U-factor: Beyond compliance to standards

Author: Jennie Lamoureux, FMPC; Alumicor, architectural representative

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Commercial building designs incorporate large spans of glass, creating a modern appearance with transparency, daylight and a sense of connection to the larger world. Aluminum remains the most commonly used material for framing these expansive views and vision areas in building envelopes' curtainwall, storefront, entrance, window and other fenestration systems.

Aluminum is light weight and easily fabricated into versatile, durable products that require little maintenance throughout their long lifespans. Curtainwall and fenestration systems' framing members can be manufactured with recycled aluminum content and recycled at the end of their use on a building. The benefits associated with expansive, aluminum-framed fenestration systems also include supporting occupants' well-being and health, and building owners' lease rates and property values.

As buildings are designed with larger and larger vision areas, it is essential to remain aware of curtainwall and other fenestration systems' impact on the thermal performance and overall energy efficiency of the building envelope.

Specification professionals help to ensure that both the design intent and performance requirements are achieved for each project. When evaluating and selecting curtainwall and other fenestration products, specifiers must be alert for disparities in thermal measurements and data.

CONSIDER THE CODE

When analyzing curtainwall and fenestration systems' energy performance criteria, first check on the applicable codes. The most recent, national model building and energy codes may not be the most current ones, or modified versions may be enforced by the authority having jurisdiction over the project in question.

Provinces, territories, municipalities and some self-legislating authorities, such as First Nations, retain responsibility for how code editions and modifications are adopted and enforced except for federal buildings, where the most recent model code is automatically applicable. The National Research Council Canada (NRC) provides a high-level list of code adoption and enforcement throughout the country.[1] Additional verification at a municipal and project-specific level also is strongly recommended.

In all known Canadian codes and their provincial adaptations, each refers to "U-factor" or "U-value." This is the industry-accepted measurement indicating the rate of thermal energy transmission in a fenestration system.

UNDERSTANDING U-FACTOR

U-factor measurements consider the combined role of the glass, opaque panels and framing members, and take into account three different ways a curtainwall or fenestration system transfers energy: convection, conduction and radiation.

