ENERGY PERFORMANCE OF WINDOWS: NAVIGATING NORTH AMERICAN AND EUROPEAN WINDOW STANDARDS

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ABSTRACT

An important element in the design of low energy buildings is the use of high performance windows coupled with passive solar design strategies. As energy efficiency becomes more important, North American designers sometimes look to Europe for energy efficient standards and technologies, such as the Passive House approach. However, comparing European and North American windows is complicated by the significant differences between European and North American energy performance rating standards. The different evaluation methods and boundary conditions also affect product design, as European and North American windows are optimized to achieve the lowest U-values under their respective rating systems.

This paper presents a review of the primary fenestration rating systems in North America and Europe, including those developed by the National Fenestration Rating Council (NFRC), the Canadian Standards Association (CSA), the International Organization for Standardization (ISO), and the Passive House Institute (PHI).

A literature review is presented to highlight the primary differences between the rating systems. These differences include boundary conditions (temperature, surface film coefficient and incident solar radiation), algorithms for calculating centre of glass heat transfer, methods of accounting for edge of glass effects, window sizes, standard material properties, and treatment of sloped glazing.

Computer modeling is used to show how the different rating systems evaluate calculated U-value and solar heat gain performance characteristics for several window configurations. Modeled results show that European and North American U-values can vary by up to 25% for a single frame and glass configuration. Center of glass solar heat gain values were shown to differ as much as 8%.

The insights gained from the literature review and simulations are summarized to highlight important considerations for designers, specifiers, and fenestration product manufacturers in both North America and Europe. This paper will help interested parties to understand the differences, to make informed product selection choices, and, if desired, to optimize product performance for North American or European regulatory regimes as needed.

INTRODUCTION

With the growing interest in the Passive House movement for energy efficient buildings, European fenestration products are being used more frequently in North American jurisdictions. This has created challenges for building designers and product manufacturers as the differences between North American, European ISO and Passive House thermal performance rating systems for windows have led to misunderstandings about the appropriate criteria for energy efficient product selection. The same window will have different U-value and solar heat gain ratings under each of these systems, and there is no straightforward way to compare North American and European product performance.

This study was undertaken to better understand the ISO and Passive House fenestration energy rating systems by comparing them with the NFRC/CSA rating system used in North America. In addition to identifying the conceptual differences between them, this study uses computer simulation methods to illustrate how these differences can result in significantly different product ratings.

LITERATURE REVIEW

NORTH AMERICAN STANDARDS

The primary organization for rating the thermal performance of windows in North America is the National Fenestration Rating Council (NFRC). The NFRC publishes several standards related to the testing or rating of window thermal performance, including thermal performance simulation standards NFRC 100 Procedure for Determining Fenestration Product U-factors (NFRC, 2010), and NFRC 200 Procedure for Determining Fenestration Product Solar Heat Gain Coefficient and Visible Transmittance at Normal Incidence (NFRC, 2010). Other standards published by the NFRC include laboratory testing standards for U-value and SHGC, procedures for determining condensation resistance, and others.

In Canada, CSA A440.2-09 Fenestration energy performance (CSA, 2009) specifies thermal performance requirements for windows. This document references NFRC 100 and NFRC 200 for determining U-value and SHGC, respectively.

EUROPEAN STANDARDS

In contrast to the NFRC/CSA focus on rating and comparing fenestration products, the ISO standards were developed to allow the energy performance of any fenestration product size or configuration to be determined under a standard set of environmental conditions. While they can be used to compare the performance of competing products, they can also be used to estimate the energy performance of fenestration product configurations contemplated for a particular building.

