TECHNOFORM

U-factors Matter in Hot Climates

Helen Sanders, PhD.
Technoform North America
helen.sanders@technoform.com

This paper was published by the Tectonic Press as part of the Facade Tectonics 2020 World Congress Conference Proceedings on August 4, 2020 and is being reshared with permission from the Facade Tectonics Institute.

Abstract

It is commonly thought that fenestration U-factor is not a key determinant in the performance of façades in hot climates, and generally the focus of code bodies and designers is on solar heat gain, especially reducing the gain through the transparent areas. The assumption is that the difference in air temperature between inside and outside is much lower in hot climates than in cold climates, so the driving force for heat transfer is less. However, the main mechanism for heat transfer through a window frame in hot climates is solar absorption and then conduction of that absorbed heat through to the room side surfaces of the frame. Exterior frame temperatures can exceed ambient air temperatures by a significant amount, especially dark colored frames, because of solar absorption. Temperature differences between inside and outside can be generated through this mechanism which are much more comparable to those seen in cold climates in winter. The use of thermal breaks and warm-edge spacer can significantly reduce this solar heat gain mechanism through the edges of fenestration.

Data from a research study by the Solar Energy Research Institute of Singapore (SERIS) reviewed herein demonstrates how the thermal performance of the window frame significantly impacts the heat transfer through, and thermal comfort performance of, fenestration systems in a hot climate. A whole building modeling study is used to illustrate the resultant impact of fenestration U-factor on energy usage compared to solar heat gain coefficient (SHGC). Thermally broken frames are shown to be a must have for buildings in hot climates, just like they are in colder climates. In addition, the use of warm-edge spacer in the Space Needle renovation demonstrates how reducing thermal transfer at the edge of glass is essential for reducing the cooling load in summer, heating load in winter, and improving thermal comfort year-round.

Keywords

Performance, energy efficiency, health - comfort- IEQ performance, thermal break, warm-edge spacer, glass performance, codes - standards – rating systems,

Introduction and Background

Conventionally, designing using fenestration with low thermal transmittance (low U-factor) is thought to be important only in cold climate zones. This is demonstrated by the relatively high U-factors allowed in climate zones 1-3 (southern, hotter regions) in the United States' model building codes compared to the northern climate zones 6-8. Table 1 shows the U-factor requirements for the International Energy Conservation Code (IECC) 2018 and the American Society of Heating, Refrigeration, Air-Conditioning Engineers' (ASHRAE) Standard 90.1 – 2016.

Climate zone	**1**	**2**	**3**	**4A/4B**	**5**	**6A/6B**	**7**	**8**
ASHRAE 90.1 2016	0.57	0.54	0.45	0.38	0.38	0.36	0.33	0.29
IECC 2018	0.50	0.50	0.46	0.38	0.38	0.36	0.29	0.29

Table 1: Whole fenestration U-factors in btu/°F.hr.ft^2 required by recent versions of US model building codes.

A key driver for conductive heat transfer through a solid material is the temperature difference between the one side and the other, where the larger the temperature difference, the larger the energy flow. The equation for conductive heat transfer is given by (Zemansky and Dittman, 1981):

$$\frac{Q}{t} = \frac{kA(T(hot) - T(cold))}{d} \qquad \text{eq. 1}$$

Where:

- Q/t is the heat conduction per unit time (e.g. watts or btu/hr)
- k is the thermal conductivity of the material
- A is the cross-sectional surface area
- T(hot) – T(cold) is the difference in temperature between the hotter surface and the colder surface or “delta T”, DT
- d is the thickness of the material (the dimension in the direction of energy flow)

The prevailing thought is that the outside facing surface of the fenestration system will have a similar temperature to the exterior ambient air and so the temperature difference, DT, or the driving force for heat transfer is relatively low in, say, the hot desert of Arizona versus the frigid plains of North Dakota. For example, the exterior air temperature in a cold climate like North Dakota, could be as low as -40°C (-40°F) and, with an inside room temperature of 21°C (70°F), the DT is 61°C (110°F). Yet in the height of summer in Arizona, the exterior air temperature can reach 43°C (110°F), which gives a DT of only 22°C (40°F) with a room temperature of 21°C (70°F). However, what is missing in this simplistic view, is the impact of solar absorption by the exterior frame material, which in direct sun can result in exterior frame temperatures significantly in excess of the outside air temperature, especially for dark frames. The solar absorption mechanism can cause the DT between outside and inside frame surfaces to come much closer to that observed in a cold climate.

If there is no thermal break between the inside and outside of the frame (e.g. a polyamide strip) or at the edge of the glass (e.g. low-conductance or “warm-edge” spacer) there is nothing to prevent that absorbed heat from conducting directly into the inside of the building, causing significant load on the air-conditioning system as well as significant thermal discomfort for occupants close to the façade. Since many façades designed for buildings in warm climates do not include thermal breaks nor low conductor insulating glass spacers because of this misconception, it is important to demonstrate that this heat transfer mechanism is meaningful for both energy and comfort performance.

