MORRISON HERSHFIELD

September 9, 2019 MH Ref: 1805087.01

Ms. Amber Mengede
Technical Manager
Starline Windows
19091 36th Ave
Surrey, BC V3Z 0P6 email: amengede@starlinewindows.com

Dear Amber:

Re: Bypass Linear Transmittance of Starline 9600 Window Wall System

Morrison Hershfield Ltd. (MH) was retained by Starline Windows to calculate the slab bypass linear transmittance of their Starline 9600 Window Wall system. The linear transmittance was evaluated for two spandrel height configurations and various insulation thicknesses inboard of the window frame. This report is a summary of this analysis.

BACKGROUND INFORMATION

MH has previously evaluated the U-values and effective R-values of the opaque spandrel sections including the slab bypass for the Starline 9600 Window Wall[1]. For this report, MH analyzed the thermal performance of the same Starline 9600 Window Wall scenarios without the slab bypass. Combined with the previously reported results, the bypass linear transmittance was calculated. The evaluated Starline 9600 Window Wall system scenarios along with a list of components are shown below in Figures 1 and 2. The material properties of the detail components are given in Appendix B.

[1] Report number 180508701, issued September 6, 2019

Framing

- Insulated aluminum frames, including couplers and deflection head
- 48 inch vertical mullion spacing
- 108 inch total height of modelled section, including spandrel and vision sections (floor to floor height)

Vision Section

- Double glazed IGU (Low-E on #2, ½ inch argon space) and warm edge spacer

Spandrel Section

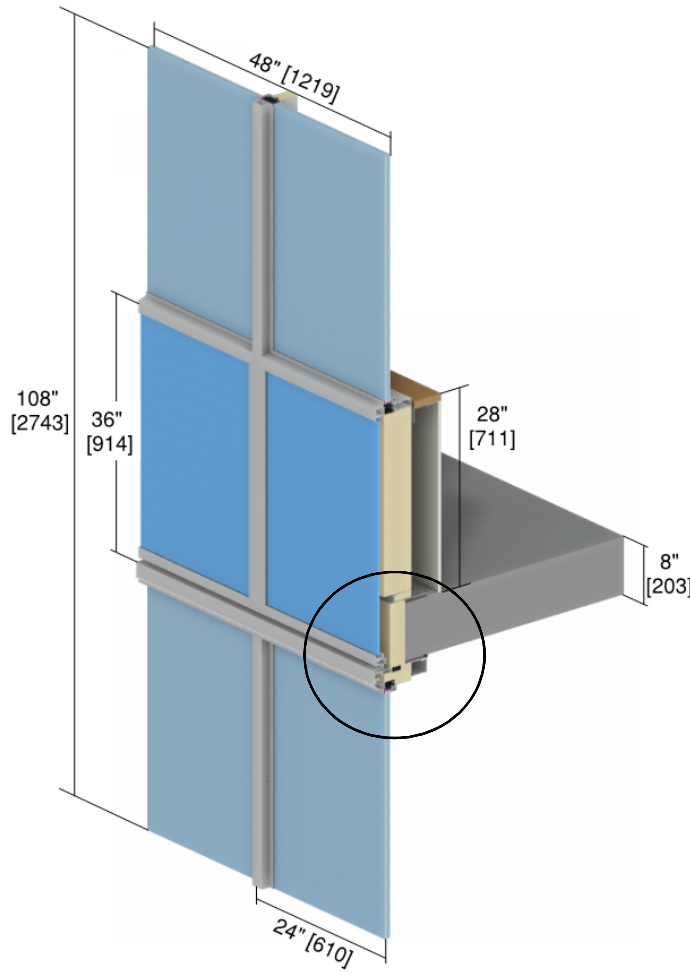
- 4 ½ inches of mineral wool in back pan
- Single spandrel glass
- 36 inch spandrel height (sill height 28 inches above slab)

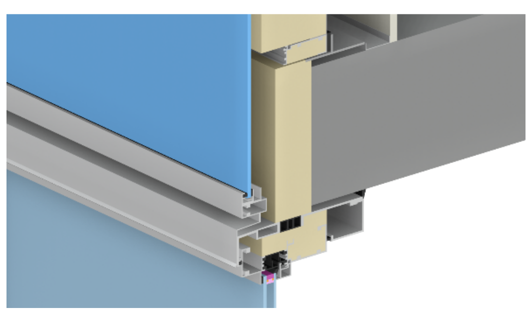
Backup Wall

- Steel-framed wall with 1 5/8 inch steel studs inboard the back-pan 2 inches (3 5/8 inches total cavity), with a wood sill and 1/2 inch drywall interior finishes

Bypass Section

- 8 inch concrete floor slab
- 2 ½ inches of mineral wool outboard of concrete floor slab
- 9600 deflection head with large thermal break





Slab Bypass

Figure 1: Geometry and Components of Starline 9600 Window Wall

Framing
- Insulated aluminum frames, including couplers and deflection head
- 48 inch vertical mullion spacing
- 108 inch total height of modelled section, including spandrel and vision sections (floor to floor height)

Spandrel Section
- 4 ½ inches of mineral wool in the back pan
- Single spandrel glass
- Floor to floor spandrel with horizontal mullion at 28 inches above slab

Backup Wall
- Steel-framed wall with 1 5/8 inch steel studs inboard the back-pan 2 inches (3 5/8 inches total cavity), with 1/2 inch drywall interior finishes

Bypass Section
- 8 inch concrete floor slab
- 2 ½ inches of mineral wool outboard of concrete floor slab
- 9600 deflection head with large thermal break

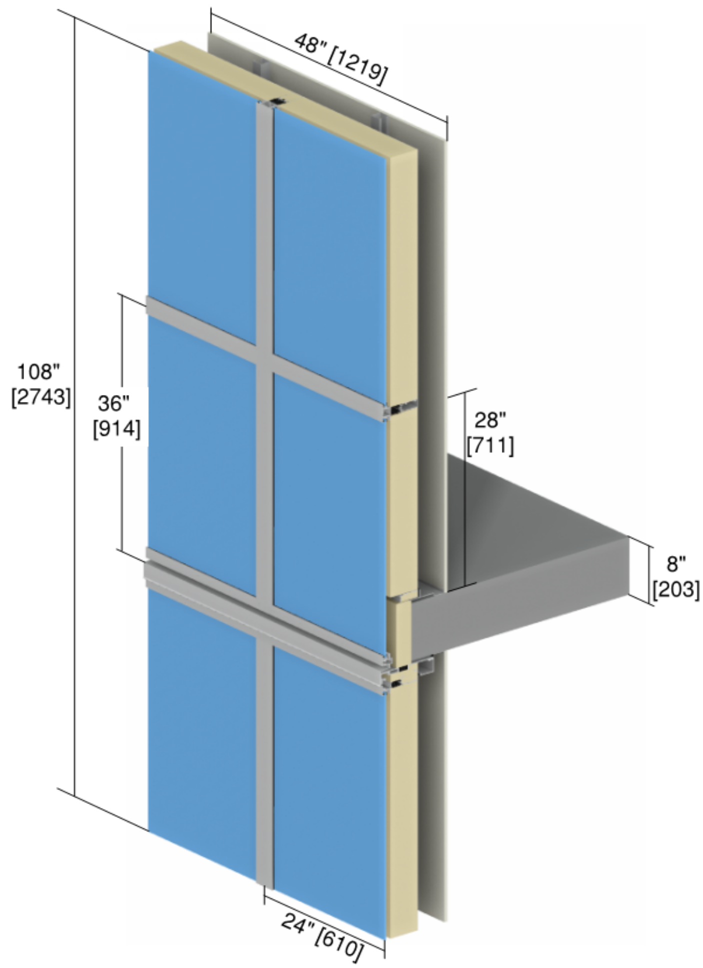


Figure 2: Geometry and Components of the Full Height Spandrel

For this analysis, four scenarios were analyzed to determine their bypass linear transmittances, as follows:

1. **Upstand Spandrel Section:** As shown in Figure 1 above
2. **Upstand Spandrel Section with Inboard Insulation**: The same geometry as Scenario 1, with the addition of 1 inch mineral wool (R-4.2), 1 1/2 inch mineral wool (R-6.3), 2 inch mineral wool (R-8.4), 2 inch rigid insulation (R-5), and 3 inch mineral wool (R-12.6) within the backup wall and inboard of the back pan
3. **Full Height Spandrel**: As shown in Figure 2 above
4. **Full Height Spandrel with Inboard Insulation**: The same geometry as Scenario 3, with the addition of 1 inch mineral wool (R-4.2), 1 1/2 inch mineral wool (R-6.3), 2 inch mineral wool (R-8.4), 2 inch rigid insulation (R-5), and 3 inch mineral wool (R-12.6) within the backup wall and inboard of the back pan.