There are several European standards related to the thermal performance of windows. The primary documents reviewed in this study include the following standards:

- ISO 10077-1 Thermal performance of windows, doors and shutters – Calculation of thermal transmittance – Part 1: General
- ISO 10077-2 Thermal performance of windows, doors and shutters – Calculation of thermal transmittance – Part 2: Numerical method for frames
- ISO 15099 Thermal performance of windows, doors and shading devices – Detailed calculations
  - Calculation procedure for U-value, g-value, and visible light transmittance
- EN 673 Glass in building – Determination of thermal transmittance (U value) – Calculation method
  - Calculation method for centre of glass U-value
- ISO 10292 Glass in building – Calculation of steady-state U values (thermal transmittance) of multiple glazing
  - Calculation method for centre of glass U-value
- EN 410 Glass in building – Determination of luminous and solar characteristics of glazing
  - Calculation procedure for solar characteristics of glazing
- BR 443 Conventions for U-value calculations
  - British conventions for calculating U-values of building enclosure components including vertical and sloped glazing, including reference sizes

COMPARISON OF STANDARDS

The literature review included North American (NFRC), European (ISO, EN), and PHI standards related to window thermal performance ratings. In North America, windows are certified using NFRC standards. In Europe, windows are certified using ISO and EN standards. PHI also requires windows be simulated following ISO standards but with one key difference: the exterior temperature is simulated at climate-specific outdoor temperatures rather than the ISO standard 0°C (though the ISO standard 0°C is acceptable for the PHI cold-temperate climate). Note that these boundary conditions are only for Passive House certified windows, and the requirements for Passive House certified buildings do not require the windows to be Passive House certified.

Although there are many differences between the various standards, the primary differences are summarized below.

- Different boundary conditions: NFRC, ISO and PHI use different temperatures, surface films, and incident solar radiation (for solar heat gain calculations). These values are shown in Table 1 and Table 2.

Table 1: Exterior and interior surfaces temperatures for U-value and SHGC calculations.

	U-value		**Solar Heat Gain**		
	Exterior Temp.	**Interior Temp.**	**Exterior Temp.**	**Interior Temp.**	**Solar Radiation**
NFRC 100 & 200	-18°C	21°C	32°C	24°C	783 W/m^2
ISO 10077-1, ISO 10077-2, ISO 15099	0°C	20°C	30°C	25°C	500 W/m^2
Passive House Window Certification Criteria	Frame: -10°C IGU: 20°C to -7°C (climate specific)	20°C	30°C	25°C	500 W/m^2

Table 2: Standard surface film coefficients for U-value calculations, vertical glazing.

	Exterior, W/m^2-K	**Interior, W/m^2-K**	**Notes**
NFRC 100 Aluminum Frame Thermally Broken Frame Thermally Improved Frame Wood/Vinyl frame	26.0	 3.29 3.00 3.12 2.44	Interior coefficients are convection only; radiation model is an automatic enclosure model for interior frame surfaces, blackbody for exterior surfaces. These values are for frame and edge of glass only; IGU coefficients are calculated in WINDOW (and vary depending on interior surface emissivity).
ISO 10077-1, ISO 10077-2, EN 673, Passive House	25	7.7	Interior coefficient is combined convection and radiation. Reduced radiation/convection boundary conditions are applied where there are facing segments at corners. For IGUs, interior coefficients are calculated based on interior surface emissivity (value shown is for standard glass, no low-e).

- Differences in calculating solar heat gain: There are two primary differences in the North American and European solar heat gain calculations. First, the NFRC Solar Heat Gain Coefficient (SHGC) is evaluated for the whole window product. The Passive House simulation software uses a centre of glass solar heat gain value, called the "g-value." ISO standards allow g-value to be determined for either the whole window or the centre of glass; however it is commonly reported as a centre of glass value. This is an important difference, since centre of glass values are higher than whole window values because the opaque frame area reduces solar heat gain in a whole window calculation. The second difference in solar heat gain calculations is the different boundary conditions, including different temperatures and incident solar radiation.

- Differences in calculation of centre of glass heat transfer: The ISO/PHI method (ISO 10077) uses a simplified calculation procedure with an assumed mean temperature difference across the gas space. The NFRC method references a different ISO standard (ISO 15099), which uses a more comprehensive calculation procedure based on heat transfer relationships solved using numerical methods. This is a significant factor affecting the variation between ISO/PHI and NFRC U-values.

