STUDY ON THE IMPROVEMENT OF THERMAL PERFORMANCE OF CURTAIN WALL SPANDRELS

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ABSTRACT

Thermal performance is an important issue in building envelope design because it impacts directly the building energy consumption, indoor thermal comfort, and the envelope durability. Curtain walls are lightweight glazed facades that are characterized by having two distinct glazed areas: a translucent vision area and an opaque spandrel area. In the curtain wall industry, thermal transmittance U-factor or thermal resistance R-value of the vision and spandrel areas, and overall U-factor or R-value of whole curtain wall are usually specified individually. To achieve good overall thermal performance, both vision and spandrel play important roles. This paper investigates materials and technologies to improve thermal performance of spandrel panels in curtain walls.

Three types of spandrel configurations are studied: conventional, vacuum insulated panel (VIP) and a combination of both of them. U-factor and/or R-value of each configuration, either nominal or weighted are reviewed and compared in this project. THERM 6.3 2D a free finite-element modeling software by the Laurence Berkeley National Laboratory (LBNL) is used to model the thermal performance for these three configurations on a unitized curtain wall system. The thermal properties are compared and discussed. eQuest® a free energy modeling tool that uses the DOE 2-2 simulation engine is used to simulate energy performance for a whole building, a 20-storey office building cladded with curtain wall. Energy consumption is compared, per these three different spandrel configurations.

INTRODUCTION

A curtain-wall system is a full-height cladding system that bypasses floor slabs. The curtain-wall system is designed to satisfy thermal performance requirements, in addition to structural integrity and deflection requirements, and wind-driven rain and air leakage control (R.L. Quirouette, 1982).

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 sufficiently improved thermal performance. The trend to maximize the area of vision glass causes reduced wall thermal performance. Therefore, the opaque spandrel area with higher thermal performance is sought to balance the poor thermal performance of the vision area.

Energy Standard for Buildings except Low-Rise Residential Buildings (ASHRAE 90.1-2010) requires that the total vertical fenestration area shall be less than 40% of the gross wall area (5.5.4.2.1). In other words, window-to-wall ration (WWR) shall be less than 40%. This requirement in curtain-wall systems indicates having a vision area of less than 40% of the total wall area, which is typically not the case. It is believed that to increase the WWR on curtain walls to values higher than 40%, spandrels with higher thermal performance need to be specified to maintain overall thermal requirements.

HYPOTHESES

To improve the thermal performance of spandrel walls, a new high efficiency insulation product, Vacuum Insulation Panel (VIP) is proposed to replace the conventional spandrel insulation. Furthermore, combing the conventional spandrel with a VIP panel is also expected to achieve higher thermal performance. The objective of this paper is to test these hypotheses.

LITERATURE REVIEW

According to proposed energy consumption, architects either specify U-factors or R-values

Table 1: Examples of specified U-factors and R-values of two curtain wall projects in Vancouver, BC

	Residential		Commercial	
	U-factor ($W/K.m^2$)	R-value ($ft^2.h.°F/Btu$)	U-factor ($W/K.m^2$)	R-value ($ft^2.h.°F/Btu$)
Vision	**2.27**	**2.5**	**1.75**	**3.25**
Spandrel	**0.94**	**6.0**	**0.94**	**6.0**
Overall	**2.00**	**2.8**	**1.59**	**3.57**

Vision

A typical double glazing IGU with 8mm and 6mm clear glass, low-E coating on surface #2, 90% Argon filled in 12mm cavity and warm edge spacer, provides nominal Rcop-4.1 at centre of panel (COP). A triple glazing IGU with three 6mm glass panes, low-E coatings on surface #2 and #5, 90% Argon filled in two layers of 9mm cavity and sealed with warm edge space, offers nominal Rcop-6.5 at centre of panel.

However, thermal bridging at aluminum frame greatly impacts the overall thermal performance. For a typical unitized curtain-wall system with R-value at center of glazing of R-4.1, the effective or weighted R-value of vision panel with double glazing IGU drops to R-3.0 (Table 2).

Table 2: U-factor and R-value of typical IGU at vision panel

	Centre of vision (Nominal)		Overall of vision (Effective)	
	U_{cop} ($W/m^2.k$)	R_{cop} ($ft^2.h.°F/Btu$)	U_v ($W/m^2.k$)	R_v ($ft^2.h.°F/Btu$)
Double glazing	**1.39**	**4.1**	**1.85**	**3.1**
Triple glazing	**0.87**	**6.5**	**1.61**	**3.5**

COP data refers to SYP's data; overall data refers to Jangho Curtain Wall's curtain wall system.

Conventional Spandrel

A conventional spandrel panel on curtain wall usually consists of single or double opaque glazing, mineral wool and galvanized metal sheet (G.M.S.) back-pan. Opaque glazing gives the desired visual effect, while mineral wool insulation provides most thermal properties and G.M.S. acts as insulation support as well as air barrier. (Figure 1) Mineral wool is widely used on curtain wall spandrel panels due to its excellent properties, such as high R-value (R-4.1), fire resistant, water repellent, chemical inert and sound absorbent.

