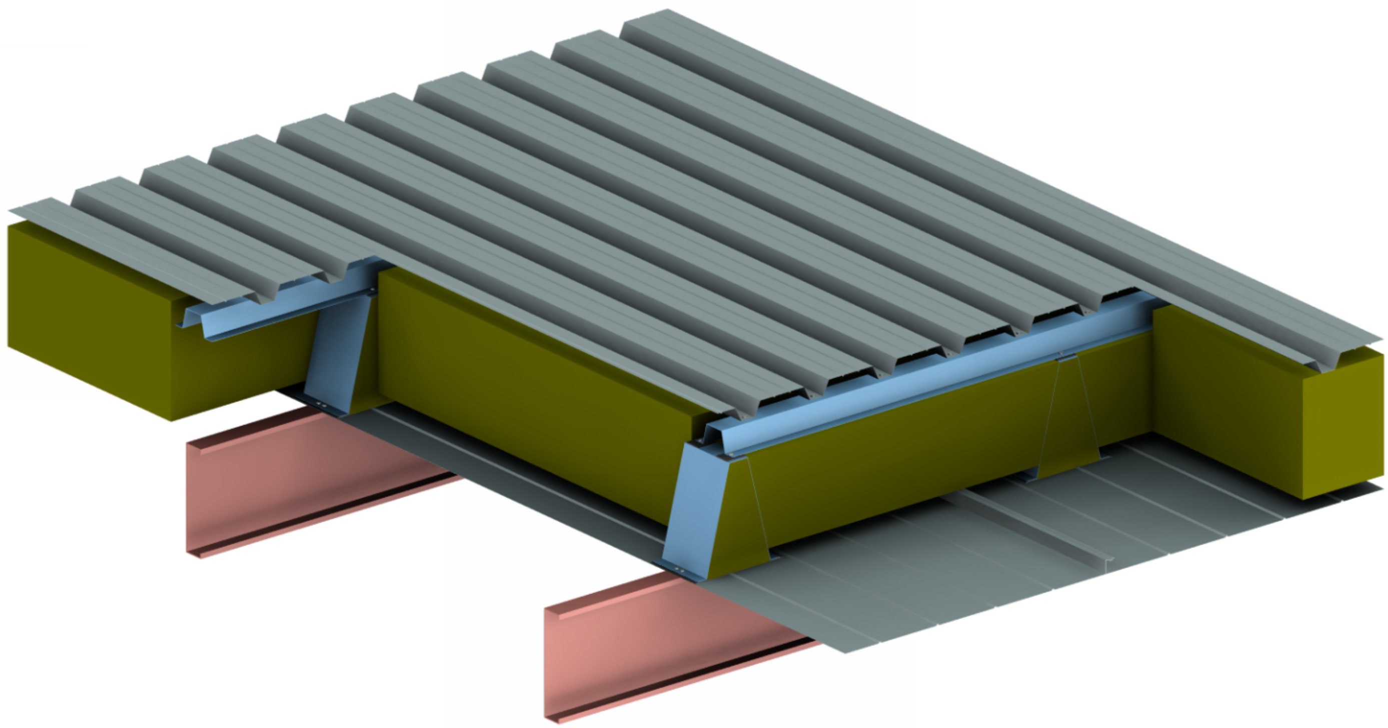
Report Number: 5140037.00
October 28th, 2014

Thermal Performance of Sheet Steel Wall and Roof Assemblies



Presented to:

Canadian Sheet Steel Building Institute
652 Bishop St. N., Unit 2A
Cambridge, ON, Canada
N3H 4V6

TABLE OF CONTENTS

1. INTRODUCTION

With the introduction of updated energy codes and standards, such as the Canadian National Energy Code for Buildings (NECB 2011), provincial jurisdictions are enacting more stringent requirements on the thermal transmittance of the building envelope. Several of the insulated sheet steel wall and roof assemblies currently offered by the Canadian Sheet Steel Building Institute (CSSBI) member companies may no longer meet the prescriptive requirements in these updated codes.

CSSBI engaged Morrison Hershfield (MH) to evaluate the thermal performance of high-performance of several insulated sheet steel roof and wall assemblies. The objective of this project is to identify sheet steel wall and roof assemblies that will comply with current Canadian codes and standards related to energy efficiency and to provide guidance to viable approaches that could improve thermal performance for sheet steel assemblies.

Using 3D heat transfer modelling, the effective R- and U-values for several wall and roof sheet steel assemblies were found using common components for metal buildings. These were compared to energy requirements in NECB 2011. Material changes to these structural attachments, including steel thicknesses and thermal break placements, were also analyzed in order to determine their impact on the heat transmittance through the assemblies.

2. MODELING OUTLINE

The thermal performance of the sheet steel assemblies was evaluated by 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 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]” and guarded hot box measurements.

The thermal analysis utilized steady-state conditions, published thermal properties of materials, and information provided by CSSBI. Boundary conditions were modeled using heat transfer coefficients to simulate convection, conduction, and radiation (i.e. film coefficients). Assumptions for the boundary conditions are summarized in Appendix A – Modelling Parameters and Boundary Conditions.

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

3. SHEET STEEL WALL ASSEMBLIES

For this analysis, three sheet steel wall assemblies were evaluated:

1. Sheet steel wall with notched z-bar to support cladding
2. Sheet steel wall with thermal chairs to support cladding
3. 2 Hour Fire Rated Exterior Sheet Steel Wall with notched Z-bar to support cladding

Assembly images, dimensions and materials of these wall assemblies are given in Appendix B – Assembly Information. A variety of configurations were evaluated for these assemblies and the thermal performance R- and U-value results are shown in the succeeding subsections of part 3.

In addition to the thermal performance values, the result tables also show comparisons to envelope prescriptive requirements. Table 1 shows the envelope prescriptive requirements for the most commonly referenced energy codes and standards in Canada, by climate zone

Table 1: Referenced Prescriptive Requirements by Climate Zone for Metal Building Walls in Canada

Code or Standard	Maximum Thermal Transmittance (W/m²K)				
	Heating Degree-Days of Building Location, in Celsius Degree-Days				
	Zone 4 <3000	Zone 5 3000 to 3999	Zone 6 4000 to 4999	Zone 7 5000 to 6999	Zone 8 >6999
NECB 2011	0.315	0.278	0.247	0.210	0.183
ASHRAE 90.1-2010 Non- Residential	0.477	0.392	0.392	0.324	0.324
OBC SB-10 Non-Residential	n/a	0.30	0.30	0.30	n/a

The results tables for the sheet steel walls show the highest climate zone that particular wall can meet according to NECB 2011 as they are the most stringent, however they can also be compared to the other codes and standards U-value requirements shown in Table 1.

3.1 Sheet Steel Walls with Notched Z-Bar

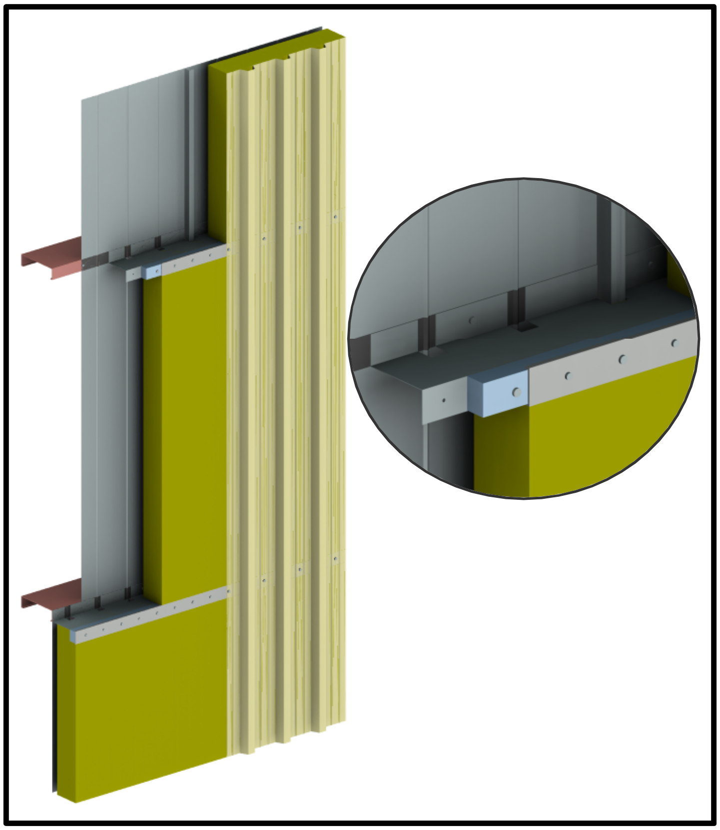


Figure 1: Sheet Steel Wall with Notched Z-Bar

The baseline sheet steel wall has 6” of mineral wool insulation (R4.2/inch) between a 24ga interior steel liner and exterior steel sheet cladding, supported by an 18ga notched z-bar with 1/8” thermal tape between the intermittent connections to the backup steel framing. Outboard of the notched z-bar is an 18ga steel u-channel with additional block insulation that attaches to the sheet steel cladding.

The wall assembly was analyzed for the following variations in configurations:

- Varying vertical spacing of the notced z-bar (Table 2)
- Varying steel liner and notched z-bar thickness (Table 3)
- Continuous vs Intermittent notched z-bar (Table 4)
- Addition of a PVC coating onto notched z-bar (Table 5)
- Varying Thermal Tape thickness (Table 6)

In each Table, the base wall assembly, described above, has been highlighted. It is the same in each table and all variations were adjusted from the base assembly.

