EDGE OF PERFECTION: DESIGNING HIGH-PERFORMANCE FAÇADES

For energy-efficient, sustainable fenestration systems and façades that deliver on design, performance, and indoor comfort, building teams deploy new edge-of-glass and frame designs with better thermal control.

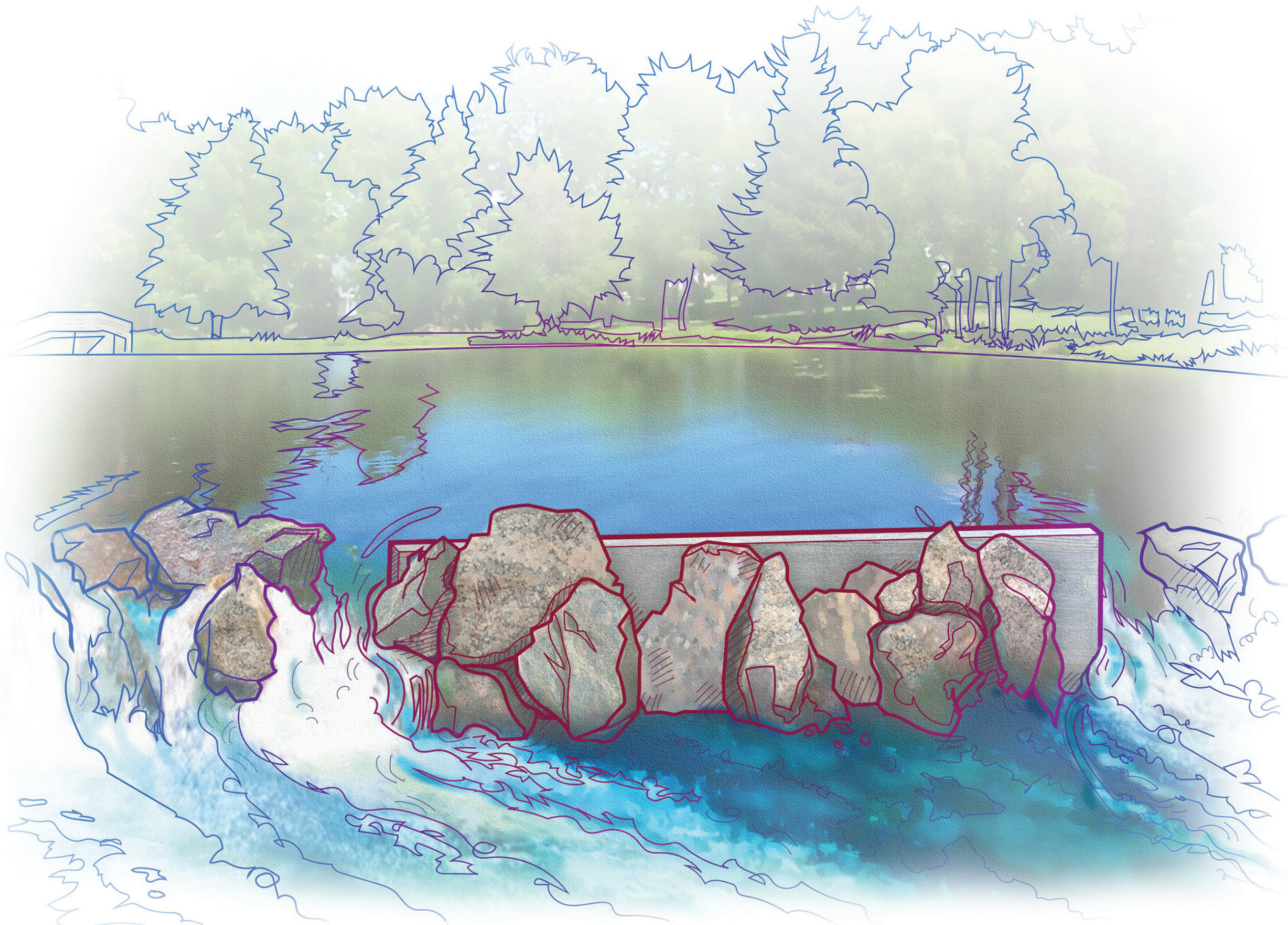
4 LEARNING OBJECTIVES

At the end of this course, the reader will be able to

+ **DESCRIBE the current challenges for designing high performance, sustainable, building envelopes.**
+ **LIST common misconceptions and issues regarding the specification of fenestration, including the relative importance of center-of-glass, edge-of-glass and frame U-factors.**
+ **SUMMARIZE key thermal zone technologies for fenestration, including thermal break and spacer advances to optimize thermal performance, durability and structural performance, and to provide aesthetic and design freedom.**
+ **IDENTIFY through case studies the applications of thermal zone technology, strategies for selecting thermal breaks and spacers, and their contribution to high-performance building envelopes in varied climate zones and building types.**

This course describes the multiple challenges in designing high-performance fenestration systems for building envelopes meeting architectural design needs to deliver energy performance, sufficient glazed area for optimized daylight admission and views, thermal comfort and condensation resistance, as well as meeting structural and durability criteria. The more stringent fenestration U-factor requirements in the most recent energy codes provide context for how to specify compliant fenestration systems. Misconceptions in specifying fenestration and its components are reviewed, with attention to the "thermal zone" impacts of windows and curtain wall, and the importance of the frame and glass edge to performance. Technologies including polyamide thermal breaks and warm-edge spacers are shown to have a significant impact on building performance, energy efficiency and sustainability. Best practices in specifying thermal breaks and edge-of-glass spacers are discussed.

Building teams face multiple and conflicting challenges in designing high-performance buildings, and many of the most contradictory and vexing of those relate to envelope design. Owners and developers demand good energy performance and interiors that are comfortable and consistent year 'round, yet they also ask for maximum transparency and glazed area to deliver big views and bright, sunny interiors. Still other trials confront architects and engineers in specifying and detailing fenestration systems: Resistance to condensation brought about by thermal bridging, for example,



Heat flow is like water flow: only by extending the dam across the whole river, edge to edge, can we significantly reduce water flow.

as well as fundamental integrity of the envelope structure and its durability and resilience over decades in place.

These attributes are essential to high-performance envelopes, yet building teams also need freedom for designing their ultimate architectural expression. With increasingly stringent building energy codes - - even as many owners require more glass area and greater interior comfort and experience - - the challenges are multiplied.

