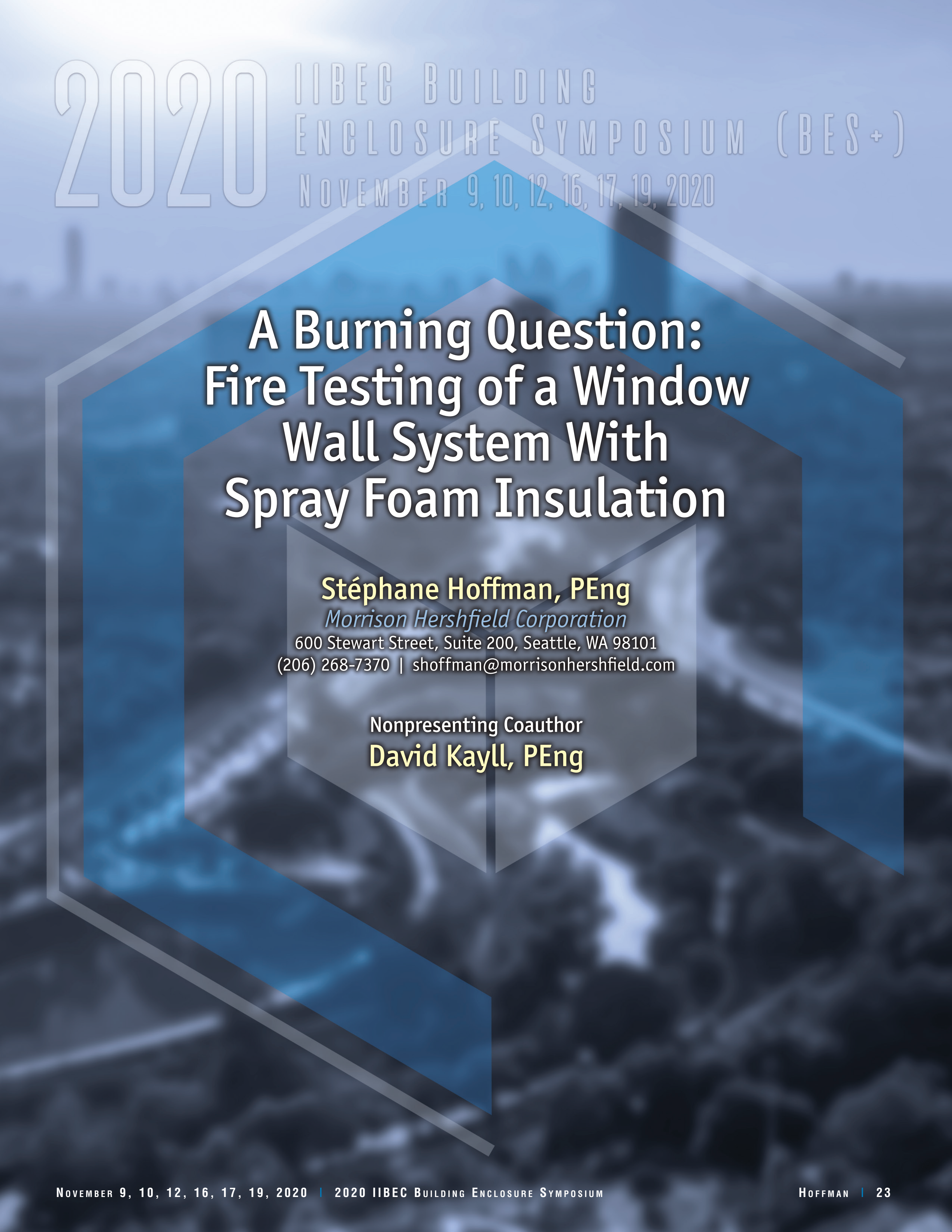

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A Burning Question: Fire Testing of a Window Wall System With Spray Foam Insulation

