
Energy Ratings for Windows: Balancing Energy Consumption and Thermal Comfort

Brittany Hanam, PEng
Associate Member ASHRAE

Graham Finch, PEng
Associate Member ASHRAE

Susan Hayes, PEng
Associate Member ASHRAE

ABSTRACT

Energy rating (ER) is a method used to compare the energy performance of windows. Its purpose is to establish the ranking of energy performance so that consumers can rate the relative energy efficiency of a window with a single number. The ER formula is based on the balance between heat loss due to conduction and air leakage and solar heat gain through the window. Since these heat gain and heat loss parameters have opposite effects on heating and cooling energy, each window can have a separate ER for heating and cooling conditions.

A number of countries use some variation of an ER to rate windows. The ISO provides an international standard method for calculating the ER for windows in ISO 18292: Energy Performance of Fenestration Systems for Residential Buildings, and in Canada, the ER formula is specified in the CSA A440 Standard.

Over the years, some potential issues have been brought forward by industry that could affect the validity of the ER as a tool for properly ranking window energy performance in a predominantly heating climate. These concerns mainly deal with the impact on thermal comfort, the selection of a reference house, and advancements in glazing technology.

This paper will present an analysis of whole house energy consumption and thermal comfort for different fenestration configurations. Computer simulations of thermal comfort parameters will be used to show considerations for balancing energy consumption with thermal comfort when comparing and selecting windows. In addition, the limitations of using a single ER to rank windows based on energy consumption will be identified.

INTRODUCTION

Windows have a significant impact on both the energy consumption and thermal comfort of a building. Choosing the right windows for a building can save energy and improve the indoor environmental quality of a space. The energy performance of windows is typically specified based on the product's U-factor and solar heat gain coefficient (SHGC). However, another metric that can be used to rate energy performance of windows is the energy rating (ER). The ER formula is based on the balance between heat loss due to thermal transmittance and air leakage and solar heat gain through the window. Since these heat gain and heat loss parameters can have opposite effects on heating and cooling energy, each window can have a separate ER for heating and cooling conditions. The ER used in the rat-

ing of windows in Canada, and discussed in this paper, refers to the heating ER only. The purpose of the ER is to help consumers rate the relative energy efficiency of windows (and glazed sliding doors) with a single number.

There are some limitations to the applicability of the ER. As explained in Clause I.6 of A440.3-09 (*User Guide to CSA A440.2-09*), the ER is intended for low-rise residential buildings under heating conditions. The ER is based on a reference house, with equal fenestration areas in each of the four cardinal directions, a standard fenestration system size, and climate conditions averaged for several cities across Canada and the Northern United States. Separate equations are available for a cooling season rating (ERC) and a specific energy rating (ERS), though these are rarely used in practice.

Brittany Hanam is a building science engineer, Graham Finch is a principal and building science research engineer, and Susan Hayes is a senior project engineer with RDH Building Engineering Ltd., Vancouver, BC, Canada.

A number of countries use some variation of an ER to rate windows. The ISO provides an international standard method for calculating the ER for windows in ISO 18292, *Energy Performance of Fenestration Systems for Residential Buildings*. In Canada, the ER formula is specified in CSA A440.2-09 *Fenestration Energy Performance* standard. The Canadian ER can only be used for fenestration in low-rise residential buildings (three stories or less), installed in a vertical orientation. The ER can be used to certify fenestration products for ENERGY STAR® in Canada (see Table 1), and is also being incorporated into building codes and standards in certain jurisdictions, including the National Building Code. Note that ENERGY STAR does not have an ER compliance path in the United States.

Over the years industry members in Canada have questioned the reliability of using the ER alone to select energy efficient windows and doors. It was observed that in certain regions, products with good ER ratings and high solar heat gain characteristics resulted in overheating discomfort and customer complaints. In these regions, the market preferred products that achieved equally good ER ratings with lower solar heat gain characteristics. There is also concern that the ER does not give a complete picture of energy use and/or thermal comfort due to its lack of a cooling component. Because of the changes in house archetypes and advances in glass coating and window framing technology in the decades since 1989 (when the ER was first developed [Enermodal 1989]), it was determined that additional research was necessary to confirm the validity of the ER for use in all regions of Canada.

