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Architectural Insulation Modules: Thermal and Structural Performance for Use in Curtainwall Construction

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Abstract

Increasing pressure to upgrade curtainwall thermal performance is occurring globally. The high vision areas and aluminium framing of typical commercial curtainwalls at a thermal disadvantage compared to other construction types. This has resulted in the engineering and design of highly insulating spandrel sections of the curtainwalls to improve on the overall U value of façade while maximizing the architectural desire for large glazing areas.

Architectural Insulation Modules are designed to be highly insulating spandrel sections that replace double glaze and triple glaze assemblies within the curtainwall framing. The modules contain Fumed Silica Vacuum Insulation Panels within the air space between two rigid structural panels such as glass or metal. The separation between the rigid plates is maintained with warm edge insulating glass technology that utilizes primary seals of polyisobutylene, secondary seal technology of structural silicone and moisture absorbing desiccant. Architectural finishes can be placed on the exterior or interior of the assembly to keep the design freedom associated with commercial curtainwall construction.

Thermal performance of 1500mm x 1500mm modules is modelled in both two dimensional and three dimensional models. In addition, the modelling is validated with hot box testing of the modules according to ASTM C1363. Architectural Insulation modules 1500 mm x 1500mm x 50 mm have been shown to achieve total U values of 0.30 (W/m2K)in hot box testing. This can then be further modelled to be placed into curtainwall spandrel areas to achieve a total spandrel U value of 0.39 (W/m2K) including framing. A comparison is made with the 3 dimensional models of typical existing spandrel curtainwall construction in North America, showing reductions in heat flow up to 68% are possible using the architectural insulation modules without extreme changes in design, materials, or engineering.

The architectural insulation modules were then placed into a full size curtainwall and tested. Air Infiltration as tested to ASTM E283 conducted at 300 Pa positive static air pressure difference.

Static Pressure Water Resistance was tested to ASTM E331 at 720 Pa positive static air pressure difference for a 15 minute duration. Water was applied to the mock-up at a minimum rate of 3.4 L/m2 min.

Dynamic Pressure Water Resistance was tested to AAMA 501.1 was conducted with a dynamic pressure equivalent of 720 Pa for a 15 minute duration. Water was applied to the mock-up at a minimum rate of 3.4 L/m2 min.

Structural Performance was tested to ASTM E 330, at positive and negative 2.4 kPa and 150% proofload of 3.6 kPa.

Interstory Lateral and Vertical Differential Movement was tested to AAMA 501.4/ 501.7, respectively. Three complete cycles were performed in the horizontal and vertical direction at the floor simulation. Testing was conducted at movements up to 47mm.

Seismic Movement was tested to AAMA 501.4-09. Testing was conducted at 89mm of interstory drift.

The study concludes that higher performing curtainwalls can be achieved without sacrificing the existing structural, seismic, air infiltration, water infiltration, and aesthetic performance, while meeting increased thermal performance.

1 Introduction

Curtainwalls on high rise buildings are the art and aesthetics associated with modern architecture especially in the iconic buildings in a major city center. The architect has a vision of the building that typically uses a large amount of transparency. This transparency from both the interior and exterior is what gives the building its most recognizable attributes. The façade must be able to look good while maintaining structural integrity of ever increasing windloads, thermal loads, and other performance metrics required by code bodies to ensure the public safety and energy performance of the building. Building codes keep getting more stringent with regards to energy performance and window to wall ratio (WWR) to meet prescriptive requirements.

ASHRAE 90.1-2007 for Climate Zone 5 (Chicago, Detroit, Cleveland, Boston) prescribes a commercial building to have a maximum WWR of 40% and requires that the glazing portion must have an assembly maximum U value of 14.5 W/m²K. The opaque steel framed wall section is prescribed to have an assembly maximum U value of 2.1 W/m²K. When calculating the overall U value of the wall using the area weighting method, it would be (0.4 x 14.5) + (0.6 x 2.1) or U façade = 7.1 W/m²K. This can also be inverted to be the R value of 0.14 m²K/W.

ASHRAE 90.1-2010 for Climate Zone 5 prescribes a commercial building to have a maximum WWR of 40% and requires that the glazing portion must have an assembly maximum U value of 2.8 W/m²K. The opaque steel framed wall section is prescribed to have an assembly maximum U value of 0.36 W/m²K. When calculating the overall U value of the wall in this situation, it would be (0.4 x 2.8) + (0.6 x 0.36) or U façade = 1.3 W/m²K. This can also be inverted to be the R value of 0.75 m²K/W.

This significant change in the prescriptive code has an impact on the assemblies that can be used for to meet the intention of the code.

The 2010 Florida Building Code has a prescriptive requirement of vision area (window) to have a U value of 2.55 W/m²K or less, a maximum of 50% vision area and the opaque wall sections to have a U value of 0.18 W/m²K or less. When calculating the overall U value of the wall in this situation, it would be (0.5 x 2.55) + (0.5 x 0.18) or U façade = 1.37 W/m²K. Overall the façade has the same performance requirement in each code. This can also be inverted to be the R value of 0.73 m²K/W. This simple calculation shows that Florida is willing to embrace 50% glazing and still requiring the same overall thermal performance. This also highlights the relationship that doubling the thermal resistance of the opaque assembly does allow the vision area to increase.

The code will provide for options to trade off assemblies provided the building energy model will show an improvement compared with the base case prescriptive requirements.

Today the curtainwall industry aspires to use 60% or even 70% of glazing due to the architectural drive for transparency. The glazing assemblies of today are able to meet the prescriptive requirements at 40% WWR. However the typical spandrel units of the curtainwall assemblies are not able to meet the prescriptive requirements of the code in the northern climates. This fact in conjunction with the desire for greater than 40% vision area dictates that curtainwall projects of today use the alternative method of compliance. Traditional construction indeed has separate opaque wall sections and vision sections that are easy to decouple. Curtainwalls have opaque (spandrel) sections that are intimately connected to the vision area by sharing an aluminium frame. This connection of spandrel and vision cannot be thermally separated. It is nearly impossible for a curtainwall unit with an aluminium framing system to meet the spirit of the ASHRAE 90.1 requirements, yet the stricter requirements of the Florida Building Code due to the intimate coupling of the vision and spandrel sections.

Again, the performance of the facade must meet the prescriptive structural requirements for the local windloads and seismic aspects. This paper intends to address both the thermal and structural performance aspects of curtainwall facades.

2 Thermal Performance and Modelling

The three dimensional modelling noted below is for a 1520mm x1520mm spandrel assembly in all cases.

Figure 1 shows a rendering of a typical curtainwall stick system using Insulating glass vision and monolithic glass spandrel sections. Today common spandrel sections also can contain double insulating glass, and metal panels, depending on the architectural influence.

