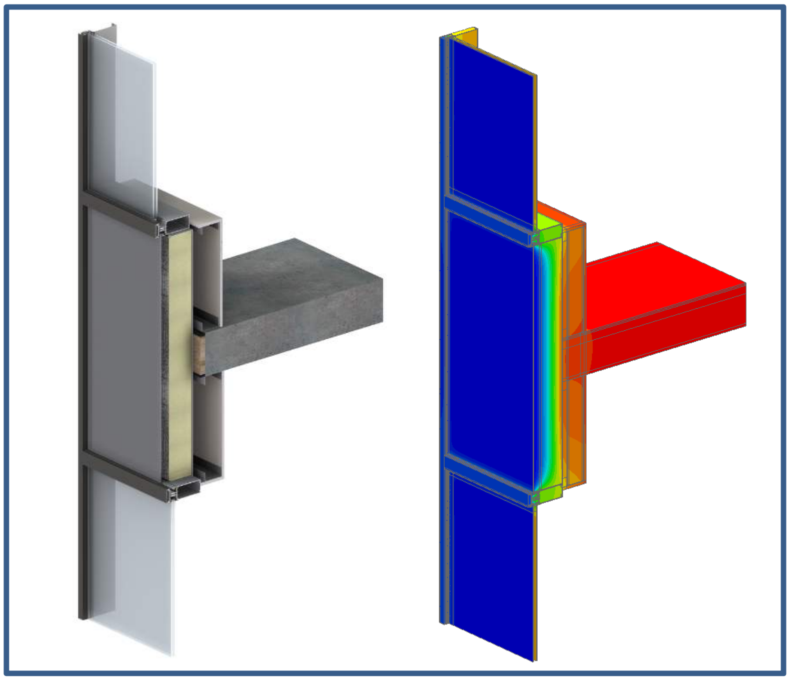
Report Number: 5160440
August 18th, 2016

MORRISON HERSHFIELD

3-Dimensional Thermal Analysis of Lenmak EnvaTherm and SpandrelTherm Backpan Assemblies



Presented to:

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Edmonton, AB

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1. INTRODUCTION AND BACKGROUND

Lenmak Exterior Innovations Inc (Lenmak) is a manufacturer of insulated back pan and panel systems for use in curtain wall opaque spandrel applications. Morrison Hershfield (MH) was contracted by Lenmak to evaluate the thermal performance, U- and R-Values, of their EnvaTherm and SpandrelTherm systems within a generic stick-built curtain wall system. These values were then compared to a generic mineral wool insulated backpan system. In addition, the systems were also examined for differences in performance when solar heating is included. This report is a summary of the overall analysis.

1.1 Backpan System Descriptions

The EnvaTherm backpan system analyzed in this report, shown in Figure 1, consists of a 24 Ga galvalume backpan with open cell, polyurethane foam. The polyurethane foam is pour filled and intended to be bonded to the 5 sides of the backpan. The foam is covered with a foil faced backing sheet, fully adhered to the foam on the front side of the system.

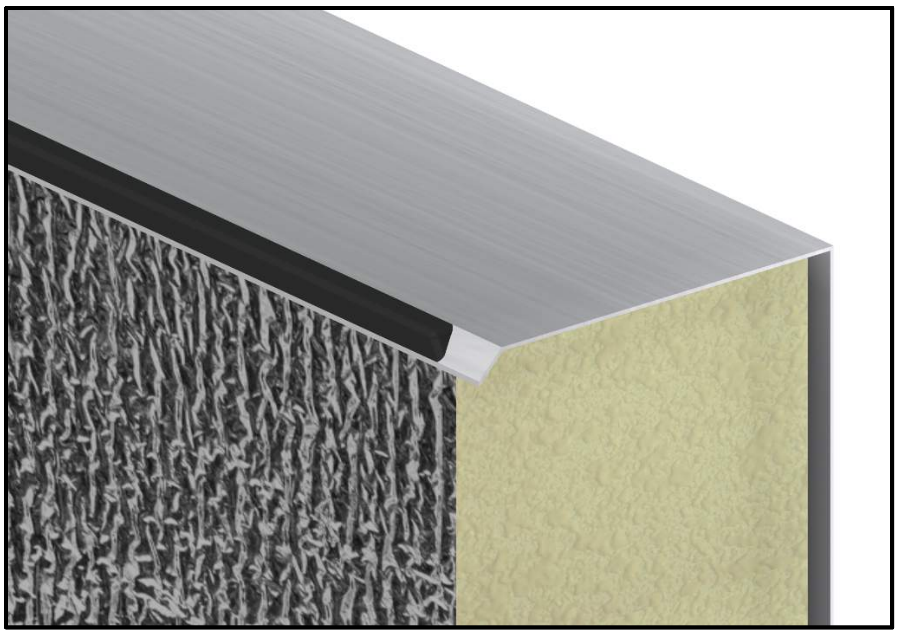


Figure 1: *EnvaTherm Backpan System with Bird Beak Flange*

The backpan edges for connection to the curtain wall system are manufactured in different configurations. Two of these configurations, the *box style* and *bird beak* flanges are shown in Figure 2. The *box style* flange extends the back pan down into the glazing pocket of the spandrel and can act as in integrated glazing adapter. The *bird beak* flange creates an angled lip around the front of the backpan, which allows for a continuous bead of sealant to be applied around the edge of the system.

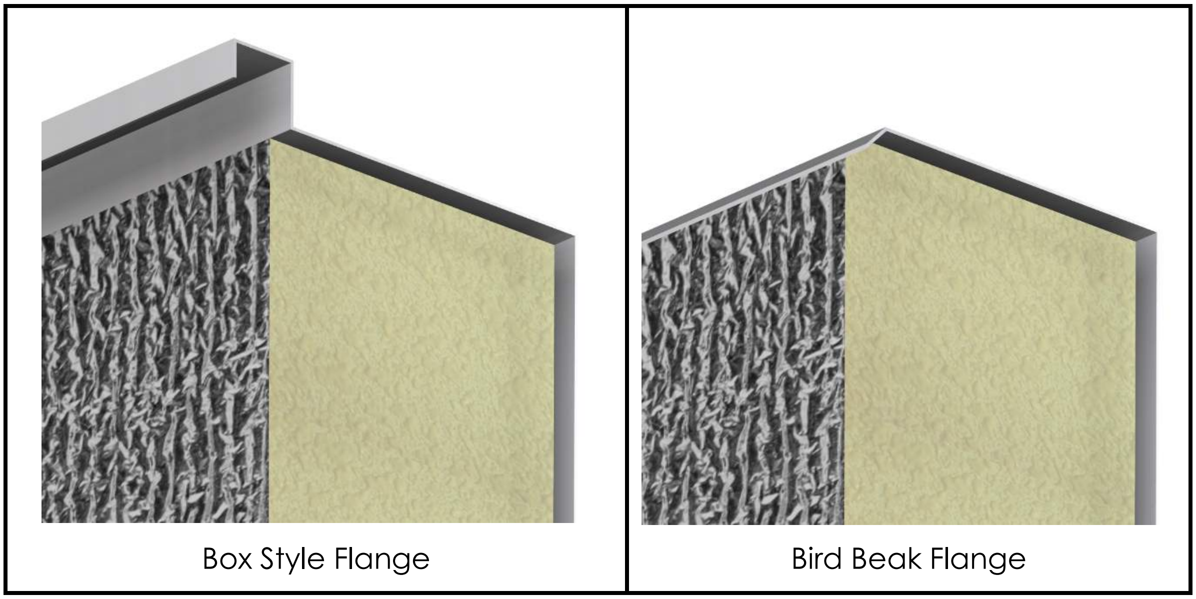


Figure 2: *EnvaTherm Backpan Flange Configurations*

The EnvaTherm system, like most insulated backpans, is intended to be protected by an exterior spandrel covering. This includes single, double glazed IGUs or composite metal panels which are held in place by the pressure plate or adapter in a captured curtain wall system. SpandrelTherm is an insulated front pan system, shown in Figure 3, which acts as a complementary exterior covering for the EnvaTherm system, in place of an IGU or metal panel at the front of the system. Similar to the EnvaTherm, the SpandrelTherm consists of a foamed in place polyurethane insulation contained within a 0.05” aluminum skin. The SpandrelTherm has a flange along the edges which extends down into the glazing pocket and is held in place by an adapter or by the EnvaTherm box flange.

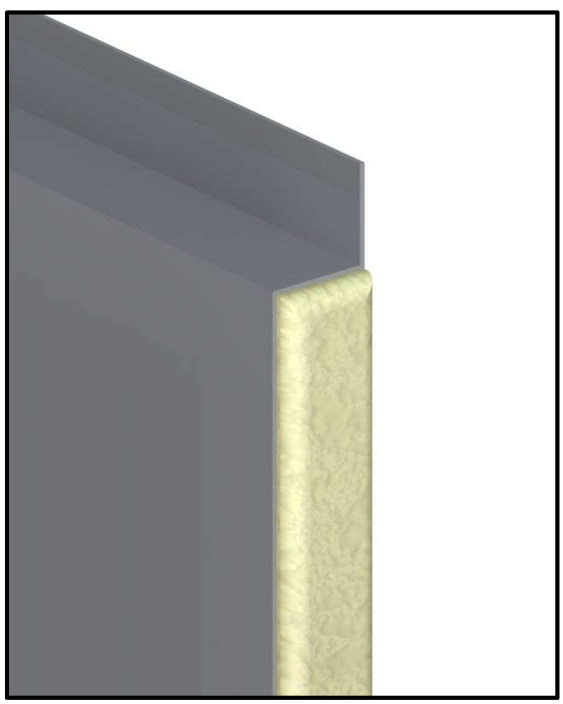


Figure 3: *SpandrelTherm Front Pan System*

For this report, the Envatherm and SpandrelTherm combination systems were compared to generic mineral wool insulated backpan system, shown in Figure 4. This system consists of semi-rigid mineral wool (R-4.2 per inch), friction fit into a similar galvalume backpan and held in place with adhered stick pins. The mineral wool insulation did not have a facer. The backpan has a front flange which is fastened and sealed to the curtain wall shoulder

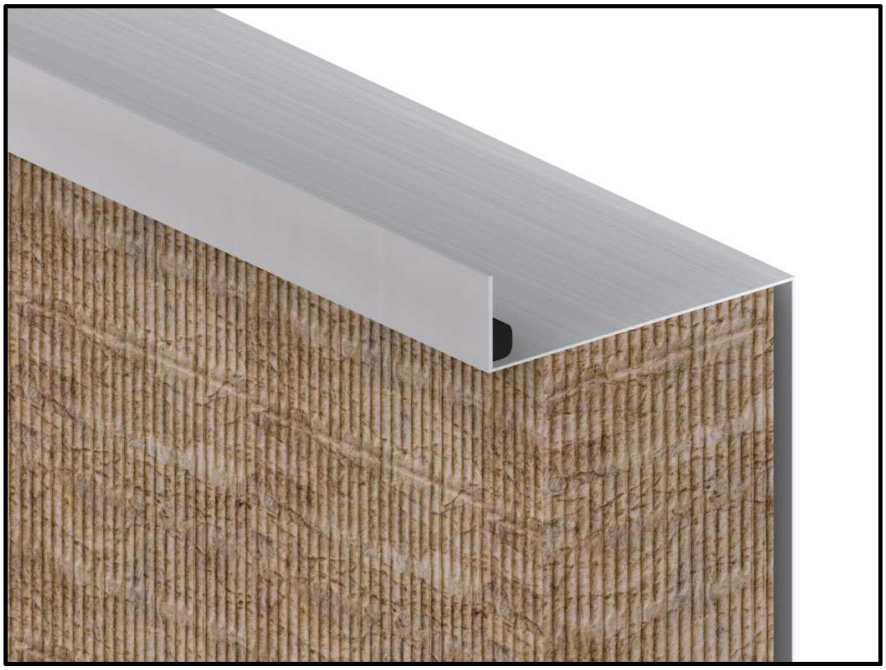


Figure 4: *Generic Mineral Wool Backpan System with Shoulder Flange*

For further information on the backpan systems, see Section 3 and for material properties see Appendix A.