As a result, better building envelope technologies have emerged, including technologies for enhanced fenestration performance. This course offers a roadmap for project teams seeking to create expressive buildings that reduce energy use and deliver good indoor environmental quality (IEQ), maximize glazed area for natural light and views, and provide durable enclosures that resist condensation and remain structurally sound and fit for purpose over decades. Case studies show how these technologies and buildings also lead the market in architectural interest, sustainability, and overall quality.

To arrive at those paradigms, building teams must first understand today's energy code requirements as well as basic misconceptions about fenestration specification that create stumbling blocks to meeting or exceeding target performance levels. A comprehensive concept for effective fenestration design - - *the thermal zone* - - provides a useful framework for analyzing and improving design choices. Materials and methods also expand the building team's capabilities for producing highly effective enclosures, and the use of polyamide thermal breaks and durable warm-edge spacers is detailed.

All these findings contribute to envelope systems that meet today's fenestration U-factor requirements laid out in recently updated and stringent energy standards such as the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) Standard 90.1 and the International Energy Conservation Code (IECC), both of which undergird most prevailing building codes. By specifying key fenestration components to meet the new rules - - including thermal breaks and enhanced insulating glass edge spacers - - savvy building teams can achieve excellent performance with innovative and artistic building façade designs.

FRAMING THE CHALLENGE

Compared to the standards through the late 1980s, minimum requirements for energy performance have increased dramatically in the prevailing commercial benchmark, ASHRAE 90.1, officially called the *Energy Standard for Buildings Except Low-Rise Residential Buildings ANSI/ASHRAE/IES Standard 90.1.* For example, design energy use intensity (EUI) measured in kBTUs per square foot per year, has gone from the 1970s baseline of 100 down to 87 in 1989. Greater increases in stringency have since been driven by the Energy Independence and Security Act of 2007. As a result, as of the 2016 iteration of the standard, the design EUI has dropped to 49 kBTU/sf-year.

Since it is “the key basis for codes and standards around the world,” according to ASHRAE, including for the IECC and many state and local jurisdictional codes, ASHRAE Standard 90.1 is driving envelope design choices. Prescriptive window-to-wall ratios (WWRs) in the 90.1 standard for climate zones 1 to 6 are given at 40%, and in the IECC it is a more restrictive 30% unless improved daylighting is implemented, in which case the WWR could be 40%.

The 50% drop in required EUI per ASHRAE Standard 90.1 has also driven down prescriptive fenestration. U-factors measure how well an enclosure (or component) thermally insulates the inside of a building from the conditions outside. In short, the U-factor of a window is a measure of the transfer of heat through it. For those buildings that use higher window areas, the performance compliance path must be used to show that the building performance is at least as good as the baseline building. In these cases, the fenestration must have even higher U-factor performance than the prescriptive requirements.

The IECC and ASHRAE Standard 90.1 prescriptively list U-factor requirements and they are getting more stringent, so building teams should review them carefully - - as well as the requirements of the local jurisdiction in which they are building. The U-factor of the whole fenestration unit is an area weighted average of the U-factors of the frame, edge of glass, and center of glass. This means that the edge-of-glass and frame performance values can have a significant impact on the window U-factor - - an impact that increases for smaller window sizes.

However, some building teams tend to focus primarily on one aspect only: The center-of-glass (COG) performance. This focus can have detrimental effects on building performance if the frame and edge are neglected. These teams concentrate on the use of high performance low-emissivity (low-E) coatings, inert gas filling, and moving from double- to triple-pane insulating glass formats, all of which improve COG but have no impact on the performance of the glass edge or frame. Forgetting to improve the thermal performance of the frame and the edge of the glass can negatively affect the whole system U-factor performance.

Here’s the main reason: The edge matters. To emphasize the point, consider a basic analogy for heat flow in a window by comparing it to water flowing in a river. If an engineer dams the center to stop water flow but neglects to dam the river all the way to its edges, water will still flow around the barrier. No matter how well the dam stops flow in the center, water will move and continue to flow around the edges – finding the path of least resistance. The engineer needs a fully dammed structure, reaching from edge to edge, to stem the water flow effectively.

Similarly, for the flow of heat through a window, no matter how well the COG inhibits heat flow, if the frame and edge of glass are not robust insulators, the heat (or cold) will move through the edges of the window, where its path of least resistance is found.

“Moreover, fenestration U-factor requirements in the most recent building code revisions for many climate zones - - that is, much of the country - - demand strategies that improve the performance of the frame and edge of glass, as well as the center of glass,” says Helen Sanders, PhD, an expert in fenestration performance and executive at Technoform Group. She points specifically to the prescriptive fenestration U-factor requirements of IECC 2015, IECC 2018, and ASHRAE Standard 90.1-2016.

To meet ASHRAE 90.1 -2016 and IECC 2015 and 2018, building teams must design vertical fenestration with (a) thermally broken frames and (b) at least a dual-pane glazing with a low-E coating on one surface. But that's not all: To meet the U-factor requirement of 0.38 BTU/°F.hr.ft^2 in climate zones 4 (covering Washington D.C., Seattle, and Portland) and 5 (covering Chicago), the fenestration must also have (c) at least one of the following:

- a higher-performance thermal break.
- a warm-edge insulating glass spacer.
- argon-filled glazing units.
- a second low-E coating on the room side (surface 4).

And for climate zone 6 (covering Minneapolis) where the U-factor must meet 0.36 BTU/°F.hr.ft^2), the fenestration system must have at least two of the features bulleted above. For climate zone 7 -- covering areas in northern Minnesota, North Dakota and southern Alaska -- as well as climate zone 8, the IECC 2015 and 2018 U-factor requirements of 0.29 BTU/°F.hr.ft^2 mean that fenestration must have *all four* of those additional features or, as an alternative, use a high-performance thermally broken frame and triple glazing with warm-edge spacer.

To determine which of the additional four design strategies to use, the building team must consider the application. For example, addition of a room-side low-E coating, (on surface 4 of a dual pane insulating glass unit (IGU) reduces the temperature of the room-side glass surface. As a result, it increases the likelihood of condensation, making it a poor choice for high humidity environments such as hospitals or laboratories. Warm-edge spacers, on the other hand, will help ensure long-term thermal performance because their performance does not change over time. In this case, it is important to specify the appropriate type of warm-edge spacer system to ensure durability of the IGU. True warm-edge spacer systems (not including stainless steel box spacer) can generally be relied upon to reduce the overall fenestration U-factor by 0.02-0.03 BTU/°F.hr.ft^2 compared to aluminum spacer.