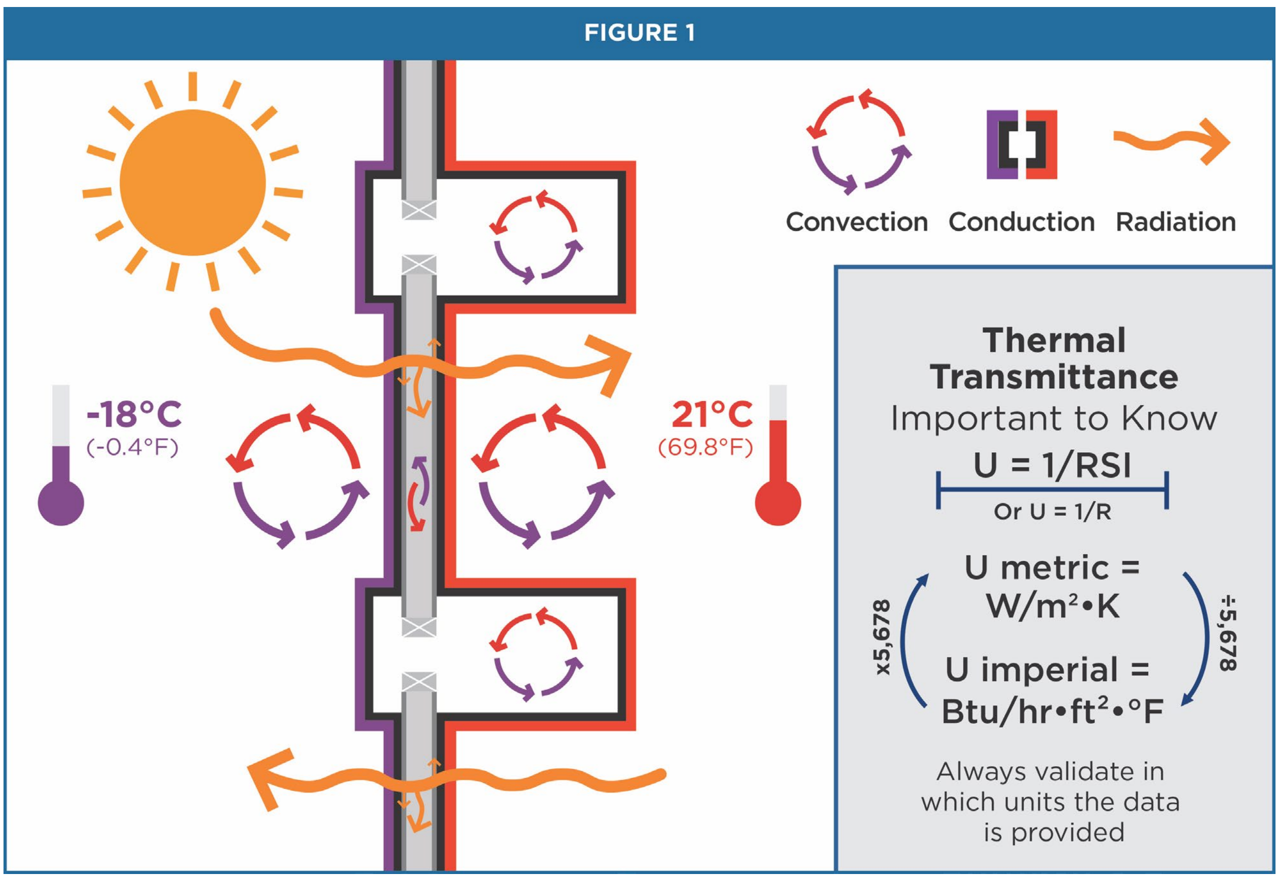


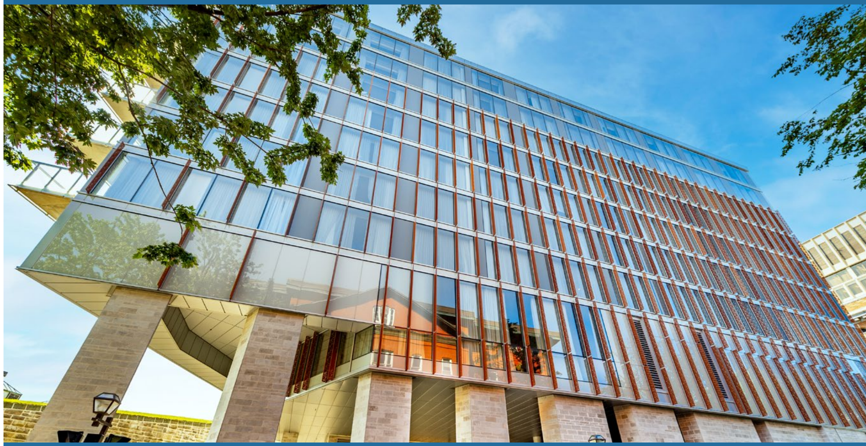
Figure 1:
U-factor, the thermal transmittance, is the inverse of the thermal resistance measurement used in the insulation industry, which is commonly expressed as effective R-value or RSI. When it comes to fenestration, it is not about measuring how well it insulates, but rather about measuring the total heat transfer through a system including convection, conduction and radiation under specific environmental conditions. The lower the U-factor, the less heat will be transferred. There are different procedures and methods to determine U-factor.

PERFORMANCE PROCEDURES

Enforced editions and revisions of the National Energy Code of Canada for Buildings (NECB) [2] reference the American National Standards Institute and National Fenestration Rating Council's ANSI/NFRC 100 *Procedure for Determining Fenestration Product U-factors*[3] and the Canadian Standards Association Group's CAN/CSA-A440.2/A440.3 *Fenestration energy performance/User Guide*[4] as procedures to obtain U-factors.

In the few cases where specialized products may be outside the scope of these two standards, the NECB refers to the procedures described in the *ASHRAE Handbook–Fundamentals*[5] and ASTM C1363 *Standard Test Method for Thermal Performance of Building Materials and Envelope Assemblies by Means of a Hot Box Apparatus*[6].

