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Thermal Performance of Buildings Envelope Details for Mid and High-Rise Buildings

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REPORT

Thermal Performance of Building Envelope Details for Mid- and High-Rise Buildings (1365-RP)

Presented to:

Technical Committee 4.4
Building Materials and Building Envelope Performance

ASHRAE Inc.
1791 Tullie Circle, NE
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EXECUTIVE SUMMARY

The reduced thermal resistance due to thermal bridging through steel and concrete framing can have a significant impact on the whole building energy performance. Uncertainty about the thermal performance of the building envelope can lead to inefficient design of HVAC systems, building operation inefficiencies, inadequate condensation resistance at intersections of components and compromised occupant comfort. ASHRAE 1365-RP's objective was to provide thermal performance data of 40 common building envelope details for mid- and high-rise construction. The goal of the project was to develop procedures and a catalogue that will allow designers quick and straightforward access to information but with sufficient complexity and accuracy to reduce uncertainty in the thermal performance of building envelope components.

Modeling for this project was done using a three-dimensional finite element analysis heat transfer software package by Siemens PLM Software; FEMAP and Nx, with Maya's TMG thermal solver. The ability of the software and techniques used to predict conductive thermal performance of building envelope details containing high conductivity (non-insulating) thermal bridges was demonstrated by calibrating and benchmarking against measured public-domain thermal performance data and deterministic analytical solutions. Validation exercises in ISO standards were modeled to demonstrate that the TMG solver will yield high precision results for **well-defined** problems. Numerous guarded hot-box test measurements, 29 in total, were compared to simulated results. Good agreement between simulated and measured thermal performance for both **steady-state** and **transient** conditions was found. Sensitivity analysis showed the importance of assuming appropriate values for contact resistance particularly between steel flanges and sheathings when modeling steel framed assemblies.

The catalogue of 40 building envelope design details was developed based on a set of generic and common interface details suitable for mid- and high-rise construction. The objectives of the catalogue are to: 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 interior finishing and cladding systems and attachment methods. Selection of details gave high priority to details that have significant thermal bridges, particularly the ones that need three-dimensional analysis, and with a focus on details excluding those already addressed in ASHRAE publications.

The primary calculated thermal performance data includes thermal transmittances and indexed surface temperatures.

Thermal transmittance was calculated and reported by three categories of thermal anomalies: clear field, linear, and point anomalies. Linear and point anomalies are reported using linear and point transmittances. This is a departure from common practice in North America of using an area weighted average approach. Linear and point transmittances were utilized to overcome drawbacks with the area weighted average method for anomalies contained within opaque assemblies. The report has detailed discussions and examples of linear and point transmittances; however, the primary benefit is quite simple. For whole building load calculations, the linear and point transmittances is simply added to the clear value U-value for a given total assembly area (wall/roof) to calculate the overall thermal transmittance. Splitting the total assembly area into individual thermal anomalies and clear field areas is not necessary. This work promises to be of great benefit to developers and users of energy standards, such as ANSI/ASHRAE/IESNA 90.1.

Temperature indices are provided to provide designers a means for an approximation of surface temperatures due to average steady-state conductive heat flow in three-dimensions. Heat and moisture storage effects, air transport, and localized temperature variations (for example, screws, surface resistances, moisture variations, etc.) were not modeled. The surface temperatures could be used to evaluate condensation resistance using dew-points calculation methods but should only be utilized with full awareness of the limitations and should not be the sole basis for hygrothermal design of opaque building envelope assemblies. The limitations are discussed in the report in addition to the broader discussion provided in the 2009 ASHRAE Handbook – Fundamentals.

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1. INTRODUCTION

Building owners are increasingly demanding that more attention be paid to sustainability and energy conservation either directly by specification or by participation in programs such as LEED®. Energy conservation requirements for LEED® and many building codes reference ASHRAE Standard 90.1 as the minimum energy requirements of a building. The drive for increasing energy conservation has generated increased demand for building envelope thermal performance data.

The reduced thermal resistance due to thermal bridging through steel and concrete framing can have a significant impact on the whole building energy performance. Designers of buildings are starting to respond by trying to better predict the heat loss through the building envelope by utilizing procedures outlined in the ASHRAE Handbooks and two-dimensional steady-state heat transfer software to determine the effective thermal resistance of assemblies. However, these methods require many assumptions to estimate the thermal performance of complex three-dimensional architectural details at intersections of walls, windows and roofs. This leads to potentially large uncertainty about the thermal performance of the building envelope, which can lead to inefficient design of HVAC systems, building operation inefficiencies, inadequate condensation resistance at intersections of components and compromised occupant comfort.

Morrison Hershfield Limited (MH) entered a research agreement with the American Society of Heating, Refrigerating and Air-Conditioning Engineers, INC (ASHRAE) for ASHRAE Research Project 1365-RP to provide thermal performance data of 40 common building envelope details for mid- and high-rise building construction. The goal of the project was to develop procedures and a catalogue that will allow designers quick and straightforward access to information but with sufficient complexity and accuracy to reduce uncertainty in the thermal performance of building envelope components.

2. HEAT TRANSFER MODEL

Task 1 for this project was to select a public domain or commercially available computer model to predict the dynamic conductive thermal performance of building envelope details containing high conductivity (non-insulating) thermal bridges. A three-dimensional finite element analysis heat transfer software package by Siemens PLM Software was selected for the project. The CAD, meshing, pre- and post-processing was done using two Siemens products called FEMAP and Nx. Both products utilize the same thermal solver (model) developed by Maya Heat Transfer Technologies called TMG Thermal.

Several time-transient heat transfer software packages were evaluated for the project. There are several software packages that could have been selected for this project with numerous strengths and weaknesses. However, the intent of this project and Task 1 was not to provide an evaluation of all the available software, but to provide rationale for the selection of suitable software. Therefore only the rationale for the software selection and a description of how the software works follows.

Three-dimensional heat transfer software was required for this project. Many assumptions are required to simulate non-continuous thermal bridges and/or thermal bridges in multiple planes using a two-dimensional model. A two-dimensional 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 for condensation resistance. In addition, to accurately model surface temperatures with relation to condensation resistance, a suitable model must also accurately model the effects of radiation to the interior and exterior spaces. Modeling convective heat loss and air leakage effects was not part of the scope of this project.

The Siemens software combined with the TMG Thermal solver was selected because the software is capable of modeling time-transient dynamic thermal behavior for: complex geometries (objects not necessarily parallel to the x-y-z axis), radiation through air spaces, phase changes, and conduction through building envelope components containing small areas of highly thermal conductive materials through larger areas of highly insulating materials.

TMG Thermal 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. Calculation points are established by the element’s centre of gravity and the midpoints of either the two-dimensional face for three-dimensional elements or the one-dimensional edge of two-dimensional elements. The element nodes are used only to define the element’s geometry but not used as calculation points; the nodal temperatures are interpolated from the elemental values. Basic output data includes elemental and nodal temperatures, thermal gradient, heat flux by conduction, and total element heat load/flux.

TMG Thermal Features and Capabilities

An overview of TMG Thermal features and capabilities to solve heat transfer problems relevant to this project follows.

Conduction: Heat transfer by conduction can be modeled for arbitrary meshes with many 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).

The ability to model the time-temperature dependency of component materials is critical to accurately modeling the dynamic thermal behavior of complex building envelope details.

Thermal Couplings: Thermal couplings is a TMG Thermal feature to model heat transfer at interfaces between dissimilar element meshes, unconnected components, and creating radiative boundary conditions.

This feature is significant for creating heat flow between complex components.

Radiation: Radiation is simulated using calculated view factors of surfaces and the corresponding material properties of the surface elements for multiple enclosures. The model checks for shadowing; i.e. determines if the view is unobstructed, partially obstructed or completely obstructed; and subdivides elements as required. Radiative sources by direct solar flux or any diffuse flux from another source can be defined by TMG Thermal to be used in conjunction with calculated view factors derived from the surface element's properties (absorptivity, reflectivity, and transmissivity).

Additional background documentation of the TMG Thermal model was provided to the Project Monitoring Subcommittee (PMS) in the form of the *TMG User's Guide* (relevant print-outs from their HTML on-line help) and *TMG Thermal Reference Guide*. These documents were kept confidential within the PMS at the request of Maya and were used solely to evaluate the selection of the software for the project.

3. MODEL CALIBRATION

Task 2 of this project was to demonstrate that the selected model is calibrated and validated (benchmarked) against measured public-domain thermal performance data or deterministic analytical solutions.

3.1 Validation of Calculation Methods using ISO Reference Cases

Validation exercises were completed from two ISO standards to demonstrate that the TMG model will yield high precision results for well-defined problems.

Cases 1 to 4 found in Appendix A for ISO 10211:2007 “Thermal bridges in building construction — Heat flows and surface temperatures — Detailed calculations” and two cases (D.1 and D.6) found in Appendix D of ISO 10077-2: 2003 “Thermal performance of windows, doors and shutters – Calculation of thermal transmittance – Part 2: Numerical Method for Frames” were completed as part of the validation exercises.

Based on the criteria set in the ISO standards and the results of modeling the reference validation cases, the TMG solver can be classified as a three-dimensional steady-state high precision calculation method for modeling building envelope thermal bridges and suitable to calculate two-dimensional thermal conductance of glazing assemblies. Summary of the results of modeling the ISO reference cases are located in Appendix A.

3.2 Calibration and Benchmarking to Guarded Hot-Box Data Sets

Simulated results using the Siemens TMG software package were compared to numerous guarded hot-box data sets to demonstrate that the techniques and procedures to produce the catalogue and the TMG model will accurately reproduce test measurements using measured (or typical) material properties and consistent boundary conditions. The data sets were from five previous research projects and 29 assemblies. A summary of references, assembly descriptions, testing conditions, and completed analysis is found in Appendix B.

Simulated results were compared to measured steady-state and transient U-values and steady-state temperature profiles from several sources, which included numerous variations of steel stud assemblies and thermally massive wall assemblies that apply to mid- and high-rise construction.

A difference of 8% between simulated and measured results criteria based on the reported precision of the guarded hot-box test method was previously used to demonstrate the accuracy of a thermal model for similar purposes as required for this project (Kosny and Desjarlais 1994, Kosny and Childs 2000, Kosny, Christian, Desjarlais 1998, Kosny 1995 & 1994, Enermodal Engineering 1996). The same acceptance criteria was applied to this project when comparing guarded hot-box measurements to simulated results to demonstrate the accuracy of the TMG model and the modeling techniques and procedures used for this project.

3.2.1 Steady-State Thermal Performance of Steel Stud Assemblies

Benchmarking efforts were heavily focused on light weight steel stud wall assemblies because of the sensitivity of measured and simulated results of steel stud assemblies to geometry, thermal properties of individual components, and contact resistance.

The simulated results using the TMG model agree with the major conclusions of previous studies into the thermal performance of steel stud assemblies, which are as follows:

1. Contact resistance between the studs and sheathing can account for up to 10% difference between test and simulated results and is an important factor (Enermodal Engineering 1996, McGowan and Desjarlais 1995).

2. The temperature depression at a steel stud is a function of sheathing thermal resistance and the related lateral heat flow can have a large impact on the overall heat loss through an assembly (Kosny and Christian 1995).

The simulated results are within ±8% of the reported measured results when using a contact resistance of 0.2 $hr{\cdot}ft^2{\cdot}{}^oF/Btu$ (0.03 m^3 $^oC/W$) as suggested by the Building Research Association of New Zealand (BRANZ, Trethowen and Cox-Smith 1996) and consistent material properties[1]. The simulated thermal resistances are on average lower by 1% than the measured thermal resistances for 24 steel stud assemblies[2].

Table 3.1 summarizes the thermal resistances for the steel assemblies using a contact resistance of 0.17 $hr{\cdot}ft^2{\cdot}{}^oF/Btu$ (0.030 m^2 $^oC/W$) between the steel flanges and sheathing interfaces, 0.057 $hr{\cdot}ft^2{\cdot}{}^oF/Btu$ (0.010 m^2 $^oC/W$) at insulation interfaces, and 0.011 $hr{\cdot}ft^2{\cdot}{}^oF/Btu$ (0.0020 m^2 $^oC/W$) for steel to steel connections.

The results of the simulations are in good agreement with the two-dimensional simulated results of ASHRAE Research Project 785-RP for specimens SS.16 to SS.18 using a contact resistance of 0.17 $hr{\cdot}ft^2{\cdot}{}^oF/Btu$ (0.030 m^2 $^oC/W$) between the studs and sheathings (Enermodal 1996). Table 3.2 shows the agreement between the simulated and measured thermal resistance for specimens SS.16 to SS.18.

[1] Simulated results are not within the 8% range of the measured values for one assembly (SS.21) when using the thermal resistance of individual materials measured at mean temperatures reported by the source paper. Simulated results were all within 8% using material properties measured at 24^{o}C. This will be discussed in section 3.2.3.

[2] The thermal resistance was measured for two temperature differences for some assemblies. The higher reported thermal resistance was selected for comparison and calculating percent difference.

Table 3.1: Comparison of Thermal Resistance for Steel Stud Assemblies

ID	Measured Thermal Resistance[3]	Simulated Thermal Resistance	% Difference
SS.1	R-6.66 (1.17 RSI)	R-6.5 (1.14 RSI)	-3.2%
SS.2	R-8.13 (1.43 RSI)	R-8.3 (1.46 RSI)	1.8%
SS.3	R-9.89 (1.74 RSI)	R-9.7(1.70 RSI)	-2.2%
SS.4	R-7.4 to 7.9 (1.30 to 1.39 RSI)[2]	R-7.7 (1.35 RSI)	-3.3%
SS.5	R-13.7 (2.41 RSI)	R-13.4 (2.36 RSI)	-2.3%
SS.6	R-13.9 (2.45 RSI)	R-13.5 (2.39 RSI)	-2.6%
SS.7	R-11.4 (2.01 RSI)	R-10.8 (1.91 RSI)	-5.1%
SS.8	R-18.9 (3.33 RSI)	R-19.0 (3.35 RSI)	0.6%
SS.9	R-8.3 (1.46 RSI)	R-7.8 (1.37 RSI)	-6.1%
SS.10	R-13.9 (2.45 RSI)	R-13.5 (2.37 RSI)	-3.2%
SS.11	R-14.5 (2.55 RSI)	R-14.2 (2.5 RSI)	-2.0%
SS.12	R-10.1 (1.78 RSI)	R-10.0 (1.77 RSI)	-0.8%
SS.13	R-16.2 (2.85 RSI)	R-16.3 (2.87 RSI)	0.7%
SS.14	R-17.1 (3.01 RSI)	R-17.7 (3.11 RSI)	3.1%
SS.15	R-15.6 (2.75 RSI)	R-15.0 (2.64 RSI)	-3.9%
SS.16	R-7.81 (1.38 RSI)	R-7.7 (1.36 RSI)	-1.8%
SS.17	R-12.52 (2.21 RSI)	R-12.5 (2.20 RSI)	-0.7%
SS.18	R-13.85 (2.44 RSI)	R-14.1 (2.49 RSI)	1.9%
SS.19	R-7.7 to 8.1 (1.35 to 1.42 RSI)[2]	R-7.9 (1.39 RSI)	-2.3%
SS.20	R-13.0 to 13.7 (2.29 to 2.41 RSI)[2]	R-13.5 (2.38 RSI)	-1.3%
SS.21	R-17.5 to 18.7 (3.09 to 3.29 RSI)[2]	R-18.7 (3.30 RSI)	0.3%
SS.22	R-7.7 to 7.9 (1.35 to 1.4 RSI)[2]	R-7.7 (1.36 RSI)	-2.9%
SS.23	R-12.7 to 13.4 (2.24 to 2.36 RSI)[2]	R-13.4 (2.36 RSI)	-0.1%
SS.24	R-17.1 to 18.1 (3.02 to 3.18 RSI)[2]	R-18.4 (3.25 RSI)	2.1%

Table 3.2: Comparison of Thermal Resistance for Steel Stud Assemblies using Different Software

ID	Measured Thermal Resistance	Simulated Thermal Resistance		% Difference from Measured Results	
		Using Frame (2D)	Using TMG (3D)	Using Frame (2D)	Using TMG (3D)
SS.16	R-7.81 (1.38 RSI)	R-7.68 (1.35 RSI)	R-7.7 (1.36 RSI)	-2.2%	-1.8%
SS.17	R-12.52 (2.21 RSI)	R-12.18 (2.15 RSI)	R-12.5 (2.20 RSI)	-2.8%	-0.7%
SS.18	R-13.85 (2.44 RSI)	R-13.87 (2.44 RSI)	R-14.1 (2.49 RSI)	-0%	1.9%

The simulated assemblies represent many variations of steel stud assemblies: flange size, steel gauge thickness, stud spacing, types of sheathing, insulation types, and many different insulation scenarios. The simulated results were sensitive to flange

[3] Surface to surface thermal resistance value (calculated value when air to air thermal resistance values reported)

size, stud spacing, insulation values of individual materials, and contact resistance. The simulated thermal resistance (surface to surface) was comparatively not as sensitive to steel gauge thickness and boundary conditions (for constant thermal resistance of materials). These findings are consistent with the reported measured values and previous simulation of steel stud assemblies using different models as per the referenced papers.

The simulated boundary conditions are important to get the same absolute surface temperatures or temperature indices as the measured values but not the relative temperatures between the studs (thermal bridges) and centre of the stud cavity. Contact resistance between the steel stud flange and sheathing is important to replicate the temperature profile of measured steel stud assemblies. The contribution of contact resistance to the thermal performance of steel stud assemblies is explored in the following section.

3.2.2 Contact Resistance in Steel Stud Assemblies

A few sources of contact resistance values were researched in the Siemens software package documentation, work completed at the Department of Mechanical Engineering at Waterloo, Ontario[4] and work done at BRANZ (Trethowen et al 1996). The work from Waterloo is difficult to apply to building envelope assemblies because the values referenced in their numerous publications are directed to the aerospace industry, microelectronics, and nano-technologies. Enough is not known about the actual contact pressure, surface roughness and geometry of the air between materials in real life building envelope assemblies to apply the Waterloo research to this project. It appears that BRANZ has made the best attempt to-date to quantify contact resistance to steel stud assemblies and good agreement was found between simulations completed for this project and guarded hot-box measurements using the values suggested by BRANZ as shown in Tables 3.1 and 3.2.

The 2009 ASHRAE Handbook – Fundamentals states that the contact resistances in buildings are too small to be of concern in many cases, but might be important for steel framing. Furthermore, contact resistance has been previously shown to be important for accurately simulating the thermal performance of steel stud assemblies. Therefore, a parametric study was completed to demonstrate the sensitivity of contact resistance using the TMG model. A parametric study for three assemblies was completed: two assemblies without exterior insulation (SS.4, SS.19) and one assembly with exterior insulation (SS.21). The parametric study was completed using the range of values suggested in the 2009 ASHRAE Handbook – Fundamentals of 0.06 hr·ft^2·^{o}F/Btu (0.01 m^2 ^{o}C/W) to 0.6 hr·ft^2·^{o}F/Btu (0.1 m^2 ^{o}C/W) for the contact resistance between the steel flange (studs and tracks) to sheathing (interior and exterior).

[4] The Microelectronics Heat Transfer Laboratory, Department of Mechanical Engineering, University of Waterloo has an archive of papers from 1966 to 2009 located at www.mhtlab.uwaterloo.ca as of May 2011.

The primary output for this project is the thermal performance data for energy transfer (U-factor or overall thermal resistance) and condensation resistance (surface temperatures). The surface temperatures are a consequence of heat flow, nevertheless comparing both the U-factor and temperature is valuable to calibrate and validate a heat transfer model. This is particularly true to demonstrate the relationship between contact resistance and the thermal performance of steel stud assemblies. The parametric study revealed that the modeled contact resistance can have a large impact on the modeled thermal resistance for steel stud assemblies without exterior insulation. Comparatively, the impact is smaller for assemblies with a lot of thermal resistance outboard of the steel studs. These results can be directly attributed to the surface temperatures near the steel studs and lateral heat flow, which is a function of the sheathing thermal resistance and contact resistance between the steel studs and sheathing.

Table 3.3 compares the thermal performance of steel stud assemblies for contact resistances suggested by the 2009 ASHRAE Handbook – Fundamentals at the steel stud to sheathing interface of 0.06 $hr \cdot ft^2 \cdot {}^oF/Btu$ (0.01 $m^2\ {}^oC/W$) to 0.6 $hr \cdot ft^2 \cdot {}^oF/Btu$ (0.1 $m^2\ {}^oC/W$). Contact resistance of 0.057 $hr \cdot ft^2 \cdot {}^oF/Btu$ (0.010 $m^2\ {}^oC/W$) was modeled at insulation interfaces, and 0.011 $hr \cdot ft^2 \cdot {}^oF/Btu$ (0.0020 $m^2\ {}^oC/W$) at steel to steel connections.

Variations of contact resistance are not presented between the steel studs to lateral insulation and insulation to sheathings because:

1. The contact resistance of the steel stud to lateral insulation does not have much of an impact on the overall thermal resistance and temperature profile.

2. Adjustment of the contact resistance between the insulation and adjacent sheathings will have the same effect as changing the thermal resistance of the materials. Differentiation would be fruitless since there is uncertainty, in the same order of magnitude, between the actual contribution of thermal resistance of individual materials in guarded hot-box measurements (at different mean temperatures) and the thermal resistance measured as per standard test methods (i.e. ASTM C-518).

Table 3.3 shows how the contact resistance between the stud flanges and sheathings can have a significant impact on the overall thermal resistance of an assembly and less impact on surface temperatures as seen by comparing the temperature indices[5]. Modeling the contact resistance between the studs and sheathings appears to be important to predict the overall thermal resistance of an assembly. Otherwise, the overall thermal resistance of steel stud assemblies will be under predicted by computer simulation.

[5] Temperature index is the ratio of a surface temperature to the overall temperature difference. A value of 0 is the outdoor air temperature and 1 is the indoor air temperature. Refer to section 5.3 for more discussion on temperature indices.

Table 3.3: Thermal Performance of Steel Stud Assemblies for Range of Contact Resistances Referenced in 2009 ASHRAE Handbook – Fundamentals at the Steel Stud to Sheathing Interface

Thermal Performance Indicator	Assembly ID & Exterior Sheathing Description								
	SS.19 - 5/8 in (16 mm) OSB			SS.21 – ½ in (13 mm) + 2″ (50 mm)			XPS SS.4 – ½ in (13 mm) Plywood		
	Simulated Contact Resistance			Simulated Contact Resistance			Simulated Contact Resistance		
	max[6]	min[7]	% DIFF	max	min	% DIFF	max	min	% DIFF
Overall Thermal Resistance - hr·ft^2·^{o}F/Btu (m^2 ^{o}C/W)	**8.8 (1.6)**	**7.4 (1.3)**	**18.1%**	**19.3 (3.4)**	**18.3 (3.2)**	**5.4%**	**8.6 (1.5)**	**7.3 (1.3)**	**15.8%**
Temperature Index at **Gypsum Warm Surface** – Centre of **Cavity**	0.96	0.96	0.1%	0.98	0.98	0.1%	0.94	0.94	0%
Temperature Index at **Gypsum Warm Surface** – Centre of **Studs**	0.87	0.83	3.7%	0.94	0.92	1.6%	0.81	0.74	7.0%
Temperature Index at **Gypsum Cold Surface** – Centre of **Cavity**	0.96	0.96	0 %	0.97	0.96	0%	0.91	0.91	0%
Temperature Index at **Gypsum Cold Surface** – Centre of **Studs**	0.76	0.73	3.1%	0.89	0.86	3.0%	0.71	0.60	10.5%
Temperature Index at **Exterior Sheathing Warm Surface** – Centre of **Cavity**	0.09	0.09	0%	0.47	0.47	0.6%	0.08	0.08	0%
Temperature Index at **Exterior Sheathing Warm Surface** – Centre of **Studs**	0.42	0.47	4.5%	0.68	0.76	7.6%	0.28	0.40	11.3%
Temperature Index at **Exterior Sheathing Cold Surface** – Centre of **Cavity**	0.05	0.05	0%	0.44	0.44	0.6%	0.03	0.03	0%
Temperature Index at **Exterior Sheathing Cold Surface** – Centre of **Studs**	0.19	0.21	1.8%	0.62	0.69	6.5%	0.09	0.12	3.5%
Temperature Index Difference Across Cavity (surface to surface)	**0.92**	**0.92**	**0.1%**	**0.96**	**0.96**	**0%**	**0.91**	**0.91**	**0%**
Temperature Index Difference Across Studs (surface to surface)	**0.68**	**0.62**	**5.5%**	**0.91**	**0.89**	**1.9%**	**0.72**	**0.61**	**10.5%**

[6] Maximum contact resistance suggested by the 2009 ASHRAE Handbook – Fundamentals of 0.6 hr·ft^2·^{o}F/Btu (0.1 m^2 ^{o}C/W)
[7] Minimum contact resistance suggested by the 2009 ASHRAE Handbook – Fundamentals of 0.06 hr·ft^2·^{o}F/Btu (0.01 m^2 ^{o}C/W)

The difficulty is that the contact resistance is unlikely to be uniform across a stud in practice; there will be more contact between the sheathing and studs at fasteners and likely less contact near the tracks (created by the gap the thickness of the track flange). The non-uniform contact with the sheathing along the stud flange needs to be considered when selecting appropriate contact resistance values for evaluating the thermal performance of steel stud assemblies. Different contact resistance values may be required for predicting the overall thermal resistance than evaluating condensation resistance.

Modeling average contact resistance along the steel stud flange appears to suffice to predict the overall thermal resistance. Furthermore, ASHRAE research project 785 RP showed that modeling fasteners has little impact on the overall thermal resistance (decreased the overall R-value by less than 0.6%). However, localized temperatures are important when evaluating condensation resistance. Evidence to support this was found when the overall thermal resistance and surface temperatures of measured assemblies was analyzed.

The difference between the simulated and measured surface temperatures at the studs was as high as 6.5% for one specimen (SS.4) where the difference was only 0.3% for the overall thermal resistance. For this assembly, the difference between the simulated and measured are within the reported manufacturer's stated accuracy of the thermocouples (±1.8^{o}F) for surface temperatures and the reported precision of the guarded hot-box test method (8%) for overall thermal resistance using contact resistances in the range suggested by the 2009 ASHRAE Handbook – Fundamentals. However, calibration of the thermocouples used for measuring the thermal performance of specimen SS.4 using ice references were reported to show the actual differences were less than 0.5^{o}F. The simulated surface temperatures were not within 0.5^{o}F of the measured surface temperatures. An extensive parametric study revealed that the surface temperatures at the cold surface of the interior gypsum was the limiting factor and is likely due to the proximity of measured temperatures to a fastener. This conclusion is supported in the reference paper by the observation that upon disassembly of the test specimen the warm side thermocouple, located in the middle of the stud, was attached to the sample surface over a screw (Barbour, Goodrow, Kosny, & Christian 1994). This demonstrates how the overall thermal resistance can be accurately predicted without attempting to model absolute temperatures.

Average surface temperatures of several locations (nine locations for the studs) were reported in the reference papers for other testing (Enermodal Engineering 1996, Desjarlais & McGowan 1997). Very good agreement was found between the measured and simulated results for both the overall thermal resistance and warm side temperature profile for these assemblies (SS.16 to SS.18)[8]. Detailed comparisons between measured and simulated surface temperatures for a range of contact resistances are located in Appendix C.

[8] The good agreement for the temperature profiles is relative and does not extend to absolute temperatures.

3.2.3 Temperature Dependent Thermal Resistance of Insulations

Guarded hot-box measurements at two mean temperatures (different temperature gradients) show that the dependency of insulation thermal resistance to mean temperature can result in up to 6.5% difference in the measured thermal resistance (Brown et al 1991, Kosny et al 1993). Lower mean temperatures result in higher measured overall thermal resistance. This difference is almost as high as the reported precision of the guarded hot-box method of 8%.

The measured thermal resistance of specimen materials, based on the mean temperature and overall thermal resistance of assemblies, for two sets of steady-state temperature conditions were provided for assemblies SS.19 to SS.24. Analysis of the temperature indices of the assemblies SS.19 and SS.21 with a hot side temperature of 68^{o}F (20^{o}C) and a cold side temperature of 23^{o}F (-5^{o}C) reveals that the temperature index at the cavity centre are not consistent with measured thermal resistance of the materials for the same mean temperature. Furthermore, the simulated thermal resistance is not in good agreement with the measured thermal resistance. This was particularly true for the assembly with 2 inches (50mm) of extruded polystyrene outboard the studs (SS.21). Tables 3.4 to 3.7 and figures of the temperature profiles at the sheathings' surfaces located in Appendix C summarize this analysis. This analysis shows how small adjustments to thermal resistance of the insulating materials correspond to a large difference in the overall thermal resistance as shown in Tables 3.5 and 3.7. Two values of contact resistance are included in the analysis to demonstrate the relative impact of the contact resistance on the overall thermal resistance and temperature profile.

This analysis appears to indicate that modeling assemblies using typical material properties measured at 24^{o}C (75^{o}F) will provide good agreement between measured and simulated thermal performance.

Table 3.4: Nominal Thermal Resistance of Materials for Specimen SS.19 Calculated from Measured Thermal Resistance Based on Mean Temperature and Cavity Centre Temperature Index

Component	**Measured ΔT at Cavity Centre**[9] **(% of total)**	T_{mean}[10] **°F (°C)**	**Thermal Resistance**		**% of Total Thermal Resistance**	
			R_{spec}[11]	R_{fitted}[12]	R_{spec}	R_{fitted}
Interior film	4%	23°F (20°C)	R-0.6 (0.11 RSI)	R-0.6 (0.11 RSI)	3.9%	4.2%
Gypsum	4%	68°F (18.5°C)	R-0.5 (0.08 RSI)	R-0.5 (0.08 RSI)	2.8%	3.1%
Fiberglass Batt	87%	65.3°F (7.1°C)	R-14.2 (2.50 RSI)	R-12.8 (2.26 RSI)	87.4%	86.6%
OSB	3.5%	44.8°F (7.1°C)	R-0.7 (0.13 RSI)	R-0.7 (0.12 RSI)	4.5%	4.6%
Exterior film	1.5%	23°F (-5°C)	R-0.2 (0.04 RSI)	R-0.2 (0.04 RSI)	1.4%	1.5%
Total	100%	-	R-16.3 (2.86 RSI)	R-14.8 (2.61 RSI)	100.0%	100.0%

Table 3.5: Simulated Thermal Resistance for Specimen SS.19 for Different Thermal Resistance of the Fiberglass Batt and Contact Resistance Between the Steel Studs and Sheathings

ID[13]	**Thermal Resistance of Fiberglass Batt**	**Contact Resistance Between the Stud Flange and Sheathings**	**Simulated Thermal Resistance**	**% Difference from Measured Results, R-7.7 (1.35 RSI)**
M043.33	R-11.9 (2.09 RSI)	R-0.17 (0.03 RSI)	R-7.5 (1.32 RSI)	-2.3%
M04.33	R-12.8 (2.25 RSI)	R-0.17 (0.03 RSI)	R-7.7 (1.36 RSI)	0.7%
M04.100	R-12.8 (2.25 RSI)	R-0.057 (0.01 RSI)	R-7.3 (1.29 RSI)	-4.2 %
M036.33	R-14.2 (2.50 RSI)	R-0.17 (0.03 RSI)	R-8.2 (1.44 RSI)	6.1%

[9] Extracted from figures in reference paper (Brown, Swinton, Haysom, 1998)
[10] Calculated from the centre of cavity temperature index; mean temperatures of the fiberglass and extruded polystyrene insulation reported in the paper are ±1.4°F (0.8°C) and yield the same calculated thermal resistance using the measured material properties
[11] R_{spec} is the calculated thermal resistance from the measured material properties reported in the reference paper
[12] R_{fitted} is the fitted thermal resistance that best matches the temperature index at the centre of cavity
[13] ID for the simulation identifier that corresponds to the figures found in Appendix C

Table 3.6: Nominal Thermal Resistance of Materials for Specimen SS.21 Calculated from Measured Thermal Resistance Based on Mean Temperature and Cavity Centre Temperature Index

Component	Measured ΔT at Cavity Centre (% of total)	T_{mean} °F (°C)	Thermal Resistance		% of Total Thermal Resistance	
			R_{spec}	R_{fitted}	R_{spec}	R_{fitted}
Interior film	2%	23°F (20°C)	R-0.6 (0.1 RSI)	R-0.6 (0.1 RSI)	2.1%	2.4%
Gypsum	2%	67°F (19.3°C)	R-0.4 (0.075 RSI)	R-0.4 (0.075 RSI)	1.6%	1.8%
Fiberglass Batt	47%	56°F (13.1°C)	R-13.6 (2.4 RSI)	R-11.9 (2.09 RSI)	50.8%	49.3%
OSB	3%	44°F (6.9°C)	R-0.7 (0.13 RSI)	R-0.7 (0.12 RSI)	2.6%	2.8%
XPS	43%	34°F (1.1°C)	R-10.8 (1.9 RSI)	R-9.9 (1.72 RSI)	40.2%	40.6%
Exterior film	3%	23°F (-5°C)	R-0.7 (0.13 RSI)	R-0.7 (0.13 RSI)	2.7%	3.1%
Total	100%	-	R-26.8 (4.7 RSI)	R-24.1 (4.24 RSI)	100.0%	100.0%

Table 3.7: Simulated Thermal Resistance for Specimen SS.21 for Different Thermal Resistance of the Fiberglass Batt and Contact Resistance between the Steel Studs and Sheathings

ID[14]	Thermal Resistance of Fiberglass Batt	Thermal Resistance of XPS	Contact Resistance Between the Stud Flange and Sheathings		Simulated Thermal Resistance	% Difference from Measured Results, R-17.5 (3.09 RSI)
			Interior	Exterior		
M043.027.33	R-11.9 (2.09 RSI)	R-10.5 (1.85 RSI)	R-0.2 (0.03 RSI)	R-0.2 (0.03 RSI)	R-18.9 (3.33 RSI)	7.3%
M043.029.33	R-11.9 (2.09 RSI)	R-9.8 (1.72 RSI)	R-0.2 (0.03 RSI)	R-0.2 (0.03 RSI)	R-18.1 (3.19 RSI)	3.3%
M0375.027.33	R-13.6 (2.40 RSI)	R-10.5 (1.85 RSI)	R-0.2 (0.03 RSI)	R-0.2 (0.03 RSI)	R19.6 (3.45 RSI)	10.9%
M043.029.33.100	R-11.9 (2.09 RSI)	R-9.8 (1.72 RSI)	R-0.2 (0.03 RSI)	R-0.06 (0.01 RSI)	R-17.9 (3.15 RSI)	1.9%
M043.027.100	R-11.9 (2.09 RSI)	R-10.5 (1.85 RSI)	R-0.06 (0.01 RSI)	R-0.06 (0.01 RSI)	R-18.6 (3.28 RSI)	5.9%

[14] ID for the simulation identifier that corresponds to figures found in Appendix C

3.2.4 Steady-State Thermal Performance of Thermally Massive Assemblies

Benchmarking was also completed for thermally massive wall assemblies that apply to mid- and high-rise construction. The model was benchmarked against assemblies with structural concrete block, concrete slab assemblies, and lightweight concrete assemblies. The simulated results have very good agreement with the measured thermal resistance. Table 3.8 summarizes the results of the massive wall assemblies. A summary of references, assembly descriptions, testing conditions, and completed analysis is found in Appendix B.

Table 3.8: Comparison of Thermal Resistance for Thermally Massive Assemblies

ID	Measured Thermal Resistance[15]	Simulated Thermal Resistance	% Difference
M.1	R-4.89 (0.86 RSI)	R-4.94 (0.87 RSI)	1.0%
M.2	R-4.88 (0.86 RSI)	R-4.83 (0.85 RSI)	-0.9%
M.3	R-12.17 (2.17 RSI)	R-12.4 (2.19 RSI)	1.0%
M.4	R-7.68 (1.35 RSI)	R-7.55 (1.33 RSI)	-1.6%

3.2.5 Transient Thermal Performance of Building Envelope Assemblies

Simulated results completed as part of Task 2 closely follow the transient profiles of the heat flux of guarded hot-box measurements. Table 3.9 summarizes the difference between the simulated and measured thermal resistances over a 24 hour period for a sinusoidal change in the cold side temperature with a constant hot side temperature. Figures and complete summaries of the transient analysis are located in Appendix D.

Table 3.9: Comparison of Simulated and Measured Heat Flow through Interior Surface

ID	Maximum % Difference between Simulated and Measured Heat Flow	Minimum % Difference between Simulated and Measured Heat Flow	Average % Difference between Simulated and Measured Heat Flow
SS.1	1.3%	0.4%	0.8%
SS.2	4.3%	0.1%	2.2%
M.1	5.2%	1.5%	3.9%
M.2	0.3%	0%	0.2%
M.4	4.2%	0.1%	1.6%

3.3 Model Calibration Summary

Based on the criteria set in the ISO standards and results of modeling the reference validation cases, the TMG solver can be classified as a three-dimensional steady-state high precision calculation method for modeling building envelope thermal bridges and suitable to

[15] Surface to surface thermal resistance (calculated value when air to air thermal resistance values reported)

calculate two-dimensional thermal conductance of glazing assemblies. These validation exercises demonstrate that the TMG solver will yield high precision results for **well-defined** problems.

Good agreement between simulated and measured thermal performance of assemblies appropriate for mid- and high-rise construction for both steady-state and transient conditions was found. This agreement demonstrates that the techniques and procedures to produce the catalogue and the TMG model will accurately reproduce test measurements using measured (or typical) material properties and consistent boundary conditions. A summary of the modeling procedures utilized for this project can be found in Section 5.

4. BUILDING ENVELOPE DESIGN DETAIL CATALOGUE

Task 3 of the project was to prepare a catalogue of 40 building envelope design details based on a set of generic and common details involving metal, concrete, and other thermally conductive materials suitable for mid- and high-rise construction.

The objectives of the catalogue are:

1. To be relevant to ASHRAE/IES Standard 90.1;
2. To be relevant to existing and future building stock and capture both retrofit and new construction details;
3. Represent both high thermal performance envelopes and standard building practice;
4. Represent typical interior finishing and cladding systems and attachment methods.

Tables 4.3 to 4.6 at the end of this section summarize the details included in the catalogue. Data sheets that identify all materials, dimensions, and material properties necessary to evaluate the thermal performance can be found in Appendix E.

4.1 Detail Selection Methodology

Selection of details was based on the following methodology.

1. Highest priority details have thermal bridges in three-dimensions;
2. Focus on details not already addressed in ASHRAE publications (build on past work);
3. Include clear wall and two-dimensional intersections when not already effectively addressed by ASHRAE publications;
4. Details should include intersections throughout a typical building, i.e. at parapets, opaque walls to glazing, intersecting walls, and balconies.

Details were primarily allocated and grouped by common wall assemblies, and then individual details were selected within the primary wall type group by secondary groupings. Secondary groupings include intersections to other envelope components, variations in insulation strategy, and cladding attachment. An overview of the detail allocation by wall type is presented in Table 4.1. Secondary groupings are summarized in Table 4.2.

The calibration exercises highlighted some important considerations for producing a catalogue to meet the project goals. The goal was to develop procedures and a catalogue that will allow designers quick and straightforward access to information but with sufficient complexity and accuracy to reduce uncertainty in the thermal performance of building envelope components. Accordingly, it was important not to get lost in the details in producing the catalogue. With these considerations in mind, assemblies were modeled in a generic manner, when possible, that embodied small differences from less significant factors. Examples of factors deemed less significant are steel gauge thickness and screws into sheathings. These factors were incorporated into each assembly, but in a consistent approach for every assembly without micro analysis.

Table 4.1: Detail Allocation by Wall Type

Wall Type	Detail Allocation	Percentage
Steel Stud	17	42.5%
Poured-in-place Concrete	6	15%
Glazing Spandrel Section	4	10%
Precast Concrete and Sandwich Panels	7	17.5%
Concrete Block	6	15%
Total	40	100%

Table 4.2: Detail Secondary Groupings

Grouping	Variations
Intersections to other building envelope components	roof, glazing assemblies, balconies, slabs, intersecting walls, beam intersections
Variations in insulation strategy	exterior, interior, and split insulation
Cladding attachment and support	cladding structural attachment type and spacing, shelf angles

4.2 Detail Catalogue Summary

Tables 4.3 to 4.6 summarize the detail catalogue and categorize the details by primary and secondary groupings.

Table 4.3: Detail Catalogue Summary – Steel Stud Details

Detail	Description	Primary Group	Secondary Groupings
1	Exterior insulated steel stud wall /w vertical z-girts – clear wall	Steel stud	Cladding attachment, insulation strategy
2	Exterior insulated steel stud wall /w horizontal z-girts – clear wall	Steel stud	Cladding attachment, insulation strategy
3	Exterior insulated steel stud wall /w combination z-girts – clear wall	Steel stud	Cladding attachment, insulation strategy
4	Exterior insulated steel stud wall /w intermittent z-girts – clear wall	Steel stud	Cladding attachment, insulation strategy
5	Exterior insulated steel stud wall /w horizontal z-girts – slab intersection /w insulation	Steel stud	Slab intersection, insulation strategy
6	Exterior insulated steel stud wall /w horizontal z-girts – clear wall	Steel stud	Slab intersection, insulation strategy

Detail	Description	Primary Group	Secondary Groupings
7	Exterior insulated steel stud wall /w horizontal z-girts – window and slab intersection	Steel stud	Window and slab intersection
8	Exterior insulated steel stud wall /w horizontal z-girts – corner wall intersection	Steel stud	Wall intersection
9	Exterior insulated steel stud wall /w horizontal z-girts – concrete parapet and slab intersection	Steel stud	Roof deck and parapet intersection, insulation strategy
10	Exterior insulated steel stud wall /w horizontal z-girts – steel roof deck and parapet intersection	Steel stud	Roof deck and parapet intersection, insulation strategy
11	Split insulated steel stud wall /w horizontal z-girts – clear wall	Steel stud	Insulation strategy
12	Exterior insulated steel stud wall /w horizontal z-girts – structural steel column & cantilever beam intersection	Steel stud	Steel structure intersection
13	Exterior insulated steel stud wall /w horizontal z-girts – interior wall intersection	Steel stud	Insulation strategy, wall intersection
14	Exterior Insulated brick veneer wall /w shelf angle	Steel stud	Slab intersection, cladding support, insulation strategy
15	Exterior Insulated brick veneer wall /w insulated shelf angle	Steel stud	Slab intersection, cladding support, insulation strategy
16	Interior insulated steel stud wall /w horizontal z-girts – structural steel floor intersection	Steel stud	Floor slab intersection, insulation strategy
17	Split insulated steel stud wall /w horizontal z-girts – structural steel floor intersection	Steel stud	Floor slab intersection, insulation strategy

Table 4.4: Detail Catalogue Summary – Poured-in-place Concrete and Spandrel Panels Details

Detail	Description	Primary Group	Secondary Groupings
18	Interior insulated concrete mass wall /w non-insulated exterior slab and insulated interior wall intersection	Poured-in-place concrete	Wall and slab intersection, insulation strategy
19	Interior insulated concrete mass wall /w non-insulated exterior slab and non-insulated interior wall intersection	Poured-in-place concrete	Wall and slab intersection, insulation strategy
20	Interior insulated concrete mass wall – concrete parapet & roof intersection	Poured-in-place concrete	Roof and parapet intersection, insulation strategy
21	Insulated concrete slab – concrete curb or wall intersection	Poured-in-place concrete	Wall or curb intersection
22	Conventional curtain wall system /w insulated spandrel panel and non-insulated steel stud wall – slab intersection	Spandrel panel	Slab intersection, insulation strategy
23	Conventional curtain wall system /w insulated spandrel panel and insulated steel stud wall – slab intersection	Spandrel panel	Slab intersection, insulation strategy
24	Split insulated steel stud wall /w horizontal z-girts and conventional curtain wall intersection	Spandrel panel / steel stud	Assembly intersection, insulation strategy
25	Conventional curtain wall system /w insulated spandrel panel and insulated steel stud wall – slab intersection – concrete parapet and roof intersection	Spandrel panel	Roof and parapet intersection, insulation strategy
26	Sliding door sill and window head – slab intersection /w concrete curb	Poured-in-place concrete	Slab and glazing intersection, insulation strategy
27	Sliding door sill and window head – slab intersection w/o concrete curb	Poured-in-place concrete	Slab and glazing intersection, insulation strategy

Table 4.5: Detail Catalogue Summary – Precast Concrete and Sandwich Panel Details

Detail	Description	Primary Group	Secondary Groupings
28	Precast panel /w rigid insulation outboard of steel studs – slab intersection	Precast concrete	Slab intersection, insulation strategy
29	Precast panel /w insulated steel studs – slab intersection	Precast concrete	Slab intersection, insulation strategy
30	Precast panel /w rigid insulation outboard of steel studs – parapet & roof intersection	Precast concrete	Parapet and slab intersection
31	Sandwich panel /w steel studs – curtain wall transition	Precast concrete / spandrel section	Curtain wall transition
32	Sandwich panel /w steel studs – slab Intersection	Precast concrete	Slab intersection
33	Sandwich panel /w steel studs – steel roof deck with OWSJ & parapet intersection	Precast concrete	Parapet and roof intersection
34	Sandwich panel /w steel studs – window intersection	Precast concrete	Window intersection

Table 4.6: Detail Catalogue Summary – Concrete Block Panel Details

Detail	Description	Primary Group	Secondary Groupings
35	Exterior insulated brick veneer concrete block wall – slab intersection /w shelf angle	Concrete block	Slab intersection, cladding support, insulation strategy
36	Exterior insulated brick veneer concrete block wall – slab intersection /w insulated shelf angle	Concrete block	Slab intersection, cladding support, insulation strategy
37	Exterior insulated brick veneer concrete block wall – parapet & roof intersection	Concrete block	Parapet and roof intersection
38	Exterior insulated brick veneer concrete block wall – non-insulated balcony slab intersection	Concrete block	Slab intersection, insulation strategy
39	Exterior insulated brick veneer concrete block wall – balcony slab supported by insulated shelf angle	Concrete block	Slab intersection, insulation strategy
40	Exterior insulated brick veneer concrete block wall – exposed slab intersection	Concrete block	Slab intersection, insulation strategy

5. MODELING PROCEDURES

Modeling procedures follow from the calibration exercises and are intended to produce thermal performance data aligned with the project goals: to allow designers quick and straightforward access to information, but with sufficient complexity and accuracy to reduce uncertainty in the thermal performance of building envelope components. Moreover, the procedure leads to results that will answer the fundamental questions of how overall geometry and materials affect the overall thermal performance.

The primary calculated thermal performance data includes thermal transmittances (U-value), and indexed temperatures (I-value). Modeling procedures to determine the thermal performance data follows. Dimensionless Z-transfer function coefficients are discussed but values were not calculated as part of this project.

5.1 General Modeling Principles

5.1.1 Cut-off Planes

Cut-off planes for the details are primarily based on symmetry of thermal bridges and standard sizes of construction materials. A cut-off plane at 3 feet (915 mm) was provided if symmetry of thermal bridges and sizes of materials did not dictate otherwise.

5.1.2 Contact Resistance

Contact resistance between materials was incorporated into the model as summarized in Table 5.1. Bolts bypassing the thermal insulation connecting steel supports were included in the models; individual screws to attach sheathings and bolts into concrete were not directly modeled.

Table 5.1: Summary of Contact Resistances

Location	**Contact Resistance** hr·ft^2·^{o}F /Btu (m^2 ^{o}C/W)
Steel flanges at sheathing interfaces	0.17 (0.030)
Insulation interfaces	0.057 (0.010)
Steel to concrete interfaces	0.057 (0.010)
Steel to steel interfaces	0.011 (0.0020)

5.1.3 Material Properties

There are many variations of building envelope wall assemblies for many combinations of insulation type, quantity, or placement of insulation. Moreover, for a given quantity of thermal bridging (for example, steel framing to attach cladding), the insulation has diminishing returns with regard to the overall assembly (effective) thermal resistance. For this project, several increments of insulation thermal resistance of the exterior insulated assemblies were evaluated in a generic manner to capture different types of insulation and thickness and the impact of diminishing returns with increasing insulation. Insulation in steel stud cavities was assumed to be filled and only modeled for one thermal conductivity value.

Constant thermal conductivities were selected using standard tabulated values (typically measured at 24^{o}C or 75^{o}F). A discussion about the significance of material properties due to the dependency of mean temperature can be found in the calibration section. The thermal conductivity, density, and specific heat are based on values provided in the 2009 ASHRAE Handbook – Fundamentals.

5.1.4 Air Cavities

Unventilated air cavities are dependent on the cavity surface temperatures, surface emittances, and geometry. Table 3, chapter 26, of the 2009 ASHRAE Handbook – Fundamentals provides the thermal resistances of plane air spaces, including the effects of radiation, conduction, and convection.

For this project, it is advantageous to model the catalogue details using constant material properties independent of temperatures because the thermal performance data must represent data for cold weather design conditions (ASHRAE Climate Zone 7) and hot weather design conditions (ASHRAE Climate Zone 2)[16].

Close examination of the possible thermal resistances of plane air spaces for the steel stud cavities in the catalogue reveals that the difference is within the uncertainty of the other material properties. This is based on the range of cavity temperatures and depths represented in this project that are enclosed with ordinary building materials (effective emittance of 0.82). A thermal resistance of 0.91 Btu/ hr·ft^{2}·^{o}F (0.16 W/m^{2} K) was selected for stud air cavities.

Voids in the masonry, brick veneer and concrete block, for the catalogue details could experience a larger range of cavity temperatures than for a steel stud cavity, since the masonry in the catalogue details are claddings and back-up walls intended for cold or hot weather conditions. Nevertheless, the difference is still lower than the variability of concrete thermal conductivities and not significant to the overall results. A thermal resistance of 0.91 Btu/ hr·ft^{2}·^{o}F (0.16 W/m^{2} K) was selected for voids in masonry.

Air cavities in the glazing assemblies were modeled using the procedures in ISO 10077-2:2003 (E) using the assumption ΔT = 10^{o}C (18^{o}F) and T_m = 10^{o}C (50^{o}F).

[16] This holds true for this project even though the TMG solver has the capability to simulate temperature dependent materials and fully account for radiation between surfaces dependent on view factors, shadowing, and differing surfaces emittances.

5.1.5 Boundary Conditions

The surface conductances of building envelope components depend on the convective and radiative heat transfer to the exterior or interior environment. Accordingly, values vary by many factors: surface emittance, temperature difference across the component or between surfaces, surface view to surrounding bodies, temperature of bodies in view, and convection variances due to geometry. Nevertheless, calibration completed for this project and ISO standards (ISO 10211-2007) acknowledge that constant heat transfer coefficients can be applied to entire surfaces to yield accurate predictions of U-values of building envelope components. The values selected for this project are based on values presented in Table 1, chapter 26, of the 2009 ASHRAE Handbook – Fundamentals and were applied consistently between details. Table 5.2 summarizes the heat transfer coefficients applied to all the details for this project.

Table 5.2: Heat Transfer Coefficients at Interior and Exterior Air for Opaque Building Envelope Components[17]

Location	Description of Condition	**Heat Transfer Coefficient** Btu/h·ft^2·^{o}F (W/m^2 K)
Exterior wall surface with generic cladding	Heat transfer coefficient to account for vented air space and cladding; surface is not directly exposed to wind	1.5 (8.3)
Exterior brick veneer and Precast Concrete surface	Surface exposed to 15 mph (24 km/h) wind	6.0 (34)
Exterior roof surface	Horizontal roof surface exposed to 15 mph (24 km/h) wind	6.0 (34)
Interior wall surface	Vertical surface exposed to indoor air and surfaces	1.5 (8.3)
Interior ceiling surface	Horizontal surface exposed to indoor air and surfaces with upward heat flow	1.6 (9.3)
Interior floor surface	Horizontal surface exposed to indoor air and surface with downward heat flow	1.1 (6.1)

Selecting heat transfer coefficients for accurate calculations can be a challenge for components where a large percentage of the overall thermal resistance is the surface resistance. However, the thermal performance data of insulated **opaque** building envelope components is the primary output of this project. There are details included in the catalogue with transition to glazing systems; thermally broken aluminum punched window and conventional curtain wall system. The heat transfer coefficients specific to glazing systems for interior surfaces were incorporated into

[17] Including the effects of radiation and convection as outlined in Table 1, chapter 26, of the 2009 ASHRAE Handbook – Fundamentals and the assumptions in Table 5.2

the modeling as summarized in Table 5.3. These coefficients are based on values suggested by Annex B of ISO 10077-2 and confirmed by the centre of glass calculations by WINDOW 5 (LBNL 2005) for double glazed window with ½ inch (13mm) air space.

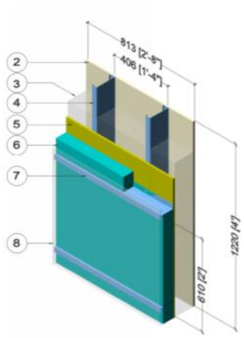
Table 5.3: Heat Transfer Coefficients for Glazing Components

Location	**Description of Condition**	**Heat Transfer Coefficient** Btu/h·ft^2·^{o}F (W/m^2 K)
Exterior surfaces	Surface exposed to 15 mph (24 km/h) wind	6.0 (34)
Interior centre of glass	Based on surface temperature of glass in view with surfaces at 70^{o}F (21^{o}C) and Δ70^{o}F (Δ39^{o}C) across the assembly	1.3 (7.5)
Interior edge of glass	Reduced radiation and convection in edges or junction between two surfaces, applied to a distance of 30 mm from sight line	0.9 (5.0)
Horizontal frame surface	Reduced radiation and convection in edges or junction between two surfaces	0.9 (5.0)
Vertical frame surface	Aluminum frame exposed to indoor air and surfaces	1.3 (7.5)

Boundary temperatures were applied to create a unit temperature difference across the assembly. The generic simulated results are not dependent on the absolute air temperatures because the selected materials are defined as constant values, independent of temperature. Furthermore, the results are calculated and presented in a format allowing the thermal performance data to be applied to both cold and hot design conditions as discussed in the following sections.

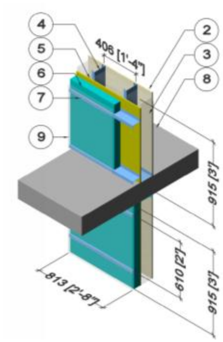
5.2 Thermal Transmittance

The basis of calculation and reporting of thermal transmittances is established by three categories of thermal anomalies as summarized below.



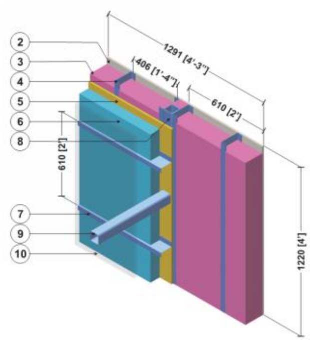
Clear Field Anomalies – thermal bridges uniformly distributed by a sufficient amount such that they can be assumed to modify the thermal transmittance of the assembly and are considered not practical to account for on an individual basis for whole building calculations.

Examples are brick ties, girts supporting cladding, and structural framing. A steel stud assembly with horizontal z-girts is shown to the left as an example.



Linear Anomalies – thermal bridges that are continuous and/or uniformly distributed typically along a considerable portion of a building perimeter or height in one dimension.

Examples are shelf angles, slab edges, balconies, corner framing, parapets, and window interfaces. A steel stud assembly with a structural concrete slab bypassing the wall assembly is shown to the left as an example.



Point Anomalies – thermal bridges that are countable points and are considered feasible to account for on an individual basis for whole building calculations.