THERMAL ANALYSIS

The thermal performance of the different assembly scenarios was evaluated by 3D thermal modelling using the Nx software package from Siemens, which is a general purpose computer aided design (CAD) and finite element analysis (FEA) package. The thermal solver and modelling procedures utilized for this study were extensively calibrated and validated to within +/- 5% of hotbox testing for *ASHRAE Research Project 1365-RP Thermal Performance of Building Envelope Details for Mid- and High-Rise Construction* and for the *Building Envelope Thermal Bridging Guide*[2]. The thermal analysis utilized steady-state conditions, published thermal properties of materials and information provided by Starline. Additional assumptions for the thermal analysis are listed in Appendix B.

The clear field spandrel and spandrel with slab u-values and effective R-values as well as the bypass linear transmittance for the upstand spandrel and full height spandrel are shown below in Table 1 and Table 2 respectfully. Descriptions of these sections are shown below in Figure 3. Example temperature profiles for each configuration are provided in Appendix C.

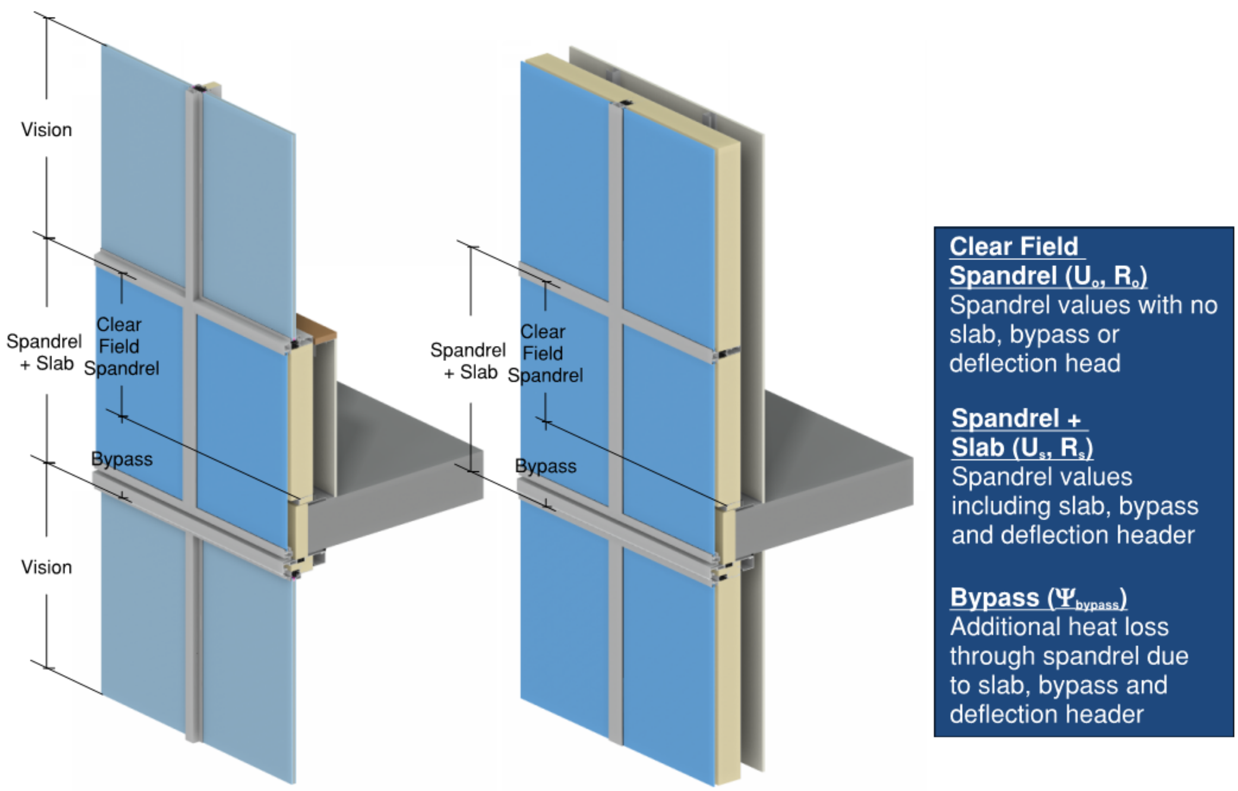


Figure 3: Depiction of Performance Value Locations

[2] https://www.bchydro.com/thermalguide

Table 1: Thermal Transmittance for Starline 9600 Window Wall System: Upstand Spandrel Section (Scenarios 1 and 2)

Scenario		Inboard Insulation Nominal R-Value ft² hr °F/Btu (m² °K/W)	Clear Field Spandrel		Spandrel with Slab		Bypass Linear Transmittance
			U_o Btu/h ft² °F (W/m² °K)	R_o ft² hr °F/Btu (m² °K/W)	U_s Btu/h ft² °F (W/m² °K)	R_s ft² hr °F/Btu (m² °K/W)	Ψ_{bypass} Btu/h ft °F (W/m °K)
1	Baseline	R-0 (0.00)	0.067 (0.38)	R-15.0 (2.64)	0.123 (0.70)	R-8.1 (1.43)	0.174 (0.30)
2	1" Inboard Insulation	R-4.2 (0.74)	0.061 (0.35)	R-16.4 (2.88)	0.118 (0.67)	R-8.5 (1.50)	0.174 (0.30)
	1.5" Inboard Insulation	R-6.3 (1.11)	0.059 (0.34)	R-16.9 (2.98)	0.116 (0.66)	R-8.6 (1.52)	0.173 (0.30)
	2" Inboard Insulation	R-8.4 (1.48)	0.058 (0.33)	R-17.3 (3.05)	0.114 (0.65)	R-8.8 (1.55)	0.173 (0.30)
	2" Inboard Rigid Insulation	R-10 (1.76)	0.057 (0.32)	R-17.6 (3.10)	0.113 (0.64)	R-8.8 (1.56)	0.173 (0.30)
	3" Inboard Insulation	R-12.6 (2.22)	0.055 (0.31)	R-18.1 (3.19)	0.111 (0.63)	R-9.0 (1.59)	0.171 (0.30)

Table 2: Thermal Transmittance for Starline 9600 Window Wall System: Full Height Spandrel (Scenarios 3 and 4)

