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

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Agenda

• Introduction
• Modeling Procedure
• Vacuum Insulated Glass (VIG)
• Whole Wall Performance
• Condensation Risk
• Energy Analysis of Modeled Buildings (Phoenix, St. Louis, Detroit, Winnipeg)
• Limitations and Opportunities for Future Development
• Acknowledgments
• Conclusion
Introduction

- A need for sustainable curtain wall construction
- Buildings account for 17-40 percent of total energy consumption
- Properly designed building enclosures can increase energy savings
- Buildings with curtain wall facades generally have lower thermal performance compared to other types of enclosure systems
- Curtain wall systems can be designed for increased energy efficiency
- This study examines the thermal performance of curtain walls with:
  - Four glass types: two insulating glass units (IGU) and two vacuum insulated glass units (VIG & HVIG)
  - Two spandrel insulation methods: industry standard mineral wool and vacuum insulated panels (VIP)
Code-Compliant Commercial Building – 40% Glass, 60% Spandrel

Figure 1: Elevation of typical curtain wall area.

Figure 2: Isometric view of typical curtain wall area.
Structural Silicone Attachment

Figure 3: Enlarged view of structural silicone attachment of glass and spandrel to curtain wall frame.
Comparisons of Glazing Types and Spandrel Types

Glass types (all have a high-performance Low-E coating, and IGUs have a warm edge spacer):

- Clear double-pane IGU (WINDOW® 5.2)
- Clear triple-pane IGU (WINDOW® 5.2)
- Clear vacuum insulating glass (VIG) unit (user-defined database)
- Clear hybrid VIG/IGU (HVIG) unit (user-defined database)

Spandrel insulation types:

- Fumed-silica VIP encapsulated in an aluminum skin (THERM® 5.2)
- Typical insulation method, mineral wool applied to energy code minimum (THERM® 5.2)
Modeling Procedures

- Parallel Path Method (PPM)
  - Parallel path heat flow
    - \( U_{av} = aU_a + bU_b + \ldots + nU_n \)

- WINDOW\textsuperscript{®} 5.2/THERM\textsuperscript{®} 5.2 software

- NFRC 100 (General Conformance)
  - Procedure for Determining Fenestration Product U-Factors

- Vision and spandrel area
Vision Area – 6' x 5'

Figure 4: Elevation of vision glass indicating COG and EOG areas.
Vacuum Insulated Glass (VIG)

- No certified or validated method currently exists to simulate the new VIG technology

- For the purposes of this study, a method was developed to simulate VIG in the LBNL software to provide a comparison to standard products using custom glass types

- Results of the VIG and HVIG simulations appeared to be conservative, generating a higher U-Factor than expected
### Vision Area Results – Typical Size 6' x 5'

#### Table 1: Calculation and comparison of vision unit total product U-Factors. Based on general conformance with NFRC 100.

<table>
<thead>
<tr>
<th>VISION TYPE</th>
<th>FRAME</th>
<th>EOG</th>
<th>COG</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area (square inch)</td>
<td>330.21</td>
<td>622.92</td>
<td>3,552.88</td>
<td>4,506.01</td>
</tr>
<tr>
<td>Percentage</td>
<td>7.33%</td>
<td>13.82%</td>
<td>78.85%</td>
<td>100.00%</td>
</tr>
</tbody>
</table>

#### VISION UNIT TYPE 1 (DOUBLE PANES WITH LOW E)

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>U-Factor</td>
<td>0.8661</td>
<td>0.3014</td>
<td>0.2891</td>
<td>—</td>
</tr>
<tr>
<td>R-Value</td>
<td>1.1546</td>
<td>3.3179</td>
<td>3.4590</td>
<td>—</td>
</tr>
<tr>
<td>Weighted U-Factor</td>
<td>0.0635</td>
<td>0.0417</td>
<td>0.2279</td>
<td>—</td>
</tr>
<tr>
<td>Composite U-Factor</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>0.33</td>
</tr>
<tr>
<td>Composite R-Value</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>3.00</td>
</tr>
</tbody>
</table>