Climate zone:	0	1	2	3	4A	4B	5	6A	6B	7	8
ASHRAE 90.1-2016	0.50	0.57	0.54	0.45	0.38		0.38	0.36		0.33	0.29
IECC 2015/18		0.50	0.50	0.46	0.38		0.38	0.36		0.29	0.29

Summarizing, to achieve the U-factor requirements in climate zones 4 and above in the most recent model codes, strategies that improve the performance of the frame and edge of glass, as well as the COG must be implemented. As with the river and an effective dam, water will flow around the edge of the dam no matter how well the dam's center is designed. To stem the flow, the edges have to be dammed, too. In fact, studies and field performance data prove the point: They show that the frame and edge-of-glass must have high thermal performance in order to allow a high-performing COG to have the greatest impact on the whole-window thermal performance.

THERMAL COMFORT AND IEQ

In addition to the energy performance challenges laid out above, building envelopes need to function suitably to control interior temperatures and other IEQ factors such as condensation and moisture ingress. The main reasons? Human health and wellness, of course, but also productivity and perceptions of the building's quality are critical measures of the project's success.

The primary drivers for envelope design start with market preferences for big views and lots of daylight. This trend also reflects growing recognition of the wellness benefits associated with daylighting and outdoor views, say experts. Commercial and institutional end-users display a strong bias toward glass façades, according to Facade Tectonics Institute, driving the use of ever-larger glass lites, more complex aperture designs, and novel glass products responsive to variable solar and environmental conditions.

Yet the same end-users don't always appreciate the impact of their windows, storefronts and curtain walls on thermal comfort. According to annual research by the International Facility Management Association (IFMA), the most common complaints from users of commercial buildings is that the temperature is too cold or too hot. (In 2009, the survey numbers were 94% for too cold and 91% for too hot.) While mechanical systems account for some of this challenge, so do “hot spots” near fenestration with poor solar control and cold, chilly and drafty areas near windows with thermal bridging, poorly insulated glazing, and excessive air infiltration or exfiltration. On top of that, data collected by Lawrence Berkeley National Laboratories in a key study shows that worker productivity performance increases with temperature up to (21-22°C) and decreases with temperatures above (23-24°C). At about (30°C), productivity drops by a full 8.9%. The European HVAC group REVHA concludes there is an approximate 1% drop in productivity for every degree drop from the optimum temperature of 71°F (21.6°C).

Adding to the challenge, thermal comfort also lowers building occupant satisfaction of other IEQ factors, such as illuminance and acoustics, according to a new influential study reported in the journal *Building and Environment*.

In addition, excessive condensation and other IEQ and moisture issues, including poor humidity control, contribute to mold growth, allergies and sickness, chronic fatigue and absenteeism in some cases, according to the National Institutes of Health and other groups.

COMMON DISCONNECTS

The apparent discrepancies between the widespread desire for more glass in the building envelope and the impact (or perceived impact) of glass on IEQ performance is only one of the significant disconnects in building design today. In fact, there are a number of areas where design intent is lost on the way to constructing a complete and high-performing enclosure, including several related to specifying fenestration and fenestration components.

The most concerning disconnect involves the delivery of the designed energy performance. The expected values for EIU derived from energy modeling rarely match the actual, measured EUIs for the completed facilities. In a study detailed by the New Buildings Institute (NBI), as-designed EUI values were compared with actual energy performance in dozens of LEED-NC buildings, and the report, published by the U.S. Green Building Council, showed results scattered all over the map. While some LEED buildings did better than predicted, many also fell short. A building with a design EUI of about 60 kBTU/sf-year, for example, reported actual EUI values of about 80 kBTU/sf-year. That’s a difference of about a third – a surprising and major gap. More importantly, all the buildings designed to be low-energy (less than 40 kBTU/sf-yr) had higher energy performance than predicted.

In fact, many building teams call this the “energy gap,” and view it as a major impediment. What’s behind the energy gap?

The wide variability of energy modeling accuracy on an individual project basis implies significant flaws,” concluded the NBI researchers Mark Frankel and Cathy Turner, which “calls into question how effectively [energy modeling] is used to predict the performance outcome of any given project.” Yet there are other issues that arise, too.

"The problems with the energy models start with inaccurate assumptions and inaccurate inputs such as U-factors that don’t consider all of the edge-of-glass and frame area inputs of fenestration, or thermal bridging at the connection points of opaque panels, parapets, shading systems and other envelope systems", says Technoform’s Sanders. "There is also no formal feedback loop from the as-built building back to the modeling team, so no model correction or optimization is routinely done."

Other causes are introduced during the construction process, and through value engineering efforts that undercut original design intent. How building systems are operated - - and the unexpected impacts of occupant behavior and even changes of building use - - add more uncertainty in ultimate EUI numbers. Many models don’t include plug loads, which are becoming an increasingly large proportion of building EUI.

These are not minor considerations, since cities and states are starting to take notice. Many jurisdictions have mandatory energy disclosure and benchmarking ordinances, and these now cover some 10 billion square feet of building space.

So we can expect more transparency, according to the Institute for Market Transformation, with some voluntary reporting related to certifications like LEED and EnergyStar for Buildings, but much more so because of mandatory reporting.

- Example impact: Incorrect Use of Center of Glass U-factor. Among the contributors is the mistaken use of the COG U-factor as the basis for energy modeling instead of the required whole fenestration value which results in significant underestimates of heat losses through fenestration. The COG U-factor does not include thermal losses through the frame and the edge-of-glass, which create significant heat loss paths if not appropriately designed. Most of all, many architects think COG U-factor and whole-unit U-factor are the same or similar - - and they are not. The key difference is that the contributions to thermal performance from the edge of glass and frame, as well as the center of glass, are correctly reflected in the whole fenestration U-factor. Generally speaking, whole fenestration U-factors are significantly higher than the COG U-factor. Further, whole fenestration U-factors are required for use in demonstrating prescriptive and performance code compliance. These are the values quoted in the tables of U-factor requirements in the prescriptive codes.