Scenario		Inboard Insulation Nominal R-Value ft² hr °F/Btu (m² °K/W)	Clear Field Spandrel		Spandrel with Slab		Bypass Linear Transmittance
			U_o Btu/h ft² °F (W/m² °K)	R_o ft² hr °F/Btu (m² °K/W)	U_s Btu/h ft² °F (W/m² °K)	R_s ft² hr °F/Btu (m² °K/W)	Ψ Btu/h ft °F (W/m °K)
1	Baseline	R-0 (0.00)	0.065 (0.37)	R-15.4 (2.71)	0.079 (0.45)	R-12.6 (2.23)	0.127 (0.22)
2	1" Inboard Insulation	R-4.2 (0.74)	0.051 (0.29)	R-19.4 (3.42)	0.067 (0.38)	R-14.9 (2.62)	0.142 (0.25)
	1.5" Inboard Insulation	R-6.3 (1.11)	0.046 (0.26)	R-21.6 (3.80)	0.063 (0.36)	R-15.9 (2.80)	0.150 (0.26)
	2" Inboard Insulation	R-8.4 (1.48)	0.042 (0.24)	R-23.7 (4.17)	0.059 (0.34)	R-16.8 (2.96)	0.156 (0.27)
	2" Inboard Rigid Insulation	R-10 (1.76)	0.039 (0.22)	R-25.3 (4.46)	0.057 (0.33)	R-17.4 (3.07)	0.162 (0.28)
	3" Inboard Insulation	R-12.6 (2.22)	0.036 (0.20)	R-27.8 (4.89)	0.054 (0.31)	R-18.5 (3.27)	0.162 (0.28)

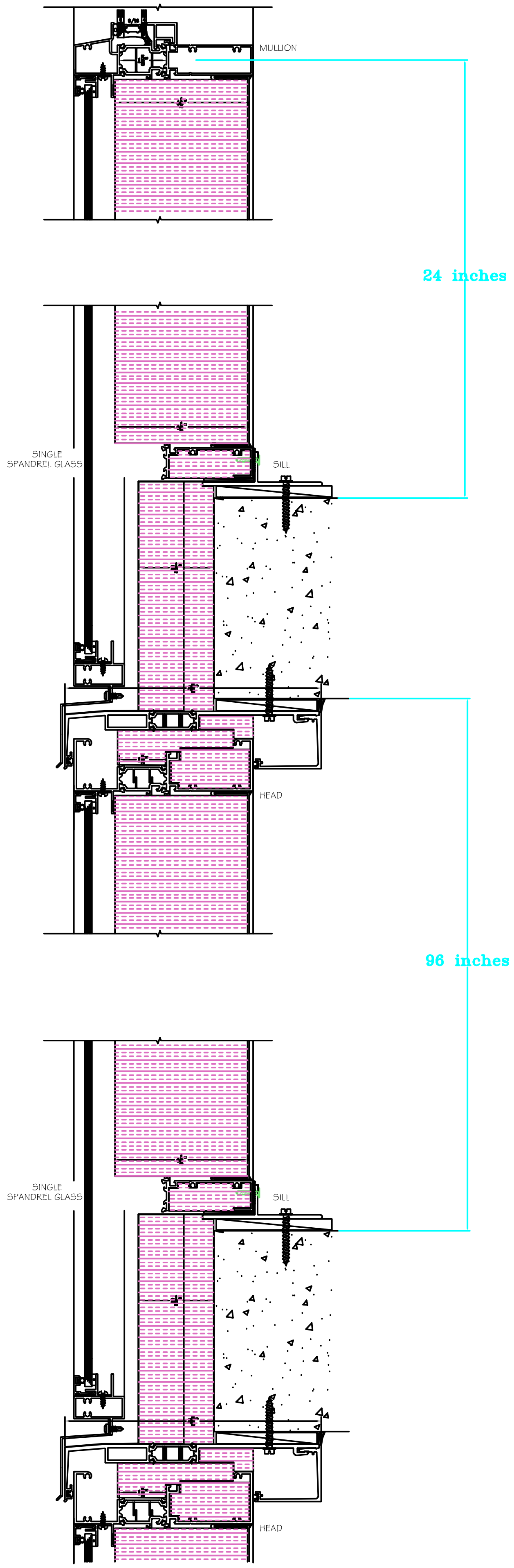
We believe that this report meets your objectives for evaluating the bypass linear transmittance of the Starline 9600 Window Wall system. If you have any questions or comments related to the above, please do not hesitate to contact the undersigned.

Yours truly,
MORRISON HERSHFIELD LIMITED

Katie Hay, P.Eng.
Building Science Consultant

Patrick Roppel, P.Eng.
Principal, Building Science Consultant

APPENDIX A: DETAIL DRAWING



Series 9600 DOUBLE GLAZED WINDOW WALL

PRELIMINARY ENERGY VALUES

FENESTRATION (FRAME, MULLIONS, SASH WITH VISION GLASS AREAS

Starline standard LowE x1(#2), argon and warm edge spacer = Fenestration values about 0.30 U and 0.32 SHGC

Starline standard LowE x2 (#2 and #4), argon and warm edge spacer = Fenestration values about 0.26 U and 0.32 SHGC

Protection to the LowE surface #4 will be required during the construction period

OPAQUE (SPANDREL, ETC.) AREAS

SINGLE GLASS AT BYPASS AREAS = ABOUT R8 depending on panel size and detailing

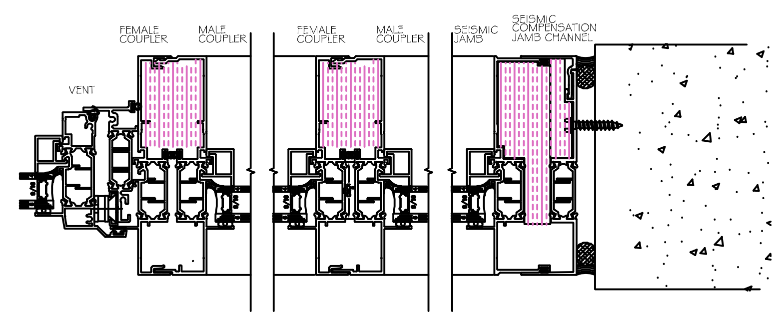
DOUBLE GLASS AT BYPASS AREAS = ABOUT R9 depending on panel size and detailing

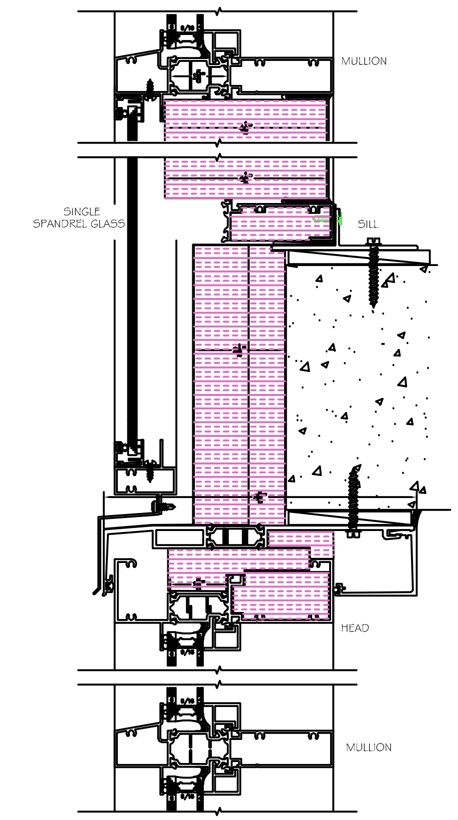
SINGLE GLASS AT FULL DEPTH AREAS = ABOUT R11 depending on panel size and detailing

DOUBLE GLASS AT FULL DEPTH AREAS = ABOUT R12 depending on panel size and detailing

SINGLE GLASS AT FULL DEPTH AREAS WITH 2" SPRAY FOAM AT INSIDE SURFACE = ABOUT R25 depending on panel size and detailing

DOUBLE GLASS AT FULL DEPTH AREAS WITH 2" SPRAY FOAM AT INSIDE SURFACE = ABOUT R25 depending on panel size and detailing





Series 9600 TRIPLE GLAZED WINDOW WALL

PRELIMINARY ENERGY VALUES

Starline standard LowE x1(#2), argon and warm edge spacer = Fenestration values about 0.25 U and 0.30 SHGC

Starline standard LowE x2 (#2 and #6), argon and warm edge spacer = Fenestration values about 0.22 U and 0.29 SHGC