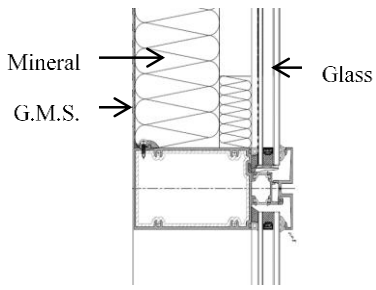


Figure 1: Conventional spandrel

Vacuum Insulation Panel (VIP) spandrel

Vacuum Insulation Panel (VIP) consists of a core material (typically fumed silica) with small pores, around 10-100 nm, which is enclosed in a thin laminate film with low gas permeability. (Figure 2) The core material is evacuated to pressures of 0.2-3 mbar which, depending on the core material, give a thermal conductivity of 2-4 mW/m·K (Axel Berge et al, 2012). The envelope is normally polymer laminates which contain metallized polymers or aluminium foils as barrier layer. It is responsible for the maintenance of the vacuum inside the panel (Markus Erb, 2005). VIP offers good compressive strength, good fire rating performance and very high R-value up to R-39/inch (Dow Corning).

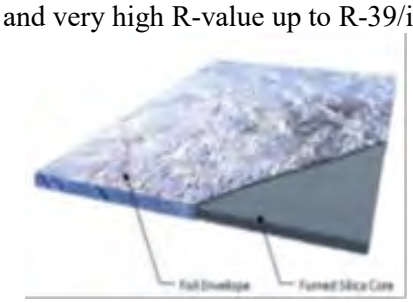


Figure 2: Vacuum Insulation Panel

Vacuum Insulation Panel used for curtain walls is typically pre-manufactured in IGU, either of double glazing or triple glazing. VIPs are protected from exterior climate by glass panes and edge seal of IGU. (Figure 3) Considering thermal bridging of the aluminized packaging envelope for each of the individual VIP's and perimeter air gap between VIP's, the resultant value of the composite panel is approximately an R-Value of 30. This could then be used in THERM to calculate the total spandrel thermal performance (Lawrence D. Carbary).

Figure 3: VIP used in IGU

For a curtain-wall system, the effective R-value is much lower than the nominal R-value due to thermal bridging. High-performance buildings require energy modeling by using effective R-values for accurate assessment and comparison of insulation systems. With a 5/8-inch VIP in double glazing IGU and considering the impact of an aluminum curtain-wall frame and edge of spandrel, the effective or overall R-value of spandrels for a typical unitized curtain-wall system at typical spandrel panel modulus drops to around R-11. (Table 3, Figure 4)

Table 3: R-values of double glazing IGU with VIPs

IGU Thickness (inch)	VIP Thickness (inch)	COP R-value (ft2.hr.F/Btu)	Overall R-value (ft2.hr.F/Btu)
1	**5/8**	**21.80**	**10.84**
1-1/8	**5/8**	**21.80**	**10.67**

COP and overall data refer to Dow Corning Architectural Insulation Modules brochure.

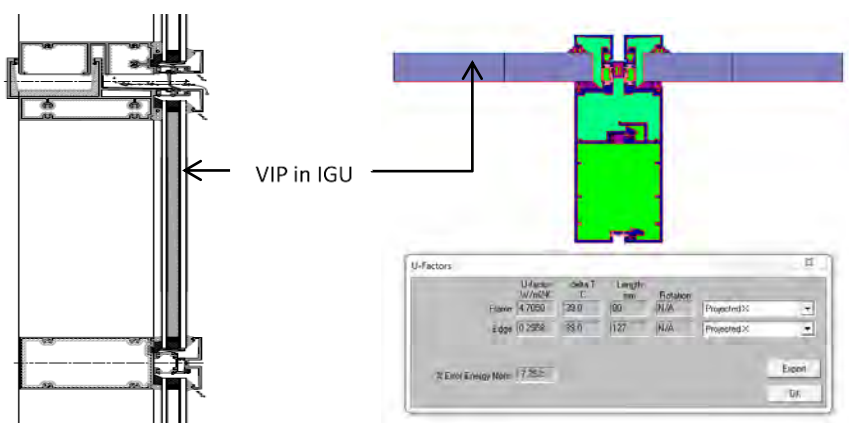


Figure 4: VIP applications and U-factors of VIP spandrel at frame and edge

Combined Conventional and VIP spandrel

Combined conventional and VIP spandrel consists of mineral wool and galvanized metal sheet (G.M.S.)

back-pan, which uses an IGU with VIP insulation integrated. Obviously both mineral wool insulation and VIP provides high thermal resistance of the curtain-wall spandrel. (Figure 5)