Table 2: Variable Spacing of Girts and Notched Z-Bar

Vertical Spacing of Z-bar in	**Insulation Thickness** in	**Insulation 1D R-Value (RSI)**	**“Effective” R-value R_o** $ft^2 \cdot hr \cdot {}^oF$ / Btu (m^2 K / W)	**Overall Thermal Transmittance U_o** Btu/$ft^2 \cdot hr \cdot {}^oF$ (W/m^2 K)	**Highest NECB 2011 Zone Requirement Met**
48	6	R-25 (4.44)	R-21.8 (3.84)	0.046 (0.260)	5
60	**6**	**R-25 (4.44)**	**R-22.5 (3.96)**	**0.044 (0.253)**	**5**
72	6	R-25 (4.44)	R-23.0 (4.05)	0.044 (0.247)	6

Table 3: Variable Steel Liner and notched Z-bar Thickness at Z-bar spacing 60" o.c. vertically

Steel Thickness Gauge	Insulation Thickness in	Insulation 1D R-Value (RSI)	"Effective" R-value R_o ft^2·hr·^{o}F / Btu (m^2 K / W)	Overall Thermal Transmittance U_o Btu/ft^2 ·hr ·^{o}F (W/m^2 K)	Highest NECB 2011 Zone Requirement Met
Liner					
24 Ga	**6**	**R-25 (4.44)**	**R-22.5 (3.96)**	**0.044 (0.253)**	**5**
18 Ga	6	R-25 (4.44)	R-22.4 (3.95)	0.045 (0.253)	5
Z-Bar					
24 Ga	6	R-25 (4.44)	R-22.9 (4.03)	0.045 (0.256)	5
18 Ga	**6**	**R-25 (4.44)**	**R-22.5 (3.96)**	**0.044 (0.253)**	**5**
12 Ga	6	R-25 (4.44)	R-22.2 (3.91)	0.044 (0.248)	5

Table 4: Continuous z-bar with thermal block vs 12" Intermittent notched Z-bar without thermal block, with z-bar spaced 60" o.c. vertically

Z-Bar	Insulation Thickness in	Insulation 1D R-Value (RSI)	"Effective" R-value R_o ft^2·hr·^{o}F / Btu (m^2 K / W)	Overall Thermal Transmittance U_o Btu/ft^2 ·hr ·^{o}F (W/m^2 K)	Highest NECB 2011 Zone Requirement Met
Continuous z-bar with Thermal Block	**6**	**R-25 (4.44)**	**R-22.5 (3.96)**	**0.044 (0.253)**	**5**
Intermittent z-bar without Thermal Block	6	R-25 (4.44)	R-21.1 (3.72)	0.047 (0.269)	5

Table 5: PVC Coated Notched Z-Bars spaced 60" o.c. vertically

PVC Coating Thickness on Thermal Chairs and Outer Rails (mils)	Insulation 1D R-Value (RSI)	"Effective" R-value R_o ft^2·hr·^{o}F / Btu (m^2 K / W)	Overall Thermal Transmittance U_o Btu/ft^2 ·hr ·^{o}F (W/m^2 K)	Highest NECB 2011 Zone Requirement Met
0 Top, 0 Bottom	**R-25 (4.44)**	**R-22.5 (3.96)**	**0.044 (0.253)**	**5**
8 Top, 4 Bottom	R-25 (4.44)	R-22.7 (3.99)	0.044 (0.251)	5

Table 6: Variable R-values of Thermal Tape on the Liner to Notched Z-Bar with Z-bar spaced at 60" o.c. vertically

Tape Thickness in	Tape R-Value (RSI)	Insulation 1D R-Value (RSI)	"Effective" R-value R_o ft^2·hr·^{o}F / Btu (m^2 K / W)	Overall Thermal Transmittance U_o Btu/ft^2 ·hr ·^{o}F (W/m^2 K)	Highest NECB 2011 Zone Requirement Met
0	R-0 (0.00)	R-25 (4.44)	R-21.4 (3.78)	0.047 (0.265)	5
1/8	**R-1 (0.23)**	**R-25 (4.44)**	**R-22.5 (3.96)**	**0.044 (0.253)**	**5**
1/4	R-3 (0.45)	R-25 (4.44)	R-22.8 (4.01)	0.044 (0.249)	5

3.2 Sheet Steel Wall with Thermal Chairs

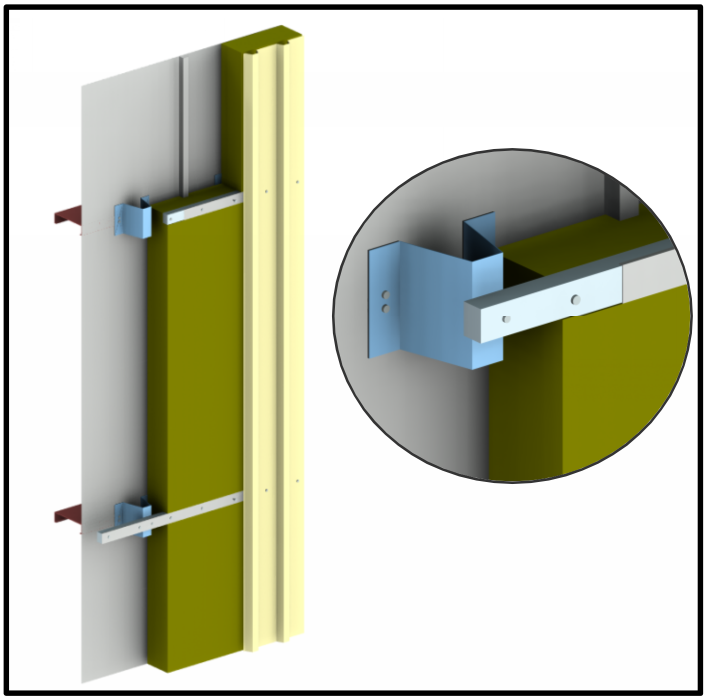


Figure 2: Sheet Steel Wall with Thermal Chair

The same sheet steel wall from section 3.1 was modelled with the use of intermittent 18 Ga thermal chairs at 24"o.c. horizontally, 60" vertically, replacing the notched z-bar. This wall assembly was analyzed for the following configurations:

- Varying horizontal thermal chair spacing (Table 7)
- Varying steel thermal chair and u-channel thickness (Table 8)

In each Table, the base wall assembly has been highlighted.

Table 7: Varying Horizontal Chair Spacing

Horizontal Thermal Chair Spacing in	Insulation Thickness in	Insulation 1D R-Value (RSI)	"Effective" R-value R_o $ft^2 \cdot hr \cdot {}^oF$ / Btu (m^2 K / W)	Overall Thermal Transmittance U_o Btu/$ft^2 \cdot hr \cdot {}^oF$ (W/m^2 K)	Highest NECB 2011 Zone Requirement Met
24	**6**	**R-25 (4.44)**	**R-24.3 (4.28)**	**0.041 (0.233)**	**6**
36	6	R-25 (4.44)	R-24.4 (4.30)	0.041 (0.233)	6
48	6	R-25 (4.44)	R-24.8 (4.36)	0.040(0.229)	6

Table 8: Variable Steel Chair and Notched U-channel Thickness at Chair Spacing of 60" o.c. vertically

Steel Thickness Gauge	Insulation Thickness in	Insulation 1D R-Value (RSI)	"Effective" R-value R_o $ft^2 \cdot hr \cdot {}^oF$ / Btu (m^2 K / W)	Overall Thermal Transmittance U_o Btu/$ft^2 \cdot hr \cdot {}^oF$ (W/m^2 K)	Highest NECB 2011 Zone Requirement Met
Thermal Chair					
24 Ga	6	R-25 (4.44)	R-24.4 (4.30)	0.041 (0.233)	6
18 Ga	**6**	**R-25 (4.44)**	**R-24.3 (4.28)**	**0.041 (0.233)**	**6**
14 Ga	6	R-25 (4.44)	R-24.2 (4.27)	0.041 (0.234)	6
U-Channel					
24 Ga	6	R-25 (4.44)	R-24.3 (4.28)	0.041 (0.233)	6
18 Ga	**6**	**R-25 (4.44)**	**R-22.5 (3.96)**	**0.041 (0.233)**	**6**
14 Ga	6	R-25 (4.44)	R-22.2 (3.91)	0.041 (0.234)	6

3.3 2 Hour Fire Rated Sheet Steel Wall

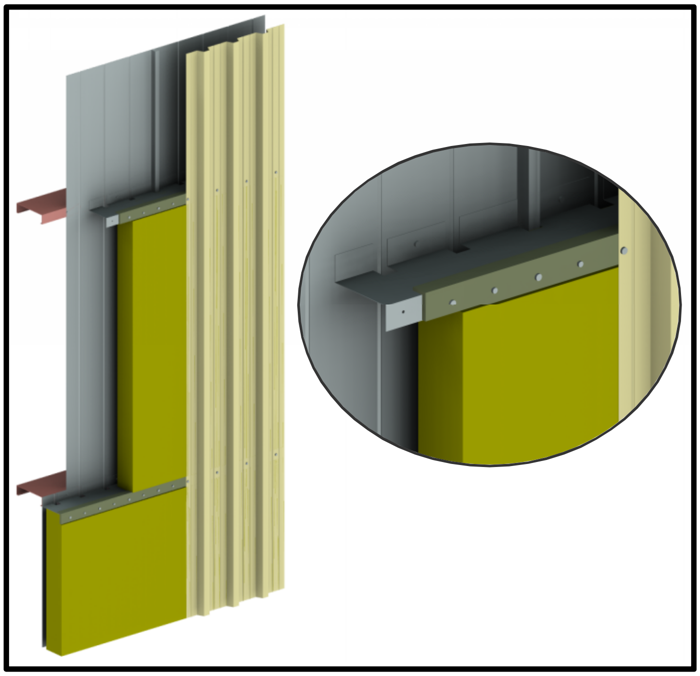


Figure 3: Fire Rated Sheet Steel Wall

The fire-rated exterior steel sheet wall is similar to the baseline notched z-bar assembly, however the U-channel with thermal block has been replaced with a ceramic fibre strip placed over the notched z-bar, at 60” o.c. and no thermal tape. The results for this specific assembly is shown in Table 9.

Table 9: Variable Spacing of Girts and Notched Z-Bar

Vertical Spacing of Z-bar in	Insulation Thickness in	Insulation 1D R-Value (RSI)	“Effective” R-value R_o ft²·hr·°F / Btu (m² K / W)	Overall Thermal Transmittance U_o Btu/ft² ·hr ·°F (W/m² K)	Highest NECB 2011 Zone Requirement Met
60	6	R-25 (4.44)	R-14.2 (2.51)	0.070 (0.400)	None

3.4 Sheet Steel Wall Insulation Type Sensitivity

As there are several insulation types that can be used in these wall assemblies, a sensitivity analysis was completed to determine the impact of the insulation type (insulation R per inch value) . Results for varying insulation thicknesses for R-4.2/inch (mineral wool), R-5/inch (XPS) and R-6/inch (Polyisocyanurate) for the notched z-bar assembly in section 3.1, spaced at 60”o.c., are shown in Table 10, Table 11 and Table 12 respectively. Figure 4 graphs the effective R-value of all insulation types in the sensitivity analysis.

