Feature

Examining Methods for Preserving and Improving the Energy Performance of a Historic, Aluminum-Framed Curtainwall System

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This paper was presented at the 2024 IIBEC/OBEC BES.

WHEN COMPARED WITH modern counterparts, historic, aluminum-framed curtainwall systems perform poorly with respect to energy transfer. These older systems are ideal candidates for replacement with more thermally efficient systems during building retrofits.

However, there are situations where replacement of the curtainwall system is not feasible. When a facade is designated as historically significant by local preservation authorities, the appearance of the curtainwall system must be maintained. It is difficult to preserve the appearances of many historic curtainwall systems with typical replacement systems, and customization may be cost prohibitive. Boundary conditions can render replacement of the curtainwall system impractical if major interventions into the facade are required to remove and replace framing and associated anchorage.

This paper explores a method that was developed to thermally retrofit in situ a historic curtainwall framing system while maintaining the system's original appearance. The change in thermal performance is modeled to estimate improvements that can be achieved through retrofitting the existing framing and is compared to the improvement of new curtainwall framing. Finally, an energy cost-benefit analysis of retrofitting versus replacement is presented that accounts for embodied energy associated with the new framing system that would be used in a replacement project.

BACKGROUND

Water management has been an issue for curtainwall systems since they started to become common in the late 19th and early 20th centuries. Rehabilitation of these systems is not a new concept. Generally, owners have relied on sealants between framing and glazed components to prevent water prevention. Therefore, curtainwall systems require periodic maintenance over their service lives. Rehabilitation programs often involve replacement of glazing seals, frame joinery seals, and glazing units that have reached the end of their service lives. If the owner wishes to improve the thermal performance of the entire curtainwall system, glazing units are typically replaced with more-efficient insulating glazing units (IGUs).

In the late 20th century, curtainwall systems became fairly standardized. Before that time, curtainwall systems tended to be customized with unique framing and glazing systems. Those older curtainwall assemblies were built as an alternative to mass walls in buildings of various heights, and most of the custom systems used aluminum as the main frame material. Aluminum was desirable due to its high strength-to-weight ratio.[1] However, relative to almost all other building materials, aluminum has a very high energy conductance. Therefore, because frame materials have less thermal resistance than most glazing, aluminum-framed systems usually experience significant thermal bridging at their frames.[2] Thermal bridging can be reduced by incorporating relatively less-conductive materials, which are referred to as "thermal breaks," in the frames. However, effective thermal breaks are often absent in early curtainwall systems.

When considering a project to update a facade that contains an older curtainwall system, it is desirable to improve the energy performance of the glazing system. Conceptually, designers have two options to improve the thermal performance of glazed portions of a facade. The existing curtainwall system can be replaced completely with a more energy-efficient system, or the existing system can be retrofitted such that it better resists energy transfer. In many cases, designers and owners only consider the incremental difference in conductance of the glazing system when comparatively evaluating these two options. However, for a more accurate comparison, the embodied energy of the replacement system and waste generated by removing the existing system should also be considered.