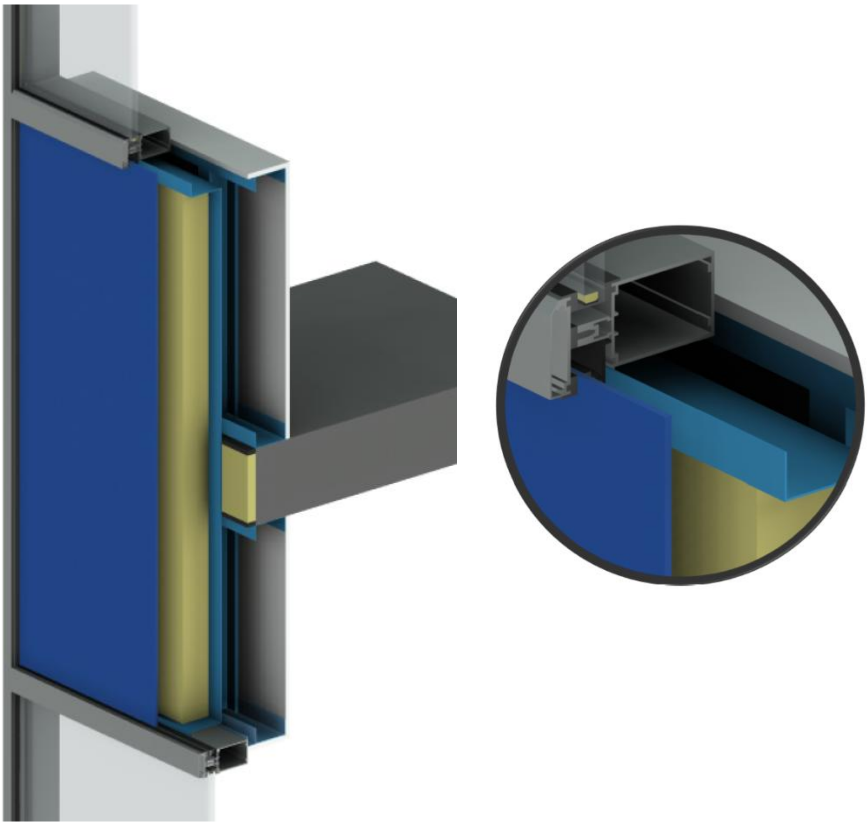

Figure 1. Typical Conventional Stick Curtainwall

This spandrel section uses 100 mm of mineral wool behind the monolithic glazing as insulation and also as a fire stopping material at the edge of the floor slab. The vision area is a double pane insulating glass unit with an aluminium spacer and a center of glass U value of 1.8 W/m²K. Three dimensional thermal modelling of this spandrel system using overall dimensions of 1520mm x1520mm to simulate real world dimensions provides a U value of 1.16 W/m²K or an R value of 0.86 m²K/W. This modelling decouples the vision from the spandrel section and accounts for edge effects and effects in the corners. This calculated thermal performance value is far below the U values suggested by ASHRAE 2010 (Zones 4-8) of 0.36 W/m²K or the 2010 Florida Building Code of 0.18 W/m²K.

Although it would seem quite intuitive and logical to add more insulation to the spandrel cavity the thermal bridging of the frames makes it quite difficult to insulate the way to compliance.

Figure 2 [1] graphically depicts the diminishing rate of return when applying spray foam to the internal stud cavities behind an assembly as shown in figure 1.

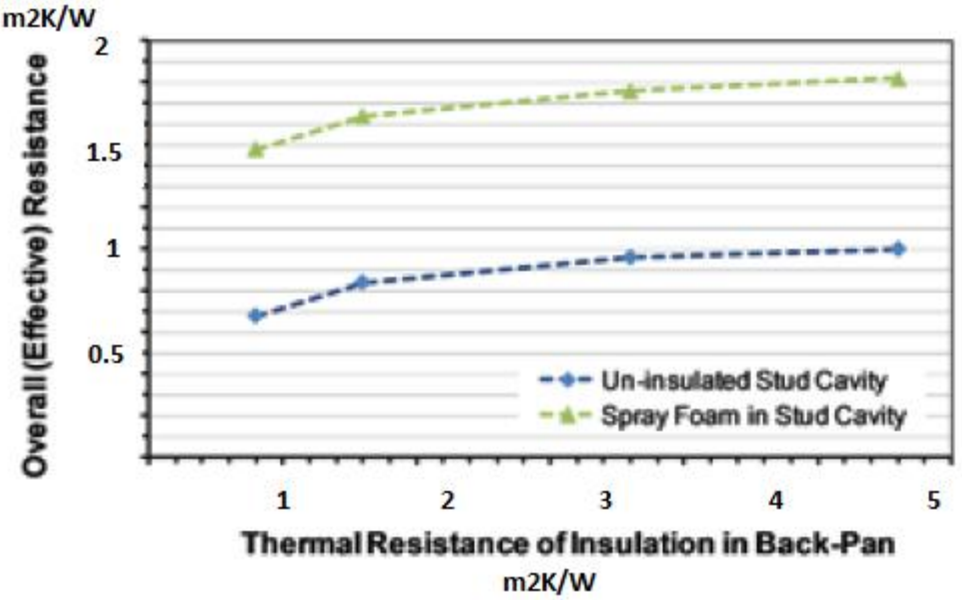

Figure 2 [2]. Diminishing Rate of Return of Spandrel Section with increased insulation

The ASHRAE Research Project 1365 "Thermal Performance of Building Envelope Details for Mid- and High-rise Buildings" has a specific comparison of a conventional curtainwall spandrel with and without spray foam insulation applied in the stud cavities of the internal walls. Lawton and Roppel [2] reported that "adding insulation to the back-pan has a similar diminishing rate of return for both systems since the aluminum structural members bypass the pack-pan for both scenarios." The use of additional insulation in the back of the spandrel is not going to provide drastic improvements. Figure 2 depicts that adding additional nominal value of R 5 m^2K/W of backpan insulation only increased the overall thermal resistance from R 0.6 m^2K/W to R 0.9 m^2K/W.

The increasing depth of back-pan insulation is not going to increase the thermal performance of a spandrel section with the typical aluminium sections used in today's curtainwalls.

A proposed solution to this issue is to use a better performing curtainwall system labelled as High Performance curtainwall. A curtainwall with thermal breaks and a conventional spandrel section is depicted in Figure 3.

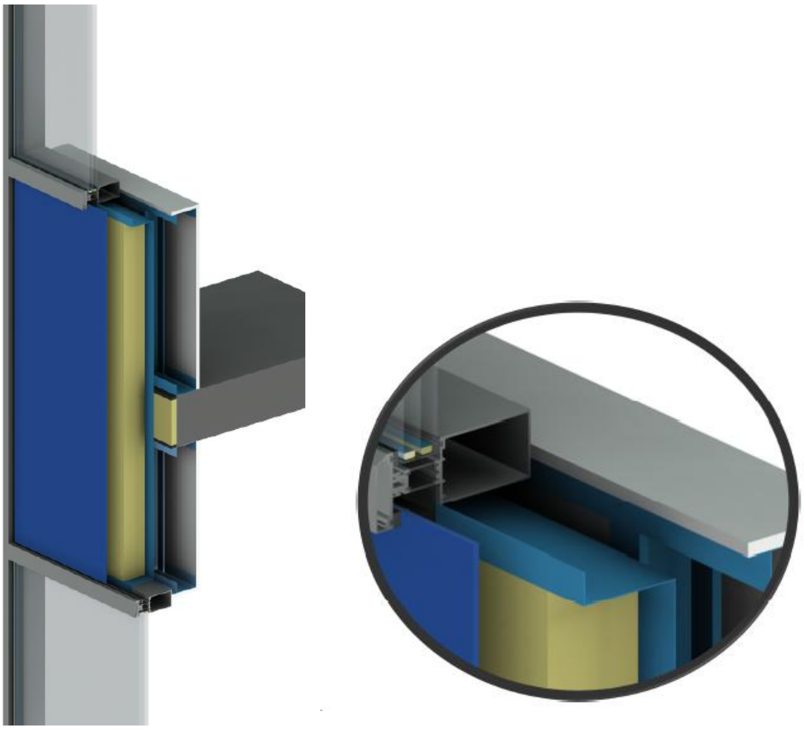

Figure 3. Spandrel section of High Performance Curtainwall

When performing the identical three dimensional thermal modelling to this scenario using an upgraded triple glazed vision assembly with a Center of Glazing U value of 1.0 W/m²K , the spandrel U value is modelled at 0.89 W/m²K or R value of 1.1 m²K /W. The aluminium system improvements have made a 31% improvement in the spandrel performance, but they are still very far from prescriptive requirements.