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ABSTRACT

Window wall assemblies are a popular exterior wall assembly for high-rise residential apartment buildings. These systems are economical because of efficiencies of factory assembly and rapid installation on site. With the exception of components deemed "minor"—including thermal breaks in the aluminum frames, sealants, etc.—window wall assemblies are considered non-combustible and, therefore, compliant with building code requirements to limit the vertical spread of fire. The thermal performance of window wall systems is relatively weak, limited by thermal bridging through the frames. Thermal performance can be increased with two-component, closed-cell polyurethane foam insulation spray-applied directly to the spandrels. However, the insulation is combustible and too large to be considered a minor component; so, the entire assembly is often considered to be combustible. This presentation describes full-scale fire exposure tests under CAN/ULC-S134, the equivalent to NFPA 285. The outcomes are used to assess if such walls are combustible. The paper will also consider if the test results can be applied to other window wall assemblies and to assess compliance with building codes in the United States, where Canadian window wall systems are often used.

SPEAKER

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With a master's-degree-level education that combines structural engineering, building science, and architecture, Stéphane Hoffman brings a well-balanced consulting approach to the building enclosure, blending scientific analysis with an understanding of aesthetics considerations. He is particularly adept at providing innovative design concepts and construction alternatives that provide value by improving durability and increasing energy efficiency. As a key technical leader at Morrison Hershfield, Hoffman has worked on projects throughout North America. He leads the company's Building Science Analytics Group, combining façade engineering, energy modeling, and enclosure component modeling to assist teams in designing high-performance buildings.

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INTRODUCTION

The use of foam insulation as part of building enclosures has received increased scrutiny in recent years, and numerous enclosure assemblies have been successfully tested to CAN/ULC S134[1] or its U.S. counterpart, NFPA 285.[2] However, most of these assembly-specific tests have been performed on stud-wall assemblies. The following paper outlines the results of testing spray-foam insulation inboard of a unitized glazing system and demonstrates that these assemblies can also meet the requirements of these standards.

BACKGROUND

In recent decades, the use of unitized glazing systems has become increasingly common—especially for high-rise construction. The improved quality from off-site assembly of these manufactured systems, along with their ease of installation and advantage in terms of shortened onsite construction schedules, continues to drive the trend toward modular construction. The opaque panels in unitized glazing systems have traditionally been insulated with mineral-wool insulation installed within the aluminum frame behind a glazed spandrel, a metal panel, or some other opaque cladding. The interior face of the mineral wool is typically flush with the interior frame and finished with a foil facer or a galvanized sheet-metal back pan.

Increasing code requirements for energy efficiency of opaque wall assemblies has led to the common practice of providing an additional layer of insulation inboard of the unitized glazing system. A recent study by Neil et al.[3] has shown the impact of the thermal bridging through the aluminum framing and, especially, the continuous vertical mullions on the effectiveness of the insulation within spandrel assemblies. While another paper by Hoffman[4] based on the results of 3-D thermal modeling for the *Building Envelope Thermal Bridging Guide*[5] has outlined the limited thermal improvement of insulating inboard of unitized glazing systems, the practice remains common and for some systems still provides an improvement over insulation only within the spandrel assembly.

In colder climates, however, the practice of insulating inboard of the unitized glazing systems raises the concern of condensation on the surfaces of the glazing system now shielded from exposure to the interior heat source. This risk is further increased if the assembly inboard of the unitized glazing system is not airtight and the interior insulation is not in continuous intimate contact with the interior face of the unitized glazing system. The increased risk of condensation is especially elevated in residential buildings, with their higher levels of interior humidity, limited ventilation, and, increasingly, a lack of perimeter heating.

WHY SPRAY-FOAM INSULATION?

The application of spray foam on the inboard face of glazing systems has been used in recent years as one means of mitigating the risk of condensation. The spray-foam insulation easily conforms to the irregular surfaces of the unitized glazing system, forming a monolithic, airtight, and vapor-resistant insulation layer, significantly reducing the potential that interior air could come into contact with the colder surfaces of the unitized glazing system. It also has the secondary benefit of providing improved acoustical performance. While the foam insulation is typically separated from the interior by an appropriate layer of gypsum sheathing, concerns of fire propagation have been raised about its performance in the event of a fire that breaches the glazing and leaps up the exterior of the building. In theory, the mineral wool insulation in the spandrel assembly should provide adequate protection from the flames on the exterior of the building. However, the fact that the aluminum framing interrupts the mineral wool insulation has been raised as a point of concern. This led to testing of a unitized window wall with spray-foam insulation outlined below for a recent high-rise residential tower in Canada to CAN/ULC-S134, *Standard Method of Fire Test of Exterior Wall Assemblies*.

