{SI}-0.8 $W/m^2·K$ windows. The shaded areas represent a range in the window performance from U_{SI}-0.70 to 1.0 $W/m^2·K$.

At window-to-wall ratios above 50%, the effectiveness of doubling the R-value of the wall largely disappears, highlighting the importance of both minimizing the window-to-wall ratio and selecting high performance glazing. Even relatively large changes to the U-value of a product may have a small overall change to the building performance if the window-to-wall ratio is too large.

RDH anticipates that the following next steps would be required to extend this analysis and apply the research findings to the Canada's Earth Tower project:

→ Identify a typical curtainwall width, height, and depth to be used as the basis of design to meet the architectural intent for the project.

→ Iteratively optimize the curtainwall parameters (IGU make-up, fastener spacing, mullion profile, etc.).

→ Collaborate with one or more glazing suppliers to identify and select specific products and technologies that could be used today to produce a next-generation curtainwall.

→ Quantify the embodied and operational carbon impact of selecting timber vs. aluminum curtainwall framing materials, as well as other choices in terms of IGU make-up, and system performance.

In conclusion, this research report identified the key parameters influencing curtainwall thermal performance. We anticipate that these insights will be used to inform the development of future high-performance curtainwall systems.

Yours truly,

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