Findings from a field test by the Solar Energy Research Institute of Singapore (SERIS) (SERIS 2016), a building energy modeling analysis by Building System and diagnostics (BSD) (BSD 2016) and a real building case study are pulled together and reviewed herein to illustrate the importance of low U-factor fenestration (especially related to edge thermal performance) in hot climate zones.

Field Test Study

Experimental Details

To demonstrate the impact of thermal breaks in aluminum fenestration systems in a hot climate, a research project conducted by SERIS will be reviewed here (SERIS, 2016). Four different aluminum framing systems were studied: A non-thermally broken system ($U_{frame} = 7\ W/m^2K$), a system with small thermal breaks ($U_{frame} = 3\text{-}4\ W/m^2K$), a frame with a medium performance thermal break system ($U_{frame} = 2.5\ W/m^2K$) and one with a high performance thermal break system ($U_{frame} = 1\text{-}2\ W/m^2K$) (fig. 1)[1].

---

[1] *Note that the frame U-factors given in w/m²K are calculated using the European standard methodology and are as such not comparable with US U-factors calculated using NFRC 100 even if translated into IP units. Because of this no unit conversions to btu/°F.hr.ft² are given to avoid confusion by comparing to US building code requirements etc.*

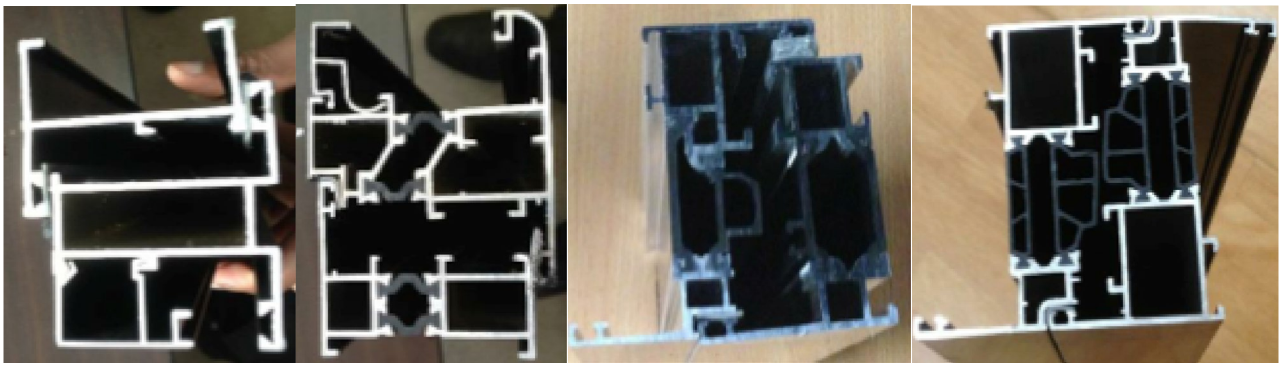

Figure 1: The four aluminum framing systems evaluated in this study. From left to right: Non-thermally broken frame, low performance thermal break, medium performance thermal break and highest performing thermally broken system.

In the latter high-performance system, the thermal break was not only wider than the others, it also included a design which reduces convective heat transfer through the resulting large hollow channels, by breaking them up into smaller sections. Each frame type was tested in a light color and dark color finish.

These frames were installed in the west-facing wall of a conditioned test room in Singapore (fig. 2).

Figure 2: The conditioned test room (left) and a close-up of the framing members in the wall of the test hut (right).

A full data acquisition system collected data every 2 seconds from thermocouples placed on the room-side and exterior surfaces of each of the frame types, a heat flux sensor on the room side of each frame (to measure heat flux from outside to inside through the frames), two air temperature and humidity sensors (inside and outside), and a pyranometer (for exterior vertical solar illuminance measurement). During the approximately 3-month data acquisition period, the indoor temperature was maintained between 23-24^{o}C while the exterior ambient temperature ranged from a low of 24^{o}C (75^{o}F) to a high of 37^{o}C (99^{o}F), maintained for around 3 hours a day. The solar illuminance peaked at 670 W/m^{2}K during day-time hours.

Results: Heat gain

The mean daily heat gain through the frames was calculated from the measured heat flux data and shows the significant impact that thermally breaking aluminum window and curtainwall frames can have on reducing interior building heat gain (fig. 3).