1.2 Curtain Wall System Description

For this report, the backpan systems described above were evaluated within the same generic stick built aluminum curtain wall system with front pressure plates, as shown in Figure 5. The curtain wall system included a silicone gasket thermal break between the mullion nose and front pressure plate and silicone setting blocks at the horizontal to vertical mullion connection.

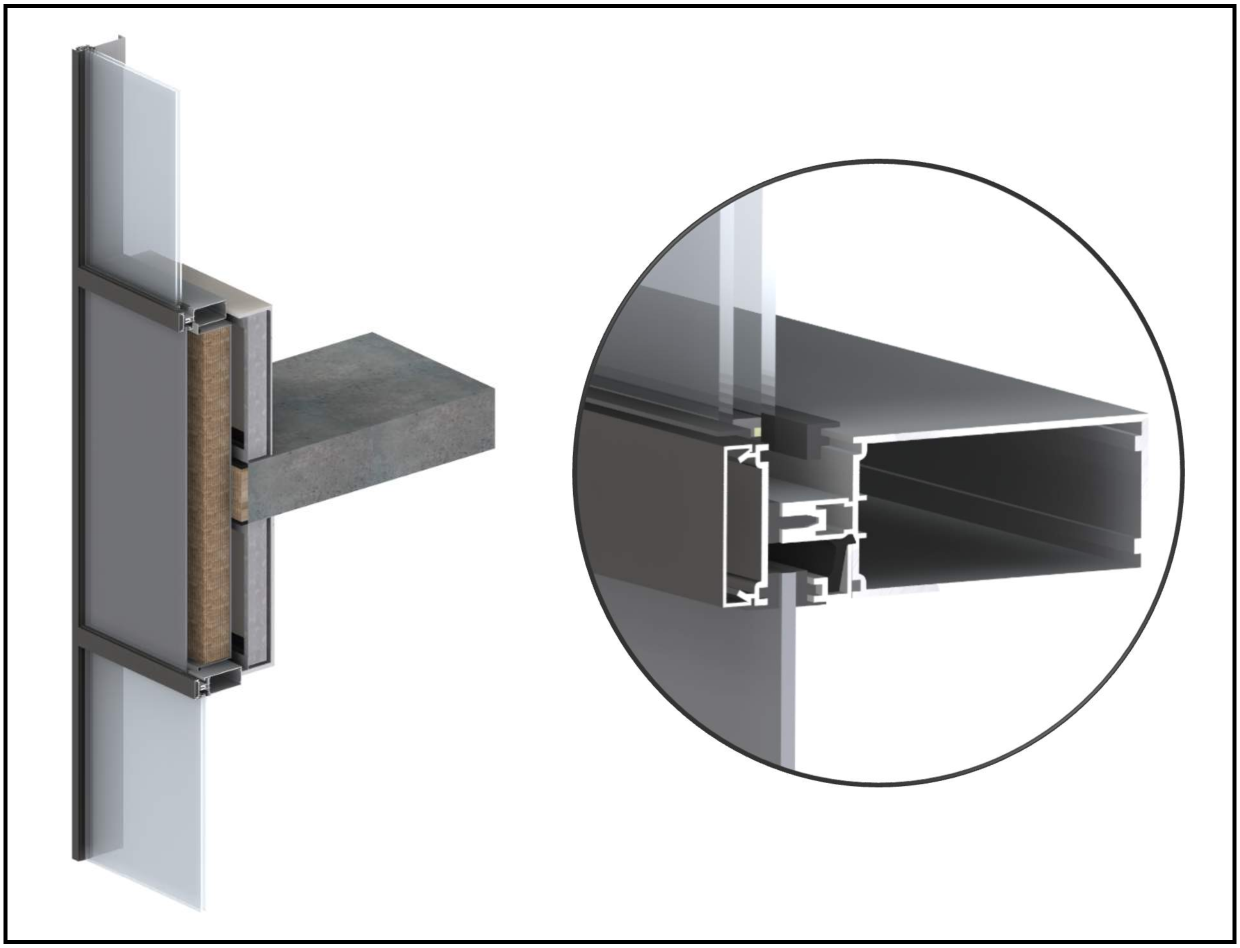


Figure 5: *Generic Stick Built Curtain Wall System with Closeup of Mullion (backpan hidden)*

While the main purpose of this analysis was to evaluate the opaque spandrel sections of the curtain wall system, portions of the vision glazing, above and below the spandrel, were also included. The insulated glazing unit consisted of the following:

6mm clear glass with Low-E coating (e=0.05) on surface #2
13mm Argon Fill (90% mix)
6mm Clear glass

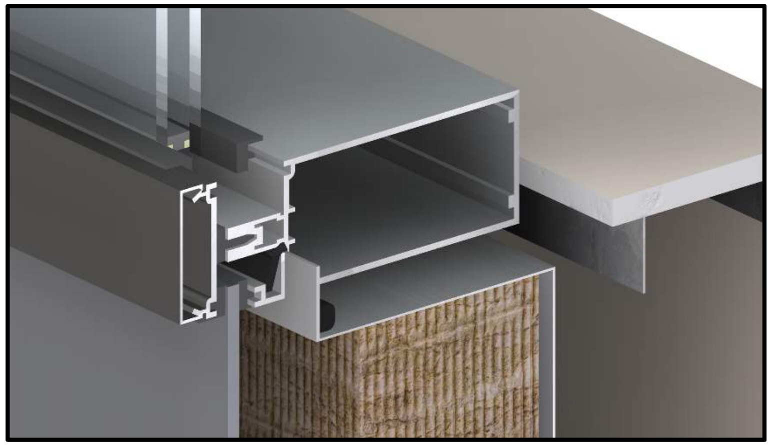
The curtain wall dimensions for this analysis were a 5’x4’ vision section, split in half by a 4’x4’ spandrel for a total curtain wall assembly size of 9’x4’. The spandrel section included the slab and anchor connections as well as interior gypsum finishes, as shown above. For further information on the curtain wall system and material properties see Appendix A.

1.3 Analyzed Scenarios

The following spandrel configuration scenarios were analyzed for this report:

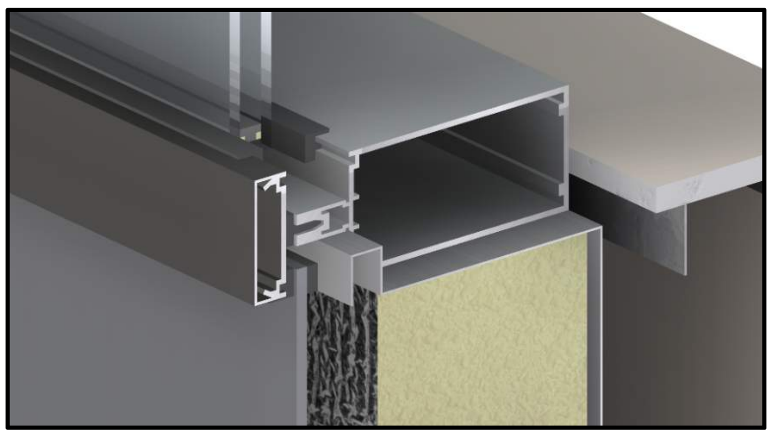
Scenario 1: Mineral Wool Backpan

- 6mm Opaci Coat Glass with Metal Spacer
- Spandrel Air space
- 4" Mineral Wool Galvalume backpan with shoulder flange
- 3 5/8" stud cavity
- ½" Gypsum



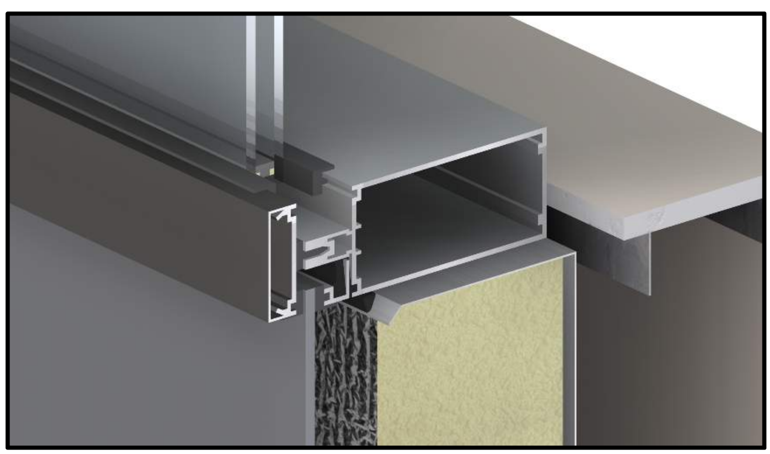
Scenario 2: EnvaTherm with Box Style Flange

- 6mm Opaci Coat Glass with Metal Spacer
- Spandrel Air space
- 5" EnvaTherm Galvalume Backpan System with Box Style Flange
- 3 5/8" stud cavity
- ½" Gypsum



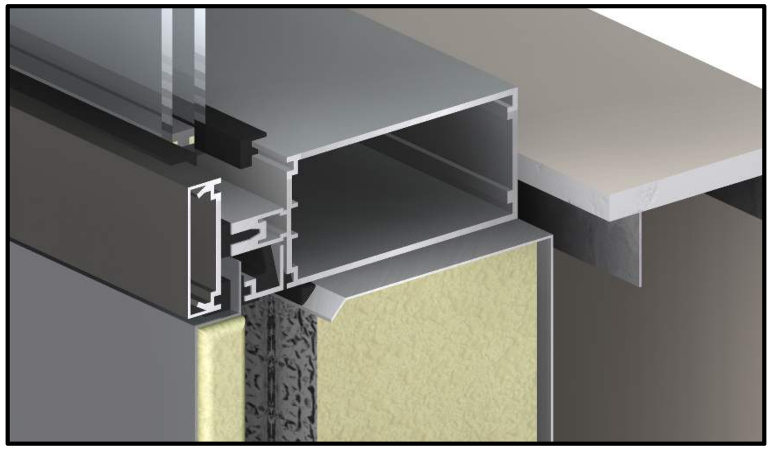
Scenario 3: EnvaTherm with Bird Beak Flange

