Thermal Analysis of Piazza StoneWorks Wall System

Report Submitted To

Prepared By

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Executive Summary

Reduced thermal resistance of the building envelope due to thermal bridging through steel framing can have a significant impact on the building's energy performance. Uncertainty about the thermal performance of the building envelope can lead to inefficient design of the HVAC system in addition to inefficiencies in the building operation and compromised occupants' comfort level.

This report has been put together by The Steel Network and Piazza StoneWorks to provide thermal performance data (R- and U-values) of the Piazza StoneWorks System when used with the Piazza Z-Track produced by the Steel Network Inc. The Piazza Continuous Rigid Insulation System is used in exterior wall assemblies to support rigid foam insulation with thicknesses ranging from 1.0 inch to 4.0 inch. In addition, the Piazza System provides viable means to attach the cladding assemblies, such as Piazza Stone, to a stable substrate instead of using long and unstable cantilevered screws to the sheathing layer. This Executive Summary includes a wall assembly catalogue that allows designers to have fast and straightforward access to information with sufficient accuracy to reduce uncertainty in the thermal performance of building envelope components.

Thermal modelling for this project was completed using three-dimensional finite element analysis heat transfer software packages by SolidWorks®, Salome, and ElmerGUI FEM. The ability of these software programs and the techniques used to predict conductive thermal performance of wall assemblies was demonstrated by calibrating and benchmarking the procedures against measured public-domain thermal performance data and deterministic analytical solutions.

The catalogue of the Piazza StoneWorks System in wall assemblies presented here was developed based on a generic and common interface detail suitable for mid- and high-rise construction. The objectives of the catalogue are: be relevant to ASHRAE/IES Standard 90.1, be relevant to existing and future building stock, represent both high thermal performance envelopes and standard building practice, and to represent typical finishing and cladding systems and attachment methods. The primary calculated thermal performance data includes thermal transmittances and thermal resistances. Thermal transmittance was calculated and reported by one main category: clear field transmittances.

Catalogue of thermal resistances and thermal transmittances of wall assemblies with Piazza StoneWorks and TSN Piazza Z-Track Rigid Insulation Framing System[1]

Assembly #	**Steel Stud Size**	**Exterior Rigid Insulation Thickness**	**Stud Cavity Insulation (min.)**	**Piazza Z-Track Size**	**Nominal Resistance R_0**	**Transmittance U_0**
					m^2.K/W (hr·ft²·°F/Btu)	**W/m^2 K (Btu/ft²·hr·°F)**
6" Steel Stud Walls						
1	600S162-43	2"	R-19 Batt	200ZT-54	3.63 (R-20.6)	0.28 (0.05)
2	600S162-43	1.5"	R-19 Batt	150ZT-54	3.54 (R-20.1)	0.28 (0.05)
3	600S162-43	3"	R-19 Batt	300ZT-54	3.80 (R-21.6)	0.26 (0.05)
4	600S162-43	4"	R-19 Batt	400ZT-54	3.96 (R-22.5)	0.25 (0.04)
5	800S162-43	2"	R-25 Batt	200ZT-54	3.99 (R-22.7)	0.25 (0.04)
6	800S162-43	3"	R-25 Batt	300ZT-54	4.16 (R-23.6)	0.24 (0.04)
7	800S162-43	4"	R-25 Batt	400ZT-54	4.33 (R-24.6)	0.23 (0.04)

[1] Details of input and output data for this assembly are provided in Section 5.

Contents

1. Introduction

Recent changes in the IECC Energy Conservation Code and ASHRAE Standard 90.1 [1] required the framing industry to develop new products and systems to enhance the thermal isolation of the building envelope. Thermal isolation is typically achieved by minimizing (or reducing) the heat flow between the interior space of the building and the exterior environment, whether this exterior environment is at a higher or a lower temperature compared to the interior space. For exterior steel stud wall assemblies, one method of obtaining better thermal isolation is to add stud cavity insulation such as batt insulation or spray foam insulation. However, this method has shown not to meet IECC and ASHRAE Standard requirements due to the development of thermal bridging which reduces the effective thermal resistance of the wall assembly. To overcome the shortage of sufficient insulation in the envelope of the building, designers have introduced wall assemblies that necessitates the installation of 1 to 4 inches of continuous rigid insulation on the outside surface of exterior stud walls before attaching the final wall cladding surface (see Figure 1). Such rigid insulation layer requires a frame to hold it in place, and with the added thickness of the wall, a stable substrate is needed to attach the wall cladding assemblies, like cement board panels and metal panels, over the rigid insulation layer.