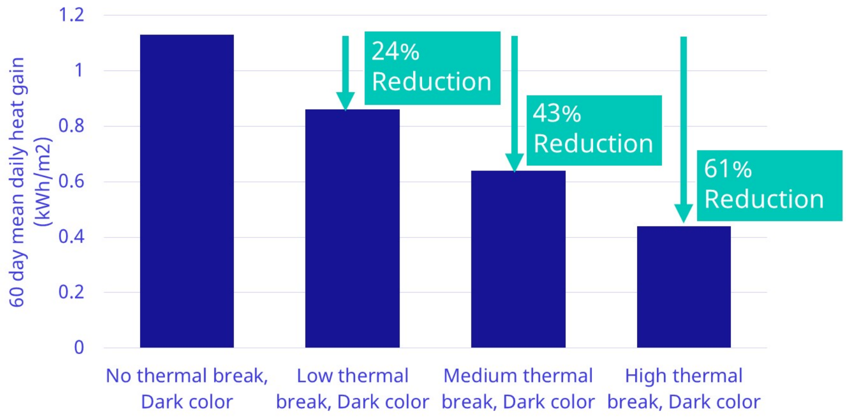

Figure 3: The 50-day mean daily heat gain for the four different types of frame in a dark color.

The highest performing thermally broken frame reduced the average heat gain by 61% compared with a dark colored unbroken frame. Even the smallest, lowest performing, thermal break reduced the solar heat gain by 24% compared to a non-thermally broken system in dark colors. Just choosing a light colored frame on its own without a thermal break reduces the heat gain by 27% compared to a dark colored frame. Using a high-performance thermal break in that same light-colored frame reduced the heat gain by 62%, and by 73% compared to the dark colored non-thermally broken frame. These data support the fact that the conductive heat transfer mechanism through the frame is driven by (i) the amount of solar absorption by the frame (dark colors absorb more than light colors) and (ii) the relative ease by which that absorbed heat is able to move from the outside elements of the frame to the room-side elements – that is, how well thermally broken the frame is.

Results: Surface temperatures

As one might anticipate, the interior room side surface temperature of the frames in the study depended significantly on whether the frames were thermally broken and on the color of the frame (i.e. how much solar absorption occurred) (fig. 4).

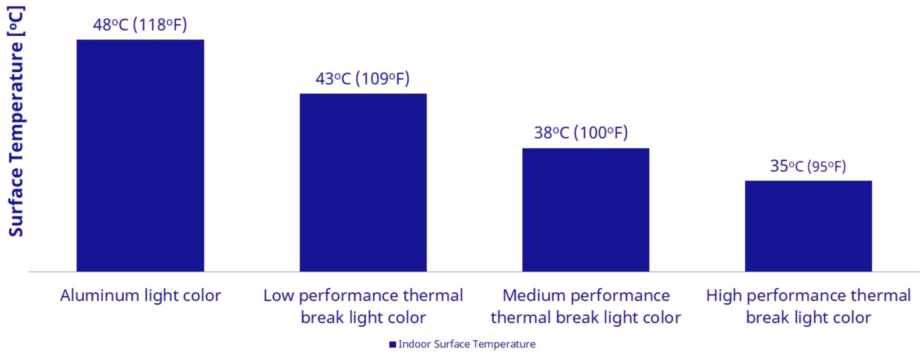

Figure 4: The maximum room-side surface temperature of the light-colored frame types for a typical day during the study.

Even with the light-colored frames, the presence of a thermal break makes a significant difference to the room-side frame surface temperature. The highest performance thermal break system reduces the inside temperature by 13°C (23°F). For the dark colored frames, the interior surfaces of the non-thermally broken sample reached 54°C (129°F), whereas the corresponding interior of the high-performance thermally broken dark aluminum frame was only 37.5°C (99.5°F), over 16°C lower.

Perhaps counter-intuitively, but readily explainable, is the higher exterior surface temperatures that the thermally broken frames exhibit compared to the non-thermally broken frames. For example, the highest performing thermally broken dark frame has a maximum external temperature of 67°C, compared to a corresponding 57°C on the dark non-thermally broken frame. This is because the solar heat absorbed by the frame is readily transferred to the interior in the uninsulated system, thus lowering the temperature of the outer portion of the frame, whereas the heat absorbed by the outside portion of the thermally broken frame can't transfer well to the interior so it stays on the outside, thus keeping the exterior frame temperature elevated.

Building Energy Modeling study

Input details

A study carried out by BSD used IES building energy modeling software to compare the energy performance of a large 24 story (8,290 m^2) prototypical office building (fig. 5) located in a hot climate zone (Singapore) using fenestration options with a range of thermal performance (table 2). The impact of reducing SHGC, while using non-thermally broken frames (high U-factor), was also evaluated (table 3).

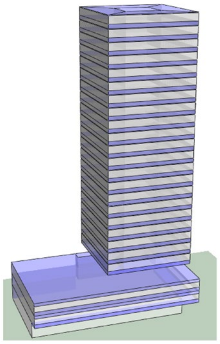

Figure 5: Image of prototypical large building modeled using IES software, viewed from front, south-facing façade.