- 6mm Opaci Coat Glass with Metal Spacer
- Spandrel Air space
- 5" EnvaTherm Galvalume Backpan System with Bird Beak Flange
- 3 5/8" stud cavity
- ½" Gypsum



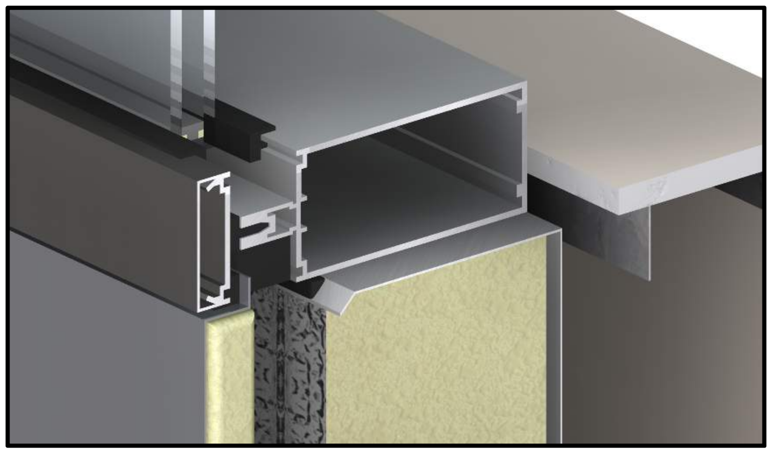
Scenario 4: SpandrelTherm and EnvaTherm with Metal Spacer

- 1” SpandrelTherm System with Metal Spacer
- Spandrel Air space
- 5” EnvaTherm Galvalume Backpan System with Bird Beak Flange
- 3 5/8” stud cavity
- ½” Gypsum



Scenario 5: SpandrelTherm and EnvaTherm with PVC Spacer

- 1” SpandrelTherm System with reduced flange and PVC Spacer
- Spandrel Air space
- 5” EnvaTherm Galvalume Backpan System with Bird Beak Flange
- 3 5/8” stud cavity
- ½” Gypsum



2. MODELING OUTLINE

The thermal modeling for this report was performed using the Nx software package from Siemens, which is a general purpose computer aided design (CAD) and finite element analysis (FEA) software suite. The thermal solver and general modeling procedures utilized for this study were extensively calibrated and validated for ASHRAE Research Project 1365-RP "Thermal Performance of Building Envelope Details for Mid- and High-Rise Construction (1365-RP)[1]. This methodology was also used to determine the thermal performance of an extensive amount of building details, including various curtain wall and window wall systems, with comprehensive results presented in the Building Envelope Thermal Bridging Guide[2]. The modeling assumptions are summarized in Appendix B.

In this approach, both the vision and spandrel sections are included within a single model to account for any lateral heat flow between these sections (See Figure 6). The thermal performance for the vision and spandrel sections are presented separately, where the division between them is in the middle of the mullion. Any additional lateral heat flow between these sections is assigned to the spandrel.

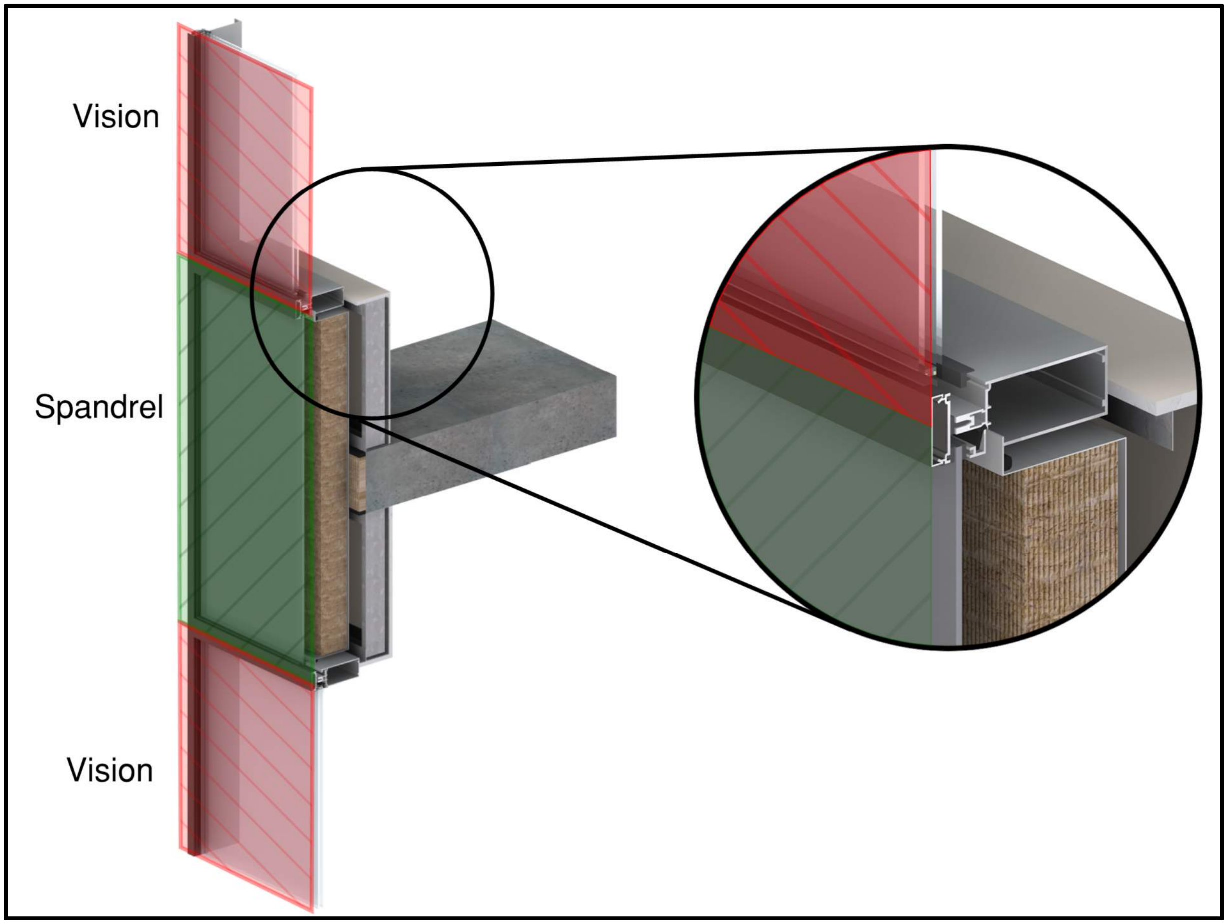


Figure 6: *Division of Curtain Wall Sections*

[1] http://www.morrisonhershfield.com/ashrae1365research/Pages/Insights-Publications.aspx
[2] http://www.bchydro.com/thermalguide

3. THERMAL ANALYSIS FOR BACKPAN SYSTEMS

The following section provides the U-value and R-value results for the evaluated insulated backpan configurations and curtain wall system described in Section 1. These values were determined without solar heating (see Section 4 for further analysis of solar heating).

3.1 Thermal Performance Indices

Tables 1 and 2 show the results for the vision and spandrel assemblies respectively. Since the glazing is the same in all scenarios (and additional heat flow is assigned to the spandrel), the vision assembly results apply to all the analyzed scenarios. The tables provide the assembly description, center of panel (COP) values[3] and assembly U- and R-Values for each scenario. Example temperature profiles for each scenario are presented in Appendix C.

Table 1: *Thermal Performance Indices for Vision Assembly*

Scenario	Center of Glass U-Value BTU/hr°Fft² (W/m²K)	Center of Glass R-Value hr°Fft²/BTU (m²K/W)	Vision Assembly U-Value BTU/hr°Fft² (W/m²K)	Vision Assembly R-Value hr°Fft²/BTU (m²K/W)
Vision Section	0.221 (1.26)	R-4.5 (0.80)	0.352 (2.00)	**R-2.8** (0.50)

Table 2: *Thermal Performance Indices for Spandrel Assemblies*

Scenario	Spandrel Exterior Cover	Glazing Adapter	Backpan	Backpan Flange	Center of Panel U-Value BTU/hr°Fft² (W/m²K)	Center of Panel R-Value hr°Fft²/BTU (m²K/W)	Spandrel Assembly U-Value BTU/hr°Fft² (W/m²K)	Spandrel Assembly R-Value hr°Fft²/BTU (m²K/W)
1	6mm Glass	Aluminum	4" Mineral Wool	Shoulder	0.050 (0.28)	R-20.2 (3.56)	0.236 (1.34)	**R-4.2** (0.74)
2	6mm Glass	Box Style	5" EnvaTherm	Box Style	0.043 (0.24)	R-23.4 (4.12)	0.217 (1.23)	**R-4.6** (0.81)
3	6mm Glass	Aluminum	5" EnvaTherm	Bird Beak	0.043 (0.24)	R-23.4 (4.12)	0.189 (1.07)	**R-5.3** (0.93)
4	1" Spandrel Therm	Aluminum	5" EnvaTherm	Bird Beak	0.037 (0.21)	R-27.4 (4.82)	0.215 (1.22)	**R-4.6** (0.82)
5	1" Spandrel Therm	PVC	5" EnvaTherm	Bird Beak	0.037 (0.21)	R-27.4 (4.82)	0.172 (0.98)	**R-5.8** (1.02)

[3] The COP value is the performance of the system away from the influence of edge effects from the mullions and other thermal bridging. Note, depending on the size of the spandrel and the degree of edge effects, a spandrel system within an actual curtain wall assembly may not reach the COP value due to the amount of lateral heat flow through the backpan.

3.2 Discussion

Spandrel panel assemblies can often fall short of expectations for thermal performance, especially when compared to the nominal amount of insulation used within the system. In most cases low effective R-values of spandrel assemblies is due to thermal bridging from adjacent mullions and other conductive components that bypass the insulation within the system. That being said, at low envelope R-values, any gains in heat flow resistance can have a notable impact on building energy use, especially in buildings that are predominately curtain wall.

For this analysis, the EnvaTherm and SpandrelTherm scenarios were compared to a generic backpan system with mineral wool insulation. 4" of mineral wool is typically the higher end of thickness currently seen within these types of backpan systems. In comparison all the EnvaTherm and SpandrelTherm scenarios resulted in higher spandrel assembly R-values. This is due to not only the higher insulation value from the foam insulation, but also how the backpans are installed in curtain wall with the type of flange around the edge of the backpans.