Table 10: Various Insulation Levels with z-bars at R-4.2/inch Insulation

Insulation Thickness in	Insulation 1D R-Value (RSI)	“Effective” R-value R_o ft²·hr·°F / Btu (m² K / W)	Overall Thermal Transmittance U_o Btu/ft² ·hr ·°F (W/m² K)	Highest NECB 2011 Zone Requirement Met
6	R-25 (4.44)	R-22.5 (3.96)	0.044 (0.253)	5
7	R-29 (5.18)	R-25.7 (4.52)	0.039 (0.221)	6
8	R-34 (5.92)	R-28.4 (5.01)	0.035(0.200)	7

Table 11: Various Insulation Levels with z-bars at 60" o.c. at R-5/inch Insulation

Insulation Thickness in	Insulation 1D R-Value (RSI)	"Effective" R-value R_o ft²·hr·°F / Btu (m² K / W)	Overall Thermal Transmittance U_o Btu/ft² ·hr ·°F (W/m² K)	Highest NECB 2011 Zone Requirement Met
6	R-30 (5.28)	R-26.0 (4.57)	0.039 (0.219)	6
7	R-35 (6.16)	R-29.6 (5.21)	0.034 (0.192)	7
8	R-40 (7.04)	R-32.7 (5.76)	0.031 (0.173)	8

Table 12: Various Insulation Levels with z-bars at R-6/inch Insulation

Insulation Thickness in	Insulation 1D R-Value (RSI)	"Effective" R-value R_o ft²·hr·°F / Btu (m² K / W)	Overall Thermal Transmittance U_o Btu/ft² ·hr ·°F (W/m² K)	Highest NECB 2011 Zone Requirement Met
6	R-36 (6.34)	R-30.1 (5.31)	0.033 (0.188)	7
7	R-42 (7.40)	R-34.2 (6.03)	0.029 (0.166)	8
8	R-48 (8.45)	R-37.8 (6.65)	0.026 (0.150)	8

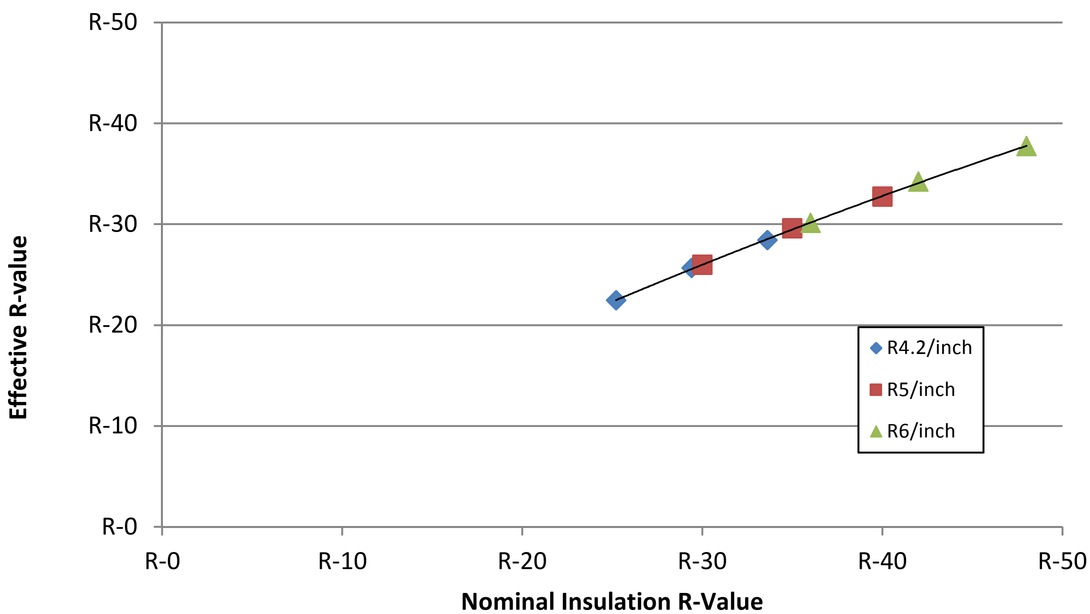


Figure 4: Nominal R-values versus Effective R-values for insulation types with the baseline girt spacing.

Figure 4 makes it clear that the effective R-value of the assembly follows the same trend, regardless of the insulation type. Therefore, the results in section 3 can be interpolated between nominal R-values of insulation for other types.

4. SHEET STEEL ROOFING ASSEMBLIES

For this analysis, three sheet steel roofing assemblies were evaluated:

1. Corrugated Sheet Steel Roof supported by thermal chairs
2. Standing Seam Roof supported by thermal chairs
3. Standing Seam Roof with Draped Insulation over purlins

Assembly images, dimensions and materials of these roof assemblies are given in Appendix B – Assembly Information. These assemblies were modelled for a variety of configurations and the thermal performance R- and U-value results are shown in the succeeding subsections of part 4.

As with the sheet steel walls in section 3, the tables in section 4 contain comparisons to envelope prescriptive requirements for NECB 2011. Table 13 shows the envelope prescriptive requirements for the most commonly referenced energy codes and standards in Canada, by climate zone, for metal building roofs.

Table 13: Referenced Prescriptive Requirements by Climate Zone for Metal Building Roofs in Canada

Code or Standard	Maximum Thermal Transmittance (W/m^2K)				
	Heating Degree-Days of Building Location, in Celsius Degree-Days				
	Zone 4 <3000	Zone 5 3000 to 3999	Zone 6 4000 to 4999	Zone 7 5000 to 6999	Zone 8 >6999
NECB 2011	0.227	0.183	0.183	0.162	0.142
ASHRAE 90.1-2010 Non- Residential	0.273	0.273	0.273	0.273	0.273
OBC SB-10 Non-Residential	n/a	0.220	0.180	0.162	n/a

4.1 Insulated Sheet Steel Roof Supported By Thermal Chairs

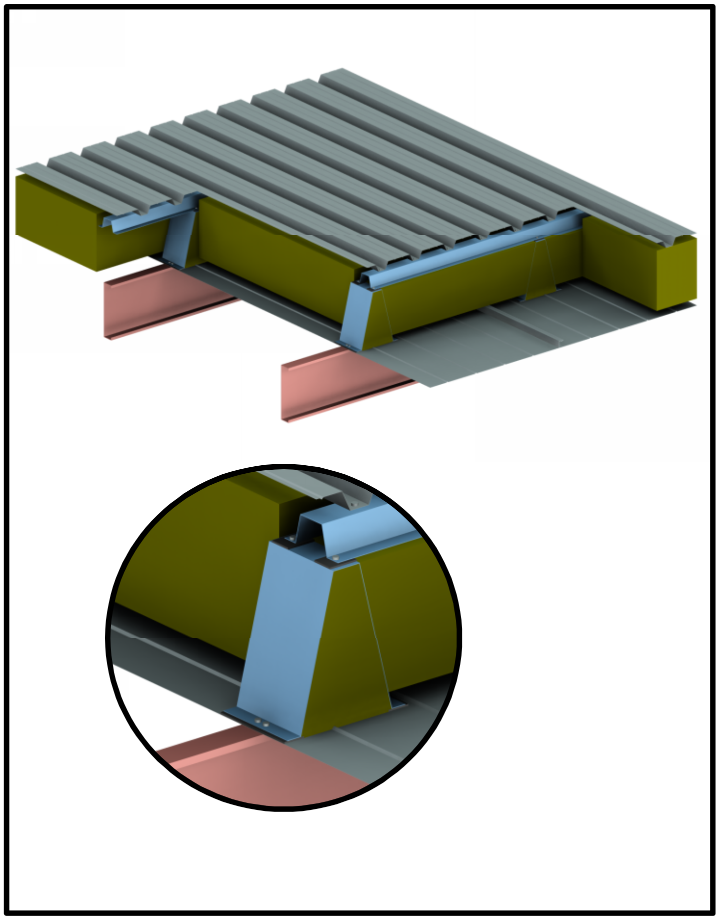


Figure 5: Insulated Corrugated Sheet Steel Roof

The baseline sheet steel roof assembly has 22ga corrugated cladding fastened to 2" high 18ga hat tracks that are supported by 10" high 18 ga thermal chairs. The thermal chairs have a 1/8" thermal tape at all steel to steel connections. The steel liner is 24ga on 14ga purlins. There is 10 ¾" of mineral wool insulation (R4.2/inch) between cladding and liner.

The wall assembly was analyzed for the following configurations:

- o Varying thermal chair and purlin spacing (Table 14)
- o Varying thermal tape thickness (Table 15)
- o Reductions in steel area of thermal chairs using perforations (Table 16)
- o Addition of a PVC coating onto thermal chairs and hat track surfaces (Table 17)
- o Change of thermal chair material from steel to plastic (Table 18)
- o Varying steel thickness for liner, cladding, chair and purlin (Table 19)

In each Table, the base roof assembly, described above, has been highlighted. It is the same in each table and all variations were adjusted from the base assembly.

Table 14: Variable Spacing of Thermal Chairs and Purlins

Chair Spacing in	Purlin Spacing in	Insulation 1D R-Value (RSI)	"Effective" R-value R_o ft^2·hr·^{o}F / Btu (m^2 K / W)	Overall Thermal Transmittance U_o Btu/ft^2 ·hr ·^{o}F (W/m^2 K)	Highest NECB 2011 Zone Requirement Met
24	48	R-45 (7.95)	R-30.5 (5.38)	0.033 (0.186)	4
24	60	R-45 (7.95)	R-32.7 (5.76)	0.031 (0.174)	6
24	72	R-45 (7.95)	R-34.3 (6.04)	0.029 (0.166)	6
36	**48**	**R-45 (7.95)**	**R-33.8 (5.96)**	**0.030 (0.168)**	**6**
36	60	R-45 (7.95)	R-35.9 (6.32)	0.028 (0.158)	7
36	72	R-45 (7.95)	R-37.4 (6.58)	0.027 (0.152)	7
48	48	R-45 (7.95)	R-39.6 (6.97)	0.025 (0.143)	7
48	60	R-45 (7.95)	R-40.4 (7.11)	0.025 (0.141)	8
48	72	R-45 (7.95)	R-41.4 (7.29)	0.024 (0.137)	8

Table 15: Variable Thermal Tape thickness on the Thermal Chair Steel-to-Steel Connections for 36"o.c. chair spacing and 48"o.c. purlin spacing

Tape Thickness in	Tape R-Value (RSI)	Insulation 1D R-Value (RSI)	"Effective" R-value R_o ft²·hr·°F / Btu (m² K / W)	Overall Thermal Transmittance U_o Btu/ft² ·hr ·°F (W/m² K)	Highest NECB 2011 Zone Requirement Met
0	R-0 (0.00)	R-45 (7.95)	R-30.4 (5.36)	0.033 (0.187)	4
1/8	**R-1 (0.23)**	**R-45 (7.95)**	**R-33.8 (5.96)**	**0.030 (0.168)**	**6**
1/4	R-3 (0.45)	R-45 (7.95)	R-34.3 (6.04)	0.029 (0.166)	6

Table 16: Reduction in thermal chair area for 36"o.c. chair spacing and 48"o.c. purlin spacing

Chair Type	Insulation 1D R-Value (RSI)	"Effective" R-value R_o ft²·hr·°F / Btu (m² K / W)	Overall Thermal Transmittance U_o Btu/ft² ·hr ·°F (W/m² K)	Highest NECB 2011 Zone Requirement Met
Baseline Thermal Chair	**R-45 (7.95)**	**R-33.8 (5.96)**	**0.030 (0.168)**	**6**
20 % Reduced Area	R-45 (7.95)	R-34.0 (5.98)	0.029 (0.167)	6
30% Reduced Area	R-45 (7.95)	R-34.4 (6.05)	0.029 (0.165)	6
40 % Reduced Area	R-45 (7.95)	R-34.6 (6.10)	0.029 (0.164)	6