This study was conducted in order to provide a thorough review of the Canadian ER and to determine if the ER in its current form is still appropriate for selecting energy efficient windows and doors for all areas of Canada. Both energy and thermal comfort implications are considered.

LITERATURE REVIEW

Energy Rating Standards

The calculation for the Canadian ER is presented in CSA A440.2-09/A440.3-09 *Fenestration Energy Performance/User Guide to CSA A440.2-09 Fenestration energy performance* (Canadian Standards Association 2009). This

standard also provides a calculation procedure for a specific energy rating (ERS) and a cooling energy rating (ERC). The ERS is an ER value calculated for a specific house, location, orientation, and window size. The ERC can be used to compare fenestration systems to avoid overheating or to reduce cooling energy consumption, and was developed in a similar manner to the ER (by averaging weather dependent values for Canadian locations). However, the ERS and ERC are rarely used in Canada.

The International Organization for Standardization (ISO) has a methodology for determining window energy performance ratings as outlined in ISO18292, *Energy Performance of Fenestration Systems for Residential Buildings—Calculation Procedure*. The standard suggests a similar rating procedure to the Canadian ER, where solar gain, air infiltration, and transmission (conduction) losses are added to determine an overall rating. The rating can be calculated for both heating and cooling conditions.

The primary difference between the ISO standard and the CSA ER calculations is in how the solar heat gain term is calculated. With the ISO standard there are two different approaches to the solar heat gain component: a gain utilization factor approach and a degree-day approach. The degree day approach does not directly incorporate solar and internal heat gains, but factors them in by calculating heat losses at hours below a certain temperature. The utilization factor approach determines energy needs for heating based on the difference between gains and losses.

The gain utilization factor is based on a ratio of total heat gains over transmission and infiltration losses. If the internal and solar heat gains are smaller than the losses, the gain utilization factor is 1 since all solar and internal heat gains are used to help offset the heating demand. However, if the internal and solar heat gains are greater than the losses, the gain utilization factor is less than 1.

While the ISO standard uses the gain utilization factor approach for its energy rating, the Canadian ER uses a combination of the degree-day approach and the gain utilization factor. The degree day approach was initially calculated by averaging the hours where the outdoor temperature was less

Table 1. Canadian ENERGY STAR Qualification Criteria for Windows (Natural Resources Canada 2013)

Zone	Heating Degree-Day Range	Compliance Paths			
		Energy Rating (ER)		U-Factor	
		Max. U-Factor of 2.0 W/m ² ·K (0.35 Btu/h·ft ² ·°F)		Maximum U-Factor, W/m ² ·K (Btu/h·ft ² ·°F)	Minimum ER
A	≤3500	21	or	1.80 (0.32)	13
B	>3500 to ≤5500	25	or	1.60 (0.28)	17
C	>5500 to ≤8000	29	or	1.40 (0.25)	21
D	>8000	34	or	1.20 (0.21)	25

than 12°C (i.e., assuming that above this temperature heating would not be required due to internal and solar gains). Adding a solar gain reduction factor ($R = 0.8$) makes this approach similar to a simplified form of the gain utilization approach.

International Energy Ratings

In addition to Canada, several countries have fenestration ER ratings. The United Kingdom, for example, has a rating that is similar to the Canadian ER and was established by the British Fenestration Rating Council (BFRC). The BFRC rating is translated to a letter rating, A to G, and is displayed on a reader-friendly label along with the rating number, window U-factor, solar factor, and effective air leakage rate.

Other European countries have window energy rating programs as well. In Denmark and Sweden, windows are solely rated on their U-factor (Avasoo 2003), and in Germany the German Fenestration Institute has adopted an energy rating system that follows the ISO standard.

Australia and New Zealand have fenestration energy rating systems called the Window Energy Rating Scheme (WERS) and NZ-WERS, respectively (WERS 2012; Burgess and Skates 2011). The WERS rating system is different from the Canadian ER system. To determine the WERS rating, windows are simulated using a software program called CHENATH, using the window U-factor, SHGC, and air leakage rate. The energy consumption of a particular window is compared to that of a reference window with single glazing, clear glass, and a non-thermally broken aluminum frame. The reference single glazed window is given one star, with higher performing windows scaled accordingly between 1 and 10. Three different ratings are given, for heating, cooling, and interior fading.