Hôtel Le Capitole de Québec – photos by Dany Caron/Pascal



The Capitole de Québec hotel extension, designed by CCM2 and Pierre Martin & Associés (PMA) Architectes, expanded the four-story historic property by nine stories. The new façade integrates with the existing structure, presenting a panorama of Old Quebec.

Framing the view, enhancing guests' comfort and supporting energy efficiency, Vitrerie Univerre Inc. installed multiple systems from Alumicor: Skyview 2300 skylights, ThermaPorte 7700 entrance systems, TerraPorte 7600 terrace doors and ThermaWall 2600 aluminum-framed, stick-built, thermally broken curtainwall.

REFERENCING THE REFERENCE

Most fenestration products are covered by ANSI/NFRC 100 and CAN/CSA-A440.2/A440.3. If specifiers want to understand which standard applies the best to a project's curtainwall or other fenestration systems, they first should be aware that CAN/CSA-A440.2/A440.3 refers to NFRC 100 and to NFRC 102 *Procedure for Measuring the Steady-State Thermal Transmittance of Fenestration Systems*[7].

Going one step further, NFRC 100 and 102 also refer to each other for various applicable conditions. These conditions include dimensions, product types, configurations and procedures. The ASHRAE Handbook–Fundamentals also refers to NFRC 100 and CAN/CSA-A440.2. In addition, ASTM C1363's standard test methodology is mentioned by both ASHRAE and NFRC 102.

Per CAN/CSA-A440.2/A440.3, Section 5 Overall coefficient of heat transfer (U-factor):

> **5.2 Determination of U-factor by measurement**
>
> The fenestration system U-factor shall be determined in accordance with NFRC 102.
>
> **5.3 Determination of U-factor by computer simulation**
>
> The fenestration system U-factor shall be determined using the simulation procedures specified in ANSI/NFRC 100, except that validation of the simulations as specified in ANSI/NFRC 100 is not required.
>
> The *NFRC Simulation Manual* and the *NFRC Technical Interpretation Manual* shall be used when performing computer simulation. In the event of a conflict with ANSI/NFRC 100 or the *NFRC Simulation Manual* or the *NFRC Technical Interpretation Manual*, this Standard shall take precedence. In the event of a conflict between ANSI/NFRC 100 and the *NFRC Simulation Manual* or the *NFRC Technical Interpretation Manual*, ANSI/NFRC 100 shall take precedence."

These intertwined standards bring to mind the question: "Which came first, the chicken or the egg?" All of these seem to nest together. In the end, NFRC 100 stands as the ultimate reference regarding the applicable conditions for determining U-factor measurements and the corresponding energy efficiency ratings for curtainwall and other fenestration products.

APPROVED APPROACHES

NFRC 100 offers three approaches to determine the U-factor values of a fenestration product or a combination of products:

1. A U-factor value based on prescriptive methods
2. A U-factor value based on project-specific conditions
3. A range of multiple U-factor values that determine the thermal performance limits of the product(s); also known as Linear Energy Analysis For Fenestration (LEAFF)

The top two approaches to obtaining U-factor values have been used for many years, and will continue to be, within the progressive evolution of NFRC 100's procedures. The third approach was more recently introduced by NFRC to ease the use and understanding of data. The data from these approaches are neither used at the same stages of a project's development or for the same types of projects.

Nevertheless, all three of these approaches generates data that are in compliance with NFRC 100, but the various data from these different approaches should never be compared, or extrapolated for comparison – such manipulations have been proven invalid.

Specification professionals are challenged to stay up to date on these various approaches and, based on their knowledge, to critically review the U-factor values for curtainwall and other fenestration systems. NFRC 100 and 102 are available free for download. NFRC also offers regular training and webinars on energy efficiency topics.

Prescriptive

The prescriptive approach leads to a standardized U-factor value appropriate for fenestration products and considers specific criteria defined by NFRC 100. This approach allows for similar product type comparisons and is a good starting point for preliminary selections. It also works well for basic projects that follow the NECB's prescriptive path.