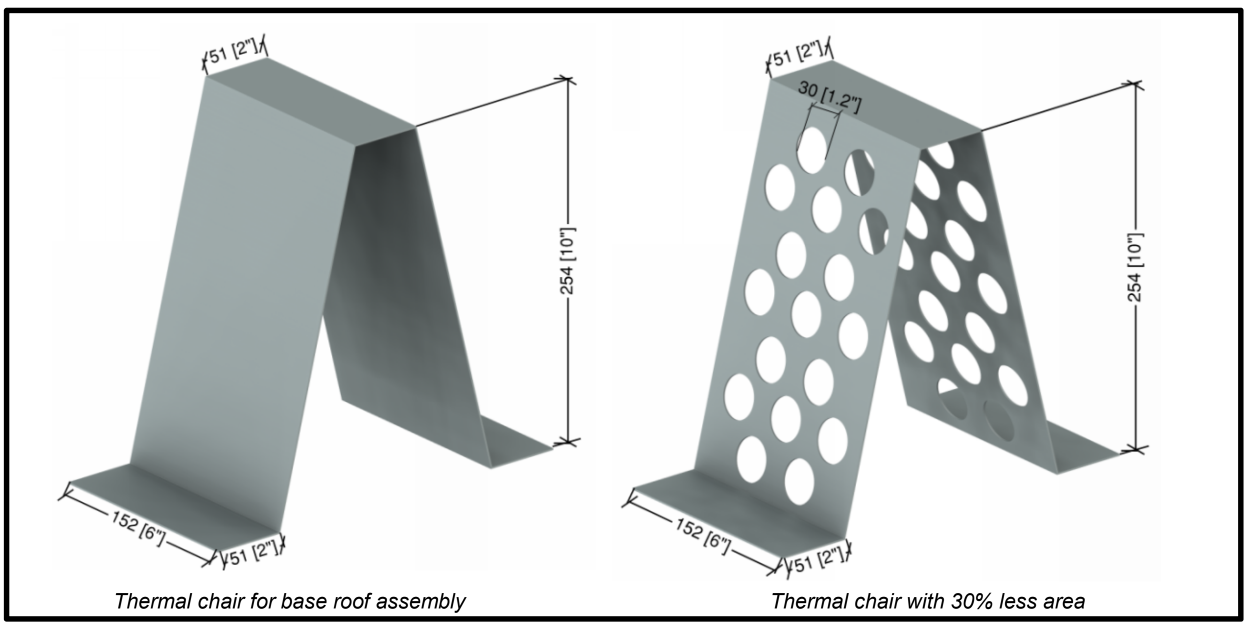


Figure 6: Thermal chairs with reduction in area

Table 17: PVC Coated Thermal Chairs and Outer Rails for 36"o.c. chair spacing and 48"o.c. purlin spacing

PVC Coating Thickness on Thermal Chairs and Outer Rails (mils)	Insulation 1D R-Value (RSI)	"Effective" R-value R_o ft²·hr·°F / Btu (m² K / W)	Overall Thermal Transmittance U_o Btu/ft² ·hr ·°F (W/m² K)	Highest NECB 2011 Zone Requirement Met
0 Top, 0 Bottom	**R-45 (7.95)**	**R-33.8 (5.96)**	**0.030 (0.168)**	**6**
8 Top, 4 Bottom	R-45 (7.95)	R-34.2 (6.03)	0.029 (0.166)	6

Table 18: Impact of Material Change of Thermal Chairs for 36"o.c. chair spacing and 48"o.c. purlin spacing

Thermal Chair Material	Insulation 1D R-Value (RSI)	"Effective" R-value R_o ft²·hr·°F / Btu (m² K / W)	Overall Thermal Transmittance U_o Btu/ft² ·hr ·°F (W/m² K)	Highest NECB 2011 Zone Requirement Met
Steel	**R-45 (7.95)**	**R-33.8 (5.96)**	**0.030 (0.168)**	**6**
Plastic	R-45 (7.95)	R-37.1 (6.53)	0.027 (0.153)	7

Table 19: Variable Liner, Cladding, Chair and Purlin Thickness for 36" o.c. chair spacing and 48"o.c. purlin spacing.

Steel Thickness Gauge	Insulation 1D R-Value (RSI)	"Effective" R-value R_o ft²·hr·°F / Btu (m² K / W)	Overall Thermal Transmittance U_o Btu/ft² ·hr ·°F (W/m² K)	Highest NECB 2011 Zone Requirement Met
Liner				
24 Ga	**R-45 (7.95)**	**R-33.8 (5.96)**	**0.030 (0.168)**	**6**
18 Ga	R-45 (7.95)	R-33.8 (5.95)	0.030 (0.168)	6
Cladding				
22 Ga	**R-45 (7.95)**	**R-33.8 (5.96)**	**0.030 (0.168)**	**6**
18 Ga	R-45 (7.95)	R-33.7 (5.94)	0.030 (0.168)	6
14 Ga	R-45 (7.95)	R-33.7 (5.93)	0.030 (0.169)	6
Chair				
22 Ga	R-45 (7.95)	R-34.1 (6.01)	0.029 (0.167)	6
18 Ga	**R-45 (7.95)**	**R-33.8 (5.96)**	**0.030 (0.168)**	**6**
14 Ga	R-45 (7.95)	R-33.6 (5.91)	0.030 (0.169)	6
Purlins				
14 Ga	**R-45 (7.95)**	**R-33.8 (5.96)**	**0.030 (0.168)**	**6**
6 Ga	R-45 (7.95)	R-33.8 (5.95)	0.030 (0.168)	6
3 Ga	R-45 (7.95)	R-33.7 (5.94)	0.030 (0.168)	6

4.2 Insulated Standing Seam Roof Supported by Thermal Chairs

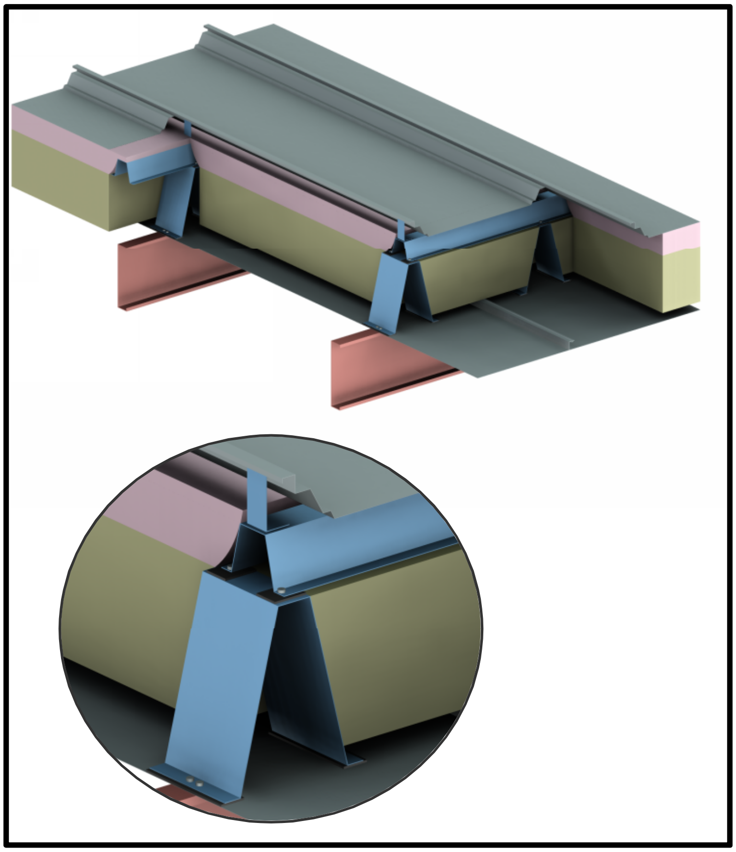


Figure 7: Insulated Standing Seam Roof Support by Thermal

The standing seem roof is similar to the baseline roof, however the cladding is supported differently. The standing seam roof supported by basic clips on a 3" high hat track instead of fastened directly to the hat tracks. The insulation between the hat tracks was replaced with a draped R-19 batt which was compressed beneath the roof and at the hat tracks. The assembly had 24"o.c. chair spacing and 48"o.c. purlin spacing.

The assembly was analyzed for various insulation configurations, shown in Table 20.

Table 20: Standing Seam Roof for 24"o.c. chair spacing and 48"o.c. purlin spacing

Insulation Placement	Insulation 1D R-Value (RSI)	"Effective" R-value R_o ft^2·hr·°F / Btu (m^2 K / W)	Overall Thermal Transmittance U_o Btu/ft^2 ·hr ·°F (W/m^2 K)	Highest NECB 2011 Zone Requirement Met
Compressed R-19 batt between and over hat tracks	R-57.6 (10.1)	R-33.4 (5.87)	0.030 (0.170)	6
Compressed R-19 batt between and over hat tracks with 1" XPS thermal block	R-57.6 (10.1)	R-36.4 (6.40)	0.028 (0.156)	7
Compressed R-19 batt between hat tracks, insulation over hat tracks	R-57.6 (10.1)	R-31.7 (5.59)	0.032 (0.179)	6
Mineral Wool between hat tracks, no compressed insulation over hat tracks	R-51.2 (9.0)	R-32.4 (5.71)	0.031 (0.175)	6

4.3 Standing Seam Roof with Draped Insulation

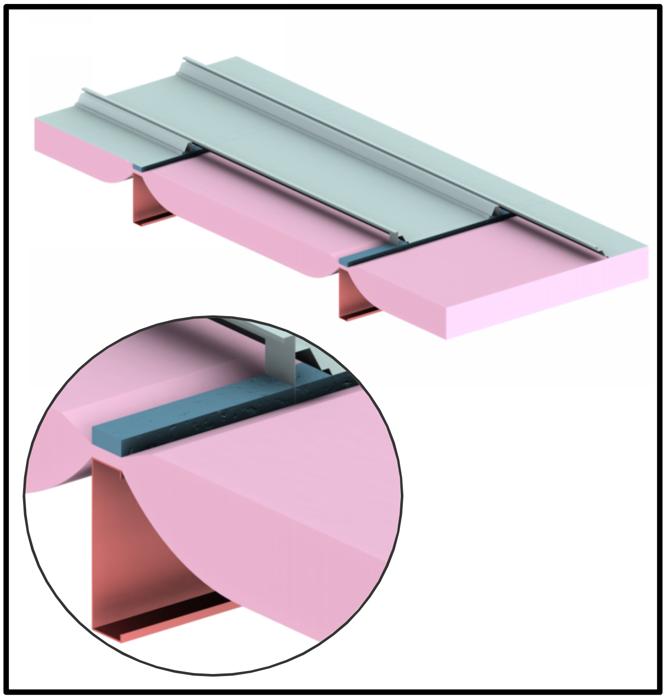


Figure 8: Standing Seam Roof with Draped Insulation

A standing seam roof with draped insulation was modelled to validate the results of this report to guarded hot-box measurements. This assembly matches the assembly shown in Table A2.3 of ASHRAE 90.1 for a standing seam roof with R-19 draped insulation and a 1" thermal spacer block[2].