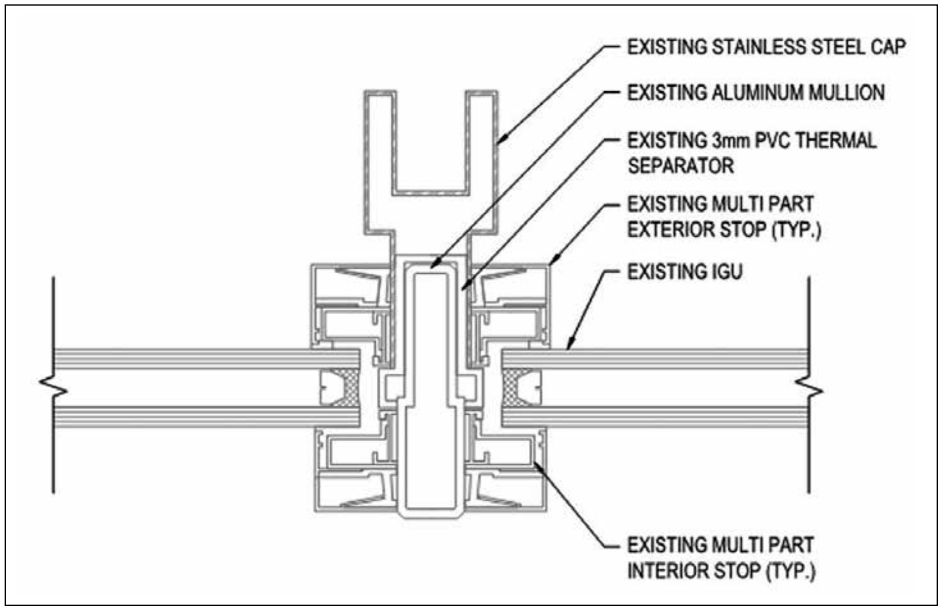

Figure 1. *Plan section view of a typical existing mullion.*

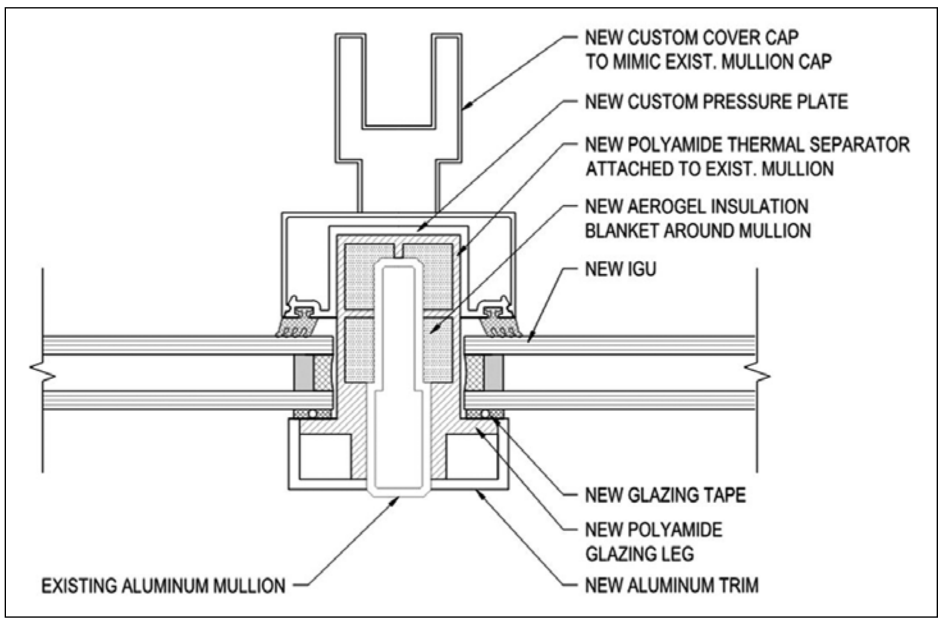

Figure 2. *Plan section view of a retrofitted mullion.*

CASE STUDY

During a retrofit design for a commercial building located in the greater Toronto area, existing curtainwall located at the podium of a multiple building complex was considered. The curtainwall was designated as historically significant, and as such, the appearance of the curtainwall after the building retrofit must maintain proportions of the original system.

The curtainwall system, built circa 1960s, was assumed to be a poor energy performer given its age and configuration. The framing system was made of hollow aluminum mullions, and glazing was captured by an intricate system of stainless steel and aluminum components forming multipart glazing stops on the interior and exterior.

Stainless steel caps in a custom design contributed to the historic appearance of the building. The existing curtainwall system contained a polyvinyl chloride (PVC) thermal break wrapping the exterior portion of the mullion. Due to its orientation, the PVC thermal break did not mitigate energy transfer to modern standards, as heat energy could transfer around the thermal break through conductive materials.