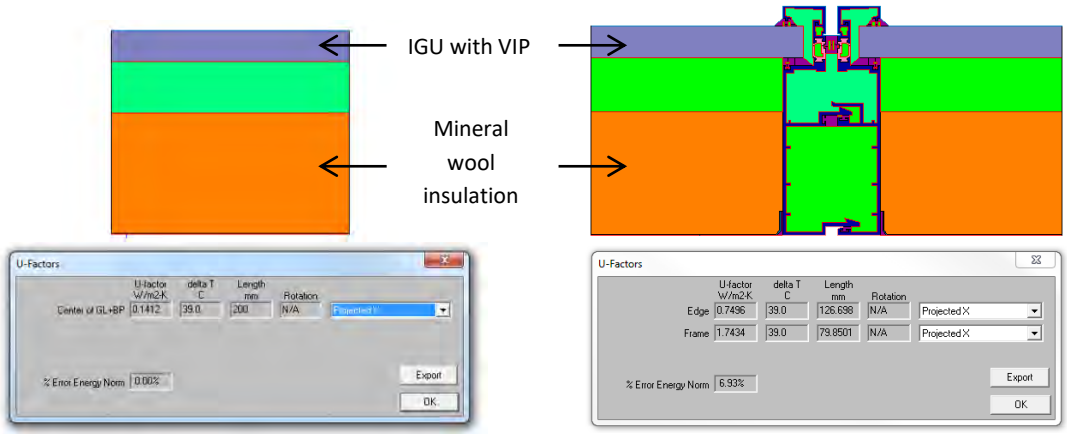


Figure 5: U-factors of combined spandrel at center of panel, frame and edge

PROBLEM STATEMENT

Even VIP has very high specific thermal resistance R-39 per inch compared to conventional mineral wool R-4.1 per inch, evidence suggests that the overall R-value of VIP spandrels might not increase much after the elimination of mineral wool insulation. Moreover, the impact of thermal bridging at the curtain wall frame for a VIP spandrel is expected to be higher than the impact for a conventional, back-insulated, spandrel; the reason is that the interior curtain wall frame is more exposed to interior conditions (higher exposed heat loss surface); on the other hand, the frame of a conventional spandrel is mostly protected by mineral wool insulation.

Certainly, a combination of conventional mineral wool insulation at the back of the spandrel with VIP at the glass is expected to offer the highest thermal resistance value.

Window to Wall Ratio (WWR) is one other important factor that affects overall thermal resistance value of curtain wall spandrel. The higher WWR, the lower the percentage of spandrel area ratio to gross curtain wall area is. Hence, the less the increase of overall R-value of spandrel is, as spandrel is changed from conventional or VIP to combined.

ASHRAE 90.1 Standard (ASHRAE, 2010) required a maximum thermal transmittance U-factor for vision part of fenestration. (Table 4).

Table 4: Building Envelope Requirements for Climate Zone 5 (A, B, C), ASHRAE 90.1-2010

Fenestration	Non-residential		Residential		Semiheated	
	Assembly Max. U	Assembly Max. SHGC	Assembly Max. U	Assembly Max. SHGC	Assembly Max. U	Assembly Max. SHGC
Metal framing (curtain wall/storefront)	U-2.56	SHGC-0.40	U-2.56	SHGC-0.40	U-2.56	SHGC-NR

ASHRAE 90.1 also requires that the total vertical fenestration area shall be less than 40% of the gross wall area (5.5.4.2.1). In other words, window to wall ration (WWR) shall be less than 40%. Actually architects often design curtain walls with larger WWR in order to increase daylight into the occupied space, or for desirable aesthetic purpose. In some cases WWR could reach 80%.

METHODOLOGY

Modeling with THERM 6.3

By integrating with a real unitized curtain wall system, the overall U-factors or R-values of three types of spandrel approaches are modeled in THERM (Figure 6).

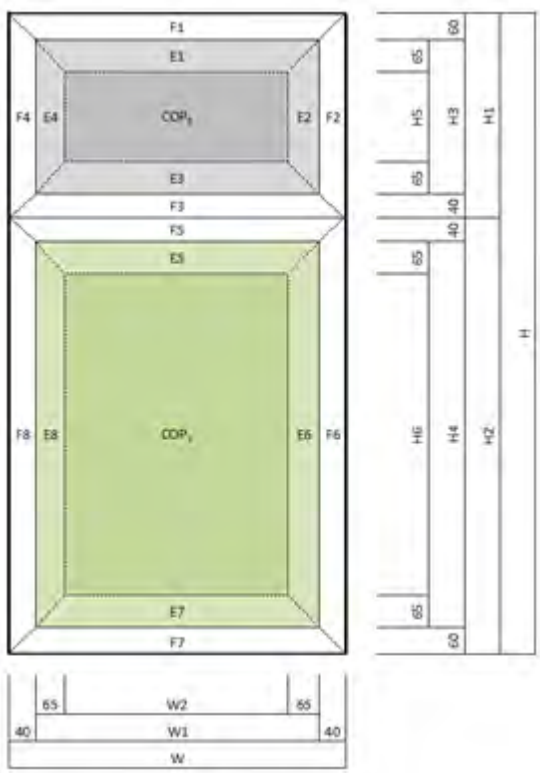


Figure 6: Components for the whole curtain wall area-weighted calculation

Per NFRC 100: Procedures for Determining Fenestration Product U-factors", the whole-product area weighted U-factor calculation is shown below. R-value is easily calculated accordingly.

$$Ut = \frac{[\sum(\mathrm{Uf} * \mathrm{Af}) + \sum(\mathrm{Ue} * \mathrm{Ae}) + \sum(\mathrm{Ucop} * \mathrm{Acop})]}{\mathrm{At}}$$

Where:

Ut = Total product U-factor, W/m2-°K.