Starline standard LowE x2 (#2 and #4), argon and warm edge spacer = Fenestration values about 0.21 U and 0.26 SHGC

Starline standard LowE x3 (#2, #4 and #6), argon and warm edge spacer = Fenestration values about 0.18 U and 0.25 SHGC

Protection to the LowE surface #6 will be required during the construction period

OPAQUE (SPANDREL, ETC.) AREAS

SINGLE GLASS AT BYPASS AREAS = ABOUT R8 depending on panel size and detailing

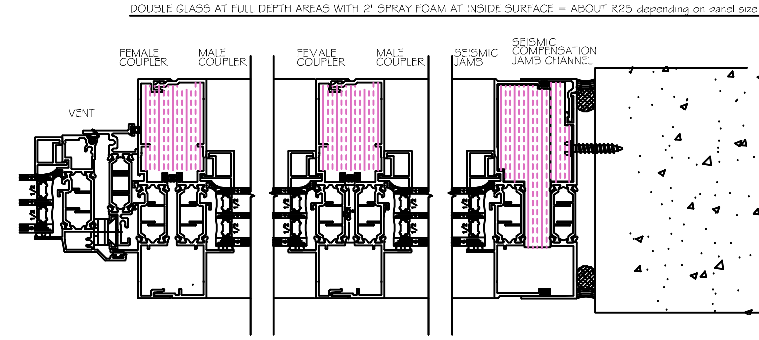
DOUBLE GLASS AT BYPASS AREAS = ABOUT R9 depending on panel size and detailing

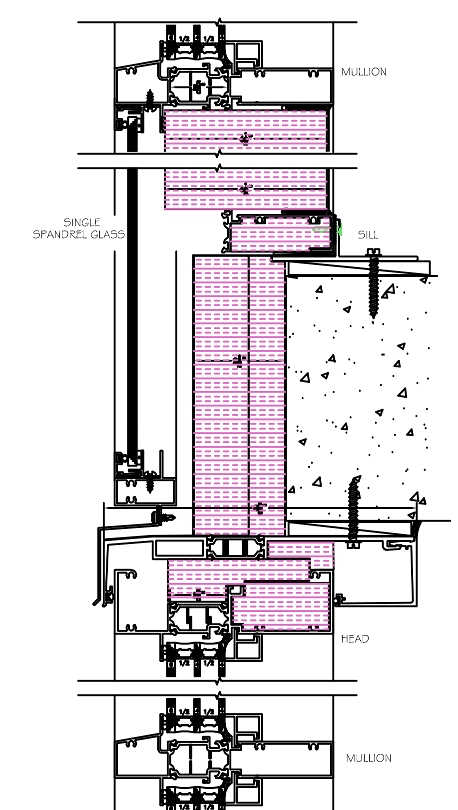
SINGLE GLASS AT FULL DEPTH AREAS = ABOUT R11 depending on panel size and detailing

DOUBLE GLASS AT FULL DEPTH AREAS = ABOUT R12 depending on panel size and detailing

SINGLE GLASS AT FULL DEPTH AREAS WITH 2" SPRAY FOAM AT INSIDE SURFACE = ABOUT R25 depending on panel size and detailing

DOUBLE GLASS AT FULL DEPTH AREAS WITH 2" SPRAY FOAM AT INSIDE SURFACE = ABOUT R25 depending on panel size and detailing





APPENDIX B: MODELLING PARAMETERS AND ASSUMPTIONS

B.1 THERMAL MODELLING ASSUMPTIONS

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

- Material properties were taken from information provided by Starline Windows and ASHRAE Handbook – Fundamentals for common materials.
- Enclosed air spaces were modelled with an equivalent thermal conductivity of the air that includes the impacts of convection and radiation within the enclosure. Calculations for this equivalent conductivity were based on ISO 10077.
- 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 15 mph.
- Interior glazing surface air films were modelled with separate radiation and convection coefficients to the interior.
- From the calibration in 1365-RP, contact resistances between materials were modelled and varied between R-0.01 and R-0.2 depending on the materials and interfaces.
- Insulation and other components were considered tight to adjacent interfaces.

B.2 TEMPERATURE INDEX

The temperature index is the ratio of the surface temperature relative to the interior and exterior temperatures. The temperature index has a value between 0 and 1, where 0 is the exterior temperature and 1 is the interior temperature. If T_i is known, Equation 1 can be rearranged for $T_{surface}$. This arrangement allows the modelled surface temperatures to be applicable to any climate.

$$T_i = \frac{T_{surface} - T_{outside}}{T_{inside} - T_{outside}} \qquad \text{EQ 1}$$

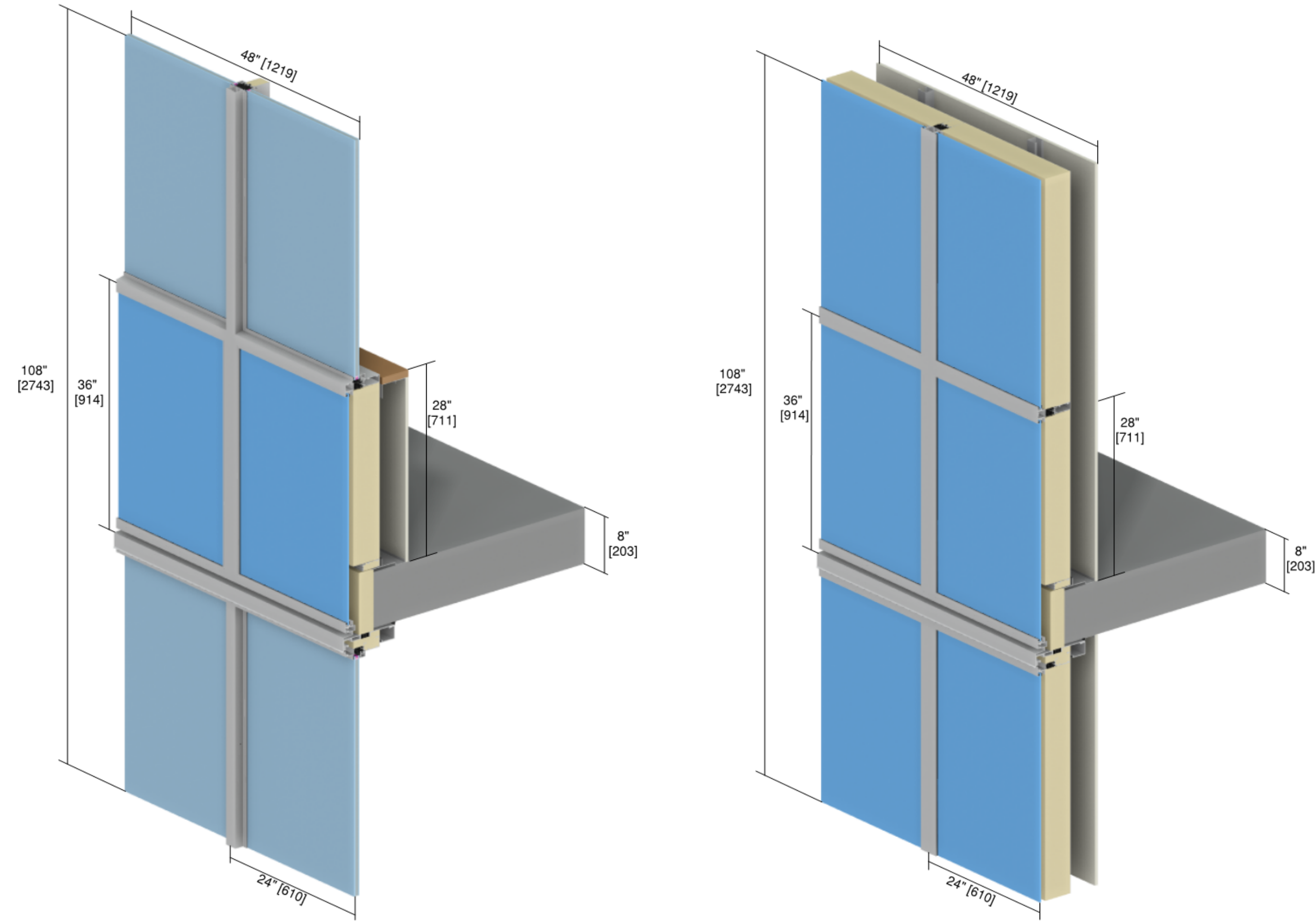
Note, these indices shown in the temperature profiles for this analysis are for general information only and are **not** intended to predict in-service surface temperatures subject to transient conditions, variable heating systems, and/ or interior obstructions that restrict heating of the assembly. For full limitations of this modelling approach, see ASHRAE 1365-RP.