In the United States, windows are rated for the ENERGY STAR program based on their U-factor and SHGC (Table 2). There is no ER approach, however, the latest criteria for certifying windows includes an option for windows in Northern climates that allows for a higher U-factor and SHGC (ENERGY STAR 2009). A 2004 study by Lawrence Berkeley National Laboratory (LBNL) looked at the impact of

relaxing U-factor requirements and balancing the increase in energy consumption with changes to the SHGC (Huang, et al. 2004). The study found that in northern zones, increasing the U-factor would result in values above code-minimum. However, the study determined that if in the future ENERGY STAR U-factor requirements are lowered (i.e., made more stringent), it could be feasible to permit higher U-factors with higher SHGCs.

ENERGY ANALYSIS

The ER is intended to assist consumers in choosing energy efficient windows or to specify a minimum level of energy performance in codes and standards such as ENERGY STAR. An energy analysis was completed to determine how the ER rates energy consumption in houses.

Several parameters were established for use throughout the analysis work for this study. Archetypical houses, a range of geographic locations, and a selection of window configurations (defined by U-factor and solar heat gain coefficient, SHGC) were selected through a review of codes and standards, climate data, and the ENERGY STAR Canada database of windows. Hourly energy simulations were completed using the whole building energy simulation program Design-Builder (an interface for EnergyPlus) to compare the annual energy consumption of different combinations of variables. The goal of the analysis was to simulate a wide range of archetype house variables to assess how the ER ranks energy consumption for different types of windows in different Canadian climates. The windows investigated included typical double glazed (U_{SI} -2.0 W/m²·K or U -0.35 Btu/h·ft²·°F, U_{SR} -1.8 W/m²·K or U -0.31 Btu/h·ft²·°F, and U_{SI} -1.5 W/m²·K or U -0.26 Btu/h·ft²·°F) and triple glazed (U_{SI} -1.2 W/m²·K or U -0.21 Btu/h·ft²·°F, and U_{SR} -0.9 W/m²·K or U -0.16 Btu/h·ft²·°F) windows with low and high solar heat gain (SHGC values of 0.50, 0.35, 0.20). Several additional combinations were also included for comparison. A complete list of energy simulation inputs, as well as verification of simulation results, can be found in the research report (RDH 2013).

Table 2. United States ENERGY STAR Qualification Criteria (ENERGY STAR 2009)

Zone	Windows and Doors		Skylights	
	U-factor, W/m ² ·K (Btu/h·ft ² ·°F)	SHGC	U-factor, W/m ² ·K (Btu/h·ft ² ·°F)	SHGC
Northern			≤3.1 (0.55)	Any
<i>Prescriptive</i>	≤1.70 (0.30)	Any		
<i>Equivalent Performance</i>	1.8 (0.31)	≤0.35		
<i>Equivalent Performance</i>	1.8 (0.32)	≤0.40		
North/Central	≤1.8 (0.32)	≤0.55	≤3.1 (0.55)	≤0.40
South/Central	≤2.0 (0.35)	≤0.40	≤3.2 (0.57)	≤0.40
Southern	≤3.4 (0.60)	≤0.40	≤4.0 (0.70)	≤0.40

The window energy analysis shows that in general, windows with a higher ER use less heating energy. On the other hand, there were a number of simulated windows that showed that having a slightly higher ER resulted in higher heating energy consumption. Figure 1 shows a plot of the annual heating energy consumption versus ER value for the fenestration configurations that were simulated in a typical house, in five Canadian climates. The house shown here is a single story house with a basement, gas furnace, and a window to wall ratio of 15%. The results show a good linear correlation between heating energy consumption and ER; in other words, as the ER number increases, annual energy consumption decreases for most cases simulated. By comparison, Figure 2 shows the annual heating energy consumption plotted versus U-factor. The correlation between energy consumption and U-factor is not as good as the ER plot (which is apparent in the lower R^2 values in Figure 2) because of the impact of solar heat gain. Several groupings are visible where products with the same U-factor but different SHGCs have different annual energy consumption. This highlights the impact of the SHGC on fenestration energy performance where higher SHGC products have lower heating energy consumption in the heating-dominated Canadian climates. This effect is not captured when windows are rated by U-factor only.

