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High Performance Curtain Wall using Vacuum Insulated Panel (VIP) Spandrels

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ABSTRACT

Commercial buildings with curtain wall facades have large expanses of vision glass and desirable aesthetics. A curtain wall system can be designed for energy efficiency and does not need to have an overall poor thermal performance. This paper studies the thermal performance of a commercial building that utilizes areas of 40% glass, and 60% spandrel with 4 different glass types, 2 insulating glass units (IGU) and 2 vacuum insulated glass units (VIG & HVIG). The glass types are paired with 2 different spandrel insulation types, mineral wool and vacuum insulated panel (VIP). Thermal modeling of the types is performed using THERM© 5.2 [1] and WINDOW© 5.2 [2] from Lawrence Berkeley National Laboratory (LBNL). Structural silicone attachment was used for the glazing and spandrel types since it is a continuous - structural attachment, thermal break, and air and water seal. The commercial building model has mullion and framing dimensions and materials that are identical for each type so that accurate comparisons can be made.

The eight combined types are evaluated and ranked based on thermal performance. The best performers, using a model building, are simulated for energy consumption and compared to the poorest performers. The selected combined types are modeled in different locations to obtain comparisons of building energy use for various climates. Basic energy modeling is performed with EFEN 1.3.10 [3], an interface to Energy Plus 5 [4].

The paper concludes that high performance glass, IGU's or VIG's, must be used with VIP insulation in the spandrel area to maximize the energy efficiency and thermal performance of a building.

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INTRODUCTION

Commercial buildings with curtain wall facades are known for large expanses of vision glass and desirable aesthetics. Generally, glass curtain walls have lower thermal performance compared to other types of enclosure systems. Often there is a desire to use vision glass for appearance and day-lighting purposes; however, the most recent advances in the glazing industry, high performance insulating glass units (IGU), still do not provide sufficient thermal performance. The trend to maximize the area of vision glass to opaque spandrel causes reduced wall thermal performance. However, a curtain wall system does not need to have poor thermal performance and can be designed for energy efficiency.

This paper describes the thermal performance of a commercial building that has areas of 40% glass and 60% spandrel (**Figures 1 and 2**). This is the ratio many current energy codes use to limit the glass area when utilizing a prescriptive path to verify compliance. The building model has a floor-to-floor height of 13 feet. The vision area is 6 feet wide and 5 feet tall (30 f^{2}). The spandrel area is 6 feet wide and 8 feet tall (48 f^{2}). The evaluation will be for the "field" of a large area of curtain wall. It does not address special conditions, such as transitions to roof, grade, or other wall systems. The different glass types (4) are studied, combined with different methods of insulating the spandrel area (2), and modeled to compare thermal and energy performance.

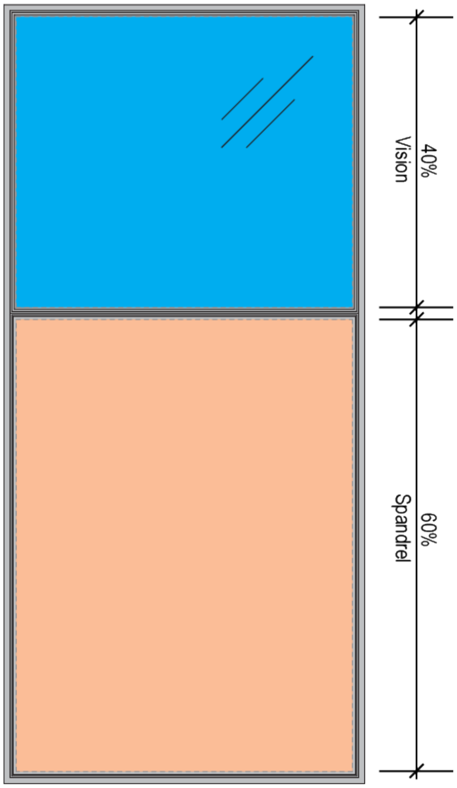


Figure 1: Elevation of typical curtain wall area.

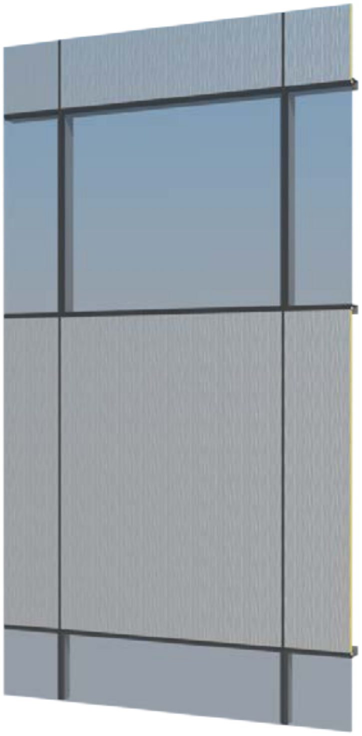


Figure 2: Isometric view of typical curtain wall area.

Structural silicone attachment was used for the glass and spandrel types since it is a continuous structural attachment, thermal break, and air and water seal (**Figure 3**). The commercial building model has mullion and framing dimensions and materials that are identical for each type so accurate comparisons can be made.

Glass types (all have a high performance Low E coating and IGU's have a warm edge spacer):

- Clear double pane IGU
- Clear triple pane IGU
- Clear vacuum insulating glass (VIG) unit
- Clear hybrid VIG/IGU (HVIG) unit

Spandrel insulation types:

- Fumed silica VIP encapsulated in an aluminum skin
- Typical insulation method, mineral wool applied to energy code minimum.

Figure 3**:** Enlarged view of structural silicone attachment of glass and spandrel to curtain wall frame.

MODELING PROCEDURE

The primary techniques to estimate thermal performance for the various curtain wall combined types used the Parallel Path Method (PPM), as described in ASHARE Fundamentals, and WINDOW© 5.2/ THERM© 5.2, by LBNL. The LBNL software is used and certified by the National Fenestration Rating Council (NFRC) to simulate and calculate center-of-glass (COG) and total product thermal performance, U-Factor, and solar heat gain coefficient (SHGC) for glazing systems. The software models two-dimensional heat transfer effects through the glazing systems based on the finite-element method. Additionally, THERM© 5.2 can help to predict localized surface temperatures for the components.

Parallel Path Heat Flow

In some instances, a component has elements that have heat flows in parallel paths but of different conductivities. In that case the following formula was used to determine the total product thermal conductivity:

$$Uav = aUa + bUb + \ldots + nUn,$$

Where

a, b, …, n are the surface-weighted path areas for a typical basic area composed of several different paths with transmittances Ua, Ub,…, Un.

Vision and Spandrel Area

The vision and spandrel areas were modeled separately. A combination of WINDOW© 5.2 and THERM© 5.2 was used to simulate and determine the total product U-Factor for the vision area. However, there is not a standard procedure for simulating spandrel conditions in WINDOW© 5.2. The U-Factor for the spandrel condition was determined through a combination of THERM© 5.2 modeling and the PPM. The two values were then averaged together, again using PPM, to provide whole wall thermal performance.