B.3 BOUNDARY CONDITIONS

Table B3.1: Boundary Conditions

Boundary Location	Heat Transfer Coefficient BTU/h ft^2 °F (W/m^2 K)	Radiation View Factor
Exterior Surfaces	6.0 (34)	--
Exterior Centre of Glass	5.4 (31)	1
Interior Centre of Glass	0.7 (4.2)	1
Interior Edge of Glass	0.3 (1.7)	--
Interior Horizontal Frame Surface	0.9 (5.0)	--
Interior Vertical Frame Surface	1.3 (7.5)	--
Interior Floor	1.1 (6.1)	--
Interior Ceiling	1.6 (9.3)	--
Interior Vertical Surfaces	1.5 (8.3)	--

B.4 MATERIAL PROPERTIES



Upstand Spandrel Section and Bypass **Floor to Floor (Full Height) Spandrel**

Figure B4.1: Model Geometry of Starline 9600 Window Wall

Table B4.1.1: Material Properties

Component	Material	Thermal Conductivity Btu in / ft² hr °F (W/m K)
IGU		
Exterior Glass: Exterior Pane	6 mm Clear with Solarban60 on #2	6.9 (1.0)
Interior Glass: Interior Pane	4 mm Clear	6.9 (1.0)
Spandrel Glazing	Glass	6.7 (0.96)
Spacer	Silicone Foam	1.2 (0.17)
Spacer: PIB	PIB	1.4 (0.20)
Spacer: Filler	Silicone	2.4 (0.35)
Gaskets	Santoprene Glazing Gasket	1.0 (0.14)
Polyshim II Tape	Butyl	1.7 (0.24)
Window Wall		
Framing and Components	Aluminum	1110 (160)
Thermal Break	Polyamide (Nylon)	1.7 (0.25)
Sealant	Silicone	2.4 (0.35)
Frame Insulation	Mineral Wool (R4.2/in)	0.24 (0.034)
Back pan	Galvanized Steel	430 (62)
Back pan Insulation	Mineral Wool (R4.2/in)	0.24 (0.034)
Interior Backup Wall and Slab		
Gypsum	Gypsum	1.1 (0.16)
Cavity	Air	Varies[2]
Steel Stud	Galvanized Steel	430 (62)
Steel Track	Galvanized Steel	430 (62)
Sill Framing Angle	Galvanized Steel	430 (62)
Sill	Wood	0.69 (0.10)
Slab	Concrete	12.5 (1.80)
Slab Bypass Insulation	Mineral Wool (R4.2/in)	0.24 (0.034)
Steel T-Bracket	Steel	347(50)
Air Spaces[2]	Air	Varies
Inboard Insulation		
Mineral Wool	Mineral Wool (R4.2/in)	0.24 (0.034)
2" Inboard Rigid Insulation	Rigid Insulation (R5/in)	0.20 (0.029)

[2]The thermal conductivities of the air spaces were determined according to ISO 10077

APPENDIX C: SIMULATED TEMPERATURE PROFILES

C.1 COMPLETE ASSEMBLY TEMPERATURE PROFILES

As an example of the thermal profiles for the Starline 9600 Window Wall, the following figures illustrate typical temperature distributions for scenarios without inboard insulation and with 2 inches of inboard mineral wool insulation. The profiles presented as a temperature index (between 0 and 1). See Appendix B.2 for more information.

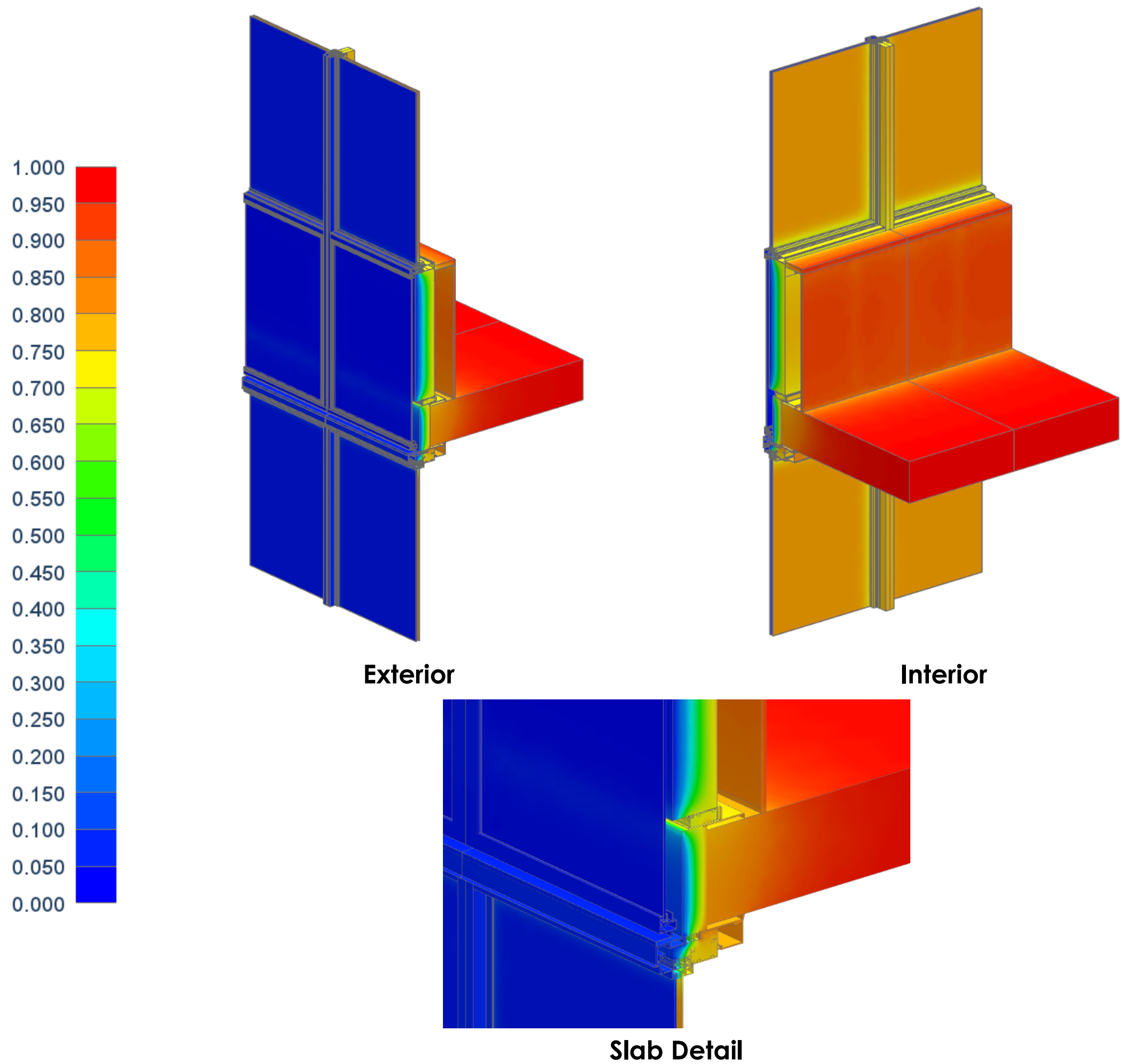


Figure C1.1: Temperature Profile of Starline 9600 Window Wall System: Scenario 1- Upstand Spandrel Section