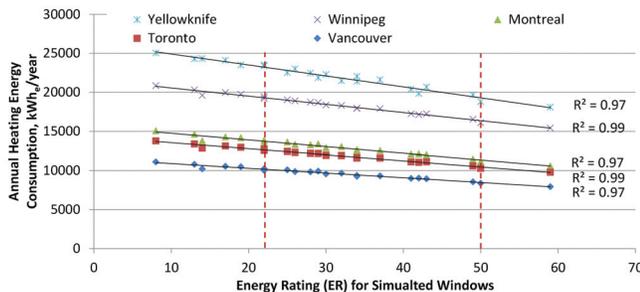


Figure 1 Plot of annual heating energy consumption versus ER for several fenestration configurations in a typical house in five Canadian climates. Dashed lines indicate typical range of ENERGY STAR windows.

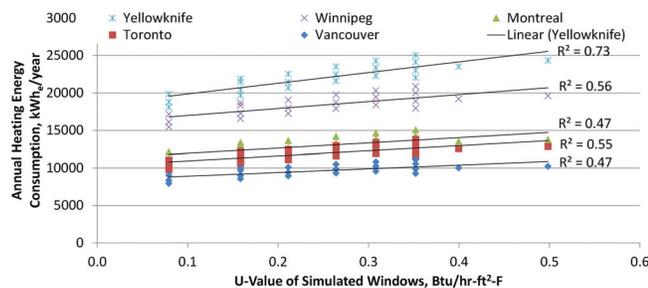


Figure 2 Plot of annual heating energy consumption versus U-factor for several fenestration configurations in a typical house in five Canadian climates.

Energy simulation results indicated that the ER does not rank cooling energy appropriately, which was expected since the ER is designed to reduce heating energy (i.e., favors high solar heat gain). However, in houses that have mechanical cooling, cooling energy consumption is very low compared to heating energy in all Canadian locations under worst-case cooling conditions (e.g., no natural ventilation). In general, cooling energy was found to be roughly 10% of overall space conditioning energy in houses that have mechanical cooling (Figure 3). Therefore, when looking at space conditioning energy consumption alone, heating energy considerations far outweigh cooling. Note that this is for low-rise residential buildings with typical window to wall ratios in the range of 15% to 20%. Higher window to wall ratios, though uncommon in houses, would likely generate different results as cooling energy could become significant.

Figure 4 shows a plot of the total annual energy consumption (including lighting, plug loads, and domestic hot water) versus ER. This plot generally shows a good correlation between total energy and the ER, though with higher error in Yellowknife.

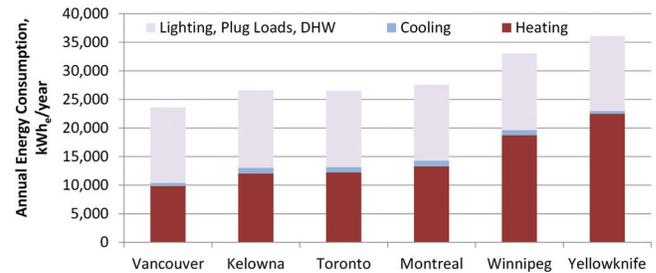


Figure 3 Plot of annual energy consumption for a typical house with air conditioning simulated in six Canadian climates, obtained from simulations. Even climates with warmer summers (Kelowna and Toronto) cooling energy is low compared to annual heating energy.

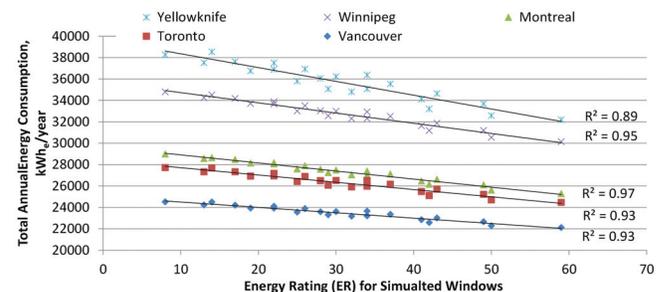


Figure 4 Plot of total annual energy consumption versus ER for several fenestration configurations in a typical house in five Canadian climates.