Project-Specific

The project-specific approach leads to a unique U-factor value based on the performance of a fenestration product, possibly in combination with other fenestration systems, to serve a particular project's requirements. This approach should be considered for any project that exceeds NECB's prescriptive requirements, or that has special design conditions, such as historically significant buildings.

The project-specific approach can be obtained by either a simulation or a physical test. As shown in Figure 2, numerous aspects can be modified to suit the project's requirements, including a fenestration product specimen's dimensions, assemblies, glazing types, interior and exterior temperatures, and more. This allows the U-factor value to be determined according to the project-specific conditions. This unique U-factor is necessary when calculating the building's energy consumption, and ultimately, for meeting energy codes' conformity by demonstration paths.

CONTEXT AND CRITERIA

The standard method for determining U-factor values is used to establish basic criteria, allowing a comparison of products during the preliminary stages of a project, or to ensure compliance with the NECB's prescriptive requirements. U-factor data determined by this approach are ubiquitous in the commercial building and fenestration industry. It is imperative to understand the context in which the values were determined to better assess how the results may be influenced.

Two components emerge in the standard method for determining U-factors:

1. The protocol, which is the procedure to be followed to carry out the computer simulation or the physical test; and
2. The specimen, which is the product itself.

FIGURE 2

This aspect is either clearly defined in the prescriptive path of the standard or can be customized on a project-specific approach. A verification of the report is always recommended.	Be careful, verifications are highly recommended. This aspect may vary or have options that are not specified by the standard, but must be mentioned in the report.	Verifications are necessary. This aspect is typically customized, can have a significant impact on U-factor, and is not specified by the standard, but must be mentioned in the report.

U-factor Influencers	Explanation	Approach	
		Prescriptive	Project Specific
Material Considerations	Material thickness, thermal break material and depth, back section depth, and gasket material and size should all be reviewed to ensure structural and thermal performance in addition of the painted or anodized finishes protecting the aluminum.	Different extrusion thicknesses, thermal break options, and gasket/tape materials and sizes can be used. Back section depths are not specified in the prescriptive path, but finish considerations are well defined.	Specific mullions can be simulated. Specific thermal breaks and back sections can be integrated into the analysis. Specific gaskets/tapes can be verified for compatibility with IGU/infill, building conditions, anchorage, and finishes, if desired.
Environmental Conditions	The greater the temperature differential is (Δ°), the more heat will transfer to cold. Remember: energy flows from warmer to cooler. Higher U-factor = lower performance. Wind can affect performance.	Exterior temperature: -18.0°C (-0.4°F) Interior temperature: 21.0°c (69.8°F) Wind speed: 5.5 m/s (12.3 mph)	These can be adapted to the project location's climate.
Product Configuration	Overall dimensions, configuration, opening direction, and combination/assemblies can impact thermal performance. Typically, more aluminum results in a higher U-factor.	Verify the opening direction. Some products assemblies can be analyzed, but larger or more complex assemblies are not part of the scope.	Products can be validated for specific sizes, operation, and configurations.
Spandrel Panel Composition	Spandrel can be made of various materials and depths. Their performance must be measured based on NFRC protocols, but has to comply with U-factor for opaque wall assemblies in the NEBC.	Spandrel products struggle to meet NEBC requirements based on prescribed dimensions and conditions of NFRC. The inclusion of spandrels in a project automatically leads to a project-specific analysis and to non-prescriptive compliance paths.	The specific spandrel composition, dimensions, and assembly with other products can be analyzed based on the project's specific design.
Component Considerations	Curtain wall cap depth, pressure plate material and shape, sun shade attachment and mullion reinforcement, and system type (such as SSG) can affect thermal performance.	The cap depth and the addition of a non-standard pressure plate can influence U-factor. The same mullion in SSG and capped options have no correlation to the U-factor.	The specific cap and pressure plate can be integrated in the analysis. The specific type of system design, including reinforcement, can also be simulated.
IGU Considerations	More chambers in an IGU and the use of low-e coating can improve thermal performance. The gas infill type, glass depth, glass type, spacer material, and spacer depth also influence structural, thermal and acoustic performance.	Each of these aspects is highly customizable and can be either optimized or devalued in the U-factor analysis.	The specific IGU required for the project can be integrated in the analysis with consideration to the IGU's full depth, glass layers' depth, glass type, spacer type and depth, gas infill and proportions of gas, low-e coating and more.