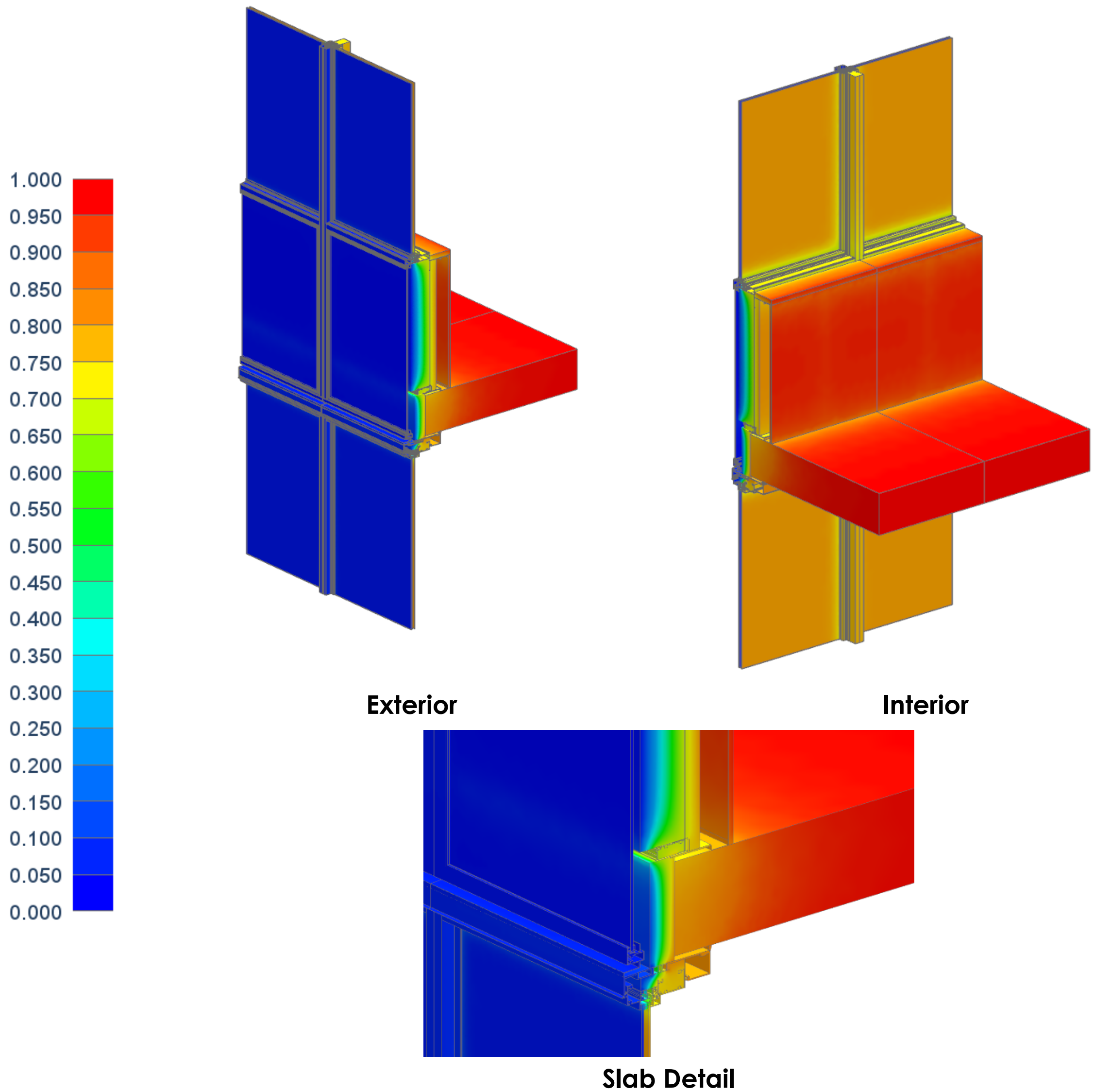


Figure C1.2: Temperature Profile of Starline 9600 Window Wall System: Scenario 2- Upstand Spandrel Section with 2" Mineral Wool Inboard Insulation

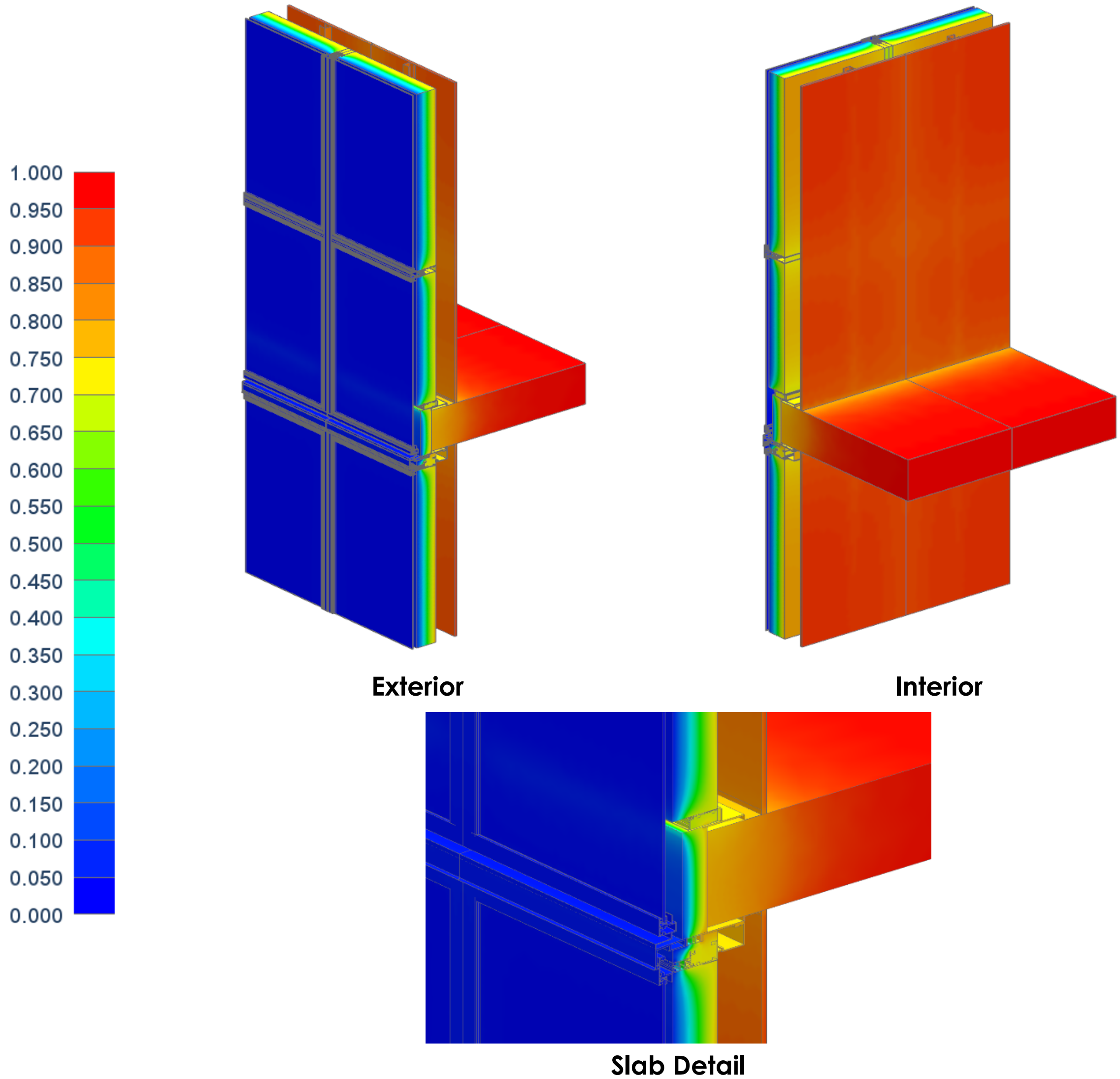


Figure C1.3: Temperature Profile of Starline 9600 Window Wall System: Scenario 3 - Full Height Spandrel