#### VISION UNIT TYPE 2 (TRIPLE PANES WITH LOW E)

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
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<tr>
<td>U-Factor</td>
<td>0.6159</td>
<td>0.2327</td>
<td>0.2164</td>
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<tr>
<td>R-Value</td>
<td>1.6236</td>
<td>4.2974</td>
<td>4.6211</td>
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<tr>
<td>Weighted U-Factor</td>
<td>0.0451</td>
<td>0.0322</td>
<td>0.1706</td>
<td>—</td>
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<tr>
<td>Composite U-Factor</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>0.25</td>
</tr>
<tr>
<td>Composite R-Value</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>4.03</td>
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</table>

#### VISION UNIT TYPE 3 (VIG WITH LOW E)

<p>| | | | | |</p>
<table>
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<tr>
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</thead>
<tbody>
<tr>
<td>U-Factor</td>
<td>1.028</td>
<td>0.0803</td>
<td>0.082</td>
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<tr>
<td>R-Value</td>
<td>0.9728</td>
<td>12.4533</td>
<td>12.1951</td>
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<tr>
<td>Weighted U-Factor</td>
<td>0.0753</td>
<td>0.0111</td>
<td>0.0647</td>
<td>—</td>
</tr>
<tr>
<td>Composite U-Factor</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>0.15</td>
</tr>
<tr>
<td>Composite R-Value</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>6.62</td>
</tr>
</tbody>
</table>

#### VISION UNIT TYPE 4 (HVIG WITH LOW E)

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>U-Factor</td>
<td>0.7219</td>
<td>0.0712</td>
<td>0.0662</td>
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<tr>
<td>R-Value</td>
<td>1.3862</td>
<td>14.0449</td>
<td>15.1057</td>
<td>—</td>
</tr>
<tr>
<td>Weighted U-Factor</td>
<td>0.0529</td>
<td>0.0098</td>
<td>0.0522</td>
<td>—</td>
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<tr>
<td>Composite U-Factor</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>0.11</td>
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<tr>
<td>Composite R-Value</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>8.70</td>
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</table>
Spandrel Area – Typical Size 6' x 8'

Two methods evaluated:

• Industry standard method
  - Mineral wool infill between curtain wall framing
  - Additional layer at mullion covers

• VIP composite panel
  - Multiple VIPs encapsulated between two aluminum skins
  - Structural silicone attachment
VIP Spandrel Area

Thermal bridging of VIP

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.
VIP Spandrel Area

Figure 7: Exploded illustration of composite panel.

Figure 8: Cut away illustration of composite panel.
VIP Spandrel Area

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.
Spandrel Area Modeling Procedure

Total product thermal performance
• Generally conforming to NFRC 100 “Procedure for Determining Fenestration Product U-Factors”

Areas included for the spandrel portion of the wall system to produce the total product U-Factor:
• **Mineral Wool:**
  - 3.47% for frame (Vertical)
  - 2.51% for frame (Horizontal)
  - 42.53% for EOP (Vertical)
  - 28.65% for EOP (Horizontal)
  - 22.83% for COP

• **VIP:**
  - 22.83% for COP
  - 71.18% for EOP
  - 5.99% for frame

Figure 10: Elevation of spandrel indicating COP and EOP areas.
# Mineral Wool Spandrel Area Results

<table>
<thead>
<tr>
<th>MINERAL WOOL</th>
<th>CONDITION</th>
<th>FRAME (VERTICAL)</th>
<th>FRAME (HORIZONTAL)</th>
<th>EOP (VERTICAL)</th>
<th>EOP (HORIZONTAL)</th>
<th>COP</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>U-Factor</td>
<td></td>
<td>0.0789</td>
<td>0.2646</td>
<td>0.1236</td>
<td>0.1657</td>
<td>0.0627</td>
<td></td>
</tr>
<tr>
<td>R-Value</td>
<td></td>
<td>12.674</td>
<td>3.779</td>
<td>8.091</td>
<td>6.035</td>
<td>15.949</td>
<td></td>
</tr>
<tr>
<td>Area</td>
<td></td>
<td>240.00</td>
<td>173.75</td>
<td>2,940.00</td>
<td>1,980.00</td>
<td>1,578.25</td>
<td>6,912.00</td>
</tr>
<tr>
<td>Percentage</td>
<td></td>
<td>3.47%</td>
<td>2.51%</td>
<td>42.53%</td>
<td>28.65%</td>
<td>22.83%</td>
<td>100.00%</td>
</tr>
<tr>
<td>Weighted U-Factor</td>
<td></td>
<td>0.0027</td>
<td>0.0067</td>
<td>0.0526</td>
<td>0.0475</td>
<td>0.0143</td>
<td></td>
</tr>
<tr>
<td>Composite U-Factor</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.12</td>
</tr>
<tr>
<td>Composite R-Value</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8.08</td>
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</tbody>
</table>