Options to Improve Thermal Performance of the Frames

Two options were considered to improve the thermal performance of the curtainwall. The first option involved retrofitting the existing core framing system to improve its thermal performance. The second option was to replace the entire curtainwall system with a more thermally efficient modern system. An upgraded IGU was assumed as part of the retrofit in both options. Therefore, the thermal resistance of glazing was considered to be the same for both options, meaning that frame improvement options could be considered in isolation when comparing the choices.

Option 1: Retrofit the Existing System

Retrofitting an existing framing system of a custom curtainwall from the 1960s while maintaining the appearance of the original system can be challenging due to geometrical constraints. It was known that the original PVC thermal separator performed poorly since heat energy was able to bypass this component through metal glazing stop components. Replacing the glazing stops with a less-conductive material was of the utmost importance. The challenge was to do so while maintaining the original geometry of the mullion and using a material that could adequately transfer wind load.

Under the geometric constraints of the base situation, polyamide was chosen to replace the glazing stop as it is a relatively less conductive material but is still rigid enough to support glazing. The aerogel insulation was chosen for its low conductivity and to fit into the tight space

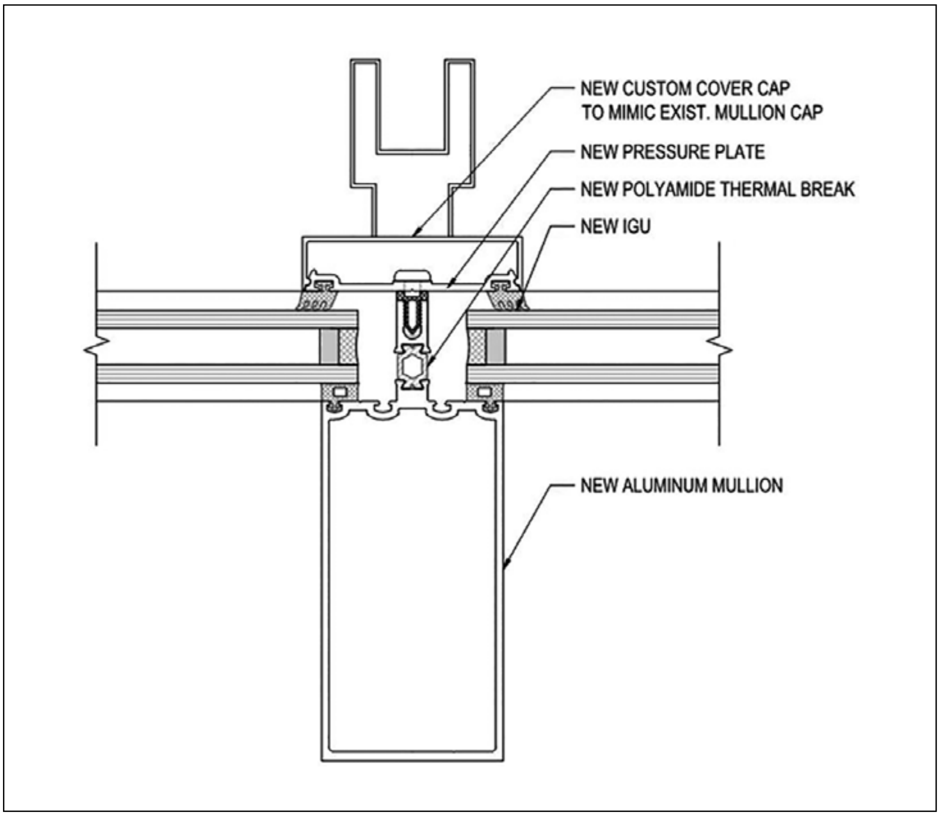

Figure 3. *Plan section view of a replacement framing system mullion.*

between the polyamide and the aluminum. Polyamide legs were required to transfer loads to the aluminum mullion/rail.

Another advantage of polyamide is that it is moisture tolerant. From a water management perspective, it was desirable to create a drained cap system because drained systems are known to perform better than face-sealed systems over the long term. In this option, intermittent weep tubes from the glazing pocket to the underside of the mullion would be required due to the geometry of the existing aluminum frame and the presence of the polyamide glazing stop.