	Base case building	Typical building, non-thermally broken aluminum	Typical building + Low performance thermal break	Typical building + Medium performance thermal break	Typical building + High performance thermal break
Window to wall ratio (WWR)	40%	60%	60%	60%	60%
Window SHGC	0.35	0.25	0.25	0.25	0.25
Window U-factor (W/m²K)	2.8	3.0	2.4	2.0	1.6
Wall U-factor (W/m²K)	0.70	0.30	0.30	0.30	0.30

Table 2: Modeling inputs for evaluation of building energy impact of fenestration U-factor with SHGC held constant.

	Base case building	Typical building, non-thermally broken aluminum	Case 1: Typical non-thermally broken aluminum, SHGC = 0.23	Case 2: Typical non-thermally broken aluminum, SHGC = 0.22	Case 3: Typical non-thermally broken aluminum, SHGC = 0.21
Window to wall ratio (WWR)	40%	60%	60%	60%	60%
Window SHGC	0.35	0.25	0.23	0.22	0.21
Window U-factor (W/m²K)	2.8	3.0	3.0	3.0	3.0
Wall U-factor (W/m²K)	0.70	0.30	0.30	0.30	0.30

Table 3: Modeling inputs for evaluation on building energy of the impact of reducing SHGC while holding U-factor constant.

Modeling Results

The cooling load and envelope thermal transmission value (ETTV) calculated for the large office building in Singapore illustrates that fenestration U-factor has a significant impact on building energy performance (fig. 6). ETTV considers heat conduction through opaque walls, heat conduction through glass windows and solar radiation through glass windows. These three components are averaged over the whole envelope area to give an ETTV value that represents the total thermal performance of the envelope. The Singapore Building Construction Authority documentation sets out the calculation of ETTV in detail (Building Construction Authority, 2004).

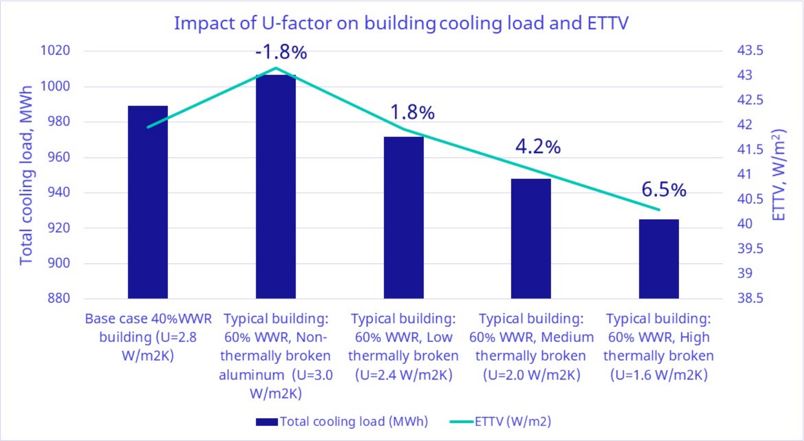

Figure 6: The total cooling load and envelope thermal transfer value (ETTV) for a prototypical 24 story building in Singapore as a function of different fenestration U-factors. The scale of the graph does not start at zero to allow discrimination of the changes which are of the order of 2-7%.

The highest performing framing system evaluated in an envelope with 60% glazed area reduces the cooling load by 6.5% compared to a base case building with only 40% window area and by 8% compared to a typical building with the same 60% window area. This is a pretty significant decrease in large core dominated buildings.

To compare the impact of solar heat gain reduction to U-factor reduction, the prototypical building was modeled with non-thermally broken fenestration with U-factor of 3.0 W/m^{2}K and solar heat gain coefficients ranging from 0.35 to 0.21 (fig. 7). A reduction in fenestration SHGC from a typical 0.35 to a more aggressive 0.21 (without thermally breaking the frame) reduces the cooling load in a 60% WWR building by 6.0% compared to a base case building with a 40% WWR. A reduction of fenestration SHGC from 0.25 to 0.21, while maintaining a poor U-factor of 3.0 W/m^{2}K, and without changing the window area (60%), results in a 7.6% reduction in cooling load. As shown above (fig. 6), a change in U-factor from 2.8 to 1.6 W/m^{2}K with this same WWR increase gives a similar impact.