Under Canadian codes, the use of combustible components, such as foam insulation, in buildings required to be of non-combustible construction, is permitted where the building is sprinklered and the assembly meets the requirement of CAN/ULC-S134 on the basis that the materials are deemed to insignificantly contribute to fire growth and spread.

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CAN/ULC S134 VS NFPA 285

Both CAN/ULC-S134, *Standard Method of Fire Test of Exterior Wall Assemblies*, and NFPA 285, *Standard Fire Test Method for Evaluation of Fire Propagation Characteristics of Exterior Wall Assemblies Containing Combustible Components*, provide a measure of how an exterior wall assembly performs when exposed to a window fire plume under post-flashover fire conditions; however, the test apparatus, fire exposure, and acceptance criteria are significantly different.

The stated intent of CAN/ULC-S134 is to determine the comparative burning characteristics of exterior wall assemblies by evaluating the following: a) fire spread over the exterior surface; b) heat flow from the fire plume to the exterior surface; and c) fire spread within the test specimen.

The CAN/ULC-S134 test standard utilizes a three-story concrete block backup wall (minimum 6 m by 10 m) with a large window opening (nominally 2.5 m by 1.4 m) centered at the ceiling of an adjacent burn chamber, with gas pipe burners distributed symmetrically throughout the chamber no higher than halfway between the floor and the bottom sill of the window opening. In CAN/ULC-S134, the gas-flow rate is linearly ramped up for 5 minutes, held at a steady state (nominally 120 g/s calibrated to achieve a specified heat flux) for 15 minutes, and then linearly decreased for a 5-minute period to 0. Flame height is observed, and heat flux measurements at 3.5 m above the window opening are observed for up to 1 hour from the start of the test.