- Different methods of evaluating thermal transmittance through the window frames: Using the NFRC standard, the frame U-value is simulated with the actual IGU in place. Using the ISO procedure, the frame U-value is simulated with a calibration panel with a specified conductivity of k = 0.035 W/m-K for the thickness of the manufacturers standard IGU width. Use of a calibration panel may standardize the conditions under which frame U-values are evaluated for the benefit of comparing frames to one another. However it results in values that do not report actual heat flow through frames, and therefore will typically result in frame U-values that are lower (better) than NFRC-simulated frame U-values.

- Different methods of accounting for thermal transmittance through the glass to frame interface (edge of glass): The NFRC standard determines an edge of glass U-value for the glazing, frame and spacer configuration measured 63.5 mm (2.5 inches) from the frame sight line. The ISO procedure uses a linear thermal transmittance or Ψ-value to account for this heat transfer. The linear transmittance is calculated by comparing simulations with the specific IGU and spacer to simulations with a calibration panel of specified conductivity inserted into the frame in place of the IGU.

- Different reference sizes for comparing whole-product energy performance: While fixed window sizes are very similar (the NFRC size is 1.20 m x 1.50 m, and the Passive House size is 1.23 m by 1.48 m), NFRC standard sizes for other operator types vary considerably (e.g. casement windows have a standard size of 1.50 m x 0.60 m, awning windows, 0.60 m x 1.50 m). NFRC standards do not offer the ability to report whole product values at other than standard sizes. Passive House uses actual project sizes and component properties (centre of glass, frame, edge) for whole building energy modeling. The ISO standards themselves do not provide standard window sizes, however other European rating organizations do have standard sizes. For example, the British Fenestration Rating Council (BFRC) standard size is a coupled window with one operable sash and one fixed lite separated by a central mullion, the whole product measuring 1.23 m by 1.48 m.

- Differences in treatment of sloped glazing: Following NFRC procedures, skylights and other sloped glazing are simulated at an angle of 20° above the horizontal. Following ISO standards, parameters are calculated in a vertical position for the purpose of comparing different products. Passive House certification criteria state that roof windows are to be modeled at a 45° inclination. These differences are significant as slope angle has a significant effect on thermal transmittance, degrading performance as the inclination increases, though this factor was not assessed further through simulations in this study.

- Evaluation of thermal transmittance through the window-wall interface (installation): Passive House is the only standard reviewed in this study that evaluates the thermal performance of the window installation, via an installation Ψ-value (perimeter linear transmittance). Installed product U-value is one of the Passive House window certification criteria, and the installation Ψ-value is used in the Passive House modeling software (PHPP).

COMPARING U-VALUE AND SOLAR HEAT GAIN VALUES FOR SELECTED WINDOWS

METHODOLOGY

U-value and solar heat gain calculations were performed for two representative North American windows, one with a vinyl frame and the other a fiberglass frame, and a European Passive House certified window with a vinyl (uPVC) frame. Each window and glass combination was simulated using both NFRC and ISO procedures. Note that ISO boundary conditions are also acceptable for PHI simulations in the cold-temperate climate zone (which includes Vancouver, Toronto, Ottawa and Montreal); other PHI boundary conditions that vary by climate zone were not simulated.

For each frame type, six different insulating glass units (IGUs) were simulated, including high and low solar heat gain coatings in double glazed, double glazed with both surface two and four low-e coatings, and triple glazed configurations. Both fixed and operable configurations were modeled for each window type.

NFRC simulations were performed following NFRC guidelines as documented in "THERM 6.3 / WINDOW 6.3 NFRC Simulation Manual" (Lawrence Berkeley National Laboratory, 2011). The software programs WINDOW 6.3 and THERM 6.3 were used for the NFRC simulations.

ISO simulations were completed following the procedure outlined in "Calculating Fenestration Product Performance in WINDOW 6 and THERM 6 According to EN 673 and EN 10077" (Lawrence Berkeley National Laboratory, 2012) and the associated spreadsheet, with the following exceptions. The software versions WINDOW 7.1 and THERM 7.1 were used since WINDOW 7.1 has the functionality required to perform EN 673 calculations, and this functionality does not work in Version 6.3. Also, the exterior combined surface film coefficient used in the models was 25 W/m^2-K per ISO 10077-1 and EN 673, instead of 23 W/m^2-K shown in the document (which appears to be from a previous version of the standard).