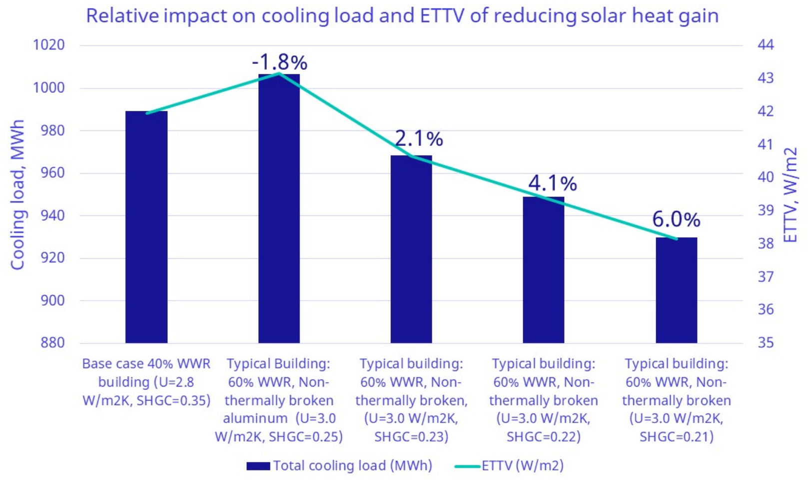

Figure 7: The impact of reducing fenestration solar heat gain coefficient, keeping fenestration U-factor constant using non-thermally broken frames. The scale of the graph does not start at zero to allow discrimination of the changes which are of the order of 2-6%.

While solar heat gain through the glass area is still the most dominant factor for cooling loads, the data shows a similar cooling load improvement can be achieved by reducing the fenestration U-factor to a level normally seen in colder climates as one achieved by reducing SHGC from 0.25 to 0.21 in the absence of a thermally broken frame. While the reduction in SHGC from 0.25 to 0.21 proportionally seems quite small compared with the U-factor reduction from 3 to 1.6 W/m^{2}K, achieving a reduction in solar heat gain coefficient from 0.25 to 0.21 becomes challenging without using dark, tinted or reflective glazing. As a result, improving the framing system can provide a reduction in cooling load without having to compromise the daylighting or aesthetic of the building, and can potentially result in a more cost-effective solution.

Discussion

Heat gain and U-factor

The data from the field test and the building energy modeling study support the fact that the solar heat gain of fenestration framing is dependent on the presence and size of a thermal break and the extent of solar absorption by the external surfaces of the frame. The U-factor of the frame is driven by the presence and size of a thermal break. Thus, we can say that the SHGC of the frame is proportional to its U-factor and its absorptivity. The equation below summarizes the relationship between frame solar heat gain assuming radiation perpendicular to the window (Wright & McGowan, 1999) (eq. 2):

$$Solar\ Heat\ Gain\ Coefficient\ of\ window\ frame = a\frac{U_f}{h}\ x\ \frac{A_p}{A_w} \qquad \text{eq. 2}$$

Where:

- a = solar absorptance of the outer surface of the frame
- U_f = frame U-factor
- h = external frame heat transfer coefficient
- A_p = projected frame area
- A_w = total wetted external surface area of the frame

Using equation 2, the contents of table 4 illustrate how the U-factor of a window frame can impact the overall SHGC of the fenestration. Two frame types are used for illustration: A non-thermally broken frame and a thermally broken frame. Inputs are frame area, glass area, ratio of wetted to projected frame area, heat transfer coefficient, frame U-factor and center of glass SHGC (0.35). Outputs are frame SHGC and window SHGC. The window SHGC is calculated as an area weighted average of the frame and center of glass SHGC's. In this scenario, the improvements in frame U-factor derived by introducing a good thermal break results in a 65% reduction in frame SHGC (0.23 to 0.08) and a 13% improvement in the overall fenestration unit SHGC (0.32 to 0.28).

	Non-Thermally Broken Frame	Thermally Broken Frame
Frame Area	0.5m^2	
Glass Area	1.5 m^2	
Ratio of wetted to projected frame area	1.2	
Heat transfer coefficient (h)	18 W/m^{2}K	
Absorption coefficient (frame)	0.7	
Center of glass SHGC	0.35	
U-factor (frame)	7 W/m^{2}K	2.5 W/m^{2}K
SHGC (frame)	**0.23**	**0.08**
SHGC (Window)	**0.32**	**0.28**

Table 4: Quantitative example of the impact of thermally broken frames on the solar heat gain of fenestration using equation 2 above and the area weighted average of the SHGC of the frame and center of glass.

For window U-factor, larger window size generally results in lower U-factors because the center of glass has higher area weighting than the frame, and the center of glass U-factor is generally lower than that of the frame. In contrast, in the case of fenestration solar heat gain, larger window sizes generally result in higher (worse) solar heat gains because the frame SHGC can be substantially lower than the center of glass – if, of course, the frame is sufficiently well thermally broken.

Based on the data reviewed in the above section, it is clear that the energy usage of a building in hot climates can be significantly impacted by frame U-factor. The U-factor performance can impact the ability of fenestration systems to achieve the SHGC needed to meet cooling load requirements.

Consider the fenestration SHGC range of 0.35 to 0.21 explored in the modeling study (fig. 6 and 7) and assume that a non-thermally broken frame has an SHGC of approximately 0.23 (table 4). It is possible to achieve an overall fenestration SHGC of 0.35-0.25 without compromising visible light transmission or color by using double silver or triple silver low-e coatings on clear glass in a dual pane IGU. The center of glass SHGC of a dual pane insulating glass unit (IGU) with a typical triple silver low-e coating is 0.27 with a visible light transmission of approximately 60%. This represents the best coating system available for maximizing light transmission and minimizing solar heat gain. Any additional reduction in SHGC must come from reduction in visible light transmission since half the sun's energy is in the visible spectrum.