At = Projected fenestration product area, m2.

Uf = Frame U-factor, W/m2-°K.

Af = Frame area, m2.

Ue = Edge-of-panel U-factor, W/m2-°K.

Ae = Edge-of-panel area, m2.

Ucop = Center-of-panel U-factor, W/m2-°K.

Acop = Center-of-panel Area, m2.

Modeling with eQuest 3-65

eQuest is a sophisticated, yet easy to use building energy use analysis tool which provides professional-level results with an affordable level of effort. This is accomplished by combining a building creation wizard, an energy efficiency measure (EEM) wizard and a graphical results display module with an enhanced DOE-2-derived building energy use simulation program.

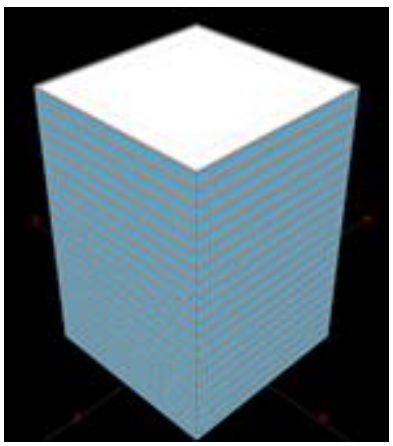


Figure 7: 3D model in eQuest

A 20-storey commercial building located in Vancouver BC, clad with curtain wall was modelled using eQuest (Figure 7). Three spandrel scenarios (conventional spandrel, VIP spandrel, and combined spandrel) studied in this paper were simulated and compared. Of these three scenarios, the vision panels of the curtain-walls were same. Furthermore, for each of scenario, three models at WWR 40%, 60% and 80% were simulated and compared. (Figure 8)

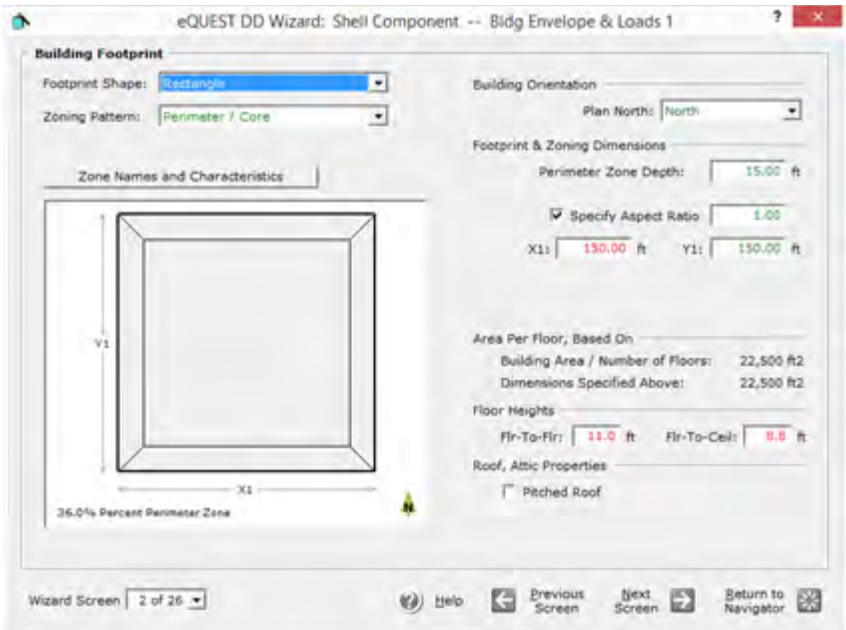


Figure 8: General building parameters in eQuest

Monthly and annual energy consumption of electric and gas by end use were reported. Graphic charts and spread sheets were plotted for easy review. Comparison of annual consumption of different conditions described above was given. Graphic charts and spread sheets were plotted as well for analysis.

ANALYSIS AND RESULTS

Modeling with THERM 6.3

Based on equation specified on NFRC 100: Procedures for Determining Fenestration Product U-factors", the whole-product area weighted U-factor calculation. U-factors of frame, edge and center of panel are modeled with THERM 6.3 for a typical curtain wall module of width 1500mm (W) and height of 3300mm (H).

Comparison of Thermal Resistance of Three Spandrel Scenarios at Particular WWR

For a WWR of 40%, the weighted R-value of spandrel by using VIP at the spandrel slightly increases to R-7.83 ft2.h.°F/Btu from R-7.48 ft2.h.°F/Btu for a conventional spandrel. Meanwhile the R-value of spandrel by combining conventional and VIP increases to R-11.54 ft2.h.°F/Btu, with 54% increase. (Figure 9)