Vision Area

The previously described glass types were used for this evaluation. The modeling procedure generally conformed to the criteria in NFRC 100 “Procedure for Determining Fenestration Product U-Factors” [5]. The first step was to model the four glass types with WINDOW© 5.2 to determine their COG thermal performance. THERM© 5.2 was then used to model the primary cross sections of the curtain wall framing system (head, jamb, and sill). The glass types were imported from WINDOW© 5.2 into THERM© 5.2. Since the curtain wall glass and framing are now combined, edge-of-glass (EOG) and frame U-Factors can be calculated. The U-Factors were extracted and averaged in a separate spreadsheet using equations based on the PPM to determine the total product U-Factor for the vision area for the types.

To verify the PPM calculation, WINDOW© 5.2 was used to calculate the total product performance using the previously modeled COG, EOG, and frame performance as calculated and imported from THERM© 5.2. WINDOW© 5.2 essentially applies the PPM to these three areas and respective U-Factors. WINDOW© 5.2 can also produce a detail report on the performance of the glass that can then be imported into energy modeling software. This will be discussed in greater detail later in the paper. Based on the size of the vision portion of the glazing system, the three different areas that are included in the calculation to produce the total product U-Factor are as follows: 7.33% for frame, 13.82% for EOG, and 78.85% for COG. Note: the EOG dimension is 2.5 in. from the edge of the curtain wall frame (**Figure 4**).

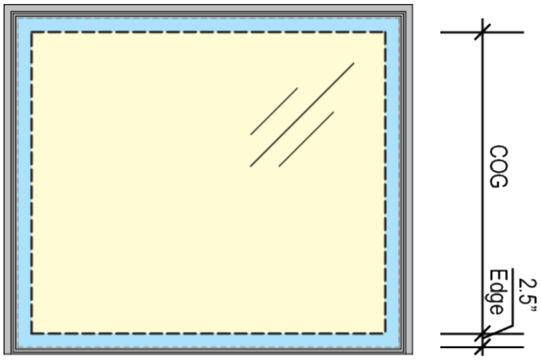


Figure 4**:** Elevation of Vision Glass indicating COG and EOG areas.

Vacuum Insulated Glass (VIG)

VIG units are a relatively new product in the construction market. There are limited manufacturers of this type of product, and currently there is not a certified or validated method to simulate a VIG in WINDOW© 5.2 or THERM© 5.2. The software does not appropriately simulate the vacuum and how energy transfers. However, for the purposes of this paper a method was developed to simulate VIG in the LBNL software to provide a comparison to standard products. It should be understood that the method employed has not been reviewed or certified by software developers, VIG manufacturers, or NFRC.

In WINDOW© 5.2, the user can create custom glass types by inputting specific performance values for the various characteristics of a specific glass, such as conductivity, emissivity, reflectivity, etc. A new custom glass type was entered into WINDOW© 5.2 for VIG. The performance values were entered and the glass type was simulated. The resultant COG value, as calculated by WINDOW© 5.2, was compared to that provided by a VIG manufacturer, primarily U-Factor, and SHGC. The values were then adjusted and modified until the calculation resulted in a close match to manufacturer's data.

The new custom glass was then used to model the VIG and HVIG types. These units were imported into THERM© 5.2 and used to calculate the frame and EOG U-Factors. This information was then exported to WINDOW© 5.2 to produce the total product U-Factor for the complete glazing type. The results of the VIG and HVIG simulations appeared to be conservative, a higher U-Factor than what might be expected (not as good). Based on conversations with a VIG manufacturer and some preliminary testing that they have performed, the thermal performance could be expected to be better than what was calculated. Besides the method of simulating the VIG, the technique in which the VIG is installed into the framing can have a large impact on the overall performance of the glazing system. These are two areas of development that need to have additional research and are not a focus of this paper.

Vision Area Results

Based on THERM© 5.2 and the PPM calculation, the total product U-Factors for the four types of vision area are included below in **Table 1**. As expected, the standard double pane IGU has the lowest performance and the HVIG has the best.

The following is the calculation used to produce the total product U-Factors:

Total Product U-Factor = (Frame Area x Frame U-Factor)+(EOG Area x EOG U-Factor)+(COG Area x COG U-Factor)

TABLE 1: Calculation and comparison of vision unit total product U-Factors.

Vision Type	Frame	EOG	COG	Total
Area (Square inch)	330.21	622.92	3552.88	4506.01
Percentage	7.33%	13.82%	78.85%	100.00%
Vision Unit Type 1 (Double Pane with Low E)				
U-Factor	0.8661	0.3014	0.2891	
R-Value	1.1546	3.3179	3.4590	
Weighted U-Factor	0.0635	0.0417	0.2279	
Composite U-Factor				**0.33**
Composite R-Value				**3.00**
Vision Unit Type 2 (Triple Pane with Low E)				
U-Factor	0.6159	0.2327	0.2164	
R-Value	1.6236	4.2974	4.6211	
Weighted U-Factor	0.0451	0.0322	0.1706	
Composite U-Factor				**0.25**
Composite R-Value				**4.03**
Vision Unit Type 3 (VIG with Low E)				
U-Factor	1.028	0.0803	0.082	
R-Value	0.9728	12.4533	12.1951	
Weighted U-Factor	0.0753	0.0111	0.0647	
Composite U-Factor				**0.15**
Composite R-Value				**6.62**
Vision Unit Type 4 (HVIG with Low E)				
U-Factor	0.7219	0.0712	0.0662	
R-Value	1.3852	14.0449	15.1057	
Weighted U-Factor	0.0529	0.0098	0.0522	
Composite U-				**0.11**

Factor				
Composite R-Value				**8.70**

Spandrel Area

Two methods of insulating the spandrel portion of the curtain wall were evaluated as a part of this study. The industry standard method of insulating a spandrel utilizes mineral wool insulation in-filled between curtain wall framing mullions and an additional layer used as mullion covers over the vertical mullions. The center of panel (COP) thickness was determined by providing the appropriate amount that will equal the current energy code minimum of approximately an R-Value of 15.6 (based on ASHRAE 90.1 2007 [6], reciprocal of the assembly U-Factor maximum of 0.064). An aluminum composite metal panel uses structural silicone attachment to the curtain wall frame to provide the weather protection and finish appearance for this type. The second type evaluated is the use of multiple VIP's encapsulated between two aluminum skins to create one large composite panel. This panel also uses structural silicone attachment to the exterior side of the curtain wall framing.

The modeling of the mineral wool type is relatively straight forward when compared to the VIP type. The mineral wool is a continuous material and the modeling can be performed directly in THERM© 5.2 without any preliminary modifications to the thermal performance of the mineral wool itself. However, due to inherent thermal bridging that occurs within the VIP metal panels, they require a substantial amount of analysis to determine the composite R-value of the core of the metal panel prior to modeling it in the curtain wall framing.

Thermal Bridging of VIP: The VIP's are composed of two basic materials, a tri-laminate aluminized polyester/polyethylene envelope and the core material contained in the envelope, a form of fumed silica. The fumed silica is placed under a high vacuum and the envelope is sealed (**Figure 5**). The thermal performance of the core material alone is approximately an R-Value of 40. However, currently the maximum panel size that can be produced is approximately 2 ft. by 3 ft. Due to the size limitation, multiple panels are used to fill the spandrel area of 6 ft. by 8 ft. The multiple panels are laid out two wide and four high in the composite panel (**Figure 6**). The VIP's are fully adhered to the aluminum skins with silicone adhesive/sealant, and a silicone sealant joint is installed around the perimeter of the composite panel. A noteworthy side benefit of the aluminum skins is they provide a significant level of protection for the individual VIP's. The thermal performance of the composite panel must be adjusted to account for the thermal bridging of the aluminized packaging envelope for each of the individual VIP's and its perimeter sealant (**Figures 7 and 8**).