Consider the following energy modeling example using fenestration with the following performance:

COG U-factor 0.30 BTU/°F.hr.ft^2 (equivalent of an air filled dual pane insulating glass unit with a regular double silver low-E coating)

Whole-fenestration U-factor 0.45 BTU/°F.hr.ft^2 (aluminum window system with the same glass infill as above)

For this example, Department of Energy's EnergyPlus program is employed to model the perimeter zone of a prototypical building in Minneapolis with a 70% window to wall ratio, such as ribbon windows from desk height to ceiling. The perimeter zone in the example is 15 feet deep by 10 feet high and 25 feet long. Energy use is calculated first using the COG U-factor, and then using the correct, whole-fenestration value.

Using COG U-factor leads to major discrepancies - - errors - - in the predicted perimeter zone EUI. In this example, the design team can expect a **15% underestimate** of perimeter zone energy use based on incorrectly using the COG across all four elevations.

Perimeter zone heating energy is understated by a whopping 28% in the example. For narrow, well daylit buildings, where the perimeter zone represents the entirety, or a high proportion, of the floor area, this will translate into a similar impact on overall building EUI. In buildings with deep floor plates, the impact of the underestimated perimeter zone is less significant to overall EUI, but it still causes significant thermal comfort issues on the perimeter zone. Likely the perimeter heating system will be undersized, and the windows will be cold and uncomfortable for occupants sitting nearby. This is certainly not the accuracy nor outcome desired by design teams - - nor their clients.

MINIMIZING ENVELOPE U-FACTOR: WINDOWS MATTER MOST

Although the amount of glazing varies widely, "all windows are a significant factor contributing to heat loss," according to Richard Fitton, a building energy-efficiency expert at the University of Salford, U.K. In fact, many of Fitton's peers agree that the biggest lever for improving the overall envelope thermal performance is improving window performance.

One might say, "Yes, but can't improving wall R-values also improve the overall performance of the building?" The answer, say experts like Fitton, is simply, "Not as much." Consider a baseline envelope design from which the design team requires a better total R-value for the vertical assemblies. The team's choices are to (a) improve wall performance, and/or (b) improve window performance. For this baseline example, consider a structure with:

- 50% fenestration area at R2 (U = 0.5 BTU/°F.hr.ft^2).
- 50% wall area of R20.

This yields an effective area weighted R-value (R(eff)) for the envelope expanses of R3.6.

If the building team chooses path (a) and boosts the wall insulating value from R20 to R40, the increase in total effective R-value for the envelope increases to only R3.8. The more seasoned building team might choose path (b) boosting the window insulating value from R2 to R4, to obtain a total effective R-value of R6.7 - - a significantly better outcome.

$$\frac{1}{R(eff)} = \left(\left(\frac{1}{R=2}\right) * 0.5\right) + \left(\left(\frac{1}{R=20}\right) * 0.5\right)$$

$$\frac{1}{R(eff)} = 0.25 + 0.025 = 0.275$$

$$R(eff) = 3.6$$

This dynamic can be rationalized physically by considering that if the walls are significantly more insulating than the windows (in this case by a factor of 10), it stands to reason that the heat will find the path of least resistance and the majority will still continue to flow through the windows, no matter how insulating you make the walls. Only making the windows less conductive to heat to stem the largest heat flow path will make a significant impact on the overall envelope performance.

Again, heat flow is just like water flow: Like the dam in a river, blocking only a portion of the river is an ineffective way to hold back water. Improving that dammed portion will still let water through. Only by extending the dam across the whole river, edge to edge, can we significantly reduce water flow.

THE WHOLE ENCHILADA

The importance of windows on building performance - - and the impact of the inappropriate use of COG U-factors - - leads to a few key conclusions about optimizing envelopes for all architectural needs, including energy use. To some these may seem basic, yet they are widely overlooked.

•The performance of the perimeter of the fenestration is critical.

If the COG resistance to heat flow is much better than the perimeter of the window (edge of glass and frame), the most effective way of improving thermal performance is to improve that of the edge of glass and frame. The important point is that *the edge matters most*.

All of the components of the fenestration assembly must work well thermally in order for the window to deliver good thermal performance, but the edge is critical in every instance. It is very important to optimum performance and excellent **whole-window U-factors** for their buildings. Put another way, Technoform's Sanders says, "The window frame and edge of glass must have high thermal performance in order to allow a high-performing COG to have the greatest impact on the whole window performance."

To see how frame and edge-of-glass assemblies make the largest impact on whole-window U-factor, compare a fenestration system with a non-thermally broken frame and an aluminum spacer to other, better window specifications.

For example, consider a window with a non-thermally broken frame with a glazing infill that has a COG U-factor of 0.29 (BTU/°F.hr.ft^2), but a conductive aluminum edge spacer. The COG performance is representative of an air-filled dual pane IGU with a standard double silver low-E coating. For this frame, the U-factor is 0.53 (BTU/°F.hr.ft^2). Improving the COG U-factor to 0.24 (by using a triple silver low-E coating and inert gas filling) improves the whole-window U-factor only by about 6% to 0.50.

However, changing the frame to one which is thermally broken and using a warm-edge spacer, on the other hand, improves whole-window U-factor by **36%** without needing to make a change to the COG performance (which adds cost and limits choice).

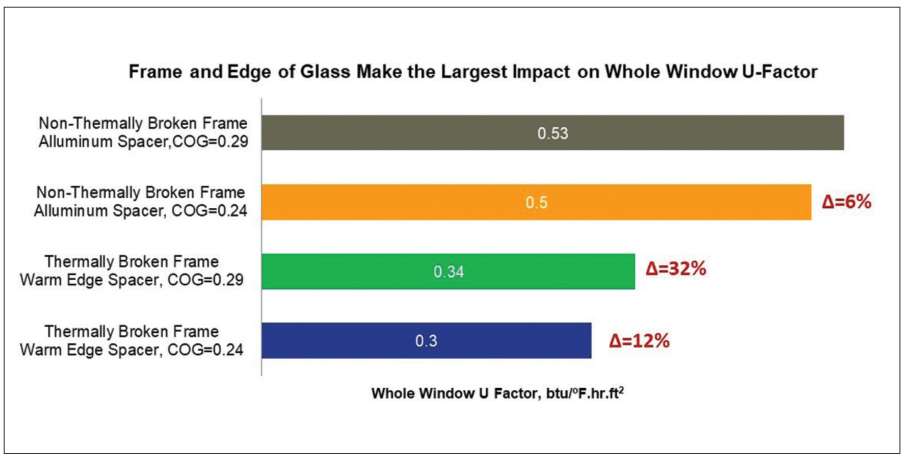
The better frame and warm-edge spacer with the original glazing (COG = 0.29) yields a whole-window U-factor of 0.34. With the better glass, the overall fenestration U-factor achieves 0.30, a 12% reduction. This demonstrates that when a window's perimeter thermal performance is sufficiently improved, enhancements in the COG can yield proportionally more impact on performance.