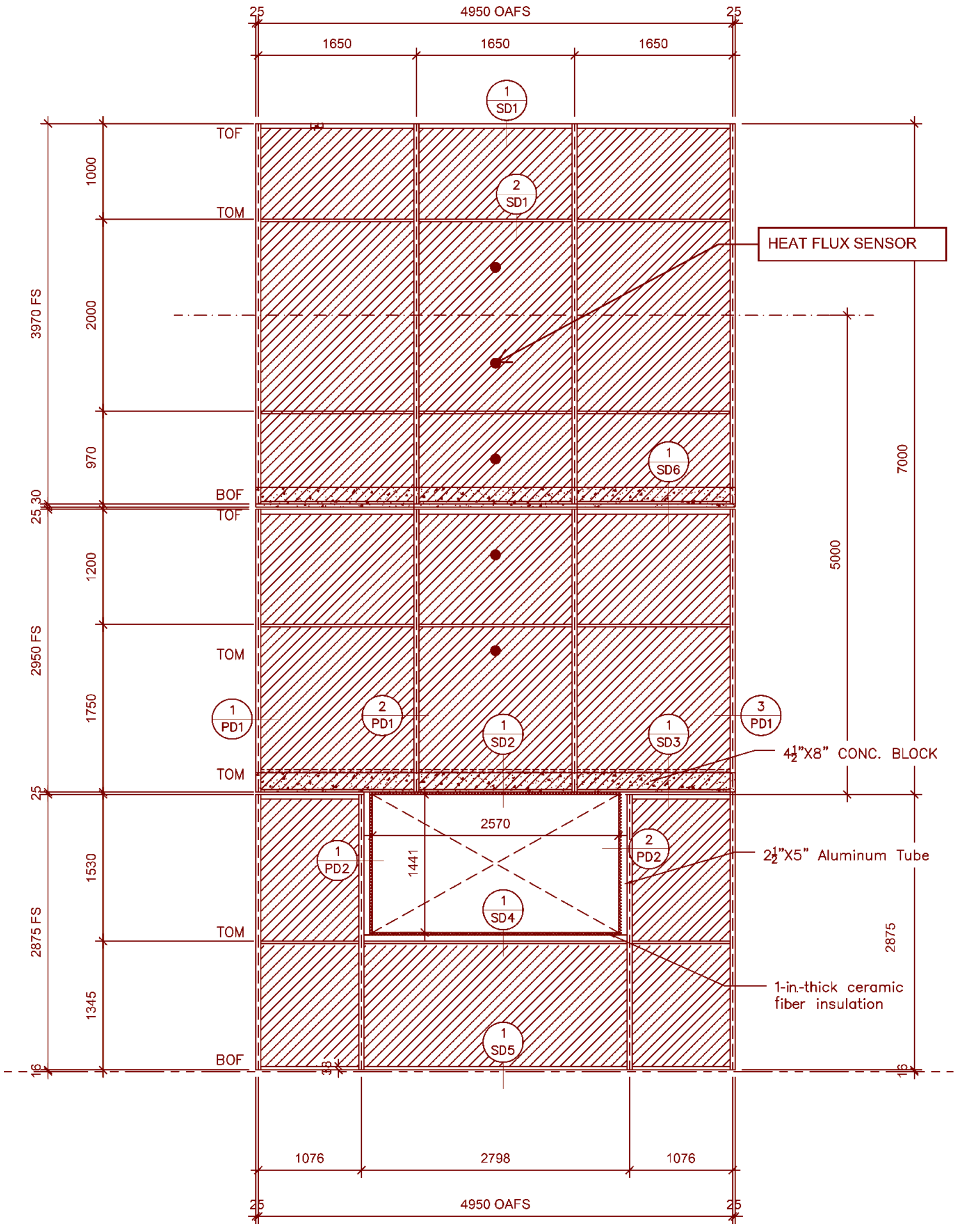

Figure 1 – Configuration of window-wall panels.[8]

A wall assembly successfully passes the CAN/ULC-S134 test if the visible flaming above the window opening is not more than 5 m and the average heat flux measured at 3.5 m above the window opening is not more than 35 kW/m^2 for the duration of the test.

NFPA 285, *Standard Fire Test Method for Evaluation of Fire Propagation Characteristics of Exterior Wall Assemblies Containing Combustible Components*, evaluates the ability of exterior wall assemblies with combustible components to resist flame spread over the exterior face of the assembly, within the assembly, and at the interior surface of the curtainwall assembly to the next story, and the ability to resist lateral flame spread to adjacent compartments.

The NFPA 285 test standard utilizes a two-story test apparatus (with stacked rooms) to measure the performance of a test specimen 4.1 m wide by 5.3 m tall, with a window opening of 1.98 m by 0.76 m adjacent to the lower room. Two gas pipe burners are used in the NFPA 285 test: One is located centrally within the lower test room approximately 0.8 m from the floor, and the second burner is placed near the top edge of the window opening outside the test room. In NFPA 285, prescribed gas-flow rates for natural gas step up at five-minute intervals up to 30 minutes. Prescribed gas-flow rates for natural gas step up at five-minute intervals up to 30 minutes into the test for both the room and window burners, at which time the gas supply is shut off and observations are stopped. Flame propagation and temperature measurements are observed for the duration of the 30-minute test.

Like CAN/ULC-S134, acceptance criteria for NFPA 285 includes conditions for visual flaming (not greater than 3.05 m above the window opening or 1.52 m horizontally from the center line of the window opening). NFPA 285 does not consider heat flux as a performance measure, but considers temperature rise instead. Acceptance criteria related to temperature conditions at the external face, interior combustible components, air cavity, and within the second-story test room must be satisfied in order to pass the NFPA 285 test.