It is expected that all parameters of these two components will be exhaustively defined, allowing an equal comparison of fenestration products.

Among the protocol's many criteria are:

- The calibration of measuring devices;
- The software versions to be used in case of simulation, or the installation of the specimen in the case of a physical test;
- The indoor and outdoor temperature differentials;
- The location of temperature reading points on the simulated or physical specimen;
- The wind speed(s); and
- Any additional reference standards.

As for the specimen, the objective is to measure its performance; however, other factors also have an impact on the resulting U-factor. Some of these factors may not be integral or consistent with the product's design. The variations in these factors can be especially important in the case of curtainwall systems. Curtainwall offers many options to customize commercial building envelopes' appearance and performance. Reviewing **Figure 2**, one can see how non-standard fenestration systems can impact an overall U-factor and why specifiers must carefully review their data.

DEFINED DIMENSIONS

To provide a framework for specimens' standard analysis, NFRC 100 prescribes dimensions for each type of fenestration product. As examples, see **Figure 3**.

FIGURE 3

Fenestration Product Type	NFRC 100 Standard Dimensions
Curtain wall, window wall, storefront, or sloped glazing	2000 by 2000 mm (79 by 79 in) with two non-operable glass lites
Fixed window	1200 by 1500 mm (47 by 59 in) with one non-operable glass lite
Dual-action window	1200 by 1500 mm (47 by 59 in) with one operable lite
Casement window	600 by 1500 mm (24 by 59 in) with one operable glass lite
Spandrel panel	2000 by 1200 mm (79 by 47 in) with two non-operable panels

Source: ANSI/NFRC 100-2020
Note: Please remember that NFRC 100 standard dimensions are not equivalent to, and should not be compared with, standard dimensions listed in the AAMA/WDMA/CSA A440-NAFS.

Standard dimensions make it easier to compare similar products' U-factor values. For different fenestration systems, standard results are not a good indicator in product type selection because they cannot be compared on an equal basis. The U-factor performance of a casement window compared with dual-action window serves as a good example.

Compliance with these dimensions and configurations remains important to compare the same type of fenestration products. Particularly in the case of aluminum curtainwall products, the ratio between the framing members and the glass is a key aspect in the measurement of thermal transmittance. Furthermore, to disregard prescribed configurations for curtainwall and only use the overall dimensions for determining standard U-factor would produce an inaccurate result as shown in **Figure 4**.

Figure 4:
This simulation shows the same model of high-performance curtainwall with an integral thermal break and with all the same components in the 2000 by 2000 mm (79 by 79 in) size. The difference between these models is that one on the left is undivided due to a mistaken assumption regarding the configuration requirement. The one on the right does is divided in two vertical lites as prescribed by NFRC-100. The difference in results comes from the aluminum mullion division that generates more heat transfer. This comparison is a good indication on how more aluminum mullions on a design can influence the performance.

FIGURE 4

Dimensions: 2000 by 2000 mm (79 by 79 in)
U-factor: 1.66 W/m²•K (0.29 Btu/hr•ft²•°F)
Center of glass: 1.36W/m²•K (0.24 Btu/hr•ft²•°F)