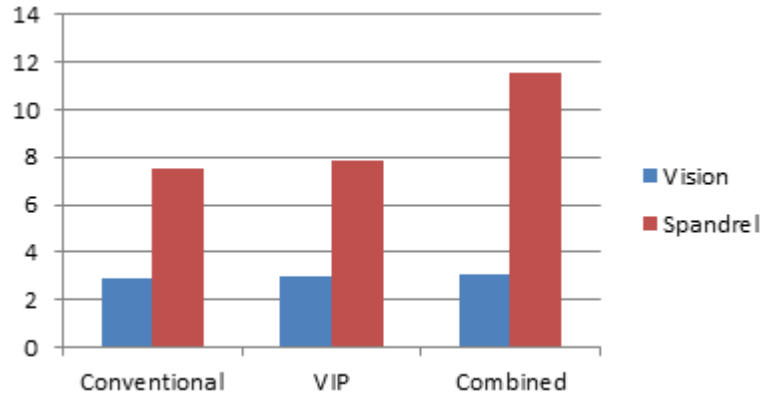


Figure 9: Comparison of spandrel R-values (ft2.h.°F/Btu) @ WWR 40%

The overall R-value of the whole curtain wall increases from R-4.60 ft2.h.°F/Btu of conventional spandrel approach to R-5.48 ft2.h.°F/Btu of combined spandrel approach, only a 19% increase, due to the poor performance of the vision panel (Figure 10).

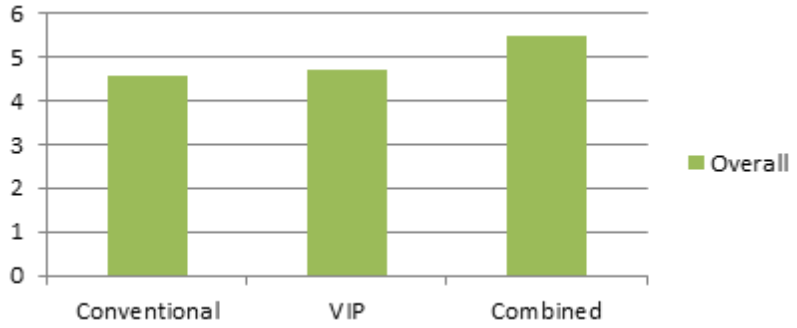


Figure 10: Comparison of overall R-values (ft2.h.°F/Btu) @ WWR 40%

By not following ASHRAE's recommendation, for most high-rise curtain-wall projects of either residential or commercial buildings, the architect designs curtain walls with a larger WWR in order to provide increased daylight into the occupied space, or for desirable esthetic purposes. In some cases the WWR could reach 80%.

For a WWR of 80%, the R-value of the spandrel by using VIP at the spandrel slightly increases to R-4.80 ft2.h.°F/Btu from R-4.35 ft2.h.°F/Btu for a conventional spandrel. Meanwhile R-value of the spandrel by combining conventional and VIP increases to R-6.19 ft2.h.°F/Btu, with 42% increase. (Figure 11)

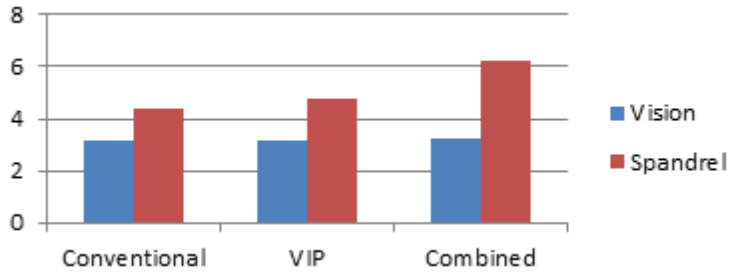


Figure 11: Comparison of spandrel R-values (ft2.h.°F/Btu) @ WWR 80%

Affected by a low R-value of the vision panel, the overall R-value of the whole curtain wall only increases

by 7%, from R-3.34 ft^2.h.°F/Btu for a conventional spandrel to R-3.58 ft^2.h.°F/Btu for a combined spandrel (with mineral wool plus VIP: Figure 12).

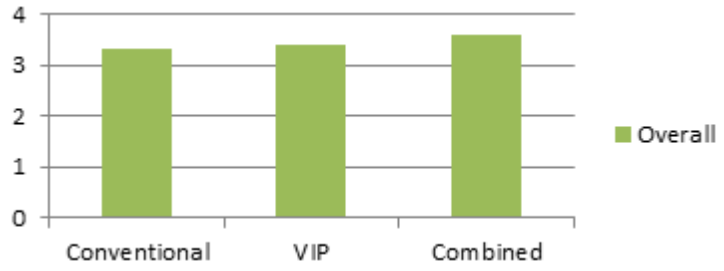


Figure 12: Comparison of overall R-values (ft2.h.°F/Btu) @ WWR 80%

EFFECT OF WWR ON SPANDREL AND CURTAIN WALL THERMAL RESISTANCE

Figure 13 plots the R-values of spandrels and overall curtain walls for all three spandrel scenarios studied in this paper at WWR 40%, 60% & 80%. Figure 13 shows similar diminished rates of return and trends in thermal resistance. From this Figure, the R-values of conventional and VIP scenarios are close to each other no matter what the WWR is. From the Figure it is also clear that for any WWR situation, even though the R-value of the combined spandrel approach increases dramatically, the R-value of overall curtain wall only increases a little.