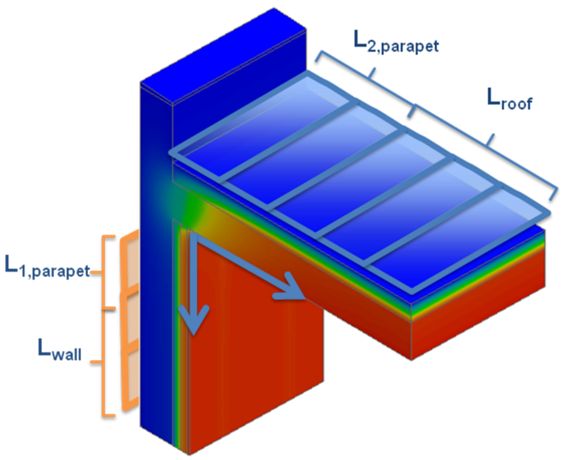
Examples are three way corners, structural steel penetrations through insulation, ducts. A steel stud assembly with a structural steel beam (to support a canopy, sign, etc.) bypassing the wall assembly thermal insulation is shown to the left as example.

For each thermal anomaly (slab, shelf angle, parapet, beam, etc.) the thermal transmittance for the whole assembly (U-value) was compared to the thermal transmittance without the thermal anomaly (clear field value, U_o).

Thermal transmittances were simulated using steady-state boundary conditions, constant material properties, and contact resistances as discussed in previous sections. Reported thermal transmittances are air-to-air values in order to provide consistent values that are not dependent on three-dimensional surface temperatures, i.e. surface resistances are included in the U-values as outlined in the previous section.

Currently, it is common practice in North America to calculate the overall thermal transmittance of the building envelope, including multiple assemblies (walls, windows, roofs, floors types), using an area weighted average approach. This approach works reasonably well when dealing with clear field and entire assembly U-values with easily defined areas; but, solely using a weighted area method for generic thermal anomalies passing through an assembly using a standard framework can be problematic. The difficulty is that assigning "effective" lengths (or areas) to complex three-dimensional heat flow paths is an arbitrary or unnecessarily complex process when considering all scenarios. Utilizing linear and point thermal transmittances is uncomplicated and well suited to quantify all thermal anomalies that interrupt clear field assemblies. Linear and point transmittances are discussed in more detail later in this section. First, a discussion about the drawbacks of assigning and utilizing "effective" lengths (or areas) for the thermal performance catalogue and why this information has not been provided in the result-data-sheets follows below.

The effective length is the distance from a thermal anomaly where the clear field heat flow is essentially not affected by the anomaly or the heat flow through the exterior/ interior surface is close to the clear field heat flow. Effective lengths were assessed by comparing the heat flow through projected areas of the interior and exterior surfaces at varying distances away from the thermal anomaly to the clear field heat flow. A target of between 1 to 2% difference between U-values was selected as the benchmark distance where the thermal anomaly has a negligible effect on the assembly heat flow. The following figure and table illustrate the procedures for calculating the effective length of a parapet thermal anomaly for the wall portion of the assembly.



$U_{o,wall}$ = 0.074 Btu/ft²·hr·°F(0.42 W/m² K)
$U_{o,roof}$ = 0.048 Btu/ft²·hr·°F (0.27 W/m² K)
$U_{assembly}$ = 0.113 Btu/ft²·hr·°F (0.64 W/m² K)

Figure 5.1: Calculation of Effective Lengths for a Parapet Thermal Anomaly

Table 5.4: Effective Length of a Parapet Thermal Anomaly Affecting the Wall Clear Field using the Interior Surface Heat Flow

$L_{1,parapet}$[18] inch (mm)	L_{wall} inch (mm)	A ft² (m²)	Q Btu/hr (W)	U Btu/ft²·hr·°F (W/m²K)	% Diff
1.5 (38)	46.5 (1182)	10.34 (0.961)	1.48 (0.432)	0.079 (0.450)	-6.4%
2.4 (62)	45.4 (1153)	10.10 (0.938)	1.41 (0.413)	0.078 (0.441)	-4.3%
3.7 (94)	44.3 (1125)	9.85 (0.915)	1.36 (0.398)	0.077 (0.435)	-3.1%
5.4 (136)	42.6 (1083)	9.48 (0.881)	1.29 (0.379)	0.076 (0.430)	-1.9%
7.0 (179)	41.0 (1041)	9.11 (0.846)	1.23 (0.361)	0.075 (0.427)	-1.2%
8.2 (207)	39.9 (1013)	8.86 (0.823)	1.20 (0.351)	0.075 (0.426)	-0.9%
9.8 (249)	38.2 (971)	8.49 (0.789)	1.14 (0.335)	0.075 (0.424)	-0.5%
11.5 (291)	36.5 (928)	8.13 (0.755)	1.09 (0.319)	0.074 (0.423)	-0.3%
13.1 (333)	34.9 (886)	7.75 (0.720)	1.04 (0.304)	0.074 (0.423)	-0.1%
14.8 (376)	33.2 (844)	7.38 (0.686)	0.99 (0.290)	0.074 (0.422)	0.0%

The procedure appears simple enough for a parapet thermal anomaly with an interior insulated wall assembly with only vertical thermal bridges (studs) and when using the heat flow through the interior surface. However, the process gets complicated when the same procedure is applied to the exterior insulated roof assembly for the same parapet thermal anomaly. The effective length for the roof portion of the parapet is almost 1400 mm (55 inches) using the interior surface heat flows. In contrast, the effective length using the exterior surface heat flows is approximately 700 mm (26 inches). A similar, but reversed, difference is evident with the wall assembly; an effective length of approximately 200 mm (8 inches) is calculated using the interior surface heat flow compared to an effective length of approximately 850 mm (33 inches) using the exterior surface heat flow. The reason for this difference is that the concrete is highly conductive compared to the thermal insulation; therefore, there is significant lateral heat flow through the concrete to/from the concrete parapet thermal anomaly. The effect of the lateral heat through the concrete of the roof and wall sections is illustrated in Figures 5.2 and 5.3 by plotting the heat flow through control areas at varying distances from the parapet thermal anomaly.

[18] Distance along roof from interior surface of wall

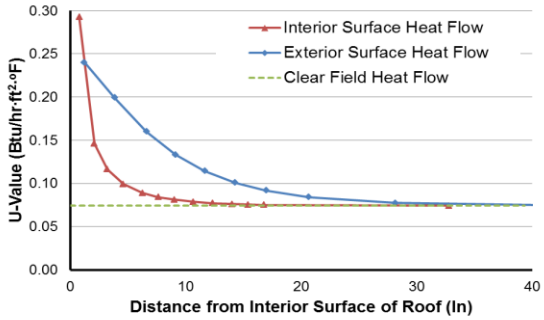


Figure 5.2.a: Wall Heat Flow Through Control Areas for Parapet Thermal Anomaly (I-P Units)

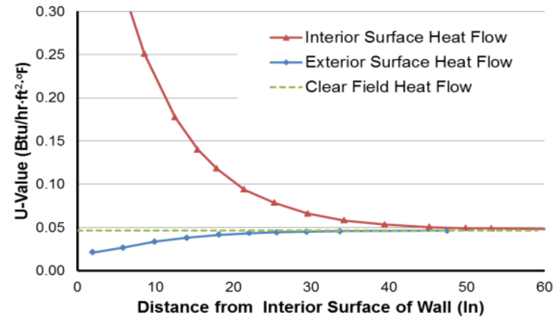


Figure 5.3.a: Roof Heat Flow Through Control Areas for Parapet Thermal Anomaly (I-P Units)

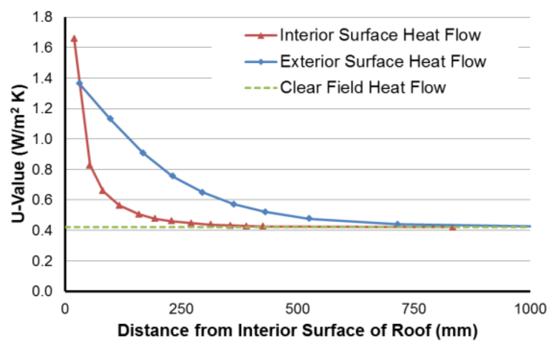


Figure 5.2.b: Wall Heat Flow Through Control Areas for Parapet Thermal Anomaly (SI Units)

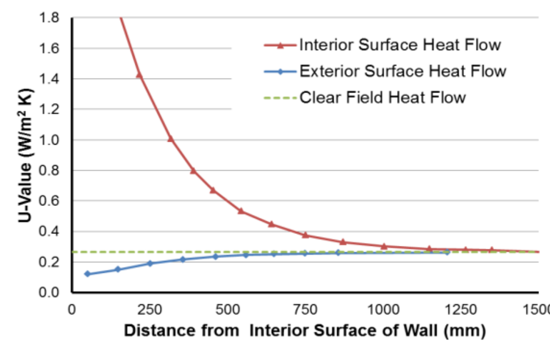
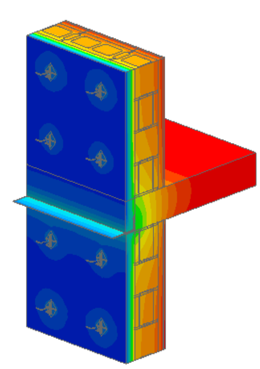


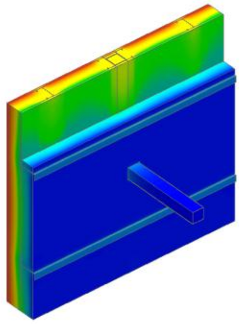
Figure 5.3.b: Roof Heat Flow Through Control Areas for Parapet Thermal Anomaly (SI Units)

The interior surface typically defines the boundary of zones for building load calculations; for this reason it is desirable to determine effective lengths using the interior surface heat flows as is customarily the procedure. However, the parapet example above shows how assigning the effective length based on the interior surface heat flow alone will not determine values meeting a consistent definition of effective length. Nevertheless, the parapet example above contains sections where the heat flow is essentially one-dimensional, the heat flow at the interior surface is equal to the exterior surface, and therefore it is feasible to devise a standard method to determine effective lengths by comparing the interior and exterior surface heat flows.



However, the same procedure does not work well for assemblies where the clear field contains complex three-dimensional heat flow paths.

For a slab edge condition (exposed concrete or shelf angle) with an exterior insulated assembly and steel passing through the insulation parallel to the slab (brick ties or horizontal girts); the heat flow through the exterior surface of the wall cladding is not affected much by the slab edge thermal anomaly. Conversely, heat can more easily flow through



the back-up wall (steel stud or concrete block) into the slab than through the exterior insulation; therefore, the slab edge thermal anomaly influences the heat flow through the interior surface. The three-dimensional heat flow paths for this example causes more flow, on average, through the interior surface than compared to the exterior surface and the heat flow does not converge to an equal heat flow for the interior and exterior surfaces as illustrated in Figures 5.2 and 5.3. Ultimately the only logical location to assign an effective length for these assemblies is between the thermal bridges bypassing the exterior insulation. When there are multiple thermal bridges bypassing the thermal insulation, assigning effective lengths and utilizing the area-weighted average method can get really awkward. For example, defining the effective area for a steel post and beam contained in a steel stud assembly with horizontal z-girts supporting the metal cladding is either a very challenging or arbitrary process and using this information with the area-weighted average method for whole building load calculations is tedious.

This work highlights a few major drawbacks for using the area-weighted average method to account for thermal anomalies contained within opaque building envelope assemblies:

1. Assigning effective areas to three-dimensional heat flow paths can be a complex procedure; judgment must be exercised and consistency is difficult to achieve.

2. A catalogue of effective lengths specific to simulated details and U-values is undesirable.

3. Utilizing the area-weighted average method to account for all the significant thermal anomalies of typical buildings is a tedious process at best.

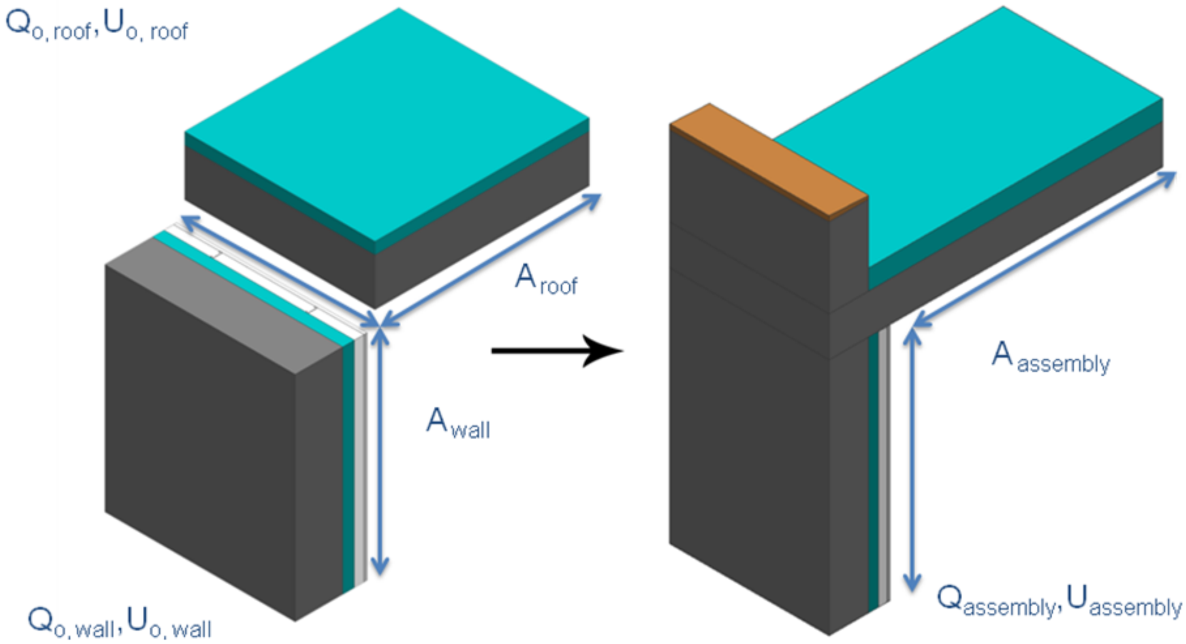
These drawbacks can be partially overcome by setting standard effective lengths for groups of anomalies. However, this simplification leads to the assigned value being at least partly arbitrary without any true significance. This leads to the concept of linear and point transmittances to overcome these drawbacks.

First, one has to accept that there cannot be effective lengths specific to each simulated detail and simplifications are necessary for a generic thermal performance catalogue to be useful for practitioners. The effective length might as well be zero.

Second, one has to be open to the idea of letting go of the area-weighted average method, at least for thermal anomalies contained within opaque building envelope assemblies, if another method provides the same end result but with a lot less effort.

The concept of linear and point thermal transmittances (Ψ or χ respectively) is quite simple. The heat flow through an assembly with a thermal anomaly is compared to the same assembly without the thermal anomaly for the same gross area. The difference in magnitude of the heat flow is attributed to the effect the thermal anomaly has on the clear field assembly. For whole building load calculations, the linear and point transmittances is simply added to the clear value U-value for a given total assembly area (wall/roof) to calculate the overall thermal transmittance. Splitting the total assembly area into areas affected by individual thermal anomalies and clear field areas is not necessary.

Next is a summary and illustration of the procedures to calculate linear transmittances for this project, using a parapet as an example. Point transmittances follow a similar process. These procedures are loosely based on European literature and standards (Anderson 2006, ISO 10211: 2007 (E)).



1. Simulate the clear field assemblies to find the individual clear field transmittances, $U_{o,\ wall}$, $U_{o,\ roof}$ (Btu/h·ft^2·^{o}F or W/m^2 K).

2. Calculate the individual clear field heat losses, $Q_{o,\ wall}$, $Q_{o,\ roof}$ (Btu/h·^{o}F or W/ K) for the assembly using the previously found clear field U-values.

3. Calculate the overall clear field transmittance, $U_{o,} = (Q_{o,\ wall} + Q_{o,\ roof})/\ A_{total}$ (Btu/h·ft^2·^{o}F or W/m^2 K). A_{total} is the total projected surface area (ft^2 or m^2). This step is not necessary if the thermal anomaly is contained within a single assembly.

4. Simulate a section that contains a length of the linear thermal anomaly and a good portion of clear field assemblies on each side. This can be ensured by selecting cut-off planes as described in Section 5.1.1.

5. Calculate the assembly transmittance with the thermal anomaly, U (Btu/h·ft^2·^{o}F or W/m^2 K)

6. Verify that the clear field transmittances are contained on either side of the thermal anomaly by following the analysis illustrated in Figure 5.1 and Table 5.4.

7. The difference between the simulated total heat flow and overall clear field heat flow for a set area is the heat flow that is ascribed to the linear transmittance. Equations summarizing the procedures follow.

The linear and point thermal transmittances are determined by the following equations using data from the simulated details.

$$\Psi = \frac{(Q - Q_0)}{L} = (U - U_o) \cdot \frac{A_{total}}{L} \qquad \text{Eq (1)}$$

$$\chi = (Q - Q_o) = (U - U_o) \cdot A_{total} \qquad \text{Eq (2)}$$

Where

Ψ is the linear thermal transmittance (Btu/h ft ^{o}F or W/m K)

χ is the point thermal transmittance (Btu/h ^{o}F or W/K)

Q is the assembly heat flow with the thermal anomaly for A_{total} (Btu/h ^{o}F or W/ K)

U is the assembly U-value with the thermal anomaly (Btu/h ft^2 ^{o}F or W/m^2 K)

Q_o is the assembly heat flow without the thermal anomaly for A_{total} (Btu/h ^{o}F or W/ K)

U_o is the assembly U-value without the thermal anomaly (Btu/h ft^2 ^{o}F or W/m^2 K)

A_{total} is the total projected surface area (ft^2 or m^2)

More discussion about using linear and point thermal transmittances in practice can be found in Section 7 entitled Utilization.

As discussed in the material property section, Appendix E, several increments of insulation thermal resistance of the exterior insulated assemblies were evaluated in a generic manner to capture different types of insulation and thickness. The thermal transmittance was calculated for increments of R5 to R25 (Btu/h ft^2 ^{o}F, 0.88 to 4.4 W/m^2 K) nominal thermal insulation. The results are presented in Appendix F in terms of nominal and assembly effective R-values to illustrate the impact of diminishing returns.

5.3 Indexed Surface Temperatures

The intent of the indexed surface temperatures is to provide designers a means for an approximation of surfaces temperatures due to average steady-state conductive heat flow in three-dimensions. These surface temperatures can be used for a quick evaluation of condensation resistance and target any potential problem areas. Evaluating the condensation resistance using dew-point methods and surface temperatures limited to steady-state conductive heat flow requires a full awareness of the limitations and should not be the sole basis for hygrothermal design of opaque building envelope assemblies.

Limitations of Evaluating Condensation Resistance using Steady-state Indexed Surface Temperatures

The indexed surface temperatures provided as part of this project are due to average steady-state conductive heat flow.

Users are cautioned to recognize that surface temperature is effected by heat and moisture storage effects, air transport, and localized variations (for example screws, localized surface resistance variations, and moisture variations, etc.), which were not modeled as part of ASHRAE 1365-RP.

Some designers and codes employ dew-point methods using uniform and steady-state conditions similar to the procedures outlined in this project; therefore, there is value for indexed surface temperatures in a catalogue of thermal performance data for building envelope details. The temperature indices can be used to target areas where the risk of condensation does not appear to

Limitations of Evaluating Condensation Resistance using Steady-state Indexed Surface Temperatures

be effectively minimized, while still considering and maintaining full awareness of the limitations stated above.

A broad discussion on the limitations of dew-point methods and other hygrothermal analysis methods is provided in the 2009 ASHRAE Handbook – Fundamentals.

Indexed surfaces temperatures are calculated as follows:

$$T_i = \frac{T_{surface} - T_{outsdie}}{T_{inside} - T_{outside}} \qquad \text{Eq (3)}$$

Where

T_i is the temperature index (-)
$T_{surface}$ is the coldest temperature of the surface
$T_{outisde}$ is the outdoor temperature
T_{inside} is the indoor temperature

Surface temperatures presented using temperature indices allow the surface temperatures to be applicable to any set of indoor and outdoor conditions. A temperature index of zero is the outdoor air temperature and a temperature index of one is the indoor air temperature.

Maximum and minimum indexed surface temperatures are provided at concealed cavity surfaces, as well as at other points of interest (e.g. lowest temperature on window framing or floor surface) depending on the detail. Multiple temperatures indices, dependent on the insulation thermal resistance, are provided for the exterior insulated steel stud assemblies. Colour isothermal plots are provided to illustrate the temperature indices variations viewed from the interior and exterior.

Limitations of Evaluating Condensation Resistance using Steady-state Indexed Surface Temperatures Continued

Temperature indices on the glazing systems are provided to facilitate evaluation of the opaque assemblies because windows are often the most vulnerable to condensation and demonstrate the relative risk. The intent is not to evaluate the glazing systems and the temperatures should not be perceived as absolute. Actual surface temperatures of windows are not only highly dependent on surface resistances but many other factors such as positioning within the opening, coatings, spacers, etc. The effects of these factors on the glazing thermal performance are not part of the scope of this project.

5.4 Dynamic Thermal Response

There are numerous approaches advocated and available data, with varying accuracy and complexity, to estimate the transient or dynamic thermal response of the building envelope for building load calculations and whole building energy simulations (Stephenson et al 1971, Brown et al 1991, Spitler et al 1999, Kemp et al 2001, Kossecka et al 2004, Iu et al 2004, Duska et al 2006, ASHRAE Handbook – Fundamentals 2009).

Z-transfer function coefficients can be determined using the same multi-dimensional numerical models used to calculate the steady-state U-values and be effectively used in whole building simulation software as shown by ASHRAE RP-1145 (Kemp et al 2001, Kossecka et al 2004). However, evaluation of the dynamic thermal response of the catalogue details was not part of the scope of work for ASHRAE RP-1365.

Z-transfer function coefficients for the multi-dimensional details included in ASHRAE RP-1365 can be considered in future ASHRAE projects to extend the collective building envelope thermal performance design catalogue. Though this additional data might be desirable for some groups; the dynamic building envelope response can probably be sufficiently approximated for most practical objectives using one of the methods and data referenced in the current 2009 ASHRAE Handbook – Fundamentals.

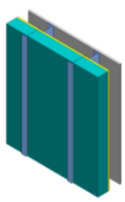
6. SIMULATION RESULTS

The thermal performance data of the 40 building envelope details are summarized in simulation results data sheets found in Appendix F.   A summary of the simulation results follow.

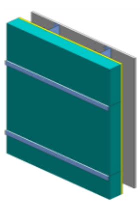
6.1 Thermal Transmittance

6.1.1 Exterior Insulated Steel Stud Assemblies Clear Field

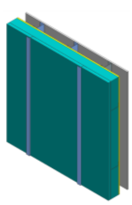
Details 1-4 are all exterior insulated steel stud walls with various cladding attachments. Detail 11 is an exterior and interior insulated steel stud wall assembly with the same cladding attachment as Detail 2. For each case, the exterior insulation was varied between R-5 and R-25 Btu/h·ft^2·°F (0.88 to 4.4 W/m^2 K). Detail 2 and Detail 11 are the clear wall values that form the basis of many of the other subsequent details.



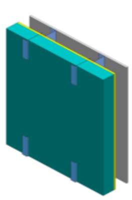
Detail 1 contains vertical z-girts. The thermal resistance of this system is between 78-43% effective compared to the nominal (1D) values for exterior insulations between R-5 to R-25. This configuration is thermally weakest of the clear field exterior insulated steel stud assemblies (Details 1 to 4), since the highly conductive vertical girts and the steel studs are in line with each other. This creates a direct thermal bridge across the entire assembly.



Detail 2 contains horizontal z-girts, which intersect with the steel studs at finite points. The thermal resistance for the horizontal girt system is between 83-52% effective compared to the nominal (1D) values with exterior insulation of R-5 to R-25. This system is a 6-21% improvement over the vertical z-girt system for the same amount of exterior insulation in the range of R-5 to R-25 as illustrated in Figure 6.1.



Detail 3 is a combined vertical and horizontal z-girt system, with R-5 insulation between the vertical girts at the exterior. The vertical girts are attached to the horizontal z-girts with insulation ranging from R-5 to R-25 and the horizontal girts are attached to the steel stud back-up wall. The thermal resistance for this assembly varies between 80-57% effective compared to the nominal (1D) values with exterior insulation of R-10 to R-30 (1.76 to 5.3 W/m^2 K).   This system provides a 25 to 43% improvement over the vertical z-girt system and an 11 to 19% improvement over the horizontal z-girt system for the same amount of exterior insulation in the range of R-10 to R-25 as illustrated in Figure 6.1.



Detail 4 has intermittently spaced vertical girts. For 12 inch spacing between girts, the thermal resistance is between 86-57% effective compared to the nominal (1D) values with exterior insulation of R-5 to R-25. When the spacing is doubled to 24 inches, the resistance is between 90-66% effective. For the largest simulated spacing, 36 inches, the thermal resistance is 92-73% effective. These results show that increasing the vertical girt spacing beyond 24 inches has little effect for low insulations levels; however, it has a better effective value than the smaller spacing as the insulation level increases.

Assembly effective thermal resistance and transmittance comparisons for the Details 1-4 are shown in the following figures. Adding insulation has diminishing rates of return for all the systems as illustrated in Figure 6.1.

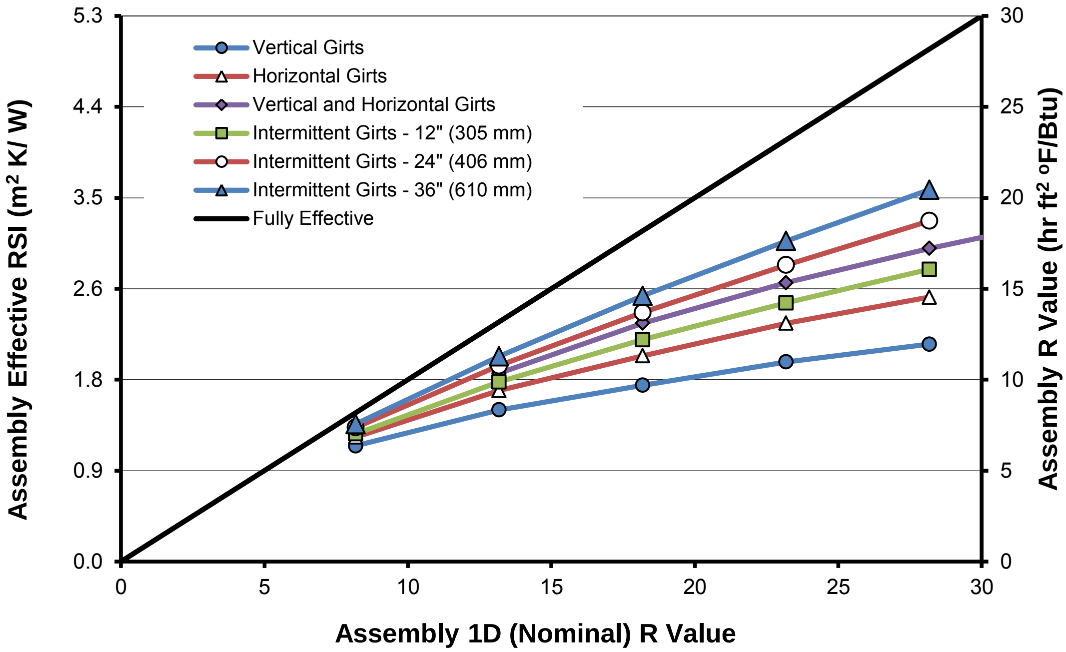


Figure 6.1: Comparison of Effective and Nominal R-values for Details 1-4

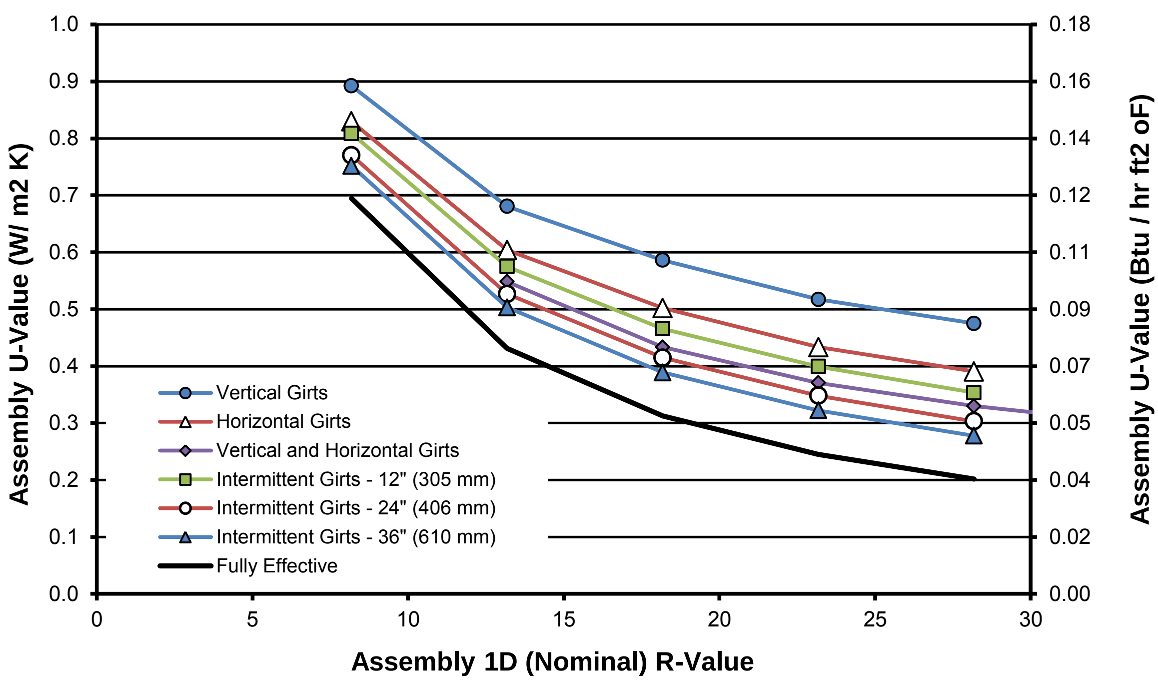
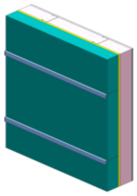


Figure 6.2: Comparison of U-values for Details 1-4



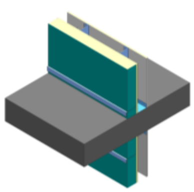
Detail 11 is a variation of Detail 2, with fiberglass batt insulation in the stud cavity. The studs have much more effect with this configuration, especially at low exterior insulations. The thermal resistance is between 70-56% effective compared to the total nominal (1D) thermal resistance of insulation provided in the system, R-12 (2.1 RSI) batt plus R-5 to R-25 exterior insulation.

Several other clear field values were found for different types of assemblies (concrete walls, precast etc.); however, they were not considered separate details for this project. These clear field values can be found within the result sheets in Appendix F as base assemblies. The same effective thermal resistance comparisons to nominal (1D) values can be inferred from that data.

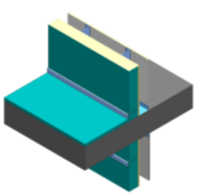
6.1.2 Slab and Floor Edges

Details 5, 5a and 6 are variations of the horizontal girt assembly in Detail 2 with a slab intersection cutting through the wall assembly. From this point, the details are compared to the clear wall values in order to illustrate the effect that the linear and point anomalies alone have on the system.

Detail 6 is an un-insulated slab and the wall was simulated for three exterior insulation levels; R-5, R-15 and R-25. Detail 5 contains varying lengths of insulation on the exterior top of slab and Detail 5a contains insulation on both top and bottom of slab. For Details 5 and 5a, an exterior insulation of R-15 for the wall assembly exterior insulation was simulated for varying lengths of slab insulation; 0, 0.2, 0.4 and 0.8 m from the wall.

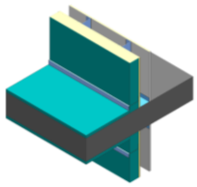


Detail 6[19] shows the significant effect that an un-insulated slab has on the heat loss through a wall assembly. For a 3.1 m (10 ft) high wall and exterior insulation in the range of R-5 to R-25, by adding a slab, the assembly thermal transmittance is increased 29-60% compared to the 'clear wall' values.



Detail 5 shows that insulating the top of the slab can reduce the heat loss from the slab. Extending the insulation 0.4 m (1.3 ft) out from the wall reduces the linear transmittance by about 12% compared to Detail 6, without any extra slab insulation. For a 3.1 m (10 ft) wall, this decreases the overall thermal transmittance by about 4% compared to no slab insulation. Increasing the length of insulation away from the wall has essentially a minimal affect after 0.4 m (1.3 ft)

[19] In each case the slab was extended 1 m (3.3 ft) from the wall. Illustrations shown in the text have been cut off for visual purposes.



Detail 5a shows that providing both top and bottom slab insulation is more effective than insulating only one side. Extending the insulation 0.4 m (2.6 ft) out from the wall reduces the linear transmittance by 36% compared to an un-insulated slab. For a 3.1 m (10 ft) wall, this decreases the overall thermal transmittance by 11% compared to no slab insulation. Increasing the insulation distance can still have a slight effect on heat loss reduction after 0.4 m (1.3 ft), but the most gains are made at this length.

Comparing the Details 5 and 5a, it can be seen that insulating both the top and bottom of the slab by a small amount is more effective than insulating only one side with more insulation. Insulating the top and bottom by only 0.2 m (0.7 ft) has a similar thermal impact as insulating just the top by over 0.8 m (2.6 ft).

For many of the details with slab edge thermal anomalies (concrete slab or shelf angle) the linear transmittance does not strictly decrease with increasing exterior insulation, as observed in other thermal anomalies. For Detail 6, the linear transmittance increases from R-5 to R-15, then decreases from R-15 to R-25. This can be explained by looking at the various heat flow paths through the assembly.

The major heat flow paths for an exterior insulated steel stud assembly with horizontal girts for cladding attachment are show in Figures 6.3, 6.4 and 6.5. For this assembly, there are three major paths to the exterior: 1) through the exterior insulation, 2) through the z-girts, 3) through the slab. Each of the paths has materials with different magnitudes of thermal conductivity and overall thermal resistance, which affect the quantity of heat flow through each path.

For an R-5 exterior insulated steel stud assembly, shown in Figure 6.3, the wall does not have much thermal resistance and heat can flow through the wall as easily as each of the other two principal heat flow paths. The thickness of the insulation is small and there is not much shared surface area between components, so there is not much lateral heat flow through the insulation, via the slab and girts.

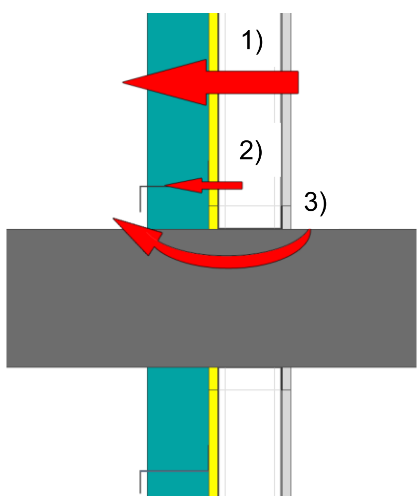


Figure 6.3 Heat Flow Paths for an R-5 Exterior Insulated Steel Stud Assembly

As the exterior insulation increases to R-15, shown in Figure 6.4, the resistance to heat transfer has increased through the wall assembly (path 1). This causes more lateral heat to flow through the lower resistance paths, girts (path 2) and slab (path 3); since the slab and z-girts have effectively not changed in thermal resistance but the relative thermal resistance of the insulation has increased. The increased lateral heat flow cancels out the gain in thermal resistance through path 1 and the linear transmittance is raised for this incremental increase in insulation.

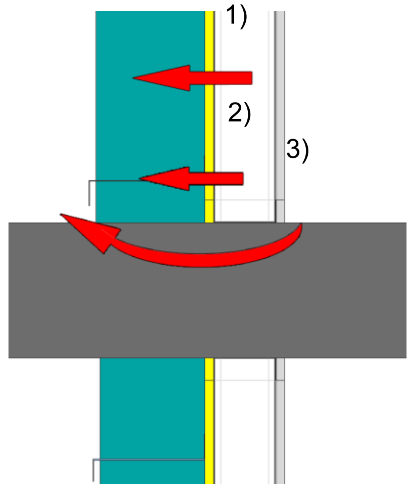


Figure 6.4 Heat Flow Paths for R-15

When the exterior insulation is further increased to R-25, shown in Figure 6.5, there is very little heat flow through path 1. As the heat flow becomes smaller through the insulation, the temperature gradient across it becomes greater, and proportionally there is more heat flow through the z-girts. The thermal resistance of the slab remains essentially unchanged for this increment in insulation; but, the relative change in thermal resistance in the insulation is not totally offset by increased lateral heat flow through the slab. Consequently the linear transmittance decreases because the increase in heat flow through the slab detail does not increase proportionally to the decrease in the clear field heat flow.

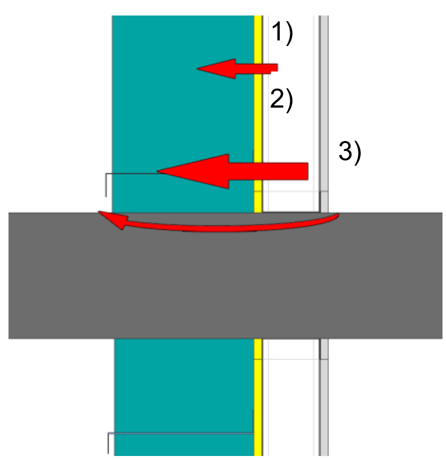
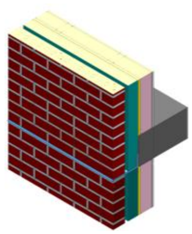


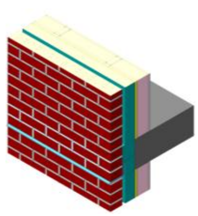
Figure 6.5 Heat Flow Paths for R-25

When analyzing solely on the overall thermal resistance and transmittance values, the proportional differences in heat flow paths are blended into the total heat loss, and are not as noticeable when analyzing trends. The heat loss through the thermal anomaly is compared to clear field heat flow when deriving linear transmittances; therefore, proportional differences between heat flow paths can become apparent.

Details 14 and 15 are brick veneer assemblies with interior and exterior insulation at a slab intersection. The difference between the details is the type of shelf angle and slab edge condition. Detail 14 has a shelf angle bolted directly to the concrete slab with insulation outboard of the angle, but the angle bypasses the insulation continuously. Detail 15 has a smaller shelf angle attached to the slab by knife edges with insulation between the angle and slab and only bypassed by the intermittent supports. The differences in the thermal bridges at the slab, heat flow path, result in different trends in linear transmittance.

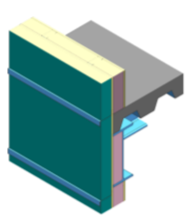


Detail 14 shows how the linear transmittance increases with increasing exterior insulation to R-15, then decreases as seen for Details 5 and 6. The increase in linear transmittance is a result of the proportion of heat flow through the wall insulation decreasing compared to an increase in flow through the slab. The decrease in linear resistance is a result of heat flow through the slab increasing proportionally by a smaller margin than the clear field value for the same increment in exterior insulation. For a 3.1 m (10 ft) high wall and exterior insulation in the range of R-5 to R-25, the shelf angle and slab increase the assembly thermal transmittance by 37-70% compared to the ‘clear wall’ values.



Detail 15 has a spaced shelf angle that is much better insulated and is more disconnected from the exterior and has similar heat flow paths at the slab as the wall assembly. The brick-ties and shelf-angle supports bypass the insulation in a similar way. The linear transmittance decreases as more insulation is provided outboard of the slab and there is no bump because the proportional heat flow paths remain fairly constant. For a 3.1 m (10 ft) high wall and exterior insulation in the range of R-5 to R-25, the spaced shelf angle and slab increase the assembly thermal transmittance by 30-41% compared to the ‘clear wall’ values.

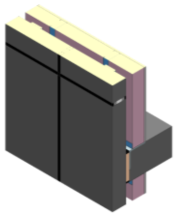
Details 16 and 17 are floor slab thermal anomalies of the interior and exterior insulated stud wall assembly clear wall (Detail 11).



Details 16 and 17 have a corrugated slab and I-beam intersection, however these do not cut through the exterior insulation and linear transmittance decreases with the increasing exterior insulation similar to Detail 15.

For a 3.05m (10 ft) high wall and for R-5 to R-25 exterior insulation, the slab increases the thermal transmittance of the assembly by between 24-15% compared to the clear wall values with R-5 to R-25 exterior insulation.

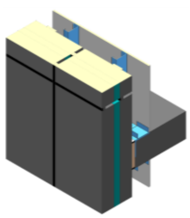
Details 28 and 29 are precast panels with different interior insulation scenarios. Detail 28 has rigid insulation outboard of the studs and an un-insulated stud cavity. Detail 29 has air between the concrete and studs with fiberglass batt in the stud cavity.



Even though the fiberglass batt assembly has a higher nominal (1D) value, the rigid outboard assembly is much more thermally effective as established by the difference in clear wall values. This same inefficiency is observed in the linear transmittance values, with the ψ value for the assembly with continuous insulation (Detail 28) being lower than the assembly with batt insulation interrupted by studs (Detail 29). For Detail 28, for a 3.1m (10 ft) pre-cast wall, adding a slab increases the thermal transmittance of the assembly by 26% compared to the 'clear wall' value. For Detail 29, the slab increases the thermal transmittance by 24%.

Note that the caulked panel joints had a very small effect on the thermal performance and could have been ignored.

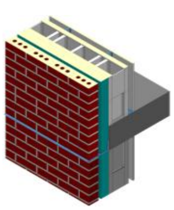
Detail 32 is a precast sandwich panel, with insulation between two concrete wythes, and an un-insulated interior stud cavity to support the interior drywall.



Compared to Details 28 and 29, the linear transmittance is lower but the caulked panel joints do have an impact. The lower linear transmittance is because there is 50 mm (2 inches) of continuous insulation at the slab for the sandwich panel compared to only 25 mm (1 inch) fire-stop insulation for the pre-cast assemblies. For a 3.1m (10 ft) high wall, the thermal transmittance of the assembly is increased by 15% by adding a slab, compared to the 'clear wall' value.

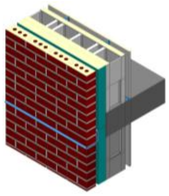
The panel joints have an effect for the simulated sandwich panels because the insulation is not continuous at the panel joints. The panel edge linear transmittance has been included in the sandwich panel result sheets in Appendix F. To find the effects of the edges, the panel perimeter should be used as the length. This allows for the edge effects of varying sizes of panels to be calculated.

Details 35 and 36 are brick veneer wall assemblies with concrete block back-up walls at a slab intersection with shelf angles. The shelf angles are comparable to Details 14 and 15. The only difference between Details 14 and 35 and Details 15 and 36 is the construction of the back-up wall.



Details 15 and 36 compare very favorably for linear transmittances; except for low levels of exterior insulation. For exterior insulation levels equal to or greater than R-10, the percent difference between assemblies for the clear field U-values and linear transmittances is less than 4%. There is a significant difference in linear transmittances for exterior insulation levels below R-10. This difference can be attributed to the difference in clear field U-values and the difference in the proportion of lateral heat flow that passes through the back-up wall to either the concrete slab or exterior insulation.

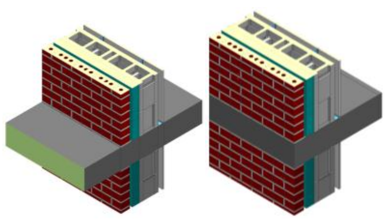
For all the exterior insulation levels there is proportionally more heat flow through the interior wall surface of the concrete block walls compared to the steel stud assemblies. For low levels of exterior insulation, there is proportionally more heat flow through the exterior surface of the wall assembly and less heat flow through the exterior surface at the concrete slab for the concrete block assembly compared to the steel stud assembly.



Details 14 and 35 follow the same trends as Details 15 and 36 respectively with regard to the relative proportions of heat flow through the interior and exterior surfaces. However, there is a greater difference in the relative proportion of heat flow through all surfaces between Details 14 and 35 than for Details 15 and 36, for all levels of exterior insulation.

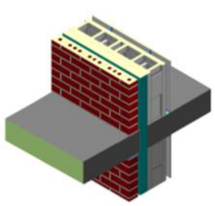
The greater variability seen between Details 14 and 35 can be attributed to the direct connection of the shelf angle and flashing to the concrete slab. Direct attachment of the angle and flashing to the slab results in 10% to 15% of the total heat flow through the exterior surface compared to only 5% to 7% for a shelf angle attached to the slab by knife edges and insulation between the angle and slab. Furthermore, lateral heat flow for the steel stud assembly is more variable than the concrete block assemblies as seen by the greater variability of heat flow proportions through the interior surfaces for the two shelf angle scenarios.

Details 38 and 40 are brick veneer wall assemblies with concrete block back-up walls at a slab intersection with the slab exposed to the exterior. The slab projects 0.8 m (2.5 ft) past the exterior surface of the brick veneer for Detail 38 and is flush to the brick veneer for Detail 40. The clear field walls are the same construction as Details 35 and 36.



The linear transmittance for Details 38 and 40 trends the linear transmittance for Details 35 and 36 well. The linear transmittance and overall heat loss is higher than the shelf angle scenarios. There is a slight difference in the U-value and linear transmittance between the projected and flush slab; but, the two scenarios can be considered effectively the same when utilizing these results in practice.

Detail 39 is a brick veneer wall assembly with a concrete block back-up wall with a concrete balcony slab that is supported by a shelf angle attached to the floor slab by knife edges and has continuous insulation between slabs. The clear field wall and detail has similarities to Details 36 and 38.



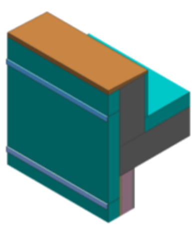
Detail 39 is similar to Detail 36 since both details have a shelf angle attached to the slab by knife edges and insulation between the angle and slab. However, Detail 36 has metal flashing bypassing the thermal insulation, whereas Detail 39 does not have metal flashing. Accordingly, the linear transmittance and overall heat loss for Detail 39 is lower than Detail 36. The similarity between Details 38 and 39 is that both details have projecting slabs; supporting the slab with a shelf angle with knife edges significantly lowers the linear transmittance and overall heat loss.

For the details where the thermal bridges extend to the exterior at a slab edge thermal anomaly, the level of exterior insulation does not have a large effect on the linear transmittance. Therefore, a constant linear transmittance value can be ascribed to each detail when using the thermal performance data in practice. For the details where exterior insulation is continuous outboard of a thermally anomaly, then the linear transmittance is dependent on the level of exterior insulation and this relationship should be accounted for in practice. In Section 6.1.9, the slab transmittances dependencies have been summarized in Tables 6.1, 6.2 and 6.3.

6.1.3 Parapets

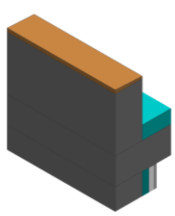
The parapet anomalies are slightly more complicated for utilizing linear transmittances since the detail is an intersection of two assemblies, a wall and roof. The linear transmittance for the parapet anomalies was covered in Section 5.2; a combined clear field U-value must be calculated for the anomaly. Utilizing linear transmittances for parapets is covered in Section 7.

Details 9, 20, 25, 30 and 37 are all exterior insulated roof assemblies intersecting with various wall assemblies. The parapet anomalies have varying insulation strategies and construction.

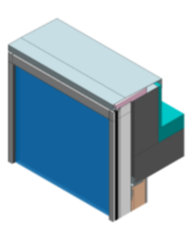


Detail 9 is a variation of the horizontal girt assembly in Detail 2 at an R-5 insulated parapet and R-20 roof intersection. The parapet is insulated on both sides and is similar in behavior to an insulated slab (Detail 6).

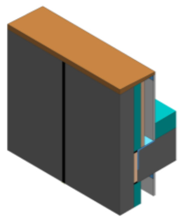
The linear transmittance decreases as the exterior wall insulation increases but the percent variation between R-5 to R-25 insulation is only 7%. A constant linear transmittance can be utilized in practice with reasonable accuracy as summarized in Table 6.1. The detail was simulated using one level of roof and parapet insulation; R-5 for the parapet and R-20 for the roof.



Detail 20 is a mass concrete wall at an un-insulated parapet and R-20 roof intersection. Although continuous insulation can quite easily be achieved for the individual assemblies, the continuous concrete at the parapet allows significant heat flow. Consequently the linear transmittance for this detail is over 60% higher than detail 9.

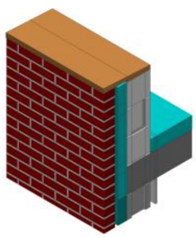


Detail 25 is a spandrel section at an insulated parapet and roof intersection. The detail is insulated similar to Detail 9 with R-5 insulation at the parapet and R-20 provided at the roof. The only major difference is the spandrel section primarily has vertical thermal bridges at the vertical mullions combined with the metal back pan which provide a highly conductive lateral heat flow path. These thermal bridges are significantly larger compared to Detail 9, which has only horizontal z-girts through the exterior insulation. As a result, the linear transmittance is much higher.



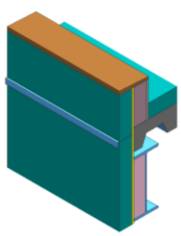
Detail 30 is a precast concrete panel at a steel stud parapet and roof intersection. The stud wall cavity is filled with spray foam, therefore, the plane of insulation from the wall to roof is only interrupted by the steel studs, anchors, and sheathing at the parapet. The insulation levels are R-10 for the wall, R-5 between the slab and panel, and R-20 for the roof.

The linear transmittance is a 35% improvement over the mass concrete wall parapet (Detail 20) but over 15% higher than the exterior insulated steel stud assembly (Detail 9) for the same level of wall and roof insulation.



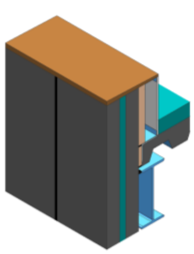
Detail 37 is a brick veneer wall assembly with concrete block back-up wall at a parapet and roof transition. The wall construction is the same as Details 35 to 40. The concrete block at the parapet is un-insulated at the roof and the roof has R-20 insulation.

The linear transmittance for this detail is dependent on the level of exterior wall insulation through the front of the concrete. The linear transmittance for this detail is a 25% improvement over the exterior insulated steel assembly (Detail 9) for R-15 to R-25 levels in exterior insulation. The linear transmittance for Detail 37 is lower than the steel stud assembly even though Detail 9 has R-5 insulation at the inside face of the parapet. The difference can be attributed to the differences in heat flow through thermal bridges bypassing the exterior insulation at the parapet and the resistance of heat flow through the concrete block compared to poured-in-place concrete.



Detail 10 is an exterior insulated stud assembly similar to Detail 9; but, the roof assembly is a composite concrete deck supported by a steel beam and open web steel joists. Furthermore, the steel stud cavities for the wall and parapet have R-12 fiberglass batt insulation.

The higher insulation levels provided in this detail result in as little as 8% to almost 50% improvement in linear transmittance compared to Detail 9 for exterior insulation levels R-5 to R-25.



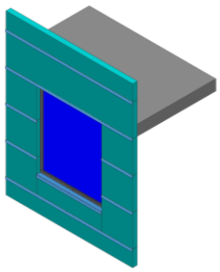
Detail 33 has a similar roof and parapet construction as Detail 10. The wall is a pre-cast sandwich panel with R-10 insulation between the concrete wythes. The inner wythe of the panel provides a significant heat flow path.

The linear transmittance for the detail is a 20% improvement over the mass concrete wall assembly (Detail 20) but is 35% higher than the exterior insulated steel assembly (Detail 9) and 12% higher than the pre-cast concrete panel assembly with a continuous plane of insulation (Detail 30).

As done previously for the slab conditions, in Section 6.1.9, the parapet transmittance dependencies on exterior insulation have been summarized in Tables 6.1, 6.2 and 6.3.

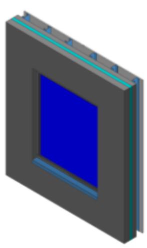
6.1.4 Glazing and Wall Intersections

The following details include transitions of opaque wall sections to aluminum framed glazing assemblies. The first two details are aluminum framed punched windows contained in a wall assembly and the second set of details are transitions from curtain wall spandrel sections to the same wall assemblies.



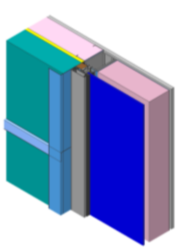
Detail 7 is an exterior insulated steel stud assembly with a floor slab and punched window transition. The linear transmittance for the effect of the slab with and without the window is reported in the result data sheets. The linear transmittance of the floor slab without the window is included in Table 6.2.

As the exterior insulation increases, there is more heat transmission at the wall/window transition and the linear transmittance increases. Note that the point transmittance shown in Appendix F is for this particular window sizing only. If the window was larger or smaller, then this point transmittance would be different. For the wall/window transition, a linear transmittance can be applied using the perimeter as the characteristic length, in order to apply to different window sizes. For this project, glazing systems were not directly analyzed.



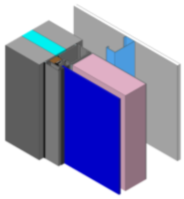
Detail 34 is a precast sandwich panel with a punched window. Similarly to Detail 7, the point transmittance is for one particular window size. Since this is the same window as in Detail 7, the assemblies can be directly compared. The linear transmittance for this detail is similar to Detail 7 for the same level of insulation.

Details 24 and 31 are wall assemblies with a transition to a curtain wall spandrel panel.



Detail 24 is an exterior insulated stud assembly to a curtain wall spandrel panel transition. The curtain wall spandrel panel insulation was simulated for R-15 insulation and the exterior insulation of the steel stud assembly was varied from R-5 to R-25. The steel stud cavity included R-12 batt insulation for all cases.

The linear transmittance is small compared to the slab and parapet thermal anomalies. The heat flow path of the individual assemblies does not appear to be affected much by lateral heat flow introduced by combining the assemblies and the difference can be attributed to the additional flashing and framing at the transition. The difference between the weighted average of the individual assembly U-values and the combined assembly U-value is approximately 20%, regardless of the level of exterior insulation.

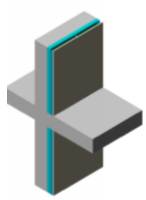


Detail 31 is a precast sandwich panel transition to a curtain wall spandrel panel. The precast sandwich panel wall has R-10 insulation and the spandrel panel has R-15 insulation.

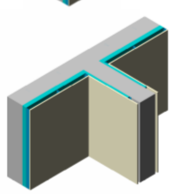
The linear transmittance is almost the same as Detail 24 for the steel stud wall to spandrel panel transition. The difference between the weighted average of the individual assembly U-values and the combined assembly U-value is approximately 18%.

6.1.5 Poured-In-place Concrete Assemblies

Details 18 and 19 are poured-in-place concrete assemblies with slab and wall intersections. The only difference between the two details is the insulation for an interior concrete wall partition. Detail 18 contains R-5 insulation for 610 mm (2 feet) into the interior along the interior wall partition, while Detail 19 has an un-insulated interior wall partition.



For a wall height of 3.1 m (10 ft), just adding a slab to the concrete mass wall increases the assembly thermal transmittance by 61% compared to the 'clear wall' value.



For a wall width of 3.1 m (10 ft), adding an interior wall partition to the assembly increases the thermal transmittance by 35% with insulation in the partition, and 51% when there is no insulation provided.