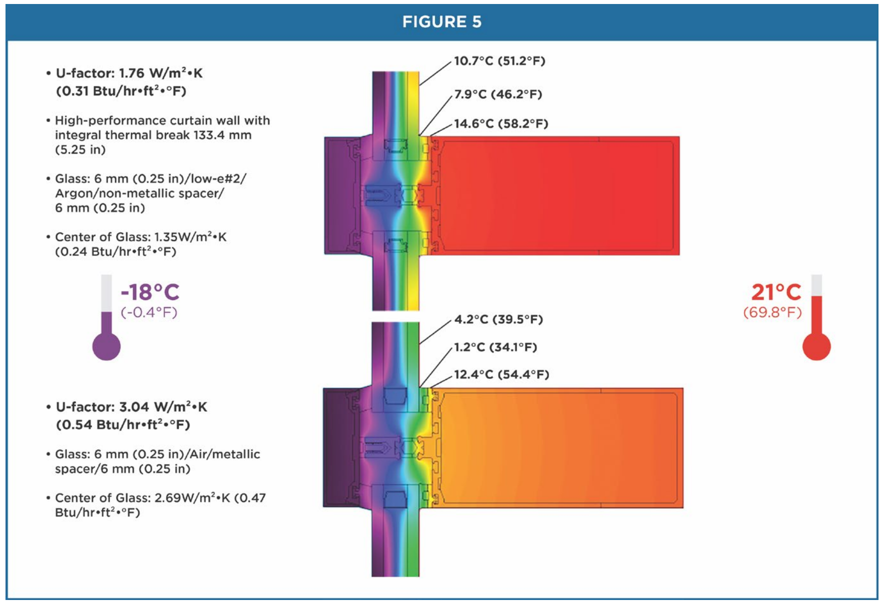
Dimensions: 2000 by 2000 mm (79 by 79 in)
U-factor: 1.80 W/m²•K (0.32 Btu/hr•ft²•°F)
Center of glass: 1.36W/m²•K (0.24 Btu/hr•ft²•°F)
Configuration as prescribed by NFRC

VALIDATING VARIABLES

Using the same curtainwall system, **Figures 5** and **6** demonstrate how altering two variables – glazing type and mullion depth – can affect U-factor values and lead to different performance results.

Figure 5:

This simulation shows the same model of high-performance curtainwall with an integral thermal break and with all the same components in the 2000 by 2000 mm (79 by 79 in) size, divided into two vertical lites, configured as prescribed for curtainwall in NFRC 100. The only difference is the insulated glass unit (IGU). The top example uses a high-performance IGU compared with a low-performance IGU on the bottom. This illustrates the importance of consistency on specification requirements between curtainwall and glass selection. A curtainwall's capacity to achieve an overall performance required in a specification heavily relies on the performance of the IGU specified.



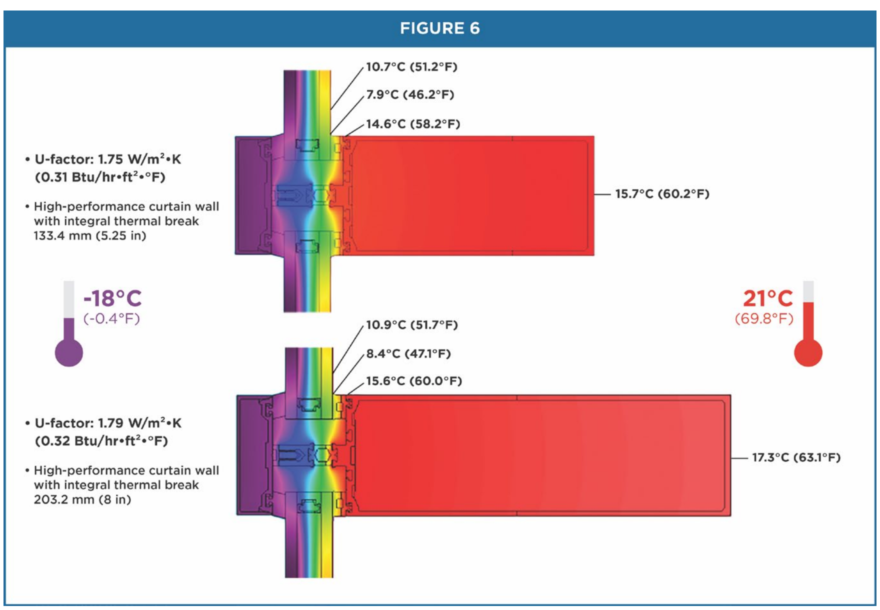


Figure 6:

This simulation shows the same model of high-performance curtainwall with an integral thermal break and with all the same components in the 2000 by 2000 mm (79 by 79 in) size, divided into two vertical lites, configured as prescribed for curtainwall in NFRC 100. The only difference is the mullion depth. Temperatures observed are superior with the deeper 203 mm (8 in) mullion, which is an interesting aspect to improve the resistance to condensation (I-index). However, the overall U-factor is higher with the deeper mullion because its warmer surface temperature and more interior surface area leads to more heat lost.