Given the variations between test apparatus, fire exposure, temperature, and

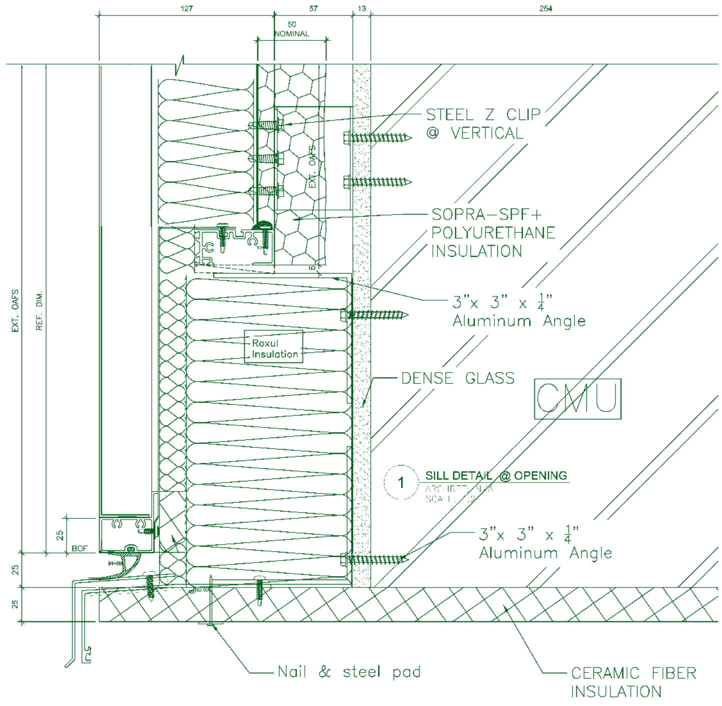

Figure 2 – Window-wall detail at head of window opening.[8]

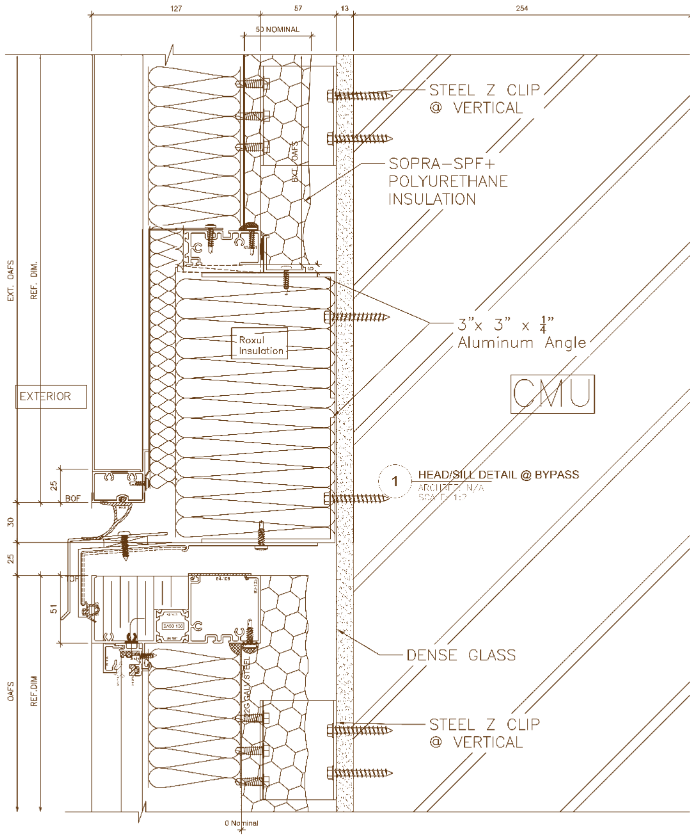

Figure 3 – Window-wall detail at simulated slab edge at horizontal joint.[8]

heat flux measurements, it is not possible to directly compare the results of the two tests. Both temperature and heat flux are indicators of the contribution of combustible components to flame spread, and it is reasonable that similar trends may be observed between the two tests with respect to flame spread at the exterior surface.