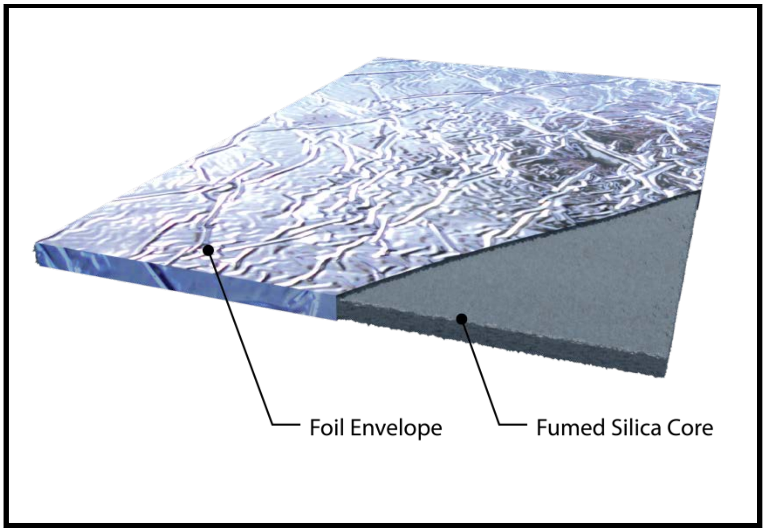


Figure 5**:** Cut away illustration of an individual VIP.

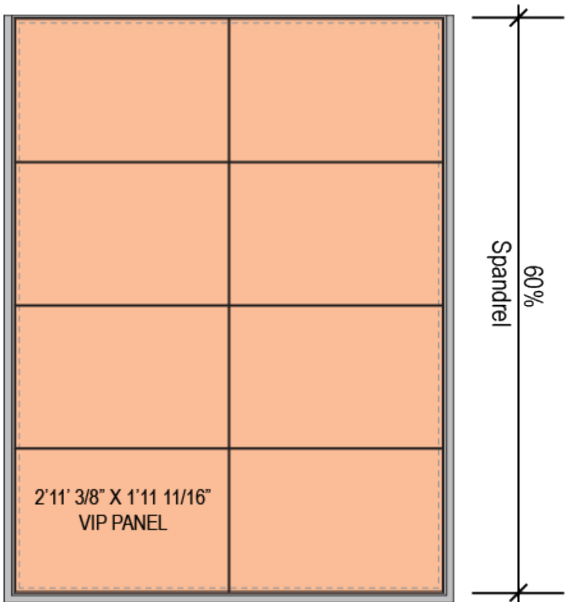


Figure 6**:** Elevation of spandrel area indicating layout of individual VIP panels within the composite panel.

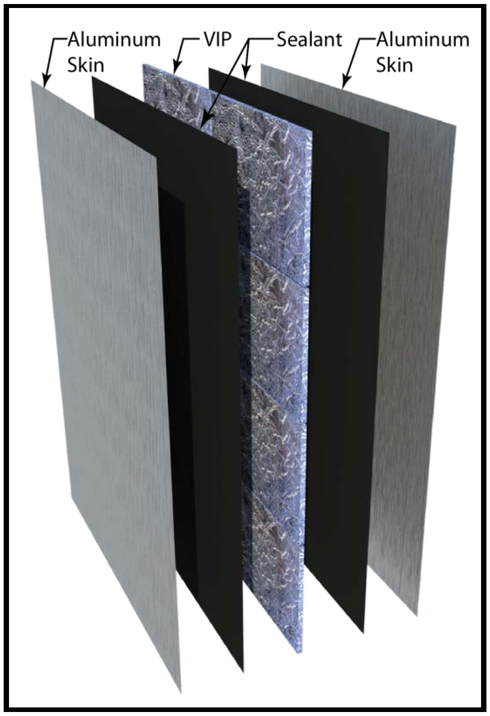


Figure 7**:** Exploded illustration of composite panel.

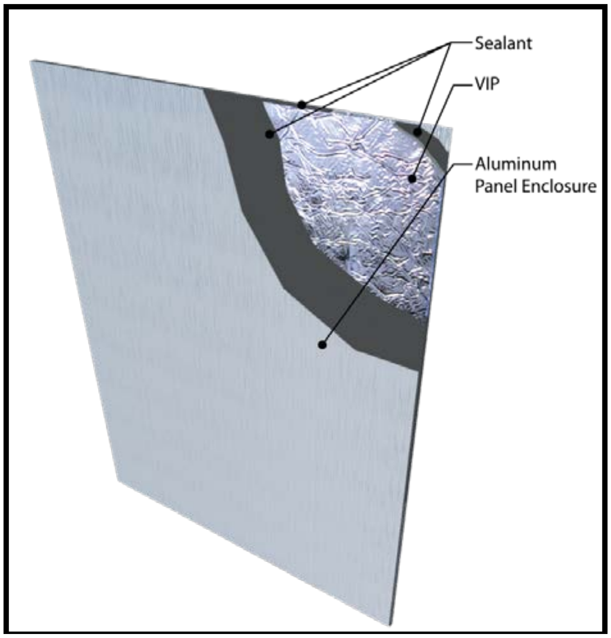


Figure 8**:** Cut away illustration of composite panel.

The PPM was again used to determine the composite U-Factor (and subsequently the R-Value) of the VIP composite panel. The conductivities of the thermal bridges from the packaging, air gaps, and the core material along with the respective total areas are averaged together to determine the resultant thermal performance. The resultant value of the composite panel is approximately an R-Value of 30. Once the adjusted core value was obtained, it could then be used in THERM© 5.2 to calculate the total product thermal performance.

Based on the percentages of the various materials in the core of the composite panel, the composite U-Factor was calculated as follows (**Figure 9**).

- Area of Foil = 0.07%, with a conductance of 6.9336 h•ft^2•°F [7]
- Area of Air = 0.29%, with a conductance of 1.0632 h•ft^2•°F
- Area of Core Material = 99.64%, with a conductance of 0.02556 h•ft^2•°F [8]

$$U\text{-Factor} = (0.0007 \times 6.9336) + (0.0029 \times 1.0632\ h \bullet ft^2 \bullet {}^\circ F) + (0.9964 \times 0.02556\ h \bullet ft^2 \bullet {}^\circ F) = \mathbf{0.033\ BTU/(h \bullet ft^2 \bullet {}^\circ F)}$$

$$R\text{-Value} = 1/0.033\ BTU/(h \bullet ft^2 \bullet {}^\circ F) = \textbf{approximately 30}$$