Three of the window configurations were also simulated independently by a German simulator using standard software (flixo professional version 6) to verify the results in this study. His results were generally within 5% of those reported in this study.

RESULTS

Figure 1 shows the centre of glass U-value simulated using NFRC and ISO standards under a range of exterior surface temperatures for a triple glazed IGU with argon gas fill and low-e coatings on surfaces two and five. The plot shows varying optimal gap sizes for both standards at selected exterior temperatures. The optimal gap size for NFRC standard conditions (-18°C) occurs at approximately 14 mm, while the optimal gap size at ISO and Passive House cold-temperate climate standard conditions (0°C) occurs at approximately 18 mm. This is why European products typically have larger IGU gap sizes; they are optimized for the warmer 0°C exterior boundary condition. By comparison, the same IGU modeled following NFRC 100 (which uses the ISO 15099 evaluation method) at the same exterior temperature of 0°C yields a much higher U-value. These results indicate that the differences in both methodology and exterior surface temperature contribute to the different U-value results.

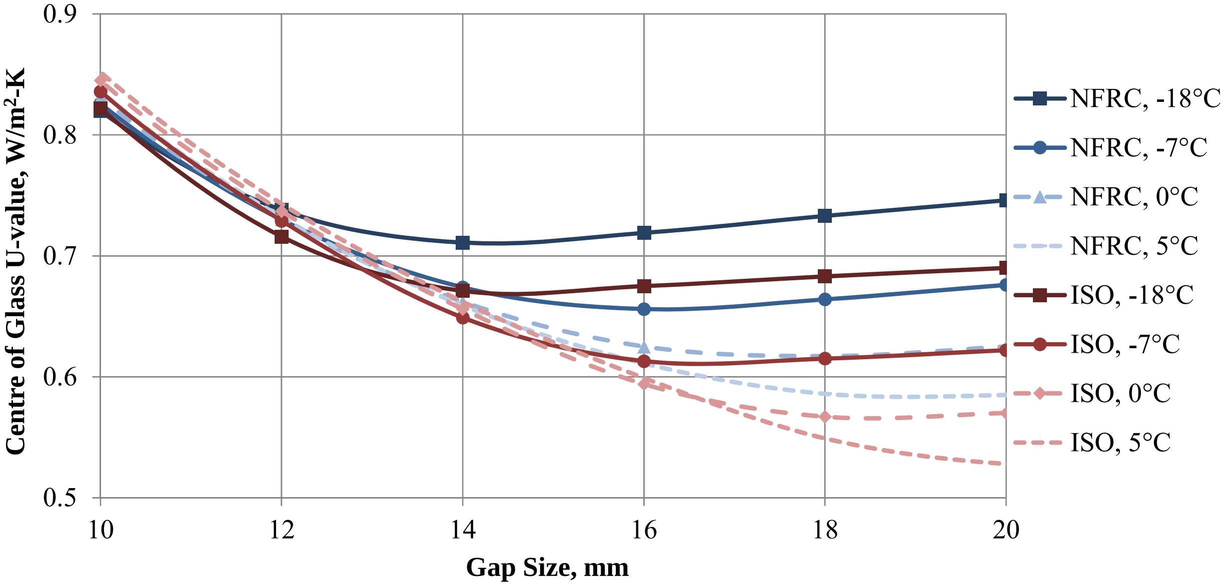

FIGURE 1: Centre of glass U-value versus gap size for NFRC and ISO procedures using different exterior surface temperatures for a triple glazed IGU with argon gas fill and two low-e coatings.

Figure 2 shows U-values calculated following NFRC and ISO standards for six different IGUs. In Figure 2, the triple glazed units had a gap size of 12.7 mm, and therefore had a similar U-value to the NFRC calculated value, as is the case in Figure 1 for smaller gap sizes. Conversely, the double glazed units had a gap size of 15.875 mm and therefore performed much better under ISO than under NFRC.

Overall, the centre of glass U-value simulation results in this study showed NFRC values were between zero and 23% higher (worse) than ISO values. Smaller gap sizes optimized for NFRC (e.g. 12.7 mm) resulted in small difference (0% to 2%) between the two standards. Larger gap sizes (e.g. 15.875 mm) resulted in greater differences (14% to 23%).