The modelled assembly for this report was compared to that found in ASHRAE 90.1. The results are shown in Table 21.

.

Table 21: Standing Seam roof with Draped R-19 Batt Insulation with purlins spaced 60"o.c.

Source	Insulation 1D R-Value (RSI)	"Effective" R-value R_o ft^2·hr·°F / Btu (m^2 K / W)	Overall Thermal Transmittance U_o Btu/ft^2 ·hr ·°F (W/m^2 K)	Highest NECB 2011 Zone Requirement Met
ASHRAE 90.1-2010	R-19 (3.35)	R-15.4 (2.71)	0.065 (0.369)	None
Modelled Assembly	R-19 (3.35)	R-15.7(2.77)	0.064 (0.361)	None

From Table 21, it can be seen that there is good agreement between this modelling and ASHRAE 90.1-2010 values based on hot-box measurements. The difference is minor and well within experimental error, however the difference may be also be attributable to a different clip configuration between the assemblies.

[2] This assembly can also be found in *Guide to Insulating Metal Buildings for Compliance to ASHRAE 90.1-2010* from North American Insulation Manufactures Association (NAIMA)

4.4 Sheet Steel Roof Insulation Type Sensitivity

The baseline roof assembly in section 4.1 was modelled for varying insulation types. Results for varying insulation thicknesses for R-4.2/inch (mineral wool), R-5/inch (XPS) and R-6/inch (Polyisocyanurate) for 36”o.c. chair spacing and 48” o.c. purling spacing, are shown in Table 22, Table 23 and Table 24 respectively. Figure 9shows the effective R-value of the systems in the sensitivity analysis compiled into one graph.

Table 22: Various Insulation Levels for 36” o.c. chair spacing and 48”o.c. purlin spacing with R-4.2/inch Insulation

Chair Height in	Insulation Thickness in	Insulation 1D R-Value (RSI)	“Effective” R-value R_o ft²·hr·°F / Btu (m² K / W)	Overall Thermal Transmittance U_o Btu/ft² ·hr ·°F (W/m² K)	Highest NECB 2011 Zone Requirement Met
4 ¼	5	R-21 (3.70)	R-19.4 (3.41)	0.052 (0.293)	None
6	6 ¾	R-28 (4.99)	R-25.0 (4.40)	0.040 (0.227)	4
8 ¼	9	R-38 (6.66)	R-30.7 (5.42)	0.033 (0.185)	4
10	**10 ¾**	**R-45 (7.95)**	**R-33.8 (5.96)**	**0.030 (0.168)**	**6**

Table 23: Various Insulation Levels for 36” o.c. chair spacing and 48”o.c. purlin spacing with R-5/inch Insulation

Chair Height in	Insulation Thickness in	Insulation 1D R-Value (RSI)	“Effective” R-value R_o ft²·hr·°F / Btu (m² K / W)	Overall Thermal Transmittance U_o Btu/ft² ·hr ·°F (W/m² K)	Highest NECB 2011 Zone Requirement Met
4 ¼	5	R-25 (4.40)	R-22.2 (3.91)	0.045 (0.256)	None
6	6 ¾	R-34 (5.95)	R-28.6 (5.04)	0.035 (0.198)	4
8 ¼	9	R-45 (7.93)	R-35.0 (6.17)	0.029 (0.162)	7
10	10 ¾	R-54 (9.46)	R-38.3 (6.74)	0.026 (0.148)	7

Table 24: Various Insulation Levels for 36” o.c. chair spacing and 48”o.c. purlin spacing with R-6/inch Insulation

Chair Height in	Insulation Thickness in	Insulation 1D R-Value (RSI)	“Effective” R-value R_o ft²·hr·°F / Btu (m² K / W)	Overall Thermal Transmittance U_o Btu/ft² ·hr ·°F (W/m² K)	Highest NECB 2011 Zone Requirement Met
4 ¼	5	R-30 (5.29)	R-25.6 (4.51)	0.039 (0.222)	4
6	6 ¾	R-41 (7.13)	R-32.9 (5.80)	0.030 (0.172)	6
8 ¼	9	R-54 (9.51)	R-40.0 (7.04)	0.025 (0.142)	8
10	10 ¾	R-64 (11.36)	R-43.4 (7.64)	0.023 (0.131)	8

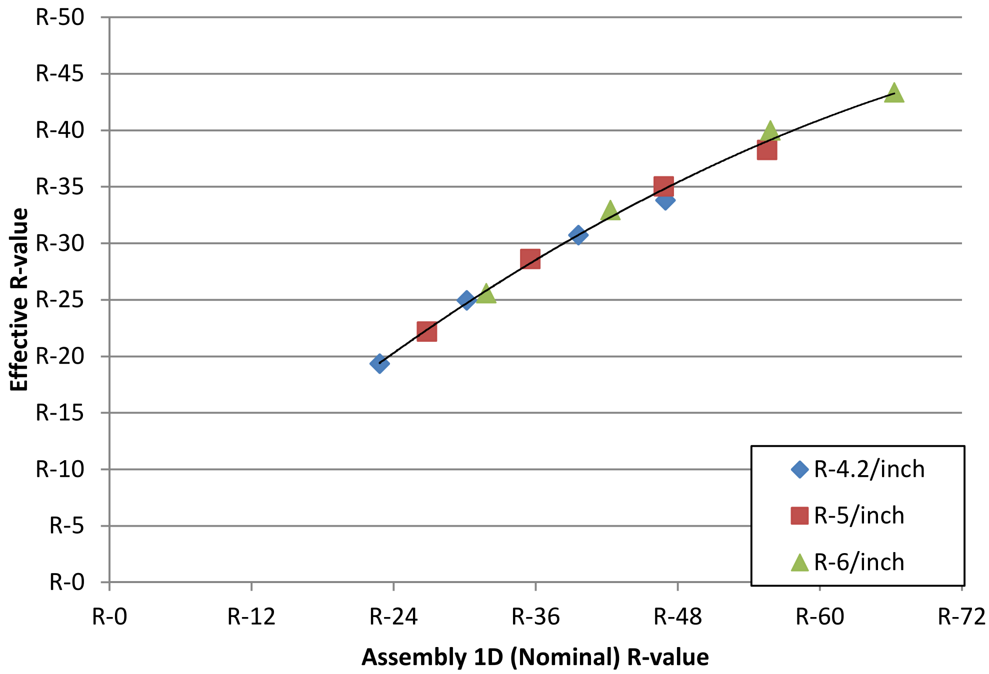


Figure 9: Nominal R-values versus Effective R-values for insulation types with the baseline chair and purlin spacing

It is clear from Figure 9 that the effective R-value of the assemblies in Section 4.1 are dependent on the nominal R-value of the insulation, not the thickness or the type. Please note that, when compressed, the actual thermal resistance of batt insulation is reduced from its nominal rating, depending on the amount of compression.

5. CONCLUSIONS

The thermal performance values given in this report show how steel sheet wall and roof assemblies can meet various prescriptive requirements across Canada. The variations in configurations also show what component changes have the largest impact. We believe the information provided in this report meets the objectives for the project set out by CSSBI for the analysis of these evaluated assemblies.

Yours Truly,
Morrison Hershfield

Neil Norris, MASc
Building Science Consultant

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

APPENDIX A – MODELLING PARAMETERS AND BOUNDARY CONDITIONS

A.1 General Modeling Approach

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

- Air cavities were assumed to have an effective thermal conductivity which includes the effects of cavity convection.
- Interior/exterior air films were taken from Table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundaments depending on surface orientation. These include air films shown in Table A1.

Table A1: Surface Film Coefficients

Component	Nominal Resistance hr· ft2· °F/BTU (m2K/W)
Exterior, surface exposed to 15mph wind	0.16 (0.03)
Interior Wall, vertical surface exposed to indoor air and radiation to other indoor surfaces	0.67 (0.12)
Interior Ceiling, horizontal surface exposed to indoor air with upward heat flow and radiation to other indoor surfaces	0.63 (0.11)

- Contact resistances between materials were modeled. These varied depending on the contact interfaces. See ASHRAE 1365-RP
- The thermal tape was not explicitly modelled, but were included as a contact resistance between steel parts.
- The temperature difference between interior and exterior was modeled as a dimensionless temperature index between 0 and 1 (see Appendix A.3).
- The thermal conductivity of compressed batt insulation was based on *ASHRAE 90.1 Metal Building U-Factors – Part 1: Mathematical Modeling and Validation by Calibrated Hot Box Measurements*

A.2 Temperature Index

For the modelling, the temperature difference was non-dimensionalized in order to be applicable for any climate (varying indoor and outdoor temperatures). This is referred to as a temperature index, T_i, as shown below in Equation 3.

$$T_i = \frac{T_{surface} - T_{outside}}{T_{inside} - T_{outside}} \quad \text{EQ 3}$$

The 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 3 can be rearranged for $T_{surface}$.