As noted previously, having a higher ER window generally resulted in lower heating energy use. This was observed in the majority of the geographic locations simulated with the exception of Yellowknife (i.e., the far north). Here, there was a significant variance in heating energy trends compared to other locations due to the low amount of solar radiation that Yellowknife receives in the winter. As a result, there is less of a benefit to using high SHGC windows.

The same trends, where higher ER correlates directly with lower heating energy consumption, were also observed in all of the archetype house parameters that were simulated. This included several variables not directly related to the windows, such as house size, presence of a basement, enclosure thermal performance, and mechanical system type. These observations suggest that a representative archetype house can be used to develop an ER system to rank windows (which was done for the Canadian ER development in Enermodal [1989]). However, when looking at different window orientations, window to wall ratios, and shading strategies, the simulations show varying trends in the ability of the ER number to rank energy consumption. This analysis suggests that rating windows with a single ER number may not necessarily indicate lower energy consumption for houses with non-typical window orientations (i.e., primarily facing one direction), high window to wall ratios, and exterior winter shading (see Figure 5 and Figure 6).

THERMAL COMFORT ANALYSIS

A thermal comfort analysis was completed to evaluate whether the energy objectives of the ER system are consistent with improving thermal comfort, and, if not, what impact this can have on the thermal comfort of a space.

A quantitative analysis of thermal comfort is challenging since it is impacted by many occupant-dependent variables.

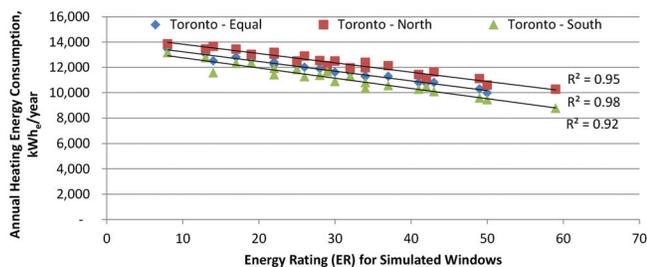


Figure 5 Plot of annual heating energy consumption versus ER for several fenestration configurations in a typical house in Toronto, with different window orientation distributions. Results are shown with windows oriented equally in all four cardinal directions, windows primarily facing north, and windows primarily facing south. The correlation for north- and south-facing windows is not as good as the correlation with windows distributed equally.

The ASHRAE Standard 55-2010, *Thermal Environmental Conditions for Human Occupancy* was used as a guideline for this analysis. Two parameters were used to assess comfort: the operative temperature, the mean of the internal air and radiant temperatures; and the window surface temperature, a proxy for radiant asymmetry. A range of comfortable temperatures was established for both operative temperature and surface temperature based on ASHRAE Standard 55, and the number of hours outside of this range were counted from hourly energy simulations. This allowed the comparison of various window types based on how many hours were outside of the comfort range for each window.

The comfort range for operative temperatures was set between 19°C to 25°C (66°F to 77°F), and the comfort range for surface temperatures was set between 15°C to 30°C (59°F to 86°F). Five windows with different combinations of U-factors and SHGCs were simulated; window parameters are shown in Table 3. Windows A, B, and C are double glazed windows, and windows D and E are triple glazed windows.

When assessing the operative temperature of a space, simulation results show that the number of warm hours, or overheating hours recorded, is much greater than the number of cold hours. Figure 7 shows a plot of the percent of time in a year that the operative temperature is outside of the defined comfort range, illustrating time that is both too warm and too cold. The percent of time overheating (dashed lines) is far greater than the percent of time underheated (solid lines) in all climates except the far north, Yellowknife. Further, windows with a high SHGC had a greater number of overheating hours than windows with a low SHGC. The window with a SHGC of 0.64 had the greatest percentage of time overheating, followed by the windows with a SHGC of 0.5. The windows with a SHGC of 0.2 had the lowest amount of overheating. The number of cold hours is relatively low for most locations except the