When using the slab and wall transmittances for the heat loss calculations, it is most convenient to use the overall floor width and height. However, when these two transmittances intersect, there is overlap in areas and the heat loss at this intersection point is accounted for twice. This contribution is small and in most cases can be considered negligible compared to the heat loss from the slab and partition wall and can be ignored. However, for particularly precise calculations there are two approaches. The first would be to subtract out the thickness of the partition wall from the length of the slab, and the thickness of the slab from the height of the partition wall, calculate the heat loss with those lengths and then add the point transmittance of the intersection. This method is unnecessarily tedious. The second method, that will minimize calculations, is to use a negative point transmittance, which is the amount that is overestimated in the heat loss per intersection. In order to remove the over accounting, the negative point transmittance can be added to the overall heat loss for every intersection. Since this is a much more simple method, the negative point transmittance has been included in the data sheets in Appendix F.

6.1.6 Conventional Curtain Wall Spandrel Panels

Details 22 and 23 are both curtain wall spandrel panel sections at a floor slab intersection. The details are set-up to compare the effects of adding closed cell foam insulation into the interior wall cavity behind the spandrel back-pan.

Detail 22 is an un-insulated stud cavity and Detail 23 has 50 mm (2 inches) of closed cell spray foam in the stud cavity. For both details, varying levels of insulation in the back-pan were considered, R1 (representing air) to R25. These details did not include a linear transmittance as the purpose was to compare the overall impact of providing insulation inboard of the spandrel panel for a standard curtain wall system. More work and details would have to be completed to provide meaningful linear transmittance values. Figure 6.6 shows the relative impact of adding insulation into the stud cavity on the overall effective thermal resistance of the spandrel section.

For Detail 22, without the spray foam, it can be seen that by adding an R-5 into the back pan, the total thermal resistance of the spandrel section increases by only a small amount, with diminishing returns as the back pan insulation further increases. This is due to having such large amounts of thermal bridging through the aluminum frame, where the heat can bypass the back pan. Additionally, the heat can also pass easily through the slab, which cuts through the steel stud cavity and aluminum frames that are connected to the slab by steel anchors. The overall thermal resistance increases by only about R-4 when R-11.5 is added to the stud cavity. The effectiveness of the insulation provided to the stud cavity is low because of the significant amount of heat flow through the slab, anchors, and perimeter stud framing bypassing the thermal insulation.

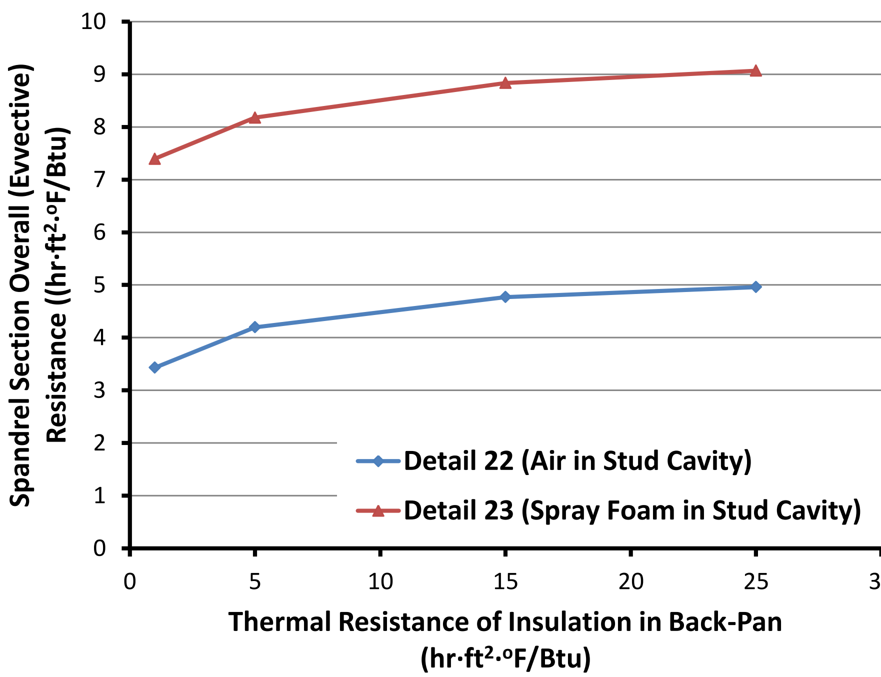


Figure 6.6.a: Spandrel Panel Comparison, with and without interior spray foam (I-P Units)

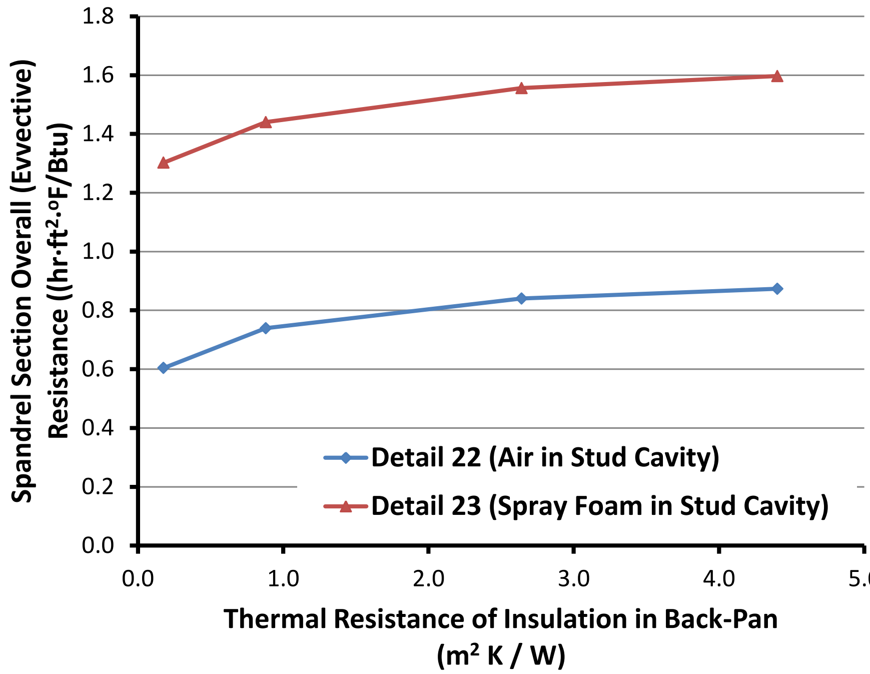
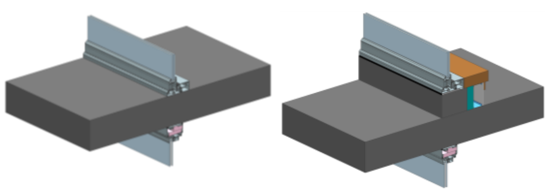


Figure 6.6.b: Spandrel Panel Comparison, with and without interior spray foam (SI Units)

6.1.7 Sliding Door and Window Head Slab Intersections

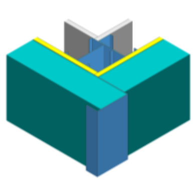
Similar to the previous curtain wall comparisons, Details 26 and 27 were selected to compare the effect of an insulated curb beneath a sliding door.



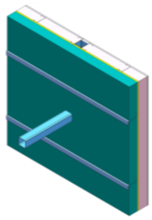
Detail 26 contains the concrete curb, while in Detail 27 the sliding door is supported directly on the slab. It was found that an insulated curb decreases the transmittance through the slab area, between the sliding door and the window head, by about 9%.

6.1.8 Miscellaneous Anomalies

The following details were included as common features, but ones that were not as easily classifiable and directly comparable as the previous groupings.



Details 8 and 8a are two configurations of exterior insulated steel stud assembly corners. The linear transmittances for the corners are essentially constant for any of the values of insulation. Detail 8a configuration is slightly more effective than the Detail 8 configuration, due to the orientation of the studs and reduced thermal bridging. Refer to Appendix E, Detail Catalogue for the orientation of the studs at the corner to reduce thermal bridging.

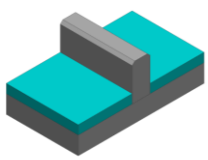


Detail 12 is a steel stud assembly with split insulation for the scenario where a steel beam bypasses the exterior insulation and is attached to a steel post located within the stud cavity. The linear transmittance was calculated for the effect of post alone and a point transmittance was calculated for the effect of the beam for the entire detail.

The beam can have a large impact on the overall thermal transmittance. For a wall height of 3.1 m (10 ft) and 3.1 m (10 ft) wide, only one beam penetration on one post causes an 9% increase in overall thermal transmittance, 17% for two beams placed horizontally, 25% for three and so on.

Detail 13 is a steel stud assembly with split insulation at an interior acoustic stud wall intersection. The extra framing and interruption of the steel stud cavity does not result in a significant increase in thermal transmittance.

For a wall height of 3.1 m (10 ft) and 3.1 m (10 ft) wide, the interior wall intersection results in, at most, a 5% increase in overall thermal transmittance.



Detail 21 is an insulated concrete roof with a concrete curb or wall bypassing the roof insulation. The thermal transmittance, for a roof 6.1 m (20 ft) long, is increased 56% compared to the nominal (1D) value of the roof.

6.1.9 Linear Transmittance Summary

Table 6.1 summarizes the linear transmittance values for anomalies where a constant linear transmittance can be used independent of the level of exterior insulation. Table 6.2 scenarios where the linear transmittance is dependent on the level of insulation and an average value does not apply. Table 6.3 is linear transmittances for interior insulated assemblies where only one level of insulation was analyzed.

Table 6.1: Summary of Linear Transmittances Independent of Exterior Insulation Level

Detail: Wall Type, Transmittance Description	Average Linear Transmittance Btu/ft·hr·^{o}F (W/m K)	Relative Variation (%)
Slabs		
Detail 6: Ext Insulated Steel Stud Wall, Un-insulated extended slab intersection	0.432 (0.748)	3.1
Detail 14: Ext/Int Insulated Brick Veneer and Steel Stud Wall, Shelf angle attached directly to slab.	0.293 (0.507)	6.0
Detail 15: Ext/Int Insulated Brick Veneer and Steel Stud Wall, Shelf angle attached to slab /w knife edges /w insulation between angle and slab	0.188 (0.326)	10.9

Detail: Wall Type, Transmittance Description	Average Linear Transmittance Btu/ft·hr·°F (W/m K)	Relative Variation (%)
Detail 35: Ext Insulated Brick Veneer and Concrete Block wall, Shelf angle attached directly to slab	0.260 (0.450)	5.5
Detail 36: Ext Insulated Brick Veneer and Concrete Block wall, Shelf angle attached to slab /w knife edges /w insulation between angle and slab	0.177 (0.306)	5.2
Detail 38: Ext Insulated Brick Veneer and Concrete Block wall, Un-insulated extended slab intersection	0.340 (0.588)	4.2
Detail 39: Ext Insulated Brick Veneer and Concrete Block wall, Balcony slab attached to floor slab /w knife edges /w insulation between angle and slab	0.128 (0.222)	8.7
Detail 40: Ext Insulated Brick Veneer and Concrete Block wall, Un-insulated flush slab intersection	0.360 (0.623)	2.7
Parapets		
Detail 9: Ext Steel Stud Wall, Insulated Concrete Parapet	0.279 (0.483)	7.4
Detail 25: Spandrel Panel, Insulated Concrete Parapet	0.389 (0.673)	3.3
Detail 37: Ext Insulated Brick Veneer and Concrete Block wall, un-insulated parapet wall at roof	0.225 (0.390)	5.0
Glazing Transitions		
Detail 24: Ext/Int Insulated Steel Stud Wall, Curtain Wall Transition	0.088 (0.152)	1.3
Misc. Transmittances		
Detail 8: Ext Insulated Steel Stud Wall, Stud Corner v1	0.091 (0.158)	1.5
Detail 8a: Ext Insulated Steel Stud Wall, Stud Corner v2	0.087 (0.150)	1.7

Table 6.2: Summary of Linear Transmittances Dependent on Exterior Insulation Level

Detail: Wall Type, Transmittance Description	Linear Transmittance Btu/ft·hr·°F (W/m K)		
	R5	R15	R25
Slabs			
Detail 7: Ext Insulated Steel Stud Wall, Insulated flush slab intersection	0.061 (0.106)	0.025 (0.044)	0.019 (0.034)
Detail 16,17: Ext/Int Insulated Steel Stud Wall, Insulated flush slab and I-Beam intersection	0.177 (0.306)	0.093 (0.162)	0.067 (0.117)
Parapets			
Detail 10: Ext/Int Insulated Steel Stud Wall, Ext/Int Insulated Steel Stud parapet w/ I-Beam	0.289 (0.500)	0.201 (0.348)	0.176 (0.304)

Detail: Wall Type, Transmittance Description	Linear Transmittance Btu/ft·hr·°F (W/m K)		
Glazing Transitions			
Detail 7: Ext Insulated Steel Stud Wall, Window Transition	0.044 (0.077)	0.062 (0.108)	0.069 (0.120)
Misc. Transmittances			
Detail 12: Ext/Int Insulated Steel Stud Wall, Steel post in stud cavity	0.034 (0.060)	0.027 (0.047)	0.023 (0.040)
Detail 13: Ext/Int Insulated Steel Stud Wall, Interior acoustic wall	0.023 (0.039)	0.010 (0.017)	0.007 (0.013)

Table 6.3: Summary of Linear Transmittances for Interior Insulated Assemblies[20]

Detail: Wall Type, Transmittance Description	Linear Transmittance Btu/ft·hr·°F (W/m K)
Slabs	
Detail 18,19: Concrete Mass Wall, Un-insulated extended slab intersection	0.465 (0.805)
Detail 28: Pre-cast panel w/ insulation outboard of studs, flush slab intersection	0.218 (0.377)
Detail 29: Pre-cast panel w/ insulation in stud cavity, flush slab intersection	0.286 (0.495)
Detail 32: Pre-cast sandwich panel with no cavity insulation, flush slab intersection	0.118 (0.205)
Parapets	
Detail 20: Concrete Mass Wall, Un-insulated Concrete Parapet	0.449 (0.778)
Detail 30: Pre-cast panel w/ insulation outboard of studs, insulated concrete parapet	0.335 (0.579)
Detail 33: Pre-cast sandwich panel w/out cavity insulation, insulated concrete parapet w/ I-beam	0.375 (0.650)
Glazing Transitions	
Detail 31: Pre-cast sandwich panel w/out cavity insulation, Curtain Wall Transition	0.082 (0.142)
Detail 34: Pre-cast sandwich panel w/out cavity insulation,	0.028 (0.048)

[20] Only one level of insulation was calculated for each concrete mass, pre-cast and sandwich panel scenario; a relationship between varying insulation levels and linear transmittance was not established. The linear transmittance is for a single insulation.

Detail: Wall Type, Transmittance Description	Linear Transmittance Btu/ft·hr·°F (W/m K)
Window Transition	
Misc. Transmittances	
Detail 18: Concrete mass wall, insulated inner concrete wall	0.262 (0.454)
Detail 19: Concrete mass wall, un-insulated inner concrete wall	0.385 (0.666)
Detail 21: Insulated roof, curb extrusion	0.536 (0.927)
Detail 32,33: Pre-cast sandwich panel w/o cavity insulation, single panel edge transmittance	0.013 (0.023)

6.2 Indexed Surface Temperatures[21]

The indexed temperatures and contour plots are shown for each detail in Appendix F. Maximum and minimum indexed surface temperatures are provided at concealed cavity surfaces, as well as at other points of interest (e.g. lowest temperature on window framing or floor surface) depending on the detail. Multiple temperatures indices, dependent on the insulation thermal resistance, are provided for the exterior insulated steel stud assemblies. A summary of the indexed surface temperatures follows. Table 7.1 shows the sheathing temperatures for the 'clear field' steel stud assemblies and Table 7.2 describes their locations. The location of the minimum and maximum temperature vary depending on orientation of exterior z-girts.

[21] **Limitations Restated from Section 5.3**

The indexed surface temperatures provided as part of this project are due to average steady-state conductive heat flow.

Users are cautioned to recognize that surface temperature is affected by heat and moisture storage effects, air transport, and localized variations (for example screws, localized surface resistance variations, and moisture variations, etc.), which were not modeled as part of ASHRAE 1365-RP.

Some designers and codes employ dew-point methods using uniform and steady-state conditions similar to the procedures outlined in this project, therefore there is value for indexed surface temperatures in a catalogue of thermal performance data for building envelope details. The temperature indices can be used to target areas where the risk of condensation does not appear to be effectively minimized, while still considering and full awareness of the limitations stated above.

A broad discussion on the limitations of dew-point methods and other hygrothermal analysis methods is provided in the 2009 ASHRAE Handbook – Fundamentals.

Table 7.1: Interior Surface Temperatures of Exterior Sheathing for Steel Stud Clear Field Assemblies

Detail		Level of Exterior Insulation									
		R-5		R-10		R-15		R-20		R-25	
		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Detail 1		0.63	0.72	0.69	0.80	0.72	0.84	0.75	0.86	0.76	0.87
Detail 2		0.63	0.76	0.69	0.84	0.72	0.86	0.75	0.87	0.76	0.90
Detail 3		0.74	0.84	0.77	0.89	0.80	0.90	0.81	0.92	0.82	0.93
Detail 4	12”	0.62	0.75	0.69	0.83	0.73	0.87	0.75	0.89	0.77	0.90
	24”	0.63	0.77	0.70	0.85	0.73	0.88	0.76	0.90	0.78	0.92
	36”	0.63	0.78	0.70	0.86	0.73	0.90	0.76	0.92	0.78	0.93
Detail 11		0.21	0.59	0.28	0.68	0.32	0.72	0.36	0.75	0.38	0.78

Table 7.2: Location of Minimum and Maximum Interior Surface Temperatures of Exterior Sheathing for Steel Stud Clear Field Assemblies

Detail	Minimum Temperature Location	Maximum Temperature Location
Detail 1	along girts at stud intersection	centre of stud cavity
Detail 2	along girts between studs	along studs between girts
Detail 3	at vertical and horizontal girt intersection, not at a stud intersection	along studs between girts
Detail 4	at girt and stud intersection	centre of stud cavity between girts
Detail 11	along girts between studs	along studs between girts

Table 7.3 shows the minimum sheathing temperatures for the insulated slab assemblies, Details 5 and 5a. Table 7.4 contains the minimum sheathing temperatures for all the insulated steel stud assemblies with horizontal z-girts.

Table 7.3: Minimum Interior Surface Temperature of Exterior Sheathing for R-15 Exterior Insulated Steel Stud Assembly at Slab Intersections

Detail	Length of Slab Insulation from Wall			
	0	0.7	1.3	2.6
Clear Wall	0.72			
Detail 5	0.58	0.61	0.62	0.62
Detail 5a	0.58	0.66	0.69	0.70

Table 7.4: Minimum Interior Surface Temperatures of Exterior Sheathing for Exterior Insulated Steel Stud with Horizontal Z-Girts Details

Detail	Location	Level of Exterior Insulation		
		R-5	R-15	R-25
Detail 2	along studs between girts	0.63	0.72	0.76
Detail 8	along studs at girts and corner intersection	0.36	0.45	0.50
Detail 8a	along studs at girts and corner intersection	0.36	0.46	0.51
Detail 9	along girt between studs, close to ceiling	0.62	0.71	0.75
Detail 10	along studs between girts	0.27	0.41	0.48
Detail 11	along studs between girts	0.21	0.32	0.38
Detail 12	along girt between studs, away from post	0.23	0.35	0.42
Detail 13	along girt between studs, away from interior wall intersection	0.27	0.33	0.39
Detail 14	cavity centre away from slab	0.39	0.59	0.66
Detail 15	cavity centre away from slab	0.39	0.59	0.69
Detail 17	along girt between studs, away from slab	0.21	0.33	0.39
Detail 24	along girt between studs, close to curtain wall	0.19	0.26	0.32

Table 7.5 contains the minimum interior concrete wall temperatures for the concrete wall, pre-cast and sandwich panel assemblies. Table 7.6 has the minimum interior surface temperatures for the glazing transitions.

Table 7.5: Minimum Interior Surface Temperatures of Concrete of Interior Insulated Assemblies

Detail	Location	Temperature Index
Detail 18	between studs, away from wall and slab	0.06
Detail 19	between studs, away from wall and slab	0.06
Detail 20	between studs, away from ceiling	0.06
Detail 28	between studs, away from slab	0.04
Detail 29	between studs, away from slab	0.05
Detail 30	between studs, away from roof	0.04
Detail 32	at panel joints, at slab	0.73
Detail 33	at panel joint, away from roof	0.82

Table 7.6: Minimum Interior Surface Temperatures of Exterior Insulated Assemblies at Glazing Transitions[22]

Detail	Location	Temperature Index		
		R-5	R-15	R-25
Detail 7	Sheathing interior surface at window sill, centre of cavity	0.39	0.39	0.39
	Window frame at bottom corner	0.61	0.62	0.63
	Glass at bottom corner	0.58	0.58	0.59
Detail 22	Interior surface of back-pan at concrete slab and vertical mullion intersection	0.52	0.57	0.59
	Frame at vertical to horizontal mullion intersection	0.56	0.56	0.57
	Glass at bottom corner	0.47	0.48	0.48
Detail 23	Interior surface of back-pan adjacent the vertical mullion at centre of cavity	0.31	0.37	0.39
	Frame at vertical to horizontal mullion intersection	0.47	0.48	0.49
	Glass at bottom corner	0.42	0.43	0.43
Detail 25	Minimum temp. on back pan, at the mullion, the between slab and bottom transom	0.34	0.38	0.39
	Min. temp. on interior frame, at mullion transom corner	0.51	0.53	0.53
	Minimum temperature ceiling, at gypsum/ceiling intersection, adjacent to curtain wall anchor	0.64	0.65	0.66

Table 7.7 contains the minimum surface temperatures for transitions with single insulation. Table 7.8 shows the minimum concrete block temperatures for the brick veneer with concrete block back-up wall assemblies.

Table 7.7: Minimum Interior Surface Temperatures of Interior Insulated Assemblies at Glazing Transitions

Detail	Location	Temperature Index
Detail 26	interior concrete surface	0.83
	glass	0.44
Detail 27	interior concrete surface	0.58
	glass	0.48
Detail 31	interior concrete surface	0.62
	Interior surface of curtain wall mullion	0.43
Detail 34	interior concrete surface	0.82
	Window frame at bottom corner	0.59
	Glass at bottom corner	0.56

[22] **Limitations Restated from Section 5.3**
Temperature indices on the glazing systems are provided to facilitate evaluation of the opaque assemblies because windows are often the most vulnerable to condensation and demonstrate the relative risk. The intent is not to evaluate the glazing systems and the temperatures should not be perceived as absolute. Actual surface temperatures of windows are not only highly dependent on surface resistances but many other factors such as positioning within the opening, coatings, spacers, etc. The effects of these factors on the glazing thermal performance are not part of the scope of this project.

Table 7.8: Minimum Exterior Surface Temperature of Block and Minimum Interior Surface Temperature for Concrete Block Back-up Wall Assemblies

Detail	Location	Temperature Index		
		R-5	R-15	R-25
Detail 35	at air-filled blocks, at bottom of slab	0.47	0.51	0.57
	at floor/gypsum intersection, at studs	0.82	0.84	0.86
Detail 36	at air-filled blocks, at bottom of slab	0.54	0.58	0.64
	at floor/gypsum intersection, at studs	0.84	0.87	0.89
Detail 37	at air filled blocks, at roof/gypsum intersection	0.57	0.66	0.68
	at roof/gypsum intersection	0.78	0.81	0.82
Detail 38	at air filled blocks, at top of slab	0.42	0.49	0.55
	at floor/gypsum intersection, at studs	0.78	0.82	0.83
Detail 38	at bottom of slab, at angle supports	0.55	0.65	0.70
	at floor/gypsum intersection, at studs	0.85	0.89	0.91
Detail 40	at air filled blocks, at top of slab	0.39	0.48	0.53
	at floor/gypsum intersection, at studs	0.77	0.81	0.83

7. UTILIZATION

The objectives of this section are to provide: perspective, suggestions on how to incorporate this work into ASHRAE publications, and suggestions for further research.

Utilizing the indexed surface temperatures for evaluation of condensation resistance is straightforward—by providing tables in the Handbook – Fundamentals. How to completely utilize the thermal transmittance data is perhaps not as clear.

We distinguish between two broad audiences that have interest in utilizing the thermal transmittance procedures and data developed for this project.

The first audience is users of the ASHRAE Handbook – Fundamentals and is the principal audience of this work. The thermal transmittance procedures and data build on the information already provided in the ASHRAE Handbook. Discussion on how this work can be incorporated into the ASHRAE Handbook – Fundamentals follows in the next section.

The second audience is the developers and users of energy standards, such as ANSI/ASHRAE/IESNA 90.1. This second audience has perhaps slightly different needs than the first audience and this project may seem as a major departure from the existing structure of energy standards such as 90.1. However, incorporating the thermal transmittance procedures and data developed for this project into existing standards does not have to be complicated and there are options. Discussion on how the output of this project can be easily utilized by practitioners using documents such as 90.1 follows in Section 7.2.

7.1 ASHRAE Handbook – Fundamentals

ASHRAE RP-1365 is related to Chapters 25, 26, and 27 of the 2009 ASHRAE Handbook – Fundamentals. The procedures and materials selected for this project are consistent with these chapters. Suggested changes follow:

Linear and Point Transmittance

Linear and point transmittance is introduced as an alternative method to the series-parallel path and zone method in Chapter 25, “Heat, Air, and Moisture Control in Building Assemblies – Fundamentals”, on page 25.7. We envision that more of a discussion of linear and point transmittance will follow in Chapter 25 in future handbooks and a description with examples of the method will be provided in Chapter 27.

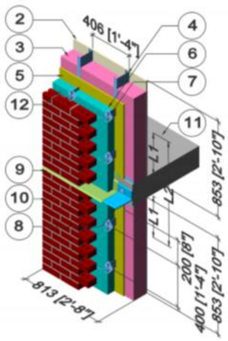
In employing the linear transmittance method to determine the overall U-value, knowing that U=Q/A, the following equations can be used:

$$Q = \Sigma\, Q_{anomalies} + Q_o \qquad \text{Eq.(4)}$$

$$U = \frac{\Sigma\left(\Psi \cdot L\right) + \Sigma\left(\chi\right)}{A_{Total}} + U_o \qquad \text{Eq.(5)}$$

These equations are simply a rearrangement of Eq (1) and Eq (2), found in Section 5.2 of this report, but take into account multiple thermal anomalies. Eq (5) essentially states that the overall U-value is the clear wall value (U_o) plus the summation of all the linear (Ψ) and point (χ) thermal anomalies. A sample calculation of using linear transmittance compared to a weighted average calculation for a three-dimensional thermal anomaly follows.

Example Calculation: *Comparing Linear Transmittance to Area Weighted Method for a Brick Veneer Shelf Angle Anomaly*



Calculate the overall U-value of the steel stud brick veneer assembly with a slab and shelf angle with exterior insulation R-15 (2.6 RSI) and interior stud cavity insulation R-12 (2.1 RSI), using the following information and methods.

Gross Wall Height	=	2.7 m (9 feet)
Gross Wall Length	=	15.2 m (50 feet)
Gross Wall Area	=	41.0 m^2 (450 ft^2)

a) Area Weighted Method

The thermal transmittance for the area around the shelf angle is 1.162 W/m^2 K (0.205 Btu/hr·ft^2·°F) for the effective lengths L_1 = 205 mm (8.1 inch), L_2 = 618.5 mm (24.4 inch) and U_o = 0.287 W/m^2K (0.0562 Btu/hr·ft^2·°F).

Calculation

1. Calculate area for the thermal anomaly and area for the clear field.

   A_b = 0.6185 m ·15.2 m = 9.4 m^2 (101.2 ft^2), A_o = 41.0 – 9.4 = 31.6 m^2 (340.1 ft^2)

2. Calculate the overall U-value

$$U = \frac{(U_b \cdot A_b + U_o \cdot A_o)}{A_{total}} = \frac{(1.162 \cdot 9.4 + 0.287 \cdot 31.6)}{41} = 0.49\, W/m^2 K$$

   (0.086 Btu/hr·ft^2·°F)

b) Linear Transmittance

From Appendix F, for this brick veneer assembly, U_o = 0.287 W/m^2K (0.0562 Btu/hr·ft^2·°F) and the linear transmittance (Ψ) of a slab with a shelf angle for this assembly is 0.5439 W/ m K (0.314 Btu/ hr·ft·°F).

Calculation

1. Calculate the overall U-value

$$U = \frac{\Psi \cdot L}{A_{total}} + U_o = 0.5439 \cdot \frac{15.2}{41} + 0.287 = 0.49\, W/m^2K \text{ (0.086 Btu/hr·ft}^2\text{·°F)}$$

This example illustrates the simplicity of the linear transmittance method compared to the area weighted method for thermal anomalies within opaque building envelope assemblies. The amount of information that must be provided is reduced and the calculation is simpler.[23]

Building Envelope Thermal Performance Data

We envision that a catalogue of building envelope thermal performance data can be provided in Chapter 27 similar to the U-value data provided for fenestrations in Chapter 15. The catalogue can include performance data not only from ASHRAE 1365-RP but also include work completed for past projects (i.e. ASHRAE 1145-RP) and future projects. Some work would need to be done to calculate the linear and point transmittances from past projects, but we do not see this as a major obstacle considering the clear field U-value is typically provided with assembly U-values.

Contact Resistance

The calibration and verification exercises for ASHRAE 1365-RP confirmed previous work in ASHRAE 785-RP that contact resistance is an important factor for modeling assemblies containing metal framing. We envision that the discussion in Chapter 27 (page 27.4) about contact resistance in the section entitled “Construction Containing Metal” will reflect the significance of contact resistance for accurate computer modeling.

7.2 ANSI/ASHRAE/IESNA 90.1

ANSI/ASHRAE/IESNA Standard 90.1-2007 *Energy Standards for Buildings Except Low - Rise Residential Buildings* has requirements for assembly U-values for exterior building envelopes which depend on:

- Climate Zone
- Category of conditioned space
    - Nonresidential
    - Residential
    - Semi-heated
- Envelope assembly (roof, walls, floors, etc.)

[23]The weighted average method is further complicated for a whole building elevation when accounting for the 3D intersections. Some have suggested that the overlapping effects be combined using mitre corners as per ASHRAE 1145-RP (Kemp et al 2001).

- Type of construction (framing type, building type etc.)

Requirements for the prescriptive compliance path are generally provided in a series of tables, one for each climate zone in Section 5 of the standard, that list the assembly maximum U-value for each assembly type, or nominal R-values of added insulation deemed to meet the maximum U-value. Appendix A provides tables and procedures for calculating the "overall assembly U-factor" for a range of common envelope assemblies. The "overall assembly U-factor" is what some would call the effective U-value of the "clear field" assembly considering the expected bridging elements as defined in the appendix or specific in the tables. These include:

- studs in frame walls
- clips or girts running through insulation on concrete walls
- framing in attic type roofs
- compressed insulation in metal building roofs

The tables do not include an allowance for heat flow through major thermal bridges such as floor edge conditions, intersections with other elements, or structural penetrations. The tables were generally developed using the parallel-path method for wood framing and isothermal-planes method for steel stud walls. The tables have been expanded and modified based on test data—some of which was sponsored by companies or interest groups that have specific interests.

The thermal transmittance determined by referring to the tables in Appendix A of Standard 90.1 can be compared to the required maximum U-value defined in the appropriate table in Section 5.5., if the prescriptive path is used to show compliance, or input into the energy simulation program in the energy cost budget method is used.

We submit that the data developed in RRP-1365 could be used to improve or extend Standard 90.1 in several ways:

1. **Improve the accuracy of existing tables in Appendix A.** A few of the modeled details in this project reflect assemblies covered by the tables in Appendix A. The tools and methods used could be employed to modify values in some tables to address where three-dimension effects significantly affect the thermal transmittance.

2. **Extend the situations addressed by Appendix A**. Many of the modeled details were selected to provide clear field thermal transmittance values for common building assemblies that do not fall within the limits of the tables in Appendix A of Standard 90.1. Notably we modeled steel stud wall assemblies with exterior insulation that is not continuous. This is the typical situation in buildings of non-combustible construction.

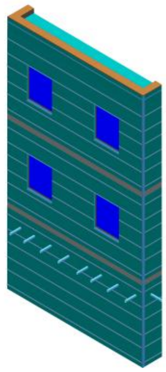
   It would be practical to develop tables similar to Table A3.3 of Standard 90.1 to provide thermal transmittance (U-values) for alternative construction approaches.

3. **Provide heat transmission data for common thermal bridges** that could be used independently or to modify the U-values of clear field building assemblies to account for the additional heat loss. We have modeled a number of common details including floor edge details, parapets and corners.

We think using the concept of linear and point transmittance as described in Section 5.2 of this report makes item 3 relatively simple. The process would be to determine the heat transfer rate of a representative area of an assembly using trusted U-values for clear field areas and adding the heat transfer associated to thermal linear and point thermal bridges. An example for a building that uses a single opaque wall type is shown below.

Example Calculation: *Using multiple linear and point transmittances for determining overall wall U-value.*

For a high-rise building calculate the overall wall U-value for the ground floor, intermediate floors, and the top floor, given the following:



1) The building is square and all 4 walls contain identical assemblies, an R-15 (2.6 RSI) exterior, R-12 (2.1 RSI) batt interior insulated steel stud assembly with horizontal z-girts.
2) Floor slabs are exterior insulated and reinforced by I-beams.
3) Each story is 10 feet (3.1 m) from mid-slab to mid-slab and 50 feet (15.2 m) wide.
4) The top story contains a corrugated roof with a parapet.
5) The bottom story contains beam and post penetrations every 5 feet horizontally from the corners.
6) Effects of windows or doors calculated separately.

Known

Using the thermal performance data from Appendix F:
Wall assembly clear field (Detail 11): $U_{o,wall}$ = 0.054 Btu/ft^2·hr·^{o}F (0.31 W/m^2 K)
Wall corner (Detail 8): ψ_{corner} = 0.089 Btu/ft·hr·^{o}F (0.154 W/m K)
Floor edge (Detail 17): ψ_{slab} = 0.093 Btu/ft·hr·^{o}F (0.162 W/m K)
Parapet (Detail 10): $\psi_{parapet}$ =0.201 Btu/ft·hr·^{o}F (0.348 W/m K)
Post (Detail 12): ψ_{post} =0.027 Btu/ft·hr·^{o}F (0.047 W/m K)
Beam (Detail 12): χ_{beam}= 0.160 Btu/hr·^{o}F (0.084 W/K)
$L_{widith} = 50\,ft\ (15.2\ m)$, $L_{height, perstory} = 10\,ft\ (3.0\ m)$, $A_{wall} = 500\,ft^2\ (46.5\ m^2)$

Calculations:

Top Level Wall

The top story includes the wall assembly and the roof assembly. The additional thermal transmittance at the parapet can be assigned to either the wall or roof. For this example it was assigned to the wall. Since each floor is divided at the mid-plane of the slab, the top floor contains a parapet anomaly and half a slab anomaly. Finally, each wall face has two corners, shared between two other walls. It is then reasonable to assume that one wall face contains the heat loss of one full corner.

$$Q_{wall,3} = Q_{parapet} + Q_{slab} + Q_{corner} + Q_{o,wall}$$

$$U_{wall,3} = \frac{\Psi_{parapet} \cdot L_{width} + 0.5 \cdot \Psi_{slab} \cdot L_{width} + \Psi_{corner} \cdot L_{height,perstory}}{A_{walll}} + U_{o,wall}$$

$$U_{wall,3} = \frac{0.201 \cdot 50 + 0.5 \cdot 0.093 \cdot 50 + 0.089 \cdot 10}{500} + 0.054$$

$$U_{wall,3} = 0.081\ Btu / ft^2 \cdot hr \cdot {}^oF\ (0.458 W / m^2 K)$$

Intermediate Level Wall

For every floor between the top and bottom floor, the wall has only the slab (top and bottom) and corners as the thermal anomalies.

$$Q_{wall,2} = Q_{slab} + Q_{corner} + Q_{o,wall}$$

$$U_{wall,2} = \frac{\Psi_{slab} \cdot L_{width} + \Psi_{corner} \cdot L_{height,perstory}}{A_{walll}} + U_{o,wall}$$

$$U_{wall,2} = \frac{0.093 \cdot 50 + 0.089 \cdot 10}{500} + 0.054$$

$$U_{wall,2} = 0.065\ Btu / ft^2 \cdot hr \cdot {}^oF\ (0.370 W / m^2 K)$$

Ground Level Wall

On this floor there are several beams extruding from the wall every 5 ft from the corners. Since this is a square building and each wall is 50 ft wide, there are 9 beam extrusions per wall.

$$Q_{wall,1} = Q_{slab} + Q_{corner} + Q_{post} + Q_{beam} + Q_{o,wall}$$

$$U_{wall,1} = \frac{\Psi_{slab} \cdot L_{width} + \Psi_{corner} \cdot L_{height,perstory} + 9 \cdot \Psi_{post} \cdot L_{height,perstory} + 9 \cdot \chi_{beam}}{A_{walll}} + U_{o,wall}$$

$$U_{wall,1} = \frac{0.093 \cdot 50 + 0.089 \cdot 10 + 9 \cdot 0.027 \cdot 10 + 9 \cdot 0.160}{500} + 0.054$$

$$U_{wall,1} = 0.073\ Btu / ft^2 \cdot hr \cdot {}^oF\ (0.414 W / m^2 K)$$

Since each of the floor heights are the same, the relative impacts of the thermal anomalies on the thermal transmittance for each floor can be seen. In this example, each floor was looked at separately in order to demonstrate calculating different wall features. The same calculations can be made for the entire wall following the same methodology. This would include every slab, corner, parapet and beam and post anomaly in a single calculation with the total wall height and width for the building as the area.

In this project the clear field U_o values are determined by simulation, not drawn from the Tables in Appendix A of Standard 90.1. However, the concept of addressing thermal bridges by use of linear and point transmission data can be used as an extension to any of the methods currently applied by ASHRAE 90.1 users.

7.3 Further Research

Possible additional research and work that can follow from this project is considerable, considering the vast amounts of building assemblies and details that are used across North America. The current catalogue is based on assemblies and details most commonly used across the continent and where information is most needed; however, there is a much wider assortment of possible assemblies and region specific details that can be considered for future work.

This project provides thermal performance data for only opaque assemblies; however, some details included transitions to glazing assemblies. While further research in applying the linear transmittance method to glazing assemblies can be done, the current knowledge and techniques used in analyzing glazing systems are extensive and thoroughly rooted in the industry. The exception is spandrel panels. Spandrel panels are an integral part of many glazing systems, but are often considered an opaque assembly and are treated as any wall assembly in load calculations. The transmittance through spandrel sections of glazing systems are highly dependent on the spacing of mullions, have complicated three-dimensional heat flow paths when considering slab edge effects, and are difficult to separate from the vision sections. There is considerable work that can be done to establish generic thermal performance data for curtain and window wall spandrel sections.

Z-transfer and other time dependent temperature input functions can be considered in further ASHRAE projects to extend the collective ASHRAE building envelope thermal performance design catalogue.

Finally, the calibration work completed for this project highlighted the importance of contact resistance for accurate computer modeling and the lack of information regarding the expected contact resistance between varying components and materials for typical building envelope assemblies. Further work can be done to provide standardized and widely accepted values available for component modelers.

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APPENDIX A – Validation of Calculation Methods using ISO Reference Cases

A.1: ISO 10211:2007(E), Case 1

Description: This is an example of two-dimensional heat transfer through a surface with known material conductivity (1 W/m.K) and known boundary conditions. The boundary conditions are given as constant temperatures. No radiation was considered.

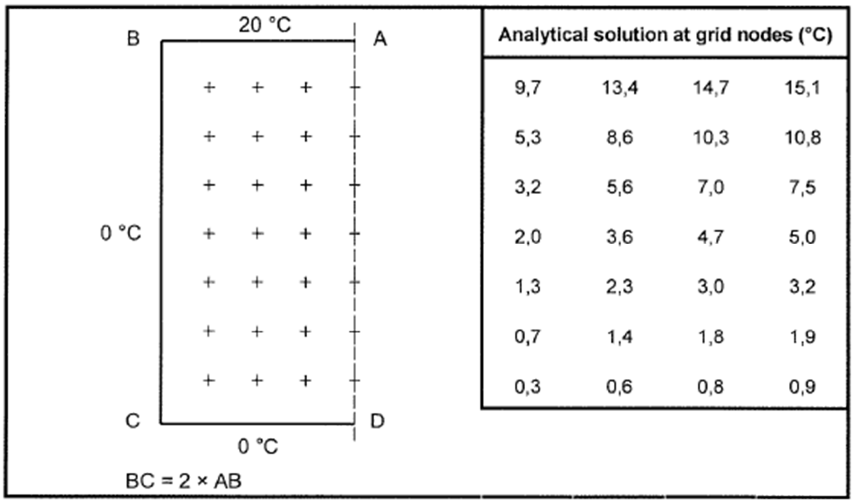


Figure A.2.1: Analytical Solution from1 ISO 10211:2007(E)

Relative Error: The difference between the temperatures calculated by the method being validated and the temperatures listed shall not exceed 0.1^{o}C.

Modeling Result: The modeling was done using FEMAP TMG. The meshing was composed of 13041 nodes and 38640 elements. Figure A.1.2 illustrates temperature distribution of a modeled case. Table A.1.1 compares temperatures at 28 points of the mesh modeled by FEMAP TMG and the temperatures listed in ISO 10211-1. The modeled temperature is in the acceptable range of deviation.

Table A.1.1: Temperature Comparison of Analytical Solution and FEMAP TMG Model

Listed Temperatures in ISO 10211-1 (^{o}C)				Modeled Temperatures with FEMAP TMG (^{o}C)				Difference (^{o}C)			
9.7	13.4	14.7	15.6	9.66	13.38	14.73	15.08	0.04	0.02	0.03	0.02
5.3	8.6	10.3	10.8	5.25	8.64	10.32	10.81	0.05	0.04	0.02	0.01
3.2	5.6	7.0	7.5	3.19	5.61	7.01	7.46	0.01	0.01	0.01	0.04
2.0	3.6	4.7	5.0	2.01	3.64	4.66	5.0	0.01	0.04	0.04	0
1.3	2.3	3.0	3.2	1.26	2.31	2.98	3.22	0.04	0.01	0.02	0.02
0.7	1.4	1.8	1.9	0.74	1.36	1.77	1.90	0.04	0.04	0.03	0
0.3	0.6	0.8	0.9	0.34	0.63	0.82	0.89	0.04	0.03	0.02	0.01

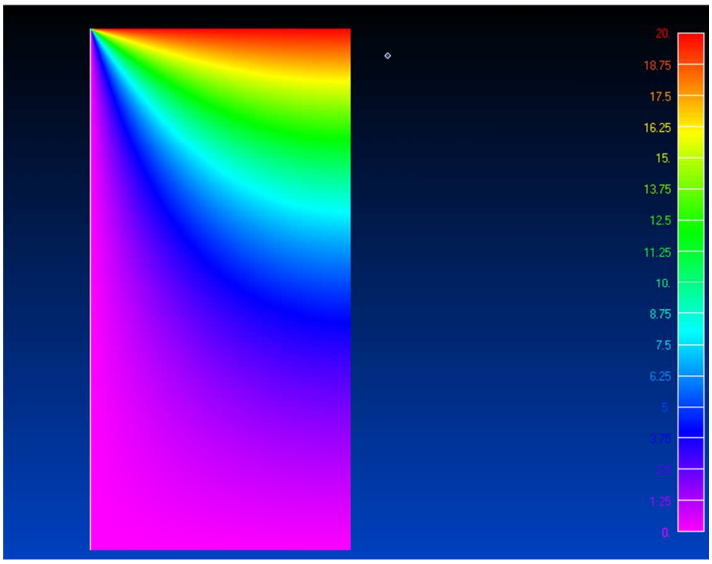
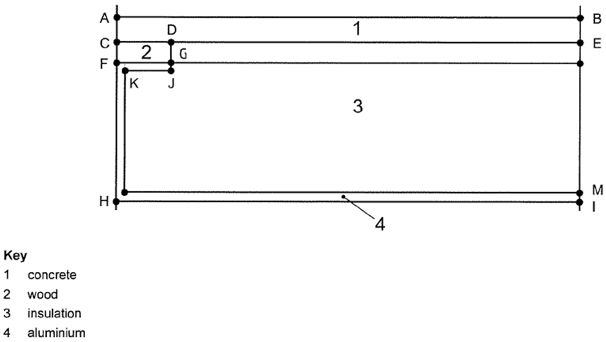


Figure A.1.2: FEMAP TMG Modeled Temperature Profile

A.2: ISO 10211:2007(E), Case 2

Description: This is an example of two-dimensional heat transfer through a surface with known material conductivity and known boundary conditions. The boundary conditions are given as known convection coefficient with known air temperature. No radiation was considered.



Dimensions mm	Thermal conductivity W/(m·K)	Boundary conditions
AB = 500	1: 1,15	AB: 0 °C with R_{se} = 0,06 m²·K/W
AC = 6	2: 0,12	HI: 20 °C with R_{si} = 0,11 m²·K/W
CD = 15	3: 0,029	
CF = 5	4: 230	
EM = 40		
GJ = 1,5		
IM = 1,5		
FG – KJ = 1,5		

Figure A.2.1: Geometry and Solution of Case 2 from ISO 10211:2007(E)

Relative Error: The difference between the temperatures calculated by the method being validated and the temperatures listed shall not exceed 0.1°C. The difference between the heat flow calculated by the method being validated and heat flow shall not exceed 0.1 W/m.

Modeling Result: The modeling was done using FEMAP TMG. The meshing was composed of 10688 nodes and 51981 elements. Figure A.2 illustrates temperature distribution of a modeled case. Table A.2.1 compares temperatures at 9 points of the mesh modeled by FEMAP and the temperatures listed ISO 10211-1. The modeled temperature is in the acceptable range of deviation.

Table A.2.1: Temperature Comparison of Analytical Solution and FEMAP TMG Model

		Listed Temperatures in ISO 10211-1 (°C)	Modeled Temperatures with FEMAP TMG (°C)	Discrepancy
Temperature [°C]	A	7.1	7.05	0.05
	B	0.8	0.76	0.04
	C	7.9	7.88	0.02
	D	6.3	6.25	0.05
	E	0.8	0.83	0.03
	F	16.4	16.40	0
	G	16.3	16.33	0.03
	H	16.8	16.77	0.03
	I	18.3	18.33	0.03
Heat Flow [W/m]		9.5	9.48	0.02

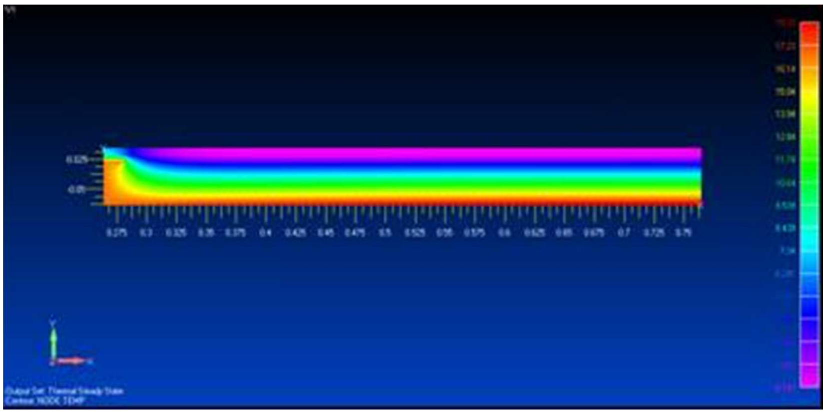
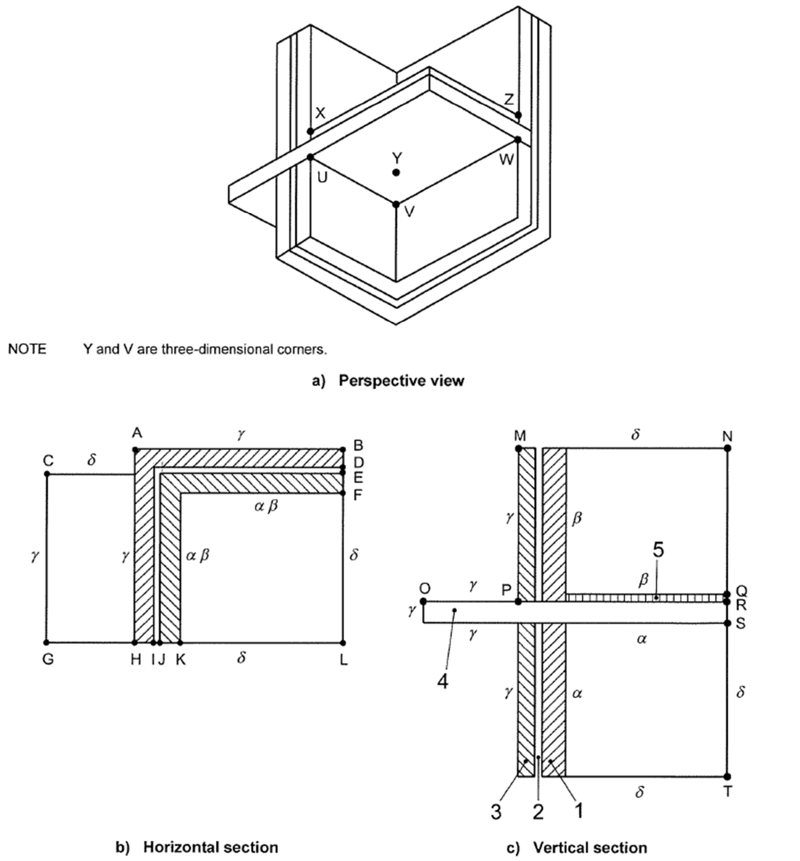


Figure A.1.2: FEMAP TMG Modeled Temperature Profile

A.3: ISO 10211:2007(E), Case 3

Description: This is an example of three-dimensional heat transfer through right planes with known material conductivity and known boundary conditions. The boundary conditions are given as known convection coefficient with known air temperature. No radiation was considered.



Dimensions mm	Thermal conductivity W/(m·K)	Boundary conditions
AB = 1300	1: 0,7	α: 20 °C with R_{si} = 0,20 m^2·K/W
BD = HI = 100	2: 0,04	β: 15 °C with R_{si} = 0,20 m^2·K/W
DE = IJ = 50	3: 1,0	γ: 0 °C with R_{se} = 0,05 m^2·K/W
EF = JK = 150	4: 2,5	δ: adiabatic
FL = KL = 1 000	5: 1,0	
CG = 1150		
GH = 600		
MP = ST = 1 000		
QR = 50		
RS = 150		
NQ = 950		
OP = 600		

Figure A.3.1: Geometry and Solution of Case 3 from ISO 10211:2007(E)

Relative Error: The difference between the lowest internal surface temperature of both environments calculated by the method being validated and the temperatures listed shall not exceed 0.1C. The difference between heat flows calculated by the method being validated and the heat flows listed shall not exceed 1%.

Modeling Result: The FEMAP TMG model composed of 127632 nodes and 470715 elements. Figure A.3.2 illustrates the modeled temperature distribution and Table A.3.1 compares the listed temperature and heat flow in ISO 10211:2007(E) with modeled ones. The discrepancies are in the acceptable range.

Table A.3.1: Temperature Comparison of Analytical Solution and FEMAP TMG Model

		Listed Temperatures in ISO 10211-1 (°C)	Modeled Temperatures with FEMAP TMG (°C)	Discrepancy
Temperature [C]	U	12.9	12.895	0.005
	V	11.3	11.329	0.029
	W	16.4	16.390	0.01
	X	12.6	12.562	0.038
	Y	11.1	11.125	0.025
	Z	15.3	15.280	0.02
Heat Flow [W/m]	α	46.3	45.98	0.69 %
	β	14.0	13.86	1 %
	γ	60.3	59.83	0.78 %

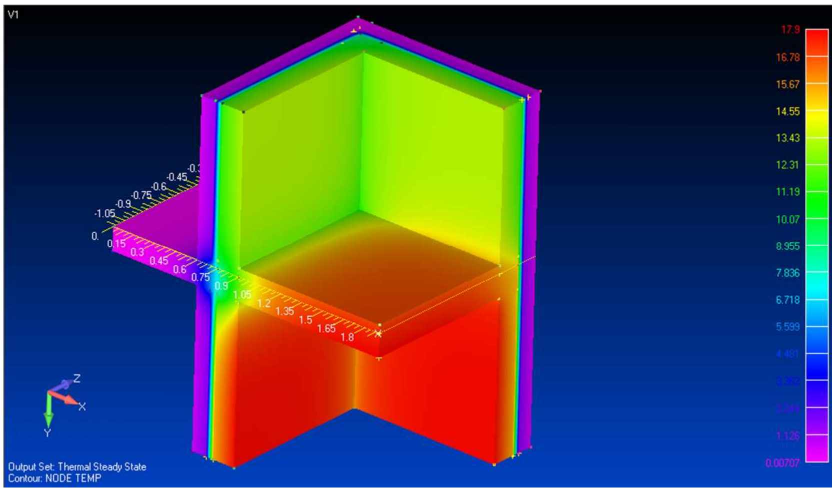
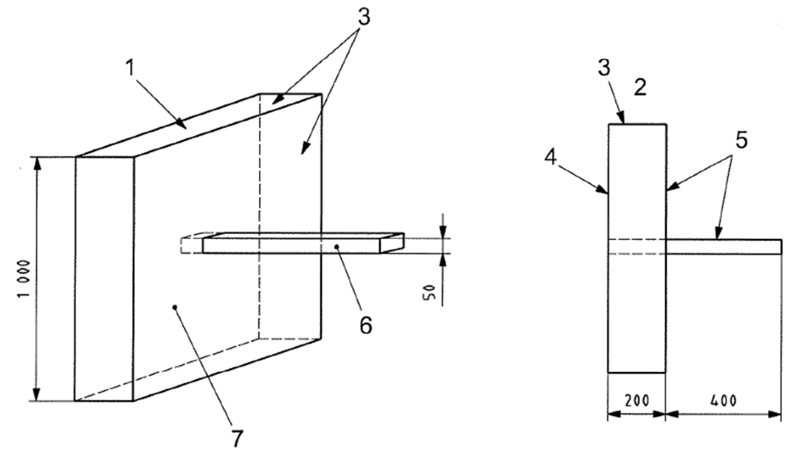


Figure A.3.2: FEMAP TMG Modeled Temperature Profile

A.4: ISO 10211:2007(E), Case 4

Description: This is a three-dimensional thermal bridge consisting of an iron bar penetrating an insulation layer, as shown in the following figure from the standard. The boundary conditions are given as known convection coefficient with known air temperature. No radiation was considered.

Dimensions in millimetres



Key

1 top
2 top view
3 adiabatic cut-off planes
4 external surface
5 internal surface
6 iron bar
7 insulation

Figure A.4 — Test reference case 4: iron bar penetrating an insulation layer

Table A.6 — Description of model for case 4

Dimensions mm	**Thermal conductivity** W/(m·K)	**Boundary conditions**
Insulation: 1 000 × 1 000 × 200	Insulation: 0,1 W/(m·K)	Internal: 1 °C with R_{si} = 0,10 m^2·K/W
Iron bar: 600 × 100 × 50	Iron bar: 50 W/(m·K)	External: 0 °C with R_{se} = 0,10 m^2·K/W
		Cut-off planes: adiabatic

Table A.7 — Numerical solution for case 4

Heat flow	0,540 W
Highest surface temperature on the external side	0,805 °C

Figure A.4.1: Geometry and Solution of Case 4 from ISO 10211:2007(E)

Relative Error: The difference between the lowest internal surface temperatures calculated by the method being validated and the temperature listed shall not exceed 0.005°C. The difference between the heat flow calculated by the method being validated and the heat flow listed, shall not exceed 1%.