APPENDIX B – ASSEMBLY INFORMATION

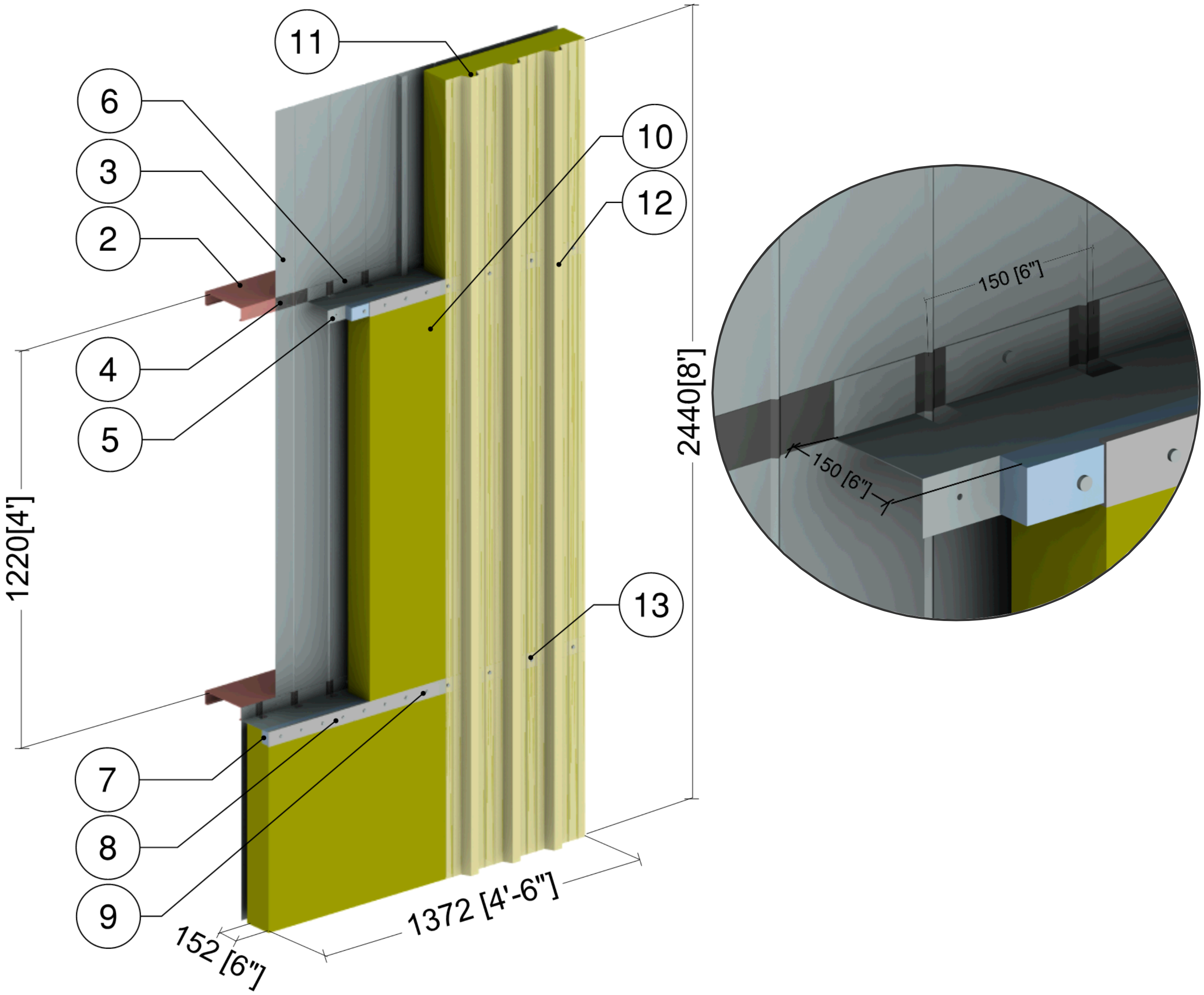
B.1 Sheet Steel Wall Assemblies

B.1.1. Material Properties

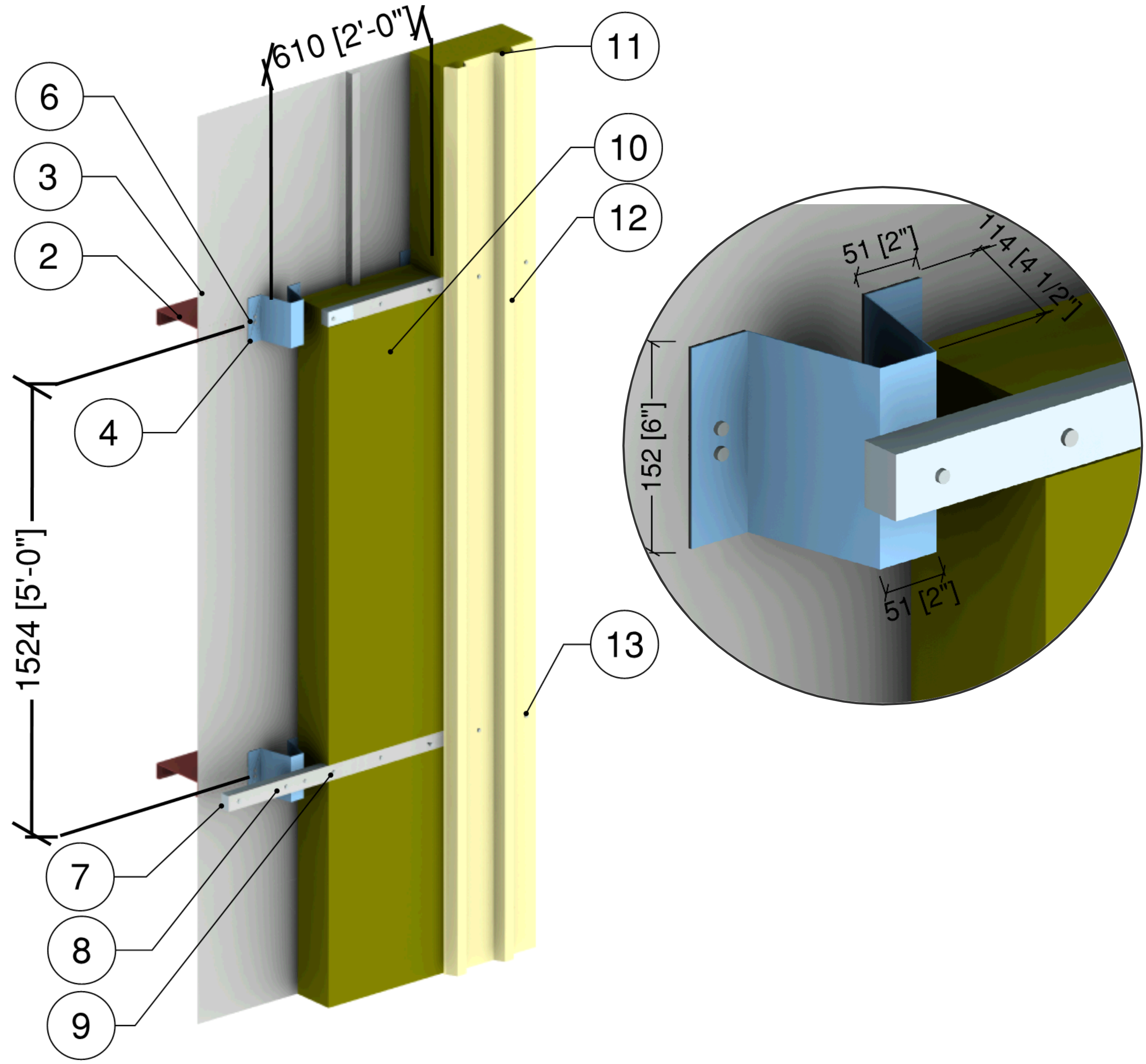
ID	Component	Thickness Inches (mm)	Conductivity Btu·in / ft²·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)
1	Interior Films (left side)[1]	-	-	R-1.3 (0.22 RSI)
2	8 x 2 Steel Girts @ 48" o.c.	0.10 (2.6)	347 (50)	-
3	Galvanized Steel Liner Panel	24 Gauge	430 (62)	-
4	Thermal Tape	1/8 (3.2)	0.097 (0.014)	-
5	Galvanized Steel Notched Z-Bar/Thermal Chair	18 Gauge	430 (62)	-
6	#12 Fasteners Girt through Liner	-	430 (62)	-
7	Thermal Block Insulation	2 (50)	0.200 (0.029)	R-10 (1.76 RSI)
8	Galvanized Steel U-Bar	18 Gauge	430 (62)	-
9	#12 Fasteners through Thermal Block Insulation @ 7.5" o.c.	-	430 (62)	-
10	Mineral Wool Insulation	4.75 (121)	0.238 (0.034)	R-20 (3.52 RSI)
11	Air Gap[2]	-	Dependent on size	-
12	Galvanized Steel Cladding	24 Gauge	430 (62)	-
13	#12 Fasteners through Cladding	-	430 (62)	-
14	Ceramic Blanket	½ (13)	0.62 (0.09)	R-0.8 (0.14)
15	Exterior Film (right side)[1]	-	-	R-0.2 (0.03 RSI)

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals
[2] The thermal conductivity of air spaces was found using ISO 100077-2

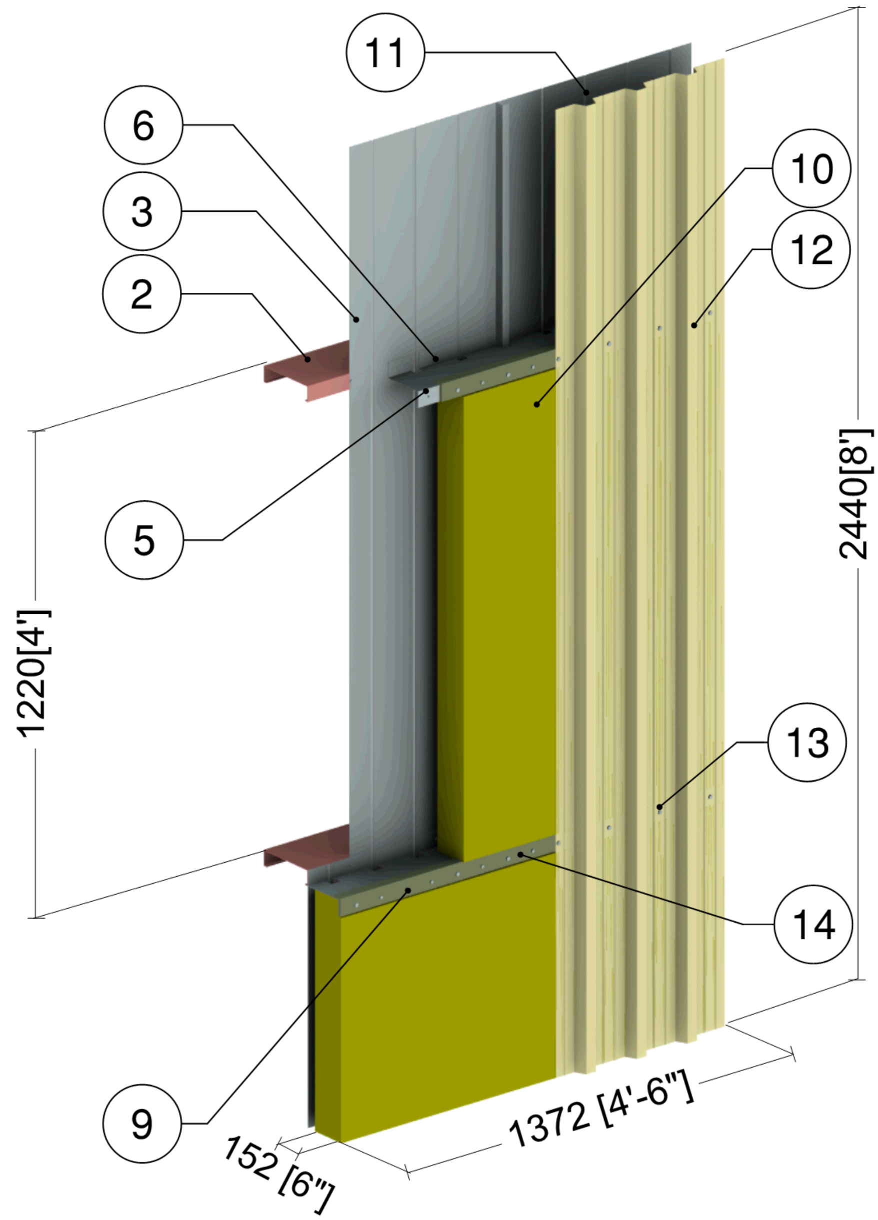
B.1.2. Sheet Steel Wall with Notched Z-Bar