For a triple silver low-e IGU in combination with a non-thermally broken frame (SHGC = 0.23), the overall fenestration SHGC will not be significantly lower than the center of glass value of 0.28 (air filled) and will likely not reach 0.25, unless the frame to glass area ratio is very high (i.e. small windows). In order to achieve an overall SHGC of 0.21 using a non-thermally broken frame, a glass package with a center of glass SHGC less than 0.21 will be needed. Achieving a center of glass SHGC of 0.21 will require a substantial reduction in the visible light transmission of the glass which could negatively impact the daylighting in the space, cause an unwelcome color shift in the light that is admitted, and potentially increase costs. Even to reach an overall fenestration SHGC of 0.25 in a non-thermally broken frame, a center of glass SHGC of approximately 0.26 or lower will be needed, depending on frame to glass area, which will also require some level of reduction in visible light transmission through the glass. Note that currently the IECC 2012, 2015 and 2018 versions (and ASHRAE Standard 90.1 – 2010, 2013, 2016) require an overall fenestration SHGC of 0.25 in climate zones 1 to 3. To meet this requirement, some level of thermally broken framing will likely be needed if designers would like to avoid the use of tinted solar control glass when using the prescriptive path.

The Edge of Glass is Important Too

Since heat follows the path of least resistance, in the situation where solar heat gain is absorbed by the external section of a well thermally broken frame, but the edge of the insulating glass is comprised of a highly conductive spacer material such as aluminum, the heat will transfer to the inside through the conductive glass edge (fig. 8). Just as for the framing system in hot climates, it is important to "thermally break" the edge of glass by using a high-performance durable warm-edge spacer.

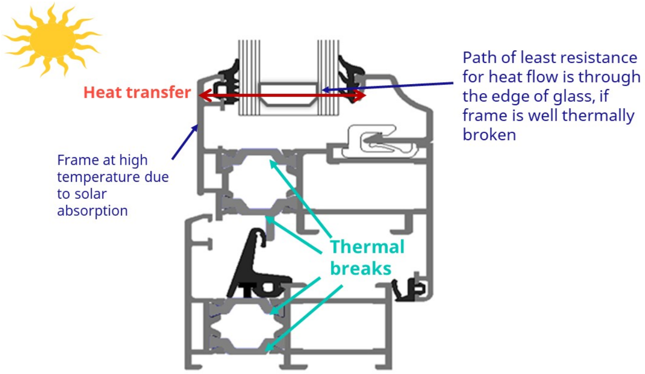

Figure 8: A section of a typical thermally broken aluminum window. The edge of glass becomes the path of least resistance for heat flow when the frame is adequately thermally broken.

An example of where the need to reduce conductive heat gains (rather than heat losses) drove the use of high performance warm-edge spacer is in the recent renovation of Seattle’s Space Needle (fig. 9). Clearly Seattle’s climate is not considered to be “hot”, however, in this project, like some large, internal load dominated buildings in colder climates, conductive heat transfer from outside to inside during summer, rather than heat losses by transfer from the interior, were the most critical to control.

Figure 9: The Space Needle in Seattle after its recent renovation. Photo by Andrea Leopardi on Unsplash.

The Space Needle renovation increased the glass area by almost 200 percent, and in addition to needing to meet Seattle’s stringent energy code and the US Green Building Council’s LEED gold performance level, the design team also did not have the flexibility to increase the chiller size. As it turned out, the chiller size was one of the most critical factors in setting the glass performance requirements. Insulating glass for vision glazing was placed in two areas: The observation deck (the Atmos level) (figure 10a) and the restaurant level (the Loupe) (figure 10b).

Figure 10 (a) The Atmos level of the Space Needle after retrofit (left), image courtesy of Olson Kundig Architects, (b) The Loupe level of the Space Needle after retrofit (right), photo copyright Nic Lehoux.

The Atmos level featured a reverse curtainwall with deep framing members extending on the outside of the façade. This original design element had to be preserved because of the building's landmark status but caused a major heat gain issue because of the large exterior framing surface area which was available to absorb the sun's heat. Since the curtainwall was structurally glazed, the only elements capable of stopping heat flow into the building was a very small spacing element in the metal curtainwall and the edge of the glass. Modeling showed that using a high-performance warm-edge spacer was essential to achieving the solar control performance that they needed to maintain the chiller size, in addition to meeting code requirements for U-factor to control heat losses. A durable plastic hybrid stainless steel (PHSS) spacer was chosen because of its thermal performance and benchmark durability.