Modeling Result: The FEMAP TMG model comprised of 29960 nodes and 108225 elements. The modeled temperature distribution is in Figure A.4.2. The modeled heat flow was 0.535W which is a 0.92% relative error from listed value. The modeled highest surface temperature on the external side was 0.81 °C which is 0.005 °C higher than the listed value. Both modeled values are within the accepted range of discrepancy.

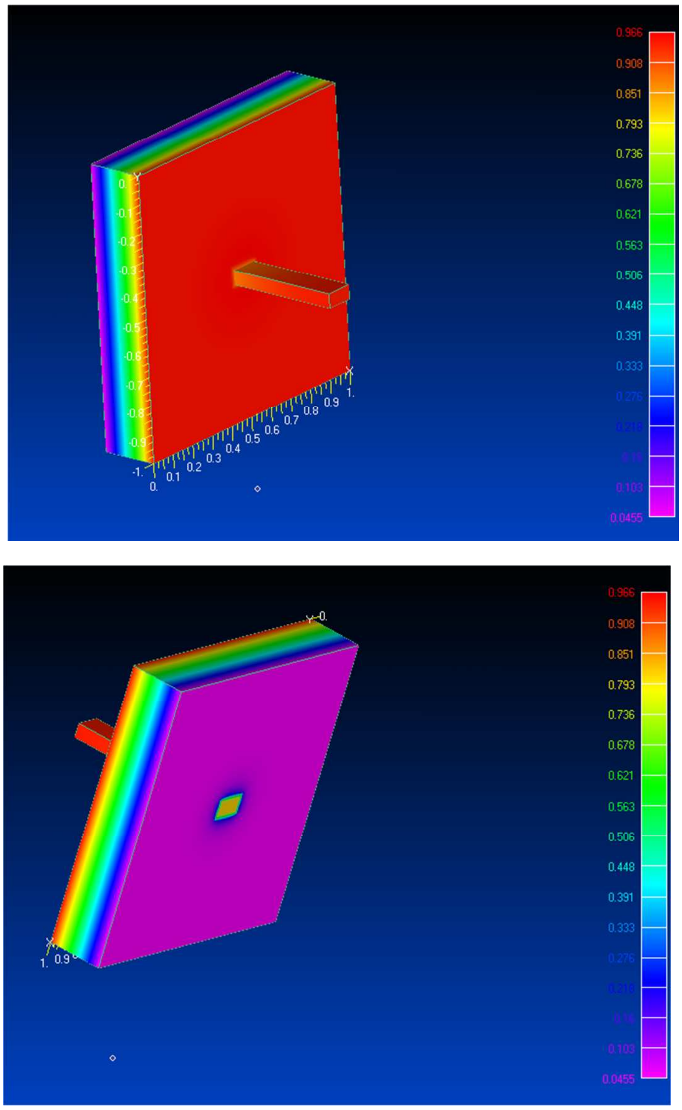
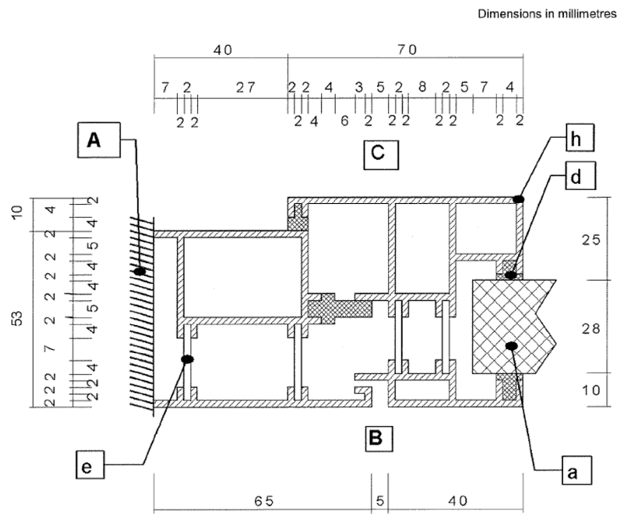


Figure A.4.2: FEMAP TMG Modeled Temperature Profile

A.5: ISO 10077-2:2003(E), Case D.1

Description: This is an example of two-dimensional heat transfer through an aluminum frame section with thermal break and insulation panel (IGU). The length of frame is 110mm and the insulation panel 190mm. The material conductivity and boundary conditions are known. The boundary conditions are given as known convection coefficient with known air temperature. Reduced convection coefficient on the interior concave corners was considered based on ISO 10077-2 2003(E) Annex B. Radiation in enclosures was considered based on ISO 10077-2 2003(E) Section 6.3.



Boundary

Key	Surface resistance R_s m^2K/W	Temperature θ °C
A adiabatic	infinity	–
B external	see annex B	0
C internal	see annex B	20

Materials

Key	Material	Thermal conductivity λ W/(m·K)
a	insulation panel	0,035
b	soft wood	0,13
c	PVC	0,17
d	EPDM	0,25
e	polyamide 6.6	0,3
f	glass	1,0
g	steel	50
h	aluminium [a]	160
i	mohair (polyester), sweep	0,14
k	polyamide	0,25
l	PU (polyurethane), rigid	0,25
m	polysulfide	0,40
n	silica gel (desiccant)	0,13
o	gas filling	0,034 [b]

[a] Introduce a remark in the report about the surface treatment, like coated or anodised, if the normal emissivity of the surface is $\varepsilon_n = 0,85$.

[b] Equivalent thermal conductivity of the gas filling.

Figure A.5.1: Geometry and Solution of Case D.1 from ISO 10077-2:2003(E)

Relative Error: The modeling result should be differing by no more than 3% in thermal transmittance of the frame section and conductance of the whole assembly.

Modeling Result: the FEMAP TMP model consisted of 48127 nodes and 142930 elements. The frame cavities were modeled with properties of air determined by ISO 10077-2 2003(E) Section 6.3.

The following figure illustrates the modeled temperature distribution. Table A.5.1 compares the modeled values and those listed in ISO 10077-2 2003(E) for thermal transmittance of the frame section and conductance of the whole assembly. The discrepancies are in the acceptable range.

Table A.5.1: Temperature Comparison of Analytical Solution and FEMAP TMG Model

	L^{2D} W/(m.K)[1]	Ψ W/(m.K)[2]
ISO 10077-2 2003(E)	0.550±0.007	3.22±0.06
FEMAP TMG	0.5595	3.305
Discrepancy	1.72 %	2.64%

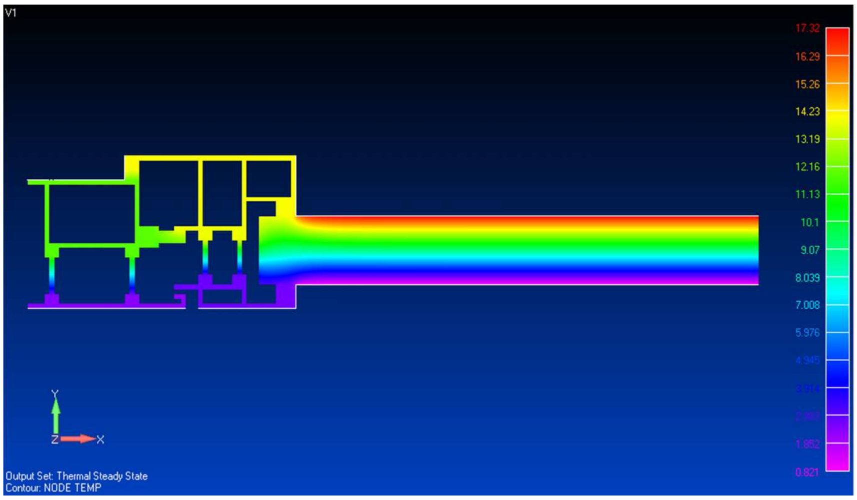


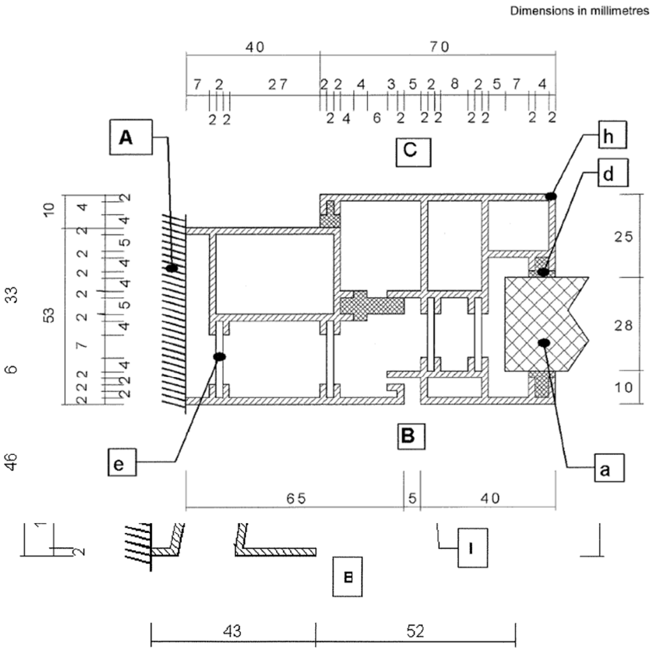
Figure A.5.2: FEMAP TMG Modeled Temperature Profile

[1] L^{2D} W/(m.K): Thermal transmittance of the frame section

[2] Ψ W/(m.K) :Conductance of the whole assembly

A.6: ISO 10077-2:2003(E), Case D.6

Description: This is an example of two-dimensional heat transfer through a sliding aluminum window frame section and insulation panel (IGU). The length of frame is 110mm and the insulation panel 190mm. The material conductivity and boundary conditions are known. The boundary conditions are given as known convection coefficient with known air temperature. Reduced convection coefficient on the interior concave corners was considered based on ISO 10077-2 2003(E) Annex B. Radiation and convection in enclosures were considered based on ISO 10077-2 2003(E) Section 6.3.



Boundary

Key	Surface resistance R_s m^2K/W	Temperature θ °C
A adiabatic	infinity	–
B external	see annex B	0
C internal	see annex B	20

Materials

Key	Material	Thermal conductivity λ W/(m·K)
a	insulation panel	0,035
b	soft wood	0,13
c	PVC	0,17
d	EPDM	0,25
e	polyamide 6.6	0,3
f	glass	1,0
g	steel	50
h	aluminium [a]	160
i	mohair (polyester), sweep	0,14
k	polyamide	0,25
l	PU (polyurethane), rigid	0,25
m	polysulfide	0,40
n	silica gel (desiccant)	0,13
o	gas filling	0,034 [b]

[a] Introduce a remark in the report about the surface treatment, like coated or anodised, if the normal emissivity of the surface is ε_n = 0,85.

[b] Equivalent thermal conductivity of the gas filling.

Figure A.6.1: Geometry and Solution of Case D.1 from ISO 10077-2:2003(E)

Relative Error: The modeling result should be differing by no more than 3% in thermal transmittance of the frame section and conductance of the whole assembly.

Modeling Results: the FEMAP TMG model consisted of 37957 nodes and 112244 elements. The frame cavities were modeled with properties of air determined by ISO 10077-2 2003(E) Section 6.3.

The following figure illustrates the modeled temperature distribution. Table A.6.1 compares the modeled values and those listed in ISO 10077-2 2003(E) for thermal transmittance of the frame section and conductance of the whole assembly. The discrepancies are in the acceptable range.

Table A.6.1: Temperature Comparison of Analytical Solution and FEMAP TMG Model

	$\mathbf{L^{2D}}$ W/(m.K)[3]	**Ψ** W/(m.K)[4]
ISO 10077-2 2003(E)	0.659±0.008	4.67±0.09
FEMAP TMG	0.6725	4.81
Discrepancy	2.04%	2.99%

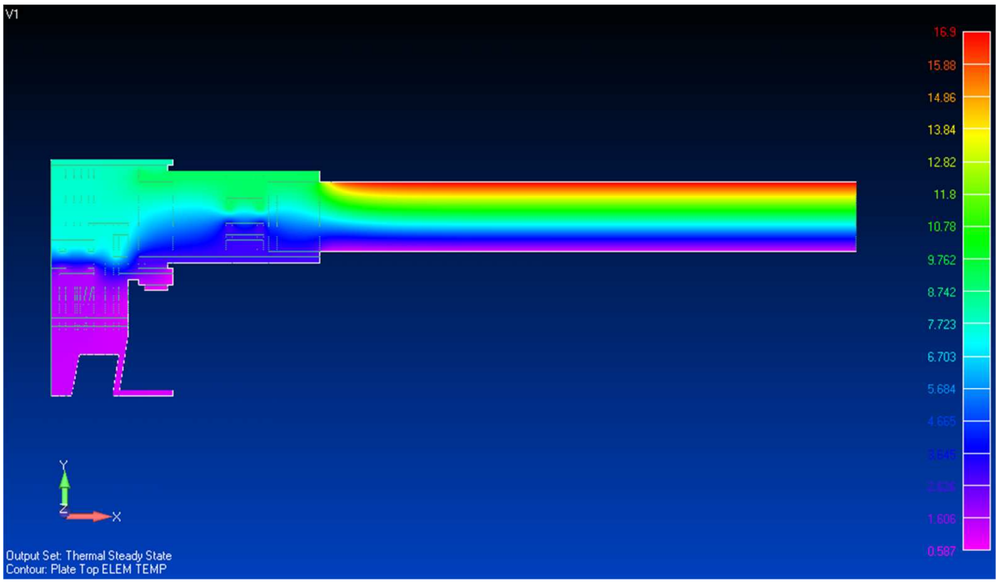


Figure A.6.2: FEMAP TMG Modeled Temperature Profile

[3] $\mathbf{L^{2D}}$ W/(m.K): Thermal transmittance of the frame section

[4] **Ψ** W/(m.K) :Conductance of the whole assembly

APPENDIX B – Summary of Model Calibration to Guarded Hot Box Data Sets

ID	Interior sheathing	Fiberglass Cavity Insulation	Cavity Depth	Steel Stud Thickness	Steel Stud Spacing (o.c.)	Steel Stud Flange	Steel Track Thickness	Steel Track Flange	Exterior Sheathing	Exterior Insulation	Cladding
SS.1	1/2" (13 mm) gypsum	R-12 (RSI 2.1)	3 5/8" (92 mm)	16 gauge	16" (406 mm)	1 5/8" (41 mm)	16 gauge	1 1/4" (32 mm)	1/2" (13 mm) gypsum	none	25 mm stucco
SS.2	5/8" (16 mm) gypsum	R-12 (RSI 2.1)	3 5/8" (92 mm)	20 gauge	16" (406 mm)	1 1/4" (32 mm)	20 gauge	1 1/4" (32 mm)	none	none	100 mm reinforced concrete
SS.3	5/8" (16 mm) gypsum	R-12 (RSI 2.1)	3 5/8" (92 mm)	20 gauge	16" (406 mm)	1 1/4" (32 mm)	20 gauge	1 1/4" (32 mm)	1/2" (13 mm) gypsum	none	90 mm clay brick
SS.4	1/2" (13 mm) gypsum	R-11 (RSI 1.9)	3 5/8" (92 mm)	0.043" (1.1 mm)	24" (610 mm)	1 5/8" (41 mm)	0.043" (1.1 mm)	not stated	1/2" (13 mm) plywood	none	none
SS.5	1/2" (13 mm) gypsum	R-11 (RSI 1.9)	3 5/8" (92 mm)	0.043" (1.1 mm)	24" (610 mm)	1 5/8" (41 mm)	0.043" (1.1 mm)	not stated	none	1" (25 mm) XPS	none
SS.6	1/2" (13 mm) gypsum	R-11 (RSI 1.9)	3 5/8" (92 mm)	0.043" (1.1 mm)	24" (610 mm)	1 5/8" (41 mm)	0.043" (1.1 mm)	not stated	1/2" (13 mm) gypsum	1" (25 mm) XPS	none
SS.7	1/2" (13 mm) gypsum	R-11 (RSI 1.9)	3 5/8" (92 mm)	0.043" (1.1 mm)	24" (610 mm)	1 5/8" (41 mm)	0.043" (1.1 mm)	not stated	none	1/2" (13 mm) XPS	none
SS.8	1/2" (13 mm) gypsum	R-11 (RSI 1.9)	3 5/8" (92 mm)	0.043" (1.1 mm)	24" (610 mm)	1 5/8" (41 mm)	0.043" (1.1 mm)	not stated	none	2" (50 mm) XPS	none
SS.9	1/2" (13 mm) gypsum	R-11 (RSI 1.9)	3 5/8" (92 mm)	0.033" (0.84 mm)	24" (610 mm)	1 5/8" (41 mm)	0.033" (0.84 mm)	not stated	1/2" (13 mm) plywood	none	none
SS.10	1/2" (13 mm) gypsum	R-11 (RSI 1.9)	3 5/8" (92 mm)	0.033" (0.84 mm)	24" (610 mm)	1 5/8" (41 mm)	0.033" (0.84 mm)	not stated	none	1" (25 mm) XPS	none
SS.11	1/2" (13 mm) gypsum	R-11 (RSI 1.9)	3 5/8" (92 mm)	0.033" (0.84 mm)	24" (610 mm)	1 5/8" (41 mm)	0.033" (0.84 mm)	not stated	none	1" (25 mm) XPS	none
SS.12	1/2" (13 mm) gypsum	R-19 (RSI 3.4)	6" (140 mm)	0.043" (1.1 mm)	24" (610 mm)	1 5/8" (41 mm)	0.043" (1.1 mm)	not stated	1/2" (13 mm) plywood	none	none
SS.13	1/2" (13 mm) gypsum	R-19 (RSI 3.4)	6" (140 mm)	0.043" (1.1 mm)	24" (610 mm)	1 5/8" (41 mm)	0.043" (1.1 mm)	not stated	none	1" (25 mm) XPS	none

ID	Interior sheathing	Fiberglass Cavity Insulation	Cavity Depth	Steel Stud Thickness	Steel Stud Spacing (o.c.)	Steel Stud Flange	Steel Track Thickness	Steel Track Flange	Exterior Sheathing	Exterior Insulation	Cladding
SS.14	1/2" (13 mm) gypsum	R-19 (RSI 3.4)	6" (140 mm)	0.043" (1.1 mm)	24" (610 mm)	1 5/8" (41 mm)	0.043" (1.1 mm)	not stated	none	1" (25 mm) Polyiso	none
SS.15	1/2" (13 mm) gypsum	R-11 (RSI 1.9)	3 5/8" (92 mm)	0.043" (1.1 mm)	24" (610 mm)	1 5/8" (41 mm)	0.043" (1.1 mm)	not stated	none	1" (25 mm) XPS	none
SS.16	5/8" (16 mm) gypsum	R-11 (RSI 2.1) w/ paper face	3 5/8" (92 mm)	18 gauge	24" (610 mm)	1 5/8" (41 mm)	18 gauge	not stated	5/8" (16 mm) gypsum	none	none
SS.17	5/8" (16 mm) gypsum	R-11 (RSI 2.1) w/ paper face	3 5/8" (92 mm)	18 gauge	24" (610 mm)	1 5/8" (41 mm)	18 gauge	not stated	5/8" (16 mm) gypsum	1" (25 mm) EPS between gypsum and studs	none
SS.18	5/8" (16 mm) gypsum	R-11 (RSI 2.1) w/ paper face	3 5/8" (92 mm)	18 gauge	24" (610 mm)	1 5/8" (41 mm)	18 gauge	not stated	5/8" (16 mm) gypsum	1.5" (38 mm) EPS between gypsum and studs	none
SS.19	1/2" (13 mm) gypsum	R-12 (RSI 2.1)	3 5/8" (92 mm)	20 gauge	16" (406 mm)	1 5/8" (41 mm)	1.03 mm	not stated	5/8" (16 mm) OSB	none	none
SS.20	1/2" (13 mm) gypsum	R-12 (RSI 2.1)	3 5/8" (92 mm)	20 gauge	16" (406 mm)	1 5/8" (41 mm)	1.03 mm	not stated	5/8" (16 mm) OSB	1" (25 mm) XPS	none
SS.21	1/2" (13 mm) gypsum	R-12 (RSI 2.1)	3 5/8" (92 mm)	20 gauge	16" (406 mm)	1 5/8" (41 mm)	1.03 mm	not stated	5/8" (16 mm) OSB	2" (50 mm) XPS	none
SS.22	1/2" (13 mm) gypsum	R-12 (RSI 2.1)	3 5/8" (92 mm)	18 gauge	16" (406 mm)	1 5/8" (41 mm)	1.31 mm	not stated	5/8" (16 mm) OSB	none	none
SS.23	1/2" (13 mm) gypsum	R-12 (RSI 2.1)	3 5/8" (92 mm)	18 gauge	16" (406 mm)	1 5/8" (41 mm)	1.31 mm	not stated	5/8" (16 mm) OSB	1" (25 mm) XPS	none
SS.24	1/2" (13 mm) gypsum	R-12 (RSI 2.1)	3 5/8" (92 mm)	18 gauge	16" (406 mm)	1 5/8" (41 mm)	1.31 mm	not stated	5/8" (16 mm) OSB	2" (50 mm) XPS	none

Assembly ID	Publication Authors	Year	Source ID	Tested Interior Temperature	Tested Exterior Temperature	Heat Flow Comparison?		Steady-state Temperature Profile Comparison?
						Steady-State	Transient	
SS.1	Brown, Stephenson	1993	Specimen #1	69.8°F (21°C)	-4°F (-20°C)	yes	yes	no
M.1	Brown, Stephenson	1993	Specimen #2	69.8°F (21°C)	-4°F (-20°C)	yes	yes	no
M.2	Brown, Stephenson	1993	Specimen #3	69.8°F (21°C)	-4°F (-20°C)	yes	yes	no
SS.2	Brown, Stephenson	1993	Specimen #4	69.8°F (21°C)	-4°F (-20°C)	yes	yes	no
M.3	Brown, Stephenson	1993	Specimen #5	69.8°F (21°C)	-4°F (-20°C)	yes	no	no
SS.3	Brown, Stephenson	1993	Specimen #6	69.8°F (21°C)	-4°F (-20°C)	yes	no	no
SS.4	Barbour, Christian, Goodrow, Kosny	1994	A1	69.8°F (21°C)	20°F (-6.7°C)	yes	no	yes
SS.5	Barbour, Christian, Goodrow, Kosny	1994	A2	69.8°F (21°C)	20°F (-6.7°C)	yes	no	yes
SS.6	Barbour, Christian, Goodrow, Kosny	1994	A4	69.8°F (21°C)	20°F (-6.7°C)	yes	no	no
SS.7	Barbour, Christian, Goodrow, Kosny	1994	A5	69.8°F (21°C)	20°F (-6.7°C)	yes	no	no
SS.8	Barbour, Christian, Goodrow, Kosny	1994	A6	69.8°F (21°C)	20°F (-6.7°C)	yes	no	yes
SS.9	Barbour, Christian, Goodrow, Kosny	1994	C1	69.8°F (21°C)	20°F (-6.7°C)	yes	no	no
SS.10	Barbour, Christian, Goodrow, Kosny	1994	C2	69.8°F (21°C)	20°F (-6.7°C)	yes	no	no
SS.11	Barbour, Christian, Goodrow, Kosny	1994	C3	69.8°F (21°C)	20°F (-6.7°C)	yes	no	no
SS.12	Barbour, Christian, Goodrow, Kosny	1994	D1	69.8°F (21°C)	20°F (-6.7°C)	yes	no	no
SS.13	Barbour, Christian, Goodrow, Kosny	1994	D2	69.8°F (21°C)	20°F (-6.7°C)	yes	no	no
SS.14	Barbour, Christian, Goodrow, Kosny	1994	D3	69.8°F (21°C)	20°F (-6.7°C)	yes	no	no
SS.15	Barbour, Christian, Goodrow, Kosny	1994	F1	69.8°F (21°C)	20°F (-6.7°C)	yes	no	no
SS.16	Desjarlais, McGowan	1997	A1	100°F (38°C)	50°F (10°C)	yes	no	yes
SS.17	Desjarlais, McGowan	1997	A2	100°F (38°C)	50°F (10°C)	yes	no	yes

Assembly ID	Publication Authors	Year	Source ID	Tested Interior	Tested Exterior	Heat Flow Comparison?		Steady-state Temperature
SS.18	Desjarlais, McGowan	1997	A3	100°F (38°C)	50°F (10°C)	yes	no	yes
SS.19	Brown, Swinton, Haysom	1998	1A	68°F (20°C)	23°F (-5°C)	yes	no	yes
SS.20	Brown, Swinton, Haysom	1998	1B	68°F (20°C)	23°F (-5°C)	yes	no	no
SS.21	Brown, Swinton, Haysom	1998	1C	68°F (20°C)	23°F (-5°C)	yes	no	yes
SS.22	Brown, Swinton, Haysom	1998	2A	68°F (20°C)	23°F (-5°C)	yes	no	no
SS.23	Brown, Swinton, Haysom	1998	2B	68°F (20°C)	23°F (-5°C)	yes	no	no
SS.24	Brown, Swinton, Haysom	1998	2C	68°F (20°C)	23°F (-5°C)	yes	no	no
M.5	Kosny, Childs	2001	RASTRA Wall	79°F (26.1°C)	20°F (-6.7°C)	yes	yes	no

Descriptions of Massive Wall Assemblies

M.1 – 5/8” (16mm) Gypsum sheathing attached with 26 gauge steel furring 24” (610 mm) o.c. to 8” precast concrete slab 1” with (25 mm) extruded polystyrene and polyethylene vapour barrier

M.2 – reverse of M.1

M.3 - .5” (90 mm) clay brick attached to 6” (140 mm) hollow CMU with wire, 5/8” (16mm) Gypsum sheathing attached with 26 gauge steel furring 24” (610 mm) o.c

M.4 – RASTRA Wall. 10” (250 mm) thick light-weight concrete forms filled with high density, reinforced structural concrete. Forms are made of EPS-bead concrete with a density of ~20 to 30 lb/ft^3.

APPENDIX C – Comparison of Temperature Indices between Simulated and Measured Results

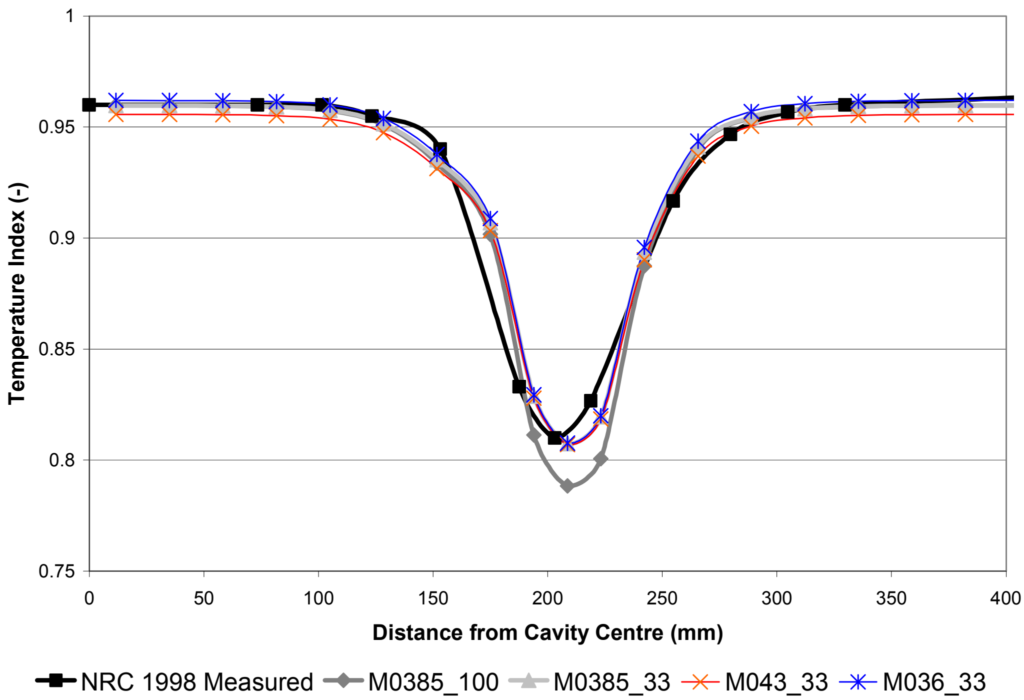


Figure C.1: Indexed Temperature Profile Comparison between Simulated and Measured Results for SS.19 at Warm Surface of Gypsum

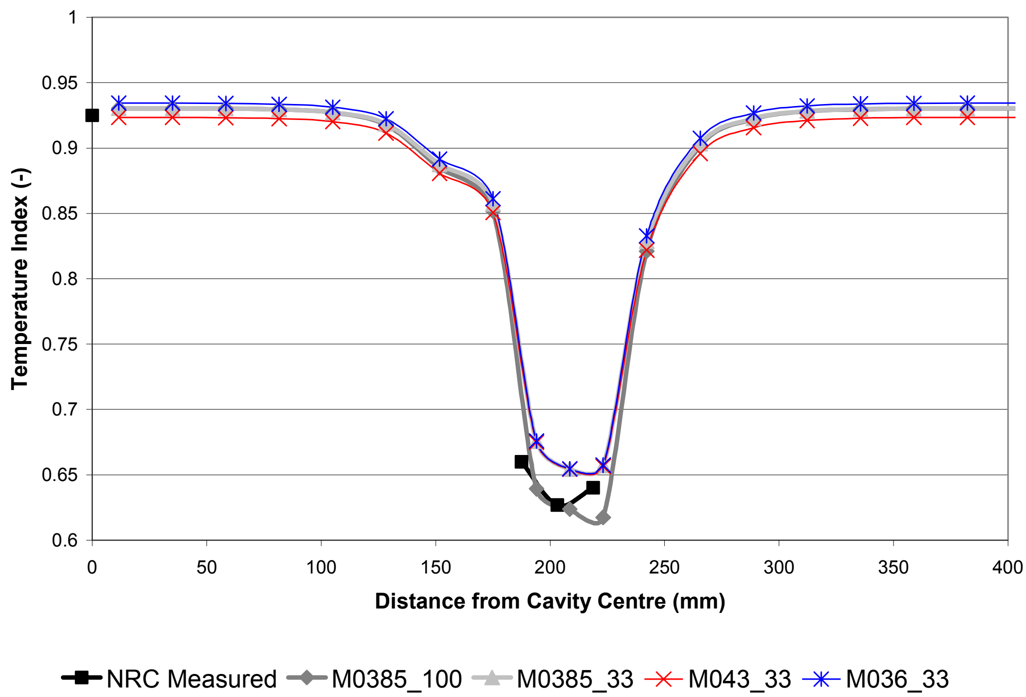


Figure C.2: Indexed Temperature Profile Comparison between Simulated and Measured Results for SS.19 at Cold Surface of Gypsum

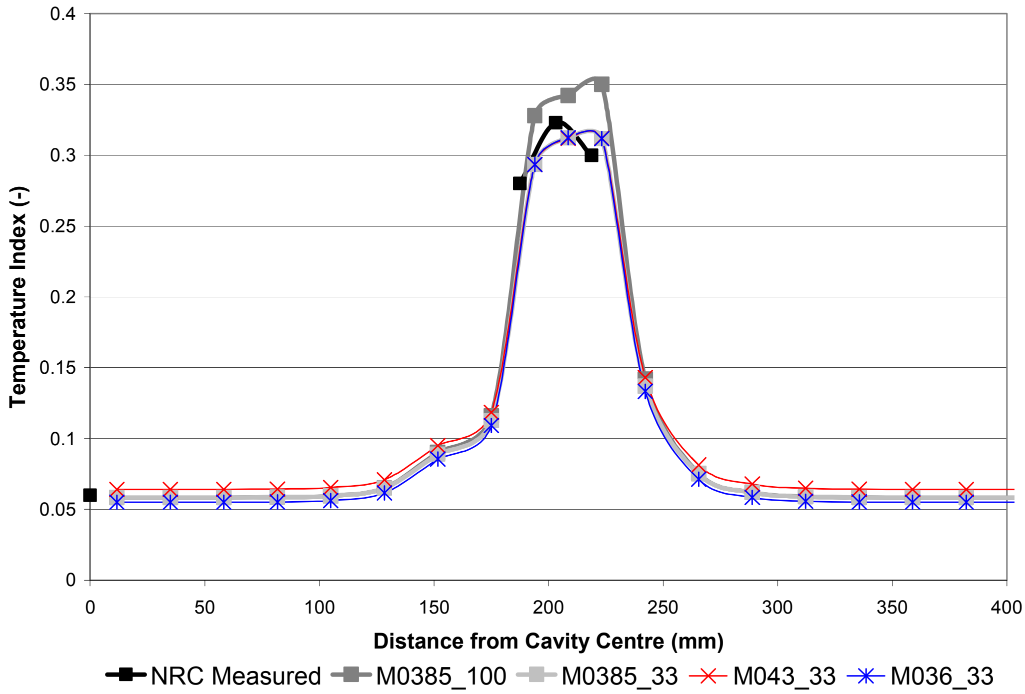


Figure C.3: Indexed Temperature Profile Comparison between Simulated and Measured Results for SS.19 at Warm Surface of OSB

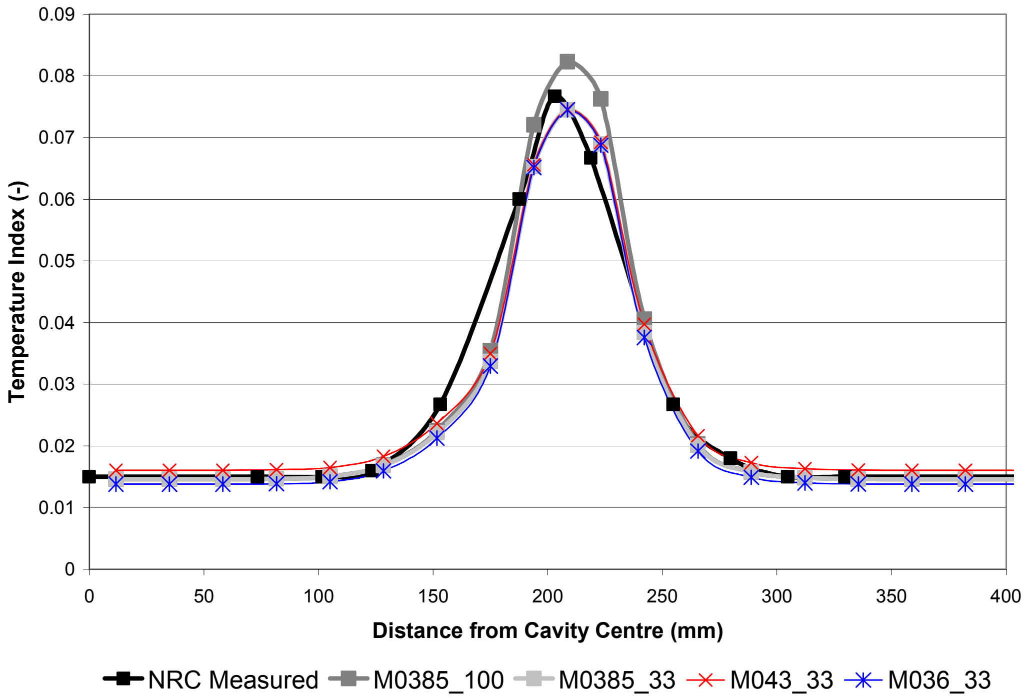


Figure C.4: Indexed Temperature Profile Comparison between Simulated and Measured Results for SS.19 at Cold Surface of OSB

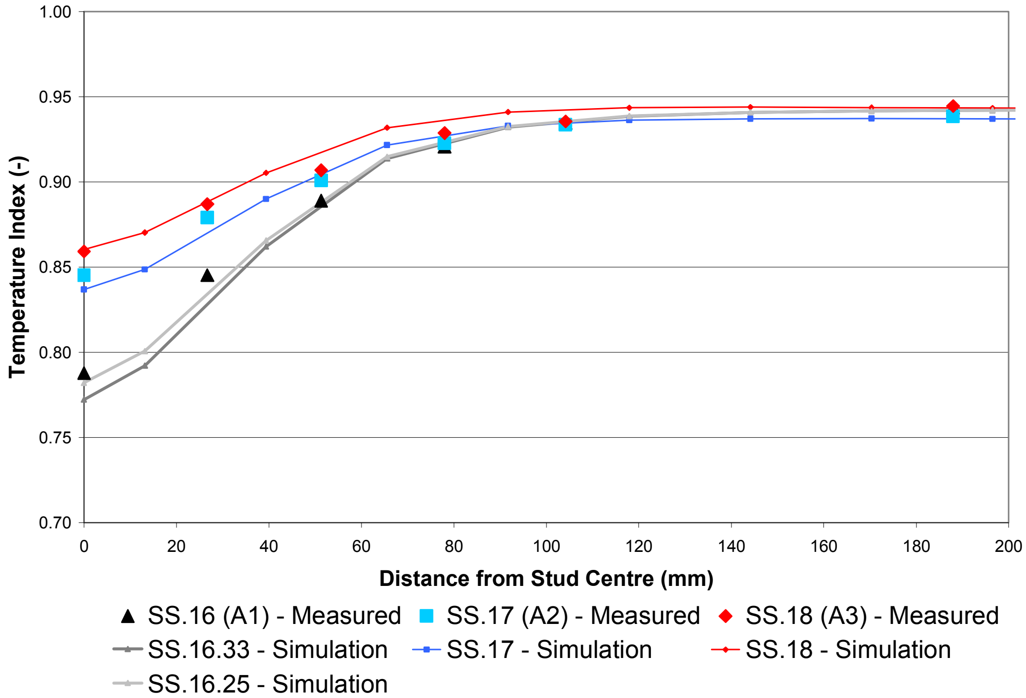


Figure C.5: Indexed Temperature Profile Comparison between Simulated and Measured Results for SS.16 to SS.18 at Interior Surface

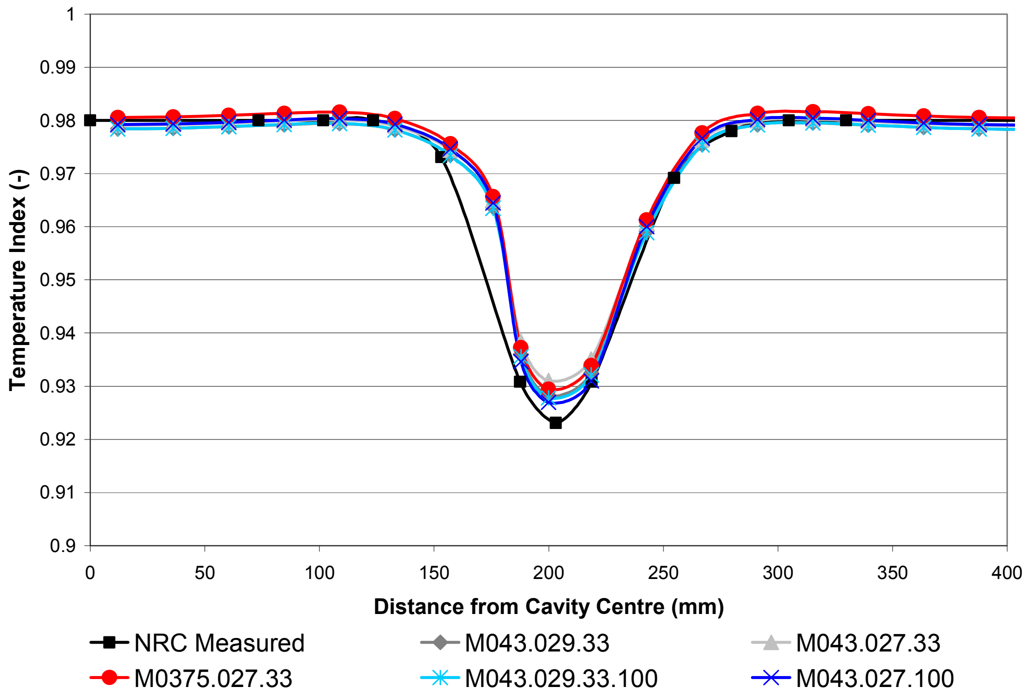


Figure C.6: Indexed Temperature Profile Comparison between Simulated and Measured Results for SS.21 at Warm Surface of Gypsum

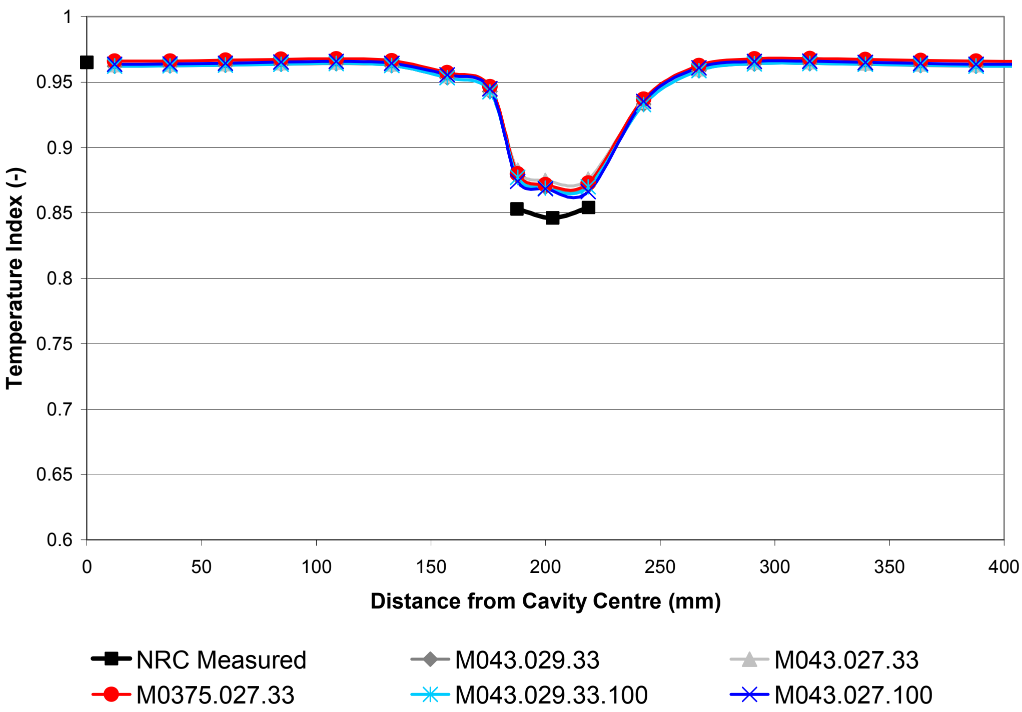


Figure C.7: Indexed Temperature Profile Comparison between Simulated and Measured Results for SS.21 at Cold Surface of Gypsum

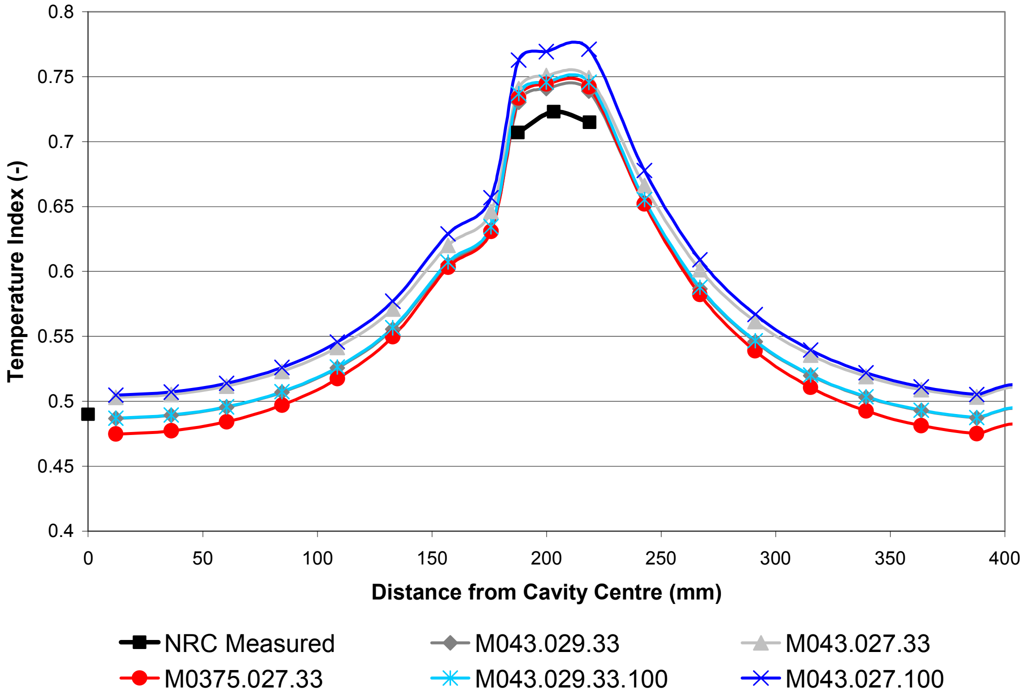


Figure C.8: Indexed Temperature Profile Comparison between Simulated and Measured Results for SS.21 at Warm Surface of OSB

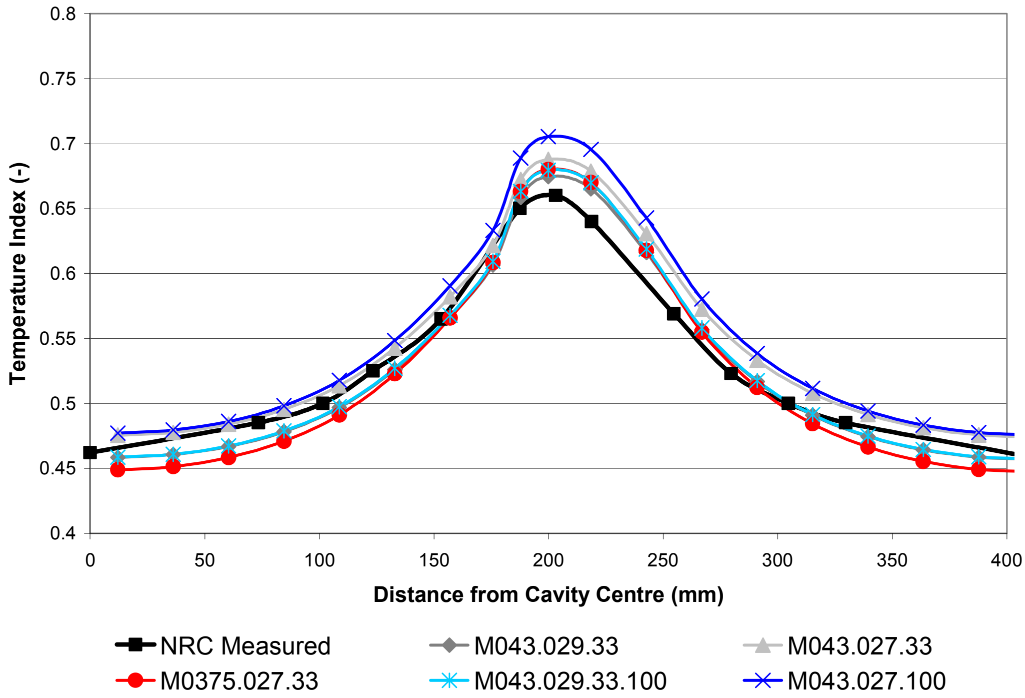


Figure C.9: Indexed Temperature Profile Comparison between Simulated and Measured Results for SS.21 at Cold Surface of OSB

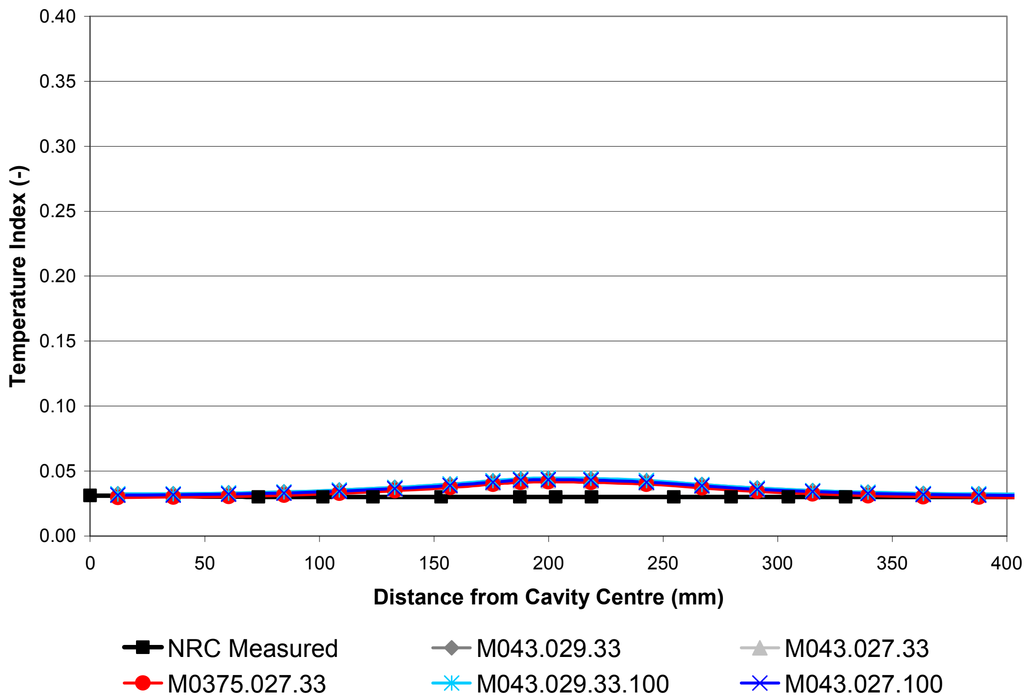


Figure C.10: Indexed Temperature Profile Comparison between Simulated and Measured Results for SS.21 at Exterior Surface of XPS

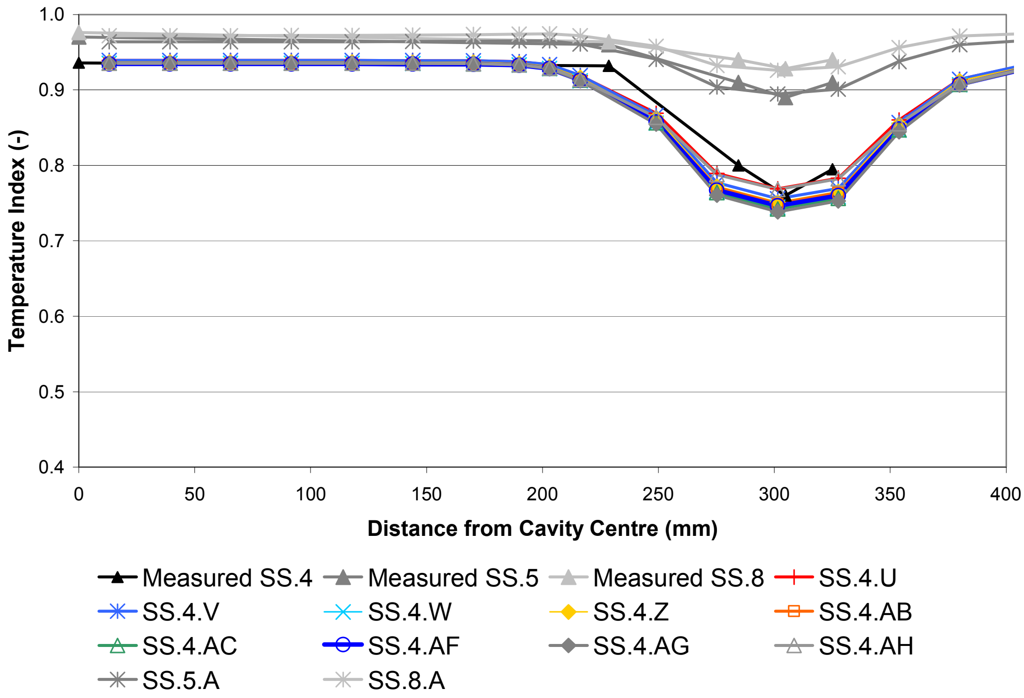


Figure C.11: Indexed Temperature Profile Comparison between Simulated and Measured Results for SS.4, SS.5, and SS.8 at Warm Surface of Gypsum

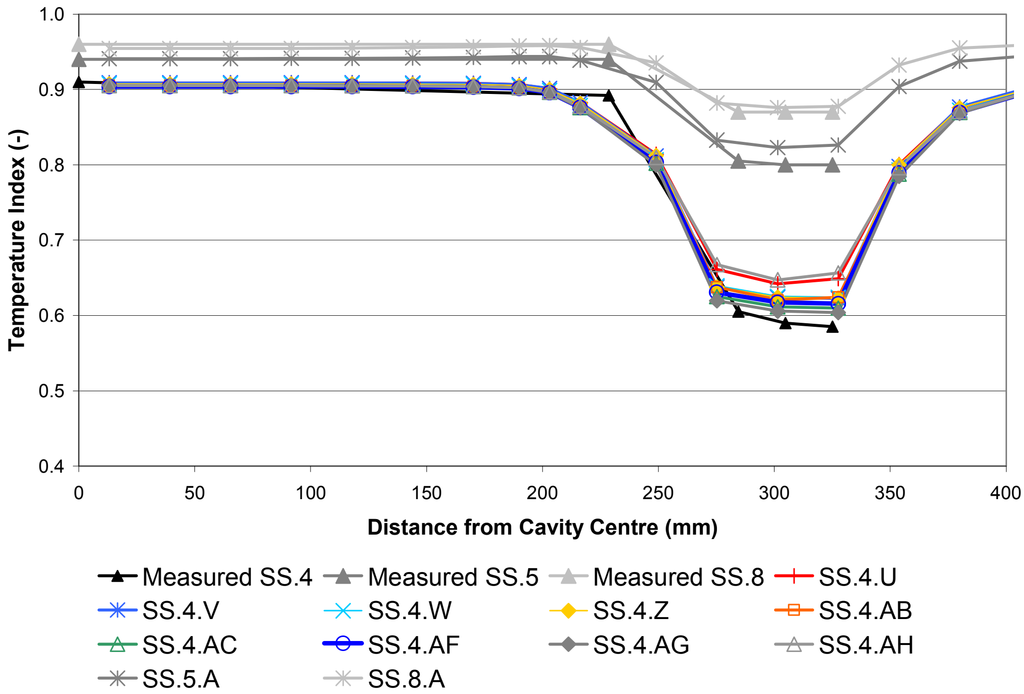


Figure C.12: Indexed Temperature Profile Comparison between Simulated and Measured Results for SS.4, SS.5, and SS.8 at Cold Surface of Gypsum

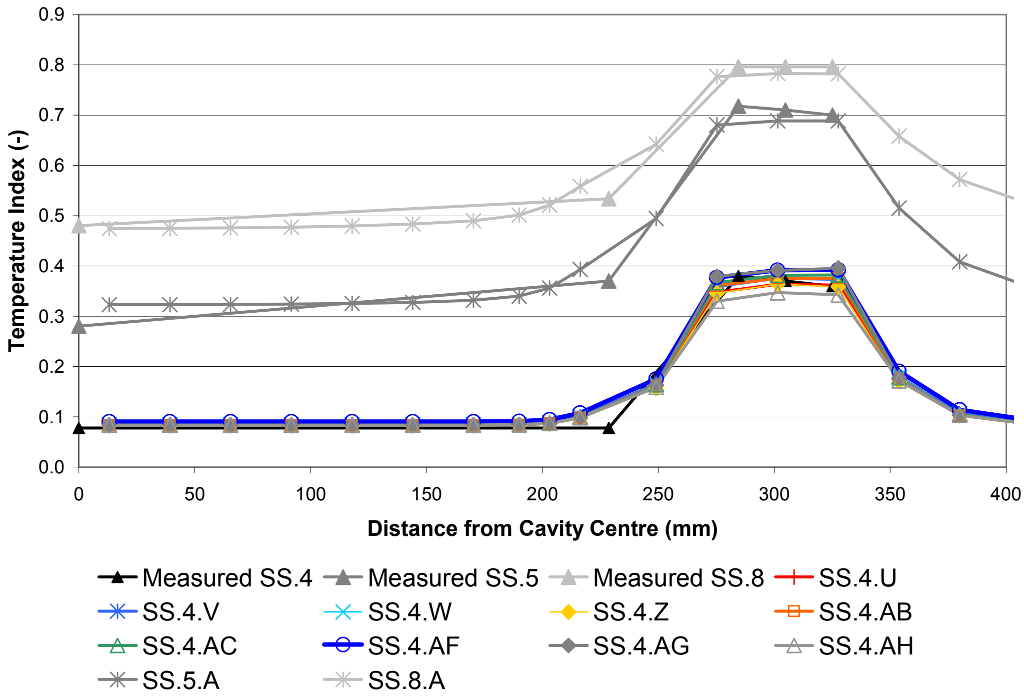


Figure C.13: Indexed Temperature Profile Comparison between Simulated and Measured Results for SS.4, SS.5, and SS.8 at Warm Surface of Sheathing