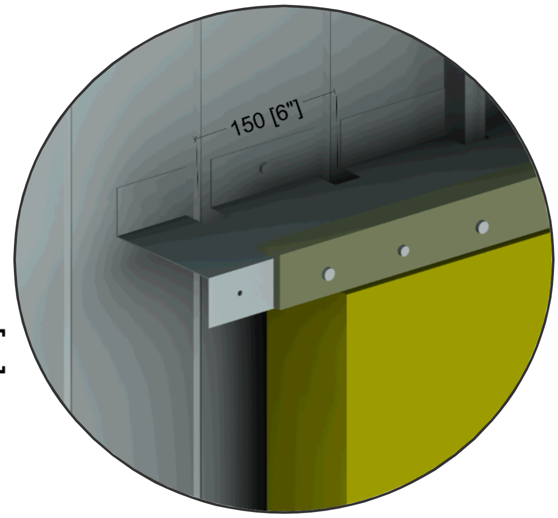


B.1.3. Sheet Steel Wall with Thermal Chairs



B.1.4. 2 Hour Fire Rated Sheet Steel Wall





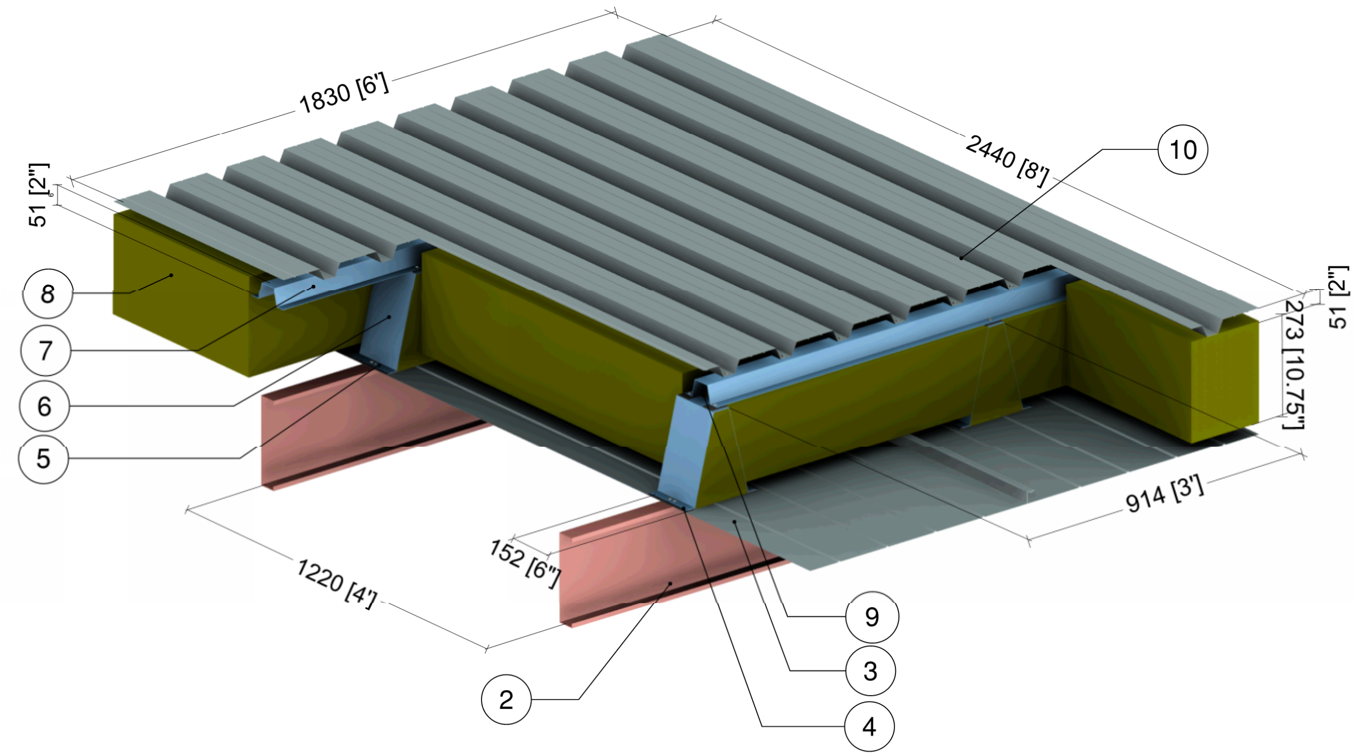
B.2 Sheet Steel Wall Assemblies

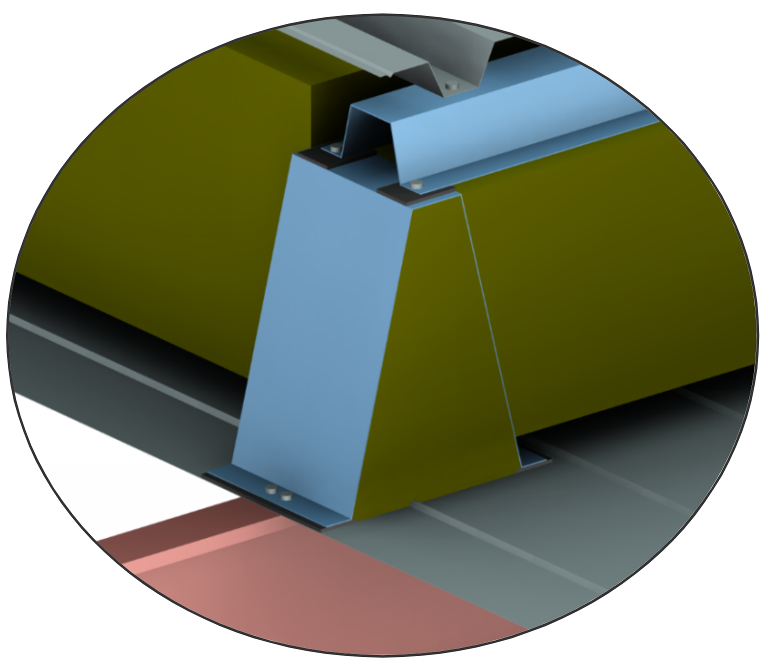
B.2.1. Material Properties

ID	Component	Thickness Inches (mm)	Conductivity Btu·in / ft^2·hr·°F (W/m K)	Nominal Resistance hr·ft^2·°F/Btu (m^{2}K/W)
1	Interior Films (left side)[1]	-	-	R-1.1 (0.20 RSI)
2	10 x 2 Galvanized Steel Purlin @ 48” o.c.	0.10 (2.6)	430 (62)	-
3	Galvanized Steel Liner	24 Gauge	430 (62)	-
4	Thermal Tape	1/8 (3.18)	0.097 (0.014)	-
5	#12 Fasteners	0.22 (5.50)	430 (62)	-
6	10-in Galvanized Steel Hat Section (Thermal Chair)	18 Gauge	430 (62)	-
7	2-in Galvanized Steel Hat Section (Outer Rail)	18 Gauge	430 (62)	-
8	Mineral Wool Insulation	10.75 (273)	0.240 (0.034)	R-45 (7.93 RSI)
9	Air Gap[2]	-	Dependent on size	-
10	Galvanized Steel Cladding	22 Gauge	430 (62)	-
11	Steel Clips	18 Gauge	430 (62)	-
12	R-19 Batt Insulation	6 (152)	0.30 (0.043)	R-19 (3.35 RSI)
13	Thermal Block	1 (25)	0.20 (0.029)	R-5 (0.88 RSI)
14	Exterior Film (right side)[1]	-	-	R-0.2 (0.03 RSI)

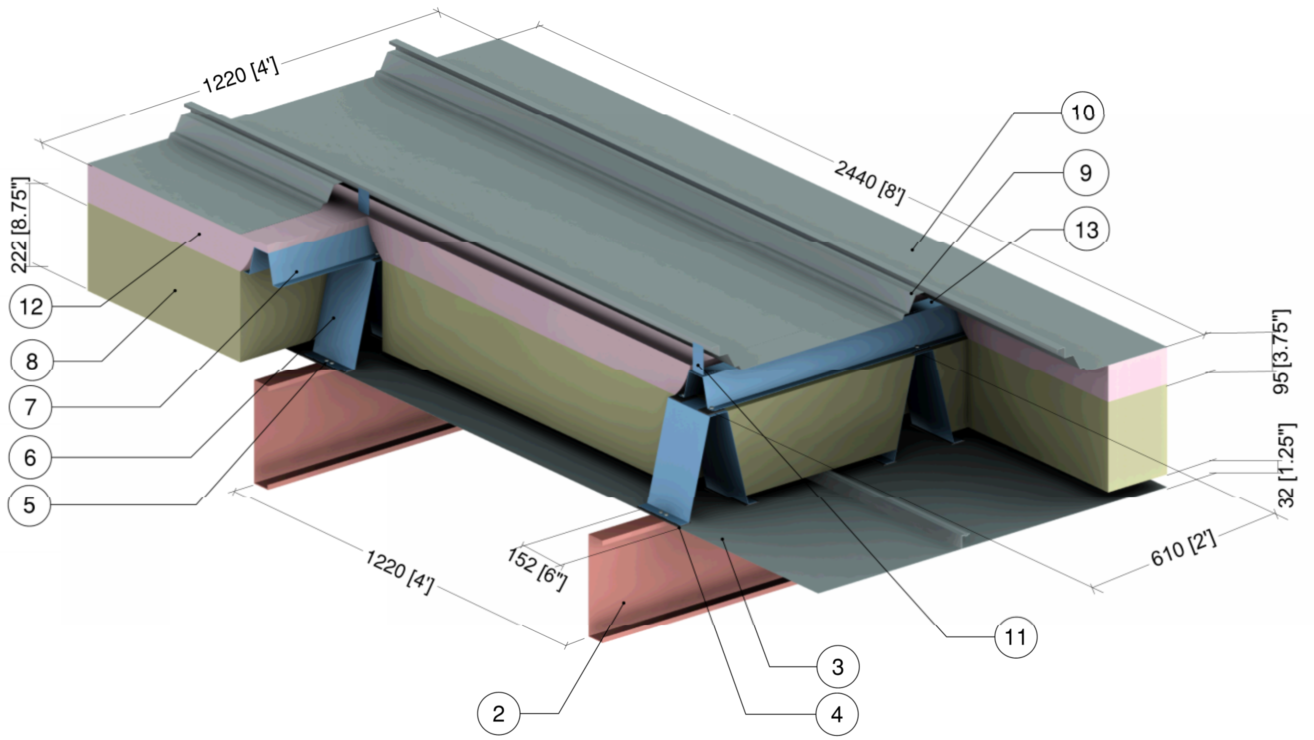
[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals for a sloped roof with reflective surface
[2] The thermal conductivity of air spaces was found using ISO 100077-2