Table 2: Calculation of spandrel total product U-Factor with industry standard mineral wool application.
### Table 3: Calculation of spandrel total product U-Factor utilizing VIP application.

<table>
<thead>
<tr>
<th>CONDITION</th>
<th>FRAME</th>
<th>EOP</th>
<th>COP</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>U-Factor</td>
<td>0.2247</td>
<td>0.0508</td>
<td>0.033</td>
<td></td>
</tr>
<tr>
<td>R-Value</td>
<td>4.45</td>
<td>19.69</td>
<td>30.30</td>
<td></td>
</tr>
<tr>
<td>Area</td>
<td>413.75</td>
<td>4,920.00</td>
<td>1,578.25</td>
<td>6,912.00</td>
</tr>
<tr>
<td>Percentage</td>
<td>5.99%</td>
<td>71.18%</td>
<td>22.83%</td>
<td>100.00%</td>
</tr>
<tr>
<td>Weighted U-Factor</td>
<td>0.0135</td>
<td>0.0362</td>
<td>0.0075</td>
<td></td>
</tr>
<tr>
<td>Composite U-Factor</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>0.0571</td>
</tr>
<tr>
<td>Weighted R-Value</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>17.50</td>
</tr>
</tbody>
</table>
Whole Wall Thermal Performance

<table>
<thead>
<tr>
<th>GLASS TYPE</th>
<th>2 PANE IGU</th>
<th>3 PANE IGU</th>
<th>VIG</th>
<th>HVIG</th>
<th>2 PANE IGU</th>
<th>3 PANE IGU</th>
<th>VIG</th>
<th>HVIG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spandrel type</td>
<td>MW</td>
<td>MW</td>
<td>MW</td>
<td>MW</td>
<td>VIP</td>
<td>VIP</td>
<td>VIP</td>
<td>VIP</td>
</tr>
<tr>
<td>U-Factor</td>
<td>0.207</td>
<td>0.173</td>
<td>0.135</td>
<td>0.121</td>
<td>0.168</td>
<td>0.133</td>
<td>0.095</td>
<td>0.081</td>
</tr>
<tr>
<td>R-Value</td>
<td>4.82</td>
<td><strong>5.77</strong></td>
<td>7.42</td>
<td>8.24</td>
<td><strong>5.97</strong></td>
<td>7.49</td>
<td>10.56</td>
<td>12.28</td>
</tr>
</tbody>
</table>

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

- Structural silicone attachment enables higher interior surface temperatures
- Warmer surface temperatures will lead to lower potential for condensation
- Higher interior RH possible
- Additional benefit can be seen when using both the HVIG and VIP together
Condensation Risk Analysis

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.
Condensation Risk Analysis

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.
Condensation Risk Analysis

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.
Condensation Risk Analysis

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.
## Condensation Risk Analysis