It has been shown that structural silicone glazing solutions provide increased thermal performance to curtainwalls. [3] This is primarily due to the fact that the structural silicone is a thermal break on the outside of the mullion framing system. It would be logical to apply this concept to improve the performance of conventional spandrels: Use insulation on the exterior of the mullions.

The concept of exterior insulation was modelled and presented at the 2013 Glass Performance Days conference in Tampere Finland in June of 2013.[4] The concept of using Vacuum Insulation Panels (VIP) within a spandrel assembly exterior of the mullions showed that a significant upgrade to thermal performance could be obtained. Modelling was done using Therm 7 software to show the 2 dimensional approach.

Comparisons were made of a double glaze assembly and triple glaze assembly using mineral wool as the spandrel insulation, using metal clad VIP, and using metal clad VIP in conjunction with mineral wool (to provide extra fire resistance). Schematic Details of this modelling exercise are captured in Figures 4-6. The models show a significant upgrade for condensation resistance with the increased interior temperatures. Increase interior frame temperatures allow increased humidity without fear of condensation in high performance medical facilities and offices in the northern climates. The models show decreasing U values that are outlined in Table 1.

Table 1. Spandrel Thermal Performance values of the three systems using 2 dimensional modelling of a 1830mm x 2430mm spandrel assembly

Spandrel System	100mm Mineral Wool	VIP	VIP with 100mm Mineral Wool
U value W/m²K	0.68	0.32	0.23
R Value m²K /W	1.47	3.1	4.3

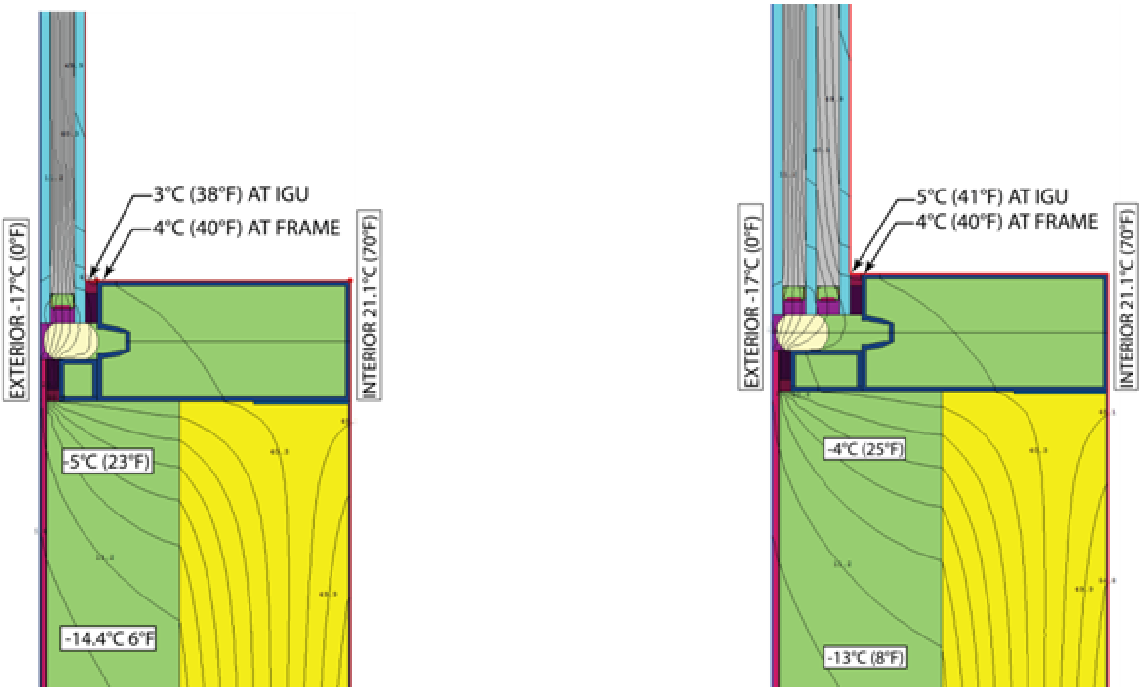

Figure 4. Double and Triple glazing in conventional curtainwall application using mineral wool

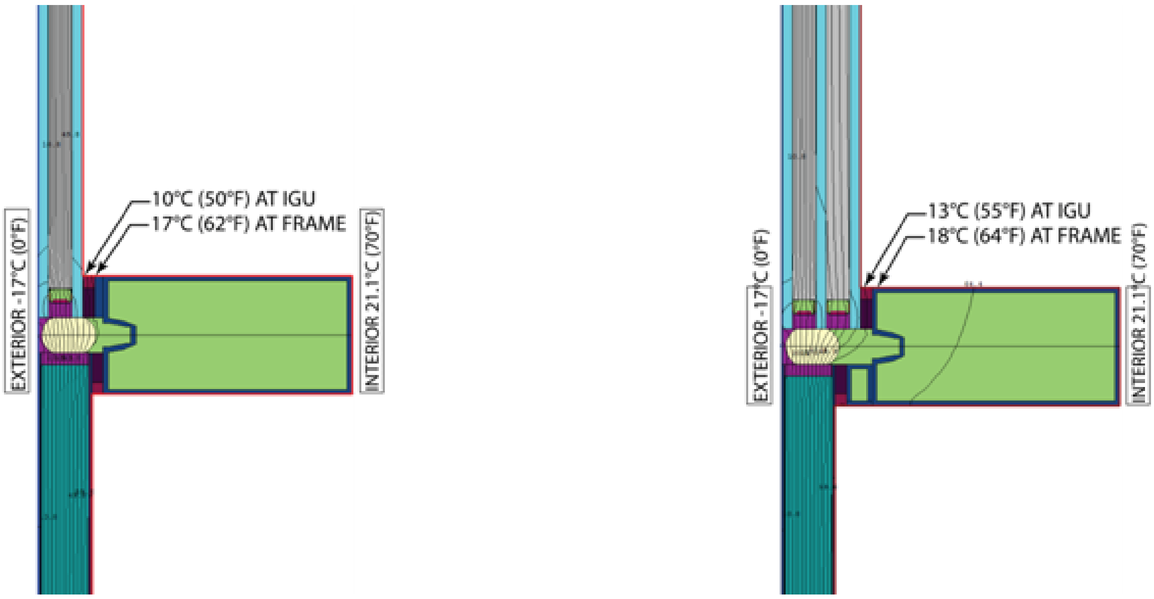

Figure 5. Double and Triple glazing using metal clad VIP's as the spandrel panels