Option 2: Replace the Existing System

The second option would involve replacing the existing system with a new, more thermally efficient curtainwall system. The existing aluminum frame contained a polyamide thermal break at the nose of the mullion. To recreate the existing look of the building, custom snap caps would be used, which would necessitate a captured system.

Discussion of Frame Improvement Options

From a heritage preservation perspective, retrofitting an existing framing system while maintaining the original appearance of the facade is the most desirable option. Preserving the facade is the most obvious benefit of retrofitting over replacing. Other benefits include extending the service life of the original system, which extends the use of the embodied energy from the production and installation of the original system.

The benefits of retrofitting an existing curtainwall system generally align with the disadvantages of replacing the existing system. Because most historic curtainwall systems were customized, matching the appearance with an off-the-shelf system is impractical. The use of custom snap caps is one option a designer must mimic the appearance of an existing system. Whether such an approach will be accepted by preservation authorities is situationally dependent.

The relative thermal benefits of retrofitting and replacement are variable. Whereas the thermal performance of a readily available replacement system is well established, the thermal improvements of the retrofit option will depend on the original conditions and the retrofit design.

Thermal Modeling

To understand possible improvements of thermal performance of the two options as compared with the existing curtainwall system at the subject building, thermal model simulations of the existing base case, the retrofit option, and the replacement option were conducted. Four cases were modeled. The base case models the existing frame and glazing configuration. Case 2 models the existing framing system with a more thermally efficient IGU. Case 3 models the retrofitted existing frame system, and Case 4 models a replacement system. Given the age of the existing glazing system, replacement of existing IGUs is assumed.

Method

A two-dimensional thermal analysis of the different options was performed using WINDOW 7.7.10 and THERM 7.7.10 two-dimensional conduction heat-transfer analysis software programs created by the Lawrence Berkeley National Laboratory of the University of California. A typical curtainwall section (curtainwall intermediate rails and vertical mullion details) was modeled in THERM for each option. The thermal performance for each option was calculated using a weighted area method, in accordance with the National Fenestration Rating Council's *Procedure for Determining Fenestration Product U-values* (ANSI/NFRC 100-2017).[3] Areas and U-values were calculated for the frames, edge of glazing, and center of glazing to determine an effective U-value for each case.

Assumptions

The modeling assumed interior and exterior temperatures of 21°C and –18°C in accordance with simulation conditions in ANSI/NFRC 100. A single, fixed vision unit within the curtainwall, measuring 1200 mm wide and 1500 mm high, was modeled for each option. Where possible, typical material properties were used from THERM's standard database of material thermal conductivities. **Table 1** summarizes the thermal conductivities of the materials used. Refer to **Table 2** for IGU configurations used in the modeling.

The glazing was constant for cases 2, 3, and 4, and differences in thermal conductance of the system were assumed to be limited to the frame.

Results

Table 3 summarizes the obtained effective U-factors (*R*-values) for each case.

Case 4 (replacement option) yielded the lowest effective U-value of cases 2 through 4. This result can be attributed to the incorporation of a conventional thermal break, rather than a thermal separator. In case 4, the heat flow through the curtainwall frame is restricted directly by a thermal break in the frames. Additionally, this thermal break is aligned with the plane of the IGU to ensure that there are only limited heat-flow paths to bypass the thermal

TABLE 1. Thermal conductivities of materials used

Material	Thermal conductivity (W/mK)
Aluminum frames (oxidized, mill finish)	160
Existing aluminum stops	160
Stainless steel	17
Polyvinyl chloride thermal spacer/anti-rotation block	0.17
Gaskets and glazing tape	0.35
Retrofit polyamide thermal break	0.3
Aerogel blanket insulation	0.02