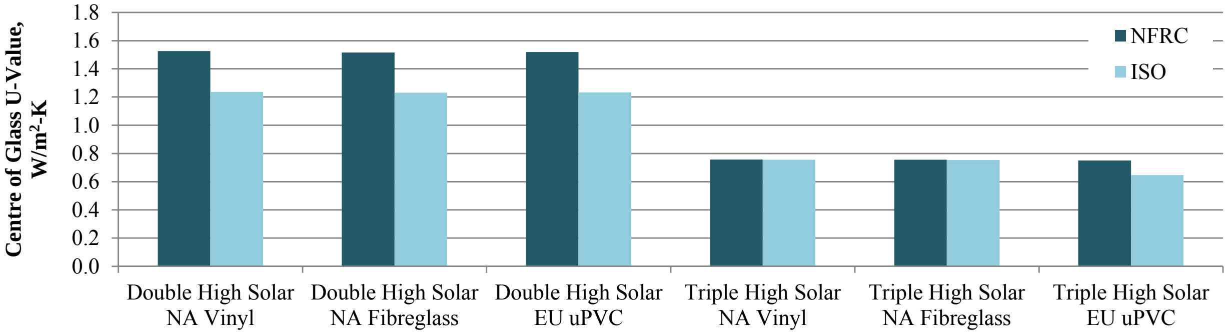

FIGURE 2: Centre of glass U-values simulated for various window configurations using NFRC and ISO procedures.

Figure 3 shows the fixed window frame U-values that were simulated in this study. Trends for the operable window configurations were similar. Frame U-values in this study showed NFRC values were between 5% lower to 24% higher compared to ISO values. The ISO values generally resulted in lower U-values since they are modeled with a calibration panel of set thermal conductivity rather than the actual IGU and spacer. The fiberglass frames showed less variation in U-value than the vinyl frames. This occurred because the default NFRC conductivity for fiberglass is lower than the default ISO conductivity for this material, which offset some of the difference due to use of the calibration panel.

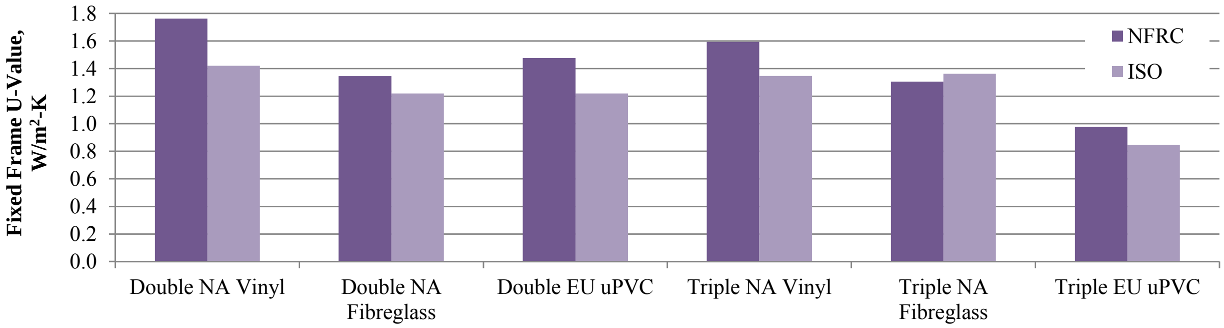

FIGURE 3: Fixed frame U-values simulated for various window configurations using NFRC and ISO procedures.

The NFRC edge of glass U-value is based on the THERM simulation of the frame, spacer and IGU. In contrast, the ISO edge of glass Ψ-value is based on a linear transmittance, calculated from the simulations both with a glazing unit and with a calibration panel. Therefore there is no true comparison between NFRC and ISO edge of glass values, as the NFRC method does not involve a calibration panel. As such, an 'edge of glass' comparison plot is not shown.