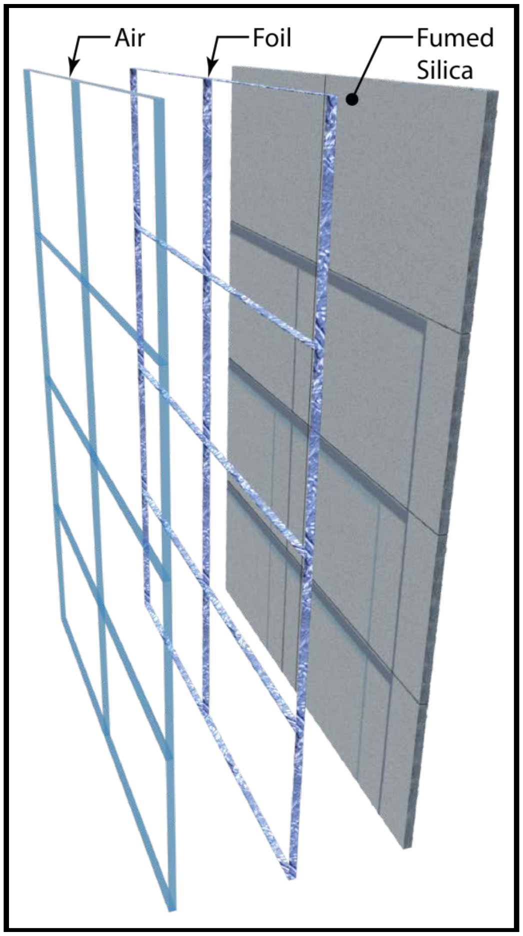


Figure 9: Exploded illustration of the core of the composite panel indicating location of the thermal bridging of the foil packaging and air at each VIP.

Total Product Thermal Performance: Similar to the vision units, the modeling procedure to determine the total product thermal performance for the spandrel types, including the effects of the frame, generally conformed to the criteria as described in NFRC 100 “Procedure for Determining Fenestration Product U-Factors”, but with some modifications. A primary difference is that the spandrel insulation was not modeled in WINDOW© 5.2 and imported into THERM© 5.2. The spandrel insulation was modeled directly in THERM© 5.2. THERM© 5.2 was then used to model the primary cross sections of the curtain wall framing system (Head, Jamb, and Sill). The frame, edge of panel (EOP), and COP U-Factors were calculated by THERM© 5.2 and averaged in a separate spreadsheet using equations based from the PPM to determine the total product U-Factor for the spandrel area.

Spandrel Area Results

For the spandrel portion of the wall system, the areas included in the calculation to produce the total product U-Factor are as follows.

- **Mineral Wool:** 3.47% for frame (Vertical), 2.51% for frame (Horizontal), 42.53% for EOP (Vertical), 28.65% for EOP (Horizontal), and 22.83% for COP (**Table 2**)

- **VIP:** 22.83% for COP, 71.18% for EOP, and 5.99% for frame. (**Table 3**)

Similar to the Vision Area, the following are the calculations used to produce the total product U-Factors.

Mineral Wool spandrel total product U-Factor formula:

> *Total Product U-Factor = (Vertical Frame Area x Vertical Frame U-Factor)+(Horizontal Frame Area x Horizontal Frame U-Factor)+(Vertical EOP Area x Vertical EOP U-Factor)+ (Horizontal EOP Area x Horizontal EOP U-Factor)+(COP Area x COP U-Factor)*

VIP spandrel total product U-Factor formula:

> *Total Product U-Factor = (Frame Area x Frame U-Factor)+(EOP Area x EOP U-Factor)+(COP Area x COP U-Factor)*

Notes:

1. The frame and EOP areas in the mineral wool spandrel are differentiated between the horizontal and vertical orientations. This is done because the insulation mullion covers only occur at the vertical members. The mullion covers have an impact on the thermal performance of the system at the frame and EOP locations.
2. The EOP dimension is 20 in. from the edge of the curtain wall frame. This was adjusted from the industry standard 2.5 in. used in glazing to account for the interaction between the frame and insulation materials. The 20 in. dimension was determined through a parametric modeling process. Multiple models were produced in THERM© 5.2, each with an increasing EOP dimension. The COP results of each model were compared to the known/tested COP value. The 20 in. dimension was a result of the model with the calculated COP that equaled the known COP. The large dimension of the EOP had a significant impact on the resultant total product thermal performance for both the mineral wool and the VIP insulation types (**Figure 10**).

Table 2**:** Calculation of spandrel total product U-Factor utilizing industry standard mineral wool application.

Mineral Wool	Condition	Frame (Vert)	Frame (Horiz)	EOP (Vert)	EOP (Horiz)	COP	Total
	U-Factor	0.0789	0.2646	0.1236	0.1657	0.0627	
	R-Value	12.674	3.779	8.091	6.035	15.949	
	Area	240.00	173.75	2940.00	1980.00	1578.25	6912.00
	Percentage	3.47%	2.51%	42.53%	28.65%	22.83%	100.00%
	Weighted U-Factor	0.0027	0.0067	0.0526	0.0475	0.0143	
	Composite U-Factor						**0.12**
	Composite R-Value						**8.08**

Table 3**:** Calculation of spandrel total product U-Factor utilizing VIP application.

	Condition	Frame	EOP	COP	Total
VIP	U-Factor	0.2247	0.0508	0.033	
	R-Value	4.45	19.69	30.30	
	Area	413.75	4920.00	1578.25	6912.00
	Percentage	5.99%	71.18%	22.83%	100.00%
	Weighted U-Factor	0.0135	0.0362	0.0075	
	Composite U-Factor				**0.0571**
	Weighted R-Value				**17.50**

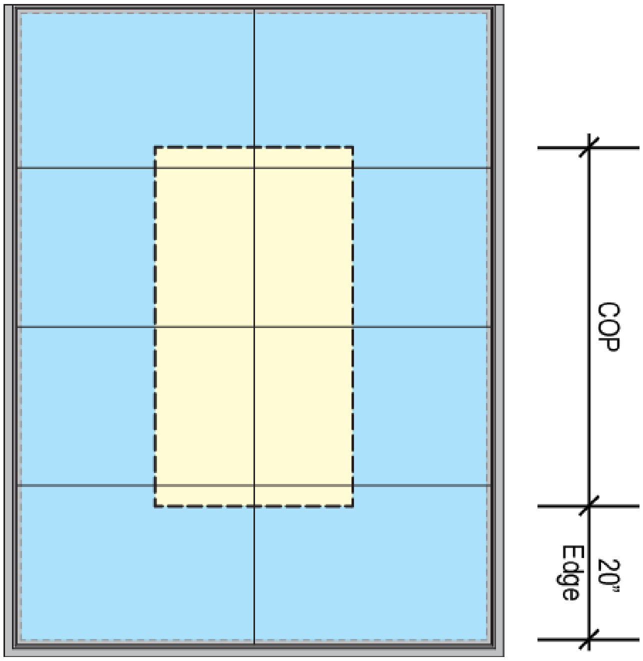


Figure 10**:** Elevation of spandrel indicating COP and EOP areas.

Whole Wall Thermal Performance

Once again, the PPM was used to calculate the average thermal performance of the vision and spandrel types when combined as a complete system. This value can only be used for an overall comparison. It cannot be directly inserted into energy analysis software. It is critical to keep the vision and spandrel areas separate when evaluating the energy consumption of a building since there are other performance characteristics that can contribute to overall energy consumption. Characteristics such as SHGC and visible light transmittance can have significant impact on the performance of the glazing, and heat capacity can impact the spandrel area. However, the resultant complete system thermal performance can still be a useful tool to compare and contrast the various glass and spandrel types and how the two separate values can have an effect on the overall system. The next two tables provide the complete system thermal performance for the eight combinations evaluated (**Table 4**). It becomes quite clear that high performance glass must work together with high performance VIP insulation in the spandrel areas to maximize the energy efficiency of the complete system.