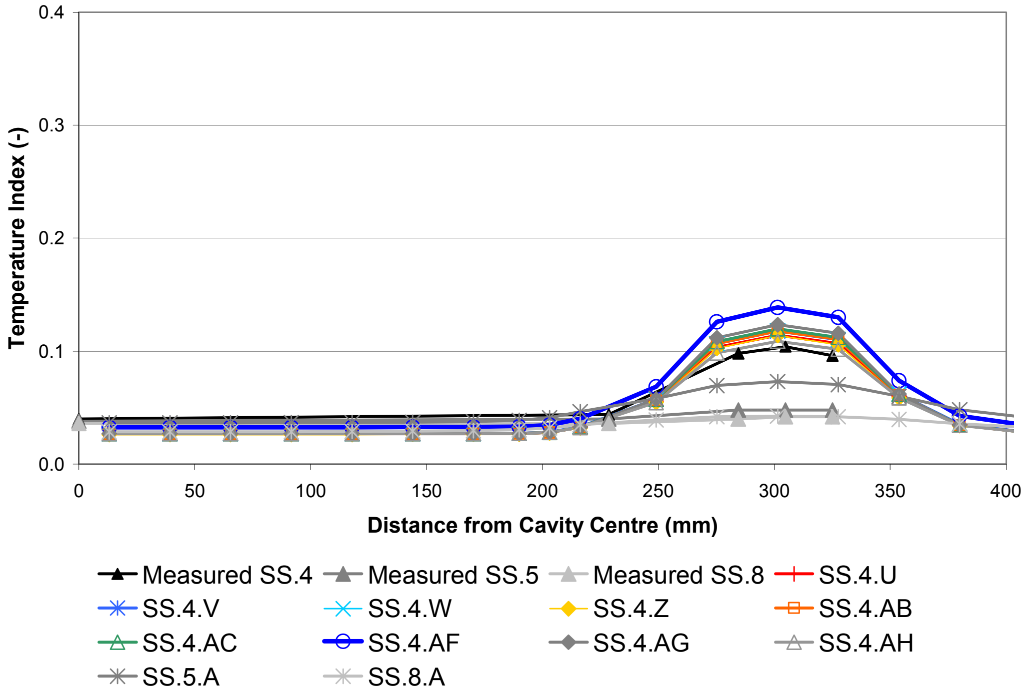


Figure C.14: Indexed Temperature Profile Comparison between Simulated and Measured Results for SS.4, SS.5, and SS.8 at Cold Surface of Sheathing

Table C.1: Comparison of Temperature Index and Thermal Resistance between Simulated and Measured Results for a Parametric Study of Specimen SS.4, SS.5, SS.8

		Measured	SS.4.A		SS.4.B		SS.4.C		SS.4.D		SS.4.E		SS.4.F		SS.4.G		SS.4.H		SS.4.I		SS.4.J		SS.4.K		SS.4.L		SS.4.M		SS.4.N	
Interior Surface Temp (°C)			18.46		18.61		18.5		18.3		18.77		18.65		19.69		17.55		18.01		18.04		18.05		18.09		18.04		18.14	
Exterior Surface Temp (°C)			-4.13		-4.28		-4.17		-3.96		-4.44		-4.33		-4.33		-4.57		-5		-3.71		-4.67		-4.7		-4.67		-4.77	
Heat Flow (W)			53.42		50.6		52.41		56.17		48.58		50.5		50.65		45.92		51.04		50.38		50.56		49.52		50.28		49.13	
RSI-Value		1.39	1.26	-9.5%	1.35	-2.7%	1.29	-7.2%	1.18	-15.9%	1.43	2.7%	1.36	-2.1%	1.42	2.0%	1.44	3.6%	1.35	-3.1%	1.29	-7.4%	1.34	-3.4%	1.38	-1.0%	1.35	-2.9%	1.39	0.3%
Gypsum - Warm	**centre of cavity**	**0.936**	**0.95**	**1.6%**	**0.95**	**1.5%**	**0.95**	**1.6%**	**0.95**	**1.5%**	**0.95**	**1.5%**	**0.95**	**1.5%**	**0.97**	**3.6%**	**0.92**	**-1.6%**	**0.94**	**0.4%**	**0.94**	**0.5%**	**0.94**	**0.4%**	**0.94**	**0.6%**	**0.94**	**0.6%**	**0.94**	**0.4%**
	centre of stud	0.76	0.81	5.3%	0.80	3.8%	0.80	3.6%	0.78	1.7%	0.84	8.4%	0.81	5.4%	0.90	14.1%	0.78	1.7%	0.77	1.3%	0.77	1.4%	0.78	1.5%	0.78	1.6%	0.76	0.4%	0.78	2.0%
Gypsum - Cold	**centre of cavity**	**0.91**	**0.92**	**1.2%**	**0.92**	**1.0%**	**0.92**	**1.2%**	**0.92**	**1.3%**	**0.92**	**1.3%**	**0.92**	**1.3%**	**0.94**	**3.3%**	**0.89**	**-1.7%**	**0.91**	**0.2%**	**0.91**	**0.4%**	**0.91**	**0.2%**	**0.92**	**0.6%**	**0.92**	**0.6%**	**0.91**	**0.3%**
	centre of stud	0.585	0.69	10.0%	0.66	7.6%	0.66	7.3%	0.64	5.4%	0.75	16.1%	0.70	11.2%	0.79	20.8%	0.69	10.6%	0.66	7.3%	0.66	7.4%	0.66	7.6%	0.66	7.6%	0.65	6.0%	0.67	8.5%
Sheathing - Warm	**centre of cavity**	**0.078**	**0.10**	**2.7%**	**0.09**	**0.8%**	**0.10**	**2.7%**	**0.09**	**0.9%**	**0.09**	**0.9%**	**0.09**	**0.9%**	**0.09**	**1.1%**	**0.08**	**0.6%**	**0.10**	**1.9%**	**0.10**	**1.7%**	**0.10**	**1.9%**	**0.09**	**1.5%**	**0.09**	**1.5%**	**0.10**	**1.9%**
	centre of stud	0.38	0.42	3.5%	0.36	-1.6%	0.45	7.3%	0.41	2.7%	0.29	-9.5%	0.31	-7.0%	0.30	-7.9%	0.27	-11.4%	0.38	-0.1%	0.38	-0.2%	0.40	1.6%	0.40	1.7%	0.41	3.0%	0.35	-2.9%
Sheathing - Cold	**centre of cavity**	**0.04**	**0.05**	**0.8%**	**0.05**	**0.9%**	**0.05**	**0.8%**	**0.05**	**0.9%**	**0.05**	**0.9%**	**0.05**	**0.9%**	**0.05**	**1.0%**	**0.05**	**0.8%**	**0.06**	**2.0%**	**0.06**	**1.9%**	**0.04**	**0.0%**	**0.04**	**-0.1%**	**0.04**	**-0.1%**	**0.04**	**0.0%**
	centre of stud	0.104	0.19	8.2%	0.20	9.7%	0.20	9.8%	0.22	11.9%	0.16	5.3%	0.17	6.6%	0.17	6.1%	0.15	4.2%	0.23	12.4%	0.23	12.3%	0.16	5.6%	0.16	5.6%	0.16	6.1%	0.14	3.6%
Interior Coefficient															15		5		6.67		6.67		6.67		6.67		6.67		6.67	
Exterior Coefficient															8.33		8.33		6.67		6.67		10		10		10		10	
Plywood									0.14		0.14		0.14		0.14		0.14		0.14		0.14		0.09		0.09		0.09		0.09	
Gypsum									0.176		0.176		0.176		0.176		0.176		0.176		0.176		0.176		0.176		0.16		0.176	
Batt									0.045		0.045		0.045		0.045		0.045		0.045		0.045		0.045		0.043		0.043		0.045	
Steel to Interior Sheathing					100				100		10		33		10		10		33		33		33		33		100		100	
Steel to Exterior Sheathing					100				100		10		10		10		10				33		33		33		33		10	
Steel to Insulation					100				100		100		100		10		10				33		100		100		100		100	

		Measured	SS.4.O		SS.4.P		SS.4.Q		SS.4.R		SS.4.S		SS.4.T		SS.4.U		SS.4.V		SS.4.W		SS.4.X		SS.4.Y		SS.4.Z		SS.4.AA		SS.4.AB	
Interior Surface Temp (°C)			18.12		18.09		18.17		17.88		17.83		17.77		17.97		17.89		17.69		17.81		17.82		18.82		17.7		17.73	
Exterior Surface Temp (°C)			-4.76		-4.7		-4.75		-5.81		-5.59		-5.2		-5.29		-5.26		-5.26		-5.31		-5.31		-5.31		-5.26		-5.27	
Heat Flow (W)			48.9		48.9		47.94		53.01		53.53		54.65		51.69		52.67		52.65		51.26		50.74		50.72		52.69		52.17	
RSI-Value		1.39	1.40	0.6%	1.39	0.3%	1.43	2.8%	1.34	-3.9%	1.31	-6.1%	1.26	-10.1%	1.35	-3.3%	1.31	-5.6%	1.30	-6.4%	1.35	-3.0%	1.36	-2.0%	1.42	2.3%	1.30	-6.5%	1.32	-5.3%
Gypsum - Warm	**centre of cavity**	**0.936**	**0.94**	**0.4%**	**0.95**	**0.9%**	**0.95**	**0.9%**	**0.94**	**0.3%**	**0.94**	**0.3%**	**0.94**	**0.2%**	**0.94**	**0.3%**	**0.94**	**0.3%**	**0.94**	**-0.1%**	**0.94**	**-0.1%**	**0.94**	**0.1%**	**0.94**	**0.1%**	**0.93**	**-0.2%**	**0.94**	**-0.1%**
	centre of stud	0.76	0.78	1.7%	0.76	0.5%	0.78	1.7%	0.76	0.2%	0.75	-0.9%	0.75	-0.9%	0.77	0.9%	0.76	-0.4%	0.74	-1.6%	0.76	0.1%	0.76	-0.4%	0.75	-0.9%	0.75	-1.1%	0.75	-1.1%
Gypsum - Cold	**centre of cavity**	**0.91**	**0.91**	**0.3%**	**0.92**	**1.0%**	**0.92**	**1.0%**	**0.91**	**-0.2%**	**0.91**	**-0.2%**	**0.91**	**-0.3%**	**0.91**	**-0.1%**	**0.91**	**-0.1%**	**0.91**	**-0.2%**	**0.91**	**-0.2%**	**0.91**	**0.0%**	**0.91**	**-0.3%**	**0.90**	**-0.7%**	**0.91**	**-0.5%**
	centre of stud	0.585	0.66	7.9%	0.65	6.2%	0.66	7.9%	0.63	4.5%	0.61	3.0%	0.61	2.9%	0.64	5.7%	0.62	3.7%	0.62	3.9%	0.65	6.2%	0.64	5.6%	0.62	3.8%	0.62	3.5%	0.62	3.5%
Sheathing - Warm	**centre of cavity**	**0.078**	**0.10**	**1.9%**	**0.09**	**1.0%**	**0.09**	**1.0%**	**0.07**	**-0.4%**	**0.08**	**0.0%**	**0.06**	**-1.3%**	**0.08**	**0.6%**	**0.08**	**0.6%**	**0.08**	**0.6%**	**0.08**	**0.6%**	**0.08**	**0.4%**	**0.08**	**0.4%**	**0.09**	**0.7%**	**0.08**	**0.6%**
	centre of stud	0.38	0.35	-3.0%	0.41	2.8%	0.39	1.5%	0.34	-3.9%	0.36	-1.9%	0.31	-7.3%	0.36	-1.6%	0.38	-0.4%	0.38	-0.4%	0.36	-2.4%	0.36	-1.8%	0.36	-1.6%	0.38	-0.4%	0.38	-0.4%
Sheathing - Cold	**centre of cavity**	**0.04**	**0.04**	**0.0%**	**0.04**	**-0.4%**	**0.04**	**-0.4%**	**0.02**	**-2.4%**	**0.02**	**-2.0%**	**0.03**	**-1.2%**	**0.03**	**-1.3%**	**0.03**	**-1.3%**	**0.03**	**-1.3%**	**0.03**	**-1.3%**	**0.03**	**-1.4%**	**0.03**	**-1.4%**	**0.03**	**-1.3%**	**0.03**	**-1.3%**
	centre of stud	0.104	0.14	3.7%	0.16	6.1%	0.16	5.5%	0.07	-3.0%	0.09	-1.1%	0.13	2.2%	0.11	1.0%	0.12	1.4%	0.12	1.4%	0.11	0.7%	0.11	0.9%	0.11	1.0%	0.12	1.4%	0.12	1.4%
Interior Coefficient			6.67		6.62		6.62		6.62		6.62		6.62		6.62		6.62		6.25		6.25		6.25		6.25		6.25		6.25	
Exterior Coefficient			10		10		10		25		20		15		15		15		15		15		15		15		15		15	
Plywood			0.09		0.09		0.09		0.09		0.09		0.14		0.09		0.09		0.09		0.09		0.09		0.09		0.09		0.09	
Gypsum			0.176		0.176		0.176		0.16		0.16		0.16		0.16		0.16		0.176		0.176		0.16		0.16		0.16		0.16	
Batt			0.045		0.04		0.04		0.045		0.045		0.045		0.045		0.045		0.045		0.045		0.045		0.045		0.046		0.045	
Steel to Interior Sheathing			200		100		33		33		100		33		33		100		100		33		50		100		50		50	
Steel to Exterior Sheathing			10		33		33		33		33		33		33		33		33		25		25		25		50		50	
Steel to Insulation			100		100		100		100		100		100		100		100		100		100		25		25		100		100	

		Measured	SS.4.AC		SS.4.AD		SS.4.AE		SS.4.AF		SS.4.AG		SS.4.AH		Measured	SS.5.A		Measured	SS.8.A	
Interior Surface Temp (°C)			17.69		17.51		17.46		17.71		17.65		17.87			19.57			17.69	
Exterior Surface Temp (°C)			-5.26		-5.17		-5.15		-4.99		-5.24		-5.33			-5.31			-5.26	
Heat Flow (W)			52.67		55.29		55.89		50.47		53.16		50.47			31.58			52.67	
RSI-Value		1.39	1.30	-6.5%	1.23	-12.5%	1.21	-13.9%	1.34	-3.3%	1.29	-7.7%	1.37	-1.1%	2.41	2.36	-2.3%	1.39	3.33	82.2%
Gypsum - Warm	**centre of cavity**	**0.936**	**0.94**	**-0.1%**	**0.93**	**-0.2%**	**0.93**	**-0.2%**	**0.93**	**-0.1%**	**0.94**	**-0.1%**	**0.94**	**-0.1%**	**0.97**	**0.97**	**-0.4%**	**0.98**	**0.97**	**-0.6%**
	centre of stud	0.76	0.74	-1.8%	0.73	-3.1%	0.72	-3.9%	0.75	-1.4%	0.74	-2.1%	0.77	0.8%	0.89	0.89	0.5%	0.93	0.93	-0.4%
Gypsum - Cold	**centre of cavity**	**0.91**	**0.91**	**-0.5%**	**0.90**	**-0.7%**	**0.90**	**-0.7%**	**0.90**	**-0.6%**	**0.91**	**-0.5%**	**0.91**	**-0.5%**	**0.94**	**0.94**	**0.4%**	**0.96**	**0.96**	**-0.1%**
	centre of stud	0.585	0.61	2.5%	0.59	0.4%	0.58	-0.8%	0.62	3.1%	0.60	1.9%	0.65	6.2%	0.8	0.82	2.3%	0.87	0.88	0.6%
Sheathing - Warm	**centre of cavity**	**0.078**	**0.08**	**0.6%**	**0.06**	**-1.3%**	**0.06**	**-1.3%**	**0.09**	**1.2%**	**0.08**	**0.6%**	**0.08**	**0.6%**	**0.28**	**0.32**	**4.3%**	**0.48**	**0.47**	**-0.5%**
	centre of stud	0.38	0.38	0.2%	0.32	-6.2%	0.32	-5.7%	0.39	1.2%	0.40	1.6%	0.35	-3.3%	0.71	0.69	-2.1%	0.8	0.78	-1.8%
Sheathing - Cold	**centre of cavity**	**0.04**	**0.03**	**-1.3%**	**0.03**	**-1.3%**	**0.03**	**-1.3%**	**0.03**	**-0.7%**	**0.03**	**-1.3%**	**0.03**	**-1.3%**	**0.04**	**0.04**	**-0.3%**	**0.04**	**0.03**	**-1.1%**
	centre of stud	0.104	0.12	1.6%	0.13	2.7%	0.13	2.9%	0.14	3.5%	0.12	1.9%	0.11	0.5%	0.05	0.07	-3.1%	0.04	0.04	0.3%
Interior Coefficient			6.25		6.25		6.25		6.25		6.25		6.25							
Exterior Coefficient			15		15		15		12.5		15		15							
Plywood			0.09		0.14		0.14		0.09		0.09		0.09							
Gypsum			0.16		0.16		0.16		0.16		0.16		0.16							
Batt			0.045		0.045		0.045		0.046		0.045		0.045							
Steel to Interior Sheathing			100		50		100		100		100		25							
Steel to Exterior Sheathing			50		50		50		50		100		25							
Steel to Insulation			100		100		100		100		100		100							

APPENDIX D – Comparison of Simulated and Measured Heat Flux for Transient Conditions

APPENDIX D.1: Specimen SS.1 - Sinusoidal Change of Cold Side Temperature, Constant Hot Side Temperature

Table D.1: Comparison of Simulated and Measured Interior Heat Flux

Time (hr)	T_h (°C)	T_c (°C)	Measured Q_{in} (W/m^2)[1]	Simulated Q_{in} (W/m^2)	% Difference
0	21	-20.0	31.4	31.9	0.5%
1	21	-16.1	30.9	31.6	0.7%
2	21	-12.5	29.2	29.8	0.6%
3	21	-9.4	26.8	27.3	0.5%
4	21	-7.0	24.5	24.9	0.4%
5	21	-5.5	22.5	22.9	0.4%
6	21	-5.0	21.1	21.5	0.4%
7	21	-5.5	20.3	20.7	0.4%
8	21	-7.0	20.2	20.7	0.5%
9	21	-9.4	20.9	21.5	0.6%
10	21	-12.5	22.3	23.0	0.7%
11	21	-16.1	24.2	25.1	0.8%
12	21	-20.0	26.7	27.6	0.9%
13	21	-23.9	29.4	30.5	1.1%
14	21	-27.5	32.2	33.4	1.2%
15	21	-30.6	35.0	36.2	1.2%
16	21	-33.0	37.5	38.8	1.3%
17	21	-34.5	39.5	40.8	1.3%
18	21	-35.0	41.0	42.3	1.3%
19	21	-34.5	41.8	43.1	1.3%
20	21	-33.0	41.9	43.0	1.2%
21	21	-30.6	41.2	42.3	1.1%
22	21	-27.5	39.8	40.8	1.0%
23	21	-23.9	37.8	38.7	0.9%
24	21	-20.0	35.4	36.2	0.8%
Maximum					1.3%
Minimum					0.4%
Average					0.8%

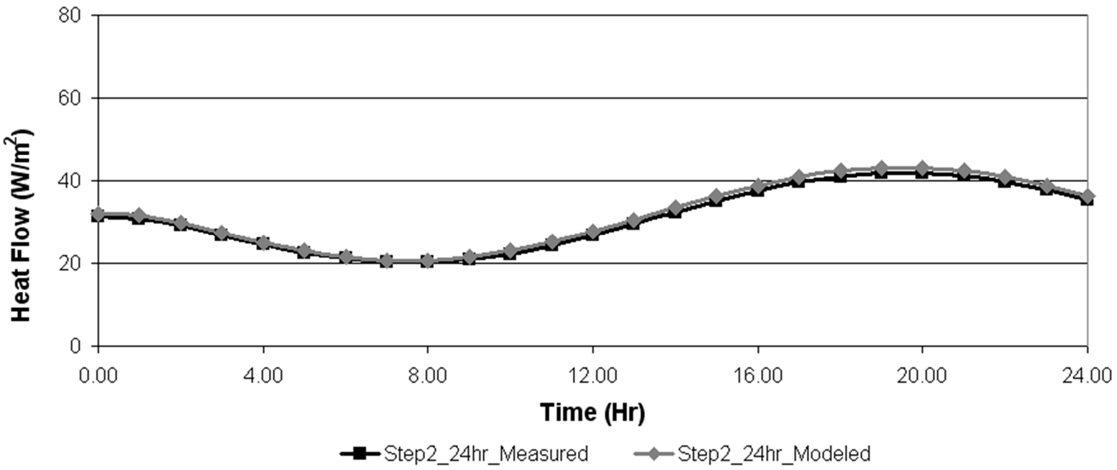


Figure D.1: Comparison of Simulated and Measured Interior Heat Flux

[1] Calculated value using z-function coefficients derived from measured data

APPENDIX D.2: Specimen SS.2 - Sinusoidal Change of Cold Side Temperature, Constant Hot Side Temperature

Table D.2: Comparison of Simulated and Measured Interior Heat Flux

Time (hr)	T_h (°C)	T_c (°C)	Measured* Q_{in} (W/m^2)[1]	Simulated Q_{in} (W/m^2)	% Difference
0	21	-20.0	31.2	31.2	0.1%
1	21	-16.1	30.3	30.3	0.1%
2	21	-12.5	29.1	29.1	0.1%
3	21	-9.4	27.6	27.6	0.1%
4	21	-7.0	26.0	26.0	0.1%
5	21	-5.5	24.4	24.4	0.2%
6	21	-5.0	22.8	22.9	0.4%
7	21	-5.5	21.5	21.6	0.7%
8	21	-7.0	20.4	20.6	1.1%
9	21	-9.4	19.7	20.0	1.7%
10	21	-12.5	19.4	19.8	2.4%
11	21	-16.1	19.5	20.0	3.0%
12	21	-20.0	20.0	20.7	3.5%
13	21	-23.9	20.9	21.7	3.9%
14	21	-27.5	22.1	23.1	4.2%
15	21	-30.6	23.6	24.6	4.3%
16	21	-33.0	25.2	26.3	4.2%
17	21	-34.5	26.8	27.9	4.1%
18	21	-35.0	28.4	29.5	3.9%
19	21	-34.5	29.7	30.8	3.6%
20	21	-33.0	30.8	31.8	3.3%
21	21	-30.6	31.5	32.4	2.9%
22	21	-27.5	31.8	32.6	2.6%
23	21	-23.9	31.7	32.4	2.2%
24	21	-20.0	31.2	31.8	1.9%
Maximum					4.3%
Minimum					0.1%
Average					2.2%

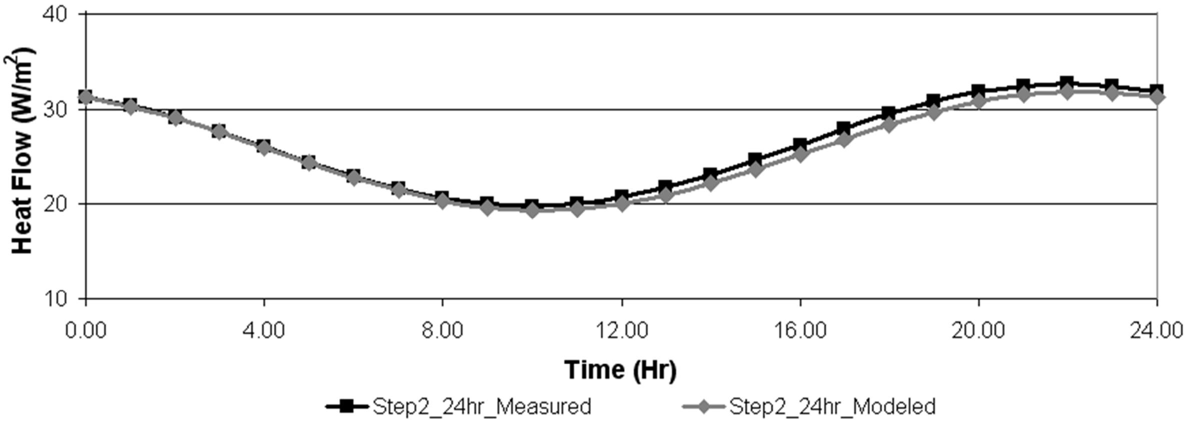


Figure D.2: Comparison of Simulated and Measured Interior Heat Flux

[1] Calculated value using z-function coefficients derived from measured data. The sign of one coefficient (C4) was reported with and without a negative sign in two different sections in the reference paper (page 11 and 4-1). A positive sign produces good agreement with simulated results. A negative sign produces unrealistic values.

APPENDIX D.3: Specimen M.1 - Sinusoidal Change of Cold Side Temperature, Constant Hot Side Temperature

Table D.3: Comparison of Simulated and Measured Interior Heat Flux

Time (hr)	T_h (°C)	T_c (°C)	Measured Q_{in} (W/m²)[1]	Simulated Q_{in} (W/m²)	% Difference
0	21	-20.0	41.9	41.2	1.5%
1	21	-16.1	42.4	41.2	2.8%
2	21	-12.5	42.5	41.1	3.3%
3	21	-9.4	42.2	40.8	3.4%
4	21	-7.0	41.5	40.2	3.3%
5	21	-5.5	40.6	39.4	3.2%
6	21	-5.0	39.5	38.4	3.1%
7	21	-5.5	38.4	37.3	3.0%
8	21	-7.0	37.3	36.2	3.0%
9	21	-9.4	36.4	35.3	3.0%
10	21	-12.5	35.7	34.6	3.2%
11	21	-16.1	35.3	34.1	3.4%
12	21	-20.0	35.2	34.0	3.7%
13	21	-23.9	35.5	34.2	4.0%
14	21	-27.5	36.2	34.8	4.3%
15	21	-30.6	37.3	35.6	4.6%
16	21	-33.0	38.6	36.8	4.8%
17	21	-34.5	40.1	38.2	5.0%
18	21	-35.0	41.7	39.7	5.1%
19	21	-34.5	43.3	41.2	5.1%
20	21	-33.0	44.9	42.7	5.1%
21	21	-30.6	46.2	44.0	5.0%
22	21	-27.5	47.2	45.0	4.9%
23	21	-23.9	47.9	45.8	4.8%
24	21	-20.0	48.8	46.2	4.6%
Maximum					5.2%
Minimum					1.5%
Average					3.9%

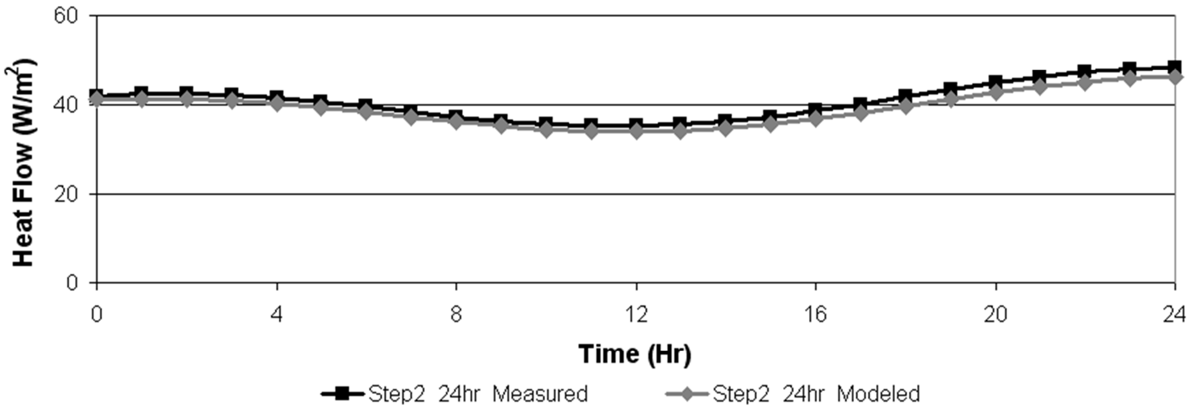


Figure D.3: Comparison of Simulated and Measured Interior Heat Flux

[1] Calculated value using z-function coefficients derived from measured data

APPENDIX D.4: Specimen M.2 - Sinusoidal Change of Cold Side Temperature, Constant Hot Side Temperature

Table D.4: Comparison of Simulated and Measured Interior Heat Flux

Time (hr)	T_h (°C)	T_c (°C)	Measured Q_{in} (W/m^2)[1]	Simulated Q_{in} (W/m^2)	% Difference
0	21	-20.0	58.8	58.8	0.0%
1	21	-16.1	57.4	57.4	0.1%
2	21	-12.5	56.0	56.1	0.1%
3	21	-9.4	54.5	54.6	0.1%
4	21	-7.0	52.9	53.1	0.2%
5	21	-5.5	51.2	51.4	0.2%
6	21	-5.0	49.4	49.6	0.3%
7	21	-5.5	47.6	47.9	0.3%
8	21	-7.0	45.9	46.2	0.3%
9	21	-9.4	44.4	44.7	0.3%
10	21	-12.5	43.0	43.3	0.3%
11	21	-16.1	42.0	42.3	0.3%
12	21	-20.0	41.3	41.6	0.3%
13	21	-23.9	40.9	41.2	0.3%
14	21	-27.5	40.8	41.1	0.3%
15	21	-30.6	41.1	41.4	0.3%
16	21	-33.0	41.7	41.9	0.2%
17	21	-34.5	42.5	42.7	0.2%
18	21	-35.0	43.4	43.6	0.2%
19	21	-34.5	44.4	44.6	0.2%
20	21	-33.0	45.4	45.6	0.3%
21	21	-30.6	46.3	46.6	0.3%
22	21	-27.5	47.0	47.3	0.3%
23	21	-23.9	47.5	47.8	0.3%
24	21	-20.0	47.7	48.1	0.3%
Maximum					0.3%
Minimum					0.0%
Average					0.2%

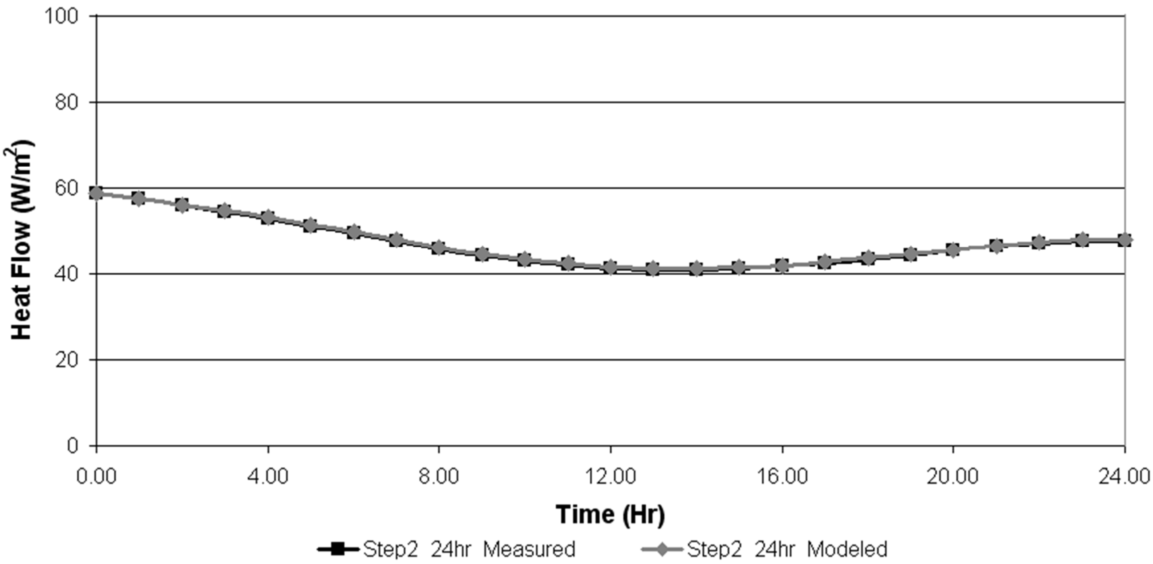


Figure D.4: Comparison of Simulated and Measured Interior Heat Flux

[1] Calculated value using z-function coefficients derived from measured data

APPENDIX D.5: M.4 - Sinusoidal Change of Cold Side Temperature, Constant Hot Side Temperature

Table D.5: Comparison of Simulated and Measured Interior Heat Flux

Time (hr)	T_h (°C)	T_c (°C)	Measured Q_{in} (W/m^2)[5]	Simulated Q_{in} (W/m^2)	% Difference
104	26.1	-8.1	21.9	21.8	4.1%
116	26.1	-8.1	22.0	22.9	4.1%
128	26.1	-8.1	22.1	23.0	4.2%
140	26.1	-8.1	22.2	23.0	3.9%
152	26.1	5.8	21.2	21.4	1.3%
164	26.1	5.8	18.2	18.4	0.8%
176	26.1	5.8	16.5	16.6	0.7%
188	26.1	5.8	15.3	15.5	1.8%
200	26.1	5.8	14.8	14.9	0.6%
212	26.1	5.8	14.4	14.5	0.3%
224	26.1	5.8	14.2	14.2	0.1%
236	26.1	5.8	14.1	14.0	0.6%
248	26.1	5.8	14.0	13.9	1.0%
260	26.1	5.8	14.0	13.8	1.5%
266	26.1	21.8	13.8	13.8	0%
272	26.1	5.8	12.6	12.4	1.4%
284	26.1	5.8	12.9	12.8	0.9%
296	26.1	5.8	13.2	13.2	0.2%
308	26.1	5.8	13.5	13.4	0.6%
320	26.1	5.8	13.7	13.5	1.6%
Maximum					4.2%
Minimum					0.1%
Average					1.6%

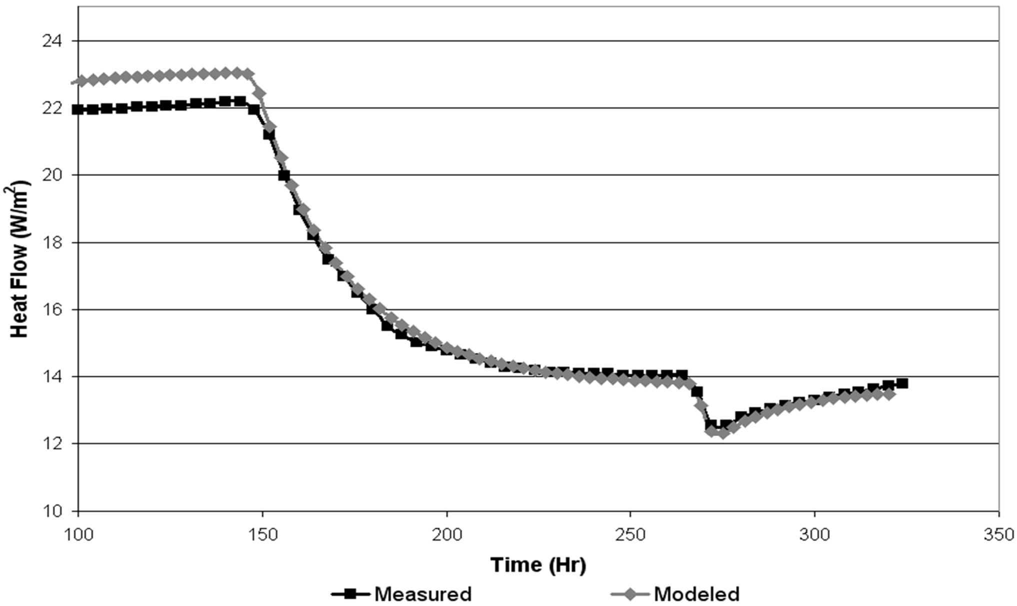
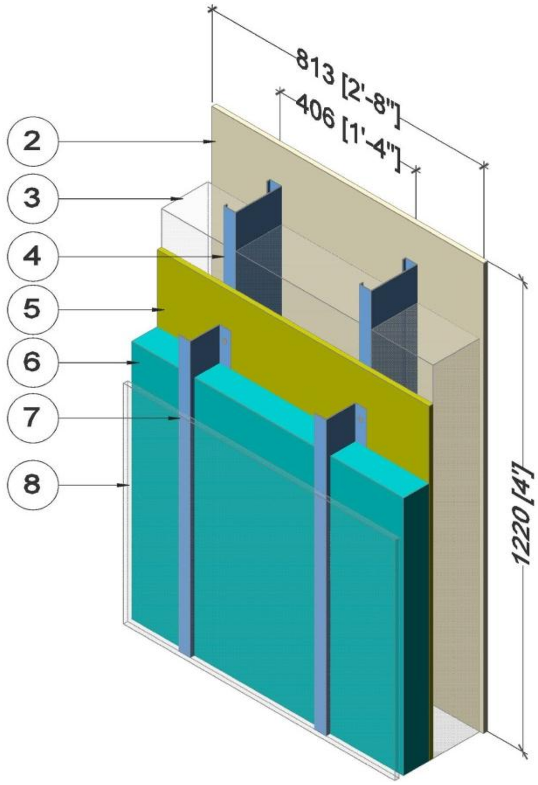


Figure D.5: Comparison of Simulated and Measured Interior Heat Flux

[5] Extrapolated from graphs in reference paper

APPENDIX E – DETAIL CATALOGUE

Detail 01 | Exterior Insulated 3 5/8″ x 1 5/8″ Steel Stud (16″ o.c.) Wall Assembly with Vertical Z-Girts (16″ o.c.) Supporting Metal Cladding – Clear Wall

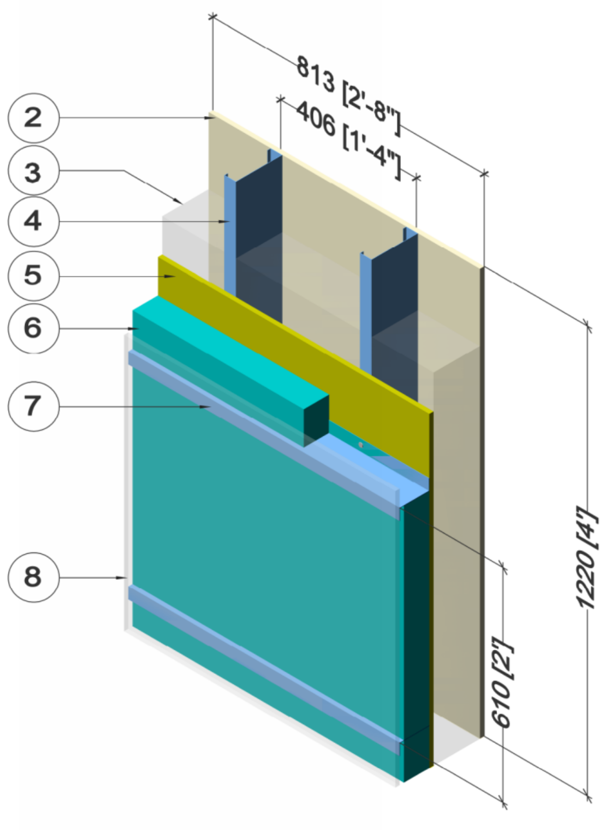


ID	Component	Thickness Inches (mm)	Conductivity Btu·in / ft^2·hr·^{o}F (W/m K)	Nominal Resistance hr·ft^2·^{o}F/Btu (m^{2}K/W)	Density lb/ft^3 (kg/m^3)	Specific Heat Btu/lb·^{o}F (J/kg K)
1	Interior Film (right side)[1]	-	-	R-0.7 (0.12 RSI)	-	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
3	Air in Stud Cavity	3 5/8" (92)	-	R-0.9 (0.16 RSI)	0.075 (1.2)	0.24 (1000)
4	3 5/8" x 1 5/8" Steel Studs	18 gauge	430 (62)	-	489 (7830)	0.12 (500)
5	Exterior Sheathing	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
6	Exterior Insulation	Varies	-	R5 to R25 (0.88 to 4.4 RSI)	1.8 (28)	0.29 (1220)
7	Vertical Z-Girts w/ 1 ½" Flange	18 gauge	430 (62)	-	489 (7830)	0.12 (500)
8	Metal cladding with ½" (13mm) vented air space is incorporated into exterior heat transfer coefficient					
9	Exterior Film (left side)[1]	-	-	R-0.7 (0.12 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation

Detail 02

Exterior Insulated 3 5/8″ x 1 5/8″ Steel Stud (16″ o.c.) Wall Assembly with Horizontal Z-Girts (24″ o.c.) Supporting Metal Cladding – Clear Wall

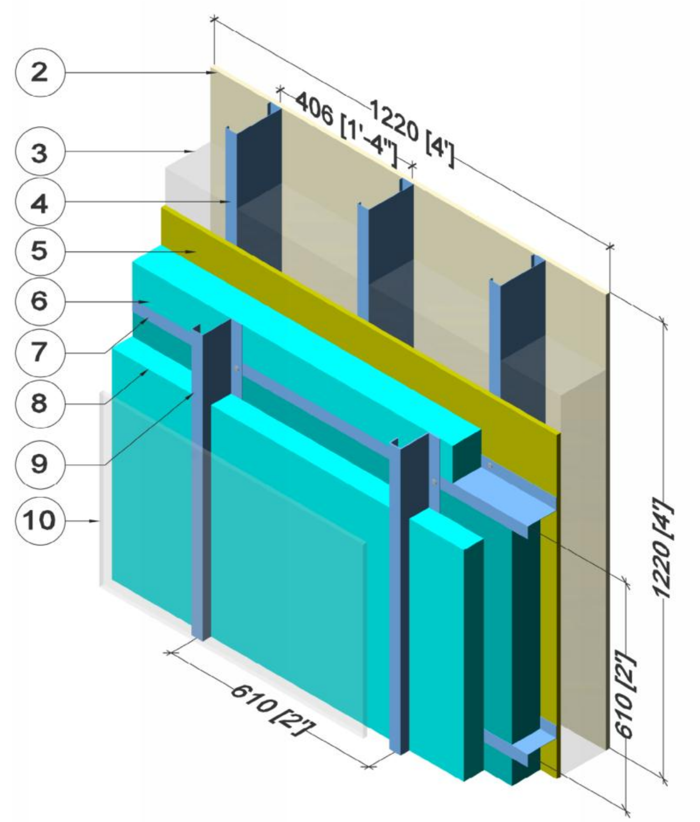


ID	Component	Thickness Inches (mm)	Conductivity Btu·in / ft²·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)	Specific Heat Btu/lb·°F (J/kg K)
1	Interior Film (right side)[1]	-	-	R-0.7 (0.12 RSI)	-	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
3	Air in Stud Cavity	3 5/8" (92)	-	R-0.9 (0.16 RSI)	0.075 (1.2)	0.24 (1000)
4	3 5/8" x 1 5/8" Steel Studs	18 gauge	430 (62)	-	489 (7830)	0.12 (500)
5	Exterior Sheathing	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
6	Exterior Insulation	Varies	-	R5 to R25 (0.88 to 4.4 RSI)	1.8 (28)	0.29 (1220)
7	Horizontal Z-Girts w/ 1 ½" Flange	18 gauge	430 (62)	-	489 (7830)	0.12 (500)
8	Metal cladding with ½" (13mm) vented air space is incorporated into exterior heat transfer coefficient					
9	Exterior Film (left side)[1]	-	-	R-0.7 (0.12 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation

Detail 03

Exterior Insulated 3 5/8″ x 1 5/8″ Steel Stud (16″ o.c.) Wall Assembly with Vertical Z-Girts (24″ o.c.) & Horizontal Z-Girts (24″ o.c.) Supporting Metal Cladding – Clear Wall

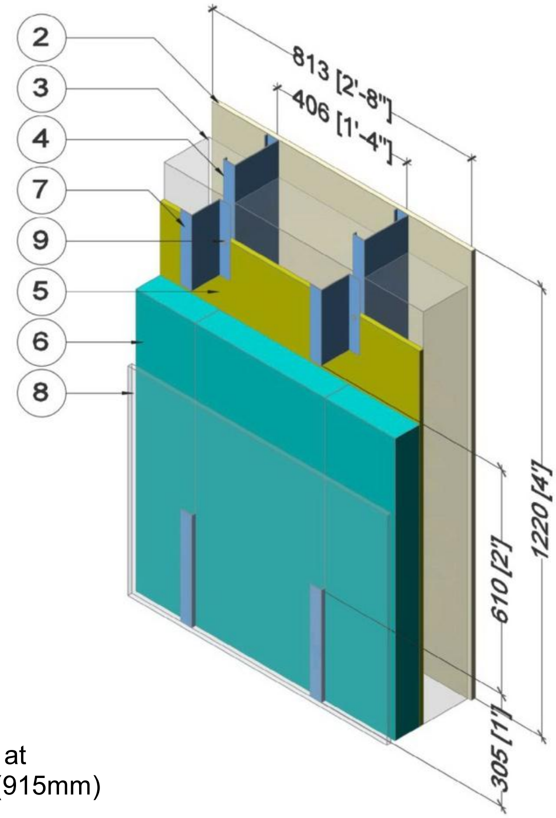


ID	Component	Thickness Inches (mm)	Conductivity Btu·in / ft²·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)	Specific Heat Btu/lb·°F (J/kg K)
1	Interior Film (right side)[1]	-	-	R-0.7 (0.12 RSI)	-	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
3	Air in Stud Cavity	3 5/8" (92)	-	R-0.9 (0.16 RSI)	0.075 (1.2)	0.24 (1000)
4	3 5/8" x 1 5/8" Steel Studs	18 gauge	430 (62)	-	489 (7830)	0.12 (500)
5	Exterior Sheathing	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
6	Exterior Insulation – Horizontal Z-Girts	Varies	-	R5 to R25 (0.88 to 4.4 RSI)	1.8 (28)	0.29 (1220)
7	Horizontal Z-Girts w/ 1 ½" flange	18 gauge	430 (62)	-	489 (7830)	0.12 (500)
8	Exterior Insulation – Vertical Z-girts	-	-	R-5 (0.88 RSI)	1.8 (28)	0.29 (1220)
9	Vertical Z-Girts w/ 1 ½" Flange	18 gauge	430 (62)	-	489 (7830)	0.12 (500)
10	Metal cladding with ½" (13mm) vented air space is incorporated into exterior heat transfer coefficient					
11	Exterior Film (left side)[1]	-	-	R-0.7 (0.12 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation

Detail 04

Exterior Insulated 3 5/8″ x 1 5/8″ Steel Stud (16″ o.c.) Wall Assembly with Intermittent Vertical Z-Girts (16″ o.c.) Supporting Metal Cladding – Clear Wall



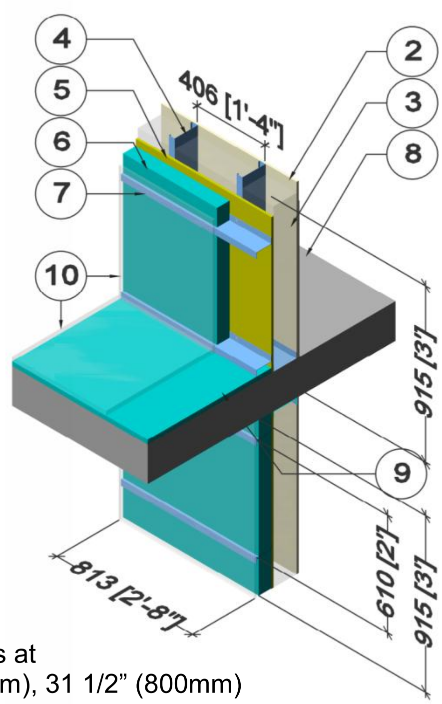
*Vertical spacing of the girts varies at 12" (304mm), 24" (610mm) & 36" (915mm)

ID	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 Film (right side)[1]	-	-	R-0.7 (0.12 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	3 5/8" (92)	-	R-0.9 (0.16 RSI)	0.075 (1.2)	0.24 (1000)
4	3 5/8" x 1 5/8" Steel Studs	18 gauge	430 (62)	-	489 (7830)	0.12 (500)
5	Exterior Sheathing	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
6	Exterior Insulation	Varies	-	R5 to R25 (0.88 to 4.4 RSI)	1.8 (28)	0.29 (1220)
7	Intermittent vertical Z-Girts w/ 1 ½" Flange	18 gauge	430 (62)	-	489 (7830)	0.12 (500)
8	Metal cladding with ½" (13mm) vented air space is incorporated into exterior heat transfer coefficient					
9	Exterior Film (left side)[1]	-	-	R-0.7 (0.12 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation

Detail 05

Exterior Insulated 3 5/8″ x 1 5/8″ Steel Stud (16″ o.c.) Wall Assembly with Horizontal Z-Girts (24″ o.c.) Supporting Metal Cladding – Slab Intersection with Top Side Insulation



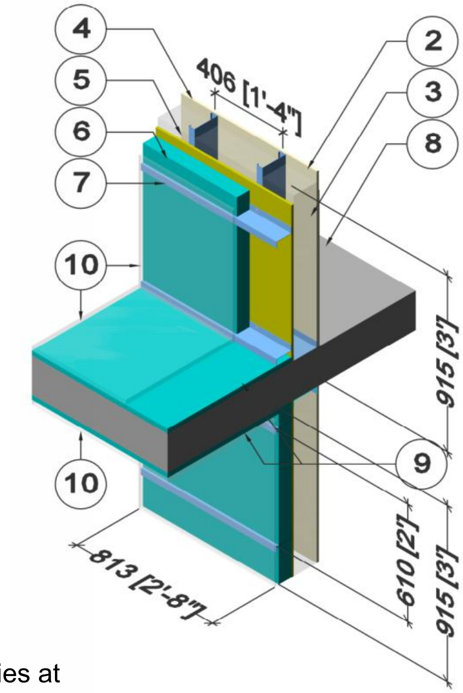
*Exterior Balcony Insulation Length varies at
0" (0mm), 7 7/8" (200mm), 15 3/4" (400mm), 31 1/2" (800mm)

ID	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 Film (right side)[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	3 5/8" (92)	-	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	Exterior Sheathing	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
6	Exterior Insulation	-	-	R-15 (2.64 RSI)	1.8 (28)	0.29 (1220)
7	Horizontal Z-Girts w/ 1 ½" Flange	18 gauge	430 (62)	-	489 (7830)	0.12 (500)
8	Concrete Slab	8" (203)	12 (1.8)	-	140 (2250)	0.20 (850)
9	Exterior Insulation, Balcony	1" (25)	-	R5 (0.88 RSI)	1.8 (28)	0.29 (1220)
10	Metal cladding/flashing/ finished soffit/pavers with vented air space is incorporated into exterior heat transfer coefficient					
11	Exterior Film (left side)[1]	-	-	R-0.2 (0.03 RSI) to R-0.7 (0.12 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation

Detail 05a

Exterior Insulated 3 5/8″ x 1 5/8″ Steel Stud (16″ o.c.) Wall Assembly with Horizontal Z-Girts (24″ o.c.) Supporting Metal Cladding – Slab Intersection with Top & Under Side Insulation



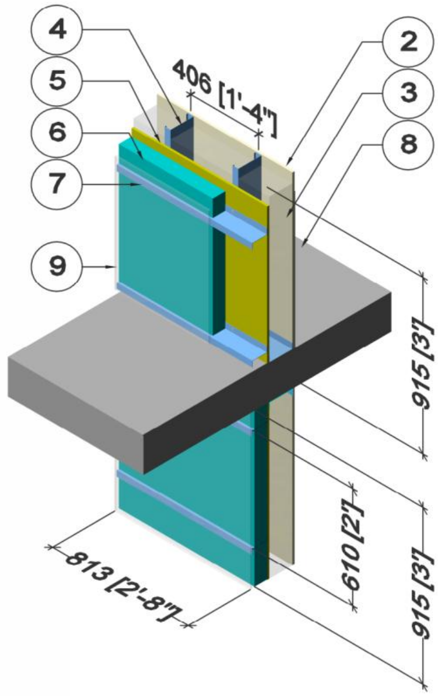
*Exterior Balcony Insulation Length varies at
0” (0mm), 7 7/8” (200mm), 15 3/4” (400mm), 31 1/2” (800mm)

ID	Component	Thickness Inches (mm)	Conductivity Btu·in / $ft^2 \cdot hr \cdot {}^oF$ (W/m K)	Nominal Resistance $hr \cdot ft^2 \cdot {}^oF/Btu$ (m^2K/W)	Density lb/ft^3 (kg/m^3)	Specific Heat $Btu/lb \cdot {}^oF$ (J/kg K)
1	Interior Film (right side)[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	3 5/8” (92)	-	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	Exterior Sheathing	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
6	Exterior Insulation	-	-	R-15 (2.64 RSI)	1.8 (28)	0.29 (1220)
7	Horizontal Z-Girts w/ 1 ½” Flange	18 gauge	430 (62)	-	489 (7830)	0.12 (500)
8	Concrete Slab	8” (203)	12 (1.8)	-	140 (2250)	0.20 (850)
9	Exterior Insulation, Balcony & Soffit	1” (25)	-	R5 (0.88 RSI)	1.8 (28)	0.29 (1220)
10	Metal cladding/flashing/ finished soffit/pavers with vented air space is incorporated into exterior heat transfer coefficient					
11	Exterior Film (left side)[1]	-	-	R-0.2 (0.03 RSI) to R-0.7 (0.12 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation

Detail 06

Exterior Insulated 3 5/8″ x 1 5/8″ Steel Stud (16″ o.c.) Wall Assembly with Horizontal Z-Girts (24″ o.c.) Supporting Metal Cladding – Slab Intersection

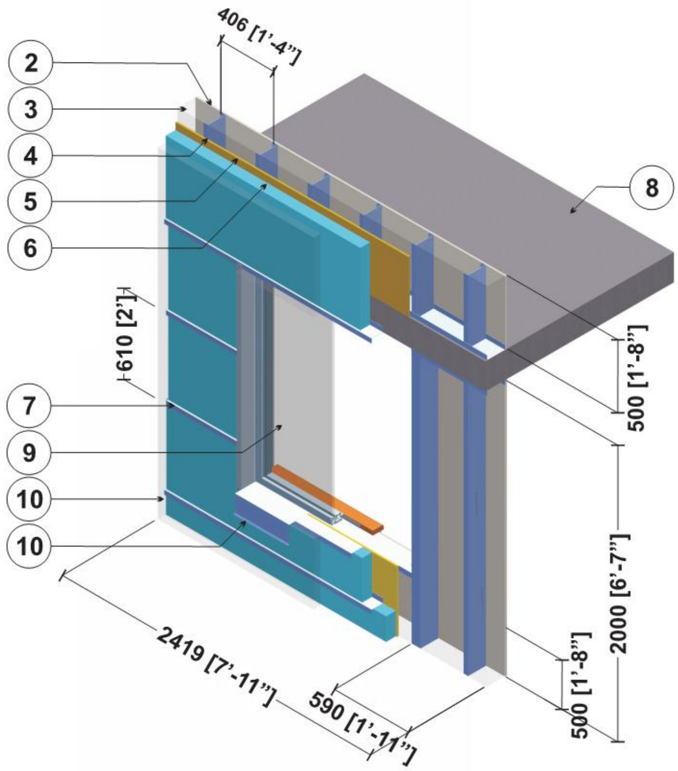


ID	Component	Thickness Inches (mm)	Conductivity Btu·in / ft²·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)	Specific Heat Btu/lb·°F (J/kg K)
1	Interior Film (right side)[1]	-	-	R-0.6 (0.11 RSI) to R-0.9 (0.16 RSI)	-	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
3	Air in Stud Cavity	3 5/8" (92)	-	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	Exterior Sheathing	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
6	Exterior Insulation	Varies	-	R-5 to R-25 (0.88 to 4.4 RSI)	1.8 (28)	0.29 (1220)
7	Horizontal Z-Girts w/ 1 ½" Flange	18 gauge	430 (62)	-	489 (7830)	0.12 (500)
8	Concrete Slab	8" (203)	1.8	-	140 (2250)	0.20 (850)
9	Metal cladding with ½" (13mm) vented air space is incorporated into exterior heat transfer coefficient					
10	Exterior Film (left side)[1]	-	-	R-0.2 (0.03 RSI) to R-0.7 (0.12 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation

Detail 07

Exterior Insulated 3 5/8″ x 1 5/8″ Steel Stud (16″ o.c.) Wall Assembly with Horizontal Z-Girts (24″ o.c.) Supporting Metal Cladding – Window & Slab Intersection

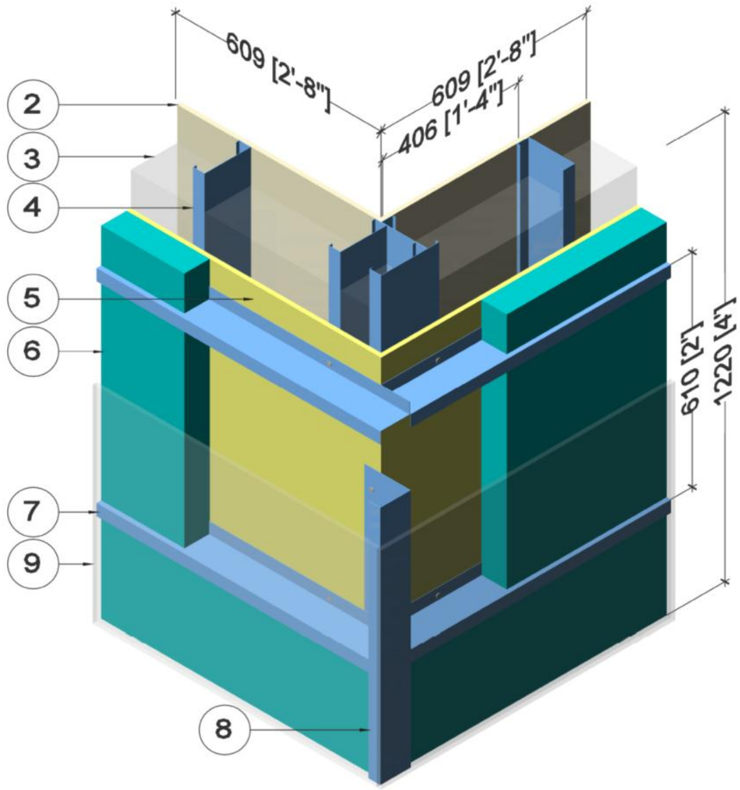


ID	Component	Thickness Inches (mm)	Conductivity Btu·in / $ft^2·hr·^oF$ (W/m K)	Nominal Resistance $hr·ft^2·^oF/Btu$ (m^2K/W)	Density lb/ft^3 (kg/m^3)	Specific Heat $Btu/lb·^oF$ (J/kg K)
1	Interior Film (right side)[1]	-	-	R-0.6 (0.11 RSI) to R-0.9 (0.16 RSI)	-	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
3	Air in Stud Cavity	3 5/8" (92)	-	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	Exterior Sheathing	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
6	Exterior Insulation	Varies	-	R5 to R25 (0.88 to 4.4 RSI)	1.8 (28)	0.29 (1220)
7	Horizontal Z-Girts w/ 1 ½" Flange	18 gauge	430 (62)	-	489 (7830)	0.12 (500)
8	Concrete Slab	8" (203)	12 (1.8)	-	140 (2250)	0.20 (850)
9	1.5m (H) x 1.2m (W) Aluminum window: double glazed & thermally broken[2]					
10	Metal cladding with ½" (13mm) vented air space is incorporated into exterior heat transfer coefficient, sill flashing & interior finish materials					
11	Exterior Film (left side)[1]	-	-	R-0.2 (0.03 RSI) to R-0.7 (0.12 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation
[2] The thermal conductivity for air spaces within window framing was found using ISO 10077-2.