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

<table>
<thead>
<tr>
<th>FIGURE NUMBER</th>
<th>FIG. 11</th>
<th>FIG. 12</th>
<th>FIG. 13</th>
<th>FIG. 14</th>
<th>FIG. 15</th>
<th>FIG. 16</th>
<th>FIG. 17</th>
<th>FIG. 18</th>
</tr>
</thead>
<tbody>
<tr>
<td>GLASS TYPE</td>
<td>2 PANE IGU</td>
<td>3 PANE IGU</td>
<td>VIG</td>
<td>HVIG</td>
<td>2 PANE IGU</td>
<td>3 PANE IGU</td>
<td>VIG</td>
<td>HVIG</td>
</tr>
<tr>
<td>Spandrel type</td>
<td>MW</td>
<td>MW</td>
<td>MW</td>
<td>MW</td>
<td>VIP</td>
<td>VIP</td>
<td>VIP</td>
<td>VIP</td>
</tr>
<tr>
<td>Cold point glass</td>
<td>38°F</td>
<td>41°F</td>
<td>47°F</td>
<td>49°F</td>
<td>50°F</td>
<td>55°F</td>
<td>62°F</td>
<td>63°F</td>
</tr>
<tr>
<td>Cold point frame</td>
<td>40°F</td>
<td>39°F</td>
<td>41°F</td>
<td>41°F</td>
<td>62°F</td>
<td>64°F</td>
<td>62°F</td>
<td>64°F</td>
</tr>
</tbody>
</table>

### Key Learning Point

<table>
<thead>
<tr>
<th>FIGURE NUMBER</th>
<th>FIG. 11</th>
<th>FIG. 12</th>
<th>FIG. 13</th>
<th>FIG. 14</th>
<th>FIG. 15</th>
<th>FIG. 16</th>
<th>FIG. 17</th>
<th>FIG. 18</th>
</tr>
</thead>
<tbody>
<tr>
<td>GLASS TYPE</td>
<td>2 PANE IGU</td>
<td>3 PANE IGU</td>
<td>VIG</td>
<td>HVIG</td>
<td>2 PANE IGU</td>
<td>3 PANE IGU</td>
<td>VIG</td>
<td>HVIG</td>
</tr>
<tr>
<td>Max RH for no condensation</td>
<td>31%</td>
<td>32%</td>
<td>35%</td>
<td>35%</td>
<td>49%</td>
<td>59%</td>
<td>76%</td>
<td>79%</td>
</tr>
</tbody>
</table>
Condensation Findings – Discussion

• Curtain wall systems utilizing mineral wool have a cold point of approximately 40°F, regardless of the glass type

• Glass type does not have much of an impact on the risk of condensation with mineral wool spandrel

• Type of spandrel insulation is the primary factor dictating the level of interior RH that can be tolerated

• VIP insulation should be utilized to increase the condensation resistance of a given system
Energy Analysis

- Basic energy modeling was performed for a five-story-tall commercial office building for four locations.
- The eight combined systems were modeled for energy use and compared.

Figure 19: Illustration of commercial office building as modeled in EFEN 1.3.10.
Figure 20: Graph of totals of Phoenix energy use sorted by use.
Model for St. Louis, Missouri

MBtu used – St. Louis

Figure 21: Graph of totals of St. Louis energy use sorted by use.
Figure 22: Graph of totals of Detroit energy use sorted by use.
Figure 23: Graph of totals of Winnipeg energy use sorted by use.
Energy Use in Building Models – Discussion

• For each location:
  - The top three performers use VIP spandrel
  - Mineral wool performs at the bottom two places

• When thermal performance is the driver, the best glass type paired with the best spandrel type will provide the lowest energy usage

• Energy benefits must be weighed against:
  - Potential condensation issues
  - Facade weight
  - Constructability
Limitations and Opportunities for Future Development

• High-performance materials presented and modeled in this paper are very new to the commercial construction industry, presenting challenges for modeling

• Modeling software needs to be advanced to provide results that can be easily obtained and understood

• Lab testing of full-size curtain wall systems modeled here needs to be performed

• Constructability of these systems will need fine tuning as with any new technology
A Note From Dr. John Straube – Sept. 2008
Building Science Corporation
Conclusions

• VIG and VIP spandrel systems should be combined to maximize building energy performance

• 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

• Colder climates have more to gain by using a higher-performing system; using the VIP insulation indicates much less potential for condensation
Acknowledgments

• Special thanks to Ryan Asava of the SmithGroupJJR for model creation
Thank You!

• Any questions?
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