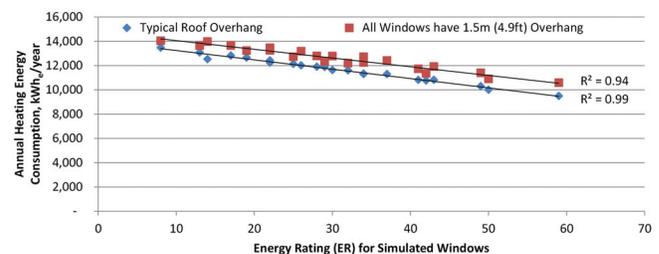


Figure 6 Plot of annual heating energy consumption versus ER for several fenestration configurations in a typical house in Toronto, with different window shading. Results are shown with a typical roof overhang (minimal shading of windows) and a 1.5 m (4.9 ft) overhang above all windows (some winter shading). The correlation is better with minimal shading than with a 1.5 m (4.9 ft) overhang.

far north. U-factor has a greater impact on the number of cold hours, with low U-factor windows performing best (i.e., triple glazing).

Broadly speaking, the correlation between ER and comfort was not as clear as the correlation between SHGC and operative temperature discomfort or the correlation between U-factor and surface temperature discomfort (Figure 8). The thermal comfort analysis generally showed that a better U-factor resulted in less cold surface and operative temperatures, but did not significantly impact overheating operative temperatures. On the other hand, the analysis did show that a higher SHGC, though it did not significantly impact high surface temperatures, had an impact on creating a higher portion of warm operative temperature hours. This is in contrast to the energy analysis, where a high SHGC resulted in lower energy consumption.

One particular concern with the ER system has been whether higher ER windows increase the occurrence of overheating in a space. Figure 9 shows a plot of the percent of time operative temperature is too high versus the ER value for the five windows presented above. The results show no correlation between ER and overheating. A higher ER does not necessarily result in overheating, though the window with the second highest ER has the second greatest percentage of time overheating. This illustrates that

Table 3. U-Factor, SHGC, and ER of Windows Shown in Thermal Comfort Analysis

Window	A	B	C	D	E
U-Factor, W/m ² ·K (Btu/h·ft ² ·°F)	2.8 (0.50)	2.0 (0.35)	2.0 (0.35)	0.9 (0.16)	0.9 (0.16)
SHGC	0.64	0.2	0.5	0.2	0.5
ER	14	8	26	32	49

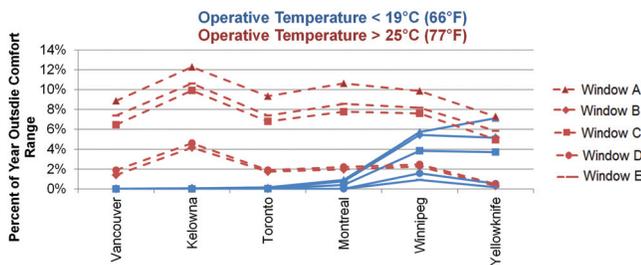


Figure 7 Plot showing the percentage of hours in a year where the operative temperatures are outside of the thermal comfort range for five windows simulated. Dashed lines show percentage of the time when the operative temperature is too warm (greater than 25°C [77°F]) and solid lines show percentage of the time when the operative temperature is too cold (less than 19°C [66°F]).

even though there is no direct correlation between overheating and the ER, having a higher ER will not necessarily lead to better thermal comfort, particularly overheating. Therefore, if the ER is used to select windows for a typical single family dwelling, additional measures may need to be taken to prevent overheating, depending on the SHGC of the window.

CONCLUSIONS AND RECOMMENDATIONS

Energy

The ER is an appropriate tool for comparing windows on the basis of energy consumption for typical Canadian houses. The ER provides a better ranking of window energy consumption than U-factor alone. Where anomalies occur (i.e., a window with a higher ER uses more energy), the differences in both the ER value and energy consumption are typically small. The ER, however, should not be the only metric that one considers when choosing windows for

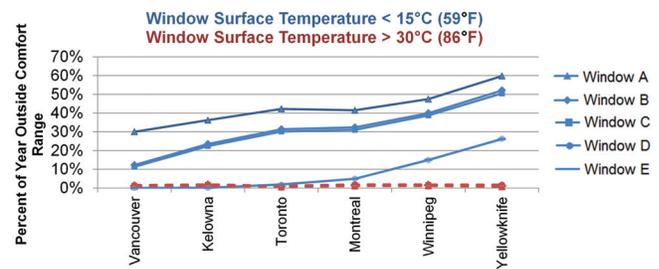


Figure 8 Plot showing the percentage of hours in a year where the window surface temperatures are outside of the thermal comfort range for five windows simulated. Dashed lines show percentage of the time when the surface temperature is too warm (greater than 30°C [86°F]) and solid lines show percentage of the time when the surface temperature is too cold (less than 15°C [59°F]).