TABLE 2. Insulating glazing unit (IGU) configurations used in modeling

Base case IGU configuration	IGU configuration for cases 2–4
6.35-mm exterior glass lite	6.35-mm exterior glass lite, with low-E coating on surface no. 2
12.7-mm air gap	12.7-mm gap filled with 90% argon/10% air
6.35-mm interior glass lite	6.35-mm interior glass lite
Stainless steel spacer with polyisobutylene primary seal and silicone secondary seal	Warm edge nonmetallic spacer
Center of glass U-value: 2.67 W/m²K	Center of glass U-value: 1.41 W/m²K

TABLE 3. Effective U-Values

	Base case	Case 2: New insulating glass units in existing frames	Case 3: Option 1 (retrofit existing system)	Case 4: Option 2 (replace existing system)
U-value W/m²K (*R*-value)	3.80 (*R* 1.5)	2.73 (*R* 2.08)	2.42 (*R* 2.35)	1.93 (*R* 2.94)
Centre of Glass U-value in W/m²K (*R*-value)	2.67 (*R* 2.13)	1.41 (*R* 4.02)	1.41 (*R* 4.02)	1.41 (*R* 4.02)
Reduction of Centre of Glass *R*-value	30%	49%	42%	27%

TABLE 4. Estimated embodied energy of a replacement frame

Density of aluminum, kg/m³	Energy density of aluminum mullion, MJ/kg	Estimated sectional area of mullion, m²	Embodied energy, MJ/m
2710	200	1.21×10^{-3}	656

break or IGUs. In case 3 (retrofit option), the existing mullion extends well beyond the plane of the glass. Because the exterior cover cap generally approaches and remains the same temperature as the exterior air, the effectiveness of the thermal separator is limited by the thickness of the thermal spacer of the system, not by its length as would be the case with a thermal break.

The reduction of COG *R*-value results in **Table 2** also illustrates the gradual increase in thermal efficiency of the aluminum frames used in cases 2, 3, and 4. In this scenario, the reductions in COG *R*-value for cases 2 and 3 are similar, and significantly higher than the reduction for case 4. This finding suggests that the inefficiencies in the existing curtainwall framing have an impact on the potential effectiveness of a retrofit.

Energy Cost-Benefit Analysis

Considering modeled conductance of the curtainwall systems, we have determined that the replacement option outperforms the retrofit option. Therefore, replacing the existing framing system with a new framing system would most substantially reduce energy flow across the wall assembly.

Major costs associated with replacing the framing system waste and energy during disposal of the original system, effort to install a replacement system (which may include significant anchorage modifications), and the embodied energy of the new system. Glazing is not considered in this analysis as it is held constant across frame options.

Embodied Energy of the Replacement Frame Option

The total embodied energy of an aluminum mullion typically used in curtainwall applications can be estimated to be approximately 200 MJ/kg.[1,4] This estimate is from "cradle to gate": it accounts for total energy used for raw supply and during production of the mullion, but it ignores energy used in delivery and installation. Given the sectional area of the mullion in question (ignoring the polyamide thermal break), one can calculate the embodied energy of a unit length of the mullion. **Table 4** shows the values used to estimate the embodied energy of the replacement option, which is approximately 656 MJ/m.

Energy Benefit of the Replacement Frame Option

The energy benefit of moving to the new frame option can be described by the improvement in modeled conductance, *ΔU,* which is defined as

TABLE 5. Energy savings based on service life

Assumed service life, years	Energy savings of replacement frames versus replacement frames, MJ	Difference between energy savings and embodied energy, MJ
10	702	46
20	1404	748
30	2106	1450
40	2807	2152
50	3509	2854