WINDOW-WALL ASSEMBLY DESCRIPTION

Window walls are different from curtainwalls in that they bear on the slab edge rather than being hung outboard of the slab edge like a traditional curtainwall system. The evolution of these traditionally residential systems is described in further detail in a paper by Torok et al.[6]

The as-built system documented in the test report[7] is summarized here. The system tested consisted of an aluminum-framed, center-glazed window wall. The aluminum mullions have a polyamide thermal break in line with the glazing. The outer half of the vertical mullions extends to provide an integral slab band cover. A horizontal deflection header is installed at the underside of the slab. The window wall sections are glazed with 0.080-in.-thick painted aluminum panels. Inboard of the aluminum panels there is 75 mm of mineral-wool insulation and a 22-ga galvanized-steel back pan. Inboard of the metal back pan, a 50-mm-thick layer of medium-density urethane spray foam was applied and covered with a layer of gypsum sheathing. The exterior joints between the window-wall panels at the vertical mullions were bedded with a silicone sealant.

CHALLENGES OF TESTING A UNITIZED GLAZING SYSTEM

When it came to undertaking CAN/ULC S134 testing of the unitized window system, there were a few challenges to overcome. The first had to do with the configuration of the panels around the specified window opening in the backup wall. The proposed assembly represented three floors of window wall panels (*Figure 1*). The first floor included the prescribed window opening flanked by two full-height panels. No vertical mullions extended through the window opening, nor was a horizontal mullion installed at the window head, but the slab-mounted deflection header was applied continuously across the window opening. The interior part of the deflection header was omitted due to lack of access. The two floors of panels above the window opening were broken up into three equal-width panels. As a result, the single vertical joint as required in CAN/ULC S134 was substituted for two joints approximately 825 mm to the left and right inside dimensions of the window opening. This was deemed to better represent the typical width of panels in window wall construction.

The other issues arose from the nature of the test facilities available. The few facilities available in North America have been built primarily with the intent of testing exterior-applied assemblies. Accordingly, the test facilities commonly have a non-combustible backup wall with the specified window opening to which the assemblies are installed. This was problematic because the window-wall assembly is typically installed from the interior bearing on the slab edge at the floor and is secure in a deflection header at the slab above. Furthermore, the spray-foam insulation is typically applied to the interior surface of the window-wall system after erection.

To simulate the slab edge at the typical bypass detail, mineral wool insulation was installed in lieu of concrete (*Figures 2* and *3*). The bituminous self-adhered membrane flashing typically installed at the slab band as part of the waterproofing of the system at the sill was omitted for this test. This detail was applied in two locations: directly above the window opening and 3 m above the window opening. This allowed the window wall to be supported on the backup

Figure 4 – Apex of burn pattern above window opening.

Figure 5 – Exposed mineral-wool insulation above window opening.

wall while simulating the projection of the non-combustive slab edge.

The dead weight of the window wall panels was supported on a metal bracket above the simulated slab edge. Lateral loads were accommodated using L-angle clips secured through the vertical mullions. The traditional strap anchors at the deflection header were installed, but in the absence of a concrete-slab band, were not considered adequate to restrain the panels. While the use of the additional lateral clips differed from typical installations, it is in keeping with how these window wall systems are installed when they bypass a shear wall. Since the primary purpose of the test is to assess the combustibility of the foam insulation, this was deemed by all parties to the testing to be an acceptable compromise.

Lastly, since the inside face of the window wall panels would not be accessible once they were erected on the backup wall, the spray foam had to be installed on the back side of the panels before they were erected. This led to a gap, typically less than 12 mm, in the spray-foam insulation at the vertical mullions between panels. Given that this gap could provide a channel for the propagation of the flames, it was determined that this gap would represent a more stringent test condition.

INSTRUMENTATION

The instrumentation documented in the test report[7] is summarized here. Three water-cooled heat-flow transducers were installed 3.5 m above the top of the window opening: one within 0.2 m +/- 0.05 m horizontally of the centerline of the opening and the other two within 0.5 +/- 0.1 m horizontally from the first. The transducers were installed with their sensor flush with the outer face of the test assembly. In addition, thermocouples were used to monitor the temperature of the test assembly. The thermocouples were located above the opening, approximately 89 mm to the right of the vertical center line at the following intervals: 1.5 m, 2.5 m, 3.5 m, 4.5 m, and 5.5 m. At each of these locations, thermocouples were placed at the outermost surface of the test assembly—one on the outer face of each representative layer within the test assembly, and one on the base wall surface. The data acquisition system was programmed to take a reading every five seconds during the testing.