•Fenestration perimeter details heavily influence condensation.

The occurrence of condensation on windows, which everyone seeks to avoid, is driven almost entirely by the fenestration frame and edge of glass, and of course, by how well the system is installed (air infiltration can cause significant condensation issues).

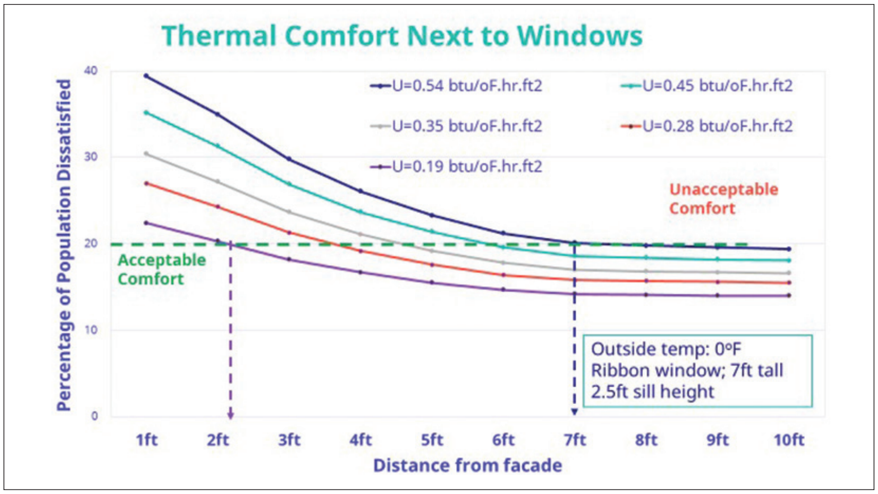
To illustrate this point: If a fenestration design improves center-of-glass COG U-factor, what

The whole window U-factor is reduced more by improving the frame and edge of glass thermal performance than by reducing the center of glass (COG) U-factor.



happens to the resulting window's ability to resist condensation? The answer is a simple very little, unless thermal bridging at the frame and edge of glass are addressed first.

Consider a window with a COG U-factor of 0.29 BTU/°f.hr.ft^2 which uses an aluminum spacer and a non-thermally broken frame. Improving the COG U-factor to 0.24 (using argon gas fill and a triple silver low-E coating) only improves the condensation resistance, as defined by the National Fenestration Rating Council (NFRC), marginally from 16.2 to 16.3 which is still very poor performance. But adding a warm-edge spacer and a thermally broken frame without changing the COG performance, boosts condensation resistance by 150% - from a condensation resistance of 16 to 43. Adding a best-in-class thermal break improves that even more, by another 37% to a condensation resistance value of 56.

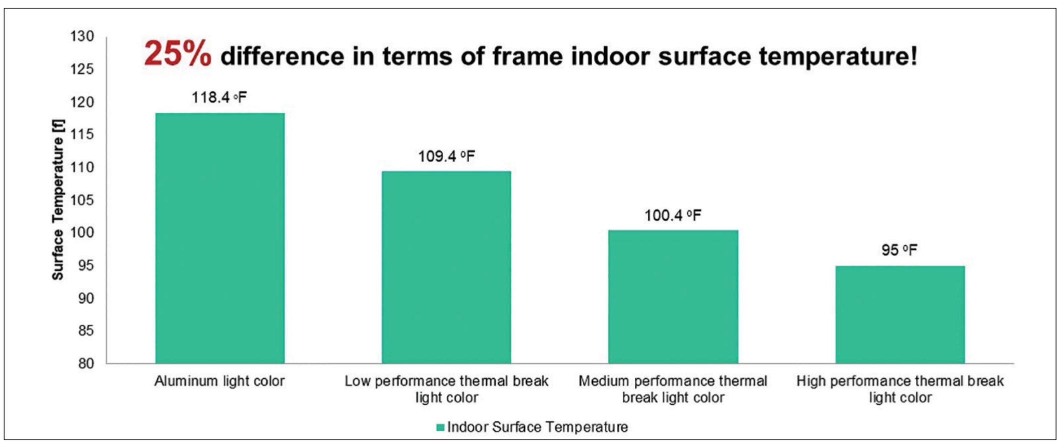


The thermal comfort next to windows is significantly influenced by their U-factor. Occupants can sit comfortably within 2ft of a window with a U-factor of 0.19 btu/°f.hr.ft^2 yet would have to sit 7ft away to be comfortable next to a window with a U-factor of 0.54 btu/°f.hr.ft^2.

• Window thermal performance drives occupant satisfaction.

Poorly designed and specified windows can create undesirable interior conditions due to thermal discomfort. Some building owners and managers call these "no-go zones" at the building perimeters where they discourage the location of seating areas, workstations and patient beds, for example. For example, a warm building interior will often have drafty, uncomfortable conditions next to cold windows. This effect is caused by convection loops created by movement of the warm indoor air and the localized cold at the window zone. Another unpleasant sensation is the radiating of a human occupant's body heat toward a cold window: The net effect is, the occupant feels cold. On a hot sunny day, outdoor heat can also radiate into the interiors and increase skin temperatures.

In cases where window performance isn't adequate to mitigate the outside environment, the area near the window is a place where occupants would rather not remain, undercutting the building's value as certain areas are rendered undesirable or unusable. Not only that, this economic impact can be used to justify the cost of higher-performance windows and to properly calculate its payback or ROI.



The room-side surface temperature of a window frame on a 99°F sunny day in Singapore. The interior temperature is significantly influenced by the presence, and the relative performance of, aluminum thermal break technology. The better the thermal break, the more comfortable the window is to sit next to.

• U-factors matter in Minneapolis *and* Miami.