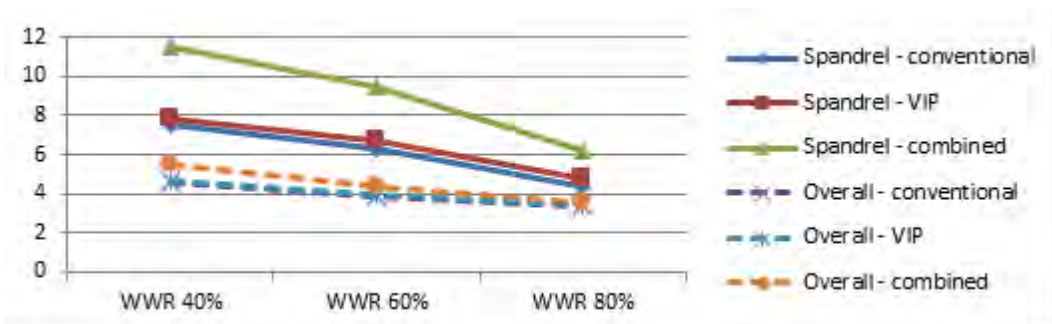


Figure 13: R-values of spandrel only and overall curtain wall at different WWRs (ft2.h.°F/Btu)

The conclusion that can be drawn from the analysis is that simply by replacing a conventional spandrel with a VIP spandrel has negligible effect on improving the thermal performance of overall curtain wall system. A combined conventional and VIP spandrel results in an increased thermal resistance of overall curtain wall system; however, such an increase diminishes when WWR is gets large. In conclusion, the benefit of using combined spandrel approach is still limited, because of the relatively poor performance of the vision panel.

Modeling with eQuest 3.65

Gas consumption includes two parts, space heat and hot water. Gas consumption related to building envelope thermal performance is for space heat but not hot water. Gas consumption for hot water remains the same for all spandrel scenarios at all WWRs. Electric consumption related to envelope thermal

performance is for space cooling. Electric consumption for other facilities such as lights, fans, pumps etc., doesn't vary significantly due to changes in the curtain wall spandrel system or WWR.

Effect of Spandrel System on Gas and Electric Consumption

For a WWR of 40%, the annual gas consumption slightly decreases from 2005.3 MBtu for a conventional spandrel scenario to 1967.3 MBtu for a VIP spandrel scenario. It drops further to 1698.7 Mega Btu, with 15% saving. Electric consumption for space cooling is unchanged for all spandrel scenarios (Figure 14).

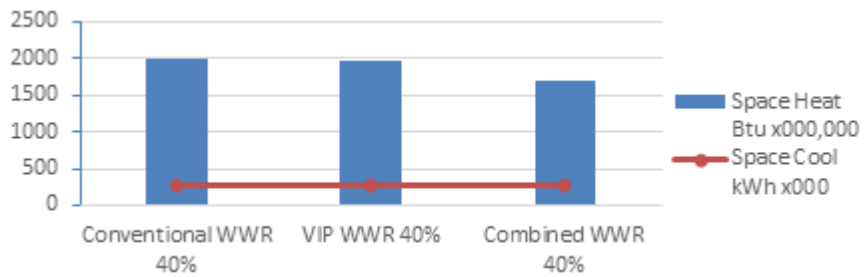


Figure 14: Comparison of annual electric and gas consumption @ WWR 40%

For a WWR of 80%, the annual gas consumption slightly decreases from 2733.7 MBtu for a conventional spandrel scenario to 2683.9 MBtu for a VIP spandrel. It drops further to 2582.5 Mega Btu, with only 6% saving. Also, electric consumption for space cooling is unchanged for all spandrel scenarios. (Figure 15)

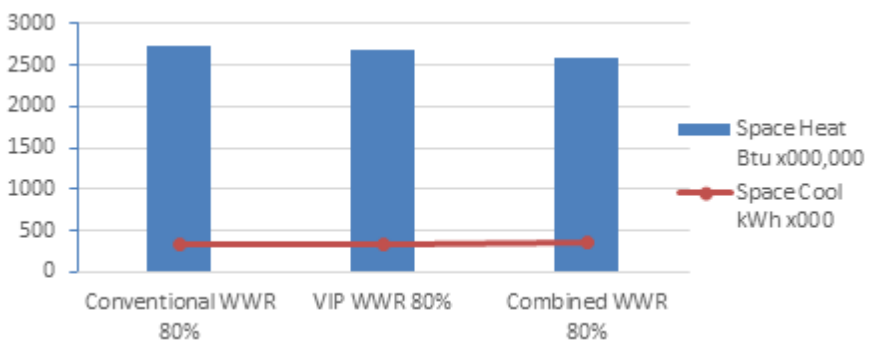


Figure 15: Comparison of annual electric and gas consumption @ WWR 80%

Effect of WWR on Gas Consumption

Electric consumption remains almost constant at any given WWR as the spandrel system changes, so only gas consumption is compared among the three curtain wall spandrel scenarios, for WWR of 40%, 60% and 80%.