PHSS spacers have the traditional box spacer shape and comprise very thin stainless steel which wraps from around the sides and back, fully extending from one primary sealing surface to the other (figure 11).

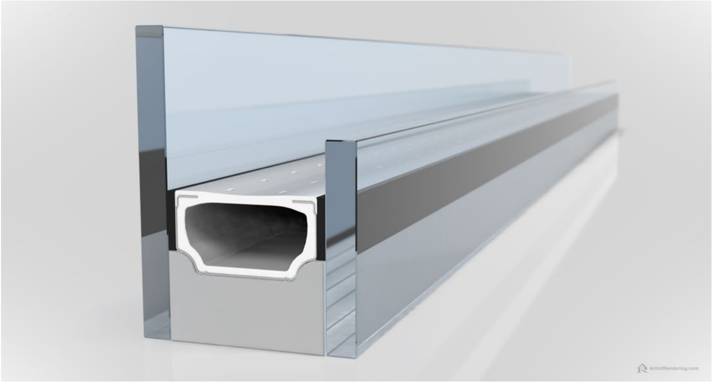

Figure 11: Image of plastic hybrid stainless steel (PHSS) spacer on the edge of an insulating glass unit. Thin stainless-steel wraps the sides and back of the spacer to provide benchmark durability, while an engineered plastic bridges the top and supports the steel on the inside surfaces to provide a high-performance thermal break.

Having all sealants in contact with stainless steel, a solid stainless-steel moisture vapor and gas barrier, and hollow channel for high desiccant capacity, provides the same benchmark durability performance experienced with a traditional stainless steel or aluminum spacer. The steel is thermally broken across the top by an engineered plastic which gives it the same high thermal performance as expected by a fully non-metal spacer (fig. 12).

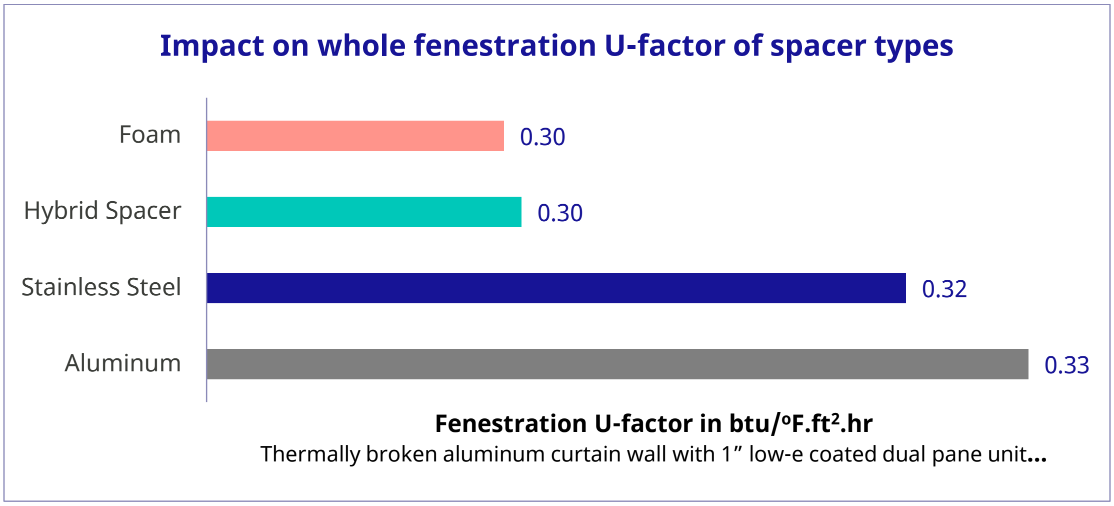

Figure 12: Whole unit U-factors for a standard curtainwall with 1” low-e coated dual pane unit with 4 different spacer types: aluminum box, stainless steel box, plastic hybrid stainless steel box (abbreviated to hybrid) and foam spacer.

A similar situation was found in the Loupe level in the Space Needle, where the 7ft wide x 10ft tall inclined floor to ceiling insulating glass units were only supported by framing members on the top and bottom edges, leaving the vertical glass edges as the weakest point for heat conduction. Again, a rigid high-performance PHSS spacer was specified to meet the peak chiller load and energy performance targets. In this application, the rigid box spacer design of the PHSS warm-edge spacer was essential because of the need to resist torsional forces at the sill and head condition which was required for the unsupported edge design.

Richard Green, P.E., Front Inc., the glass design engineer for the project, stated “we had to coordinate quite tightly with the HVAC designers at Arup. We needed to get as good of a performance as possible out of the glazing system. Getting the right insulating glass spacers in there made the difference. Spacers tend to be a fabricator’s choice. Many use stainless steel as standard; we needed better.”

Conclusion and Future Work

The results of the field study, building energy modeling analysis, and experience from a real case study support the conclusion that reducing the thermal conductance of fenestration frames and edge of glass is critical to managing the energy performance of buildings in hot climates.