Detail 08

Exterior Insulated 3 5/8″ x 1 5/8″ Steel Stud (16″ o.c.) Wall Assembly with Horizontal Z-Girts (24″ o.c.) Supporting Metal Cladding – Corner Intersection

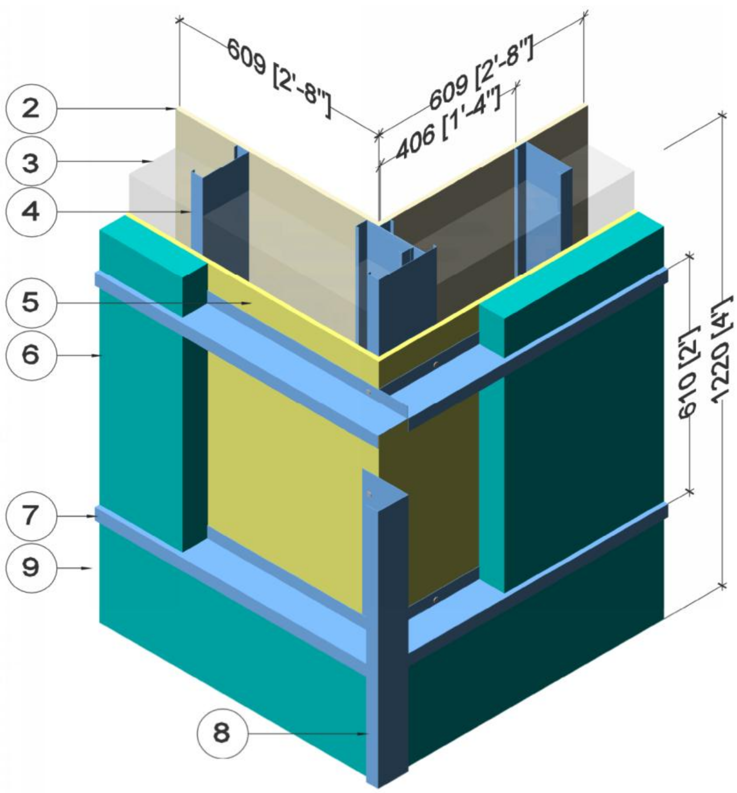


ID	Component	Thickness Inches (mm)	Conductivity Btu·in / ft^2·hr·°F (W/m K)	Nominal Resistance hr·ft^2·°F/Btu (m^{2}K/W)	Density lb/ft^3 (kg/m^3)	Specific Heat Btu/lb·°F (J/kg K)
1	Interior Film (right side)[1]	-	-	R-0.7 (0.12 RSI)	-	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
3	Air in Stud Cavity	3 5/8" (92)	-	R-0.9 (0.16 RSI)	0.075 (1.2)	0.24 (1000)
4	3 5/8" x 1 5/8" Steel Studs	18 gauge	430 (62)	-	489 (7830)	0.12 (500)
5	Exterior Sheathing	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
6	Exterior Insulation	Varies	-	R5 to R25 (0.88 to 4.4 RSI)	1.8 (28)	0.29 (1220)
7	Horizontal Z-Girts w/ 1 ½" Flange	18 gauge	430 (62)	-	489 (7830)	0.12 (500)
8	Corner Break Shape w/ 1 ½" Flange	18 gauge	430 (62)	-	489 (7830)	0.12 (500)
9	Metal cladding with ½" (13mm) vented air space is incorporated into exterior heat transfer coefficient					
10	Exterior Film (left side)[1]	-	-	R-0.7 (0.12 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation

Detail 08a

Exterior Insulated 3 5/8″ x 1 5/8″ Steel Stud (16″ o.c.) Wall Assembly with Horizontal Z-Girts (24″ o.c.) Supporting Metal Cladding – Corner Intersection, Alternative Framing

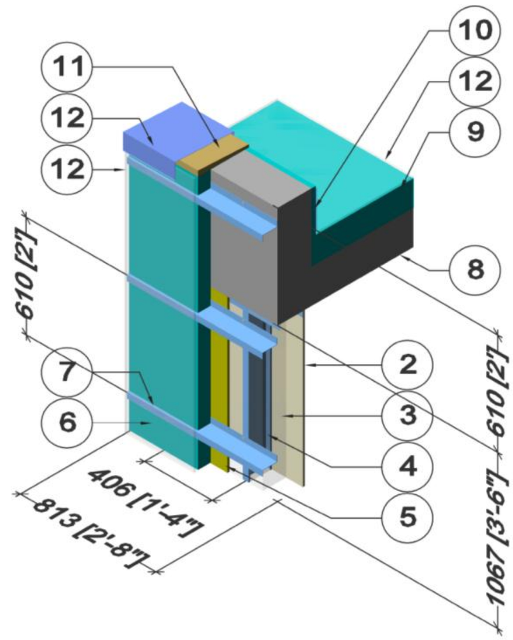


ID	Component	Thickness Inches (mm)	Conductivity Btu·in / ft²·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)	Specific Heat Btu/lb·°F (J/kg K)
1	Interior Film (right side)[1]	-	-	R-0.7 (0.12 RSI)	-	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
3	Air in Stud Cavity	3 5/8" (92)	-	R-0.9 (0.16 RSI)	0.075 (1.2)	0.24 (1000)
4	3 5/8" x 1 5/8" Steel Studs	18 gauge	430 (62)	-	489 (7830)	0.12 (500)
5	Exterior Sheathing	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
6	Exterior Insulation	varies	-	R5 to R25 (0.88 to 4.4 RSI)	1.8 (28)	0.29 (1220)
7	Horizontal Z-girts w/ 1 ½" Flange	18 gauge	430 (62)	-	489 (7830)	0.12 (500)
8	Corner Break Shape w/ 1 ½" Flange	18 gauge	430 (62)	-	489 (7830)	0.12 (500)
9	Metal cladding with ½" (13mm) vented air space is incorporated into exterior heat transfer coefficient					
10	Exterior Film (left side)[1]	-	-	R-0.7 (0.12 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation

Detail 09

Exterior Insulated 3 5/8″ x 1 5/8″ Steel Stud (16″ o.c.) Wall Assembly with Horizontal Z-Girts (24” o.c.) Supporting Metal Cladding – Concrete Parapet & Slab Intersection

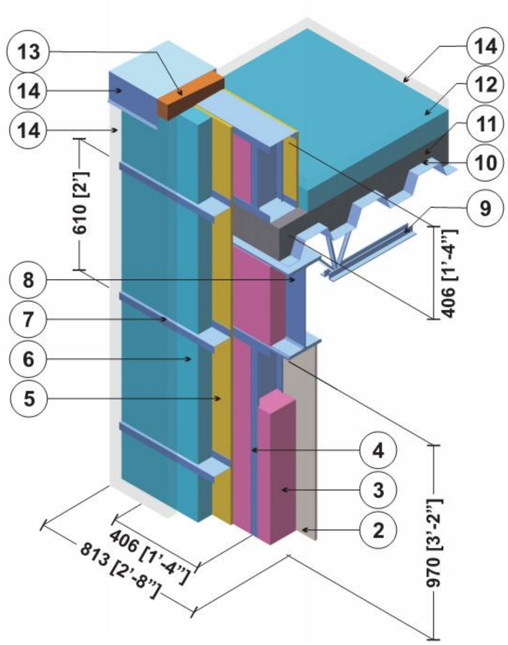


ID	Component	Thickness Inches (mm)	Conductivity Btu·in / ft²·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)	Specific Heat Btu/lb·°F (J/kg K)
1	Interior Film (right side)[1]	-	-	R-0.6 (0.11 RSI) to R-0.7 (0.12 RSI)	-	-
2	Gypsum Board	1/2” (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
3	Air in Stud Cavity	3 5/8” (92)	-	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 Track	18 gauge	430 (62)	-	489 (7830)	0.12 (500)
5	Exterior Sheathing	1/2” (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
6	Exterior Insulation	Varies	-	R5 to R25 (0.88 to 4.4 RSI)	1.8 (28)	0.29 (1220)
7	Horizontal Z-Girts w/ 1 ½” Flange	18 gauge	430 (62)	-	489 (7830)	0.12 (500)
8	Concrete Slab & Parapet	8” (203)	12.5 (1.8)	-	140 (2250)	0.20 (850)
9	Roof Insulation	4” (102)	-	R-20 (3.5 RSI)	1.8 (28)	0.29 (1220)
10	Parapet Insulation	1” (25)	-	R-5 (0.88 RSI)	1.8 (28)	0.29 (1220)
11	Wood Blocking	5/8” (16)	0.63 (0.09)	R-1 (0.18 RSI)	27.8 (445)	0.45 (1880)
12	Metal cladding with ½” (13mm) vented air space is incorporated into exterior heat transfer coefficient, metal cap flashing & finish roof materials					
13	Exterior Film (left side)[1]	-	-	R-0.2 (0.03 RSI) to R-0.7 (0.12 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation

Detail 10

Exterior and Interior Insulated 3 5/8″ x 1 5/8″ Steel Stud (16″ o.c.) Wall Assembly with Horizontal Z-Girts (24″ o.c.) Supporting Metal Cladding – Steel Roof Deck with Open Web Steel Joist & Parapet Intersection

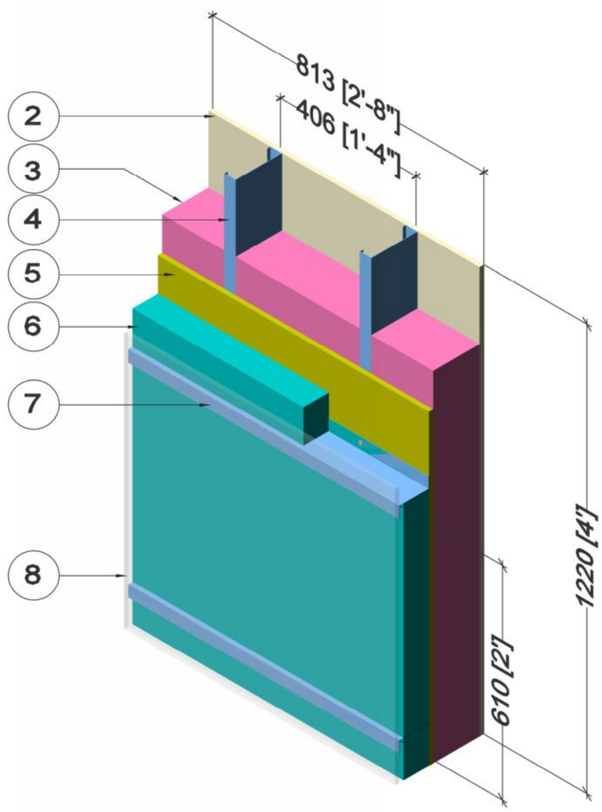


ID	Component	Thickness Inches (mm)	Conductivity Btu·in / ft²·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)	Specific Heat Btu/lb·°F (J/kg K)
1	Interior Film (right side)[1]	-	-	R-0.6 (0.11 RSI) to R-0.7 (0.12 RSI)	-	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
3	Fiberglass Batt Insulation in Stud Cavity	3 5/8" (92)	0.29 (0.042)	R-12 (2.1 RSI)	0.9 (14)	0.17 (710)
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	Exterior Sheathing	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
6	Exterior Insulation	varies	-	R5 to R25 (0.88 to 4.4 RSI)	1.8 (28)	0.29 (1220)
7	Horizontal Z-girts w/ 1 ½" Flange	18 gauge	430 (62)	-	489 (7830)	0.12 (500)
8	Steel Beam (W410)	-	347 (50)	-	489 (7830)	0.12 (500)
9	Open Web Steel Joist	-	347 (50)	-	489 (7830)	0.12 (500)
10	Steel Deck	1/16" (1.6)	347 (50)	-	489 (7830)	0.12 (500)
11	Concrete Topping	6" (152)	6.3 (0.9)	-	120 (1920)	0.20 (850)
12	Exterior Insulation, Roof	4" (102)	-	R-20 (3.5 RSI)	1.8 (28)	0.29 (1220)
13	Wood Blocking	5/8" (16)	0.63 (0.09)	R-1 (0.18 RSI)	27.8 (445)	0.45 (1880)
14	Metal cladding with ½" (13mm) vented air space/ metal cap flashing/ finish roof materials is incorporated into exterior heat transfer coefficient					
15	Exterior Film (left side)[1]	-	-	R-0.2 (0.03 RSI) to R-0.7 (0.12 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation

Detail 11

Exterior and Interior Insulated 3 5/8″ x 1 5/8″ Steel Stud (16″ o.c.) Wall Assembly with Horizontal Z-Girts (24″ o.c.) Supporting Metal Cladding – Clear Wall

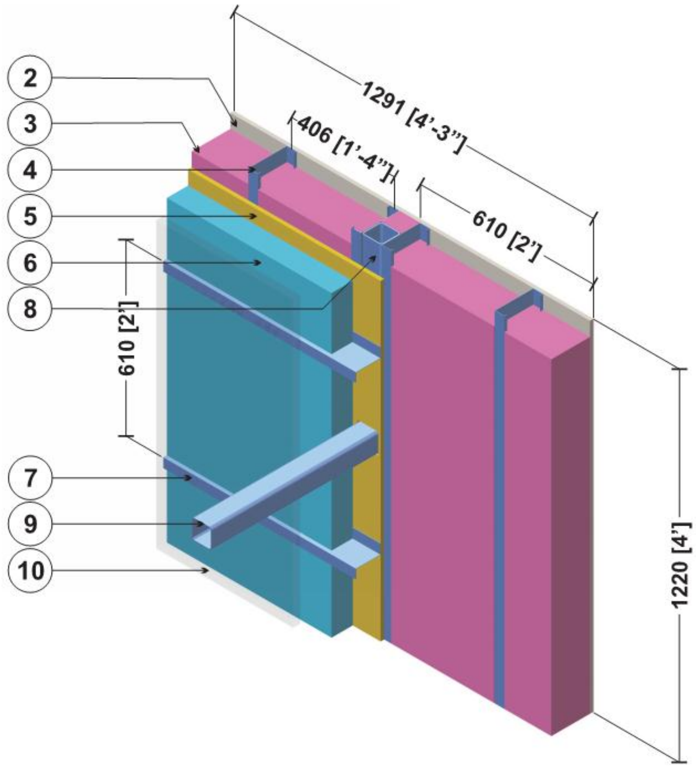


ID	Component	Thickness Inches (mm)	Conductivity Btu·in / ft²·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)	Specific Heat Btu/lb·°F (J/kg K)
1	Interior Film (right side)[1]	-	-	R-0.7 (0.12 RSI)	-	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
3	Fiberglass Batt Insulation in Stud Cavity	3 5/8" (92)	0.29 (0.042)	R-12 (2.1 RSI)	0.9 (14)	0.17 (710)
4	3 5/8" x 1 5/8" Steel Studs	18 gauge	430 (62)	-	489 (7830)	0.12 (500)
5	Exterior Sheathing	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
6	Exterior Insulation	varies	-	R5 to R25 (0.88 to 4.4 RSI)	1.8 (28)	0.29 (1220)
7	Horizontal Z-girts w/ 1 ½" Flange	18 gauge	430 (62)	-	489 (7830)	0.12 (500)
8	Metal cladding with ½" (13mm) vented air space is incorporated into exterior heat transfer coefficient					
9	Exterior Film (left side)[1]	-	-	R-0.7 (0.12 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation

Detail 12

Exterior and Interior Insulated 3 5/8″ x 1 5/8″ Steel Stud (16″ o.c.) Wall Assembly with Horizontal Z-Girts (24″ o.c.) Supporting Metal Cladding – Structural Steel Column & Cantilever Beam Intersection (Canopy Support)

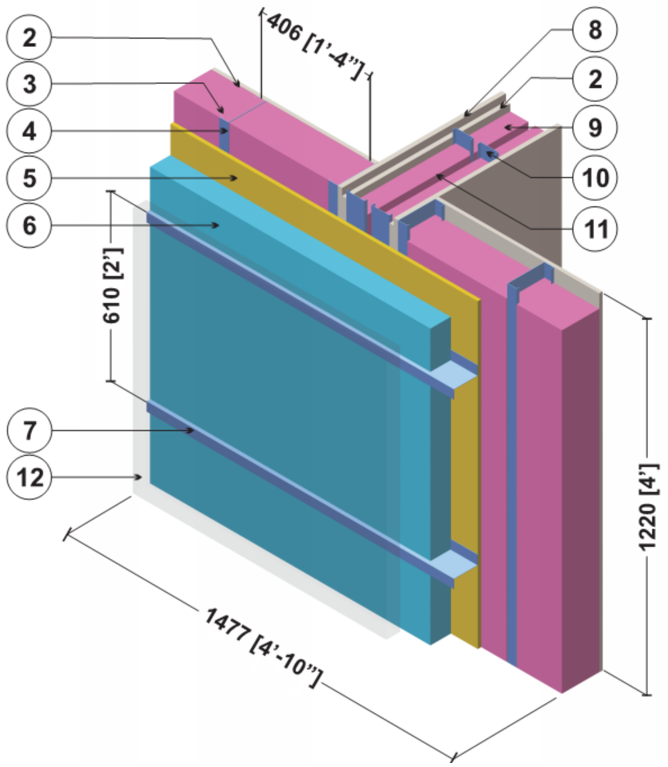


ID	Component	Thickness Inches (mm)	Conductivity Btu·in / ft²·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)	Specific Heat Btu/lb·°F (J/kg K)
1	Interior Film (right side)[1]	-	-	R-0.7 (0.12 RSI)	-	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
3	Fiberglass Batt Insulation in Stud Cavity	3 5/8" (92)	0.29 (0.042)	R-12 (2.1 RSI)	0.9 (14)	0.17 (710)
4	3 5/8" x 1 5/8" Steel Studs	18 gauge	430 (62)	-	489 (7830)	0.12 (500)
5	Exterior Sheathing	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
6	Exterior Insulation	Varies	-	R5 to R25 (0.88 to 4.4 RSI)	1.8 (28)	0.29 (1220)
7	Horizontal Z-girts w/ 1 ½" Flange	18 gauge	430 (62)	-	489 (7830)	0.12 (500)
8	Steel Post (HSS 76x76x3.2)	1/8" (3.2)	347 (50)	-	489 (7830)	0.12 (500)
9	Steel Beam (HSS 76x76x3.2)	1/8' (3.2)	347 (50)	-	489 (7830)	0.12 (500)
10	Metal cladding with ½" (13mm) vented air space is incorporated into exterior heat transfer coefficient					
11	Exterior Film (left side)[1]	-	-	R-0.2 (0.03 RSI) to R-0.7 (0.12 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation

Detail 13

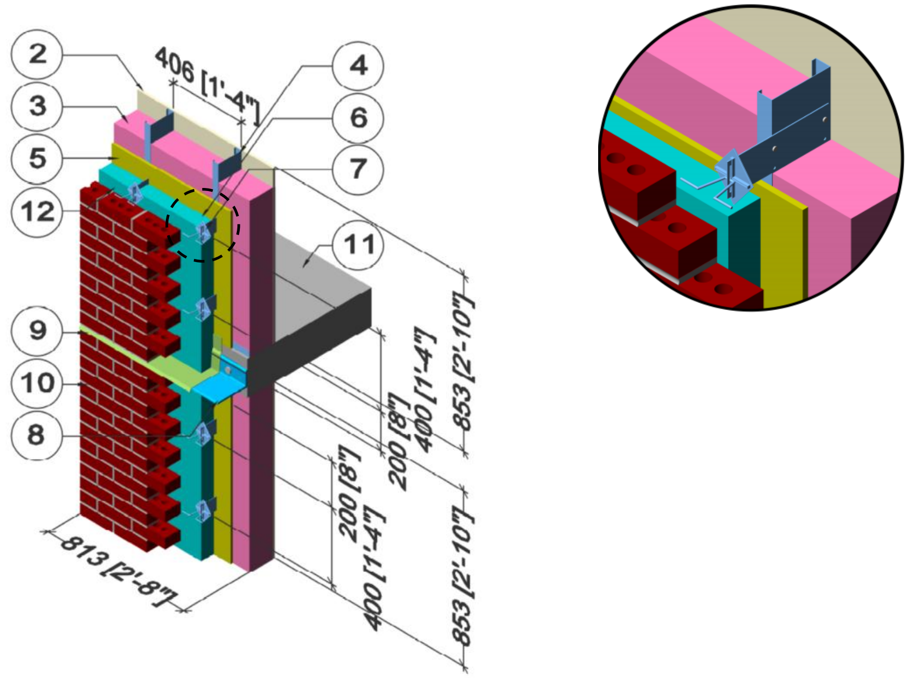
Exterior and Interior Insulated 3 5/8″ x 1 5/8″ Steel Stud (16″ o.c.) Wall Assembly with Horizontal Z-Girts (24″ o.c.) Supporting Metal Cladding – Interior Wall Intersection



ID	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 Film (right side)[1]	-	-	R-0.7 (0.12 RSI)	-	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
3	Fiberglass Batt Insulation in Stud Cavity	3 5/8" (92)	0.29 (0.042)	R-12 (2.1 RSI)	0.9 (14)	0.17 (710)
4	3 5/8" x 1 5/8" Steel Studs	18 gauge	430 (62)	-	489 (7830)	0.12 (500)
5	Exterior Sheathing	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
6	Exterior Insulation	Varies	-	R5 to R25 (0.88 to 4.4 RSI)	1.8 (28)	0.29 (1220)
7	Horizontal Z-girts w/ 1 ½" Flange	18 gauge	430 (62)	-	489 (7830)	0.12 (500)
8	Gypsum Board	5/8" (16)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
9	Acoustic Batt Insulation	2 5/8" (67)	0.29 (0.042)	-	0.9 (14)	0.17 (710)
10	2 5/8" x 1 5/8" Steel Studs	18 gauge	430 (62)	-	489 (7830)	0.12 (500)
11	Air Gap	1" (25)	-	R-0.9 (0.16 RSI)	0.075 (1.2)	0.24 (1000)
12	Metal cladding with ½" (13mm) vented air space is incorporated into exterior heat transfer coefficient					
13	Exterior Film (left side)[1]	-	-	R-0.7 (0.12 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation

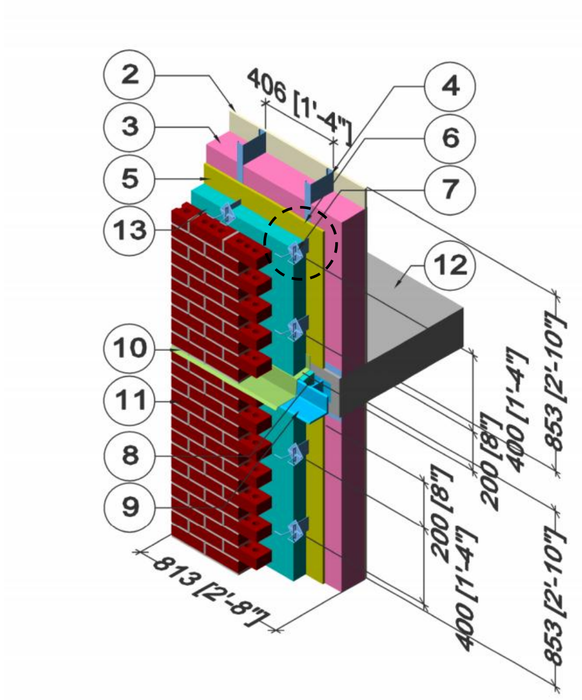
Detail 14 | Exterior and Interior Insulated Wall Assembly with Shelf Angle & Brick Ties Supporting Brick Veneer – Slab Intersection

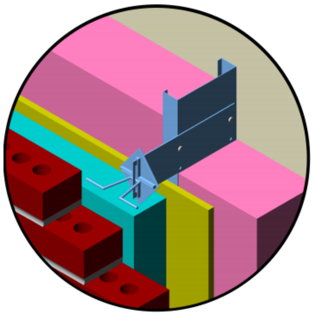


ID	Component	Thickness Inches (mm)	Conductivity Btu·in / $ft^2 \cdot hr \cdot {}^oF$ (W/m K)	Nominal Resistance $hr \cdot ft^2 \cdot {}^oF/Btu$ (m^2K/W)	Density lb/ft^3 (kg/m^3)	Specific Heat $Btu/lb \cdot {}^oF$ (J/kg K)
1	Interior Film (right side)[1]	-	-	R-0.6 (0.11 RSI) to R-0.9 (0.16 RSI)	-	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
3	Fiberglass Batt Insulation in Stud Cavity	3 5/8” (92)	0.29 (0.042)	R-12 (2.1 RSI)	0.9 (14)	0.17 (710)
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	Exterior Sheathing	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
6	Exterior Insulation	Varies	-	R5 to R25 (0.88 to 4.4 RSI)	1.8 (28)	0.29 (1220)
7	Brick Ties	14 gauge	347 (50)	-	489 (7830)	0.12 (500)
8	Shelf Angle	3/8” (10)	347 (50)	-	489 (7830)	0.12 (500)
9	Flashing	20 gauge	347 (50)	-	489 (7830)	0.12 (500)
10	Brick Veneer	3 5/8” (92)	5.4 (0.78)	-	120 (1920)	0.19 (720)
11	Concrete Slab	8” (203)	12.5 (1.8)	-	140 (2250)	0.20 (850)
12	Air Gap	1" (25)	-	R-0.9 (0.16 RSI)	0.075 (1.2)	0.24 (1000)
13	Exterior Film (left side)[1]	-	-	R-0.2 (0.03 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation

Detail 15 Exterior and Interior Insulated Wall Assembly with Spaced Shelf Angle & Brick Ties Supporting Brick Veneer – Slab Intersection



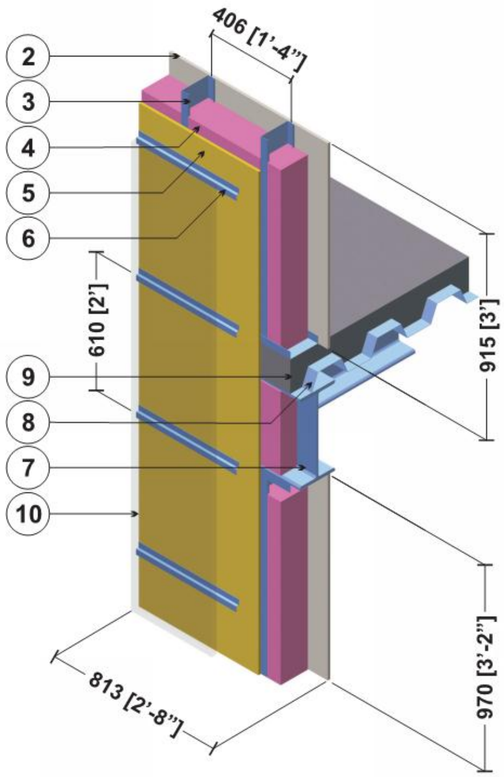


ID	Component	Thickness Inches (mm)	Conductivity Btu·in / $ft^2 \cdot hr \cdot {}^oF$ (W/m K)	Nominal Resistance $hr \cdot ft^2 \cdot {}^oF/Btu$ (m^2K/W)	Density lb/ft^3 (kg/m^3)	Specific Heat $Btu/lb \cdot {}^oF$ (J/kg K)
1	Interior Film (right side)[1]	-	-	R-0.6 (0.11 RSI) to R-0.9 (0.16 RSI)	-	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
3	Fiberglass Batt Insulation in Stud Cavity	3 5/8" (92)	0.29 (0.042)	R-12 (2.1 RSI)	0.9 (14)	0.17 (710)
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	Exterior Sheathing	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
6	Exterior Insulation	Varies	-	R5 to R25 (0.88 to 4.4 RSI)	1.8 (28)	0.29 (1220)
7	Brick Ties	14 gauge	347 (50)	-	489 (7830)	0.12 (500)
8	Exterior Insulation Behind Shelf Angle	varies	-	R5 to R25 (0.88 to 4.4 RSI)	1.8 (28)	0.29 (1220)
9	Spaced Shelf Angle	3/8" (10)	347 (50)	-	489 (7830)	0.12 (500)
10	Flashing	20 gauge	347 (50)	-	489 (7830)	0.12 (500)
11	Brick Veneer	3 5/8" (92)	5.4 (0.78)	-	120 (1920)	0.19 (720)
12	Concrete Slab	8" (203)	12.5 (1.8)	-	140 (2250)	0.20 (850)
13	Air Gap	1" (25)	-	R-0.9 (0.16 RSI)	0.075 (1.2)	0.24 (1000)
14	Exterior Film (left side)[1]	-	-	R-0.2 (0.03 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation

Detail 16

Interior Insulated 3 5/8″ x 1 5/8″ Steel Stud (16″ o.c.) Wall Assembly with Horizontal Z-Girts (24″ o.c.) Supporting Metal Cladding – Structural Steel Framed Floor Intersection

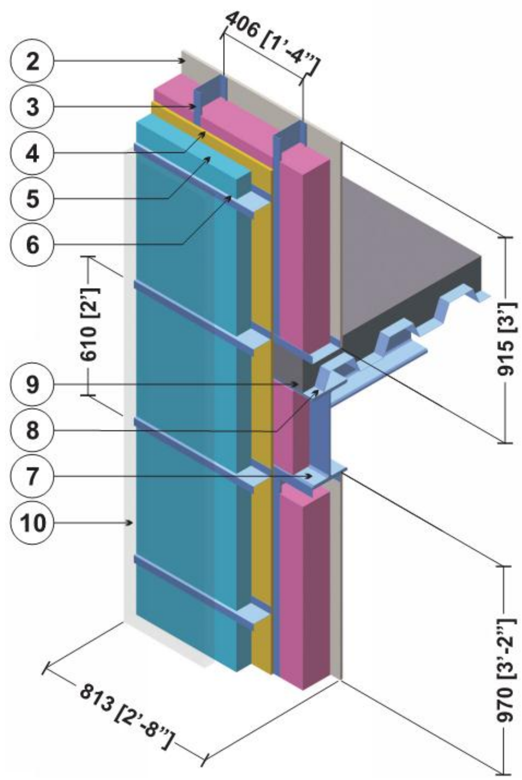


ID	Component	Thickness Inches (mm)	Conductivity Btu·in / ft^2·hr·^{o}F (W/m K)	Nominal Resistance hr·ft^2·^{o}F/Btu (m^{2}K/W)	Density lb/ft^3 (kg/m^3)	Specific Heat Btu/lb·^{o}F (J/kg K)
1	Interior Film (right side)[1]	-	-	R-0.6 (0.11 RSI) to R-0.9 (0.16 RSI)	-	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
3	Fiberglass Batt Insulation in Stud Cavity	3 5/8" (92)	0.29 (0.042)	R-12 (2.1 RSI)	0.9 (14)	0.17 (710)
4	3 5/8" x 1 5/8" Steel Studs with Metal Tracks	18 gauge	430 (62)	-	489 (7830)	0.12 (500)
5	Exterior Sheathing	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
6	Horizontal Z-girts w/ 1 ½" Flange	18 gauge	430 (62)	-	489 (7830)	0.12 (500)
7	Steel Beam (W410)	-	347 (50)	-	489 (7830)	0.12 (500)
8	Steel Deck	1/16" (1.6)	347 (50)	-	489 (7830)	0.12 (500)
9	Concrete Topping	6" (152)	6.3 (0.9)	-	120 (1920)	0.20 (850)
10	Metal cladding with ½" (13mm) vented air space is incorporated into exterior heat transfer coefficient					
11	Exterior Film (left side)[1]	-	-	R-0.7 (0.12 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation

Detail 17

Exterior and Interior Insulated 3 5/8″ x 1 5/8″ Steel Stud (16″ o.c.) Wall Assembly with Horizontal Z-Girts (24″ o.c.) Supporting Metal Cladding – Structural Steel Framed Floor Intersection

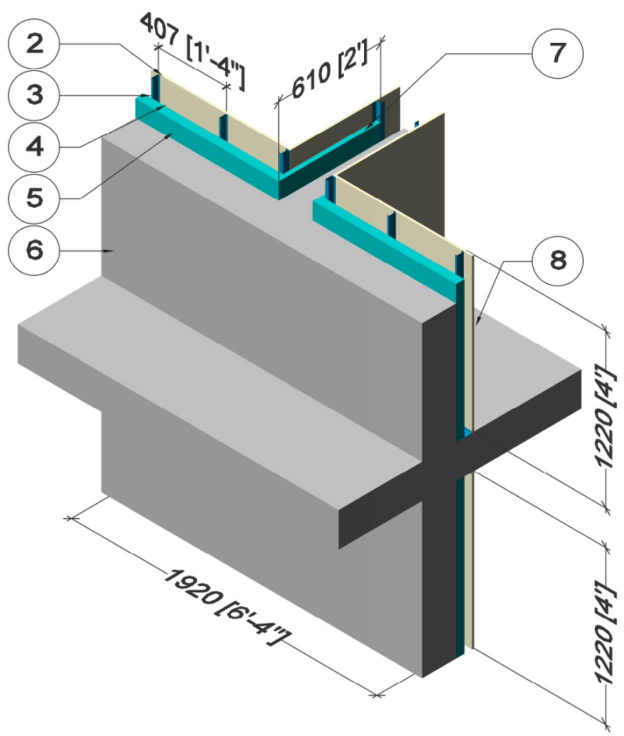


ID	Component	Thickness Inches (mm)	Conductivity Btu·in / ft²·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)	Specific Heat Btu/lb·°F (J/kg K)
1	Interior Film (right side)[1]	-	-	R-0.6 (0.11 RSI) to R-0.9 (0.16 RSI)	-	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
3	Fiberglass Batt Insulation	3 5/8" (92)	0.29 (0.042)	R-12 (2.1 RSI)	0.9 (14)	0.17 (710)
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	Exterior Sheathing	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
6	Exterior Insulation	varies	-	R5 to R25 (0.88 to 4.4 RSI)	1.8 (28)	0.29 (1220)
7	Horizontal Z-girts w/ 1 ½" Flange	18 gauge	430 (62)	-	489 (7830)	0.12 (500)
8	Steel Beam (W410)	-	347 (50)	-	489 (7830)	0.12 (500)
9	Steel Deck	1/16" (1.6)	347 (50)	-	489 (7830)	0.12 (500)
10	Concrete Topping	6" (152)	6.3 (0.9)	-	120 (1920)	0.20 (850)
11	Metal cladding with ½" (13mm) vented air space is incorporated into exterior heat transfer coefficient					
12	Exterior Film (left side)[1]	-	-	R-0.7 (0.12 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation

Detail 18

Interior Insulated Concrete Mass Wall with 1 5/8″ Steel Stud (16″ o.c.) Supporting Interior Finish – Insulated Interior Wall and Non-insulated Slab Intersection

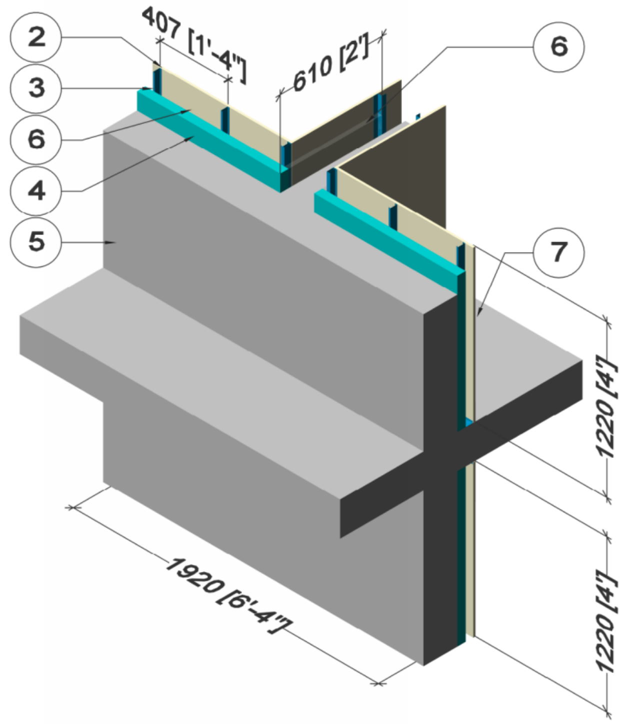


ID	Component	Thickness Inches (mm)	Conductivity Btu·in / ft²·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)	Specific Heat Btu/lb·°F (J/kg K)
1	Interior Film (right side)[1]	-	-	R-0.6 (0.11 RSI) to R-0.9 (0.16 RSI)	-	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
3	1 5/8" Steel Studs with Top and Bottom Tracks	20 gauge	430 (62)	-	489 (7830)	0.12 (500)
4	Air in Stud Cavity	1 5/8" (41)	-	R-0.9 (0.16 RSI)	0.075 (1.2)	0.24 (1000)
5	Interior Insulation	2" (51)	-	R-11 (1.9 RSI)	1.8 (28)	0.29 (1220)
6	Exterior Concrete Mass Wall	8" (203)	12.5 (1.8)	-	140 (2250)	0.20 (850)
7	Interior Partition Insulation	1" (25)	-	R-5 (0.88 RSI)	1.8 (28)	0.29 (1220)
8	Concrete Slab, Floor & Balcony	8" (203)	12.5 (1.8)	-	140 (2250)	0.20 (850)
9	Exterior Film (left side)[1]	-	-	R-0.2 (0.03 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation

Detail 19

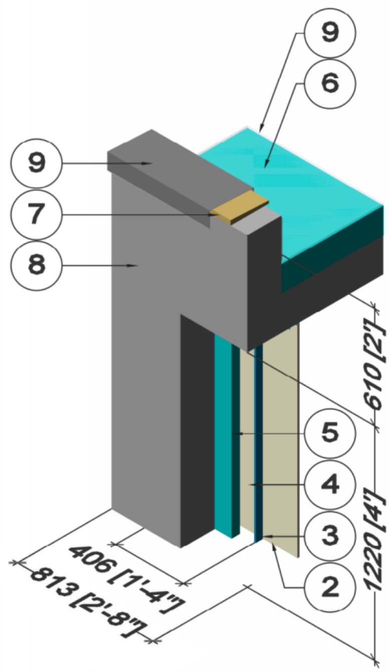
Interior Non-insulated Concrete Mass Wall with 1 5/8″ Steel Stud (16″o.c.) Supporting Interior Finish – Non-Insulated Interior Wall and Non-insulated Slab Intersection



ID	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 Film (right side)[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	1 5/8” Steel Studs with Metal Tracks	20 gauge	430 (62)	-	489 (7830)	0.12 (500)
4	Interior Insulation	2” (51)	-	R-11 (1.9 RSI)	1.8 (28)	0.29 (1220)
5	Exterior Concrete Mass Wall	8” (203)	12.5 (1.8)	-	140 (2250)	0.20 (850)
6	Air in Stud Cavity and Interior Partition	Varies	-	R-0.9 (0.16 RSI)	0.075 (1.2)	0.24 (1000)
7	Concrete Slab, Floor & Balcony	8” (203)	12.5 (1.8)	-	140 (2250)	0.20 (850)
8	Exterior Film (left side)[1]	-	-	R-0.2 (0.03 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation

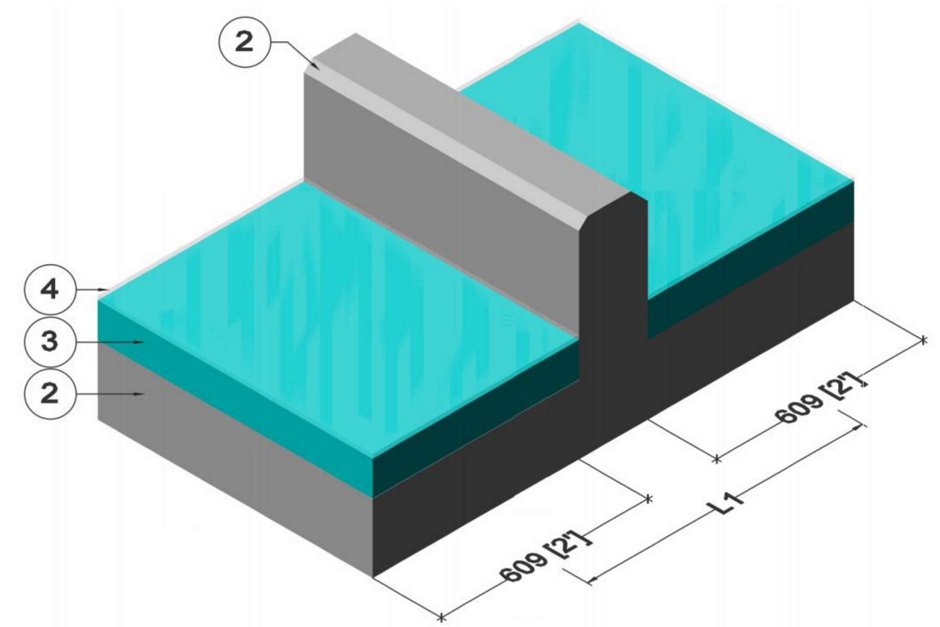
Detail 20 | Interior Insulated Concrete Mass Wall with 1 5/8″ Steel Stud (16″ o.c.) Supporting Interior Finish – Concrete Parapet & Roof Intersection



ID	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 Film (right side)[1]	-	-	R-0.6 (0.11 RSI) to R-0.7 (0.12 RSI)	-	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
3	1 5/8" Steel Studs with Top Tracks	20 gauge	430 (62)	-	489 (7830)	0.12 (500)
4	Air in Stud Cavity	1 5/8" (42)	-	R-0.9 (0.16 RSI)	0.075 (1.2)	0.24 (1000)
5	Interior Insulation	2" (51)	-	R-11 (1.9 RSI)	1.8 (28)	0.29 (1220)
6	Roof Insulation	4" (102)	-	R-20 (3.5 RSI)	1.8 (28)	0.29 (1220)
7	Wood Blocking	5/8" (16)	0.63 (0.09)	R-1 (0.18 RSI)	27.8 (445)	0.45 (1880)
8	Concrete Slab & Parapet	8" (203)	12.5 (1.8)	-	140 (2250)	0.20 (850)
9	Metal cap flashing/ finish roof material is incorporated into exterior heat transfer coefficient					
10	Exterior Film (left side)[1]	-	-	R-0.2 (0.03 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation

Detail 21 | Insulated Concrete Slab – Concrete Curb or Wall Intersection

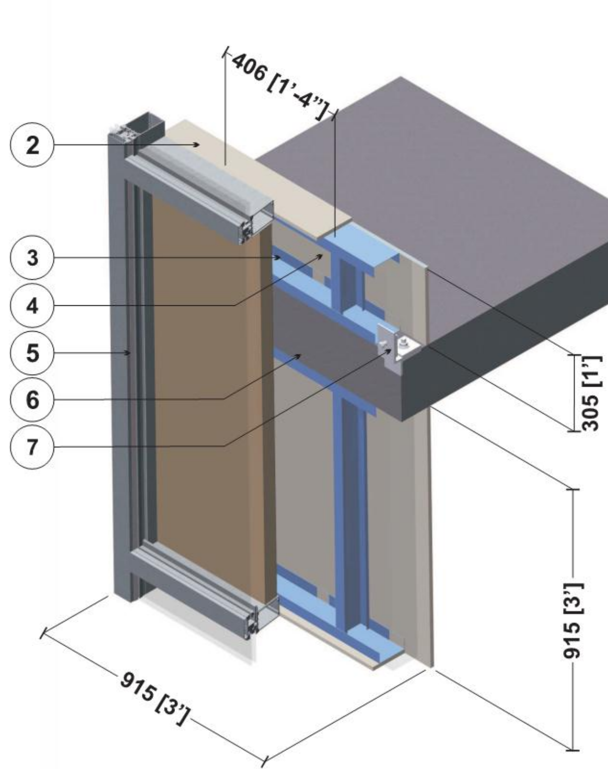


ID	Component	Thickness Inches (mm)	Conductivity Btu·in / ft^2·hr·^{o}F (W/m K)	Nominal Resistance hr·ft^2·^{o}F/Btu (m^{2}K/W)	Density lb/ft^3 (kg/m^3)	Specific Heat Btu/lb·^{o}F (J/kg K)
1	Interior Film (bottom)[1]	-	-	R-0.6 (0.11 RSI)	-	-
2	Concrete Slab, Curb or Wall	8" (203)	12.5 (1.8)	-	140 (2250)	0.20 (850)
3	Roof Insulation	4" (102)	-	R-20 (3.5 RSI)	1.8 (28)	0.29 (1220)
4	Finish roof material is incorporated into exterior heat transfer coefficient					
5	Exterior Film (top)[1]	-	-	R-0.2 (0.03 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation

Detail 22

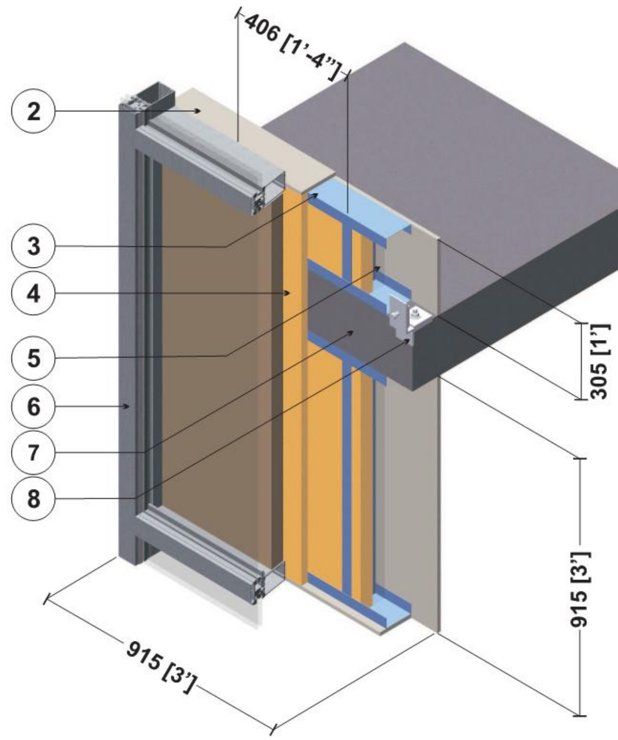
Conventional Curtain Wall System with Insulated Spandrel Panel and 3 5/8″ x 1 5/8″ Steel Stud (16″ o.c.) – Slab Intersection & No Interior Insulation in Stud Cavity



ID	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 Film (right side)[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	3 5/8" x 1 5/8" Steel Studs with Top and Bottom Tracks	18 gauge	430 (62)	-	489 (7830)	0.12 (500)
4	Air in Stud Cavity	4 5/8" (118)	-	R-0.9 (0.16 RSI)	0.075 (1.2)	0.24 (1000)
5	Conventional curtain wall system with insulated back pan (Pressure plates with minimal thermal break) [2]					
6	Concrete Slab	8" (203)	12 (1.8)	-	140 (2250)	0.20 (850)
7	Anchor at vertical mullions	-	347 (50)	-	489 (7830)	0.12 (500)
8	Exterior Film (left side)[1]	-	-	R-0.2 (0.03 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation & surface emissivity. Window values supplemented by ISO 1007-2, Annex B.
[2] The thermal conductivity of air spaces within curtain wall framing was found using ISO 10077-2.

Detail 23 Conventional Curtain Wall System with Insulated Spandrel Panel and 3 5/8″ x 1 5/8″ Steel Stud (16″ o.c.) – Slab Intersection & Spray Foam Insulation in Stud Cavity

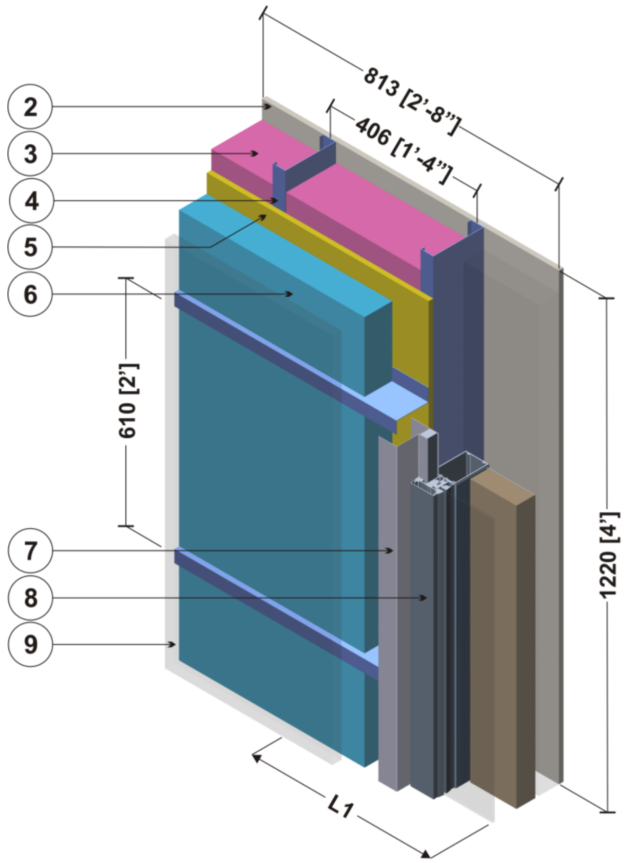


ID	Component	Thickness Inches (mm)	Conductivity Btu·in / ft²·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)	Specific Heat Btu/lb·°F (J/kg K)
1	Interior Film (right side)[1]	-	-	R-0.6 (0.11 RSI) to R-0.9 (0.16 RSI)	-	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
3	3 5/8" x 1 5/8" Steel Studs with Top and Bottom Tracks	18 gauge	430 (62)	-	489 (7830)	0.12 (500)
4	Spray Foam Insulation in Stud Cavity	2" (51)	0.17 (0.025)	-	2.4 (39)	0.35 (1470)
5	Air in Stud Cavity	2 5/8" (67)	-	R-0.9 (0.16 RSI)	0.075 (1.2)	0.24 (1000)
6	Conventional curtain wall system with insulated back pan (Pressure plates with minimal thermal break)[2]					
7	Concrete Slab	8" (203)	12.5 (1.8)	-	140 (2250)	0.20 (850)
8	Anchor at vertical mullions	-	347 (50)	-	489 (7830)	0.12 (500)
9	Exterior Film (left side)[1]	-	-	R-0.2 (0.03 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation & surface emissivity. Window values supplemented by ISO 1007-2, Annex B.
[2] The thermal conductivity of air spaces within curtain wall framing was found using ISO 10077-2.