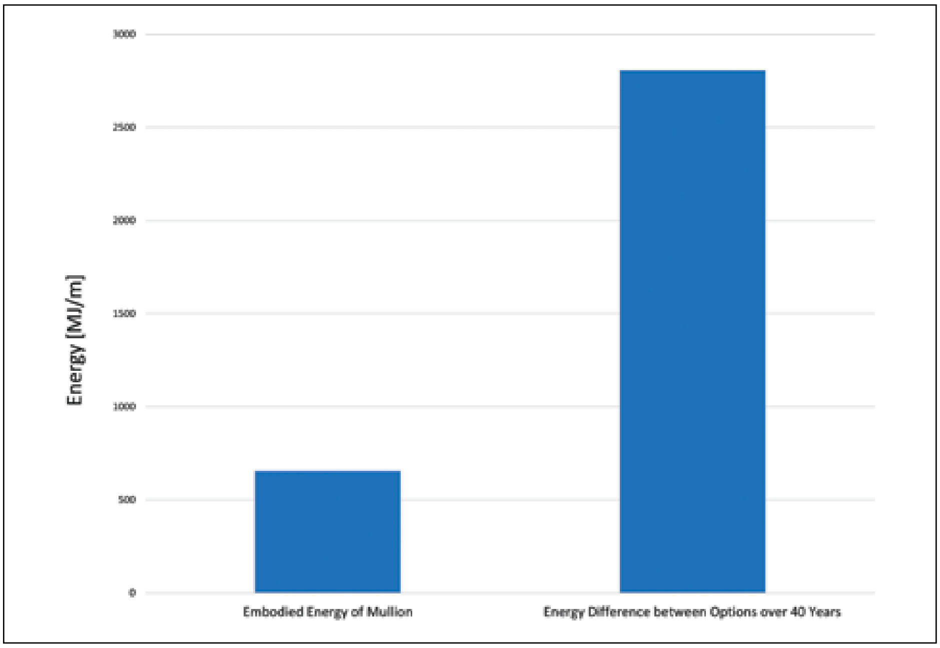

Figure 4. *Comparison of energy between retrofit and replacement curtainwall systems.*

the difference in conductance (U-value) between the retrofit option and the replacement option:

$$\Delta U = U_{Retrofit} - U_{Replacement} \quad (1)$$

To determine the difference in heat flow across a unit area of retrofit and replacement curtainwall systems considered over time, the Toronto Canadian Weather Year for Energy Calculation (CWEC) data file[5] was used. First, the difference in heat flow, ΔQ, between the two curtainwall systems was calculated by multiplying ΔU by the average change in temperature, ΔT (Kelvin), during a given time period:

$$\Delta Q = \Delta U \times \Delta T \quad (2)$$

Multiplying by a given time period gives the heat flow over the time period. In the CWEC data file, average outdoor temperatures are given over an hour for one year. Summing the incremental heat energy flow for each hour period over a year gives the difference in energy flow over a year between the retrofit option and the replacement option.

Using this procedure, it was determined that the heat flow through the retrofit curtainwall system was approximately 210 MJ/m^2 more than the replacement system given the assumed constant internal design temperature of 20°C. As there were 3 m. of frame per square meter of glazing in the models, we can assume that the difference in energy flow between the retrofit frame and the replacement frame is 70 MJ per meter of frame per year. **Table 5** shows the cumulative savings over assumed useful lifespans of the curtainwall.

Comparison of Embodied Energy of Replacement Frame to Benefit of Replacement Frame

The breakeven time frame for the incremental energy benefit in this analysis is approximately 9.4 years. That is the point where the estimated embodied energy for a unit length of replacement section is equal to the energy saved by using that section instead of the retrofit option. Comparing the embodied energy per meter to the energy benefit of replacement frames, we see that there is a net energy benefit to replacing the frames if the replacement framing system lasts at least 9.4 years. Based on the difference in U-values between the retrofit and the replacement options, it is clear from the energy cost-benefit analysis that replacing the frames is a better long-term option than retrofit for the situation analyzed when considering energy use. Refer to **Fig. 4** that shows energy savings of the replacement system over 40 years compared to embodied energy of the replacement system.

Discussion

For the curtainwall system in this case study, the cost-benefit analysis takes into account the net energy benefit of retrofitting or replacing the framing system as well as the costs of embodied energy of the new framing system. It was determined that with an estimated 40- to 50-year lifespan for the new framing used in the replacement option, energy transfer savings for a replacement system outweigh the embodied energy of the replacement system.