Table 4: Whole wall U-Factor and R-Value comparison.

Glass Type	2p IGU	3p IGU	VIG	HVIG	2p IGU	3p IGU	VIG	HVIG
Spandrel Type	MW	MW	MW	MW	VIP	VIP	VIP	VIP
U-Factor	0.207	0.173	0.135	0.121	0.168	0.133	0.095	0.081
R-Value	4.82	5.77	7.42	8.24	5.97	7.49	10.56	12.28

Condensation Risk

An additional benefit can be gained by using VIG, but more importantly with VIP at the spandrel. By using structural silicone attachment of the VIP composite panel to the outside surface of the curtain wall framing, the interior surface temperatures of the curtain wall mullions are higher than they would be with mineral wool at the spandrel. This can have a significant impact on the interior relative humidity (RH) that can be tolerated for an interior environment. Warmer surface temperatures of the frame and glass will lead to lower potential for condensation to form at high interior RH. Additional benefit can be seen when using both the HVIG and VIP together. **See Figures 11 – 18, and Table 5**.

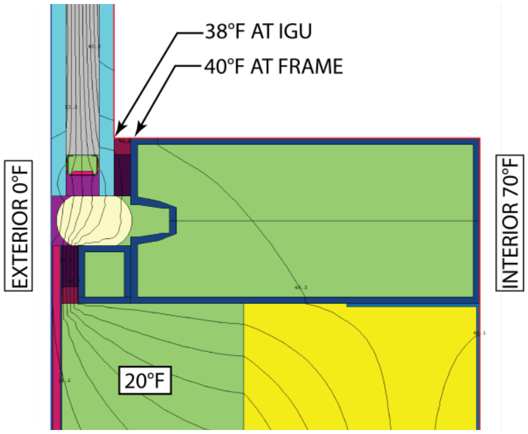


Figure 11**:** Double pane IGU vision unit and mineral wool spandrel insulation THERM© 5.2 model.

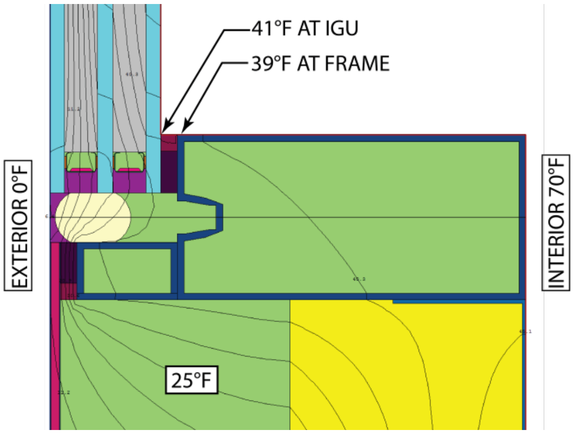


Figure 12**:** Triple pane IGU vision unit and mineral wool spandrel insulation THERM© 5.2 model.

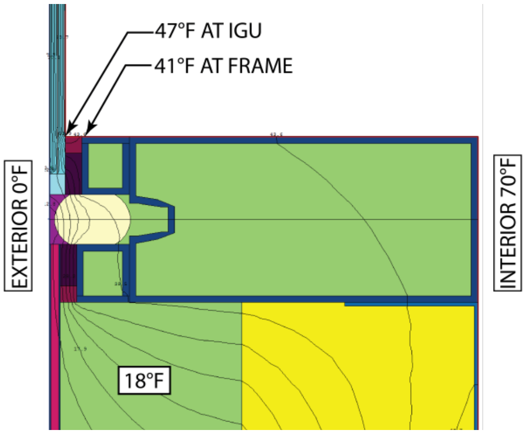


Figure 13**:** VIG vision unit and mineral wool spandrel insulation THERM© 5.2 model.

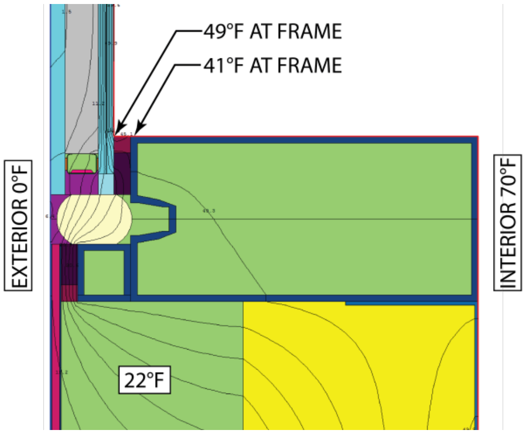


Figure 14**:** HVIG vision unit and mineral wool spandrel insulation THERM© 5.2 model.

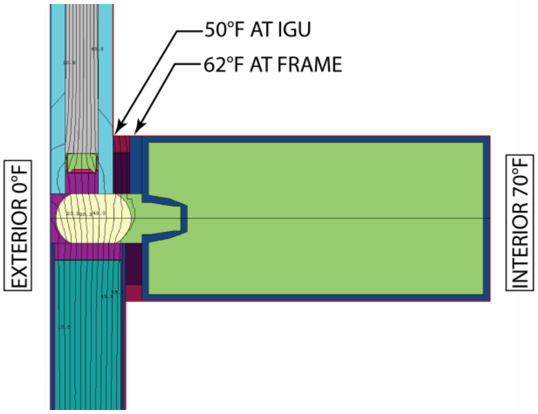


Figure 15**:** Double pane IGU vision unit and VIP spandrel insulation THERM© 5.2 model.

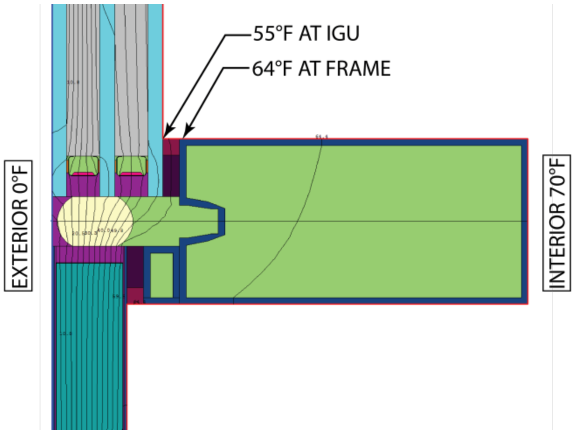


Figure 16**:** Triple pane IGU vision unit and VIP spandrel insulation THERM© 5.2 model.

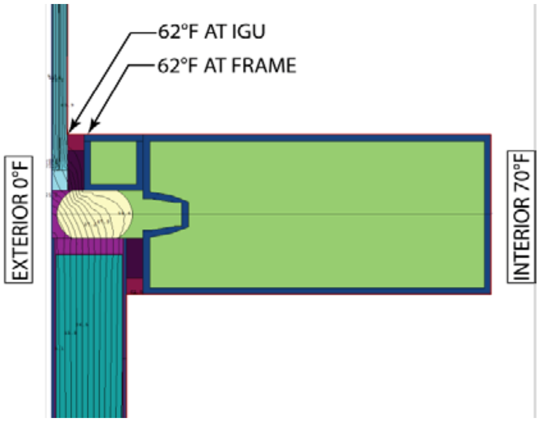


Figure 17**:** VIG vision unit and VIP spandrel insulation THERM© 5.2 model.