Detail 24

Exterior and Interior Insulated 3 5/8″ x 1 5/8″ Steel Stud (16″ o.c) Wall Assembly with Horizontal Z-Girts (24″ o.c.) Supporting Metal Cladding – Conventional Curtain Wall Intersection

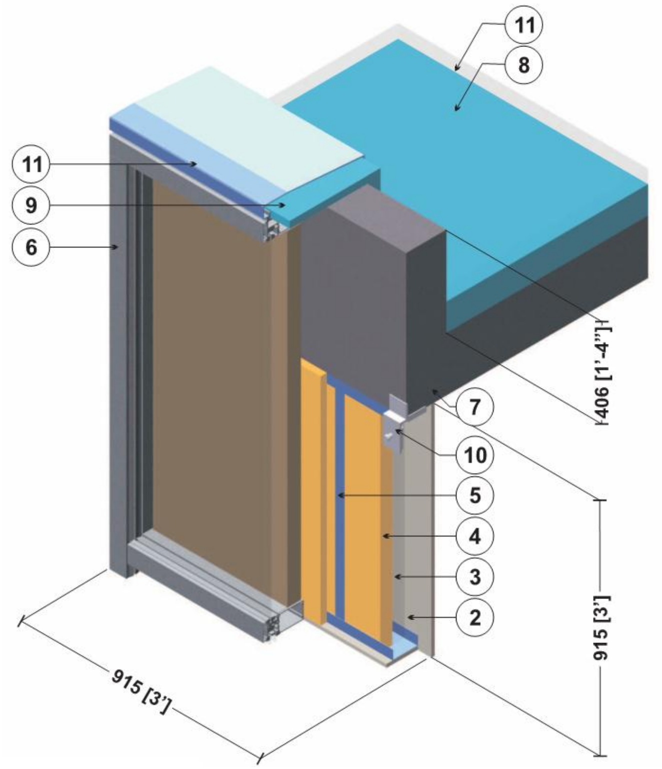


ID	Component	Thickness Inches (mm)	Conductivity Btu·in / ft²·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)	Specific Heat Btu/lb·°F (J/kg K)
1	Interior Film (right side)[1]	-	-	R-0.7 (0.12 RSI)	-	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
3	Fiberglass Batt Insulation in Stud Cavity	3 5/8" (90)	0.29 (0.042)	R-12 (2.1 RSI)	0.9 (14)	0.17 (710)
4	3 5/8" x 1 5/8" Steel Studs	18 gauge	430 (62)	-	489 (7830)	0.12 (500)
5	Exterior Sheathing	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
6	Exterior Insulation	varies	-	R5 to R25 (0.88 to 4.4 RSI)	1.8 (28)	0.29 (1220)
7	Horizontal Z-girts w/ 1 ½" Flange with Closure Flashing	18 gauge	430 (62)	-	489 (7830)	0.12 (500)
8	Conventional curtain wall system with insulated back pan (Pressure plates with minimal thermal break)[2]					
9	Metal cladding with ½" (13mm) vented air space is incorporated into exterior heat transfer coefficient					
10	Exterior Film (left side)[1]	-	-	R-0.2 (0.03 RSI) to R-0.7 (0.12 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation & surface emissivity.
[2] The thermal conductivity of air spaces within curtain wall framing was found using ISO 10077-2.

Detail 25

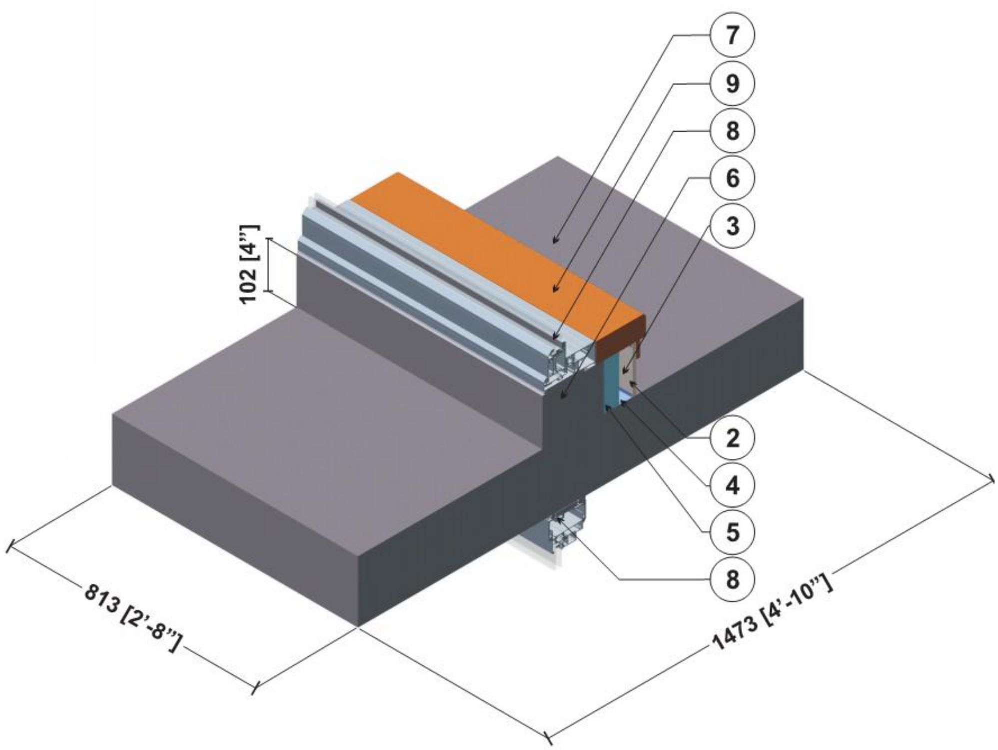
Conventional Curtain Wall System with Insulated Spandrel Panel and 3 5/8″ x 1 5/8″ Steel Stud (16″ o.c.) – Concrete Parapet, Roof Intersection & Spray Foam Insulation in Stud Cavity



ID	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 Film (right side)[1]	-	-	R-0.6 (0.11 RSI) to R-0.7 (0.12 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	2 5/8" (67)	-	R-0.9 (0.16 RSI)	0.075 (1.2)	0.24 (1000)
4	Spray Foam Insulation in Stud Cavity	2" (51)	0.17 (0.025)	-	2.8 (39)	0.35 (1470)
5	3 5/8" x 1 5/8" Steel Studs with Top and Bottom Tracks	18 gauge	430 (62)	-	489 (7830)	0.12 (500)
6	Conventional curtain wall system with insulated back pan (Pressure plates with minimal thermal break)					
7	Concrete Slab & Parapet	8" (203)	12.5 (1.8)	-	140 (2250)	0.20 (850)
8	Roof Insulation	4" (102)	-	R-20 (3.5 RSI)	1.8 (28)	0.29 (1220)
9	Parapet Insulation	1" (25)	-	R5 (0.88 RSI)	1.8 (28)	0.29 (1220)
10	Anchor at vertical mullions	-	347 (50)	-	489 (7830)	0.12 (500)
11	Metal cap flashing/ finish roof materials is incorporated into exterior heat transfer coefficient					
12	Exterior Film (left side)[1]	-	-	R-0.2 (0.03 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation & surface emissivity. Window values supplemented by ISO 1007-2, Annex B.
[2] The thermal conductivity of air spaces within curtain wall framing was found using ISO 10077-2.

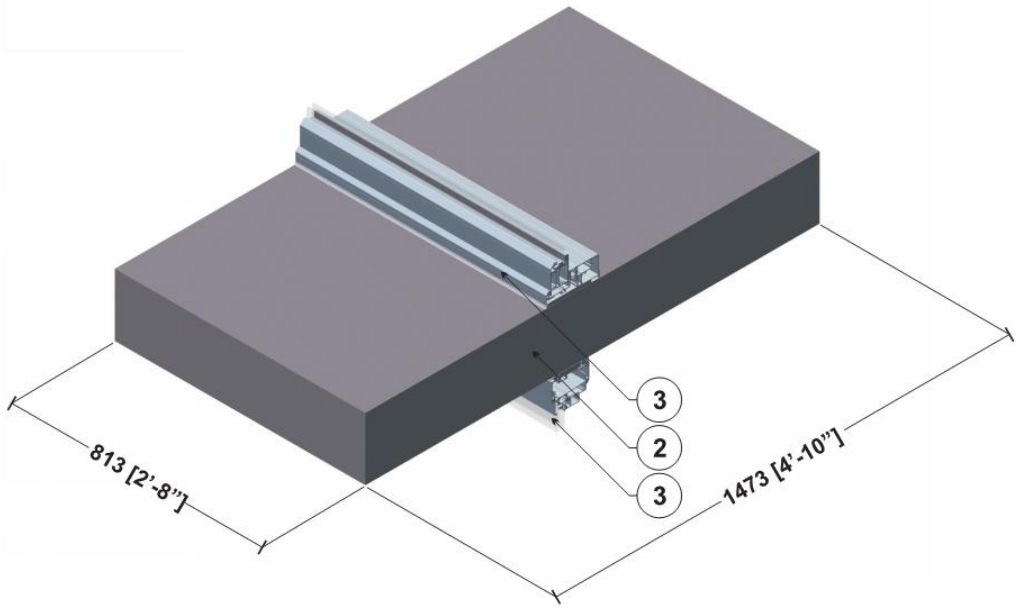
Detail 26 Interior Insulated Concrete Curb at Sliding Door Sill and Window Head – Slab Intersection



ID	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 Film (right side)[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	2 5/8" (67)	-	R-0.9 (0.16 RSI)	0.075 (1.2)	0.24 (1000)
4	2 5/8" x 1 5/8" Steel Studs with Top and Bottom Tracks	18 gauge	430 (62)	-	489 (7830)	0.12 (500)
5	Interior Insulation	2" (50)	-	R-10 (1.8 RSI)	1.8 (28)	0.29 (1220)
6	Concrete Curb	6" (152)	12.5 (1.8)	-	140 (2250)	0.20 (850)
7	Concrete Slab	8" (203)	12.5 (1.8)	-	140 (2250)	0.20 (850)
8	Thermally Broken Aluminum Window & Sliding Door[2]					
9	Wood Sill	2" (50)	0.63 (0.09)	-	1.8 (28)	0.29 (1220)
10	Exterior Film (left side)[1]	-	-	R-0.2 (0.03 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation
[2] The thermal conductivity of air spaces within sliding door and window framing was found using ISO 10077-2.

Detail 27 | Exterior Insulated Concrete Curb at Sliding Door Sill and Window Head – Slab Intersection

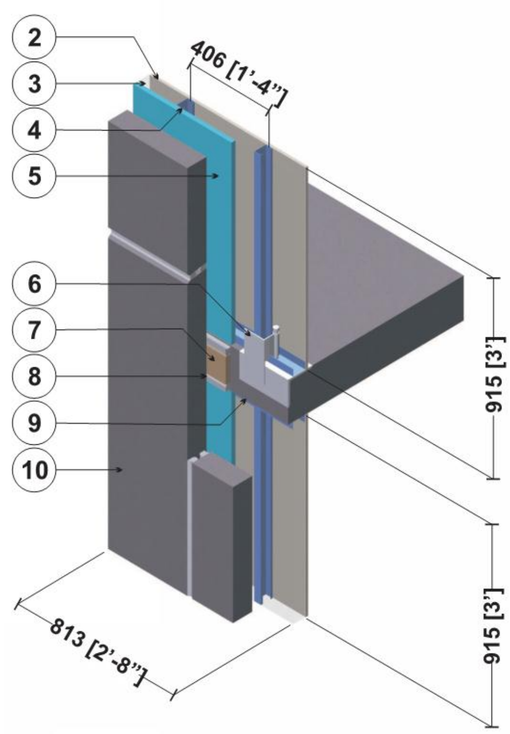


ID	Component	Thickness Inches (mm)	Conductivity Btu·in / ft²·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)	Specific Heat Btu/lb·°F (J/kg K)
1	Interior Film (right side)[1]	-	-	R-0.6 (0.11 RSI) to R-0.9 (0.16 RSI)	-	-
2	Concrete Slab	8" (203)	12.5 (1.8)	-	140 (2250)	0.20 (850)
3	Thermally Broken Aluminum Window & Sliding Door[2]					
4	Exterior Film (left side)[1]	-	-	R-0.2 (0.03 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation
[2] The thermal conductivity of air spaces within sliding door and window framing was found using ISO 10077-2.

Detail 28

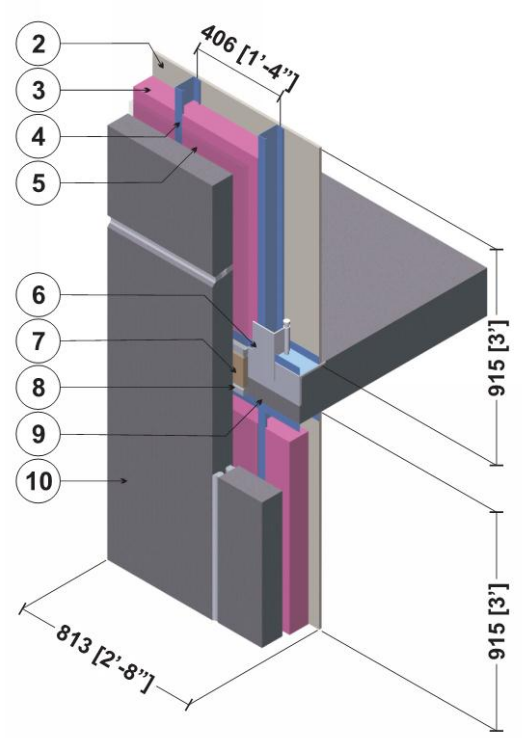
Precast Wall Assembly with 3 5/8″ x 1 5/8″ Steel Stud (16″ o.c.) and Rigid Insulation Outboard of Studs – Slab Intersection



ID	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 Film (right side)[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	3 5/8" (92)	-	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	Rigid Insulation	2" (51)	-	R-10 (1.8 RSI)	1.8 (28)	0.29 (1220)
6	Gravity and Slot Anchors at Slab	-	347 (50)	-	489 (7830)	0.12 (500)
7	Semi Rigid Insulation	1" (25)	0.28 (0.04)	-	4.5 (72)	0.17 (710)
8	Silicone Sealant	1/2" (13)	2.4 (0.35)	-	-	-
9	Concrete Slab	8" (203)	12.5 (1.8)	-	140 (2250)	0.20 (850)
10	Precast Wall Panel	4" (102)	12.5 (1.8)	-	140 (2250)	0.20 (850)
11	Exterior Film (left side)[1]	-	-	R-0.2 (0.03 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation

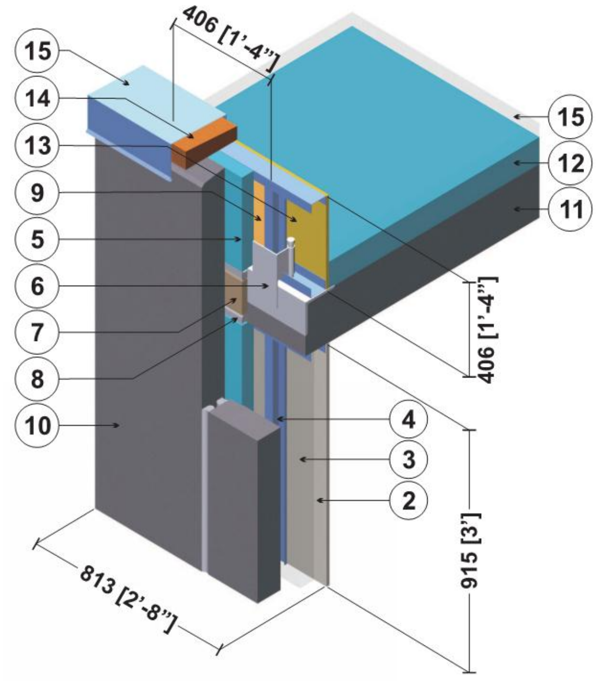
Detail 29 Precast Wall Assembly with 3 5/8" x 1 5/8" Steel Stud (16" o.c.) and Insulation in Stud Cavity – Slab Intersection



ID	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 Film (right side)[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	Fiberglass Batt Insulation in Stud Cavity	3 5/8" (92)	0.29 (0.042)	R-12 (2.1 RSI)	0.9 (14)	0.17 (710)
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	Air in Stud Cavity	2" (51)	-	R-0.9 (0.16 RSI)	0.075 (1.2)	0.24 (1000)
6	Gravity and Slot Anchors at Slab	-	347 (50)	-	489 (7830)	0.12 (500)
7	Semi Rigid Insulation	1" (25)	0.28 (0.04)	-	4.5 (72)	0.17 (710)
8	Silicone Sealant	1/2" (13)	2.4 (0.35)	-	-	-
9	Concrete Slab	8" (203)	12.5 (1.8)	-	140 (2250)	0.20 (850)
10	Precast Wall Panel	4" (102)	12.5 (1.8)	-	140 (2250)	0.20 (850)
11	Exterior Film (left side)[1]	-	-	R-0.2 (0.03 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation

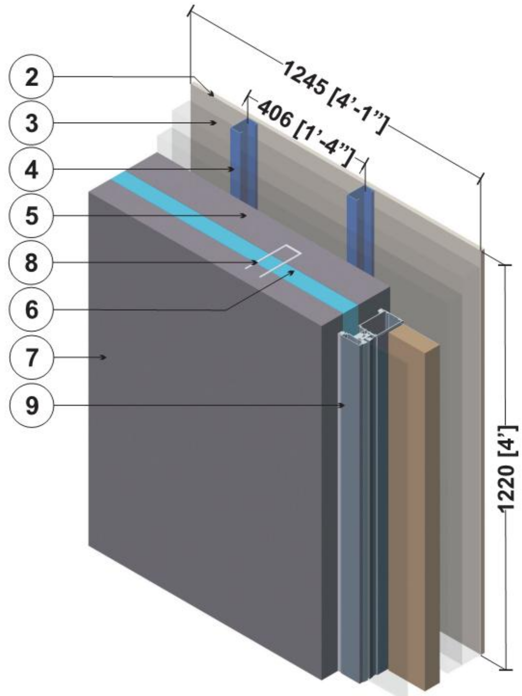
Detail 30 | Precast Wall Assembly with 3 5/8″ x 1 5/8″ Steel Stud (16″ o.c.) and Rigid Insulation Outboard of Studs – Parapet & Roof Intersection



ID	Component	Thickness Inches (mm)	Conductivity Btu·in / ft^2·hr·°F (W/m K)	Nominal Resistance hr·ft^2·°F/Btu (m^2K/W)	Density lb/ft^3 (kg/m^3)	Specific Heat Btu/lb·°F (J/kg K)
1	Interior Film (right side)[1]	-	-	R-0.6 (0.11 RSI) to R-0.7 (0.12 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	3 5/8" (92)	-	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	Rigid Insulation	2" (51)	-	R-10 (1.8 RSI)	1.8 (28)	0.29 (1220)
6	Gravity and Slot Anchors at Roof	-	347 (50)	-	489 (7830)	0.12 (500)
7	Semi Rigid Insulation	1" (25)	0.28 (0.04)	-	4.5 (72)	0.17 (710)
8	Silicone Sealant	1/2" (13)	2.4 (0.35)	-	-	-
9	Spray Foam Insulation in Stud Cavity	1" (25)	0.17 (0.025)	-	2.8 (39)	0.35 (1470)
10	Precast Wall Panel	4" (102)	12.5 (1.8)	-	140 (2250)	0.20 (850)
11	Concrete Slab	8" (203)	12.5 (1.8)	-	140 (2250)	0.20 (850)
12	Roof Insulation	4" (102)	-	R-20 (3.5 RSI)	1.8 (28)	0.29 (1220)
13	Exterior Sheathing	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
14	Wood Blocking	5/8" (16)	0.63 (0.09)	R-1 (0.18 RSI)	27.8 (445)	0.45 (1880)
15	Flashing & roof finish materials are incorporated into exterior heat transfer coefficient					
16	Exterior Film (left side)[1]	-	-	R-0.2 (0.03 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation

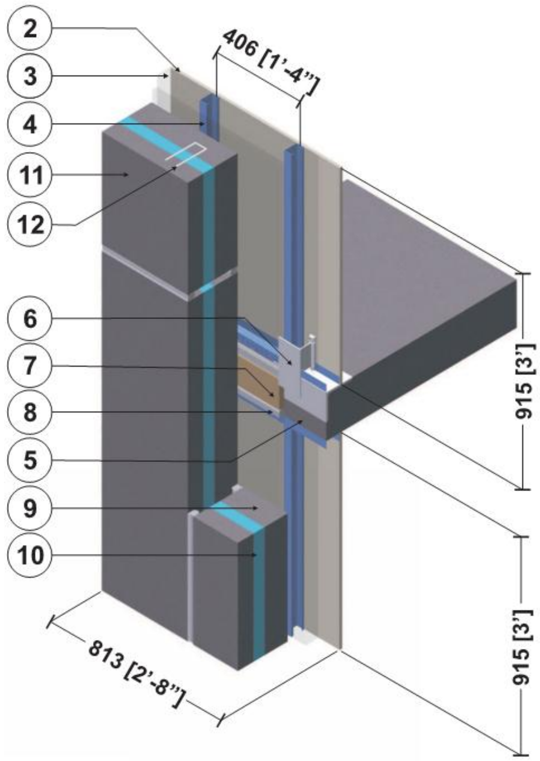
Detail 31 Precast Sandwich Panel Wall Assembly with 3 5/8″ Steel Stud (16″ o.c.) – Curtain Wall Transition



ID	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 Film (right side)[1]	-	-	R-0.7 (0.12 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	5 5/8" (143)	-	R-0.9 (0.16 RSI)	0.075 (1.2)	0.24 (1000)
4	3 5/8" Steel Studs	18 gauge	430 (62)	-	489 (7830)	0.12 (500)
5	Precast Sandwich Panel, Interior Concrete	4" (102)	12.5 (1.8)	-	140 (2250)	0.20 (850)
6	Precast Sandwich Panel, Insulation	2" (50)	-	R-10 (1.8 RSI)	1.8 (28)	0.29 (1220)
7	Precast Sandwich Panel, Exterior Concrete	4" (102)	12.5 (1.8)	-	140 (2250)	0.20 (850)
8	Precast Sandwich Panel, Structural Ties @ 24" (610) o.c.	16 gauge	430 (62)	-	489 (7830)	0.12 (500)
9	Conventional curtain wall system with insulated back pan (Pressure plates with minimal thermal break)[2]					
10	Exterior Film (left side)[1]	-	-	R-0.2 (0.03 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation
[2] The thermal conductivity of air spaces within curtain wall framing was found using ISO 10077-2.

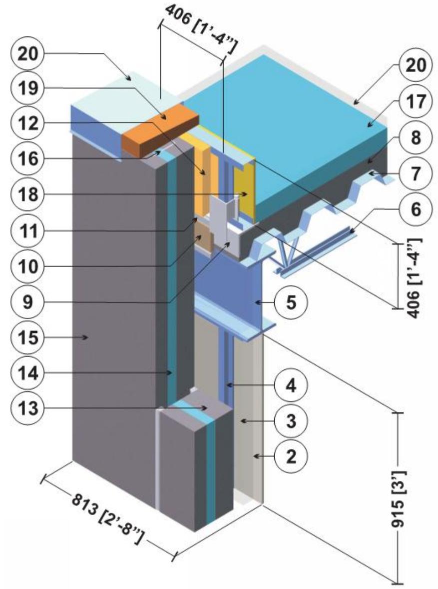
Detail 32 | Precast Sandwich Panel Wall Assembly with 3 5/8″ Steel Stud (16″ o.c.) – Slab Intersection



ID	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 Film (right side)[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	5 5/8" (143)	-	R-0.9 (0.16 RSI)	0.075 (1.2)	0.24 (1000)
4	3 5/8" Steel Studs with Top and Bottom Tracks	18 gauge	430 (62)	-	489 (7830)	0.12 (500)
5	Concrete Slab	8" (203)	12.5 (1.8)	-	140 (2250)	0.20 (850)
6	Gravity and Slot Anchors at Slab	-	347 (50)	-	489 (7830)	0.12 (500)
7	Semi Rigid Insulation	1" (25)	0.28 (0.04)	-	4.5 (72)	0.17 (710)
8	Silicone Sealant	1/2" (13)	2.4 (0.35)	-	-	-
9	Precast Sandwich Panel, Interior Concrete	4" (102)	12.5 (1.8)	-	140 (2250)	0.20 (850)
10	Precast Sandwich Panel, Insulation	2" (51)	-	R-10 (1.8 RSI)	1.8 (28)	0.29 (1220)
11	Precast Sandwich Panel, Exterior Concrete	4" (102)	12.5 (1.8)	-	140 (2250)	0.20 (850)
12	Precast Sandwich Panel, Structural Ties @ 24" (610) o.c.	16 gauge	430 (62)	-	489 (7830)	0.12 (500)
13	Exterior Film (left side)[1]	-	-	R-0.2 (0.03 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation

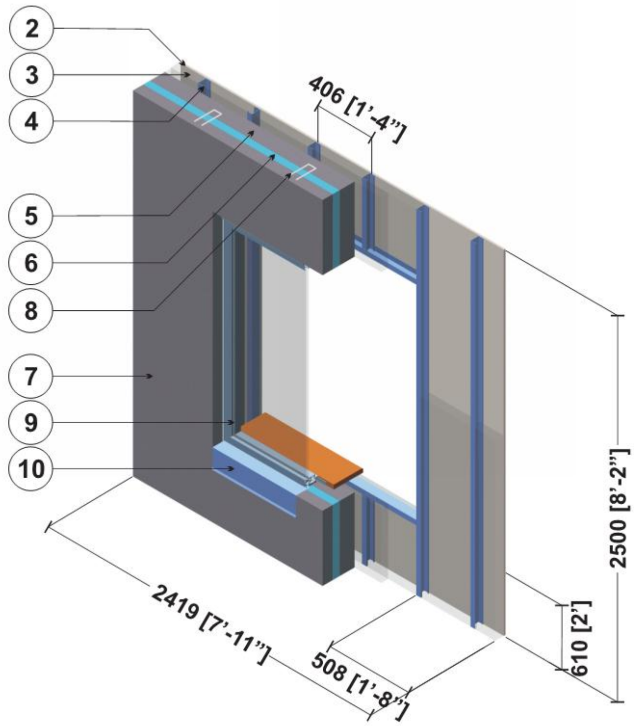
Detail 33 Precast Sandwich Panel Wall Assembly with 3 5/8″ Steel Stud (16″ o.c.) – Steel Roof Deck with Open Web Steel Joist & Parapet Intersection



ID	Component	Thickness Inches (mm)	Conductivity Btu·in / ft^2·hr·°F (W/m K)	Nominal Resistance hr·ft^2·°F/Btu (m^2K/W)	Density lb/ft^3 (kg/m^3)	Specific Heat Btu/lb·°F (J/kg K)
1	Interior Film (right side)[1]	-	-	R-0.6 (0.11 RSI) to R-0.7 (0.12 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	5 5/8" (143)	-	R-0.9 (0.16 RSI)	0.075 (1.2)	0.24 (1000)
4	3 5/8" Steel Studs with Top and Bottom Tracks	18 gauge	430 (62)	-	489 (7830)	0.12 (500)
5	Steel Beam (W410)	-	347 (50)	-	489 (7830)	0.12 (500)
6	Open Web Steel Joist (550C)	-	347 (50)	-	489 (7830)	0.12 (500)
7	Steel Deck	1/16" (1.6)	347 (50)	-	489 (7830)	0.12 (500)
8	Concrete Topping	6" (152)	6.3 (0.9)	-	120 (1920)	0.20 (850)
9	Gravity and Slot Anchors at Slab	-	347 (50)	-	489 (7830)	0.12 (500)
10	Semi Rigid Insulation	1" (25)	0.28 (0.04)	-	4.5 (72)	0.17 (710)
11	Silicone Sealant	1/2" (13)	2.4 (0.35)	-	-	-
12	Spray Foam Insulation	2" (51)	0.17 (0.025)	-	2.8 (39)	0.35 (1470)
13	Precast Sandwich Panel, Interior Concrete Panel	4" (102)	12.5 (1.8)	-	140 (2250)	0.20 (850)
14	Precast Sandwich Panel, Insulation	2" (51)	-	R-10 (1.8 RSI)	1.8 (28)	0.29 (1220)
15	Precast Sandwich Panel, Exterior Concrete Panel	4" (102)	12.5 (1.8)	-	140 (2250)	0.20 (850)
16	Precast Sandwich Panel, Structural Ties @ 24" (610) o.c.	16 gauge	430 (62)	-	489 (7830)	0.12 (500)
17	Roof Insulation	4" (102)	-	R-20 (3.5 RSI)	1.8 (28)	0.29 (1220)
18	Exterior Sheathing	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
19	Wood Blocking	5/8" (16)	0.63 (0.09)	R-1 (0.18 RSI)	27.8 (445)	0.45 (1880)
20	Flashing & roof finish material are incorporated into exterior heat transfer coefficient					
21	Exterior Film (left side)[1]	-	-	R-0.2 (0.03 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation

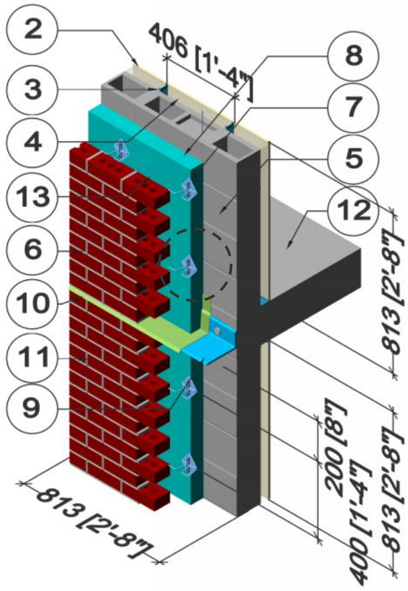
Detail 34 Precast Sandwich Panel Wall Assembly with 3 5/8″ Steel Stud (16″ o.c.) – Window Intersection

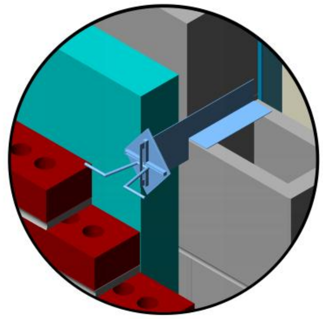


ID	Component	Thickness Inches (mm)	Conductivity Btu·in / $ft^2 \cdot hr \cdot {}^oF$ (W/m K)	Nominal Resistance $hr \cdot ft^2 \cdot {}^oF/Btu$ (m^2K/W)	Density lb/ft^3 (kg/m^3)	Specific Heat $Btu/lb \cdot {}^oF$ (J/kg K)
1	Interior Film (right side)[1]	-	-	R-0.7 (0.12 RSI)	-	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
3	Air in Stud Cavity	6 5/8” (168)	-	R-0.9 (0.16 RSI)	0.075 (1.2)	0.24 (1000)
4	3 5/8” Steel Studs with Metal Tracks	18 gauge	430 (62)	-	489 (7830)	0.12 (500)
5	Precast Sandwich Panel, Interior Concrete	4” (102)	12.5 (1.8)	-	140 (2250)	0.20 (850)
6	Precast Sandwich Panel, Insulation	2” (50)	-	R-10 (1.8 RSI)	1.8 (28)	0.29 (1220)
7	Precast Sandwich Panel, Exterior Concrete	4” (102)	12.5 (1.8)	-	140 (2250)	0.20 (850)
8	Precast Sandwich Panel, Structural Ties	16 gauge	430 (62)	-	489 (7830)	0.12 (500)
9	1.5m (H) x 1.2m (W) Aluminum window: double glazed & thermally broken[2]					
10	Flashing/ finish material is incorporated into exterior heat transfer coefficient					
11	Exterior Film (left side)[1]	-	-	R-0.2 (0.03 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation
[2] The thermal conductivity for air spaces within window framing was found using ISO 10077-2.

Detail 35 | Exterior Insulated Concrete Block Wall Assembly with Shelf Angle & Brick Ties Supporting Brick Veneer – Slab Intersection

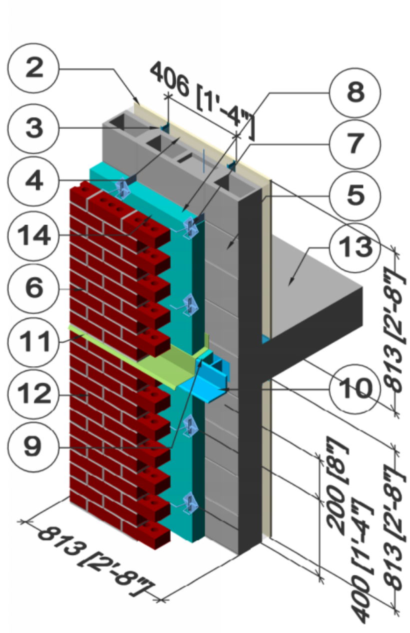


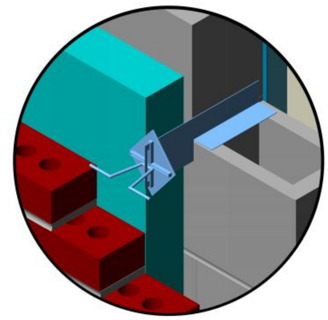


ID	Component	Thickness Inches (mm)	Conductivity Btu·in / $ft^2 \cdot hr \cdot {}^oF$ (W/m K)	Nominal Resistance $hr \cdot ft^2 \cdot {}^oF/Btu$ (m^2K/W)	Density lb/ft^3 (kg/m^3)	Specific Heat $Btu/lb \cdot {}^oF$ (J/kg K)
1	Interior Film (right side)[1]	-	-	R-0.6 (0.11 RSI) to R-0.9 (0.16 RSI)	-	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
3	1 5/8" Steel Studs with Metal Tracks	20 gauge	430 (62)	-	489 (7830)	0.12 (500)
4	Air in Stud Cavity	1 5/8" (41)	-	R-0.9 (0.16 RSI)	0.075 (1.2)	0.24 (1000)
5	Standard Concrete Block	7 5/8" (190)	3.5 (0.5)	-	119 (1900)	0.19 (800)
6	Cement Mortar	-	3.5 (0.5)	-	113 (1800)	0.12 (500)
7	Masonry Ties @ 16" (406) o.c.	14 gauge	347 (50)	-	489 (7830)	0.12 (500)
8	Insulation	Varies	-	R-5 to R-25 (0.88 to 4.4 RSI)	1.8 (28)	0.29 (1220)
9	Shelf Angle	3/8" (10)	347 (50)	-	489 (7830)	0.12 (500)
10	Flashing	20 gauge	347 (50)	-	489 (7830)	0.12 (500)
11	Brick Veneer	3 5/8" (92)	5.4 (0.78)	-	120 (1920)	0.19 (720)
12	Concrete Slab	8" (203)	12.5 (1.8)	-	140 (2250)	0.20 (850)
13	Air Gap	1" (25)	-	R-0.9 (0.16 RSI)	0.075 (1.2)	0.24 (1000)
14	Exterior Film (left side)[1]	-	-	R-0.2 (0.03 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation

Detail 36 | Exterior Insulated Concrete Block Wall Assembly with Spaced Shelf Angle & Brick Ties Supporting Brick Veneer – Slab Intersection

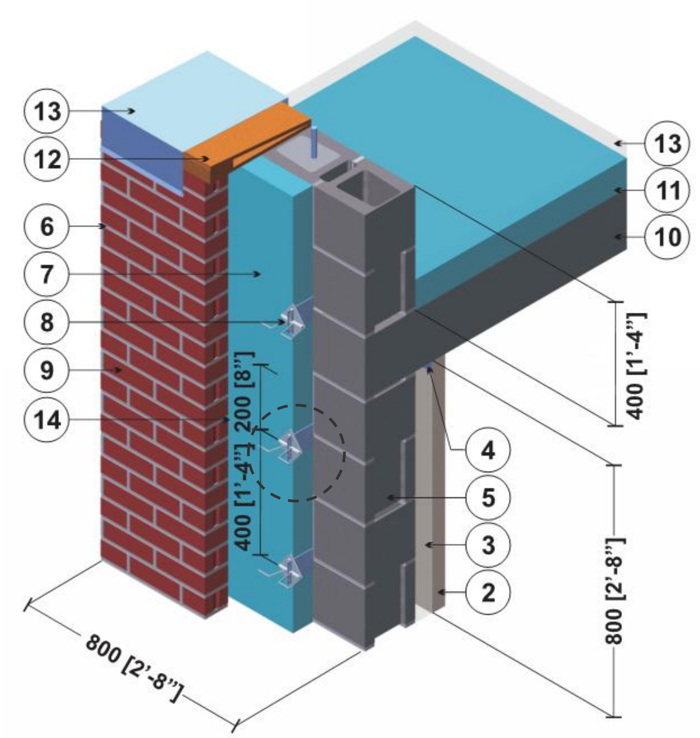


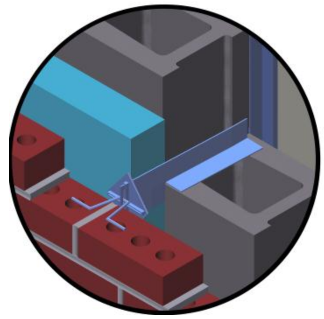


ID	Component	Thickness Inches (mm)	Conductivity Btu·in / ft²·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)	Specific Heat Btu/lb·°F (J/kg K)
1	Interior Film (right side)[1]	-	-	R-0.6 (0.11 RSI) to R-0.9 (0.16 RSI)	-	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
3	1 5/8" Steel Studs with Metal Tracks	20 gauge	430 (62)	-	489 (7830)	0.12 (500)
4	Air in Stud Cavity	1 5/8" (41)	-	R-0.9 (0.16 RSI)	0.075 (1.2)	0.24 (1000)
5	Standard Concrete Block	7 5/8" (190)	3.5 (0.5)	-	119 (1900)	0.19 (800)
6	Cement Mortar	-	3.5 (0.5)	-	113 (1800)	0.12 (500)
7	Masonry Ties @ 16" (406) o.c.	14 gauge	347 (50)	-	489 (7830)	0.12 (500)
8	Insulation	Varies	-	R-5 to R-25 (0.88 to 4.4 RSI)	1.8 (28)	0.29 (1220)
9	Insulation Behind Shelf Angle	Varies	-	R5 to R25 (0.88 to 4.4 RSI)	1.8 (28)	0.29 (1220)
10	Spaced Shelf Angle	3/8" (10)	347 (50)	-	489 (7830)	0.12 (500)
11	Flashing	20 gauge	347 (50)	-	489 (7830)	0.12 (500)
12	Brick Veneer	3 5/8" (92)	5.4 (0.78)	-	120 (1920)	0.19 (720)
13	Concrete Slab	8" (203)	12.5 (1.8)	-	140 (2250)	0.20 (850)
14	Air Gap	1" (25)	-	R-0.9 (0.16 RSI)	0.075 (1.2)	0.24 (1000)
15	Exterior Film (left side)[1]	-	-	R-0.2 (0.03 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation

Detail 37 | Exterior Insulated Concrete Block Wall Assembly with Masonry Ties Supporting Brick Veneer – Parapet & Roof Intersection

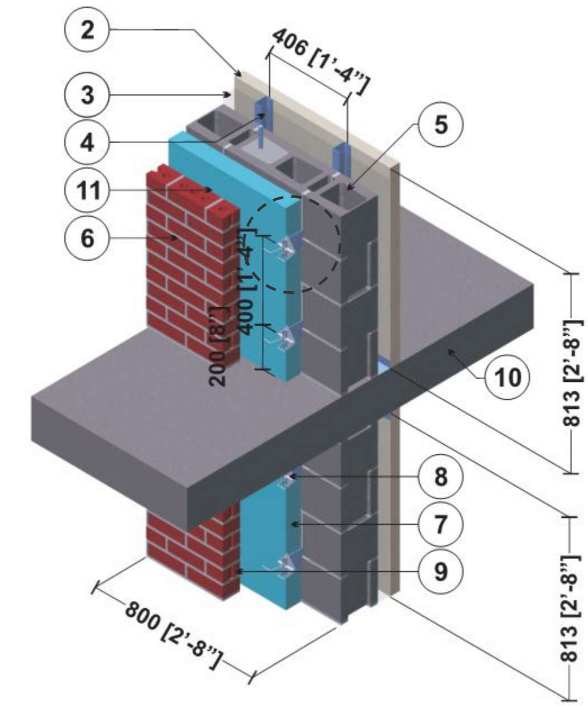


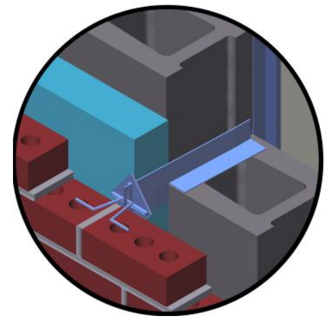


ID	Component	Thickness Inches (mm)	Conductivity Btu·in / ft²·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)	Specific Heat Btu/lb·°F (J/kg K)
1	Interior Film (right side)[1]	-	-	R-0.6 (0.11 RSI) to R-0.7 (0.12 RSI)	-	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
3	Air in Stud Cavity	1 5/8" (41)	-	R-0.9 (0.16 RSI)	0.075 (1.2)	0.24 (1000)
4	1 5/8" Steel Studs with Metal Tracks	20 gauge	430 (62)	-	489 (7830)	0.12 (500)
5	Standard Concrete Block	7 5/8" (190)	3.5 (0.5)	-	119 (1900)	0.19 (800)
6	Cement Mortar	-	3.5 (0.5)	-	113 (1800)	0.12 (500)
7	Insulation	Varies	-	R-5 to R-25 (0.88 to 4.4 RSI)	1.8 (28)	0.29 (1220)
8	Masonry Ties @ 16" (406) o.c.	16 gauge	430 (62)	-	489 (7830)	0.12 (500)
9	Brick Veneer	3 5/8" (92)	5.4 (0.78)	-	120 (1920)	0.19 (720)
10	Concrete Slab	8" (203)	12.5 (1.8)	-	140 (2250)	0.20 (850)
11	Roof Insulation	4" (102)	-	R-20 (3.5 RSI)	1.8 (28)	0.29 (1220)
12	Wood Blocking	5/8" (16)	0.63 (0.09)	R-1 (0.18 RSI)	27.8 (445)	0.45 (1880)
13	Flashing & roof finish materials are incorporated into exterior heat transfer coefficient					
14	Air Gap	1" (25)	-	R-0.9 (0.16 RSI)	0.075 (1.2)	0.24 (1000)
15	Exterior Film (left side)[1]	-	-	R-0.2 (0.03 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation

Detail 38 | Exterior Insulated Concrete Block Wall Assembly with Masonry Ties Supporting Brick Veneer – Balcony Slab Intersection

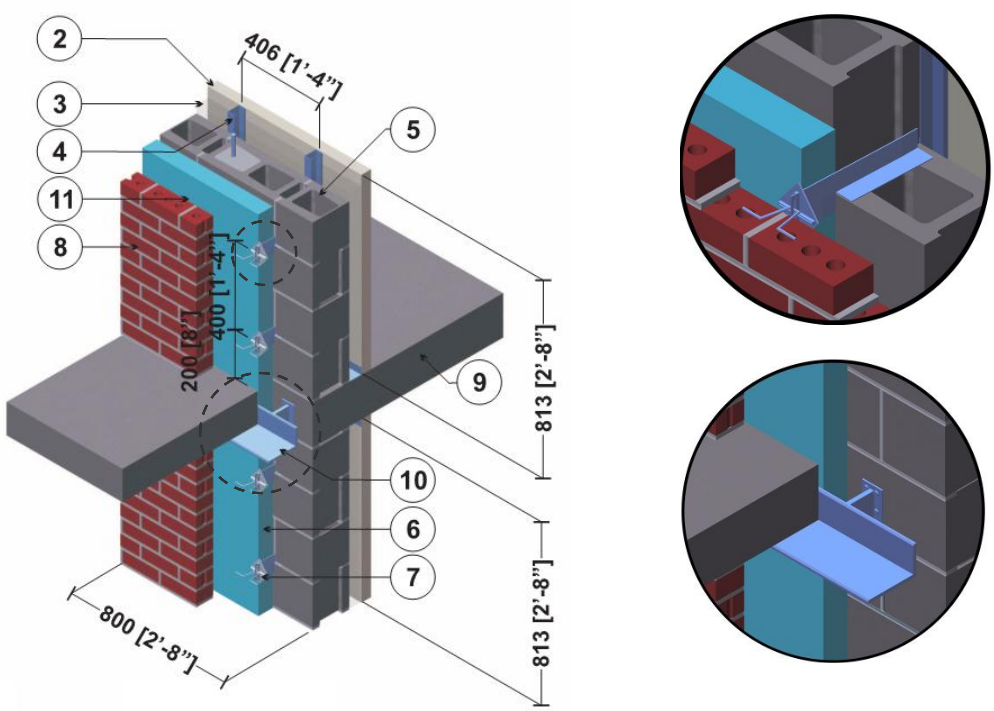




ID	Component	Thickness Inches (mm)	Conductivity Btu·in / ft^2·hr·^{o}F (W/m K)	Nominal Resistance hr·ft^2·^{o}F/Btu (m^{2}K/W)	Density lb/ft^3 (kg/m^3)	Specific Heat Btu/lb·^{o}F (J/kg K)
1	Interior Film (right side)[1]	-	-	R-0.6 (0.11 RSI) to R-0.9 (0.16 RSI)	-	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
3	Air in Stud Cavity	1 5/8" (41)	-	R-0.9 (0.16 RSI)	0.075 (1.2)	0.24 (1000)
4	1 5/8" Steel Studs with Metal Tracks	20 gauge	430 (62)	-	489 (7830)	0.12 (500)
5	Standard Concrete Block	7 5/8" (190)	3.5 (0.5)	-	119 (1900)	0.19 (800)
6	Cement Mortar	-	3.5 (0.5)	-	113 (1800)	0.12 (500)
7	Insulation	Varies	-	R-5 to R-25 (0.88 to 4.4 RSI)	1.8 (28)	0.29 (1220)
8	Masonry Ties @ 16" (406) o.c.	14 gauge	347 (50)	-	489 (7830)	0.12 (500)
9	Brick Veneer	3 5/8" (90)	5.4 (0.78)	-	120 (1920)	0.19 (720)
10	Concrete Slab	8" (203)	12.5 (1.8)	-	140 (2250)	0.20 (850)
11	Air Gap	1" (25)	-	R-0.9 (0.16 RSI)	0.075 (1.2)	0.24 (1000)
12	Exterior Film (left side)[1]	-	-	R-0.2 (0.03 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation

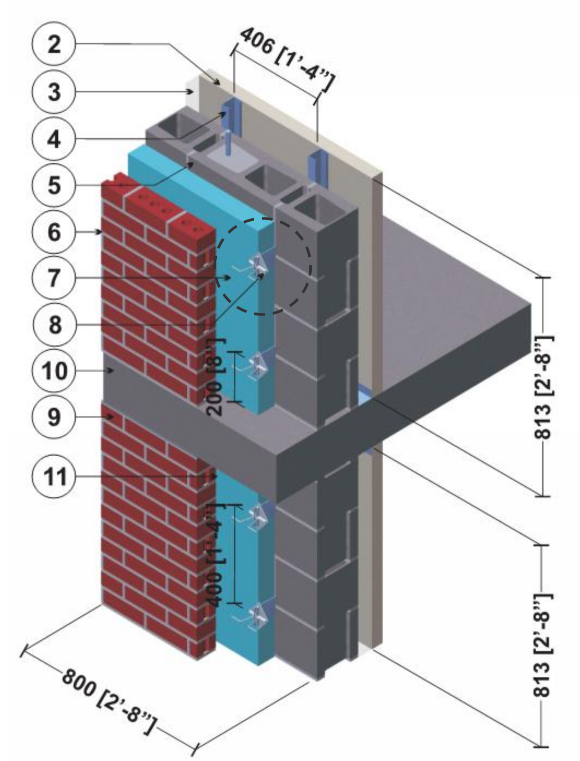
Detail 39 Exterior Insulated Concrete Block Wall Assembly with Masonry Ties Supporting Brick Veneer – Angle Supported Slab & Slab Intersection

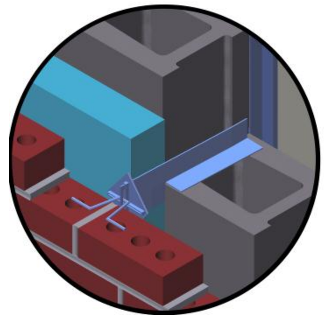


ID	Component	Thickness Inches (mm)	Conductivity Btu·in / ft²·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)	Specific Heat Btu/lb·°F (J/kg K)
1	Interior Film (right side)[1]	-	-	R-0.6 (0.11 RSI) to R-0.9 (0.16 RSI)	-	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
3	Air in Stud Cavity	1 5/8" (41)	-	R-0.9 (0.16 RSI)	0.075 (1.2)	0.24 (1000)
4	1 5/8" Steel Studs with Metal Tracks	20 gauge	430 (62)	-	489 (7830)	0.12 (500)
5	Standard Concrete Block	7 5/8" (190)	3.5 (0.5)	-	119 (1900)	0.19 (800)
6	Insulation	Varies	-	R-5 to R-25 (0.88 to 4.4 RSI)	1.8 (28)	0.29 (1220)
7	Masonry Ties @ 16" (406) o.c.	14 gauge	347 (50)	-	489 (7830)	0.12 (500)
8	Brick Veneer	3 5/8" (92)	5.4 (0.78)	-	120 (1920)	0.19 (720)
9	Concrete Slab	8" (203)	12.5 (1.8)	-	140 (2250)	0.20 (850)
10	Slab & Brick (Anchored to Slab at 16" o.c.) Support Angle	-	347 (50)	-	489 (7830)	0.12 (500)
11	Air Gap	1" (25)	-	R-0.9 (0.16 RSI)	0.075 (1.2)	0.24 (1000)
12	Exterior Film (left side)[1]	-	-	R-0.2 (0.03 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation

Detail 40 Exterior Insulated Concrete Block Wall Assembly with Masonry Ties Supporting Brick Veneer – Balcony Slab Intersection





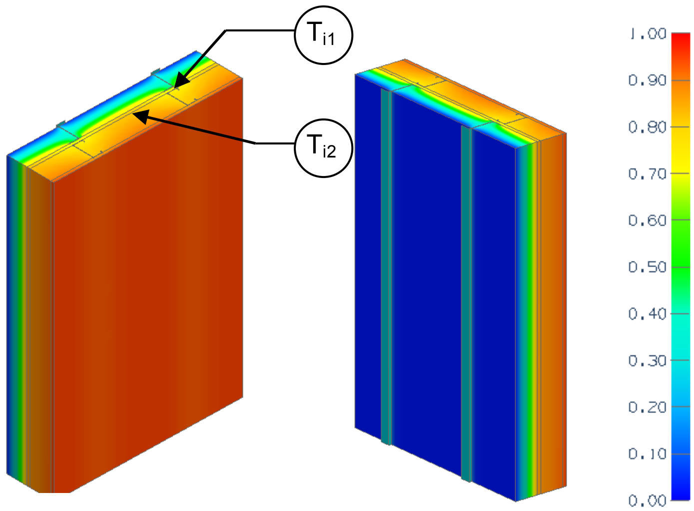
ID	Component	Thickness Inches (mm)	Conductivity Btu·in / ft²·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)	Specific Heat Btu/lb·°F (J/kg K)
1	Interior Film (right side)[1]	-	-	R-0.6 (0.11 RSI) to R-0.9 (0.16 RSI)	-	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
3	Air in Stud Cavity	1 5/8" (41)	-	R-0.9 (0.16 RSI)	0.075 (1.2)	0.24 (1000)
4	1 5/8" Steel Studs with Metal Tracks	20 gauge	430 (62)	-	489 (7830)	0.12 (500)
5	Standard Concrete Block	7 5/8" (190)	3.5 (0.5)	-	119 (1900)	0.19 (800)
6	Cement Mortar	-	3.5 (0.5)	-	113 (1800)	0.12 (500)
7	Insulation	Varies	-	R-5 to R-25 (0.88 to 4.4 RSI)	1.8 (28)	0.29 (1220)
8	Masonry Ties @ 16" (406) o.c.	14 gauge	347 (50)	-	489 (7830)	0.12 (500)
9	Brick Veneer	3 5/8" (90)	5.4 (0.78)	-	120 (1920)	0.19 (720)
10	Concrete Slab	8" (203)	12.5 (1.8)	-	140 (2250)	0.20 (850)
11	Air Gap	1" (25)	-	R-0.9 (0.16 RSI)	0.075 (1.2)	0.24 (1000)
12	Exterior Film (left side)[1]	-	-	R-0.2 (0.03 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation

APPENDIX F – SIMULATION RESULTS DATA SHEETS

Detail 01

Exterior Insulated 3 5/8″ x 1 5/8″ Steel Stud (16″ O.C.) Wall Assembly with Vertical Z-Girts (16″ O.C.) Supporting Metal Cladding – Clear Wall



View from Interior   View from Exterior

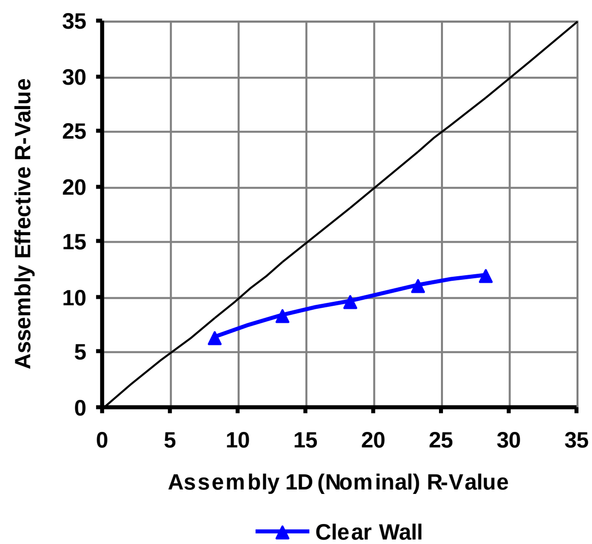
Thermal Performance Indicators

Assembly 1D (Nominal) R-Value	R_{1D}	R-3.18 (0.56 RSI) + exterior insulation
Transmittance / Resistance	U_o, R_o	"clear wall" U- and R-value
Surface Temperature Index[1]	T_i	0 = exterior temperature 1 = interior temperature

[1]Surface temperatures are a result of steady-state conductive heat flow with constant heat transfer coefficients. Limitations are identified in final report.

Nominal (1D) vs. Assembly Performance Indicators

Exterior Insulation 1D R-Value (RSI)	R_{1D} ft^2·hr·^{o}F / Btu (m^2 K / W)	R_o ft^2·hr·^{o}F / Btu (m^2 K / W)	U_o Btu/ft^2 ·hr ·^{o}F (W/m^2 K)
R-5 (0.88)	R-8.2 (1.44)	R-6.4 (1.12)	0.157 (0.89)
R-10 (1.76)	R-13.2 (2.32)	R-8.3 (1.47)	0.120 (0.68)
R-15 (2.64)	R-18.2 (3.20)	R-9.7 (1.71)	0.103 (0.59)
R-20 (3.52)	R-23.2 (4.08)	R-11.0 (1.93)	0.091 (0.52)
R-25 (4.40)	R-28.2 (4.96)	R-12.0 (2.11)	0.084 (0.48)

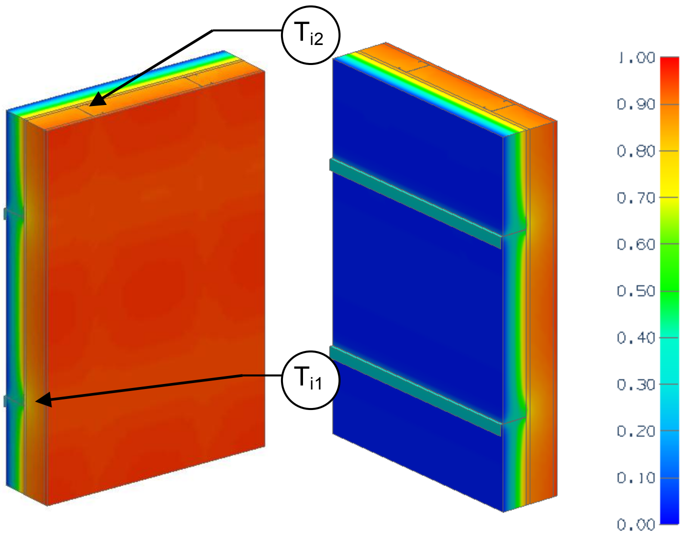


Temperature Indices

	R5	R10	R15	R20	R25	
T_{i1}	0.63	0.70	0.72	0.75	0.76	Min T on sheathing, along girts at stud intersection
T_{i2}	0.72	0.80	0.84	0.86	0.87	Max T on sheathing, centre of stud cavity

Detail 02

Exterior Insulated 3 5/8″ x 1 5/8″ Steel Stud (16″ O.C.) Wall Assembly with Horizontal Z-Girts (24″ O.C.) Supporting Metal Cladding – Clear Wall



View from Interior   View from Exterior

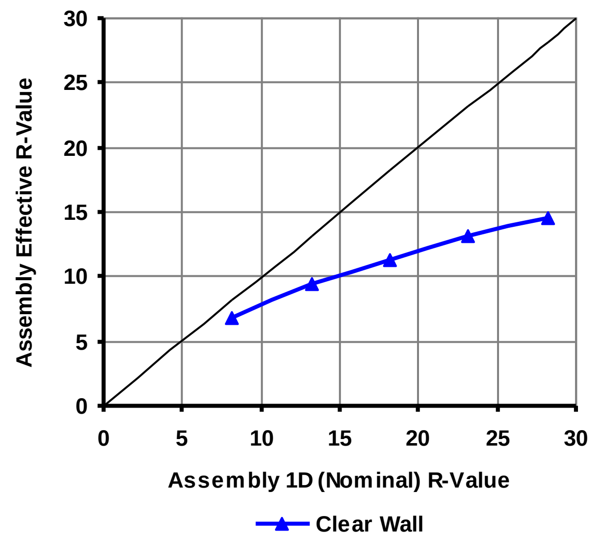
Thermal Performance Indicators

Assembly 1D (Nominal) R-Value	R_{1D}	R-3.18 (0.56 RSI) + exterior insulation
Transmittance / Resistance	U_o, R_o	"clear wall" U- and R-value
Surface Temperature Index[1]	T_i	0 = exterior temperature 1 = interior temperature

[1]Surface temperatures are a result of steady-state conductive heat flow with constant heat transfer coefficients. Limitations are identified in final report.