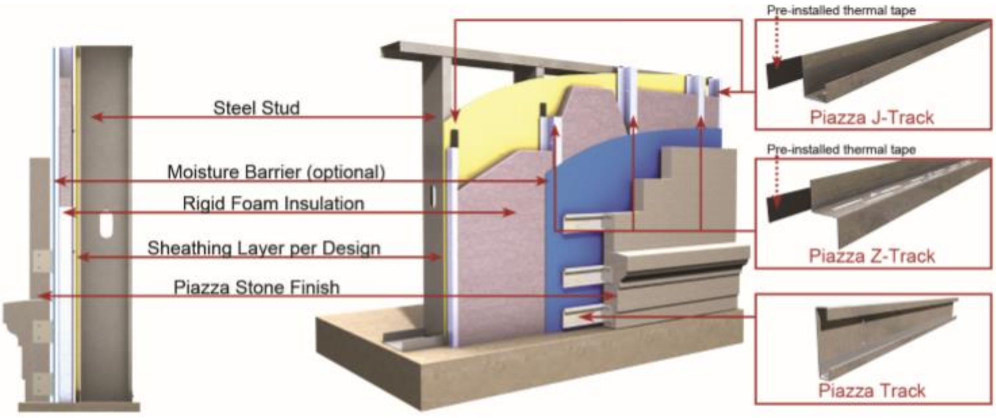


Figure 1: Piazza Wall System

Existing building component systems lack sufficient accommodation for cladding assemblies since there is no viable means to attach to a stable substrate like plywood or gypsum sheathing over the thick rigid insulation layer other than long and unstable cantilevered screws. Over time, and lacking a product that addressed this need, designers have either reduced or abandoned altogether the use of such cladding in their designs, waiting for the steel framing industry to provide a solution. The Piazza Continuous Rigid Insulation Framing System is an engineered installer-friendly set of steel framing tracks and angles designed to be an integral part of the continuous rigid insulation, and at the same time provide a stable component for direct substrate attachment (see Figure 2). The Piazza System is designed to maintain an acceptable thermal isolation of the steel stud wall assembly under the requirements of the IECC and ASHRAE Standard. The product provides the following features:

- Pre-engineered framing system to support weight of rigid insulation, cladding material, and resist wind loads
- Accommodates 1, 1.5, 2, 3 or 4 inches of continuous rigid insulation layer per design
- 1" thermal tape preinstalled on each piece for an integrated continuous thermal break
- Slotted steel material to minimize thermal conductivity through the rigid insulation layer

- Unique rigid insulation engagement feature keeps rigid foam insulation from sliding or popping out of place without the need for specialty fasteners with washers
- Utilizes typical screws to attach the system
- Wide flanges for increased target area for screws when installing sheathing or alternative finishes
- Mill-certified high strength steel and added galvanized coating layer

This report provides thermal performance modelling and analysis of a typical exterior wall assembly that include continuous rigid insulation supported by the Piazza System, with Piazza StoneWorks as cladding. The report provides details about the heat transfer model and its parameters, then provides the validation process and cases of the model in Appendix A, and finally provides the input and output data of the assembly. As a guidance to the readers, Table 1 below provides a glossary of terms used in the report.

Table 1: Glossary of terms used in the report

Term	Symbol	Units SI (Imperial)	Description
Conductivity	K	W/m.K (Btu·in/ft^2.hr. °F)	The ability of a material to transmit heat in terms of energy per unit area per unit thickness for each degree of temperature difference
Average Conductivity	K_{av}	W/m.K (Btu·in/ft^2.hr. °F)	The averaged thermal conductivity of a component consisting of several materials treated as homogeneous material
Heat Flow	Q	W (Btu/hr)	The amount of energy per unit time that passes through an assembly under a specific temperature range ΔT
Thermal Resistance	R	m^2.K/W (hr·ft^2·°F/Btu)	Material resistance to heat flow
Thermal Transmission	U	W/m^2 K (Btu/ft^2·hr·°F)	Heat flow coefficient per unit time through a unit area of an assembly per temperature degree difference.
Assembly Thermal Resistance	R_o	m^2.K/W (hr·ft^2·°F/Btu)	Clear field thermal resistance when there is only one base clear field assembly (uniformly distributed thermal bridges)
Assembly Thermal Transmittance	U_o	W/m^2 K (Btu/ft^2·hr·°F)	Clear field thermal transmittance when there is only one base clear field assembly (uniformly distributed thermal bridges)

2. Heat Transfer Analysis

2.1 Conceptual Approach for Assembly 1

Thermal problems are usually in concept quite simple, though as this report shows the practical analysis can quickly become tedious and difficult. The general approach used to determine an R-Value for this wall assembly was as follows:

1. Determine constraints. In this problem, the following constraints were chosen. Units in this section are exclusively in metric for convenience of calculations.
    a. Outside temperature of 305K
    b. Outside windspeed of 2 m/s
    c. Inside temperature of 293K
    d. Inside windspeed of 2 m/s
2. Calculate convection coefficients. Temperature-specific properties were obtained to calculate the convection coefficients on the inside and outside of the wall assembly.
3. Apply boundary conditions and initial conditions to the ElmerGUI model. In this step, the convection coefficient and respective temperatures of the inside and outside of the wall assembly were applied to the model. Furthermore, the model was set up so that the initial temperature was set to 299K, and sufficient time (approx. 10K hours) was given to sufficiently approximate steady-state conditions.
4. Calculate heat flow based on surface temperature. In this step, the average temperature of each surface was used in conjunction with the coefficient of convection to determine heat flow (Q).
5. Calculate R and U based on surface temperatures and heat flow. The governing equations for steps 4 and 5 are as follows:

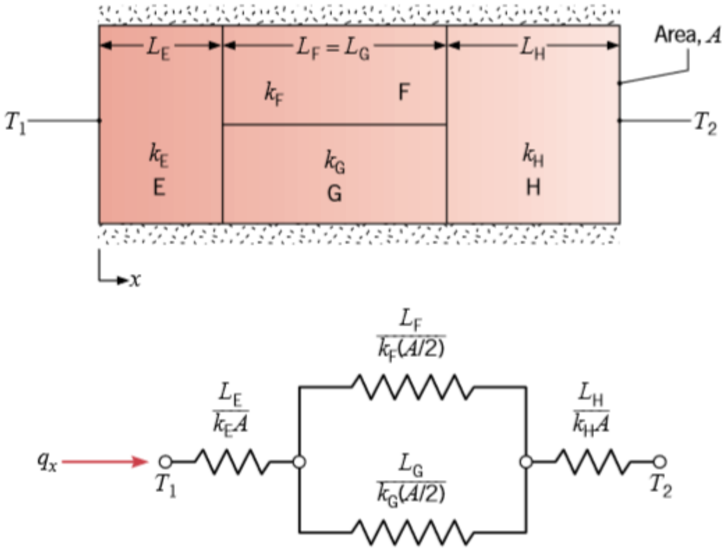
$$q = hA(T_S - T_\infty)$$

$$R_{tot} = \frac{\Delta T}{q}$$

2.2 Conceptual Approach for Assemblies 2-7

Having established a baseline value for the thermal resistance of one wall assembly, the remaining assemblies can be calculated from theoretical principles based on simple 1D geometrical changes. See Appendix 3 for a comparison of the two methods. What follows in this section is a brief explanation of the theoretical method.

1. Break the top-view cross section of the assembly down into successive section lengths, dividing the assembly whenever the geometric orientation of materials changes.
2. Obtain values for the thermal conductivity of each of the materials in each section, the length of each section, and the cross-sectional area of the different components of each layer of the cross-section.



3. Calculate the R values using a method identical to calculating the resistance through an electrical circuit for each section based off the values obtained in step 3. The R value for each material section is calculated using the equation:

$$R = \frac{L}{kA}$$

The total resistance for a section containing multiple materials in parallel, as demonstrated in the middle section of the diagram above, is calculated with the equation:

$$\frac{1}{R_{section}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_n}$$

4. Calculate the total R value by combining all the resistance values in series using the equation below:

$$R_{tot} = R_1 + R_2 + \cdots + R_n$$

2.2 Software Selection

The second task is to select a public domain or a commercially available computer model to predict the dynamic conductive thermal performance of the building envelope assembly containing high conductivity (non-insulating) thermal bridging. Several time-transient heat transfer software packages were evaluated for the project. There are several software packages that could have been selected with numerous strengths and weaknesses. However, the intent of Task 1 was not to provide an evaluation of all the available software, but to provide a rationale for the selection of a suitable software.

A three-dimensional finite element analysis heat transfer software package -SolidWorks® by Dassault Systèmes- was selected for the CAD modelling of the project. The meshing was completed using the Salome modelling software. Lastly, Elmer simulation software was chosen as the thermal solver for the project. The rationale for the software selection and a description of how the software works follows.

2.3 Thermal Solver

A two-dimensional heat model cannot capture the actual heat flow path through complex three-dimensional intersections, and therefore cannot accurately estimate thermal transmittance (U-value) and surface temperatures that are often of interest. In addition, a suitable simulation must model the effects of radiation to the interior and exterior spaces to accurately represent surface temperatures with relation to condensation resistance.

Elmer Thermal Solver is a finite element based, finite volume method**,** for solving transient and steady-state heat transfer problems by conduction, convection, radiation, and phase change. The solver uses a finite volume scheme to solve the governing equations for steady-state or transient loads:

Conduction: Heat transfer by conduction can be modelled for arbitrary meshes with several different element characteristics. The elements can have varying thermal conductivity, density, and specific heat dependent on both time and temperature; change phase; and have isotropic or orthotropic thermal conductivity (ability to specify conductivity dependent on direction).

Convection is the heat transfer mode in which heat transfers between a solid face and an adjacent moving fluid (or gas). Convection has two elements:

- Energy transfer due to random molecular motion (diffusion), and
- Energy transfer by bulk or macroscopic motion of the fluid (advection).

3. Thermal Modelling

3D thermal analysis requires less assumptions compared to 2D analysis when it comes to account for heat flow through non-continuous thermal conductivity and/or thermal conductivity in multiple planes. ASHRAE 1365-RP [3] procedures were followed during this project to determine the thermal performance of the building envelope assemblies. This approach was selected and further validated for the SolidWorks® Software and ElmerGUI software. In addition, a convergence study was performed to achieve the optimum element parameters and mesh size in this project.

3.1 Material Properties

The material properties for the wall assemblies were mainly obtained from manufacturers' material testing datasheets and were inputted into the ElmerGUI software.

It is known that the insulation material has diminishing returns with regard to the overall assembly (effective) thermal resistance. The insulation material in the steel stud cavities was only modelled for one thermal conductivity value.

Constant thermal conductivities were selected using standard tabulated values (typically measured at 24 °C or 75 °F). The thermal conductivity, density, and specific heat are based on values provided in the ASHRAE Handbook – Fundamentals [4].

3.2 Air Cavities and Gaps

The ASHRAE Handbook [4] provides the thermal resistances of plane air gaps, including the effects of radiation, conduction, and convection. In this project, the thermal resistance for the planar air in the empty stud cavities is calculated based on the gap size, with the resistance dependent on the cavity surface temperatures, surface emittances, and geometry. For confined air gaps such as that between the rigid insulation layer and the sheathing layer, the model follows ISO 10077-2 [5] to calculate the average conductivity K_{av} of the air.

3.3 Surface Film and Contact Resistances

The resistances of surface air film and contact surfaces affect the final resistance of the building envelope assembly. The resistance values selected for this project were based on values presented in ASHRAE Handbook [4] and the BC Hydro Guide [6]. Table 2 below summarizes the heat transfer coefficients applied to the exterior and interior surfaces of the assemblies in addition to the assumptions for contact surfaces.