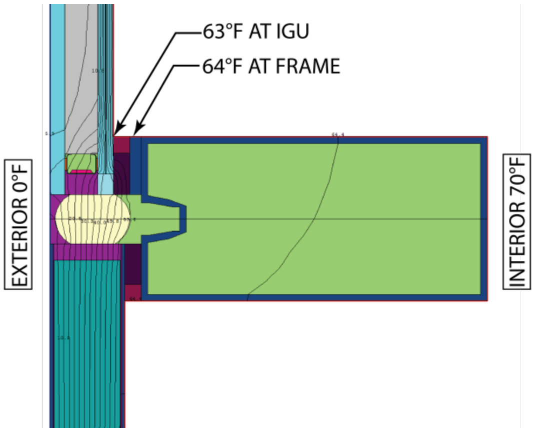


Figure 18**:** HVIG vision unit and VIP spandrel insulation THERM© 5.2 model.

Table 5**:** Comparison of glass and frame cold point temperatures.

Figure Number	Fig. 11	Fig. 12	Fig. 13	Fig. 14	Fig. 15	Fig. 16	Fig. 17	Fig. 18
Glass Type	2p IGU	3p IGU	VIG	HVIG	2p IGU	3p IGU	VIG	HVIG
Spandrel Type	MW	MW	MW	MW	VIP	VIP	VIP	VIP
Cold Point Glass	38 °F	41 °F	47 °F	49 °F	50 °F	55 °F	62 °F	63 °F
Cold Point Frame	40 °F	39 °F	41 °F	41 °F	62 °F	64 °F	62 °F	64 °F

DISCUSSION

As indicated in the figures and the table, all of the curtain wall systems utilizing mineral wool spandrel insulation have a cold point of approximately 40°F regardless of the glass type. From the standpoint of trying to reduce the risk of condensation, the glass type does not have much of an impact. The spandrel insulation is the primary factor that dictates the level of interior RH that can be tolerated without risk of condensation. This is in large part due to thermal bridging inherent to the aluminum composite metal panel spandrel system. The air space directly adjacent to the metal panel is still quite cold. This cold air space is in direct contact with the aluminum curtain wall frame, bypassing the system's thermal break. This effect can be reduced if the aluminum panel was replaced with an opaque IGU. However it will not be completely eliminated, because the air space is still insulated from the heat of the room by the mineral wool insulation.

The only way to completely eliminate this issue is to utilize the VIP structurally attached with silicone to the exterior side of the curtain wall frame. As indicated in the figures and the table, when using the VIP the cold point is no longer dictated by the spandrel insulation. Unlike the system with the mineral wool, there is no air space to cause the thermal short circuit. The cold point with these systems is primarily driven by the glass type. The cold point increases as the performance of the glass increases. Note the cold point on the frame does not significantly change as the glass type changes. This again is because it is almost fully insulated from the cold exterior air, and there is also significant exposure to the warm interior air. It is clear that VIP insulation should be utilized to increase the condensation resistance of a given system.

Energy Analysis

Basic energy modeling was performed using EFEN 1.3.10, an interface to energy Plus 5. A commercial office building, five stories tall, was modeled for four representative locations - Detroit, Michigan; St Louis, Missouri; Phoenix, Arizona; and Winnipeg, Manitoba Canada. The 8 combined types were modeled for energy use and compared to each other. They were then ranked based on thermal performance. **Figure 19** illustrates the commercial office building.

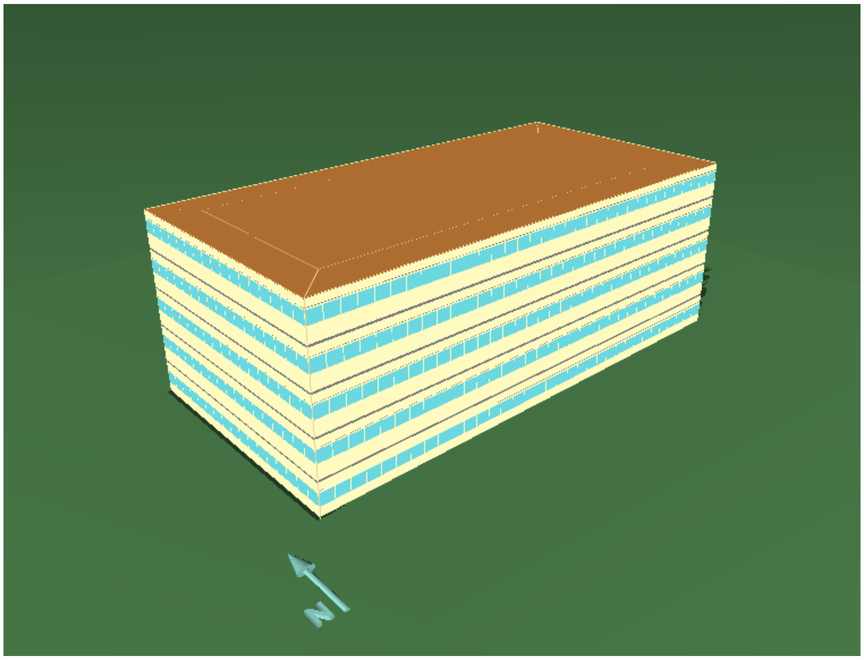


Figure 19: Illustration of commercial office building as modeled in EFEN 1.3.10.

The glass types used for EFEN 1.3.10 were exported from THERM$^{©}$ 5.2 and WINDOW$^{©}$ 5.2 programs, referenced above, into the EFEN program per the program features. This particular building model used a built up roof R-Value of 41.8 hr-ft^{2}-F/BTU in all climate zones. The spandrel areas were programmed to have an R value of 17.2 hr-ft^{2}-F/BTU and 8.1 hr-ft^{2}-F/BTU by using the standard types built into the program for the VIP and Mineral wool spandrels respectively. The spandrels were not able to be imported as custom types and the standard designs within the EFEN program were used. Other features of the program, such as daylighting controls, air infiltration, internal loads, schedules, service hot water, and type of HVAC system were all kept constant. The simulation of energy is an annual simulation based on weather files obtained for the specific city as captured by the EFEN program. The energy model was performed to compare the differences in energy use based only on the type of glass and spandrel insulation.

Model for Phoenix, Arizona

The data obtained for the Phoenix model is shown below in **Table 6**.