The U-factor of the edges of fenestration impact building performance and occupant enjoyment in varied settings. For example, the use of thermal breaks can have a notable effect on the temperatures of window frame indoor surfaces in hot climates, since solar radiation absorbed by the exterior frame turns into heat and – without a thermal barrier – will conduct through the frame to the building interior.

A non-thermally broken light colored aluminum window frame on a sunny, 99ºF (37ºC) summer day can create room-side frame surface temperatures of up to 118˚F (48ºC) and higher, making them very uncomfortable to sit near. Darker frames become even hotter. By adding a basic thermal break, the interior frame temperature can drop by 10˚F. Using high-performance thermal break technology, interior surfaces drop to 95ºF (35ºC), by over 20ºF, up to 25% cooler. The solar heat gain coefficient of a window is actually dependent on the U-factor of the frame and edge of glass. Lower frame and edge of glass U-factors result in lower whole window solar heat gain coefficients.

The takeaway from these key points are: **Start at the Edge**. Focus on improving the thermal (U-factor) performance of the frame and edge of glass first, whether it be in a building designed for a cold or a hot climate. By doing this, the building team will achieve higher-performing fenestration – from an energy, condensation and comfort perspective — without limiting design choices regarding the COG, and potentially improve long-term performance because gas-filling may not be necessary to meet energy targets.

In addition, choices in thermal performance influence durability and structural performance.

Savvy building teams will evaluate durability and structural performance as well as thermal performance of solutions since thermal performance is only as good as the durability of the system. Not all solutions that improve thermal performance are created equal, so…

THERMAL ZONE DETAILS MATTER

Clearly, the *thermal zone* - - the perimeter of the window (frame and edge of glass) – must be designed carefully. Yes, the devil is in the details. Evaluating thermal solutions for fenestration systems, as seen in the discussion above, must be done carefully. Not all solutions are created equal when it comes to improving thermal performance or durability.

***Fenestration Thermal Breaks*:**

Consider the mechanisms of heat transfer at the window edge: About 85% of the thermal bridging of the windows occurs around the edge and frame. *Conduction* through solids makes up about 50% of this energy flow. Convection — air circulation in cavities of the frame — totals about 35% of this energy flow. Last, *radiation* comprises 15% of this energy flow at the window edge.

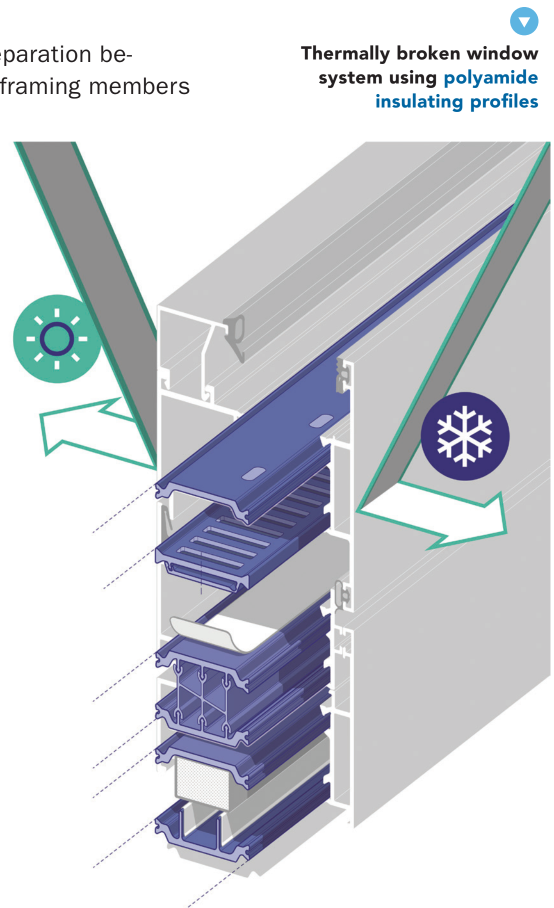
To reduce the energy losses from all three processes through the perimeter of windows, industrial designers have developed effective **thermal break systems** with various performance attributes. Widely used thermal break components include:

- ***Polyurethane pour-and-debridge.*** In these, a polyurethane polymer liquid poured into a pocket in a window frame's metal extrusion hardens, and a portion of the metal forming the pocket is cut out to prevent metal-to-metal contact. In this way, the hardened polyurethane acts as an insulator between two separated metal pieces.

- ***Polyamide structural insulating profiles.*** A rigid polyamide strip, mechanically crimped between two metal extrusions in the window frame, serves as an insulator.

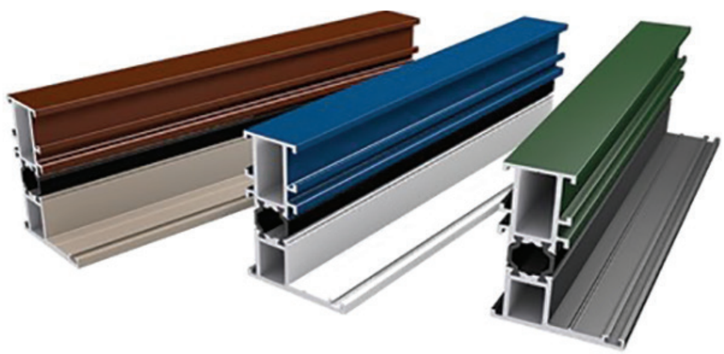
In general, the longer the separation between the inside and outside framing members caused by the thermal break, the better the U-factor performance because of the reduction in the conduction of heat. NFRC defines a thermally broken window system, as system members with a minimum of 5.30 mm (0.210 in) separation provided by a low conductance material (where thermal conductivity ≤ 0.5 W/mK, (≤ 3.6 BTU·in/h·ft^2·ºF) or open air space between the interior and exterior surfaces. Systems are called "thermally improved" if they have a separation between 1.6mm and 5.3mm, and are thus lower performing thermally. Polyamide thermal breaks are available in lengths of 3 inches or

Thermally broken window system using **polyamide insulating profiles**



more. The reduction in heat transfer by convection in combination with conduction reduction can be addressed by the use of more complex polyamide thermal break structures, which use fins or attached foam to break up convection currents in the large chambers in the extruded frame members. In the highest performing frame designs, low-E coatings are also being added to reduce the radiation component of heat transfer.