Table 1 : Surface film and contact surfaces resistance values

Location	**Description**	**Thermal Resistance** $m^2.K/W$ ($hr \cdot ft^2 \cdot °F/Btu$)
Exterior wall surface	Vertical surface to account for generic cladding	0.12 (0.7)
Interior Wall surface	Vertical surface exposed to indoor air	0.12 (0.7)
Contact - Steel to sheathing	Steel flanges at sheathing interface	0.03 (0.17)
Contact - Insulation	Insulation layers interface	0.01 (0.057)

4. Model Validation

Several validation studies for steel stud wall assemblies are available in the literature due to the sensitivity of the assembly to geometry, thermal properties of individual components, and contact resistance. The current model using SolidWorks® software was validated against 2 previous modelling cases: one case from ISO 10211:2007(E) [7], two cases from the BC Hydro Guide [6], and one theoretical calculation. The details of the validation cases are all given in Appendix A of this report. It was found that the current simulated results are in good agreement with the results of the previous studies with respect to the thermal performance of steel stud assemblies.

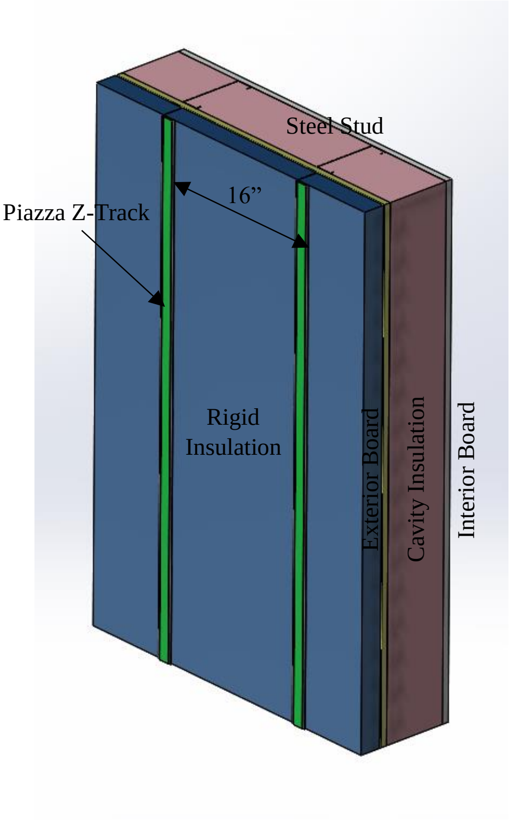
5. Steel Stud Wall Assemblies Models and Results

This section gives the details of the exterior steel stud wall assemblies modelled in this study and the thermal performance results obtained from the models.

The basic configuration of the wall assembly consists of a 6-inch standard steel stud wall spaced 16 inches on-center and sheathed on the inside with a 5/8” gypsum board and on the outside with a 5/8” layer of DensGlass sheathing. Exterior rigid insulation layer has been considered to be 2 inches. Full stud wall cavity batt insulation and partial stud wall cavity spray foam insulation have been considered. The Piazza Continuous Rigid Insulation Z-Track System is included in the models as a horizontal element to separate the exterior rigid insulation units at 16 inches on center. A layer representing a confined air gap between the rigid insulation layer and the exterior sheathing layer is included in the models. This layer accounts for the thickness of the thermal tape that is attached on the back of the Piazza Z-Tracks. Film layers are accounted for on the far inside and outside of the models to represent indoor air and generic cladding, respectively. The size of the thermal model was always 32” wide and 48” tall, with continuous boundary conditions assumed on all edges. The Piazza StoneWorks Track, clips, and stone were considered on the outside of the rigid insulation.

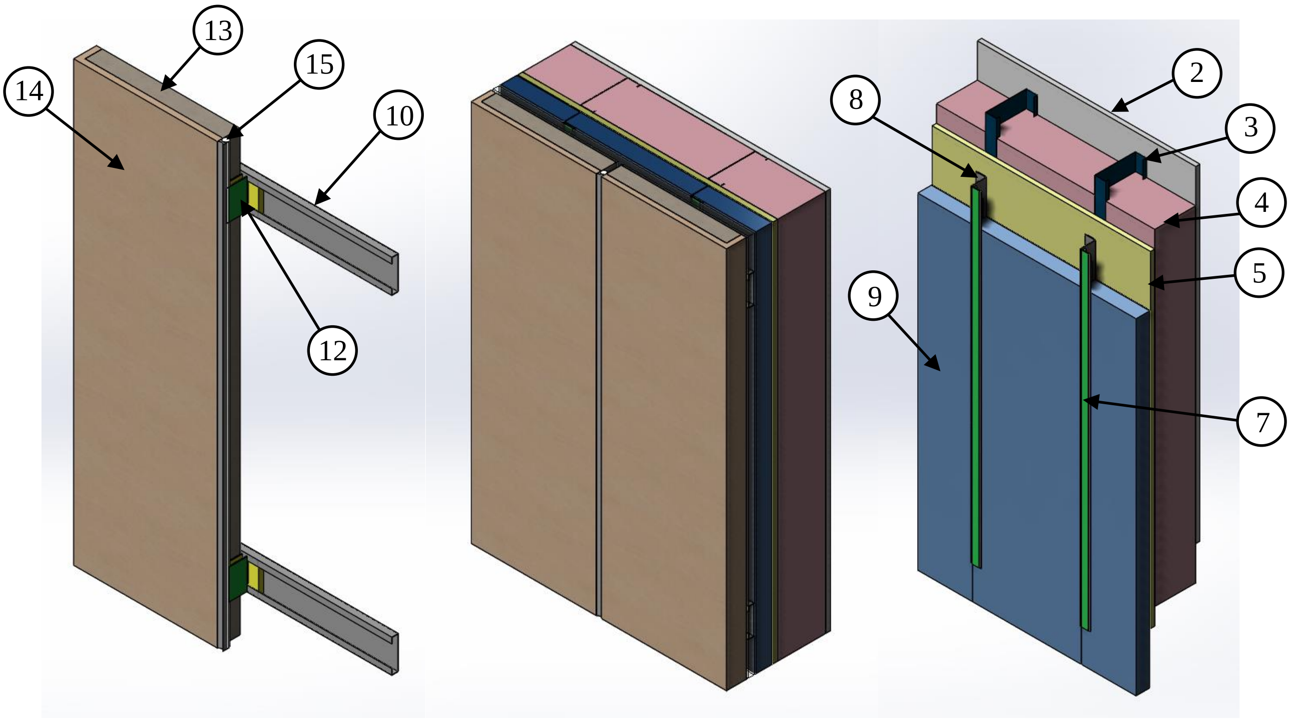
The input data and the output thermal results of one assembly model is detailed next in this section.