Figure 4 shows the whole window U-value simulation results for several of the configurations simulated, all fixed type windows. Whole window U-values in this study showed NFRC values were between 14% lower to 18% higher than ISO values. The North American triple glazed windows have NFRC/ISO U-values that are close due to the smaller 12.7 mm gap size. The double glazed windows simulated have a larger gap size (15.875 mm) and therefore perform significantly better under ISO. Comparing Figure 4 (whole window U-values) to Figure 1 (centre of glass U-values), it is evident that the centre of glass has a large impact on the whole window results as the two plots follow the same trend.

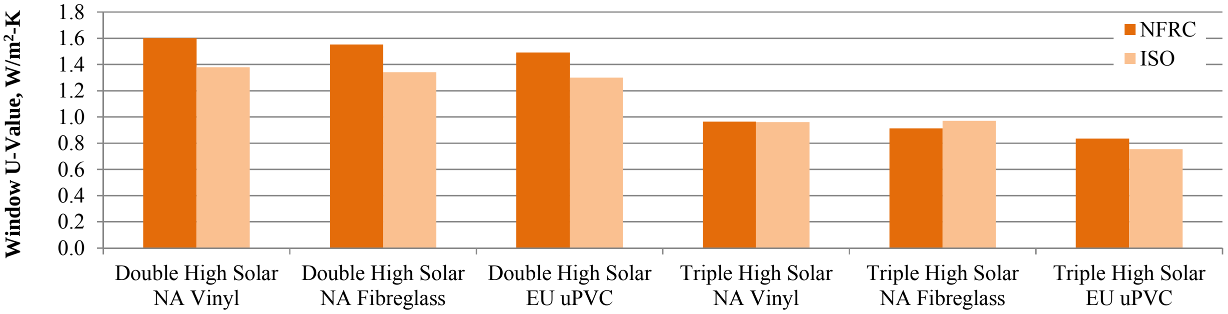

FIGURE 4: Whole window U-values simulated for various window configurations using NFRC and ISO standards.

Figure 5 shows centre of glass and whole window solar heat gain values calculated using NFRC and ISO standards. Solar heat gain values for the centre of glass were between 1% and 8% lower using NFRC compared to ISO procedures. The greater differences resulted for the low solar heat gain glazing. Whole window solar heat gain values are up to 50% lower than centre of glass values due to the reduced glazing area when the frame is included.

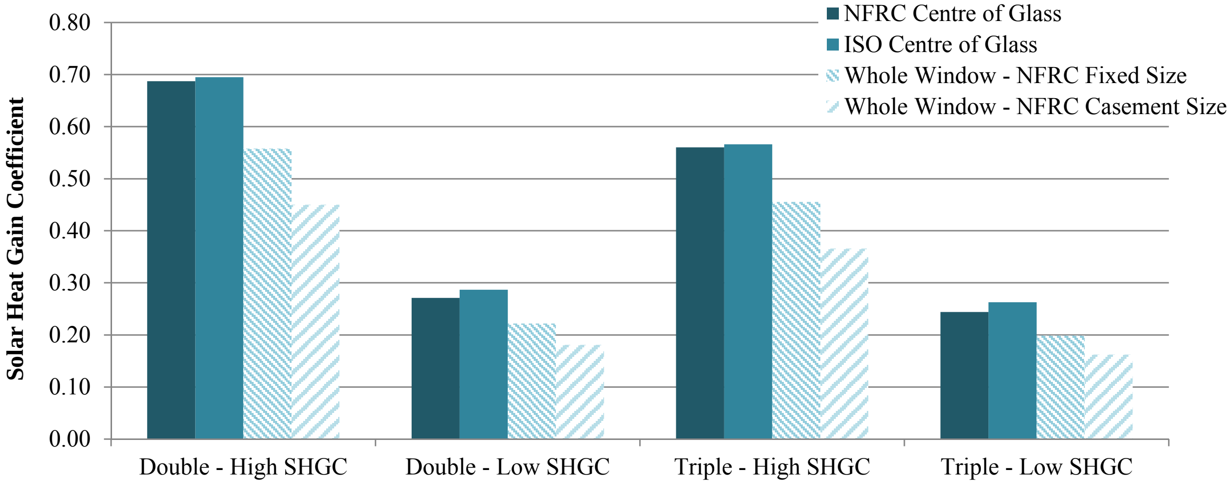

FIGURE 5: Centre of glass and whole window solar heat gain values simulated for various window configurations using NFRC and ISO procedures.