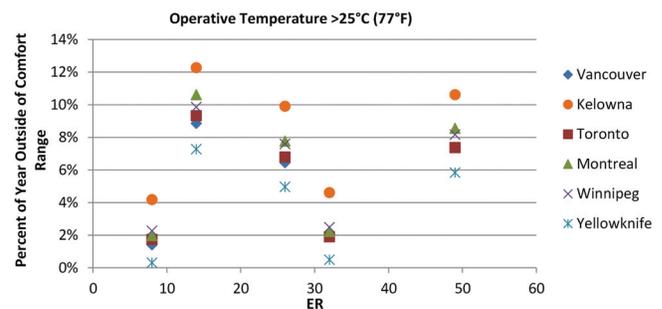


Figure 9 Plot showing the percentage of hours in a year where the operative temperatures are higher than the thermal comfort range of 25°C (77°F) versus ER for five windows simulated.

a non-typical home. In particular, the ER on its own is not an appropriate measure to compare windows under the following non-typical conditions for houses and low-rise residential buildings:

1. Far north locations, including the Canadian Territories
2. Windows with significant winter exterior shading
3. A house with windows oriented primarily in one direction

Despite these minor exceptions, the current ER formula works in most common house situations, in most locations in Canada, and is therefore an appropriate metric for rating the relative energy performance of windows. However, for houses that are non-typical, that have more site-specific design or energy efficient design, it would be best to select windows based on U-factor and SHGC rather than ER alone. If the ER is incorporated into standards then it should be accompanied by explanatory text regarding when it is appropriate and when it is not appropriate. Likewise, if the U-factor alone is used to select energy efficient windows, explanatory text regarding the potential energy savings of a high or a moderate SHGC should also be provided. While the ER should be maintained, provisions to keep the alternate U-factor compliance path are necessary because of these non-typical conditions.

Thermal Comfort

Although the ER is appropriate for selection based on lower energy consumption, a high SHGC window can result in overheating, which may be a concern even in typical houses with typical (15% to 20%) window to wall ratios. The ER cannot be used to assess thermal comfort performance, particularly overheating. Overheating should be evaluated on a case-by-case basis, depending on project-specific factors such as location, orientation, shading, and window to wall ratio. Additional guidance is needed to assist consumers in selecting appropriate windows (and SHGC factors) for energy consumption and thermal comfort.

Recommendations for Future Work

Although the ER metric performs relatively well for rating heating energy consumption of windows in Canada, several opportunities for improvements and further work were identified in this study.

The far north was consistently identified as an anomaly where the ER may not appropriately rate windows. However, the ER still resulted in a better ranking of heating energy consumption than U-factor alone. A different ER calculation, one with solar heat gain weighted differently, would likely provide better results for the far north region. One option would be to have a separate ER calculation (i.e., different location-dependent parameters) for different climate zones. However, this would require the maintenance of multiple ER values for each window configuration.

The possibility of adding either a standardized cooling energy rating (ERC) or some other rating to indicate thermal comfort could be investigated, particularly for warmer climate zones. This would be an additional rating to the current ER. There would still be some trade-off in balancing this ERC value with the current ER to help select a window for both summertime and wintertime conditions.

The ER serves as a good indication of energy performance for the average consumer; however, the best energy performance will be obtained with building-specific design. Published education and guideline documentation would assist consumers in understanding the issues and would help them make informed decisions regarding the best windows for their situation. One or two brief bulletins could be developed to assist consumers, as well as manufacturers, installers, sales professionals, and consultants in selecting the best windows for their situation beyond just the ER. Other things can be considered such as unique building features and thermal comfort.

This work could also be used to inform studies in other countries or jurisdictions that are considering the use of an ER system to rate the energy efficiency of windows, or considering incorporating a minimum SHGC to offset a better U-factor in codes or standards.

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