The modelled mineral wool backpan contains a *shoulder* flange, which extends from the backpan in front of the curtain wall shoulder and to the curtain wall neck. This is connected to the aluminum spacer for the glass pane. The *box* flange, similar to the *shoulder* flange, hooks down to the curtain wall neck, but extends out closer to the curtain wall thermal break, acting as the glazing spacer. Since the *shoulder* and *box* flanges are similar, the effective R-value of the EnvaTherm assembly with the *box* flange is only slightly better than the generic mineral wool assembly due to the additional insulation value from the foam. The *bird break* flange for the EnvaTherm backpan folds the edge of the pan away from the curtain wall mullion and stops at the edge of the curtain wall shoulder. The EnvaTherm with *bird beak* flange results in a higher R-value than both other previous Scenarios[4].

The impact of flanges becomes even more evident when the SpandrelTherm is added to the front of the system. In Scenario 4, the SpandrelTherm has a flange which extends down behind the pressure plate all the way to the curtain wall neck, just past the thermal break. For this analysis, it is held in place with a gasket and aluminum spacer. Since the pan is made from conductive aluminum, heat can flow from the curtain wall neck and aluminum spacer and through the pan, bypassing the curtain wall thermal break and the SpandrelTherm insulation (See Figure 7).

[4] Though not performed for this analysis, it is likely that the change in flange type would impact the mineral wool system in similar proportions as between Scenarios 2 and 3 of the EnvaTherm system.

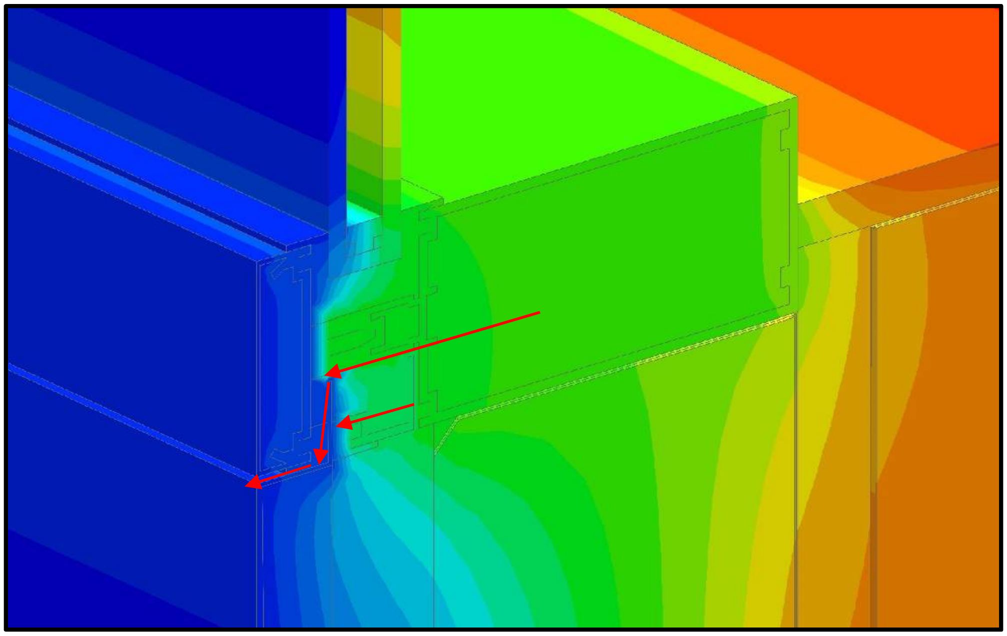


Figure 7: *Heat Flow Paths through mullion in Scenario 4 SpandrelTherm Assembly*

While counterintuitive, using EnvaTherm with this SpandrelTherm configuration results in a lower R-value for the overall spandrel than using EnvaTherm alone with and a single pane of glass for the exterior.

In Scenario 5, the SpandrelTherm flange was cut back from the curtain wall neck and a less conductive PVC spacer block was used to keep the front pan in place. This was done in order to see if the impacts of the flange could be lessened. This approach results in an overall higher R-value for the spandrel than the other analyzed scenarios.

4. IMPACT OF SOLAR RADIATION

The U-value and R-value is a measure of an assembly's ability to transmit (or resist) heat flow per degree of temperature difference across it, averaged across the assembly. For opaque assemblies, solar radiation adds additional heat to the exterior surface of the assembly to which it will transmit/resist. The impact of solar radiation is typically accounted for in energy calculations as an increase in the apparent temperature difference across the spandrel assembly according to the amount of solar radiation hitting the surface. This changes the overall heat flow through the assembly (in W or BTU/hr) rather than a change in U-value of the assembly (W/m^{2}K or BTU/hrft^{2o}F).

For this analysis, the impact of solar radiation was looked at from a total heat flow perspective with the 3D thermal model (instead of as part of the averaged U- and R-value) in order capture localized temperature and heat flow effects. The following four scenarios were examined: Scenario 1 (Mineral Wool), Scenario 3 (EnvaTherm with Bird Break), Scenario 4 (SpandrelTherm and EnvaTherm with Aluminum Spacer) and Scenario 5 (SpandrelTherm and EnvaTherm with PVC Spacer).

The amount of solar radiation used in this analysis was determined for the peak conditions for Calgary, AB (Lat 51^o). The overall solar flux, including atmospheric effects, was found to be approximately 1240 W/m^2. The curtain wall assembly was oriented vertically and facing south for maximum impact. The scenarios were examined for an interior temperature of 21^{o}C and three exterior temperatures, -30^{o}C, 10^{o}C and 30^{o}C.

4.1 Solar Radiation Heat Flow Results

Table 3 below shows the total heat flow through the spandrel assemblies in Watts, with and without the peak solar radiation in Calgary for the varying exterior temperatures. These values are for the modelled size of spandrel under specific exterior conditions and are meant to indicate the impacts of solar radiation. These values are not intended to be for design purposes. Negative indicates heat loss from interior, positive indicates heat gain to the interior. Please note this is for the spandrel section only and does not include heat gain through the vision glazing. Example temperature images are included in Appendix C.

Table 3: *Thermal Performance Indices for Spandrel Assemblies*

Scenario	Description	Exterior Temperature °C	Overall Heat Flow Through Spandrel Assembly (W)		Change in Heat Flow (W)	% Difference
			Without Solar	With Solar		
1	Glass Spandrel, 4" Mineral Wool Backpan, Aluminum spacer	-30 °C	-54	-47	-6.5	-12%
		10 °C	-12	-5	-6.8	-59%
		30 °C	+10	+17	+7.1	+74%
3	Glass Spandrel, 5" EnvaTherm Backpan, Aluminum Spacer	-30 °C	-43	-38	-5.4	-12%
		10 °C	-10	-5	-5.5	-55%
		30 °C	+8	+14	+6.5	+86%
4	1" Spandrel Therm, 5" EnvaTherm Backpan, Aluminum Spacer	-30 °C	-51	-48	-2.6	-5%
		10 °C	-11	-8	-2.9	-26%
		30 °C	+9	+12	-3.1	+34%
5	1" Spandrel Therm, 5" EnvaTherm Backpan, PVC Spacer	-30 °C	-36	-34	-2.2	-6%
		10 °C	-8	-6	-2.3	-29%
		30 °C	+6	+9	-2.4	+37%

4.2 Discussion

Table 3 shows that, for all the analyzed scenarios, the overall heat loss out of the spandrel section decreases when there is solar radiation present in cold exterior temperatures. This outcome is intuitive as solar heating will increase the exterior surface temperatures of the system. In cold exterior temperatures this will reduce the temperature difference between inside and outside surfaces, which reduces heat loss to the exterior. In warm exterior temperatures, solar radiation works together with the exterior temperature to warm the exterior surfaces higher than the inside temperature. This in turn increases the temperature difference and subsequently increase heat gain to the interior.

Between the base assembly with a mineral wool backpan and the EnvaTherm only backpan, while there is a difference in the overall heat flow, there is only a small difference in the impact of solar heating on the assembly. Both systems show similar heat flow changes due to solar radiation. This may be due to the similarities in the configuration of the insulation layer between the base assembly and the EnvaTherm assembly. In both cases, solar heating drops the heat flow through the spandrel by approximately 60% for the cold exterior temperatures examined and increased the heat flow to the interior by upto 86% for the warm exterior temperature.

For the SpandrelTherm assembly with aluminum spacer, providing 1" of foam in the front does have a noticeable impact on reducing solar heating effects. This, despite the fact that, with the aluminum spacer and without solar heating, it performed worse in overall U-value than just the EnvaTherm backpan alone. With the SpandrelTherm assembly, the heat loss out of the spandrel is reduced by up to 26% with solar heating in the cold exterior temperatures examined and increased heat gain by 34% with the warm exterior temperature. Using a PVC spacer for the front panel instead of aluminum shows about the same impact.

The reason why the SpandrelTherm panel is less impacted by solar radiation may be due to the placement of insulation layers. As the SpandrelTherm insulation is the first layer being hit by the sun, it appears to have an increased ability to reduce the impact of solar heating. In the other scenarios, solar heating is able to get further into the system before reaching the insulated backpan, potentially allowing the heat to find lateral heat paths around the insulating layer.

It must be noted that this is very dependent on climate, as well as how long the location is under cooling or heating conditions. In heating climates (greater than 5400 heating degree days), allowing in more solar radiation may even be advantageous for energy as it could help counteract cold exterior temperatures. Typically, however, making the most use out of solar heating is undertaken in the vision glazing design.

One final discussion point, it is possible that due to the different conductivities and emissivities of components in curtain wall assemblies, solar heating may impact localized areas of the curtain wall system differently. This aspect of the curtain wall spandrel's energy performance may not be apparent when spandrels are analyzed without solar heating. In whole building energy simulation a wall assembly is typically input as an averaged U-value for the entire wall. For a curtain wall system, this would typically mean combining the thermal transmittance of the spandrel panel and surrounding framing together as a single value, since accounting for the mullions and panel separately would be impractical and cumbersome in most design cases. As shown in the tables in this section of the report, it is possible that localized increases in temperature from solar radiation on the more conductive mullions can cause an increase in heat flow compared to the center of the panel under the same conditions. This impact would not be apparent if the entire spandrel was averaged as a single U-value. It is unclear how large a difference this could make on a whole building energy model, which is beyond the scope of this report.

5. CONCLUSIONS

In summary, the following information can be gathered from this report regarding the analyzed EnvaTherm and SpandrelTherm assemblies.