Another benefit of polyamide thermal breaks,

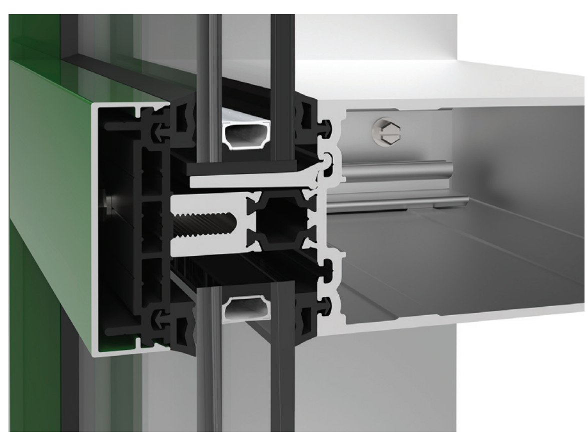


which have a track record of installed applications dating back to the mid-1970s, is that they allow windows to be easily produced with different finishes on the inside and outside since they combine two separate extrusions. This also allows for cost savings as well as the selection of the desired and appropriate finish for both interior and exterior applications. In addition, window systems have been developed which allow the exterior aesthetic to remain the same even if the depth of the mullion needs to be increased, U-factor performance increased or the infill changed from a dual pane to a triple pane on different parts of the building. This is easily facilitated by providing different lengths of the polyamide thermal break. This allows building teams to have the flexibility of specifying fenestration systems with various structural and thermal performance specifications for each building exposure or application area on a building, yet with matching geometries and finishes.

In terms of structural performance, the polyamide insulating profiles should meet the American Architectural Manufacturers Association (AAMA) standard Technical Information Report A8-08, "Structural Performance of Composite Thermal Barrier Framing Systems." Meeting this key standard, the polyamide thermal breaks can extend to at least 3 inches for the highest thermal performance values achievable. Polyamide thermal breaks are routinely used in applications with high structural requirements such as impact rated, blast resistant and over-sized fenestration.

Polyamide is the chemical name for what is commonly called nylon. The nonhazardous, benign material is used in toothbrushes and many other household items. Polyamide is also commonly employed in automotive, sports-gear and carpet applications, because of its high durability and resiliency. Polyamide provides a true mechanical bond yielding long-term performance, and it exhibits an expansion rate similar to that of aluminum. Polyamide has exceptionally low shrinkage, too, exceeding the requirements for AAMA's standard 505-98 for dry shrinkage and

Bob Evans Farms headquarters, images courtesy of YKK



composite performance in its thermal cycling test procedure. Polyamide is environmentally sound, according to experts, as it is recyclable and stable with high chemical resistance.

For these reasons, polyamide is used in the production of articles with very tight tolerances. In addition, the polyamide products provide for interchangeable profiles, allowing multiple configurations. The multi-duty strips can also receive gaskets, screw boots, and other hardware.

- Thermal Break Case Studies

In some commercial and institutional facilities, the use of polyamide insulating profile thermal break technology demonstrates the inherent value of design freedom, such as two-finish options, and creating a consistent, attractive exterior look while maintaining proper minimum performance as required to meet energy use goals.

For the Bob Evans Farms corporate headquarters in Albany, Ohio, the project team including M+A Architects and Corna Kokosing Construction specified a high-performance curtain wall with dual polyamide thermal barriers, allowing for three different design widths. A matching commercial swing door system, with advanced thermal design performance, is made with polyamide struts and foam. Designed to meet LEED Gold, the envelope system was tested using thermal imaging post construction by Mays Consulting, demonstrating excellent thermal performance for the entire envelope system.

In another case, the firm SmithGroupJJR designed a modern curtain wall system for the Georgia State Law Building in Atlanta. Working to achieve LEED Silver certification, the team specified a unique inside-glazed curtain wall system designed with high-performance

Georgia State Law Building, Atlanta

dual polyamide thermal breaks. According to the curtain wall maker YKK AP America, the vertical envelope with dual thermal barriers "yields best-in-class thermal performance and exceeds not only current codes but also the most stringent green building codes and standards" in 2015, when it opened.

For Cornell University's Gates Hall in Ithaca, N.Y., the Pritzker Prize-winning architect Thom Mayne's firm, Morphosis Architects, detailed a high-performing unitized curtain wall with custom-perforated metal panel system and, within its frames, a 1.25-inch polyamide thermal barrier. The uniquely shaped barriers provide both an integrated structural support element and internal shaping that reduces convection while also allowing for movement of the IGU's. According to the project team at W&W Glass, "The high-performance, structurally glazed and thermally broken curtain wall system consisted of roughly 600 unitized frames and 35,000 square feet of glass."

Gates Hall, courtesy of YKK

Polyamide Pressure Plates:

In addition to conventional thermal breaks, the use of glass filled polyamide in pressure plates instead of aluminum can improve curtain wall U-factors by 20% and boost condensation resistance factors by about 10%. Polyamide pressure plates do not have the health and safety concerns of the fiberglass alternative. Polyamide pressure plates are available in 2-in. and 2.5-in widths from several suppliers.

Insulating "Warm-Edge" Spacers:

Similarly, insulating (or warm-edge) spacers can be used for improving the thermal performance of IGUs.

The essential functions of insulating glass spacer are to:

- Carry desiccant
- Provide a moisture barrier
- Create a gas seal
- Provide a surface for sealant adhesion (metal surfaces are optimum for silicone adhesion)
- Accommodate stresses caused by climatic loads (wind, atmospheric pressure, temperature)
- Create an insulating barrier

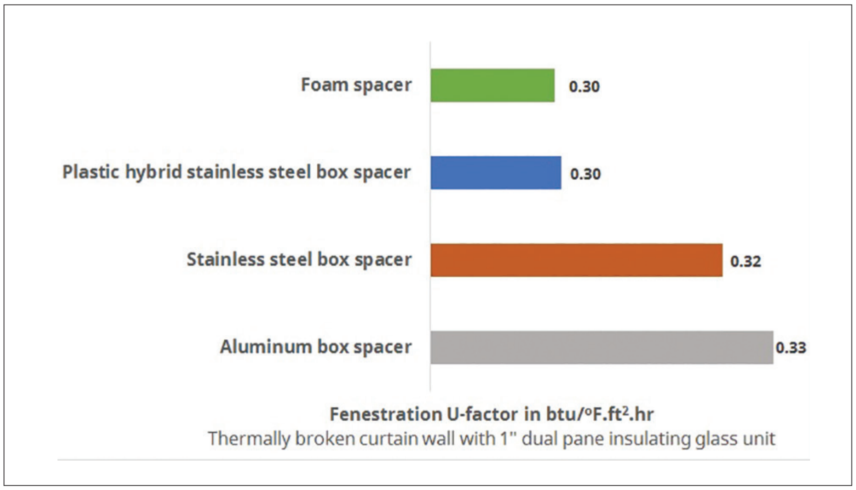


Chart 1: Whole unit U-factor performance of a thermally broken curtain wall at NFRC standard size (1200x1500mm) with a 1" low-E dual pane IGU with different edge spacers with 6mm (1/4") silicone sealant.