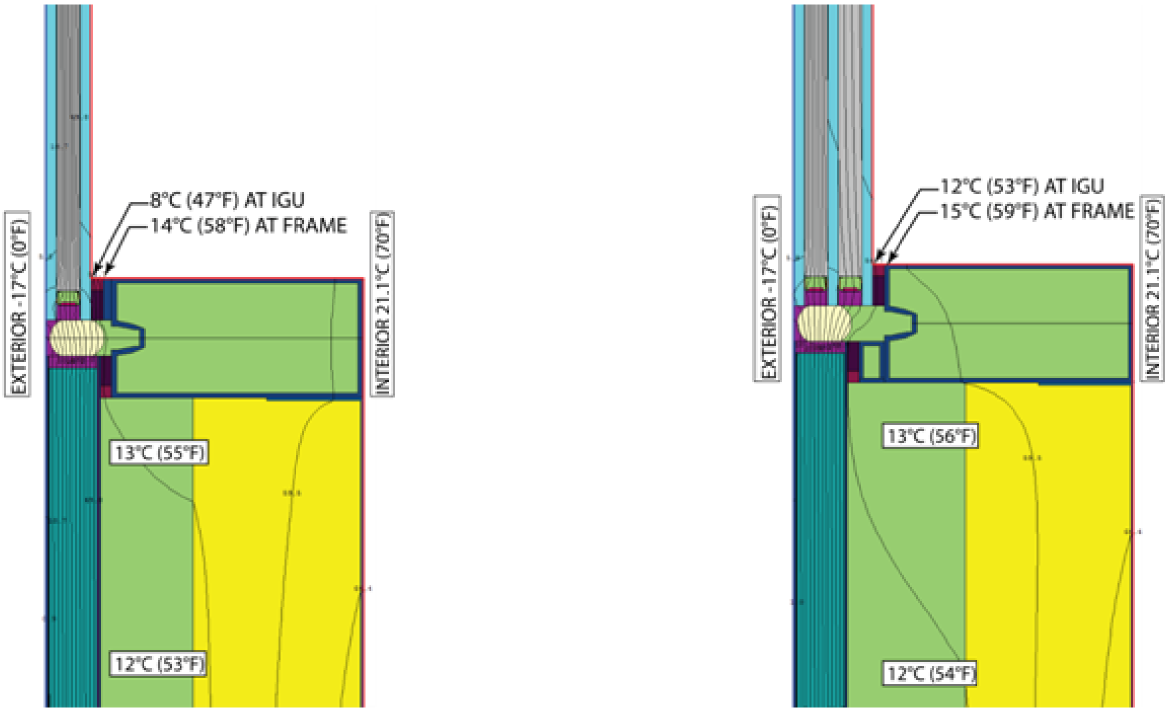

Figure 6. Double and Triple glazing using a combination of VIP's and mineral wool

The above models show the exterior insulation concept will have much more impact on the spandrel thermal performance values compared to continually adding insulation into the backpan as depicted in Figure 1 by Lawton and Roppel.

Performance Testing.

Fabrication of Architectural Insulation Modules (AIM) has been done using the concept of placing the VIP's within the airspace of an Insulating Glass Unit. This module could then be placed into a typical curtainwall assembly using typical construction practices. The desire for aesthetic freedom with regards to colors, patterns and depth in the spandrel section brought about the fabrication of the Triple Glaze AIM in conjunction with the Double Glaze AIM. The modules could be attached with structural silicone (figures 5 and 6) or mechanically fastened (Figures 1 and 3). The edge assemblies are proven performance insulating glass spacer systems that include a rigid warm edge spacer, desiccant, primary seal of polyisobutylene and a secondary seal of structural silicone. This assembly will protect the VIPs from damage and aging. This concept is highlighted in Figure 7

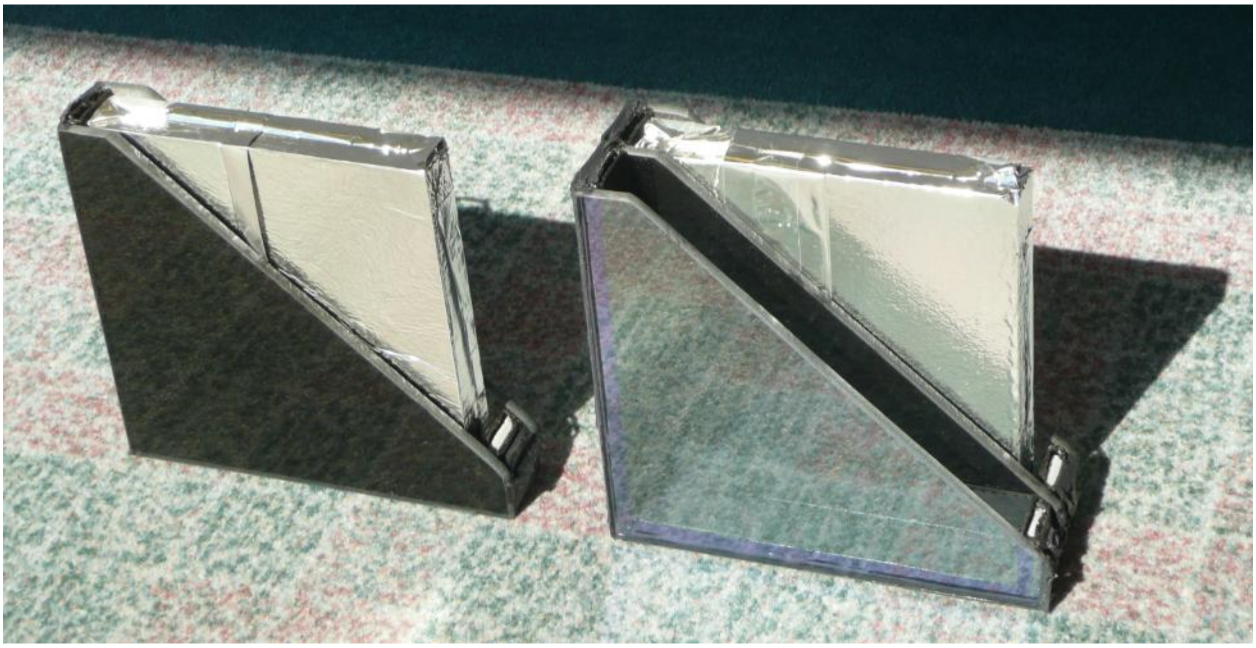

Figure 7. Double Glaze AIM with ceramic frit on surface 2 and Triple Glaze AIM with Low E on surface 2 and ceramic frit on surface 4.

The assemblies shown in figure 7 were subjected to hot box testing according to ASTM C1363 using NFRC 100 conditions. The assemblies each measured 1500mm x1500mm x 50mm. The double glaze used VIPs that were 38mm in thickness between two pieces of 6mm heat strengthened glass. The triple glaze assembly used two cavities each 16mm thick with three pieces of 6mm heat strengthened glass. The VIP in the rear cavity was 15mm in thickness, a ceramic frit was applied to surface #4 and a reflective low E coating was applied to surface #2. The results for these two tests are provided in Table 2. Comparative benchmark tests were done on vision units made of a standard 25mm low E IG unit with aluminium spacer along with a 44mm Triple IG with two low E coatings and argon using an aluminium spacer. The identical sized units in table 2 below were all tested without any framing. The unique size noted above is based on a curtainwall module width of 1520mm using a 63mm wide mullion framing system.