- The use of the EnvaTherm backpan, with the box style or bird beak flange type, provides higher effective R-values than the analzyed mineral wool backpan system with shoulder flange.
- The flanges of the backpan have a large impact on the thermal performance of the spandrel as it can create additional thermal bridging past the curtain wall thermal break, depending on the type of flange
- Use of the SpandrelTherm and EnvaTherm can also increase the effective R-value of the spandrel than EnvaTherm alone, as long as the flange for the SpandrelTherm does not extend to the curtain wall neck.
- The increases in effective R-value of the EnvaTherm/SpandrelTherm systems over the mineral wool backpan are, at most, R-1.6 for the scenarios in this report. This is an improvement in heat flow resistance of 38% compared to the base scenario.
- While not directly studied here, previous research has shown in building energy simulations with low overall building envelope R-values, small improvements in the envelope can have notable impact on energy use for space heating. For more information see The Building Envelope Thermal Bridging Guide
- The EnvaTherm backpan and Mineral Wool backpan both show reductions in heat loss and increases in heat gain in cold and warm exterior temperatures respectively when there is solar radiation.
- The Mineral Wool backpan scenario shows a slightly larger reduction in heat flow than the EnvaTherm backpan when solar heating in included, however the EnvaTherm still shows less heat flow through the system overall.
- The SpandrelTherm blunts the impact of solar radiation. As a result the differences in heat loss or heat gain compared to the system without solar radiation is not as large as the EnvaTherm or Mineral Wool backpans alone.

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Aug 18th/16

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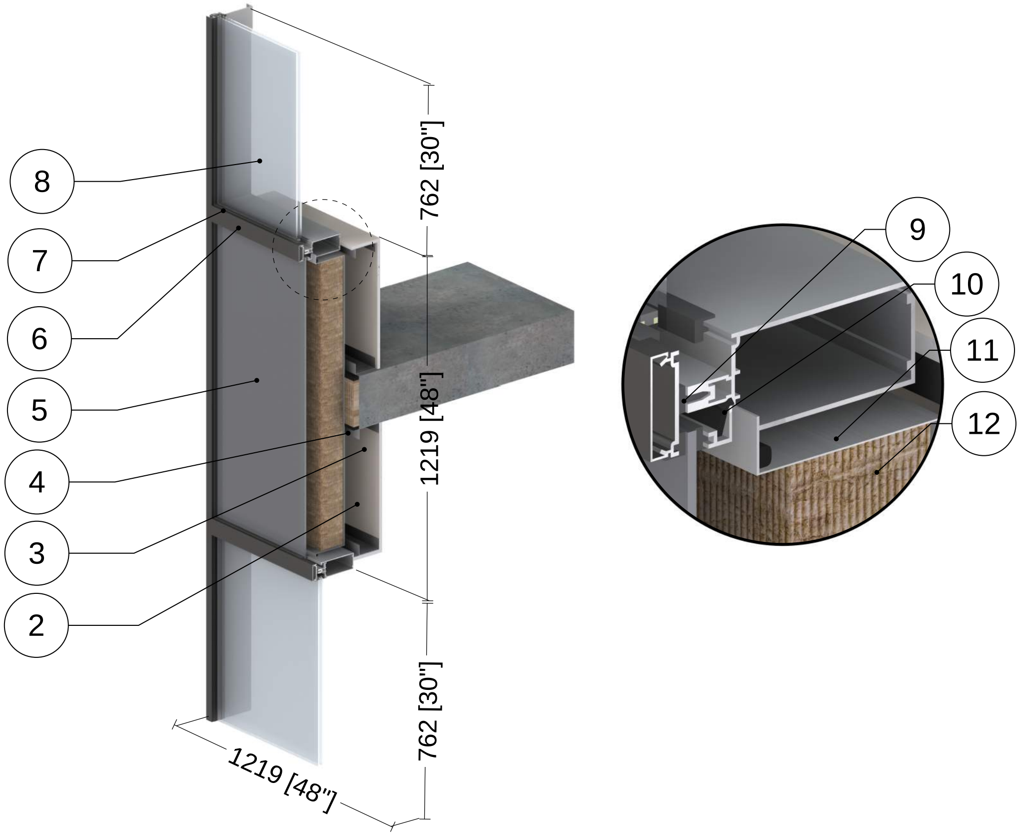
Building Science Consultant

APPENDIX A– ASSEMBLY INFORMATION AND MATERIAL PROPERTIES

Scenario 1

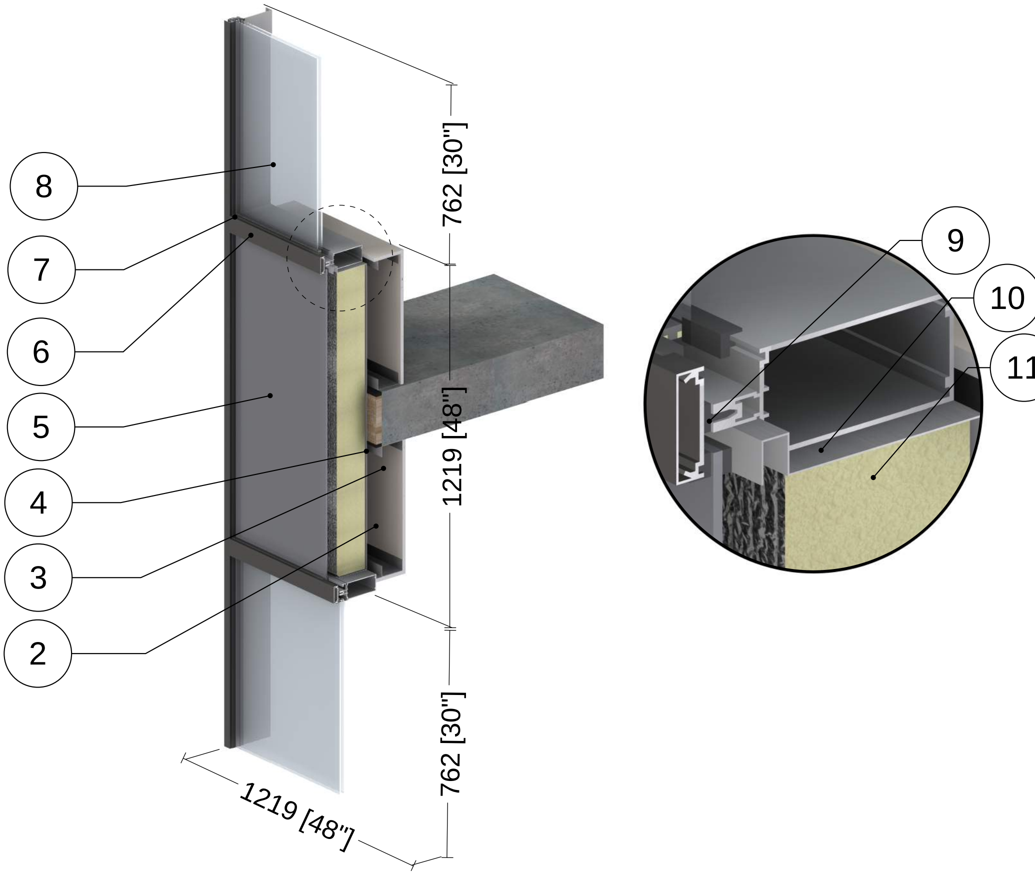
Generic Curtain Wall System – Mineral Wool Backpan w/ Shoulder Flange



	Component	Thickness Inches (mm)	Conductivity Btu·in / ft²·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)	Specific Heat Btu/lb·°F (J/kg K)
1	Interior Air Films[1]	-	-	R-0.6 (0.11 RSI) to R-0.9 (0.16 RSI)	-	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
3	Air in Stud Cavity	4 5/8" (118)	-	R-0.9 (0.16 RSI)	0.075 (1.2)	0.24 (1000)
4	3 5/8" x 1 5/8" Steel Studs with Top and Bottom Tracks	18 gauge	430 (62)	-	489 (7830)	0.12 (500)
5	Single Pane Glass	¼" (6)	(6.7 (0.96)	-	155 (2500)	0.20 (800)
6	Aluminum Framing	11 gauge	1109 (160)	-	171 (2739)	0.21 (900)
7	EPDM Gaskets	¼" (7)	1.7 (0.25)	-	62 (997)	0.49 (2000)
8	Double Glazed Insulated Glazing Unit, Argon Fill, Low-E on Surface #2, COG = 0.221 **BTU/hr·ft²·°F** (0.126 W/m²K)					
9	EPDM Thermal Break	¼" (7)	1.7 (0.25)	-	62 (997)	0.49 (2000)
10	Aluminum Spacer	11 gauge	1109 (160)	-	171 (2739)	0.21 (900)
11	Galvalume Backpan	24 gauge	347 (50)	-	489 (7830)	0.12 (500)
12	Mineral Wool Insulation	4" (102)	0.24 (0.034)	R-16.8 (2.96 RSI)	4 (64)	0.20 (850)
13	Exterior Air Films	-	-	R-0.2 (0.0. RSI)	-	-

Scenario 2

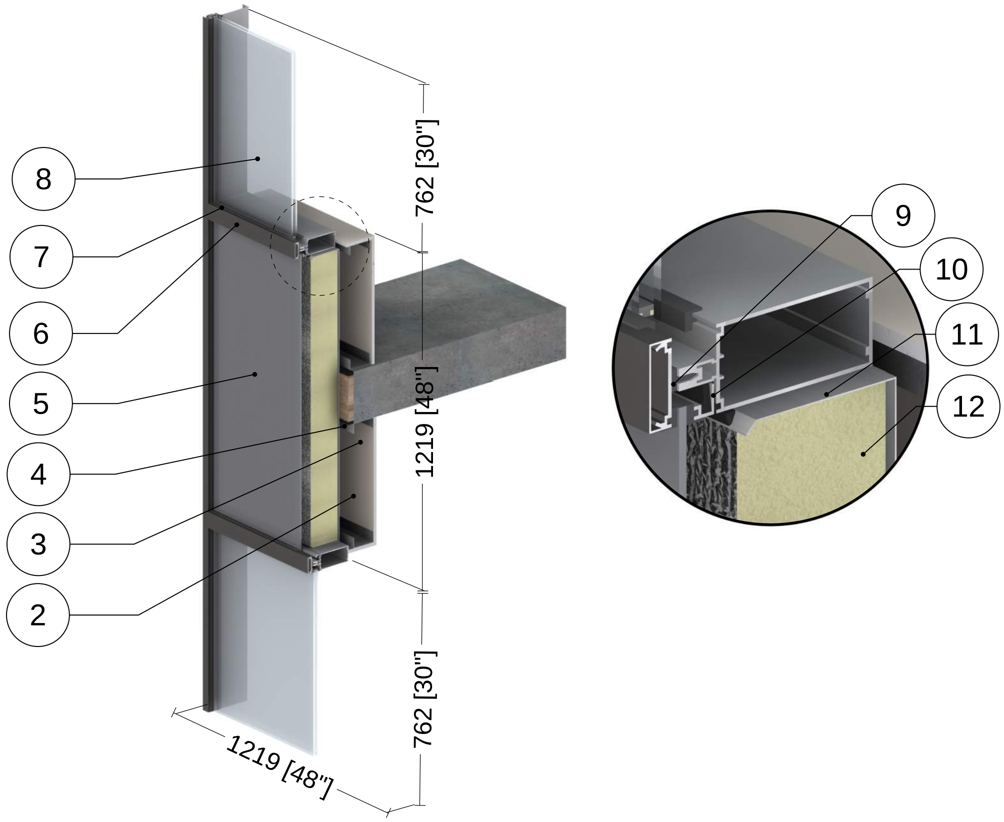
Generic Curtain Wall System – EnvaTherm Backpan w/ Box Style Flange