Figure 16: Annual gas consumption at different WWRs

As shown in Figure 16, gas consumption increases as WWR increases. Moreover, gas consumption at VIP spandrel scenario is close to gas consumption at conventional spandrel scenario, no matter what WWR is. Gas consumption at combined scenario decreases as spandrel changes from conventional system to combined system. As WWR increases from 40% to 80%, consumption saving by changing spandrel from conventional system to combined system decreases from 15% to 6%. Increasing spandrel thermal resistance helps less and less on gas consumption as WWR increases.

CONCLUSIONS

From results modelled by THERM 6.3, simply replacing a conventional spandrel with a VIP spandrel provides almost no improvement of thermal performance for the overall curtain-wall system. A combined (conventional plus VIP) spandrel approach increases the thermal resistance of the overall curtain-wall system, but the increase is not obvious, especially when WWR is high. Therefore, the benefit of using the combined spandrel approach is limited.

Results simulated by eQuest 3.65 draws similar conclusions as the Therm 6.3 modelling. Converting a conventional spandrel of curtain wall to a VIP spandrel doesn't save energy consumption. Saving on energy consumption by using a combined spandrel instead of a conventional spandrel is not obvious either. The energy saving becomes even less as WWR increases. Therefore, it is not recommended to upgrade a conventional spandrel of curtain wall to a VIP spandrel, as the cost of the VIP spandrel is much higher than the conventional spandrel.

FUTURE WORK

Even though VIP is a new material with very high thermal resistance, replacing a conventional spandrel with VIP provides little improvement in the thermal performance, and doesn't reduce energy consumption. The benefit of combining conventional and VIP spandrel in reducing energy consumption is limited, especially for high WWR. Future work may include life cycle cost (LCC) analysis to forecast necessities of upgrading conventional to combined spandrel of curtain wall.

However, increasing spandrel thermal resistance doesn't significantly improve the overall thermal performance of the curtain-wall, unless the vision wall is upgraded. Especially since architects prefer high WWRs of curtain walls, costs on improving spandrel thermal properties don't balance the energy saving.

Future work may include research on improving the thermal performance of the vision panel as well.

REFERENCES

1) R.L. Quirouette, Building Envelope Design Using Metal and Glass Curtain Wall Systems, Building Practice Note, 1982

2) Dow Corning Vacuum Insulation Panel, Dow Corning Construction Solution journal

3) Axel Berge and Par Johansson, Literature Review of High Performance Thermal Insulation, 2012

4) Markus Erb, Vacuum Insulation Panel Properties and Building Applications, 2005

5) Lawrence D. Carbary, High Performance Curtain Wall Using Vacuum Insulated Panel (VIP) Spandrels