Table 2. ASTM C1363 hot box results.

Assembly	U value W/m²K	R Value m²K/W
25mm Double IG	1.87	0.53
44mm Triple IG	1.02	0.98
50mm Triple Glaze AIM	**0.48**	**2.07**
50mm Double Glaze AIM	**0.30**	**3.36**

These thermal test results of the AIM units are unmatched for a structural panel that is intended to be used in a spandrel assembly outside of the supporting mullions in a curtainwall.

This data and assembly information were then put into the three dimensional models to understand the impact that can be obtained.

Figure 8 shows a conventional curtainwall comparable to Figure 1in the spandrel area. The Double Glaze AIM is substituting the monolithic glazing and the mineral wool remains in place. Mineral wool in this application is kept due to firestopping concerns at the floor slab edge. AIM units increase thermal performance while additional mineral wool is used to meet smoke, fire, and acoustic requirements.

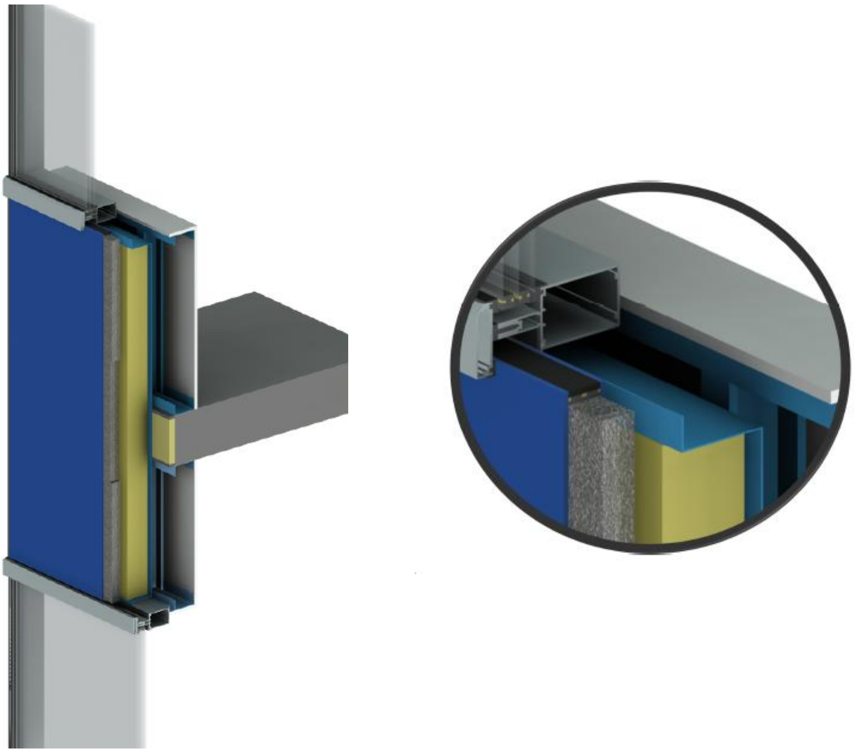

Figure 8. Conventional curtainwall with addition of the double glaze AIM.

This spandrel assembly in the three dimensional model provides a U value of 0.54 W/m²K or R value of 1.8 m²K/W. This assembly has more than twice the thermal resistance of the stick system shown in Figure 1. This is due to putting the key insulation on the outside of the mullions. When referring to Figure 2 we could not fit enough insulation into backpan or stud assemblies to get this kind of performance.

Figure 9 shows a benchmark high performance unitized curtainwall system with triple glaze IG units that have a center of glass U value of 0.10 W/m²K and the standard 100mm of mineral wool.

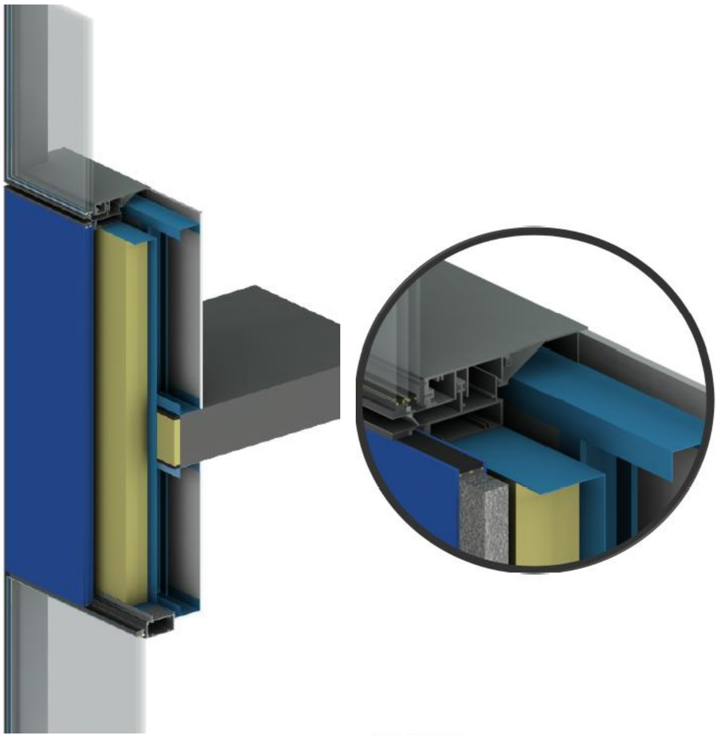

Figure 9. Benchmark Unitized Curtainwall using Triple glazing in both vision and spandrel

This benchmark curtainwall has a modelled U value of the spandrel of 1.2 W/m²K.

Figure 10 is the detailing of using the Double Glaze AIM in the spandrel section and Figure 11 is the detailing of using the Triple Glaze AIM in the spandrel section.