Table 6**:** Phoenix energy use sorted by use

City	Glazing	Spandrel	Gas MBtu	Electric kWh	Electric MBtu	Total MBtu
Phoenix	HVIG	VIP	440	1520831	5189	**5629**
Phoenix	VIG	VIP	451	1529228	5218	**5669**
Phoenix	3 pane	VIP	559	1558889	5319	**5879**
Phoenix	HVIG	MW	618	1542342	5263	**5881**
Phoenix	VIG	MW	632	1556539	5311	**5943**
Phoenix	2 pane	VIP	621	1597381	5450	**6071**
Phoenix	3 pane	MW	742	1584736	5407	**6149**
Phoenix	2 pane	MW	805	1620908	5531	**6335**

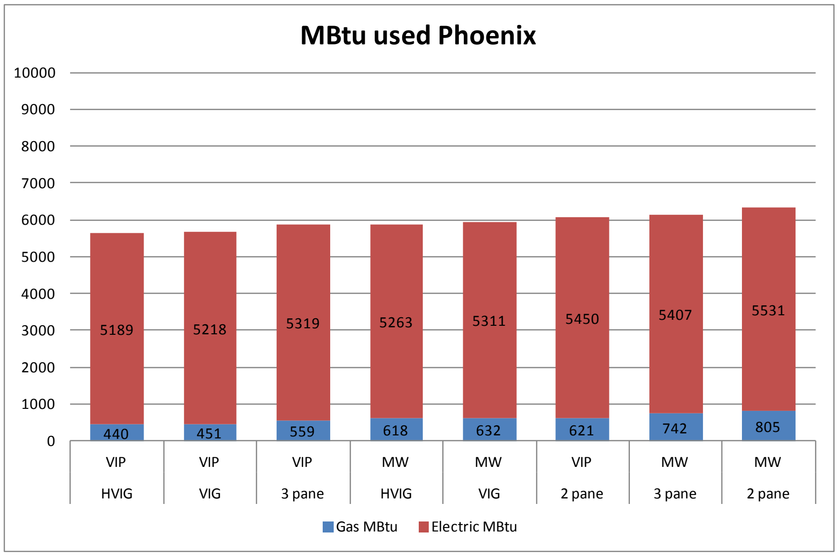


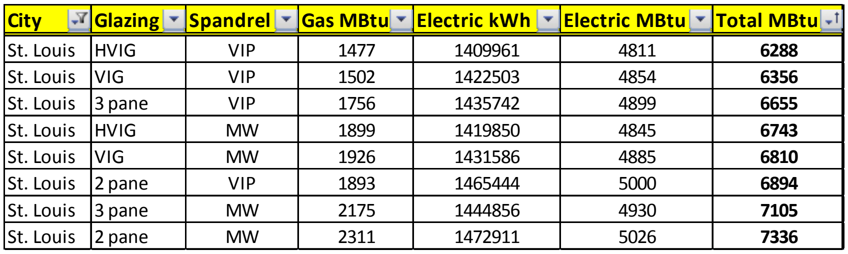
Figure 20**:** Graph of totals in Table 6 of Phoenix energy use sorted by use

Phoenix energy use is clearly dominated by electrical use for cooling of the building. The difference between the most energy used and the least is 11%. This includes a significant reduction (56%) in the gas usage for the limited heating required.

Model for St. Louis Missouri

The energy use in St. Louis is shown below in **Table 7**.

Table 7**:** Results for St Louis.



City	Glazing	Spandrel	Gas MBtu	Electric kWh	Electric MBtu	Total MBtu
St. Louis	HVIG	VIP	1477	1409961	4811	**6288**
St. Louis	VIG	VIP	1502	1422503	4854	**6356**
St. Louis	3 pane	VIP	1756	1435742	4899	**6655**
St. Louis	HVIG	MW	1899	1419850	4845	**6743**
St. Louis	VIG	MW	1926	1431586	4885	**6810**
St. Louis	2 pane	VIP	1893	1465444	5000	**6894**
St. Louis	3 pane	MW	2175	1444856	4930	**7105**
St. Louis	2 pane	MW	2311	1472911	5026	**7336**

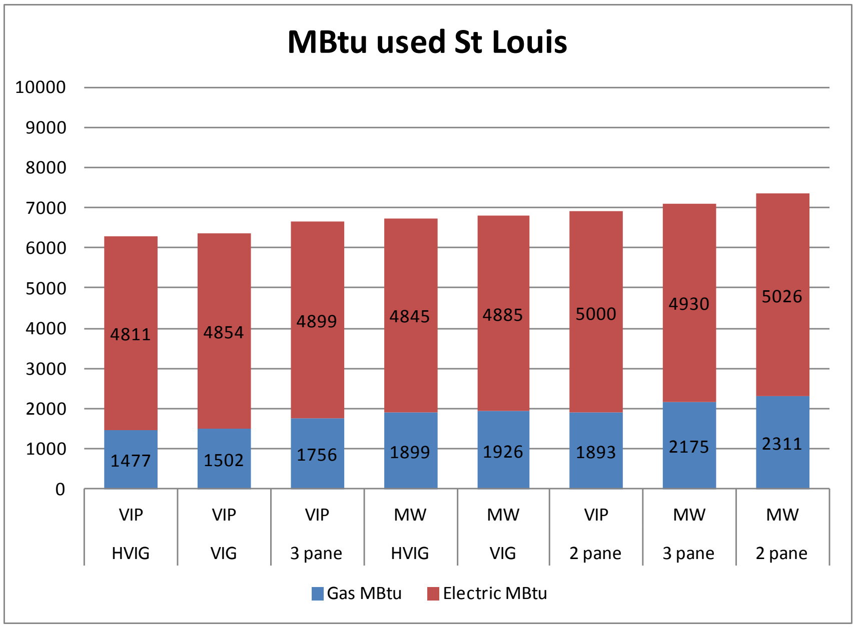


Figure 21**:** Graphical results for St Louis.

St. Louis energy use is dominated by electrical use for cooling of the building, however the gas use represents the cooler winter climate effects. The difference between the most energy used and the least is 14%. Gas usage reduction is 36%.

Results for Detroit

The energy use in Detroit is shown below in **Table 8**.

Table 8**:** Results for Detroit.

City	Glazing	Spandrel	Gas MBtu	Electric kWh	Electric MBtu	Total MBtu
Detroit	HVIG	VIP	1945	1313547	4482	**6427**
Detroit	VIG	VIP	1977	1325433	4523	**6500**
Detroit	3 pane	VIP	2302	1331844	4544	**6846**
Detroit	HVIG	MW	2481	1315589	4489	**6970**
Detroit	VIG	MW	2515	1326756	4527	**7042**
Detroit	2 pane	VIP	2479	1358772	4636	**7115**
Detroit	3 pane	MW	2831	1333608	4550	**7381**
Detroit	2 pane	MW	3005	1359106	4637	**7642**