CONCLUSIONS

This paper presents a literature review and simulation results to understand and illustrate the differences between North American, European, and Passive House window thermal performance rating standards. Differences between window ratings systems can create challenges in qualifying North American fenestration products for Passive House buildings, and in qualifying European products for use in North American jurisdictions. This study seeks to identify and quantify differences between the rating systems, in order to provide a better understanding of fenestration ratings for designers and specifiers.

Several important considerations in selecting windows can be drawn from this study. Firstly, it is important to be aware that NFRC, ISO, and Passive House U-values cannot be compared as they are based on different calculation procedures. For example, when comparing a product from Europe and a product from North America, designers should ask for and compare values determined under the same standards. Going forward, it may be useful for the industry to add subscripts for NFRC and ISO U-values to distinguish European from North American U-values (e.g. U_{NFRC}, U_{ISO}). Those comparing certified Passive House window U-values should be aware that results are climate-specific, and have been determined according to different boundary conditions for different climates. For the cold-temperate climate, Passive House recognizes both U-values determined at 0°C and 5°C.

Most North American windows will not currently match European performance values even when evaluated to European standards because they have been optimized for the narrower gas gaps that yield the lowest U-values under NFRC boundary conditions and evaluation methods. North American manufacturers could develop products with lower ISO U-values by increasing gas gaps to dimensions optimized to yield the lowest U-values under ISO/PHI conditions and evaluation methods, though these products would not perform as well under the NFRC system. In particular, high performance products with triple glazing and low conductivity frames (insulated vinyl, fibreglass or wood) from Europe and North America will typically achieve similar U-values under NFRC certification, but different U-values under ISO or PHI certification. In these cases, the European ISO/PHI product U-values will typically be better (lower), and the difference may be as high as 25%.

It is also important for designers to be aware of different solar heat gain metrics. Passive House solar heat gain “g-values” are centre of glass values, whereas the NFRC Solar Heat Gain Coefficients (SHGC) are whole window values. This study showed whole window values can be up to 50% lower than centre of glass values. Further, NFRC centre of glass solar heat gain values (not reported on NFRC labels but available in the NFRC certified products database) are typically slightly lower than when evaluated to ISO or PHI standards. For example, Passive House recommends glazing with a g-value greater than 0.5; an NFRC centre of glass value of 0.45 might achieve this (depending on the glazing), and an overall NFRC SHGC of 0.35 may also meet this requirement (depending on the frame and glazing).

The certification criteria for Passive House buildings are different from the Passive House certification criteria for components such as windows. Passive House buildings are not required to use Passive House certified windows, though it helps to make the building certification process easier. For Passive House certified window products, window certification criteria is climate dependant, and windows for buildings in colder climate zones have more stringent requirements. Window certification criteria are not based solely on energy use, but on lowering surface temperatures to reduce the potential for condensation and mould growth and increase occupant thermal comfort.

Certified U-values are often used for selecting windows and analyzing energy consumption of a building, however each of the certification programs (NFRC, ISO and Passive House) have strengths and weaknesses, and neither may facilitate optimal window selection for a particular building. Window U-values vary with temperature and surface air films, and therefore vary when evaluated under different climate conditions. NFRC U-values are modeled at an outdoor temperature of -18°C which is not representative of average winter temperatures in many North American locations, and is also colder than the winter design temperature in many locations. This value is often less accurate for use in annual energy modeling and predictions and for optimal design in many locations. However, this value may be more appropriate for peak design and equipment sizing calculations as it provides a worst case temperature. On the other hand, the ISO outdoor temperature of 0°C, and the Passive House climate specific outdoor temperatures may be more accurate for annual energy calculations, but less accurate for peak heating and sizing calculations. Higher outdoor temperatures result in better (lower) window U-values. There is no easy solution to this issue as consistent conditions are needed for rating and comparing products, but it is useful for designers to be aware that the optimal window for a particular climate may not be indicated by certified U-values from a particular rating system.

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