The choice of insulated glazing units (IGUs) and the depth of the mullions are outside NFRC 100's prescribe approach. As shown above, these have a notable influence in the curtainwall system's U-factor and thermal transmission. It is very important to ensure the framing specification is coordinated with the glass specification and the separate components combined can achieve the desired U-value required for the project.

There are a variety of IGUs that may improve the overall performance of a fenestration product, especially for aluminum curtainwall systems. An overall system U-factor will depend on the choice of glazing. The use of high-performance IGUs may compensate for lower thermal performance elsewhere in the curtainwall system's design. It is possible to separate the system's overall performance (Ut) from the performance of the aluminum framing (Uf). Again, keep in mind that the frame's lower thermal performance may be mitigated by the IGU's higher performance.

Frequently, the IGU is selected and specified independent of the fenestration system's framing based on project-specific needs. For optimal performance, these should be reviewed together. It is imperative to ensure consistency between the complete system's specified U-factor and the IGU's capacity to support the overall system requirements. For example, specifying a U-factor of 1.65 $W/m^2 \cdot K$ (0.29 $Btu/hr \cdot ft^2 \cdot °F$) for both the IGU and the overall fenestration product is a required performance impossible to achieve.

As for the importance of mullion depth, this also is dependent on the particular needs of the project. Structural performance and safety should always be the first priority. In general, a deeper mullion will have a positive affect on condensation resistance, but it also can have a negative affect on thermal transmittance. This is an important consideration when designing the project and its curtainwall and fenestration systems, as well as in analyzing the data provided as proof of compliance to meet thermal performance specifications, building codes, structural requirements and energy efficiency goals.

NFRC's LEAFF approach to determining U-factor values introduces new possibilities to ensuring high thermal performance in curtainwall and other fenestration systems. This approach relies on computer simulations to validate the IGU's performance and then to define the performance intervals of a fenestration product. Because the glazing unit is an essential and influential component of the fenestration system, this method might generate more practical, applicable data about a product's capabilities.[8]

Musée d'art de Joliette, QC (https://www.alumicor.com/en/project/en/) – photos by Musée d'art de Joliette – Steve Montpetit, Eruoma Awashish, Romain Guilbault

Vitrerie Nouvelle Vision installed Alumicor's ThermaWall 2600 aluminum-framed, stick-built, thermally broken, curtainwall on the Musée d'art de Joliette's 2,900 m^2 (31,216 ft^2) extension. The addition was designed by Les architects fabg and constructed by Groupe Gyeseer. The exterior's translucent and transparent façade not only support operational energy-efficiency and interior comfort, but also allows for improved promotion of the permanent exhibits, as well as more space for temporary exhibits.