Figure 2: Typical wall assembly model



Assembly 1: Exterior and Interior Insulated 6"x1-5/8" Steel Stud (16" o.c.) w/ TSN Piazza Continuous Rigid Insulation System 200ZT-54 for 2" Exterior Rigid Insulation Layer

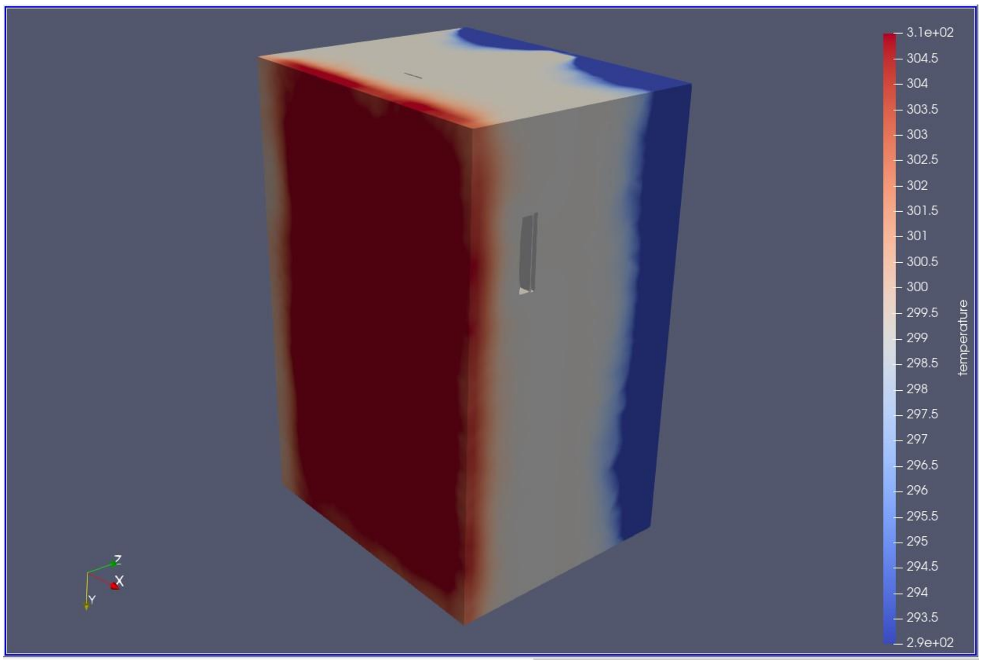
Assembly 1: Material/ Geometry Data Sheet



ID	Component	Thickness	Conductivity	Density	Specific Heat
		mm (inch)	W/m.K (Btu·in/ft^2.hr. F)	kg/m^3 (lb/ft^3)	J/kg.K (Btu/lb·°F)
1	Interior Film[1]	N/A	N/A	N/A	N/A
2	Gypsum Board	15.9 (5/8”)	0.188 (1.29)	769 (48.0)	1090 (0.260)
3	600S162-43 Steel Stud	43mil	36 (247.5)	7830 (489)	500 (0.119)
4	Batt Insulation in Stud Cavity	152.4 (6”)	0.043 (0.3)	20 (1.25)	1030 (0.246)
5	Exterior Sheathing	15.9 (5/8”)	0.135 (0.93)	769 (48.0)	1090 (0.260)
6	Airspace Between Rigid Insulation and Exterior Sheathing	3.2 (1/8”)	-	1 (0.069)	1000 (0.239)
7	Thermal Tape	1.6 (1/16”)	-	80 (5.0)	1090 (0.260)
8	Piazza Z-Track 200ZT-54	54mil	36 (247.5)	7830 (489)	500 (0.119)
9	Rigid Insulation	50.8 (2”)	0.029 (0.2)	160 (10.0)	1470 (0.351)
10	Piazza PT12-54	-	36 (247.5)	-	-

11	Airspace Between Rigid Insulation and Piazza Stone	22.5 (0.886”)	-	1 (0.069)	1000 (0.239)
12	Piazza PTLB200-54	-	36 (247.5)	-	-
13	Piazza Stone Core	47.6 (1.874”)	0.0289 (0.2)	160 (10.0)	1470 (0.3511)
14	Piazza Stone	15.875 (0.625”)	1.7 (11.7)	160 (10.0)	1470 (0.3511)
15	Silicone Caulking	-	0.2 (1.39)	1.1 (0.069)	1050 (0.2507)
16	Exterior Film[1]	N/A	N/A	N/A	N/A