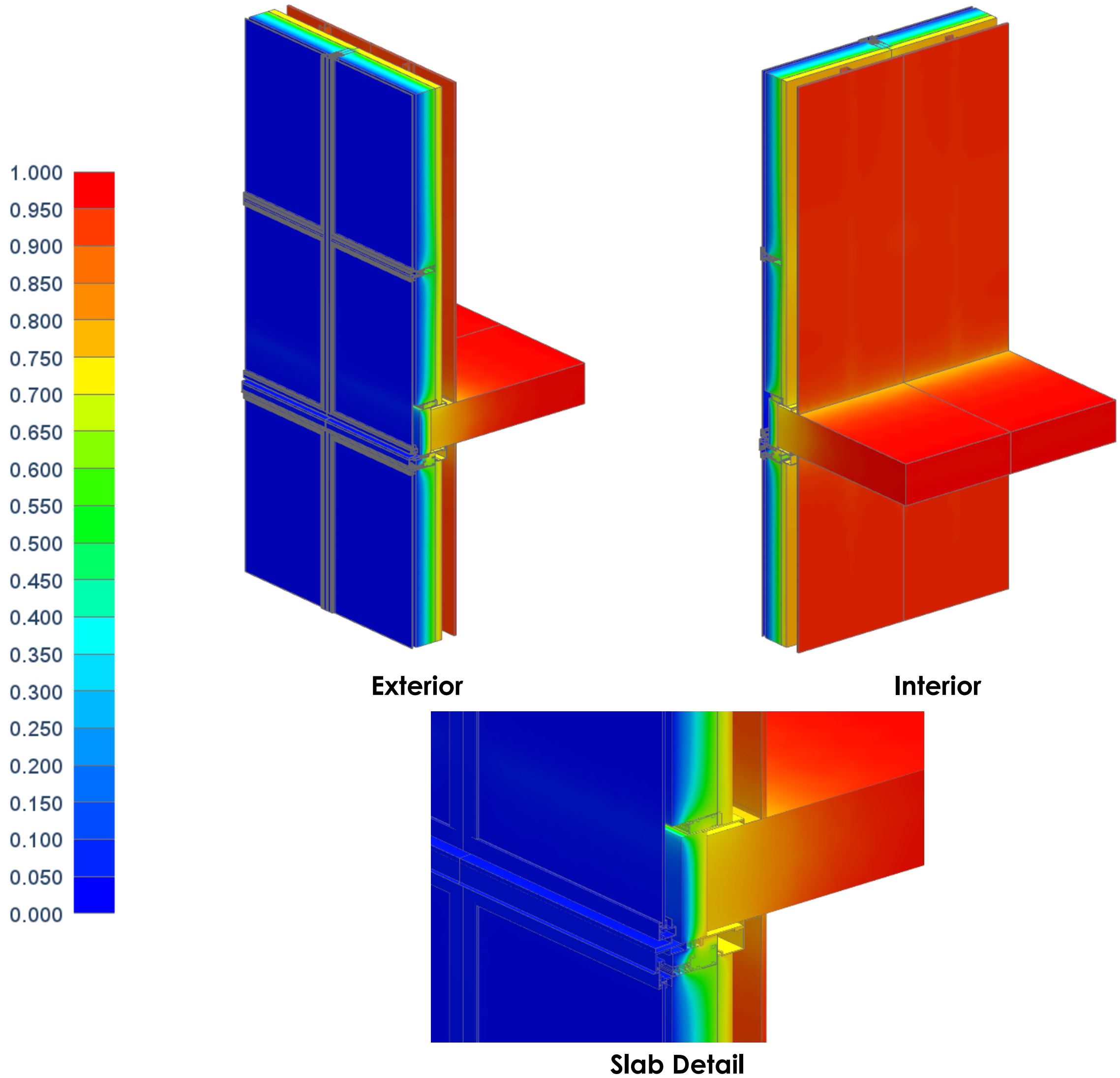


Figure C1.4: Temperature Profile of Starline 9600 Window Wall System: Scenario 4 - Full Height Spandrel with 2" Inboard Mineral Wool Insulation

C.2 CLEAR WALL ASSEMBLY TEMPERATURE PROFILES

As an example of the thermal profiles for the Starline 9600 Window Wall clear wall sections, the following figures illustrate typical temperature distributions for scenarios without inboard insulation and with 2 inches of inboard mineral wool insulation. The profiles presented as a temperature index (between 0 and 1). See Appendix B.2 for more information.

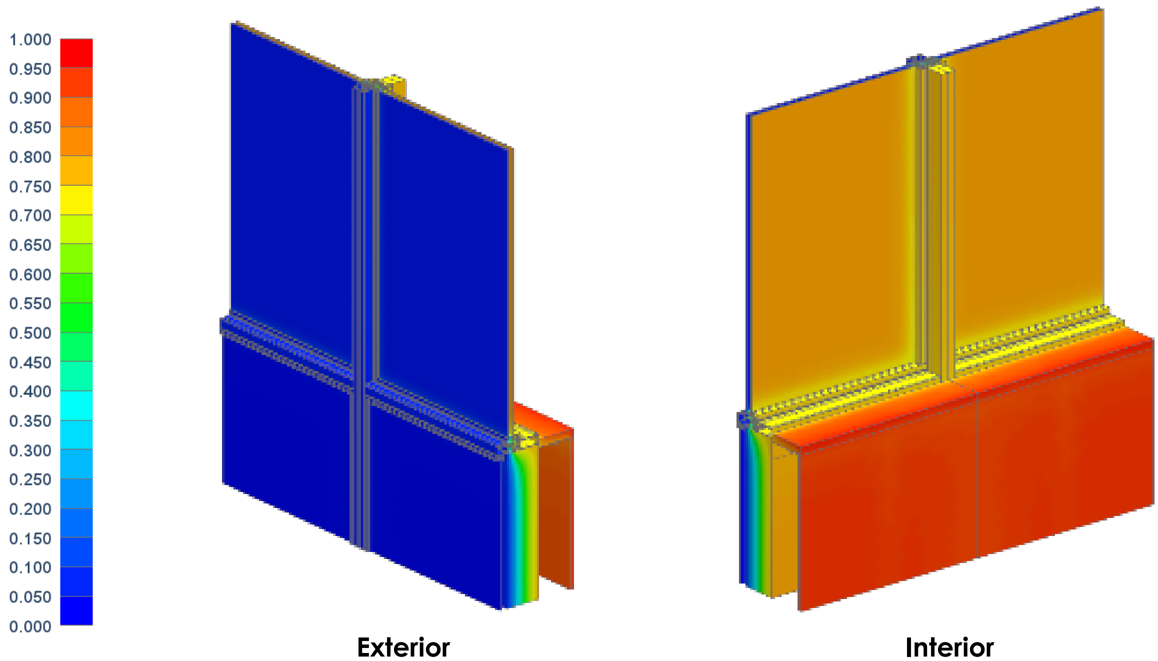


Figure C2.1: Temperature Profile of Starline 9600 Window Wall Clear Field Spandrel and Glazing: Scenario 1-Upstand Spandrel Section