The first 5 functions are the most important because they have a direct impact on the lifetime of the unit. Only when the edge seal effectively addresses those functions, can we start to consider improving the thermal insulation performance, since the long term thermal performance is dependent on durability.

There is always a finite diffusion of moisture vapor into (and inert gas out of) an IGU and so the key is to minimize the flow of moisture into the unit (and the flow of inert gas out of the unit) through both edge seal design and fabrication process control. So the type of moisture and gas barrier used in spacers is an important factor. Solid metal barriers, such as the walls of aluminum, stainless steel and plastic hybrid stainless steel box spacers, are optimal since solid metals have zero diffusion rates. The only diffusion paths are through the primary sealant and any penetrations in the spacer (such as connection points). Metalized plastic films are often used as a moisture and gas barrier in non-metal spacer (such as foam or thermoplastic), and have a range of gas and moisture permeation rates.

Desiccant carrying capacity is therefore also a key determinant of lifetime. The role of the desiccant is to absorb the moisture coming into the cavity. When the desiccant capacity is used up, any additional moisture will appear as liquid in the cavity, cause corrosion of coatings, and obscure the view through it. All other things being equal, the higher the desiccant capacity, the longer the lifetime. Box spacers generally have the highest desiccant carrying capacity because they can be filled with loose bead desiccant in two to four of the sides.

Sealant adhesion to the spacer is very important for durability, especially for dual seal silicone-based systems. Poor adhesion can lead to premature seal failure. The benchmark for good silicone adhesion are metal surfaces such as aluminum and stainless steel.

In terms of thermal performance of spacers, those that have better thermal performance than aluminum box spacer are generally referred to as "warm-edge. This means that stainless steel spacer is considered warm-edge, however, as can be seen from Chart 1 stainless steel spacer only improves the fenestration U-factor by about 0.01 BTU/°F.hr.ft², whereas much higher warm-edge performance is delivered by plastic hybrid stainless steel or non-metal spacer, such as foam. The same differentiation is seen in condensation resistance, where plastic hybrid stainless steel or non-metal spacers deliver much better performance than stainless steel as shown in Chart 2.

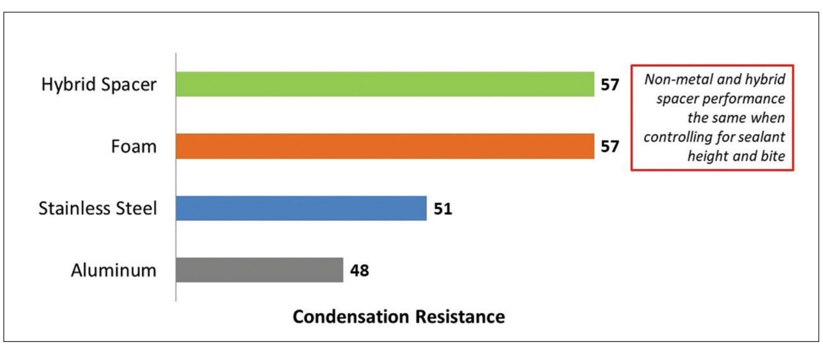


Chart 2: Condensation resistance of a thermally broken fixed aluminum window at NFRC standard size (1200x1500mm) with a 1" low-E coated dual pane IGU using different edge spacers with 6mm (1/4") silicone depth.

When considering durability and structural performance, the go-to is a box spacer with a solid metal back, and when considering thermal performance, the best performing systems are either plastic hybrid stainless-steel (PHSS) box spacer or 100% non-metal systems. The spacer category that meets both criteria is the PHSS box spacer which also delivers additional design freedom through matte finishes, color choices and the ability to use in radiused shapes and bent insulating glass.

In fact, hybrid warm-edge spacers have been used widely across a wide range of building types to meet energy efficiency and sustainability needs for more than 15 years. Examples of the use of PHSS spacer in bent IGU include the Apple Store in Dubai designed by Foster + Partners, and the LEED Gold-rated Manulife Tower in Calgary designed by Skidmore, Owings & Merrill LLP.

In an example of a building seeking "extreme thermal performance," the Bullitt Center in Seattle, designed by architect Miller Hull to meet the requirements of the Living Building Challenge, the project team designed every component to last 250 years, including its windows using hybrid warm-edge spacers in triple-pane, low-E glazing systems to improve the center's thermal control, condensation resistance, and acoustic performance.

Other examples include the University of Central Missouri's new 69,000-square-foot health and wellness center in Warrensburg, Mo., designed by Kansas City-based architect Gould Evans. With large glazed areas employed to maximize daylight and create a bold design statement, the hybrid warm-edge spacers maximized the sustainability of the new facility.

Manulife Tower in Calgary used PHSS spacer in bent IGUs.

THERMAL ZONE TECHNOLOGY: THE EDGE MATTERS

Key to a successful building envelope design is a focus on specifying high performance at "the edge" of fenestration. The edge matters. With a focus on edge performance, a higher and more balanced fenestration performance – U-factor, thermal comfort and condensation resistance - is achieved. High-performance fenestration designs benefit from proper design and specification of their thermal zone components. For the window frame, that means the use of a high performance thermal break, such as wide polyamide struts, with additional fins or foam to reduce convection to achieve the highest levels of performance. For the edge of glass, it means specifying a durable, true warm-edge IGU spacer, such as a PHSS box spacer. In addition, custom and adaptable off-the-shelf polyamide solutions -- such as insulating struts and polyamide pressure plates -- can improve the performance of curtain wall systems further, meeting energy, comfort and aesthetic goals in the final assembled envelope.

With the proper components, building envelopes can meet today's stringent energy codes without sacrificing glazed area, achieve sustainable building certifications, and provide a comfortable indoor environment.