Future Work: Thermal Comfort Assessment

In addition to energy performance, there is evidence to suggest that the high temperatures on the interior of non-thermally broken frames may also cause occupant thermal discomfort even in hot climates. The extremely high frame interior surface temperatures for non-thermally broken frames recorded in the field test (48-54°C, depending on the absorptivity of the frame) illustrates this potential for discomfort. Proximity of occupants to very hot room-side curtainwall frame may impact their thermal comfort because of the high radiant temperature of those surfaces. Radiant temperature is a key driver of thermal discomfort, along with humidity and air-flow, even when the average ambient temperature of the room is theoretically in the “comfort” range. The closer occupants are to the fenestration, the more that the thermal environment they are likely experiencing will be impacted by the radiant surfaces of the window, and the more likely they will experience thermal discomfort. Any thermal discomfort felt will derive from the average mean radiant temperatures of the surfaces surrounding the occupant (glass, frame, opaque walls, floor etc.) and the impact of any direct solar impingement through the glass, plus any additional or compensating effect of air flow, humidity, operating temperature etc.

Further work could be done to further quantify this discomfort by calculating mean radiant temperatures for facades with a range of frame to glass areas and fenestration performance, and separating the impact of discomfort from direct solar impingement through the vision area from radiant heat transfer from the temperature of the surrounding opaque frame area and glass.

Conclusion: Key Take-aways

Thermally breaking the frames and using high performance warm-edge spacer can significantly reduce solar heat gains through the façade, reducing energy usage and improving thermal comfort. Key takeaways are:

- Un-insulated frames and edges of glass admit a significant amount of heat into buildings through solar absorption and secondary conduction mechanisms causing high cooling loads and localized thermal discomfort in the proximity of the façade.
- Solar heat gain through fenestration frames is dependent on the absorption of the frame and its U-factor. To achieve low solar heat gain fenestration use wide, complex thermal breaks to reduce conduction and light-colored frames to reduce solar absorption.
- Conversely to U-factor, whole unit SHGC generally increases with size of the window, because the frame SHGC is lower than that of the center of glass. However, if not well thermally broken, the frame can have a comparable solar heat gain coefficient to the center of glass and can make meeting SHGC requirements more difficult without resorting to reducing the visible light transmittance of the glazing.
- In hot climates, the building energy impact of reducing conductive heat gains through the frame and edges (U-factor) can be significant. Using a high-performance fenestration package with wide thermal breaks that would be used in a cold climate zone (U=1.6 W/m^{2}K), rather than a non-thermally broken system with a SHGC of 0.25, delivered a similar impact on cooling load as reducing the SHGC from 0.25 to 0.21 without using thermal breaks in a prototypical building. Designers should consider improving fenestration (including frame and edge of glass) U-factor as well as improving solar heat gain coefficient of the center of glass, as this strategy will likely provide more flexibility in glass choice, better daylighting, and potentially reduced cost.
- High-performance thermal breaks and warm-edge spacer should be utilized in fenestration in buildings in all climate zones.

Lastly, SHGC calculations according to NFRC 200 (NFRC) do not consider the impact of different frame colors, as it uses a standard absorption coefficient of 0.5. Thus, fenestration with darker frame colors will likely have higher actual solar heat gain coefficient than anticipated based on a typical NFRC calculation. The impact on building envelope performance will depend on the frame to glass ratio in the building itself. The more frame, the higher the impact.

Acknowledgments

The authors would like to acknowledge the Solar Energy Research Institute of Singapore (SERIS) for their work on the field evaluation of thermal breaks, and the support for that study of Technoform, the Building and Construction Authority of Singapore, Meinhardt, Yongnam and the Singapore Green Building Council. Thank you to Building System and Diagnostics (BSD) for their contract building energy modeling services.

References

Building Construction Authority, “Guidelines on Envelope Thermal Transfer Value for Buildings”, version 1.01 (2004). https://www.bca.gov.sg/PerformanceBased/others/ETTV.pdf
Building Systems and Diagnostics (BSD), “A Report on Thermal Performance of Fenestration For Green Mark Version 5.0”, (2016).
National Fenestration Rating Council (NFRC), ANSI/NFRC 200-2017, Procedure for Determining Fenestration Product Solar Heat Gain Coefficient and Visible Transmittance at Normal Incidence, 2017.
Solar Energy Research Institute of Singapore (SERIS), “Pilot Study on Energy Savings Potential of Thermally Broken Aluminium Frames in the Tropical Climate”, (2016), commissioned by Technoform.
Wright, John L, Alex McGowan, “Calculating the Solar Heat Gain of Window Frames”, ASHRAE Transactions, 106 part 2 (1999)
Zemanski, Mark W, Richard H. Dittman, Heat and Thermodynamics, sixth edition, McGraw-Hill, 1981, p86-87.