The analysis presented here is for one frame retrofit option for one existing curtainwall. In this case, the constraints of the original system and the mandate to keep the original proportions meant that the thermal performance that can be obtained from an off-the-shelf system could not be matched by the subject retrofit option. In other cases, it may be possible to use the energy cost-benefit analysis method to determine the target value improvement of a retrofit design and iterate with various options and models until targets are achieved. Many older curtainwall sections are highly customized. If retrofitting options are not constrained by heritage geometry requirements, it is likely that substantially improved thermal performance of a retrofit mullion can be achieved by adding more-robust thermal management systems.

Considering the simplified analysis presented herein, the curtainwall assembly should be replaced. However, the analysis ignores some important considerations. In some situations, heritage requirements may dictate that the appearance of the facade cannot be altered. In some cases where strict heritage preservation requirements require that the appearance of the curtainwall must be maintained, the presented analysis suggests that thermal improvement on par with modern systems with efficient thermal breaks may not be possible. In that case, a retrofit method using moisture-tolerant materials with low conductivities is an option that will provide some energy savings.

CHALLENGES WITH RETROFITTING

When using the retrofit approach, it can be difficult to incorporate water penetration management techniques into the system. Thermal separators used in the assembly can impede water drainage. Additionally, moisture-tolerant materials must be used if drainage is desired. Geometry can restrict airflow and air pressures within a mullion that would help cavities drain. Alternatively, a face-sealed approach to the retrofit can be considered. In this manner, all glass-to-metal and metal-to-metal interfaces at the exterior of the framing would need to be sealed with an ultraviolet-stable sealant. The long-term effectiveness of the approach partially depends on the scale of the project. The exposed supplementary seals become a maintenance item of the curtainwall system since the service life of the seals exposed to weather will be shorter than the service lives of the frame and glazing components. Replacement options that use readily available glazing systems with proven test data remove the uncertainties associated with a face-sealed approach.

ANALYSIS OF OTHER ASSEMBLIES

The analysis presented herein can be applied to any glazing system and is not limited to the retrofit of existing curtainwall systems. Window wall systems are candidates for frame rehabilitation, and the typical mullion profile and interior glazing method make it relatively easy to achieve water management of these systems.

LIMITATIONS

There are several limitations to the analysis. The materials chosen were from generic databases. The analysis looks at the situation purely from an energy perspective and ignores monetary cost comparisons between the options. Assumptions were made to isolate the contribution of the frames to the difference in conductance for the various cases. While the glazing system is held constant, the interaction between glazing and relative conductance of the frames was not explored by varying the glazing configuration. Embodied energy is simplified into production of a new aluminum section and ignores waste associated with removing the existing system.

WHEN SHOULD RETROFIT BE CONSIDERED?

Given the original frame configuration, it would be difficult to achieve improved energy performance while maintaining the original appearance of the curtainwall system. A combination of factors led to this conclusion, including the original configuration of the curtainwall frame and glazing. It is likely that retrofits will be more attractive if all of the following are true:

- Boundary conditions make replacement very costly or impractical.
- Heritage requirements dictate the appearance of the facade cannot be altered.
- Existing geometry is such that robust thermal breaks/separators can be added.

CONCLUSION

When considering thermal improvement options for existing glazing systems, it is important to take into account the embodied energy of a new system as well as differences in system heat energy conductance values for the various options under consideration. In the situation presented in this case study, an energy cost-benefit analysis indicated that the retrofit design was not the preferred option. Only one iteration of the design was analyzed; other retrofit designs that are more thermally efficient could be possible. Clear challenges exist when the thermal retrofit designer is faced with heritage preservation requirements with respect to historic glazing systems.

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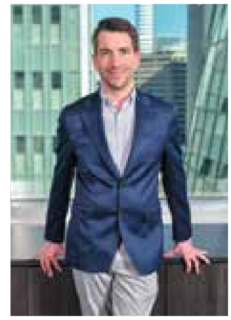

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