	Component	Thickness Inches (mm)	Conductivity Btu·in / ft²·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)	Specific Heat Btu/lb·°F (J/kg K)
1	Interior Air Films[1]	-	-	R-0.6 (0.11 RSI) to R-0.9 (0.16 RSI)	-	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
3	Air in Stud Cavity	4 5/8" (118)	-	R-0.9 (0.16 RSI)	0.075 (1.2)	0.24 (1000)
4	3 5/8" x 1 5/8" Steel Studs with Top and Bottom Tracks	18 gauge	430 (62)	-	489 (7830)	0.12 (500)
5	Single Pane Glass	¼" (6)	(6.7 (0.96)	-	155 (2500)	0.20 (800)
6	Aluminum Framing	11 gauge	1109 (160)	-	171 (2739)	0.21 (900)
7	EPDM Gaskets	¼" (7)	1.7 (0.25)	-	62 (997)	0.49 (2000)
8	Double Glazed Insulated Glazing Unit, Argon Fill, Low-E on Surface #2, COG = 0.221 **BTU/hr·ft²·°F** (0.126 W/m²K)					
9	EPDM Thermal Break	¼" (7)	1.7 (0.25)	-	62 (997)	0.49 (2000)
10	Galvalume Backpan	24 gauge	347 (50)	-	489 (7830)	0.12 (500)
11	Polyurethane Foam	5" (127)	0.25 (0.036)	R-20.0 (3.52 RSI)	1.8 (28)	0.29 (1220)
12	Exterior Air Films	-	-	R-0.2 (0.0. RSI)	-	-

Scenario 3

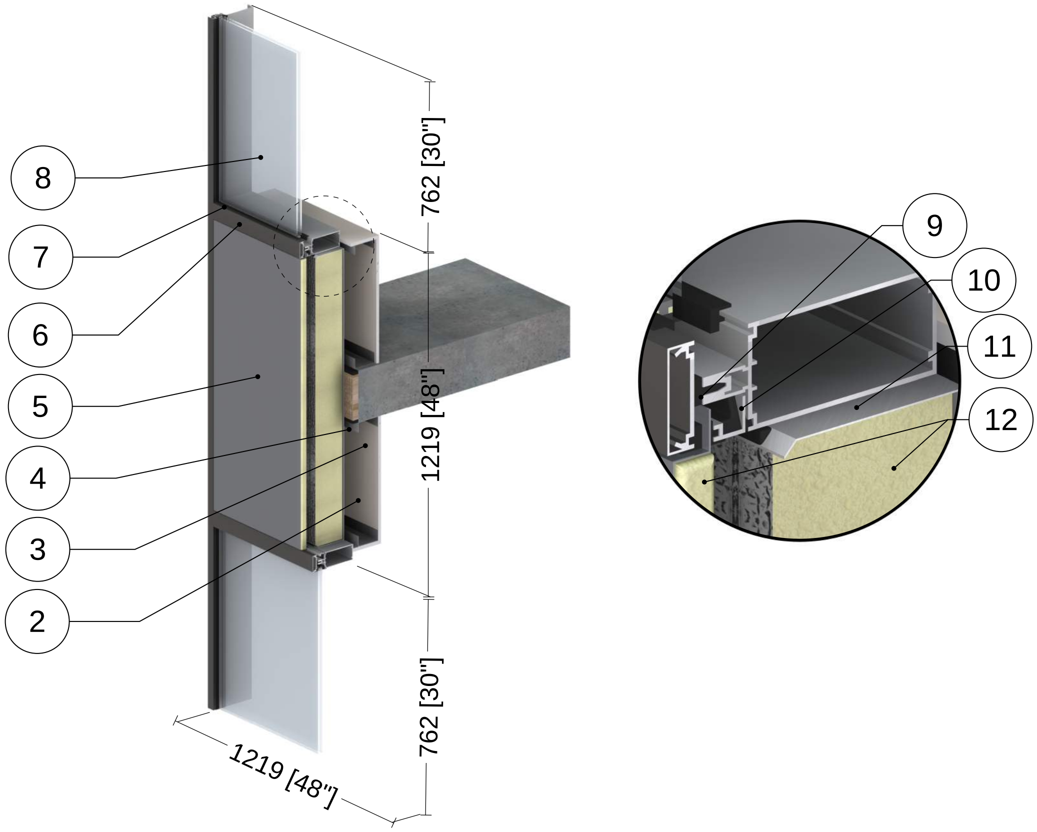
Generic Curtain Wall System – EnvaTherm Backpan w/ Bird Beak Flange



	Component	Thickness Inches (mm)	Conductivity Btu·in / ft²·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)	Specific Heat Btu/lb·°F (J/kg K)
1	Interior Air Films[1]	-	-	R-0.6 (0.11 RSI) to R-0.9 (0.16 RSI)	-	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
3	Air in Stud Cavity	4 5/8" (118)	-	R-0.9 (0.16 RSI)	0.075 (1.2)	0.24 (1000)
4	3 5/8" x 1 5/8" Steel Studs with Top and Bottom Tracks	18 gauge	430 (62)	-	489 (7830)	0.12 (500)
5	Single Pane Glass	¼" (6)	(6.7 (0.96)	-	155 (2500)	0.20 (800)
6	Aluminum Framing	11 gauge	1109 (160)	-	171 (2739)	0.21 (900)
7	EPDM Gaskets	¼" (7)	1.7 (0.25)	-	62 (997)	0.49 (2000)
8	Double Glazed Insulated Glazing Unit, Argon Fill, Low-E on Surface #2, COG = 0.221 **BTU/hr·ft²·°F** (0.126 W/m²K)					
9	EPDM Thermal Break	¼" (7)	1.7 (0.25)	-	62 (997)	0.49 (2000)
10	Aluminum Spacer	11 gauge	1109 (160)	-	171 (2739)	0.21 (900)
11	Galvalume Backpan	24 gauge	347 (50)	-	489 (7830)	0.12 (500)
12	Polyurethane Foam	5" (127)	0.25 (0.036)	R-20.0 (3.52 RSI)	1.8 (28)	0.29 (1220)
13	Exterior Air Films	-	-	R-0.2 (0.0. RSI)	-	-

Scenario 4

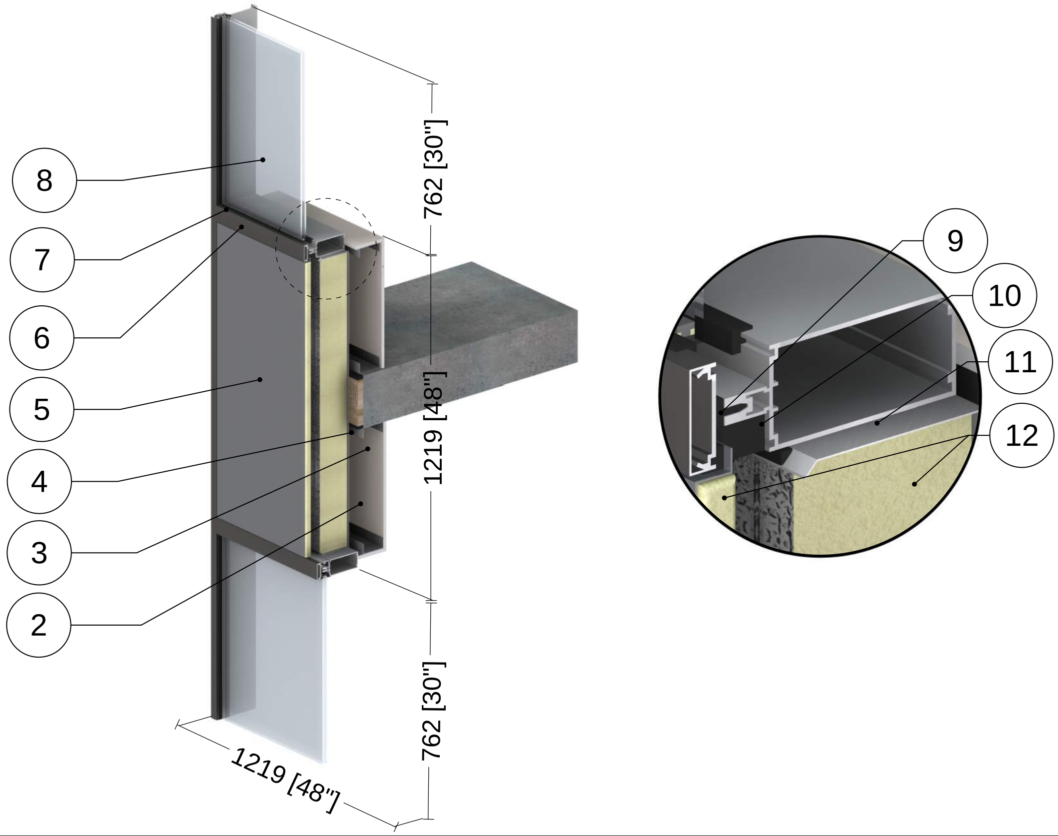
Generic Curtain Wall System – SpandrelTherm and EnvaTherm Backpan w/ Bird Beak Flange



	Component	Thickness Inches (mm)	Conductivity Btu·in / ft²·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)	Specific Heat Btu/lb·°F (J/kg K)
1	Interior Air Films[1]	-	-	R-0.6 (0.11 RSI) to R-0.9 (0.16 RSI)	-	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
3	Air in Stud Cavity	4 5/8" (118)	-	R-0.9 (0.16 RSI)	0.075 (1.2)	0.24 (1000)
4	3 5/8" x 1 5/8" Steel Studs with Top and Bottom Tracks	18 gauge	430 (62)	-	489 (7830)	0.12 (500)
5	Aluminum Panel	18 gauge	1109 (160)	-	171 (2739)	0.21 (900)
6	Aluminum Framing	11 gauge	1109 (160)	-	171 (2739)	0.21 (900)
7	EPDM Gaskets	¼" (7)	1.7 (0.25)	-	62 (997)	0.49 (2000)
8	Double Glazed Insulated Glazing Unit, Argon Fill, Low-E on Surface #2, COG = 0.221 **BTU/hr·ft²·°F** (0.126 W/m²K)					
9	EPDM Thermal Break	¼" (7)	1.7 (0.25)	-	62 (997)	0.49 (2000)
10	Aluminum Spacer	11 gauge	1109 (160)	-	171 (2739)	0.21 (900)
11	Galvalume Backpan	24 gauge	347 (50)	-	489 (7830)	0.12 (500)
12	Polyurethane Foam	5" (127)	0.25 (0.036)	R-20.0 (3.52 RSI)	1.8 (28)	0.29 (1220)
13	Exterior Air Films	-	-	R-0.2 (0.0. RSI)	-	-