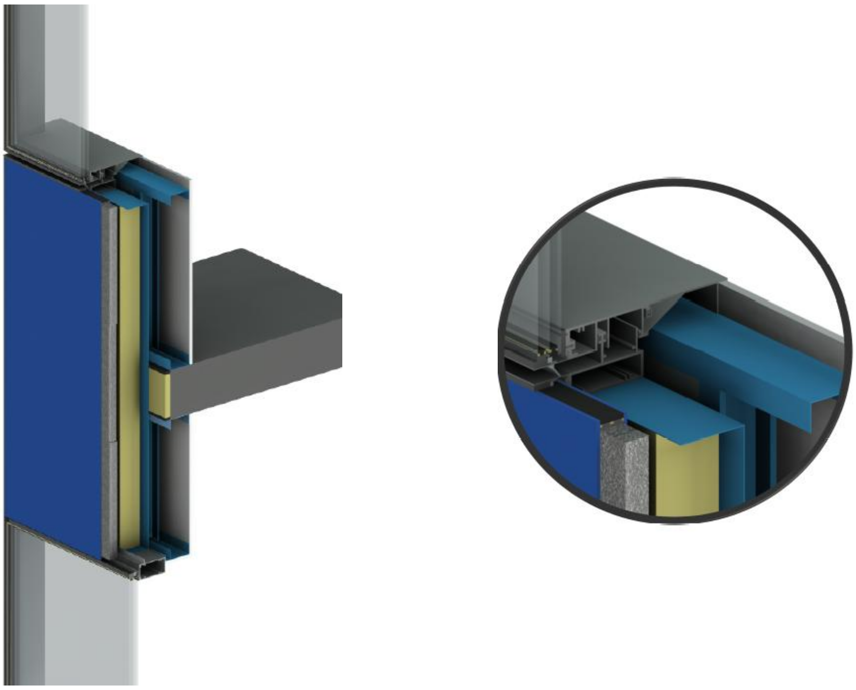

Figure 10. Unitized curtainwall using Double Glaze AIM

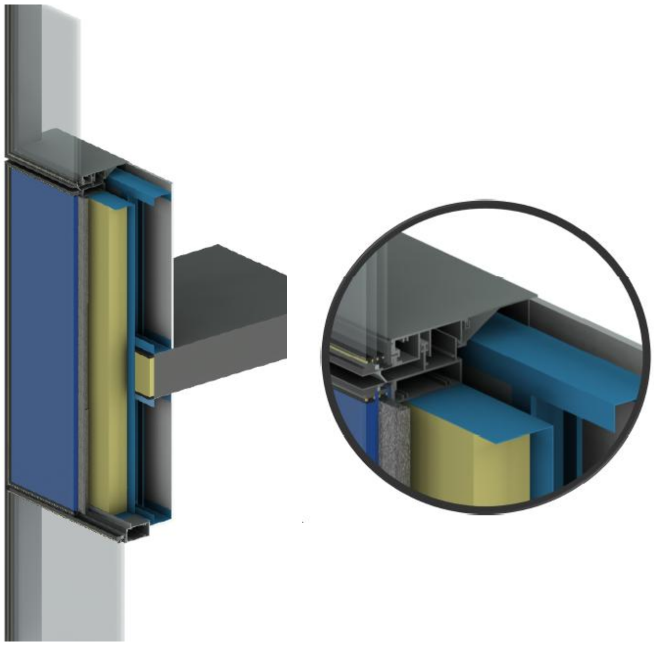

Figure 11 Unitized curtainwall using Triple Glaze AIM

The three dimensional modelling of the unitized wall utilizing the double glaze AIM (VIP thickness 38mm showed the Spandrel section U value of 0.39 W/m²K and the model with the Triple Glaze AIM (VIP thickness 15mm) had a U value of 0.53 W/m²K . The AIMs used in this scenario represent a tripling and doubling of the thermal resistance.

The double glaze AIM has the most thermal resistance; however the triple glaze AIM has an architectural appeal due to the flexibility of adding coatings and patterns on surface 2 and a visual depth in the cavity between surface 2 and 3.

Table 3. Three dimensional modelled results of 1520mm x 1520mm spandrel sections

Assembly	U value W/m²K	R Value m²K/W
Typical conventional stick curtainwall	1.16	0.86
Conventional stick curtainwall with Double Glaze AIM (VIP thickness 38mm)	**0.54**	**1.85**
Typical High Performance stick curtainwall	0.89	1.12
High Performance stick curtainwall with Double Glaze AIM (VIP Thickness 38mm)	**0.41**	**2.45**
High Performance stick curtainwall with Triple Glaze AIM (VIP thickness 15mm)	**0.51**	**1.95**
Benchmark unitized curtainwall	1.21	0.83

Unitized curtainwall with Double Glaze AIM (VIP Thickness 38mm)	**0.39**	**2.59**
Unitized curtainwall with Triple Glaze AIM (VIP thickness 15mm)	**0.54**	**1.87**

The modelled results presented show that vacuum insulation panels placed within claddings of glass and aluminium allow curtainwalls to become more thermally efficient than what is in use today primarily due to the concept of placing the insulation layer on the exterior of the structural mullions and transoms in a curtainwall.

The hot box test results on full size vision and spandrel glaze assemblies without any framing show that upgraded thermal performance is available using technology that is readily available. The test results provide the design community with the assurance that high performance can be obtained in architecturally pleasing glass based technology that has proven durability performance using edge assemblies used today with insulating glass technology.

3 Performance Mock-up Testing

The Architectural Insulation Modules (AIMs) are a component of a curtainwall assembly, and very similar in nature (from a materials, application, and logistics perspective) to standard insulating glass units. As such, a test to verify the AIMs can perform within its final installed assembly was considered technically prudent and a necessity for general validation. In maintaining the importance and value of predictive modelling, emphasis on the value of validation of these modelled results through testing. Testing for the individual components and for how these individual components behave and withstand full assembly testing provides the validation and demonstrates that the Architectural Insulation Module, and its incorporation into curtain wall assemblies, is a proven solution.

In collaboration with BISEM-USA, a specialist curtainwall design, fabrication, and installation contractor, a performance mock-up test configuration, the tested curtainwall system, and test procedure was designed and developed. The system was tested in accordance with AAMA 501 [5], as published by the American Architectural Manufacturers Association (AAMA), an industry-recognized and accepted independent performance test standard for air and water resistance, and structural, seismic and thermal performance. With the latest technologies from Dow Corning and Guardian, BISEM developed the new curtainwall with a systems approach, providing thermal performance and also meeting industry established performance criteria for air and water resistance, and structural and seismic performance.

BISEM contracted with an independent testing facility, Architectural Testing, Inc., to conduct performance testing on the BISEM Vacuum Wall system mock-up. Actual structural tests confirmed that the curtainwall would remain in place on the building for both specifically prescribed and overload conditions, without over deflecting, while also being a component that provides a complete envelope that defends against air and water infiltration.

3.1 Performance Mock-up Test – Configuration and Procedure

The performance mock-up configuration guidelines, test procedures and the associated referenced standards for individual tests are documented in AAMA 501, *Method of Tests for Exterior Walls*. AAMA 501 is an amalgamation of individual test that validate and/or confirm physical performance attributes of the exterior wall assembly. Some tests were developed through ASTM International (formerly known as the American Society for Testing and Materials), others established and developed by AAMA. AAMA 501 is viewed as a widely accepted industry Standard in North American curtainwall and exteriors wall construction performance testing. Figure 12 shows the designed configuration of the performance mock-up test, identifying size and location of each of the components of the assembly.