Assembly 1: Thermal Data Sheet



Nominal Resistance (1D) vs. Assembly Performance Indicators

Exterior Insulation 1D m^2.K/W (hr.ft^2·°F/Btu)	R$_0$ m^2.K/W (ft^2·hr·°F/Btu)	U$_0$ W/m^2 K (Btu/ft^2·hr·°F)
1.76 (R-10)	3.63 (R-20.6)	0.28 (0.05)

Assembly 2: Exterior and Interior Insulated 6"x1-5/8" Steel Stud (16" o.c.) w/ TSN Piazza Continuous Rigid Insulation System 150ZT-54 for 1.5" Exterior Rigid Insulation Layer

Nominal Resistance (1D) vs. Assembly Performance Indicators

Exterior Insulation 1D m^2.K/W (hr.ft^2·°F/Btu)	R_0 m^2.K/W (ft^2·hr·°F/Btu)	U_0 W/m^2 K (Btu/ft^2·hr·°F)
1.32 (R-7.5)	3.54 (R-20.1)	0.28 (0.05)

Assembly 3: Exterior and Interior Insulated 6"x1-5/8" Steel Stud (16" o.c.) w/ TSN Piazza Continuous Rigid Insulation System 300ZT-54 for 3" Exterior Rigid Insulation Layer

Nominal Resistance (1D) vs. Assembly Performance Indicators

Exterior Insulation 1D m^2.K/W (hr.ft^2·°F/Btu)	R_0 m^2.K/W (ft^2·hr·°F/Btu)	U_0 W/m^2 K (Btu/ft^2·hr·°F)
2.64 (R-15)	3.80 (R-21.6)	0.26 (0.05)

Assembly 4: Exterior and Interior Insulated 6"x1-5/8" Steel Stud (16" o.c.) w/ TSN Piazza Continuous Rigid Insulation System 400ZT-54 for 4" Exterior Rigid Insulation Layer

Nominal Resistance (1D) vs. Assembly Performance Indicators

Exterior Insulation 1D m^2.K/W (hr.ft^2·°F/Btu)	R_0 m^2.K/W (ft^2·hr·°F/Btu)	U_0 W/m^2 K (Btu/ft^2·hr·°F)
3.52 (R-20)	3.96 (R-22.5)	0.25 (0.04)

Assembly 5: Exterior and Interior Insulated 8"x1-5/8" Steel Stud (16" o.c.) w/ TSN Piazza Continuous Rigid Insulation System 200ZT-54 for 2" Exterior Rigid Insulation Layer

Nominal Resistance (1D) vs. Assembly Performance Indicators

Exterior Insulation 1D m^2.K/W (hr.ft^2·°F/Btu)	R_0 m^2.K/W (ft^2·hr·°F/Btu)	U_0 W/m^2 K (Btu/ft^2·hr·°F)
1.76 (R-10)	3.99 (R-22.7)	0.25 (0.04)

Assembly 6: Exterior and Interior Insulated 8"x1-5/8" Steel Stud (16" o.c.) w/ TSN Piazza Continuous Rigid Insulation System 300ZT-54 for 3" Exterior Rigid Insulation Layer

Nominal Resistance (1D) vs. Assembly Performance Indicators

Exterior Insulation 1D m^2.K/W (hr.ft^2·°F/Btu)	R_0 m^2.K/W (ft^2·hr·°F/Btu)	U_0 W/m^2 K (Btu/ft^2·hr·°F)
2.64 (R-15)	4.16 (R-23.6)	0.24 (0.04)

Assembly 7: Exterior and Interior Insulated 8"x1-5/8" Steel Stud (16" o.c.) w/ TSN Piazza Continuous Rigid Insulation System 400ZT-54 for 4" Exterior Rigid Insulation Layer

Nominal Resistance (1D) vs. Assembly Performance Indicators

Exterior Insulation 1D m^2.K/W (hr.ft^2·°F/Btu)	R_0 m^2.K/W (ft^2·hr·°F/Btu)	U_0 W/m^2 K (Btu/ft^2·hr·°F)
3.52 (R-20)	4.33 (R-24.6)	0.23 (0.04)

6. Conclusions

This report provides the thermal performance data (R- and U-values) of the Piazza Continuous Rigid Insulation Framing System when used in a common steel stud exterior wall assembly to support rigid foam insulation with thickness of 2” and the Piazza StoneWorks cladding system. The R- data obtained from the current thermal analysis suggest that the Piazza StoneWorks System, along with other assembly components, meet the R value requirements of the current ASHRAE code for multiple geographical zones. The report gives details of the modelling procedure, plus calibration and benchmarking method for the variations of the steel stud assembly. The report provides a summary of the input and output data needed by designers. The primary output thermal performance data includes thermal transmittances and thermal resistances.

7. References

[1] ASHRAE. (2010). ASHRAE 90.1 Energy Standard for Buildings Except Low-Rise Residential Buildings. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc.

[2] SolidWorks® 2018 User Guide, Dassault Systèmes, Massachusetts, USA.

[3] ASHRAE. 1365-RP (2011). Thermal Performance of Building Envelope Details for Mid- And High-Rise Buildings. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc.

[4] ASHRAE. (2013). Handbook of Fundamentals. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc.

[5] ISO 10077-2:2003 (E). Thermal performance of windows, doors and shutters – Calculation of thermal transmittance – Part 2: Numerical method for frames‖, Geneva, Switzerland.

[6] BC Hydro Power (2016). Building Envelope Thermal Bridging Guide – Version 1.1 Report prepared by Morrison Hershfield.