Scenario 5

Generic Curtain Wall System – SpandrelTherm w/ PVC Spacer and EnvaTherm Backpan w/ Bird Beak Flange



	Component	Thickness Inches (mm)	Conductivity Btu·in / ft²·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)	Specific Heat Btu/lb·°F (J/kg K)
1	Interior Air Films[1]	-	-	R-0.6 (0.11 RSI) to R-0.9 (0.16 RSI)	-	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
3	Air in Stud Cavity	4 5/8" (118)	-	R-0.9 (0.16 RSI)	0.075 (1.2)	0.24 (1000)
4	3 5/8" x 1 5/8" Steel Studs with Top and Bottom Tracks	18 gauge	430 (62)	-	489 (7830)	0.12 (500)
5	Aluminum Panel	18 gauge	1109 (160)	-	171 (2739)	0.21 (900)
6	Aluminum Framing	11 gauge	1109 (160)	-	171 (2739)	0.21 (900)
7	EPDM Gaskets	¼" (7)	1.7 (0.25)	-	62 (997)	0.49 (2000)
8	Double Glazed Insulated Glazing Unit, Argon Fill, Low-E on Surface #2, COG = 0.221 **BTU/hr·ft²·°F** (0.126 W/m²K)					
9	EPDM Thermal Break	¼" (7)	1.7 (0.25)	-	62 (997)	0.49 (2000)
10	PVC Spacer	1" (25)	1.3 (0.19)	-	86 (1390)	0.24 (1000)
11	Galvalume Backpan	24 gauge	347 (50)	-	489 (7830)	0.12 (500)
12	Polyurethane Foam	5" (127)	0.25 (0.036)	R-20.0 (3.52 RSI)	1.8 (28)	0.29 (1220)
13	Exterior Air Films	-	-	R-0.2 (0.0. RSI)	-	-

APPENDIX B – ASHRAE 1365-RP METHODOLOGY AND MODEL ASSUMPTIONS

B.1 General Modeling Approach

For this report, a steady-state conduction model was used. The following parameters were also assumed:

- Air cavity conductivities were taken from ISO 10077 and Table 3, p. 26.13 of 2013 ASHRAE Handbook – Fundamentals
- Interior/exterior air films were taken from Table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation. The exterior air films were based on an exterior windspeed of 15mph.
- Material properties were taken from information provided by Lenmak and from ASHRAE Handbook – Fundamentals
- The slab edge and interior finishes were included in the model and their impacts were included in the spandrel U- and R-Values, see Appendix B.2
- From the calibration in 1365-RP, contact resistances between materials were modeled. This varied between R-0.01 and R-0.2 depending on the materials. These values, along with other modeling parameters, are given in ASHRAE 1365-RP, Chapter 5.

B.2 Thermal Transmittance

The methodology presented in ASHRAE 1365-RP separates the thermal performance of assemblies and details in order to simplify heat loss calculations. The thermal transmittance of an assembly is divided into three categories: clear field, linear and point transmittances.

The clear field transmittance is the heat flow from the wall or roof assembly, including uniformly distributed thermal bridges that are not practical to account for on an individual basis, such as mullions surrounding the spandrel. This is defined as a U-value, U_o (heat flow per area). Linear transmittances are for details that can be accounted for in a linear nature, such as corners, slab edges, balconies etc. Point transmittances are for single areas of thermal bridging that can be practically accounted for, such as beam penetrations.

Previous modelling in the Building Envelope Thermal Bridging Guide has shown that for curtain wall systems with interior furrings (stud cavities inboard of the spandrel) that contain no interior insulation, the slab edge has no significant impact on the overall U- and R-values of the spandrel assembly. Therefore, for this report, a separate linear transmittance for the slab edge was not determined and was included within the clear field U- and R-value of the spandrel assembly.

APPENDIX C – SIMULATED TEMPERATURE PROFILES

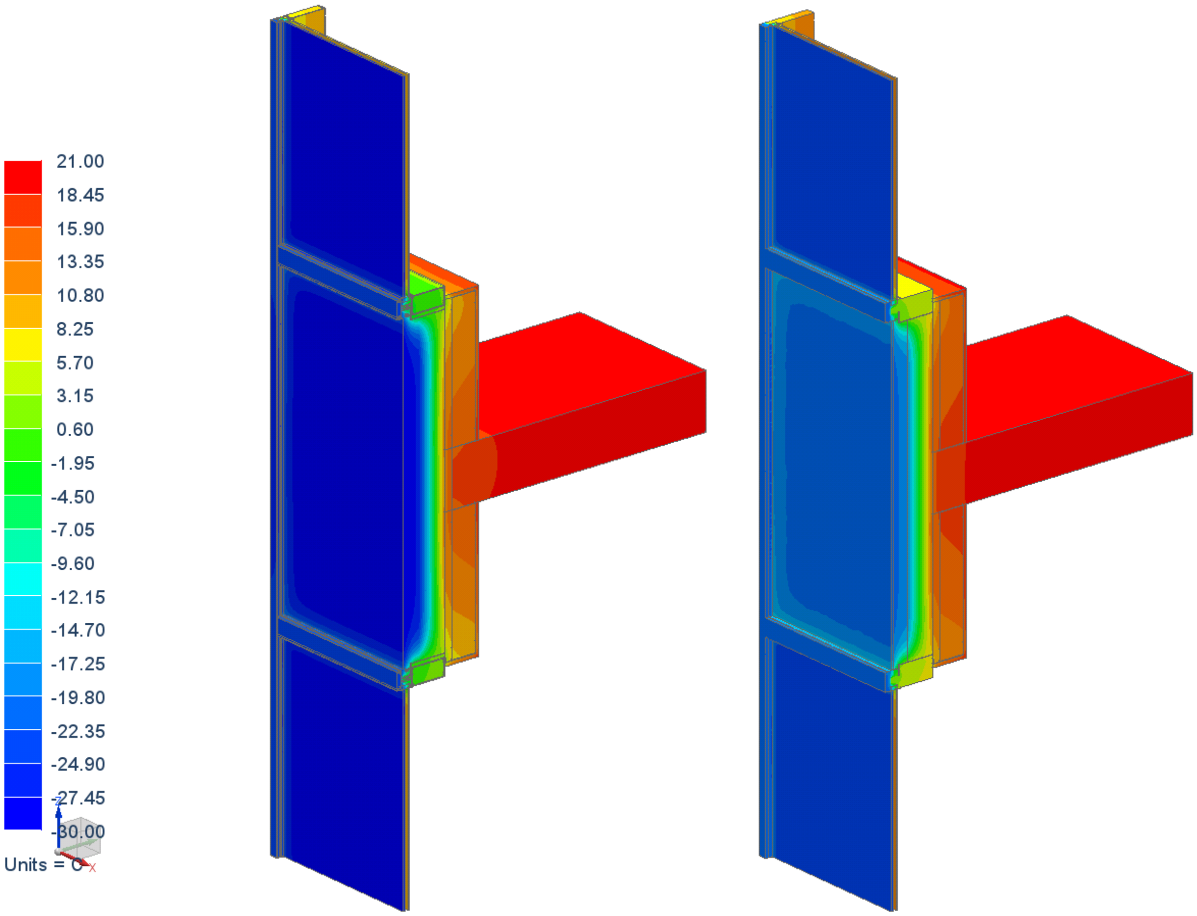


Figure C.1 Scenario 1 at -30°C, Base Mineral Wool Assembly with shoulder flange, without and with solar