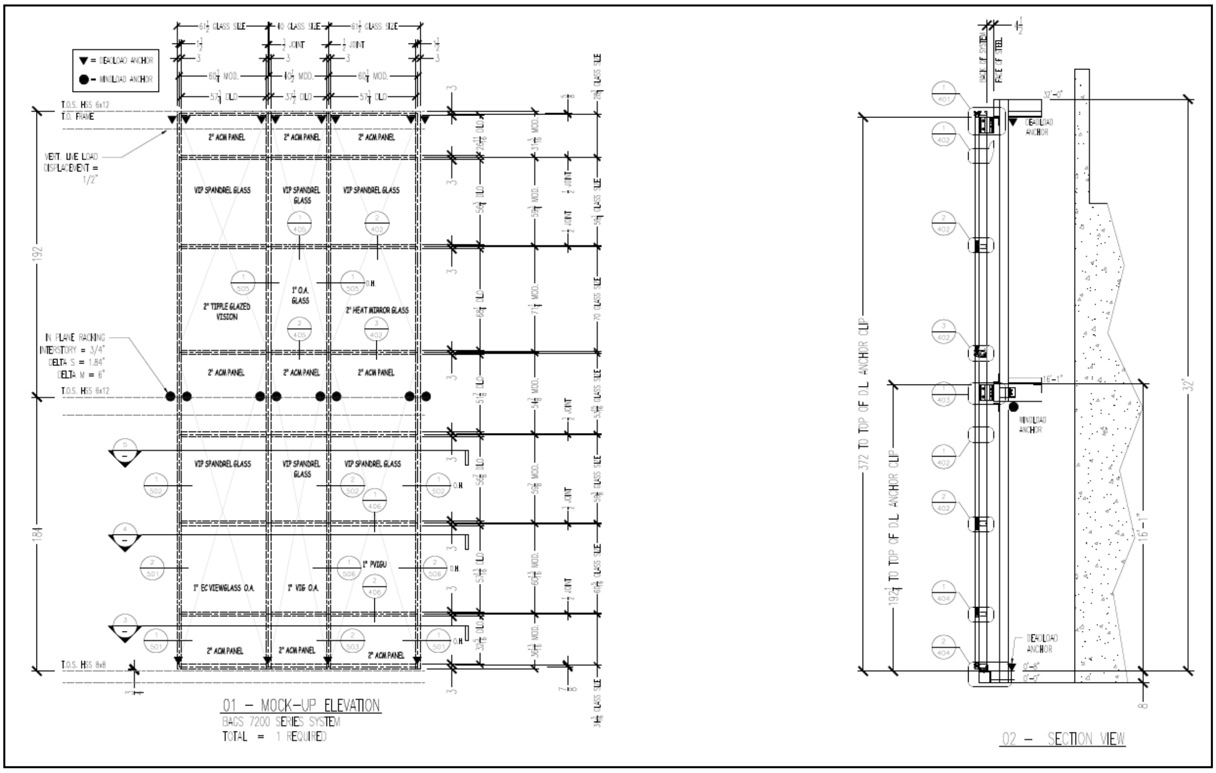

Figure 12. Drawing of Curtainwall Performance Mock-up Configuration

Figure 13 shows the completed installation of the performance mock-up prior to being tested at BISEM-USA's facility in Sacramento, California.

Figure 13. Curtainwall Performance Mock-up Configuration

For an appreciation for of the comprehensive nature of the AAM 501 test process, a brief description of the individual tests conducted and their technical significance is provided.

Air infiltration resistance of the overall curtainwall assembly is tested in accordance with ASTM E283, *Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors* [6]. Uncontrolled air infiltration is contributing factor to several performance characteristics in a curtainwall assembly; specifically, the capacity to manage water infiltration and the overall energy performance of the curtain wall. There is a correlation between uncontrolled air infiltration and energy consumption in commercial buildings. The test measures the amount of uncontrolled air leakage that occurs over the net area of the test mock-up at a prescribed interior/exterior pressure differential (for commercial applications) of 300 Pa. With the Architectural Insulation modules as part of the performance mock-up test, it is possible confirmation of their capacity to function as an air barrier within the context of the larger system as a standard piece of non-vision insulating glass would.

Water penetration resistance under a constant static pressure is tested to ASTM E 331, *Standard Test Method for Metal Curtain Walls and Doors by Uniform Static Air Pressure* [7]. The test measures the amount of uncontrolled water leakage that occurs over the net area of the test mock-up at a prescribed interior/exterior static pressure differential of positive 720 Pa (for commercial applications) for a 15 minute duration. Water, in a prescribed and uniform spray pattern, is applied to the mock-up at a minimum rate of 3.4 L/m2 min. With the Architectural Insulation modules as part of the performance mock-up test, it is possible confirmation of their capacity to function as a water barrier within the context of the larger system as a standard piece of non-vision insulating glass would.

Water penetration resistance under dynamic pressure is tested to AAMA 501.1, *Standard Test Method for Metal Curtain Walls for Water Penetration Using Dynamic Pressure* [8]. The test measures the amount of uncontrolled water leakage that occurs over the net area of the test mock-up at a prescribed wind speed of 34.3 m/s that is generated by an airplane engine or equivalent. The wind speed corresponds to an interior/exterior static air pressure differential of 720 Pa (for commercial applications). Water, in a prescribed and uniform spray pattern, is simultaneously applied to the mock-up for a 15 minute duration. The generated wind and water spray simulate a high wind and rain event that may cause water infiltration across the system and/or its joints/interfaces. With the Architectural Insulation modules as part of the performance mock-up test, it is possible confirmation of their capacity to function as a water barrier within the context of the larger system as a standard piece of non-vision insulating glass would. Particularly in a simulated combined wind and rain event.

The structural performance of the curtain wall and the Architectural Insulation Modules are tested to ASTM E 330, *Structural Performance of Exterior Windows, Curtain Walls, and Doors by Uniform Static Test Method* [9]. The specific uniform loading for this test sequence is selected to be a design pressure of positive and negative 2.4 kPa, and at a 150% proof-loading positive and negative 3.6 kPa. It is viewed that at the aforementioned design pressure, a large majority of medium to large commercial projects would be captured within this design parameter. With the test representing a design wind event, it is important to understand how the Architectural Insulation modules, its atypical edge seal spacer configuration, and the Vacuum Insulation Panels themselves behave and to confirm that no deleterious effects are upon those component. The deflection of the framing members cannot exceed L/175, or 19 mm maximum; where L is the clear span of the framing member. Typically, the allowable maximum deflection of infill material components is 25 mm maximum. In the instance of proof-load conditions, there can be no permanent deformation of framing members in excess of 0.02 of the clear span of members. This structural test and can confirm that performance with the Architectural Insulation Modules as a part of the performance mock-up confirms the modules' capacity to provide to transfer loads to the curtainwall framing member whilst not over deflecting and not negatively impacting the edge seal configuration and/or the Vacuum Insulation panels.

Interstory vertical differential movement is tested to AAMA 501.7, *Recommended Static Test Method For Evaluating Windows, Window Wall, Curtain Wall And Storefront Systems Subjected To Vertical Inter-Story Movements* [10]. Three complete cycles are performed in the vertical direction at the simulated floor slab at a movement magnitude of 19mm. This test simulates the day-to-day live load deflection of a floor slab. Whilst the test is more of a movement capacity confirmation of the curtain wall system itself, some in-plane loading does occur in the glass (and hence the Architectural

Insulation Modules) and verification sought to ensure the movement is not negatively impacting the edge seal configuration and/or the Vacuum Insulation panels.

Interstory lateral differential movement is a test that confirms a curtain wall system capacity to manage movement caused by high wind or seismic events (whichever governs). The test is conducted in accordance with AAMA 501.4, *Recommended Static Test Method for Evaluating Curtain Wall and Storefront Systems Subjected to Seismic and Wind Induced Interstory Drifts* [11]. Three complete cycles are performed in the horizontal direction at the simulated floor line. Testing was conducted at lateral movements up to 47 mm (Δs), and at a maximum of 89 mm (ΔM) of interstory drift. Whilst the test is more of a movement capacity confirmation of the curtain wall system itself, some in-plane loading does occur in the glass (and hence the Architectural Insulation Modules) and verification sought to ensure the movement is not negatively impacting the edge seal configuration and/or the Vacuum Insulation panels.