[7] ISO 10211-2007 (E). Thermal Bridges in Building Construction - Heat Flows And Surface Temperatures – Part 1 Detailed Calculations. Brussels: European Committee for Standardization.

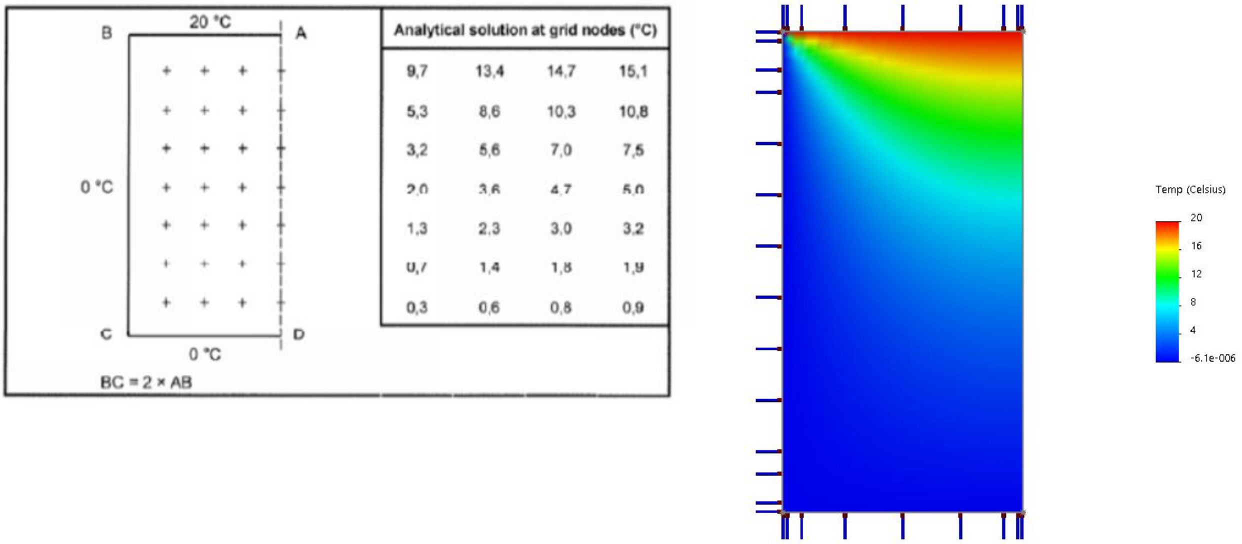
[8] CEN. (2007). ISO 14683 Thermal bridges in building construction - Linear thermal transmittance - Simplified methods and default values. Brussels: European Committee for Standardization.

[9] F. Incropera et al, “One-Dimensional, Steady-State Conduction,” in *Fundamentals of Heat and Mass Transfer*, John Wiley & Sons, Inc., Ed. 6, 2007, pp. 95-200.

Appendix A: Model Validation Cases

Case 1: ISO 10211:2007(E), Comparison to Analytical Solution

This validation case deals with a comparison to a two-dimensional heat transfer through a surface with known material conductivity (1.0 W/m.K) and constant temperature boundary conditions as given in the figure below. No radiation was considered. Modelling of this case was completed using SolidWorks® software with a mesh consisting of 1251 nodes and 3561 elements. The figure illustrates the temperature distribution, and the table below compares the temperatures at 28 points of the model to the corresponding temperatures listed in ISO 10211-2007(E) [7]. The table shows an acceptable range of agreement between current analysis and the analytical solution.



Analytical solution at grid nodes (°C)			
9,7	13,4	14,7	15,1
5,3	8,6	10,3	10,8
3,2	5,6	7,0	7,5
2,0	3,6	4,7	5,0
1,3	2,3	3,0	3,2
0,7	1,4	1,8	1,9
0,3	0,6	0,8	0,9

Analytical solution from ISO 10211:2007(E) and current temperature profile

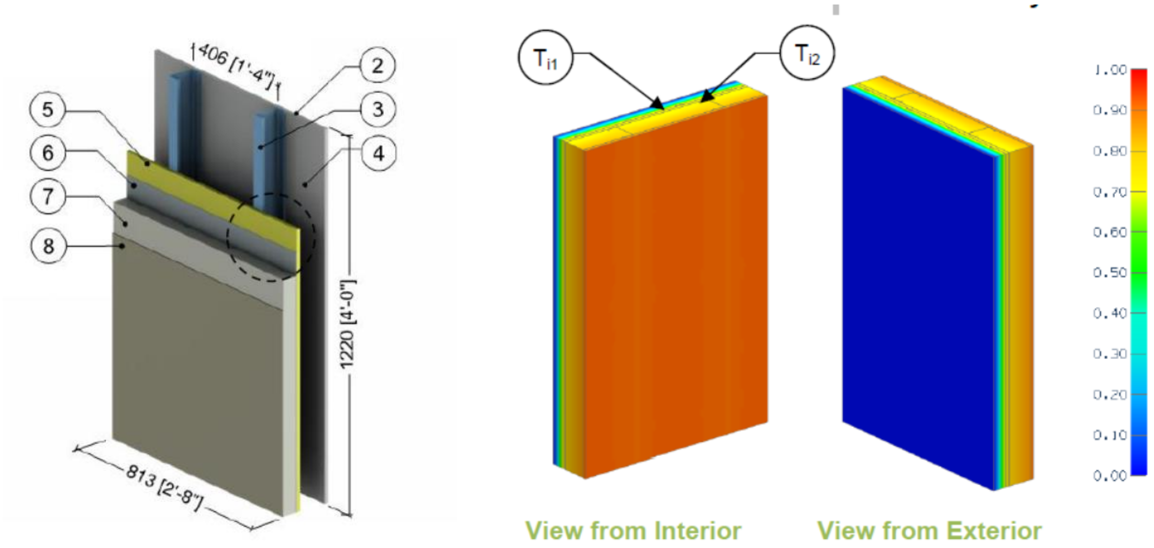
Comparison between reference analytical solution and current analysis