FINDINGS

Testing was performed in accordance with the CAN/ULC-S134 test method. Once ambient conditions were met, the burners were ignited. Per the specified method, a 5-minute flame-growth period was followed by a 15-minute steady-state period and then a 5-minute ramp-down period.

The observations documented in the test report[7] are summarized here. The ramp-up period was started, and within three minutes, the flames were reaching outside of the burn room. By the end of the ramp up, the deflection header was starting to buckle. Within the first 30 seconds of the steady-state period, heavy smoke was visible. At the one-minute mark, there was no visibility above 4 m, and within 2.5 minutes, there was no visibility down to 2 m. At 3.5 minutes into the test, the buckling of the window header was more pronounced, but it remained attached. By the 6.5-minute mark, flaming was visible at the center panel and left joint above the window opening. At the 8-minute mark, flaming was visible at both vertical joints above the window opening. Pieces of the metal panel started falling off after 9.5 minutes. Just before the 10-minute mark, a large piece of material from the center exterior metal panel fell off. After the 15-minute steady-burn period, panel base flaming decreased. Three minutes into the ramp-down period, flaming was still visible at the top left section above the window opening. At the end of the ramp-down period, small flaming continued. All flames self-extinguished within 45 minutes after the start of the test.

Following the test, a cone-shaped pattern was visible on the exterior metal panels. The apex of this pattern extended 2.5 m above the window opening (*Figure 4*). The metal skin of the exterior metal panel had fallen off, exposing the mineral-wool insulation to a height of 1.4 m (*Figure 5*) above the window opening. The slab-mounted deflection header at the opening was approximately 90% consumed. The top row of exterior metal panels showed only smoke damage and slight warping of the exterior metal panels. The window wall panels were then dismantled and observed for signs of damage. The top row of window wall panels showed no damage to the spray foam layer. The next row of window wall panels immediately above the window opening showed damage. The exterior metal panels on either side of the opening showed signs of smoke damage and warping. There was some sign of charring of the spray-foam insulation at the vertical window-wall panel joint, and the aluminum vertical mullion was also damaged (*Figure 6*). The center panel was more damaged. The exterior metal skin was melted to a height of 1.4 m. Approximately half the thickness of the spray-foam insulation remained. There was also damage to the vertical mullion. After removal of the panels, the gypsum boards were reviewed and found to have no sign of damage.

The maximum flame spread above the window opening was 3 m. Based on the measurements, the maximum average heat flux was determined per the standard to be 20.1 kW/m², which occurred 18.7 minutes into the fire test. Based on these two findings, the assembly met the conditions of acceptance outlined in CAN/ULC-S134.

Figure 6 – View of localized charring of spray foam at vertical above-window opening.

CONCLUSION

The results of this test demonstrate that, despite some challenges in adapting the erection of the window wall assembly to accommodate the requirements of standards and the nature of the test facility, spray-foam insulation applied to the interior face of a residential window wall system with an exterior aluminum spandrel panel and a metal back pan insulated with mineral wool can comply with the requirements of CAN/ULC-S134. The nature of this standard is that it is assembly-specific and any significant changes of materials or dimensions would require its own testing.

The biggest variable is the configuration of the window-wall frames that can vary significantly from manufacturer to manufacturer, as do the specific details at the deflection header and the slab bypass. In particular, window-wall systems which bear on the slab edge are different from curtainwall systems that are hung outboard of the slab edge with fire staffing and a smoke seal between the slab and the spandrel panel. While the result of the window-wall test can provide insight on the potential performance of curtainwalls with spray-foam insulation, further testing will be required to demonstrate performance.

Likewise, while the variations outlined between CAN/ULC-S134 and NFPA 285 do not allow for a direct correlation of the results, both temperature and heat flux are indicators of the contribution of combustible components to flame spread. Therefore, while a separate test to demonstrate performance to NFPA 285 would be required, it is reasonable to assume that similar trends would be observed with respect to flame spread at the exterior surface and further that the assembly would have a reasonable chance of meeting the temperature rise criteria stipulated by that standard.

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