A summary of the test procedure and sequence of the test conducted follows:

1. Pretesting
2. Air infiltration test – Static Pressure
3. Water infiltration test – Static
4. Water infiltration test – Dynamic
5. Structural test Uniform Load – Design Load
6. Repeat - Water infiltration test – Static Pressure
7. Repeat - Water infiltration test – Dynamic Pressure
8. Interstory Vertical Displacement
9. Repeat - Water infiltration test – Static
10. Repeat - Water infiltration test – Dynamic Pressure
11. Interstory Horizontal Displacement
12. Repeat - Water infiltration test – Static
13. Repeat - Water infiltration test – Dynamic Pressure
14. Structural Test Uniform Load – Proof Load (over load)
15. Interstory Horizontal Displacement (seismic) – Proof

The repeat static and dynamic water infiltration test after structural and movement capacity test are meant to confirm the performance characteristic of the curtain wall assembly after each of these events. If a non-conforming performance occurs at any of these stages, a reason for the failure can be attributed to a specific event on the test process.

3.2 Performance Mock-up Test - Results

Table 4 is a summary of the results of the performance mock-up test. It can be seen that the criteria established in the test procedures were met, and qualitative observation of the Architectural Insulation Modules after testing showed no deleterious effects to the edge seals or the Vacuum Insulation Modules.

Table 4. Summary of Final Test Results

Test	**Measured**	**Allowed**	**Result**
Preload @ + 1.2 kPa	N/A	N/A	N/A
Air Infiltration Test Static Pressure @ 300 Pa	0.05 L/s m2	0.3 L/s m2	PASS
Water Infiltration Test Static Pressure @ 720 Pa	No uncontrolled leakage	No uncontrolled leakage	PASS
Water Infiltration Test Dynamic @ 720 Pa	No uncontrolled leakage	No uncontrolled leakage	PASS
Structural Test Uniform Load Design Load @ +/-1.2 kPa; +/- 2.4 kPa	See Figure 15 See Table 5	See Figure 15 See Table 5	PASS

Repeat - Water Infiltration Test Static @ 720 Pa	No uncontrolled leakage	No uncontrolled leakage	PASS
Repeat - Water Infiltration Test Dynamic @ 720 Pa	No uncontrolled leakage	No uncontrolled leakage	PASS
Interstory Vertical Displacement 3 Cycles @ 19mm	No visible damage	No visible damage	PASS
Repeat - Water Infiltration Test Static @ 720 Pa	No uncontrolled leakage	No uncontrolled leakage	PASS
Repeat - Water Infiltration Test Dynamic @ 720 Pa	No uncontrolled leakage	No uncontrolled leakage	PASS
Interstory Horizontal Displacement 3 Cycles @ 47mm	No visible damage	No visible damage	PASS
Repeat - Water Infiltration Test Static @ 720 Pa	No uncontrolled leakage	No uncontrolled leakage	PASS
Repeat - Water Infiltration Test Dynamic @ 720 Pa	No uncontrolled leakage	No uncontrolled leakage	PASS
Structural Test Uniform Load Proof Load @ +/- 1.8 kPa; +/- 3.6 kPa	See Figure 15 See Table 6	See Figure 15 See Table 6	PASS
Interstory Horizontal Displacement Proof Load @ 89mm	No visible damage	No visible damage	PASS

Figure 14 shows the placement of the linear transducers on the performance mock-up to measure the relative deflection of key components during the structural capacity test. Figures 14 and 15 represent the location of the transducers on the Architectural Insulation Modules.

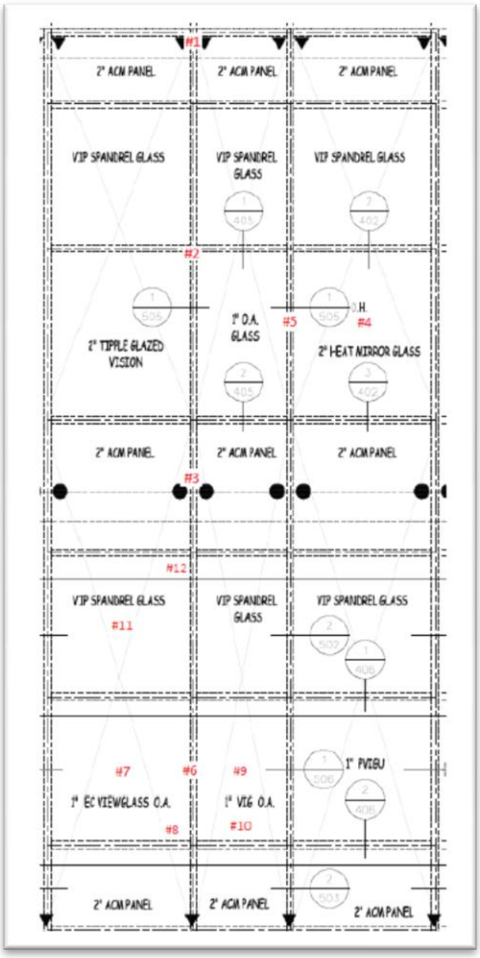

Figure 14. Elevation Showing Transducer Locations for Mock-up

Figure 15. Location of Transducer on the Architectural Insulation Module

Table 5 shows the relative deflection of the Architectural Insulation Modules under design pressure of 2.4 kPa. Transducer #11 is placed at the mid-point of the Architectural Insulation Module. Transducer #12 is placed at an adjacent mullion. The difference between the two values is the relative deflection of the Architectural Insulation Module.

Table 5. Uniform Load Deflection at Architectural Insulation Module at Design Pressure

Indicator Location	Positive 2.4 kPa	Net Deflection	Negative 2.4 kPa	Net Deflection	Allowed	Result
11	32 mm	16 mm	50 mm	21	25	PASS
12	16 mm	--	29 mm	--	--	--

Table 6 shows the permanent set (or permanent deformation) values of the Architectural Insulation Modules under proof-load pressure of 3.6 kPa. Transducer #11 is placed at the mid-point of the Architectural Insulation Module. Transducer #12 is placed at an adjacent mullion. The difference between the two values is the relative permanent set of the Architectural Insulation Module.

Table 6. Permanent Set of the Architectural Insulation Module at Proof-Load Pressure

Indicator Location	Positive 3.6 kPa	Net Deflection	Negative 3.6 kPa	Net Deflection	Allowed*	Result
11	0.8 mm	0.3 mm	0.3 mm	0 mm	--	PASS
12	0.5 mm	--	0.3 mm	--	--	--

***General Note**: Allowable amounts are based on 0.02 of their clear span for framing members.

4 Conclusions

The study concludes that higher performing curtainwalls can be achieved without sacrificing the existing structural, seismic, air infiltration, water infiltration, and aesthetic performance, while meeting increased thermal performance. The Architectural Insulation Modules not exhibit deleterious effects when subjected to air water, structural, and seismic loading. The edge seals were observed to maintain their integrity and the Vacuum Insulation Panels did not appear affected by the repeated loading conditions of the AAMA 501 test regimen.

It is likely that most curtainwalls will need to go through an alternative method of compliance to meet the spirit of the codes of today and in the future due to the architectural drive for high share of vision area. Curtainwalls use aluminium framing to couple the vision and opaque areas of the wall and the spirit of the codes is still within conventional construction where these areas are separate. The modelled results of the unitized curtainwall with a double glaze AIM approach the ASHRAE 2010 requirement for opaque assemblies. Proprietary curtainwall systems and astute curtainwall engineers will be able to maximize the performance of this type of assembly to meet prescriptive individual project requirements.

The Architectural Insulation Modules (AIMs) described here provide the architectural community another tool to use to maximize the transparency of the wall while still meeting the code.

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