ISO 10211-1 (Temperature °C)				Current Analysis (Temperature °C)				Difference (%)			
9.70	13.40	14.70	15.10	9.41	13.13	14.26	15.44	3%	2%	3%	2%
5.30	8.60	10.30	10.80	5.09	8.34	10.09	10.58	4%	3%	2%	2%
3.20	5.60	7.00	7.50	3.17	5.54	6.86	7.20	1%	1%	2%	4%
2.00	3.60	4.70	5.00	1.98	3.46	4.56	4.95	1%	4%	3%	1%
1.30	2.30	3.00	3.20	1.25	2.28	2.94	3.17	4%	1%	2%	1%
0.70	1.40	1.80	1.90	0.67	1.34	1.75	1.86	4%	4%	3%	2%
0.30	0.60	0.80	0.90	0.29	0.59	0.78	0.89	3%	2%	3%	1%

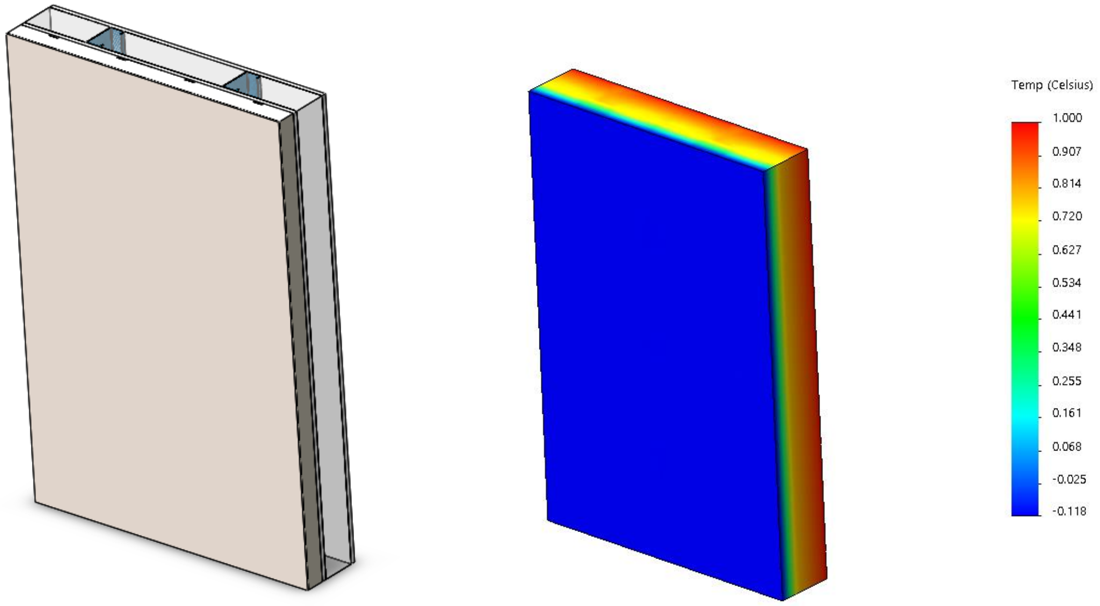
Case 2: BC Hydro Guide, Comparison to Detail 5.1.1:

This validation case deals with a comparison to a three-dimensional thermal analysis of a steel stud wall assembly consisting of an exterior insulated 3 5/8” x 1 5/8” steel studs spaced 16” o.c. [6]. The wall is assumed to be sheathed on the interior with ½” gypsum board and on the exterior with ½” sheathing. The wall is insulated with 2” exterior insulation board in addition to an 1/8” lamina layer. The thermal model size is 32” wide and 48” tall with continuous boundary conditions assumed on all edges.

The figures below illustrate the geometry and thermal performance views of the reference case, in addition to the geometry and thermal results of a pervious analysis. The following table shows the assembly performance comparison (clear field thermal resistance and transmittance of the reference case and the current analysis).



Original geometry data and isometric thermal image of BC Hydro Detail 5.1.1 [6]



Geometry data and isometric thermal image of validation analysis

Comparison between reference analysis solution and validation analysis

Exterior Insulation 1D m²^2.K/W (hr.ft^2·°F/Btu)	Assembly 1D R_{1D} m^2.K/W (ft^2·hr·°F/Btu)	Ref. Detail 5.1.1 R_0 m^2.K/W (ft^2·hr·°F/Btu)	Current Analysis R_0 m^2.K/W (ft^2·hr·°F/Btu)
1.32 (R-7.5)	1.80 (R-10.2)	1.76 (R-10.0)	1.72 (R-9.72)

Case 3: Theoretical Calculation of Thermal Resistance

In Straightforward 2D assemblies, a theoretical calculation of thermal resistance can be performed based on material properties and geometry. In heat transfer terms, this is an analysis of the total resistance of a “composite wall.”

In this validation exercise, the composite wall under consideration was the gypsum, 6” metal studs, R-19 Batt insulation, and DenGlass sheathing. The results of this theoretical calculation closely tracked with an ElmerGUI simulation of the same geometry, as noted in the table below.

Theoretical Calculation	ElmerGUI Simulation Result	Difference
R-6.94	R-6.52	6.05%