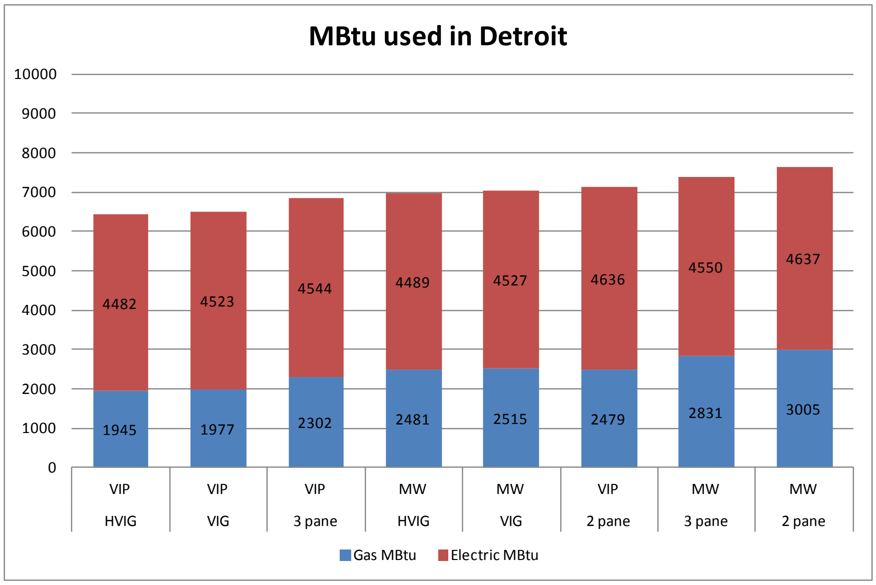


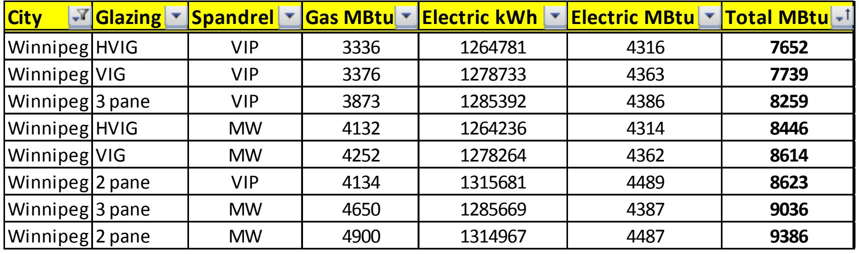
Figure 22: Graphical results for Detroit.

Detroit energy use is dominated by electrical use for cooling of the building however the gas use represents the cooler winter climate effects. The difference between the most energy used and the least is 18% and gas usage is reduced by 35% with the highest performing system.

Results for Winnipeg Manitoba Canada

The energy use in Winnipeg is shown below in **Table 9**.

Table 9**:** Results for Winnipeg.



City	Glazing	Spandrel	Gas MBtu	Electric kWh	Electric MBtu	Total MBtu
Winnipeg	HVIG	VIP	3336	1264781	4316	**7652**
Winnipeg	VIG	VIP	3376	1278733	4363	**7739**
Winnipeg	3 pane	VIP	3873	1285392	4386	**8259**
Winnipeg	HVIG	MW	4132	1264236	4314	**8446**
Winnipeg	VIG	MW	4252	1278264	4362	**8614**
Winnipeg	2 pane	VIP	4134	1315681	4489	**8623**
Winnipeg	3 pane	MW	4650	1285669	4387	**9036**
Winnipeg	2 pane	MW	4900	1314967	4487	**9386**

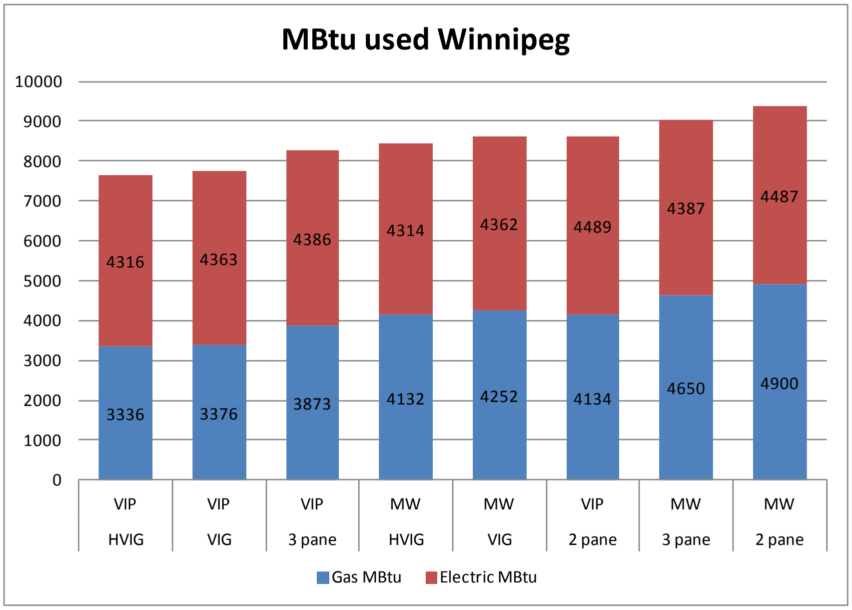


Figure 23**:** Graphical results for Winnipeg.

Winnipeg energy use is dominated by gas use for heating of the building however the electric use represents the summer sunshine heating effects. The difference between the most energy used and the least is 18%, but the gas savings is 32% by the highest performing system.

DISCUSSION

For each location the top three performers use the VIP within the spandrel area and the mineral wool spandrel resides at the bottom two places. They also indicate the top performers for glass to be the HVIG and VIG types and the lower performers to be the triple pane and double pane IGU types respectively.

It is clear that when thermal performance is the driver, the best glass type paired with the best spandrel type will provide the least energy usage. Conversely the lowest performing glass type paired with the lowest performing spandrel type will provide the most energy usage.

What becomes very interesting is that in all four locations, the double pane IGU type with the VIP spandrel type used less energy than the triple pane IGU type with the mineral wool spandrel type. When making this consideration and trade-off in cold climates, the benefits of the condensation resistance of the VIP spandrel type appear to make the double pane IGU type a significant winner. When we review the benefits of the HVIG glass and the VIP spandrel, the top performers in the energy models, is it really acceptable to use mineral wool insulation in these instances knowing the potential condensation issues described by the THERM© 5.2 models? These are the kinds of trade-off decisions that can be made with regards to this modeling.

Limitations and Opportunities for Future Development

Some of the high-performance materials presented and modeled in this paper are very new to the commercial construction industry. The authors believe that it is important to highlight the potential benefits of these near future technologies. Modeling these new technologies with today’s tools presents a challenge. The existing energy programs don’t include VIG or VIP technologies. The thermal modeling programs don’t quite understand VIG or HVIG. There is a need to advance the modeling software to provide results that can be easily obtained and understood. Framing details for the new glazing technology are not well documented. The placement of the glass unit within the frame can have a great impact on the performance of the system. The units evaluated, utilized industry standard glazing methods and frame components. The benefits of using VIG or HVIG can likely be further realized if it is installed in an optimized location on the frame. This may require a change in frame dimension to accommodate the optimized location. Further analysis and study of this is also needed. The authors used the existing tools with logic and experience as their approach to developing the models that indicate the trends for these new and exciting materials.

Lab testing of full size curtain wall systems modeled in this paper has not been performed for characteristics such as air and water infiltration, structural and thermal performance, and fire resistance. The constructability of these systems will need fine tuning as with any new technology.

CONCLUSION

Modeling indicates that VIG and VIP spandrel systems should be combined together to maximize building energy performance. It also indicated the same ranking for energy use for each of the locations. Whether or not the climate was heating or cooling dominated, the U-Factor (R-Value) of the spandrel and glass types can be used to determine overall energy trends. Combining this information with a thermal model of a wall at cold temperatures can predict condensation risk. In specific instances a VIP can indeed upgrade the performance of a double glazed IGU to where the use of a triple glazed IGU or VIG can be offset.

On the other hand the highest performance systems compared to the code minimum system presented in this paper saves 18% more energy in Winnipeg, 18% in Detroit, 14% in St. Louis, and 11% in Phoenix. This indicates that colder climates have more to gain by using a higher performing system and by using the VIP insulation indicates much less potential for condensation. The VIP system can be a true benefit to both the building owner and the occupants.

ACKNOWLEDGEMENTS

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