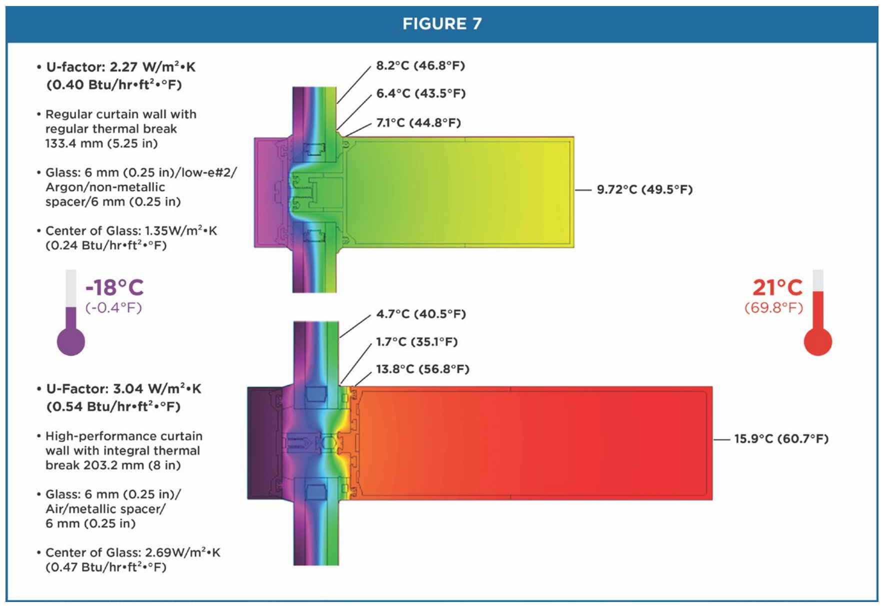
COMPARING CURTAINWALL

In Figure 7, two U-factor simulations are demonstrated. Both are in compliance with NFRC 100, and thereby in compliance with CAN/CSA-A440.2/A440.3. One shows a low-performance curtainwall specimen with aluminum framing that has a basic thermal break, but is optimized with a high-performance IGU and a shallow mullion. The other curtainwall specimen has a high-performance, thermally broken aluminum framing and a deep mullion, but it also has a low-performance IGU with air infill, a metal spacer and no low-emissivity coating.

Analyzing the range in attainable thermal performance, the low-performing curtainwall helps validate the best achievable U-factor, and the high-performing curtainwall assists in determining the worst U-factor. These differences presented by these voluntary choices demonstrate the need to verify beyond the system manufacturer's promoted U-factor and to affirm compliance with NFRC/CSA standards.

Figure 7:

This simulation shows two different models of curtainwall in the 2000 by 2000 mm (79 by 79 in) size, divided into two vertical lites, configured as prescribed for curtainwall in NFRC 100. The top example is a regular, low-performance curtainwall with a minimal thermal break, a high-performance IGU and a shallow mullion. The bottom example is a high-performance curtainwall with an integral thermal break, a low-performing IGU and a deep mullion. These illustrate how, even when both are in accordance with NFRC 100 prescribed requirements, U-factors can be calculated in a way to demonstrate the best or the worst that a product can achieve. Be aware that U-factor comparisons of products based only on compliance to the standard can lead to incorrect conclusions.



In summary, it is a specifications professional's responsibility to look beyond conforming to a fenestration standard, to question thermal performance data being presented and to validate the full context in which the U-factor was obtained and is required. The first step is to verify whether the required data are or should be based on project-specific requirements, or if they are or should be based on a prescribed approach. For U-factor values determined according to the standard method, the next step is for a specifier to evaluate which criteria should be considered to adequately compare the thermal performance of curtainwall and other fenestration systems.

Simply stating a U-factor without the compliance requirements is likely to cause confusion and to miss the intended performance requirements. In the aluminum framing specifications, clearly state which compliance path is expected. If following a non-prescriptive path, remember to include all items necessary to determine performance such as elevations, sizes and configurations, materials and components, local climate conditions, and IGU considerations. Coordinating the specifications for the glass and aluminum framing will help ensure the performance requirements are met for curtainwall or other fenestration systems.

AUTHOR'S BIOGRAPHY

Jennie Lamoureux, FMPC, is an architectural representative at Alumicor, the board chair for Construction Specifications Canada's (CSC-DCC) Montreal chapter and an active member of the Association de vitrerie et fenestration du Québec's (AVFQ) Technical Committee – Commercial Sector. She also is a member of the Fenestration and Glazing Industry Alliance's (FGIA) Architectural Products Council's Methods of Test Committee and has earned an FGIA FenestrationMaster Professional Certification (FMPC). She works closely with Canadian architectural design professionals to evaluate, select and specify aluminum-framed curtainwall, storefront, entrance and window systems for commercial building envelopes. She can be reached at j.lamoureux@alumicor.com.

Hôtel Le Capitole de Québec – photos by Dany Caron/Pascal

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