APPENDIX

Modelling Results by THERM 6.3

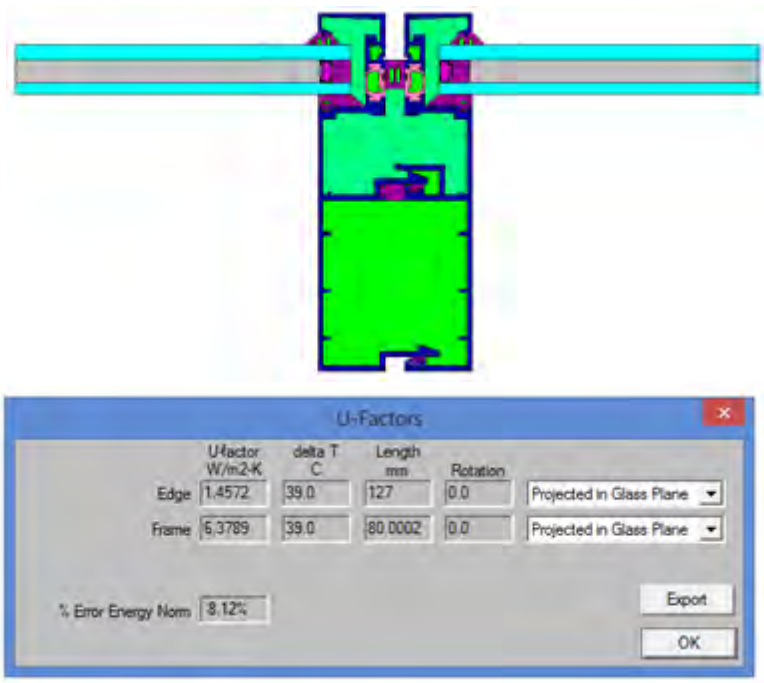


Figure 17: Frame and Edge U-factors at vertical mullion of vision panel

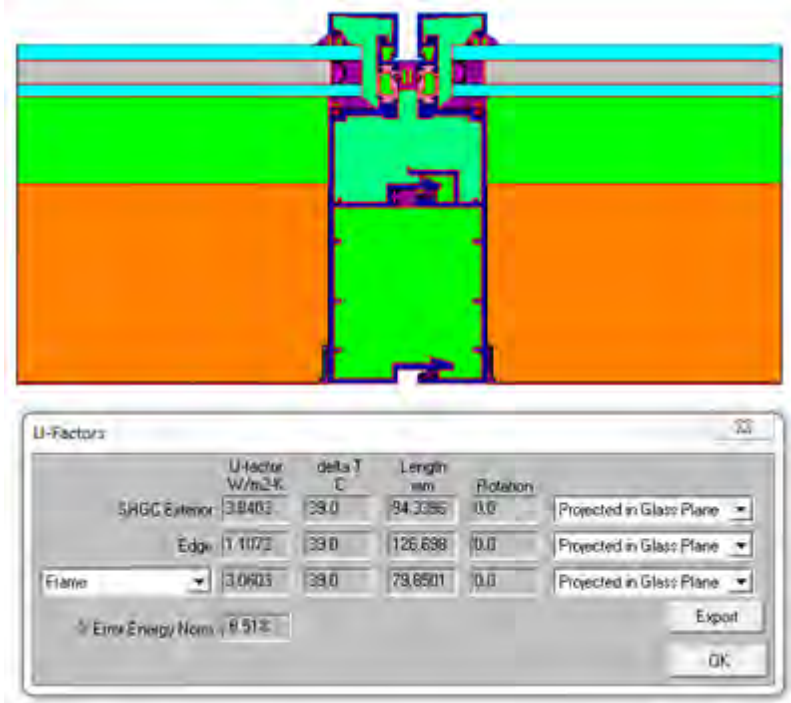
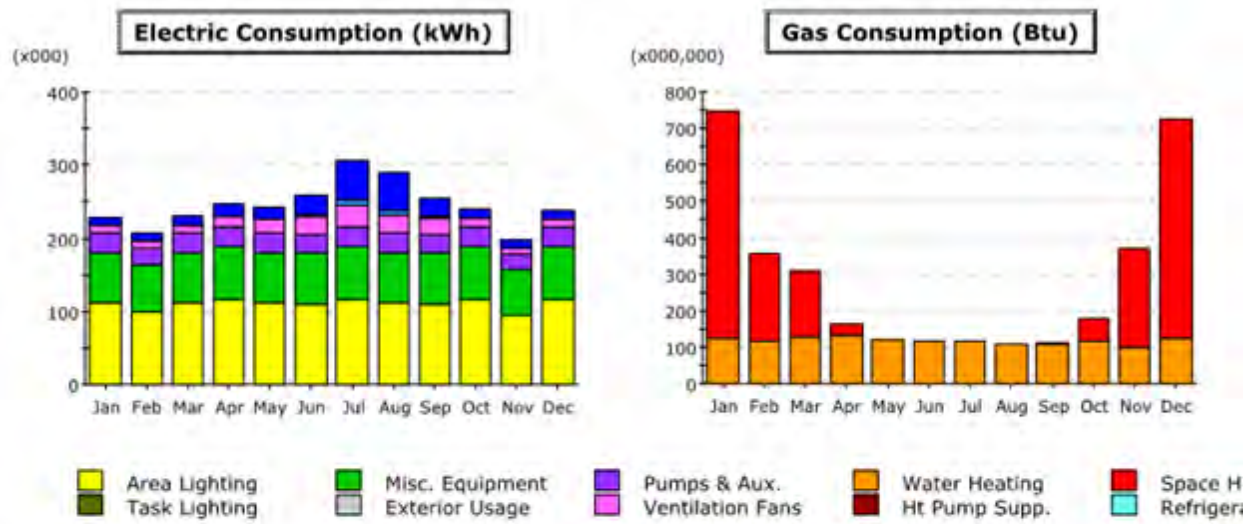


Figure 18: Frame and Edge U-factors at vertical mullion of conventional spandrel

Modelling Results by eQuest 3-65

Project/Run: BSCI 9750_20140824_conventional - Baseline Design Run Date/Time: 08/28/14 @ 01:16



Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	12.2	11.0	12.1	16.0	14.8	27.0	55.2	52.0	26.5	12.7	10.4	12.7	262.6
Heat Reject.	0.0	-	-	0.4	0.3	2.1	7.3	7.0	2.2	-	-	-	19.3
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	10.2	9.1	10.9	15.0	20.0	24.8	29.0	25.4	21.0	12.7	8.7	10.5	197.5
Pumps & Aux.	25.6	23.2	25.6	26.8	25.6	25.6	26.8	25.6	25.6	26.8	22.0	26.8	306.1
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	69.9	63.2	69.9	72.3	69.8	69.5	72.7	69.8	69.5	72.6	61.2	72.7	833.1
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	111.0	100.4	111.0	115.9	111.0	110.9	116.1	111.0	110.9	116.0	95.8	116.1	1,326.0
Total	228.8	207.1	229.6	246.4	241.5	259.9	307.0	290.9	255.7	240.9	197.9	238.8	2,944.8

Gas Consumption (Btu x000,000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	619.1	242.5	178.2	30.7	0.4	-	-	-	4.9	62.0	268.1	599.5	2,005.3
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	125.4	115.4	127.7	131.0	121.1	116.8	116.8	109.5	109.0	116.6	101.2	126.2	1,415.7
Vent. Fans	-	-	-	-	-	-	-	-	-	-	-	-	-
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	-	-	-	-	-	-	-	-	-	-	-	-	-
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	744.5	357.9	305.8	161.7	121.4	115.0	116.8	109.5	113.9	178.6	369.3	725.7	3,420.9

Figure 19: Electric and gas consumption for conventional spandrel scenario at WWR 40%