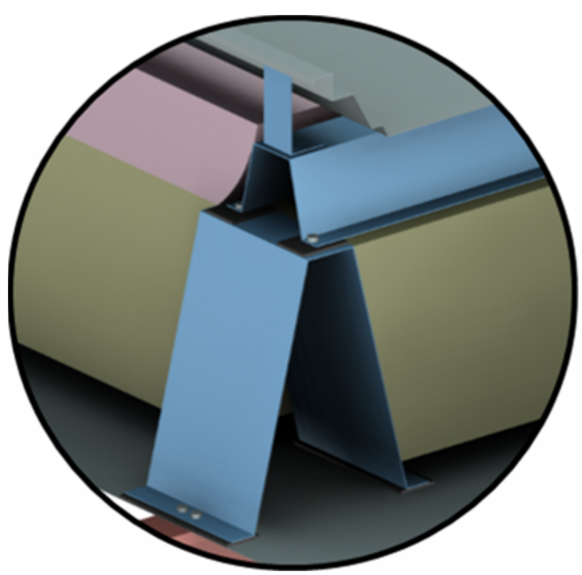
B.2.2. Insulated Sheet Steel Roof Supported by Thermal Chairs



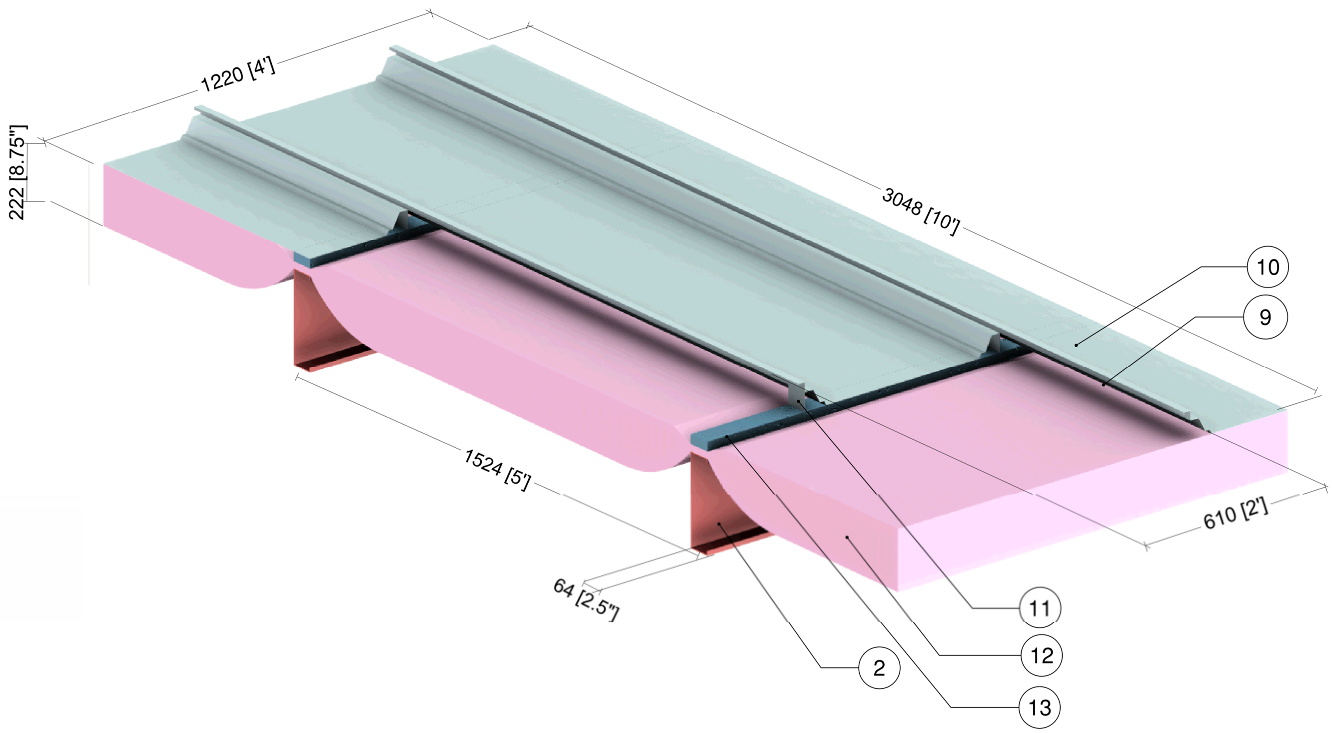


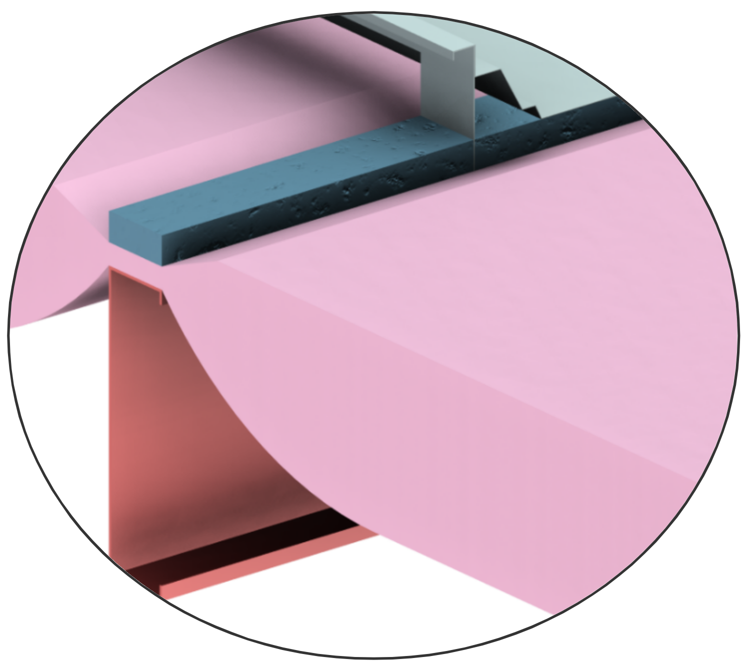
B.2.3. Insulated Standing Seam Roof Supported by Thermal Chairs





B.2.4. Standing Seam Roof with Draped Insulation





APPENDIX C – EXAMPLE TEMPERATURE PROFILES

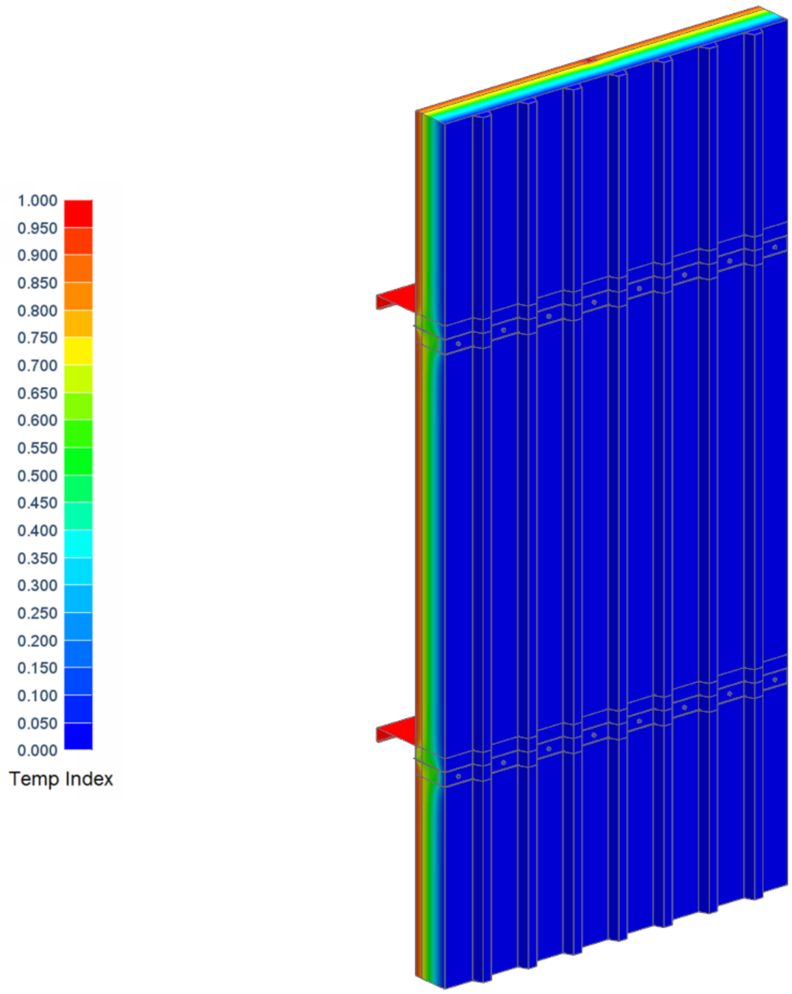


Figure C1: Thermal Image of Insulated Sheet Steel Wall Assembly

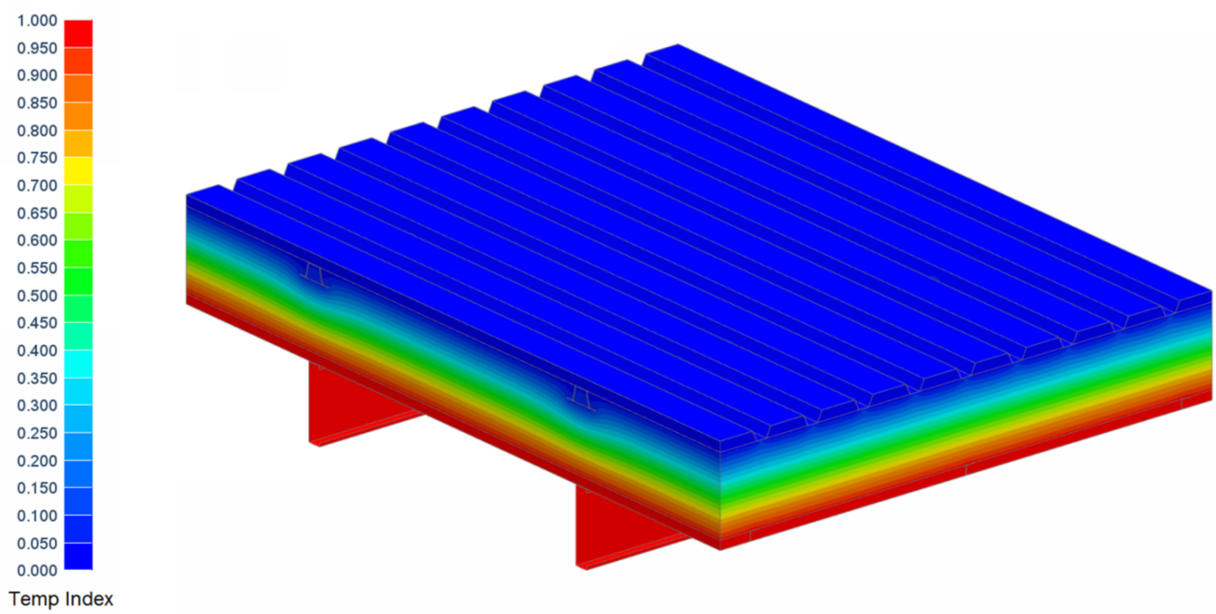


Figure C2: Thermal Image of Corrugated Roof Assembly