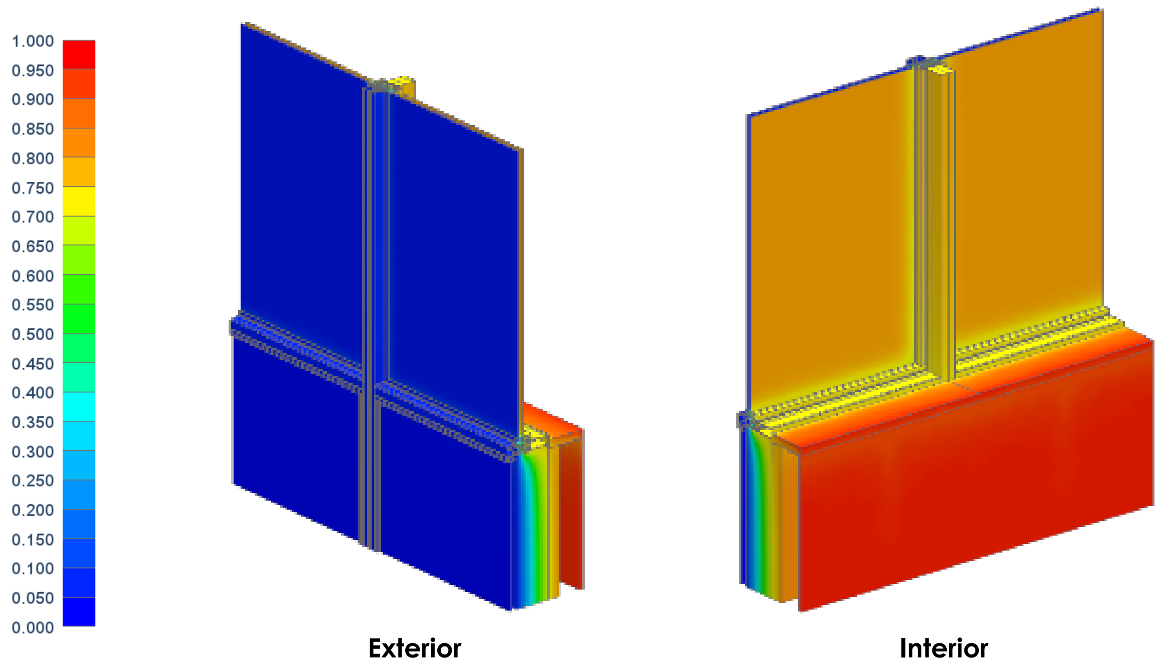


Figure C2.2: Temperature Profile of Starline 9600 Window Wall Clear Field Spandrel and Glazing: Scenario 2-Upstand Spandrel Section with 2" Mineral Wool Inboard Insulation

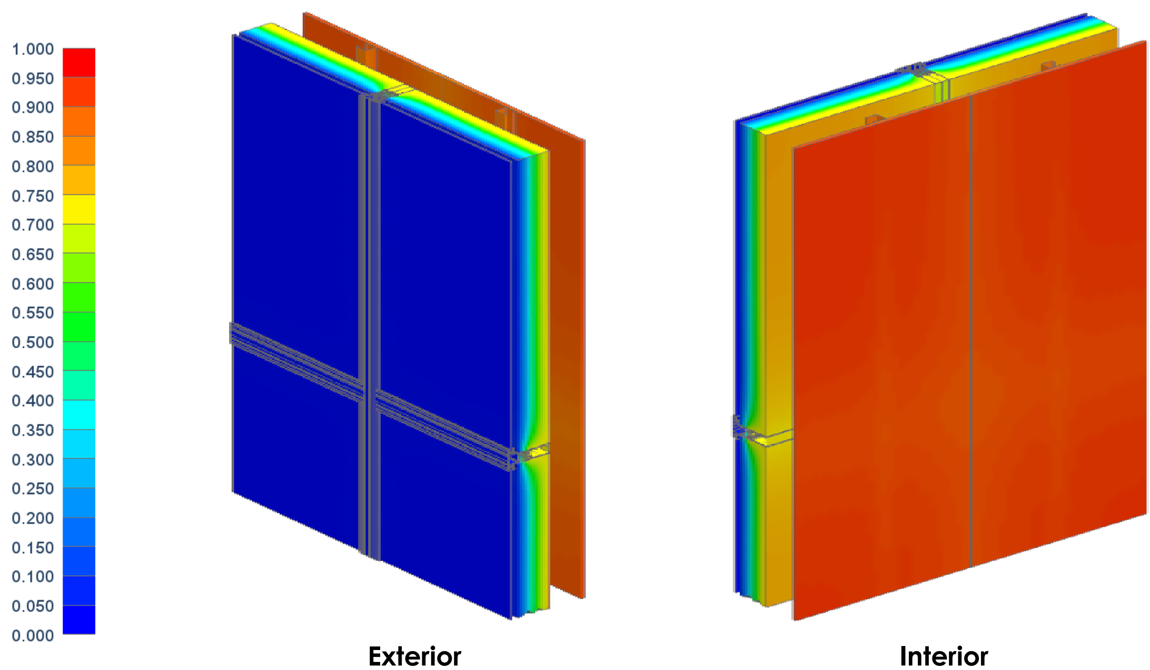


Figure C2.3: Temperature Profile of Starline 9600 Window Wall Clear Field Spandrel: Scenario 3 - Full Height Spandrel

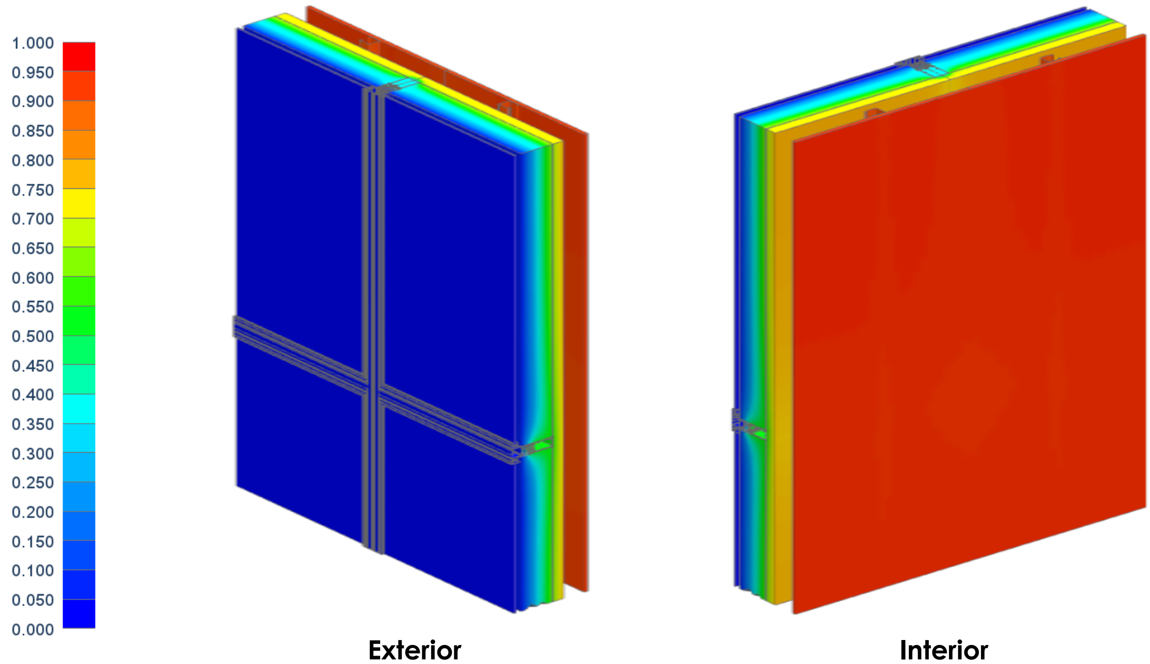


Figure C2.4: Temperature Profile of Starline 9600 Window Wall Clear Field Spandrel: Scenario 4 - Full Height Spandrel with 2" Inboard Mineral Wool Insulation