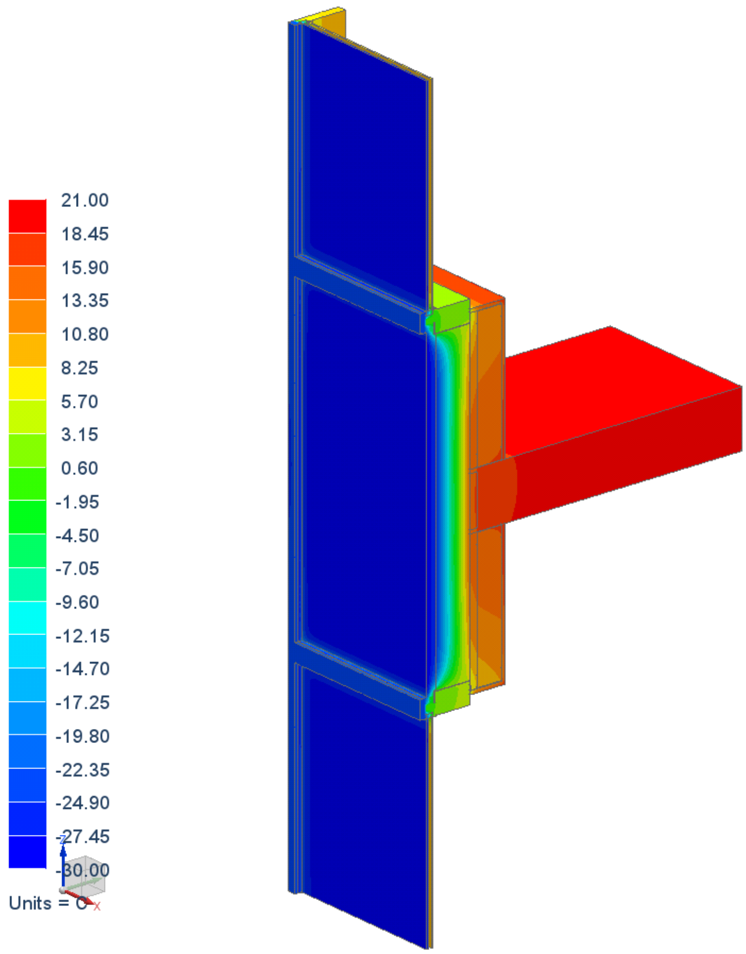


Figure C.2 Scenario 2 at -30°C, Envatherm with box flange, without solar

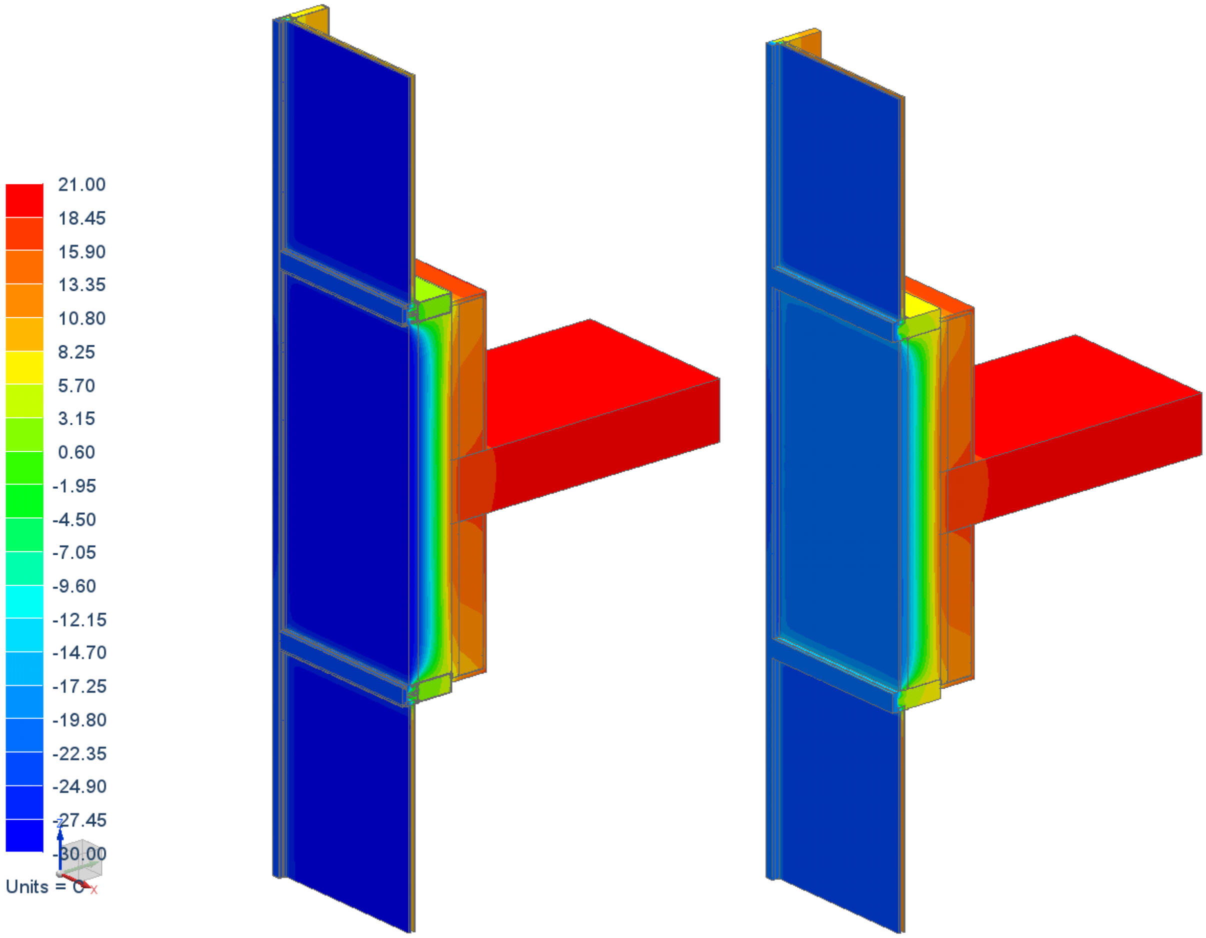


Figure C.3 Scenario 3 at -30^{o}C EnvaTherm with bird beak flange, without and with solar

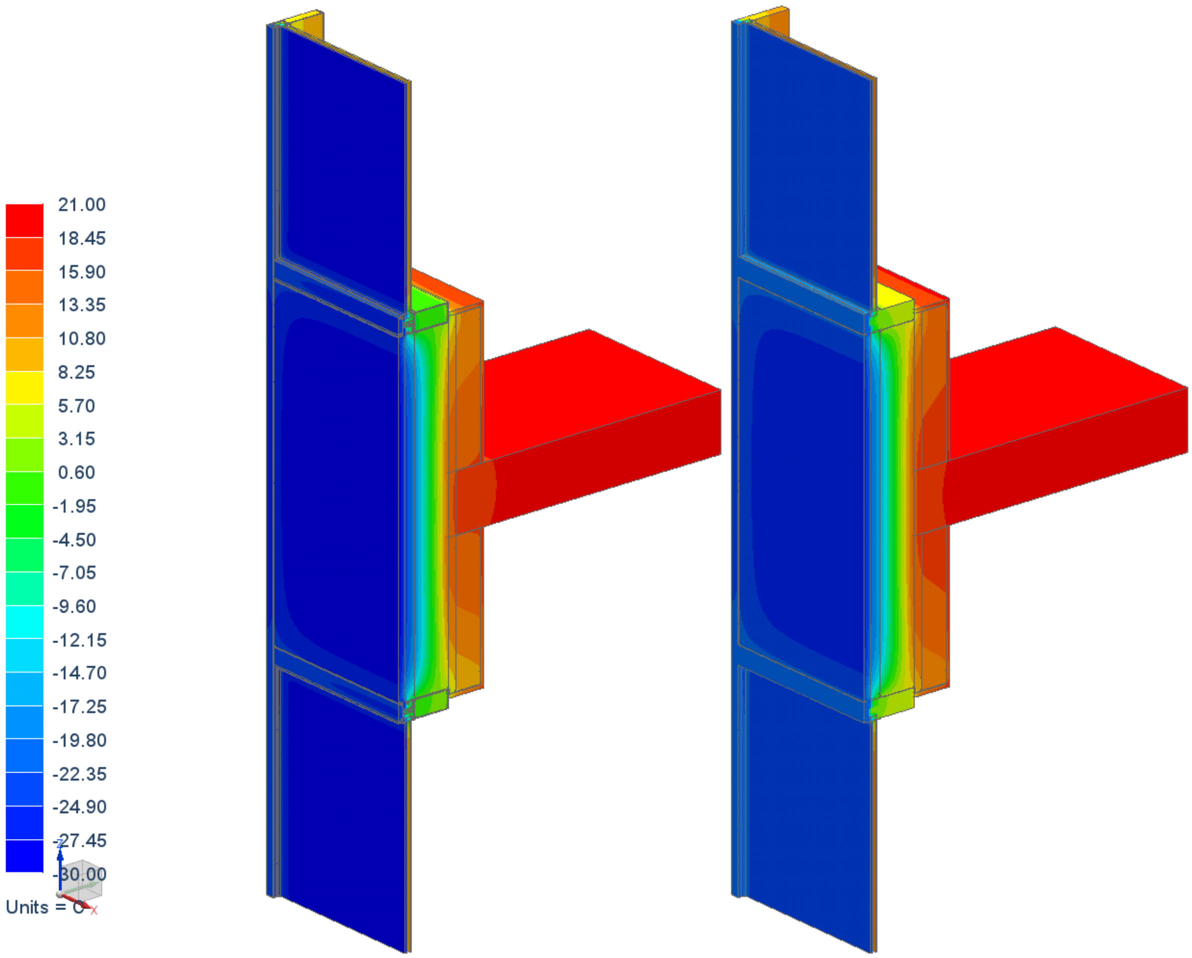


Figure C.4 Scenario 4 at -30°C, SpandrelTherm with Aluminum Spacer, without and with solar

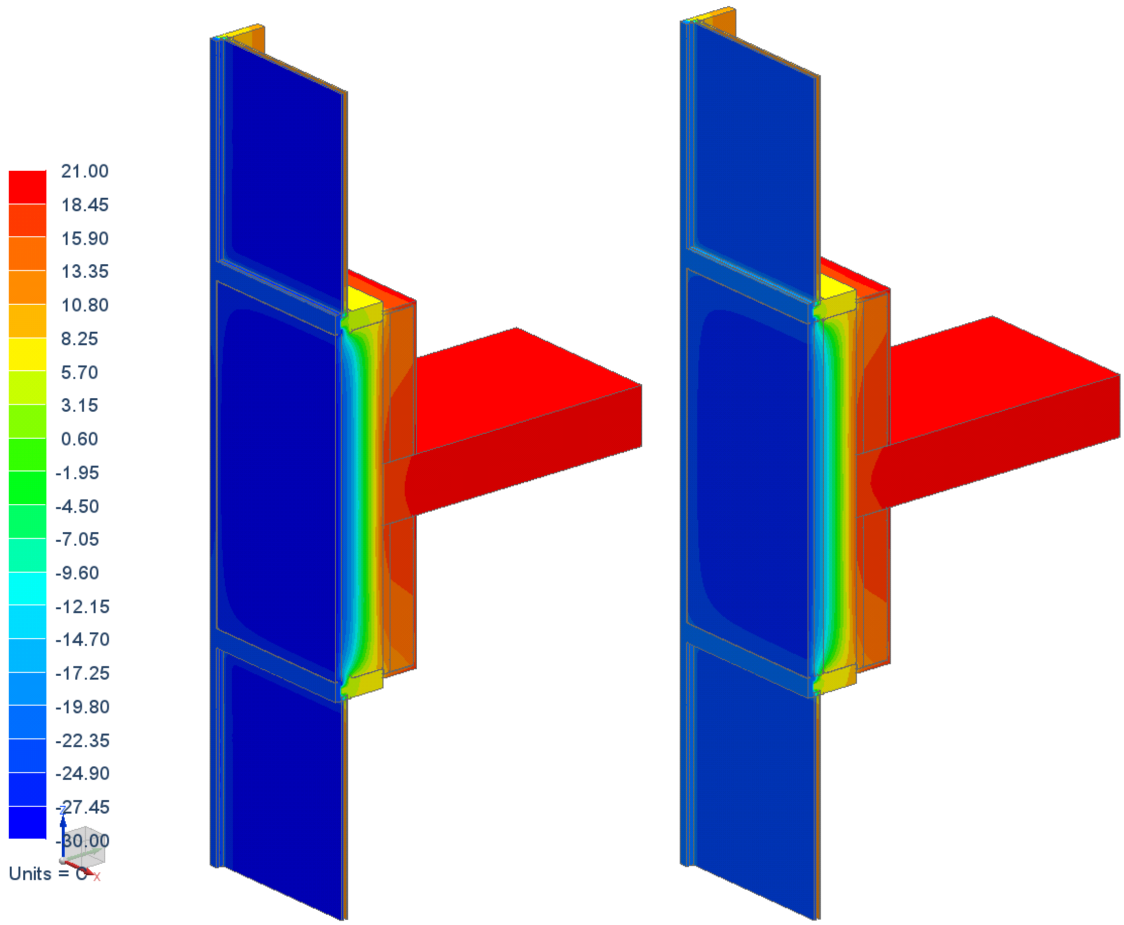


Figure C.5 Scenario 5 at -30°C, SpandrelTherm with PVC Spacer without and with solar