Nominal (1D) vs. Assembly Performance Indicators

Exterior Insulation 1D R-Value (RSI)	R_{1D} ft^2·hr·^{o}F / Btu (m^2 K / W)	R_o ft^2·hr·^{o}F / Btu (m^2 K / W)	U_o Btu/ft^2 ·hr ·^{o}F (W/m^2 K)
R-5 (0.88)	R-8.2 (1.44)	R-6.8 (1.21)	0.146 (0.83)
R-10 (1.76)	R-13.2 (2.32)	R-9.4 (1.66)	0.106 (0.60)
R-15 (2.64)	R-18.2 (3.20)	R-11.3 (1.99)	0.088 (0.50)
R-20 (3.52)	R-23.2 (4.08)	R-13.1 (2.31)	0.076 (0.43)
R-25 (4.40)	R-28.2 (4.96)	R-14.5 (2.56)	0.069 (0.39)

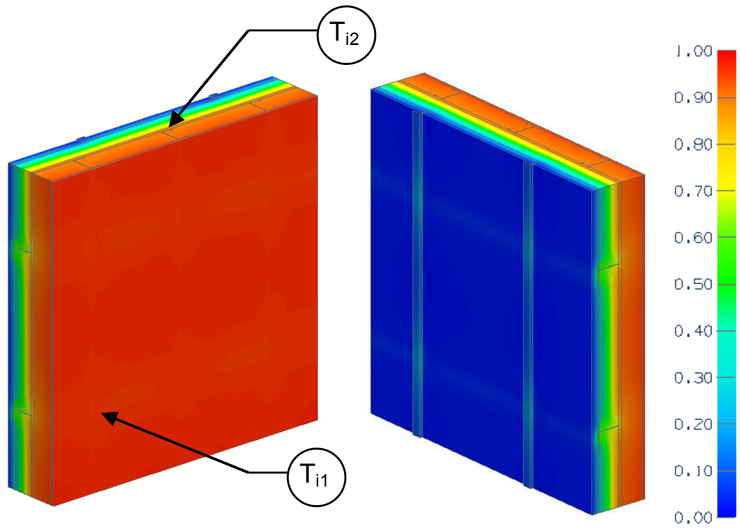


Temperature Indices

	R5	R10	R15	R20	R25	
T_{i1}	0.62	0.69	0.72	0.75	0.76	Min T on sheathing, along girts at stud intersection
T_{i2}	0.76	0.83	0.87	0.89	0.90	Max T on sheathing, along studs between girts

Detail 03

Exterior Insulated 3 5/8″ x 1 5/8″ Steel Stud (16″ O.C.) Wall Assembly with Vertical Z-Girts (24″ O.C.) & Horizontal Z-Girts (24″ O.C.) Supporting Metal Cladding – Clear Wall



View from Interior   View from Exterior

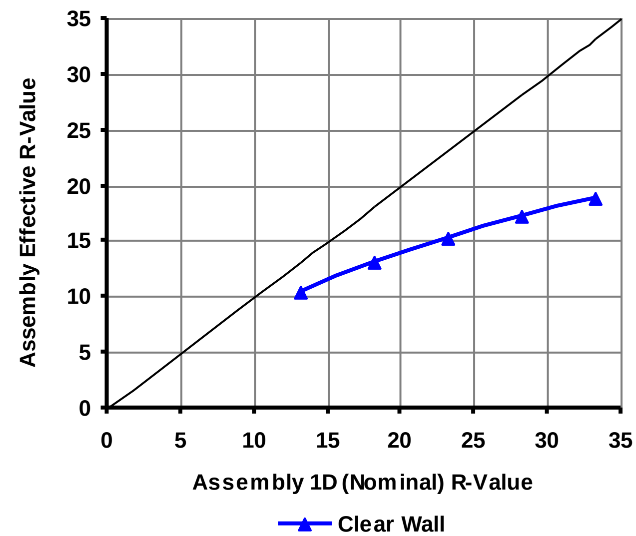
Thermal Performance Indicators

Assembly 1D (Nominal) R-Value	R_{1D}	R-3.18 (0.56 RSI) + horizontal exterior insulation + vertical exterior insulation R-5 (0.88 RSI)
Transmittance / Resistance	U_o, R_o	“clear wall” U- and R-value
Surface Temperature Index[1]	T_i	0 = exterior temperature 1 = interior temperature

[1]Surface temperatures are a result of steady-state conductive heat flow with constant heat transfer coefficients. Limitations are identified in final report.

Nominal (1D) vs. Assembly Performance Indicators

Exterior Insulation 1D R-Value (RSI)	R_{1D} ft^2·hr·^{o}F / Btu (m^2 K / W)	R_o ft^2·hr·^{o}F / Btu (m^2 K / W)	U_o Btu/ft^2 ·hr ·^{o}F (W/m^2 K)
R-10 (0.88)	R-13.2 (2.32)	R-10.4 (1.82)	0.097 (0.55)
R-15 (1.76)	R-18.2 (3.20)	R-13.1 (2.31)	0.076 (0.43)
R-20 (2.64)	R-23.2 (4.08)	R-15.3 (2.70)	0.065 (0.37)
R-25 (3.52)	R-28.2 (4.96)	R-17.2 (3.03)	0.058 (0.33)
R-30 (4.40)	R-33.2 (5.84)	R-18.9 (3.33)	0.053 (0.30)

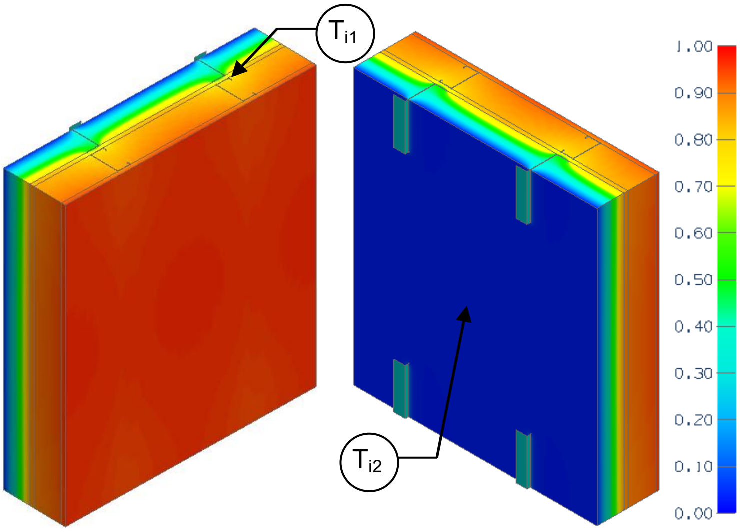


Temperature Indices

	R10	R15	R20	R25	R30	
T_{i1}	0.74	0.77	0.80	0.81	0.82	Min T on sheathing, at vertical and horizontal girt intersection, not at a stud intersection
T_{i2}	0.85	0.89	0.90	0.91	0.93	Max T on sheathing, along studs between girts

Detail 04

Exterior Insulated 3 5/8″ x 1 5/8″ Steel Stud (16″ O.C.) Wall Assembly with Intermittent Vertical Z-Girts (16″ O.C.) Supporting Metal Cladding – Clear Wall



View from Interior   View from Exterior

Thermal Performance Indicators

Assembly 1D □Nominal) R-Value	R_{1D}	R-3.18 (0.56 RSI) + horizontal exterior insulation
Transmittance / Resistance	U_o, R_o	"clear wall" U- and R-value. Results for three vertical spacings (12", 24", 36") are presented below
Surface Temperature Index[1]	T_i	0 = exterior temperature 1 = interior temperature

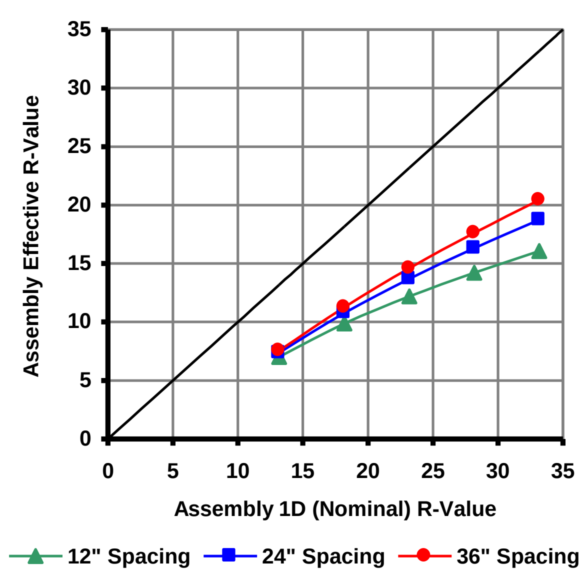
[1]Surface temperatures are a result of steady-state conductive heat flow with constant heat transfer coefficients. Limitations are identified in final report.

Nominal (1D) vs. Assembly Performance Indicators

Exterior Insulation 1D R-Value (RSI)	R_{1D} ft^2·hr·^{o}F / Btu (m^2 K / W)	12" Vertical Spacing R_o ft^2·hr·^{o}F / Btu (m^2 K / W)	12" Vertical Spacing U_o Btu/ft^2 ·hr ·^{o}F (W/m^2 K)	24" Vertical Spacing R_o ft^2·hr·^{o}F / Btu (m^2 K / W)	24" Vertical Spacing U_o Btu/ft^2 ·hr ·^{o}F (W/m^2 K)	36" Vertical Spacing R_o ft^2·hr·^{o}F / Btu (m^2 K / W)	36" Vertical Spacing U_o Btu/ft^2 ·hr ·^{o}F (W/m^2 K)
R-5 (0.88)	R-8.2 (1.44)	R-7.0 (1.24)	0.142 (0.81)	R-7.4 (1.30)	0.136 (0.77)	R-7.6 (1.33)	0.132 (0.75)
R-10 (1.76)	R-13.2 (2.32)	R-9.9 (1.74)	0.101 (0.58)	R-10.8 (1.90)	0.093 (0.53)	R-11.3 (1.99)	0.089 (0.50)
R-15 (2.64)	R-18.2 (3.20)	R-12.2 (2.15)	0.082 (0.47)	R-13.7 (2.41)	0.073 (0.42)	R-14.6 (2.57)	0.068 (0.39)
R-20 (3.52)	R-23.2 (4.08)	R-14.2 (2.50)	0.070 (0.40)	R-16.3 (2.87)	0.061 (0.35)	R-17.6 (3.10)	0.057 (0.32)
R-25 (4.40)	R-28.2 (4.96)	R-16.1 (2.83)	0.062 (0.35)	R-18.7 (3.30)	0.053 (0.30)	R-20.4 (3.60)	0.049 (0.28)

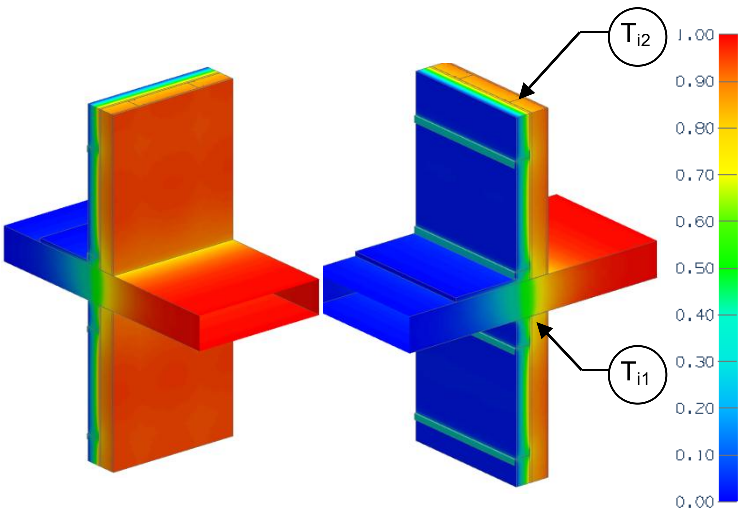
Temperature Indices

Spacing	T_i	R5	R10	R15	R20	R25	
12"	T_{i1}	0.62	0.69	0.73	0.75	0.77	Min T on sheathing, at girt and stud intersection
	T_{i2}	0.75	0.83	0.87	0.89	0.90	Max T on sheathing, centre of stud cavity between girts
24"	T_{i1}	0.63	0.70	0.73	0.76	0.78	Min T on sheathing, at girt and stud intersection
	T_{i2}	0.77	0.85	0.88	0.90	0.92	Max T on sheathing, centre of stud cavity between girts
36"	T_{i1}	0.63	0.70	0.73	0.76	0.78	Min T on sheathing, at girt and stud intersection
	T_{i2}	0.78	0.86	0.90	0.92	0.93	Max T on sheathing, centre of stud cavity between girts



Detail 05

Exterior Insulated 3 5/8″ x 1 5/8″ Steel Stud (16″ o.c.) Wall Assembly with Horizontal Z-Girts (24″ o.c.) Supporting Metal Cladding – Slab Intersection with Top Side Insulation



View from Interior   View from Exterior

Thermal Performance Indicators

Assembly 1D (Nominal) R-Value	R_{1D}	R- 3.18 (0.56 RSI) + exterior insulation
Transmittance / Resistance without Anomaly	U_o, R_o	“clear wall” U- and R-value, without slab (Detail 2, R15)
Surface Temperature Index[1]	T_i	0 = exterior temperature 1 = interior temperature
Linear Transmittance	ψ	Incremental increase in transmittance per linear length of slab

[1]Surface temperatures are a result of steady-state conductive heat flow with constant heat transfer coefficients. Limitations are identified in final report.

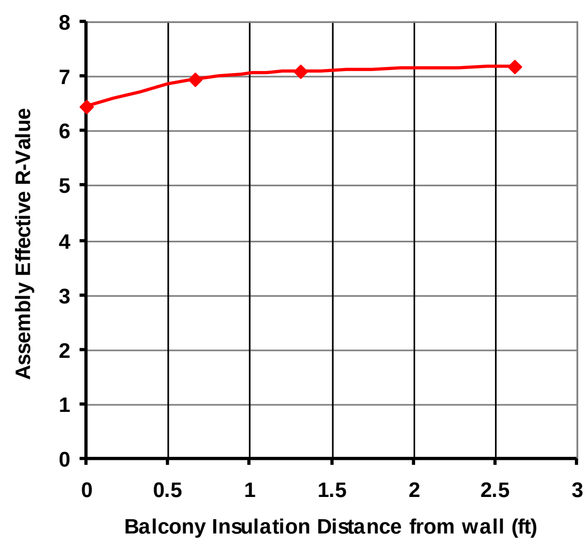
Nominal (1D) vs. Assembly Performance Indicators

Base Assembly –Wall

R_{1D} ft^2·hr·^{o}F / Btu (m^2 K / W)	R_o ft^2·hr·^{o}F / Btu (m^2 K / W)	U_o Btu/ft^2 ·hr ·^{o}F (W/m^2 K)
R-15 (2.64)	R-18.2 (3.20)	0.088 (0.50)

Slab Linear Transmittance

Balcony Insulation Distance from wall (ft)	R ft^2·hr·^{o}F / Btu (m^2 K / W)	U Btu/ft^2 ·hr ·^{o}F (W/m^2 K)	ψ Btu/ft hr ^{o}F (W/m K)
0.00 (0.0)	R-6.5 (1.14)	0.155 (0.88)	0.445 (0.770)
0.66 (0.2)	R-7.0 (1.22)	0.144 (0.82)	0.402 (0.695)
1.31 (0.4)	R-7.1 (1.25)	0.141 (0.80)	0.395 (0.683)
2.62 (0.8)	R-7.1 (1.26)	0.139 (0.79)	0.393 (0.680)

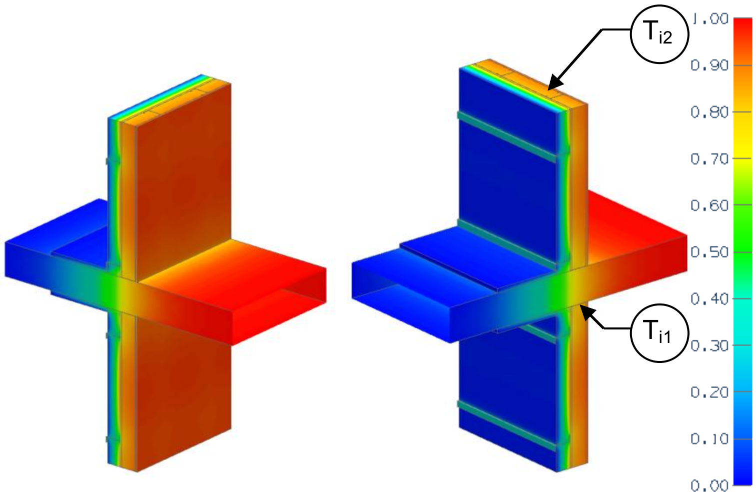


Temperature Indices

D(ft)	0	0.66	1.31	2.62	
T_{i1}	0.58	0.61	0.62	0.62	Min T on sheathing, at slab, between studs
T_{i2}	0.84	0.84	0.85	0.85	Max T on sheathing, at studs, between girts

Detail 05a

Exterior Insulated 3 5/8″ x 1 5/8″ Steel Stud (16″ o.c.) Wall Assembly with Horizontal Z-Girts (24″ o.c.) Supporting Metal Cladding – Slab Intersection with Top & Under Side Insulation



View from Interior   View from Exterior

Thermal Performance Indicators

Assembly 1D (Nominal) R-Value	R_{1D}	R- 3.18 (0.56 RSI) + exterior insulation
Transmittance / Resistance without Anomaly	U_o, R_o	"clear wall" U- and R-value, without slab (Detail 2, R15)
Surface Temperature Index[1]	T_i	0 = exterior temperature 1 = interior temperature
Linear Transmittance	ψ	Incremental increase in transmittance per linear length of slab

[1]Surface temperatures are a result of steady-state conductive heat flow with constant heat transfer coefficients. Limitations are identified in final report.

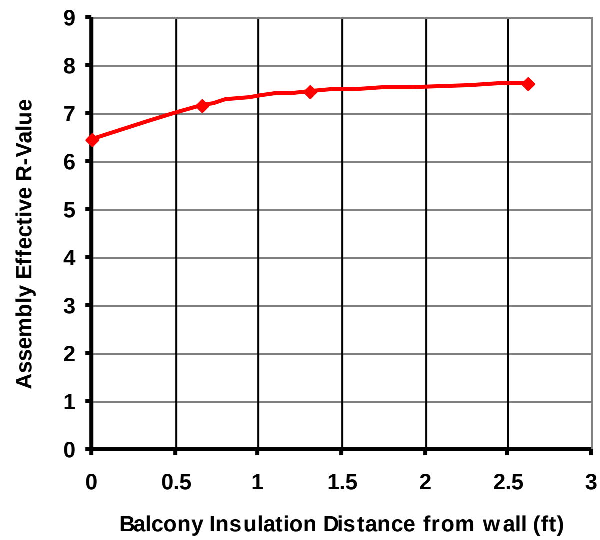
Nominal (1D) vs. Assembly Performance Indicators

Base Assembly – Wall

R_{1D} ft^2·hr·^{o}F / Btu (m^2 K / W)	R_o ft^2·hr·^{o}F / Btu (m^2 K / W)	U_o Btu/ft^2 ·hr ·^{o}F (W/m^2 K)
R-15 (2.64)	R-18.2 (3.20)	0.088 (0.50)

Slab Linear Transmittance

Balcony Insulation Distance from wall (ft)	R ft^2·hr·^{o}F / Btu (m^2 K / W)	U Btu/ft^2 ·hr ·^{o}F (W/m^2 K)	ψ Btu/ft hr ^{o}F (W/m K)
0.00 (0.0)	R-6.5 (1.14)	0.155 (0.88)	0.445 (0.770)
0.66 (0.2)	R-7.2 (1.26)	0.140 (0.79)	0.342 (0.592)
1.31 (0.4)	R-7.5 (1.32)	0.134 (0.76)	0.306 (0.529)
2.62 (0.8)	R-7.6 (1.34)	0.131 (0.75)	0.287 (0.496)

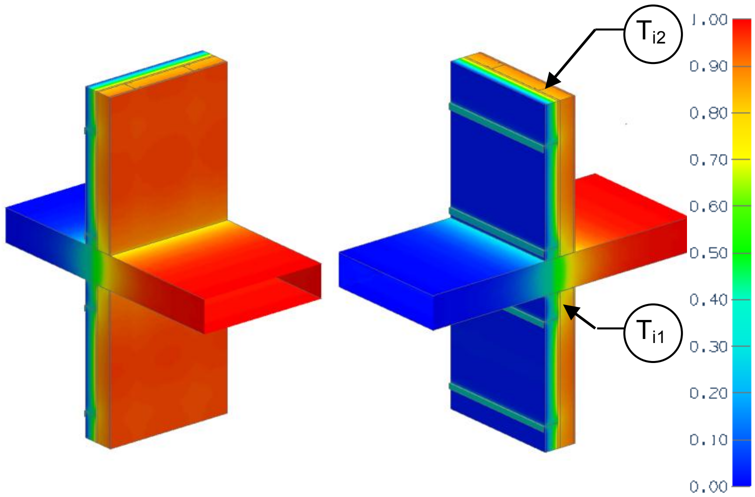


Temperature Indices

D(ft)	0	0.66	1.31	2.62	
T_{i1}	0.58	0.66	0.69	0.70	Min T on sheathing, at slab, between studs
T_{i2}	0.84	0.85	0.85	0.85	Max T on sheathing, at studs, between girts

Detail 06

Exterior Insulated 3 5/8″ x 1 5/8″ Steel Stud (16″ O.C.) Wall Assembly with Horizontal Z-Girts (24″ O.C.) Supporting Metal Cladding – Slab Intersection



View from Interior　　View from Exterior

Thermal Performance Indicators

Assembly 1D (Nominal) R-Value	R_{1D}	R- 3.18 (0.56 RSI) + exterior insulation
Transmittance / Resistance without Anomaly	U_o, R_o	“clear wall” U- and R-value without slab (Detail 11)
Surface Temperature Index[1]	T_i	0 = exterior temperature 1 = interior temperature
Linear Transmittance	ψ	Incremental increase in transmittance per linear length of slab

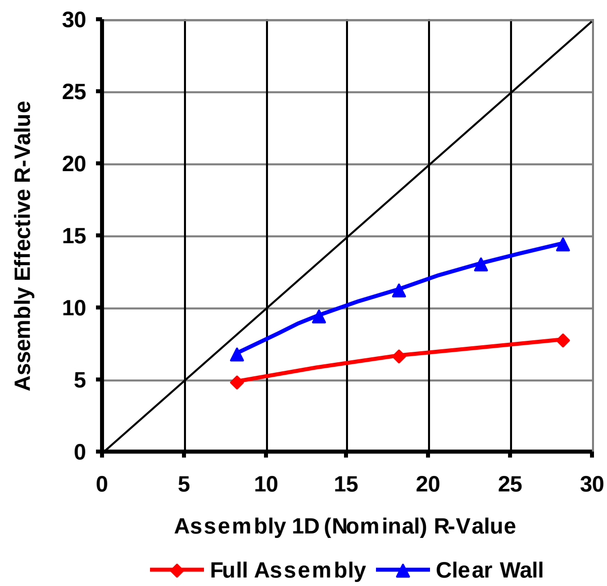
[1]Surface temperatures are a result of steady-state conductive heat flow with constant heat transfer coefficients. Limitations are identified in final report.

Nominal (1D) vs. Assembly Performance Indicators

Exterior Insulation 1D R-Value (RSI)	R_{1D} ft²·hr·°F / Btu (m² K / W)	R_o ft²·hr·°F / Btu (m² K / W)	U_o Btu/ft² ·hr ·°F (W/m² K)	R ft²·hr·°F / Btu (m² K / W)	U Btu/ft² ·hr ·°F (W/m² K)	ψ Btu/ft hr °F (W/m K)
R-5 (0.88)	R-8.2 (1.44)	R-6.9 (1.21)	0.146 (0.83)	R-4.74 (0.83)	0.211 (1.20)	0.433 (0.749)
R-15 (2.64)	R-18.2 (3.20)	R-11.3 (1.99)	0.088 (0.50)	R-6.45 (1.14)	0.155 (0.88)	0.445 (0.770)
R-25 (4.40)	R-28.2 (4.96)	R-14.6 (2.56)	0.069 (0.39)	R-7.61 (1.34)	0.131 (0.75)	0.418 (0.724)

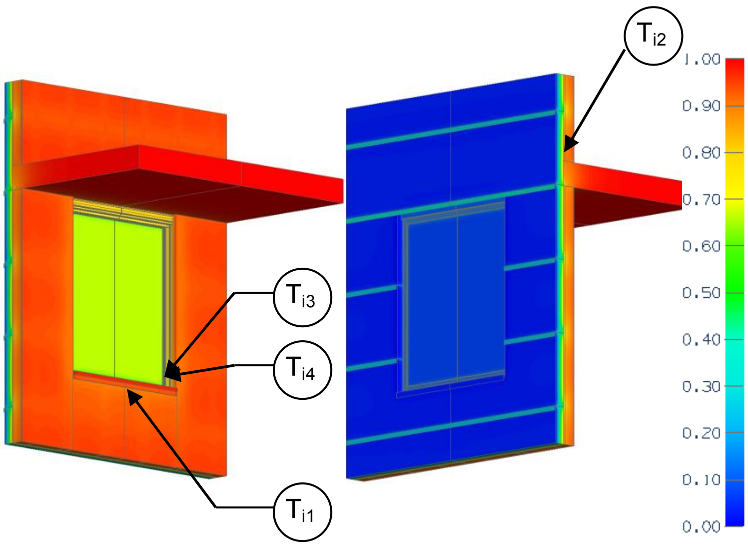
Temperature Indices

	R5	R15	R25	
T_{i1}	0.50	0.58	0.63	Min T on sheathing, at slab, between studs
T_{i2}	0.73	0.84	0.88	Max T on sheathing, at studs, between girts



Detail 07

Exterior Insulated 3 5/8″ x 1 5/8″ Steel Stud (16″ o.c.) Wall Assembly with Horizontal Z-Girts (24″ o.c.) Supporting Metal Cladding – Window & Slab Intersection



View from Interior   View from Exterior

Thermal Performance Indicators

A□sembly 1D (Nominal) R-Value	R_{1D}	R-3.18 (0.56 RSI) + horizontal exterior insulation
Transmittance / Resistance without Anomaly	U_o, R_o	“clear wall” U- and R-value, without slab and window (Detail 2)
Surface Temperature Index[1]	T_i	0 = exterior temperature 1 = interior temperature
Linear Transmittance	ψ_s, ψ_g	Incremental increase in transmittance per linear length of s = slab g = glazing transition
Point Transmittance	χ_g	Incremental increase in transmittance from glazing transition

[1]Surface temperatures are a result of steady-state conductive heat flow with constant heat transfer coefficients. Limitations are identified in final report.

Nominal (1D) vs. Assembly Performance Indicators

Base Assembly – Wall

Exterior Insulation 1D R-Value (RSI)	R_{1D} ft^2·hr·^{o}F / Btu (m^2 K / W)	R_o ft^2·hr·^{o}F / Btu (m^2 K / W)	U_o Btu/ft^2 ·hr ·^{o}F (W/m^2 K)
R-5 (0.88)	R-8.2 (1.44)	R-6.8 (1.21)	0.146 (0.83)
R-15 (2.64)	R-18.2 (3.20)	R-11.3 (1.99)	0.088 (0.50)
R-25 (4.40)	R-28.2 (4.96)	R-14.5 (2.56)	0.069 (0.39)

Flush Slab Linear Transmittance

R_s ft^2·hr·^{o}F / Btu (m^2 K / W)	U_s Btu/ft^2 ·hr ·^{o}F (W/m^2 K)	ψ_s Btu/ft^2 ·hr ·^{o}F (W/m^2 K)
R-6.4 (1.13)	1.56 (0.89)	0.061 (0.106)
R-10.8 (1.90)	0.093 (0.53)	0.025 (0.044)
R-13.9 (2.45)	0.072 (0.41)	0.019 (0.034)

Window Transition Linear Transmittance

Exterior Insulation 1D R-Value (RSI)	R ft^2·hr·^{o}F / Btu (m^2 K / W)	U Btu/ft^2 ·hr ·^{o}F (W/m^2 K)	χ_g[2] Btu/hr ^{o}F (W/K)	ψ_g[3] Btu/ft hr ^{o}F (W/m K)
R-5 (0.88)	R-6.0 (1.05)	0.168 (0.95)	0.79 (0.42)	0.044 (0.077)
R-15 (2.64)	R-9.0 (1.59)	0.111 (0.63)	1.12 (0.59)	0.062 (0.108)
R-25 (4.40)	R-10.9 (1.91)	0.092 (0.52)	1.24 (0.66)	0.069 (0.120)

[2]The point transmittance is for this specific sizing of window only. See material sheets for dimensions

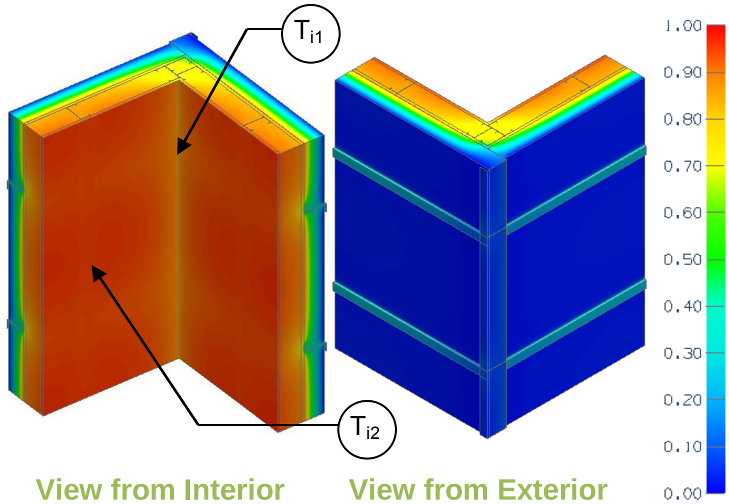
[3]For the linear transmittance, use the window perimeter

Temperature Indices

	R5	R15	R25	
T_{i1}	0.39	0.39	0.39	Min T on sheathing, interior surface at window sill, centre of cavity
T_{i2}	0.79	0.88	0.91	Max T on sheathing, at slab floor, at studs, away from window
T_{i3}	0.61	0.62	0.63	Min T on window frame, at bottom corner
T_{i4}	0.58	0.58	0.59	Min T on window glass, at bottom corner

Detail 08

Exterior Insulated 3 5/8″ x 1 5/8″ Steel Stud (16″ O.C.) Wall Assembly with Horizontal Z-Girts (24″ O.C.) Supporting Metal Cladding – Corner Intersection



View from Interior View from Exterior

Thermal Performance Indicators

Assembly 1D (Nominal) R-Value	R_{1D}	R- 3.18 (0.56 RSI) + exterior insulation
Transmittance / Resistance without Anomaly	U_o, R_o	"clear wall" U- and R-value, without corner (Detail 2)
Surface Temperature Index[1]	T_i	0 = exterior temperature 1 = interior temperature
Linear Transmittance	ψ	Incremental increase in transmittance per linear length of corner

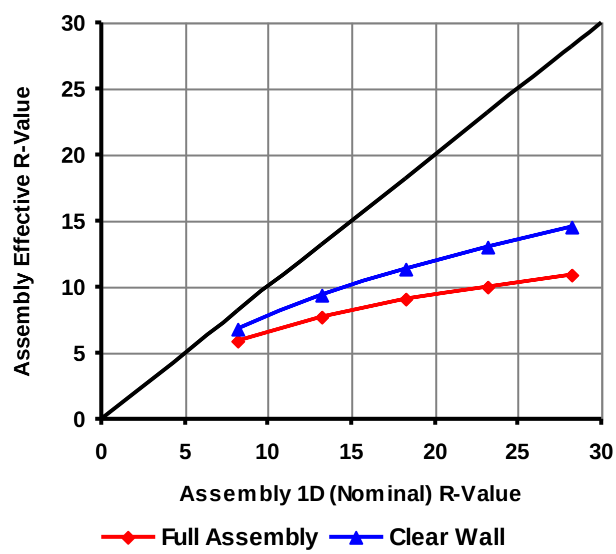
[1]Surface temperatures are a result of steady-state conductive heat flow with constant heat transfer coefficients. Limitations are identified in final report.

Nominal (1D) vs. Assembly Performance Indicators

Exterior Insulation 1D R-Value (RSI)	R_{1D} ft²·hr·°F / Btu (m² K / W)	R_o ft²·hr·°F / Btu (m² K / W)	U_o Btu/ft² ·hr ·°F (W/m² K)	R ft²·hr·°F / Btu (m² K / W)	U Btu/ft² ·hr ·°F (W/m² K)	ψ Btu/ft hr °F (W/m K)
R-5 (0.88)	R-8.2 (1.44)	R-6.8 (1.21)	0.146 (0.83)	R-5.9 (1.04)	0.169 (0.96)	0.092 (0.160)
R-10 (1.76)	R-13.2 (2.32)	R-9.4 (1.66)	0.106 (0.60)	R-7.7 (1.36)	0.129 (0.73)	0.091 (0.158)
R-15 (2.64)	R-18.2 (3.20)	R-11.3 (1.99)	0.088 (0.50)	R-9.0 (1.59)	0.111 (0.63)	0.089 (0.154)
R-20 (3.52)	R-23.2 (4.08)	R-13.1 (2.31)	0.076 (0.43)	R-10.1 (1.77)	0.099 (0.56)	0.092 (0.160)
R-25 (4.40)	R-28.2 (4.96)	R-14.5 (2.56)	0.069 (0.39)	R-10.9 (1.92)	0.091 (0.52)	0.091 (0.158)

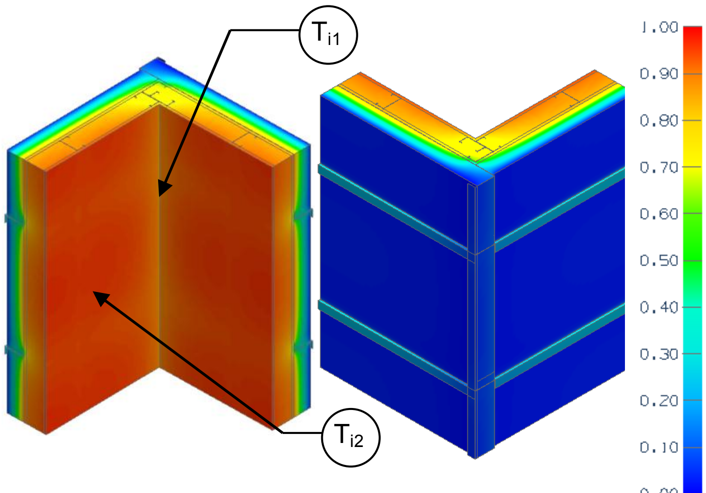
Temperature Indices

	R5	R10	R15	R20	R25	
T_{i1}	0.36	0.42	0.45	0.48	0.50	Min T on sheathing, along studs at girts and corner intersection
T_{i2}	0.76	0.83	0.87	0.89	0.90	Max T on sheathing, at steel studs, between girts, away from corner



Detail 08a

Exterior Insulated 3 5/8″ x 1 5/8″ Steel Stud (16″ O.C.) Wall Assembly with Horizontal Z-Girts (24″ O.C.) Supporting Metal Cladding – Corner Intersection, Alternative Framing



View from Interior   View from Exterior

Thermal Performance Indicators

Assembly 1D (Nominal) R-Value	R_{1D}	R- 3.18 (0.56 RSI) + exterior insulation
Transmittance / Resistance without Anomaly	U_o, R_o	"clear wall" U- and R-value, without corner (Detail 2)
Surface Temperature Index[1]	T_i	0 = exterior temperature 1 = interior temperature
Linear Transmittance	ψ	Incremental increase in transmittance per linear length of corner

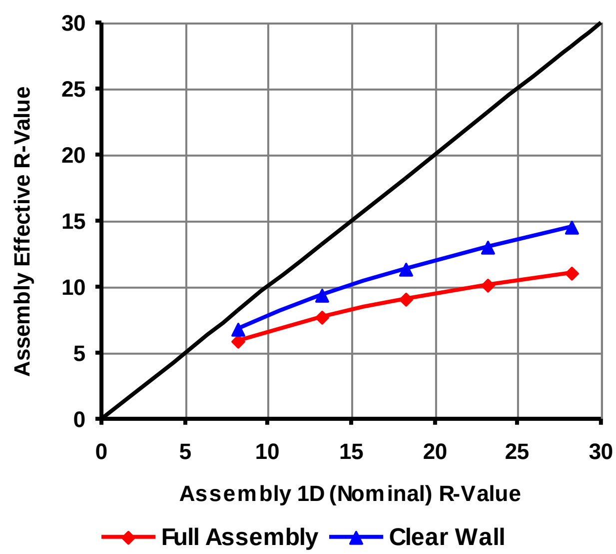
[1]Surface temperatures are a result of steady-state conductive heat flow with constant heat transfer coefficients. Limitations are identified in final report.

Nominal (1D) vs. Assembly Performance Indicators

Exterior Insulation 1D R-Value (RSI)	R_{1D} ft²·hr·°F / Btu (m² K / W)	R_o ft²·hr·°F / Btu (m² K / W)	U_o Btu/ft² ·hr ·°F (W/m² K)	R ft²·hr·°F / Btu (m² K / W)	U Btu/ft² ·hr ·°F (W/m² K)	ψ Btu/ft hr °F (W/m K)
R-5 (0.88)	R-8.2 (1.44)	R-6.9 (1.21)	0.146 (0.83)	R-5.9 (1.05)	0.168 (0.96)	0.089 (0.153)
R-10 (1.76)	R-13.2 (2.32)	R-9.4 (1.66)	0.106 (0.60)	R-7.8 (1.37)	0.128 (0.73)	0.087 (0.152)
R-15 (2.64)	R-18.2 (3.20)	R-11.3 (1.99)	0.088 (0.50)	R-9.1 (1.61)	0.110 (0.62)	0.085 (0.147)
R-20 (3.52)	R-23.2 (4.08)	R-13.1 (2.31)	0.076 (0.43)	R-10.2 (1.79)	0.098 (0.56)	0.088 (0.152)
R-25 (4.40)	R-28.2 (4.96)	R-14.6 (2.56)	0.069 (0.39)	R-11.1 (1.95)	0.090 (0.51)	0.086 (0.149)

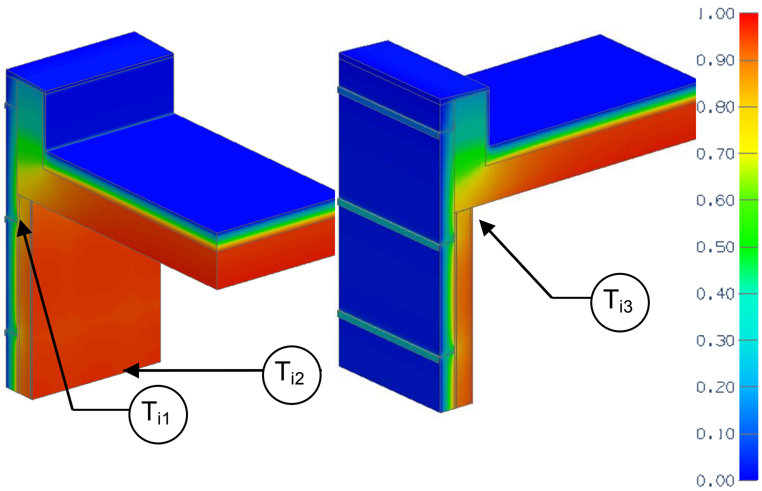
Temperature Indices

	R5	R10	R15	R20	R25	
T_{i1}	0.36	0.42	0.46	0.48	0.51	Min T on sheathing, along studs at girts and corner intersection
T_{i2}	0.76	0.83	0.86	0.89	0.90	Max T on sheathing, at steel studs, between girts, away from corner



Detail 09

Exterior Insulated 3 5/8″ x 1 5/8″ Steel Stud (16″ O.C.) Wall Assembly with Horizontal Z-Girts (24″ O.C.) Supporting Metal Cladding – Concrete Parapet & Slab Intersection



View from Interior View from Exterior

Thermal Performance Indicators

Assembly 1D (Nominal) R-Value	R_{1Dr}, R_{1Dw}	Two base assemblies : r = insulated roof w = steel stud wall assembly w/ horizontal z Girts (Detail 2)
Transmittance / Resistance without Anomaly	U_{or} R_{or}, U_{ow} R_{ow}	"clear field" U- and R-values. Separate values presented for the two base assemblies
Surface Temperature Index¹	T_i	0 = exterior temperature 1 = interior temperature
Linear Transmittance	ψ	Incremental increase in transmittance per linear length of parapet

¹Surface temperatures are a result of steady-state conductive heat flow with constant heat transfer coefficients. Limitations are identified in final report.

Nominal (1D) vs. Assembly Performance Indicators

Base Assembly – Wall

Wall Exterior Insulation 1D R-Value (RSI)	R_{1Dw} ft^2·hr·^{o}F / Btu (m^2 K / W)	R_{ow} ft^2·hr·^{o}F / Btu (m^2 K / W)	U_{ow} Btu/ft^2 ·hr ·^{o}F (W/m^2 K)
R-5 (0.88)	R-8.2 (1.44)	R-6.8 (1.21)	0.146 (0.83)
R-10 (1.76)	R-13.2 (2.32)	R-9.4 (1.66)	0.106 (0.60)
R-15 (2.64)	R-18.2 (3.20)	R-11.3 (1.99)	0.088 (0.50)
R-20 (3.52)	R-23.2 (4.08)	R-13.1 (2.31)	0.076 (0.43)
R-25 (4.40)	R-28.2 (4.96)	R-14.5 (2.56)	0.069 (0.39)

Base Assembly - Roof

R_{1Dr} ft^2 hr ^{o}F / Btu (m^2 K / W)	R_{or} ft^2 hr ^{o}F / Btu (m^2 K / W)	U_{or} Btu/ft^2 ·hr ·^{o}F (W/m^2 K)
R-21.4 (3.77)	R-21.4 (3.77)	0.047 (0.27)

Parapet Linear Transmittance

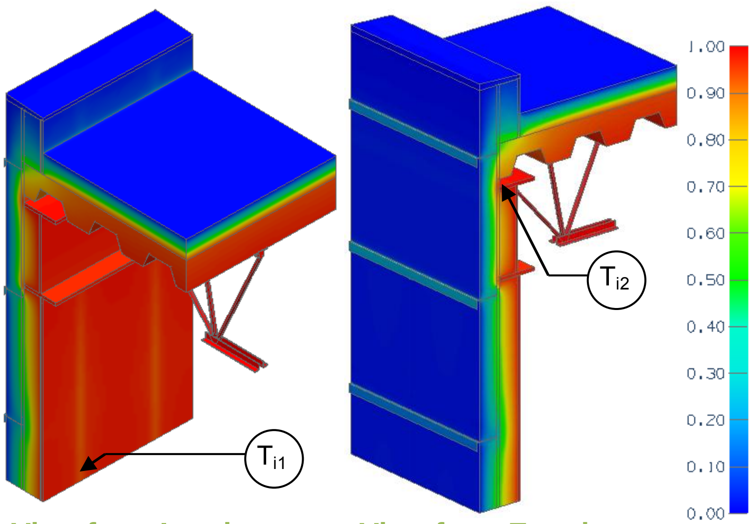
Wall Exterior Insulation 1D R-Value (RSI)	R ft^2·hr·^{o}F / Btu (m^2 K / W)	U Btu/ft^2 ·hr ·^{o}F (W/m^2 K)	ψ Btu/ft hr ^{o}F (W/m K)
R-5 (0.88)	R-8.0 (1.40)	0.125 (0.71)	0.313 (0.541)
R-10 (1.76)	R-9.5 (1.67)	0.105 (0.60)	0.284 (0.491)
R-15 (2.64)	R-10.4 (1.83)	0.096 (0.55)	0.271 (0.468)
R-20 (3.52)	R-11.0 (1.94)	0.091 (0.52)	0.266 (0.460)
R-25 (4.40)	R-11.5 (2.02)	0.087 (0.49)	0.261 (0.452)

Temperature Indices

	R5	R10	R15	R20	R25	
T_{i1}	0.62	0.68	0.71	0.73	0.75	Min T on sheathing, along girt between studs, close to ceiling
T_{i2}	0.75	0.83	0.86	0.88	0.90	Max T on sheathing, at studs, away from ceiling
T_{i3}	0.74	0.77	0.79	0.80	0.80	Min T on ceiling, at gypsum and studs

Detail 10

Exterior and Interior Insulated 3 5/8″ x 1 5/8″ Steel Stud (16″ o.c) Wall Assembly with Horizontal Z-Girts (24″ o.c.) Supporting Metal Cladding – Steel Roof Deck with Open Web Steel Joist & Parapet Intersection



View from Interior   View from Exterior

Thermal Performance Indicators

Assembly 1D (Nominal) R-Value	R_{1Dr}, R_{1Dw}	Two base assemblies : r = roof w = wall (Detail 11)
Transmittance / Resistance without Anomaly	U_{or} R_{or} U_{ow} R_{ow}	“clear field” U- and R-values. Separate values presented for the two base assemblies
Surface Temperature Index¹	T_i	0 = exterior temperature 1 = interior temperature
Linear Transmittance	ψ	Incremental increase in transmittance per linear length of parapet

¹Surface temperatures are a result of steady-state conductive heat flow with constant heat transfer coefficients. Limitations are identified in final report.

Nominal (1D) vs. Assembly Performance Indicators

Base Assembly – Wall

Wall Exterior Insulation 1D R-Value (RSI)	R_{1D} ft^2·hr·^{o}F / Btu (m^2 K / W)	R_{ow} ft^2·hr·^{o}F / Btu (m^2 K / W)	U_{ow} Btu/ft^2 ·hr ·^{o}F (W/m^2 K)
R-5 (0.88)	R-19.2 (3.38)	R-13.40 (2.36)	0.075 (0.42)
R-10 (1.76)	R-24.2 (4.26)	R-16.28 (2.87)	0.061 (0.35)
R-15 (2.64)	R-29.2 (5.14)	R-18.49 (3.25)	0.054 (0.31)
R-20 (3.52)	R-34.2 (6.02)	R-20.50 (3.61)	0.049 (0.28)
R-25 (4.40)	R-39.2 (6.90)	R-22.14 (3.90)	0.045 (0.26)

Base Assembly – Roof

R_{1D} ft^2·hr·^{o}F / Btu (m^2 K / W)	R_{or} ft^2·hr·^{o}F / Btu (m^2 K / W)	U_{or} Btu/ft^2 ·hr ·^{o}F (W/m^2 K)
R-21.2 (3.74)	R-21.0 (3.69)	0.048 (0.27)

Parapet Linear Transmittance

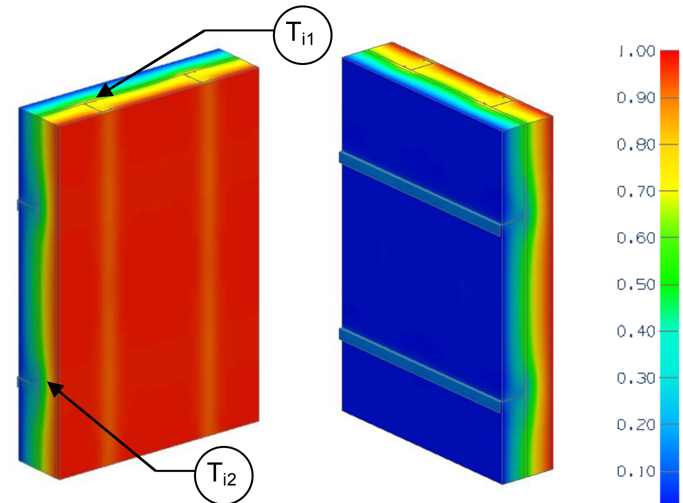
Wall Exterior Insulation 1D R-Value (RSI)	R ft^2·hr·^{o}F / Btu (m^2 K / W)	U Btu/ft^2 ·hr ·^{o}F (W/m^2 K)	ψ Btu/ft hr ^{o}F (W/m K)
R-5 (0.88)	R-9.8 (1.73)	0.102 (0.58)	0.289 (0.500)
R-10 (1.76)	R-11.7 (2.05)	0.086 (0.49)	0.227 (0.393)
R-15 (2.64)	R-12.8 (2.26)	0.078 (0.44)	0.201 (0.348)
R-20 (3.52)	R-13.7 (2.41)	0.073 (0.41)	0.187 (0.324)
R-25 (4.40)	R-14.5 (2.54)	0.069 (0.39)	0.176 (0.304)

Temperature Indices

	R5	R10	R15	R20	R25	
T_{i1}	0.27	0.35	0.41	0.45	0.48	Min T on sheathing, along studs between girts
T_{i2}	0.80	0.84	0.96	0.96	0.97	Min T on interior surfaces, at sheathing, away from joist

Detail 11

Exterior and Interior Insulated 3 5/8″ x 1 5/8″ Steel Stud (16″ o.c) Wall Assembly with Horizontal Z-Girts (24″ o.c.) Supporting Metal Cladding – Clear Wall



View from Interior   View from Exterior

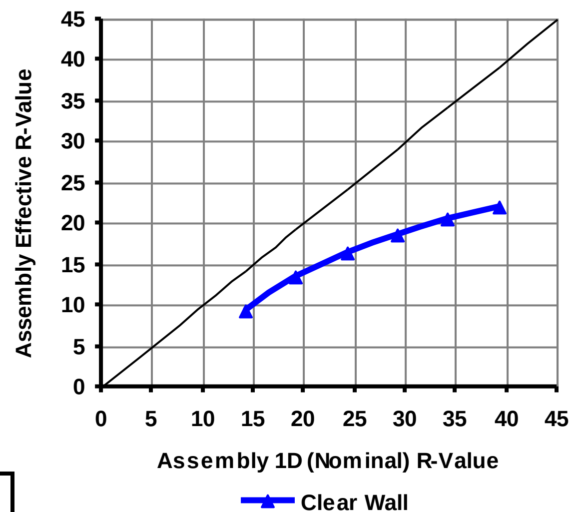
Thermal Performance Indicators

Assembly 1D (Nominal) R-Value	R_{1D}	R-14.2 (2.5 RSI) + exterior insulation
Transmittance / Resistance	U_o, R_o	"clear wall" U- and R-value
Surface Temperature Index[1]	T_i	0 = exterior temperature 1 = interior temperature

[1]Surface temperatures are a result of steady-state conductive heat flow with constant heat transfer coefficients. Limitations are identified in final report.

Nominal (1D) vs. Assembly Performance Indicators

Exterior Insulation 1D R-Value (RSI)	R_{1D} ft^2·hr·^{o}F / Btu (m^2 K / W)	R_o ft^2·hr·^{o}F / Btu (m^2 K / W)	U_o Btu/ft^2 ·hr ·^{o}F (W/m^2 K)
R-0 (0)	R-14.2 (2.50)	R-9.2 (1.62)	0.109 (0.62)
R-5 (0.88)	R-19.2 (3.38)	R-13.4 (2.36)	0.075 (0.42)
R-10 (1.76)	R-24.2 (4.26)	R-16.3 (2.87)	0.061 (0.35)
R-15 (2.64)	R-29.2 (5.14)	R-18.5 (3.25)	0.054 (0.31)
R-20 (3.52)	R-34.2 (6.02)	R-20.5 (3.61)	0.049 (0.28)
R-25 (4.40)	R-39.2 (6.90)	R-22.1 (3.90)	0.045 (0.26)

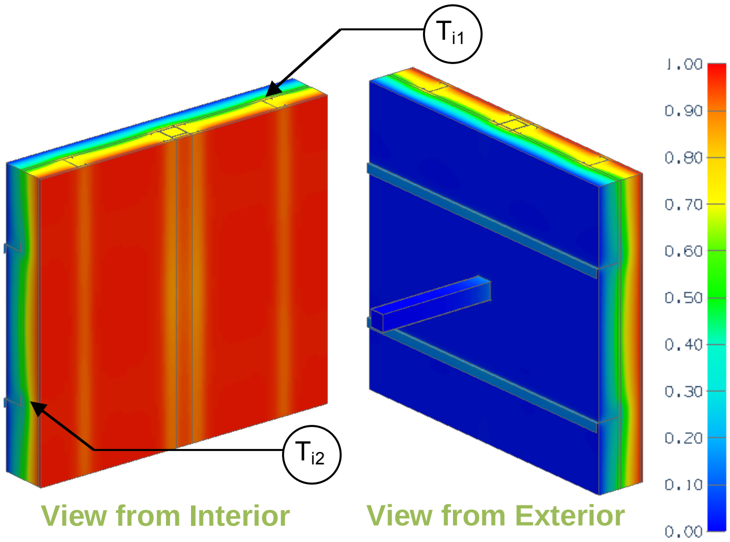


Temperature Indices

	R0	R5	R10	R15	R20	R25	
T_{i1}	0.06	0.21	0.28	0.32	0.36	0.38	Min T on sheathing, along girts between studs
T_{i2}	0.35	0.59	0.68	0.72	0.75	0.78	Max T on sheathing, along studs between girts

Detail 12

Exterior and Interior Insulated 3 5/8″ x 1 5/8″ Steel Stud (16″ o.c) Wall Assembly with Horizontal Z-Girts (24″ o.c.) Supporting Metal Cladding – Structural Steel Column & Cantilever Beam Intersection (Canopy Support)



View from Interior   View from Exterior

Thermal Performance Indicators

Assembly 1D (Nominal) R-Value	R_{1D}	R- 14.2 (2.5 RSI) + exterior insulation
Transmittance / Resistance without Anomaly	U_o, R_o	“clear wall” U- and R-value, without beam and post (Detail 11)
Surface Temperature Index[1]	T_i	0 = exterior temperature 1 = interior temperature
Linear Transmittance	ψ	Incremental increase in transmittance per length of steel column
Point Transmittance	χ	Incremental increase in transmittance for steel beam attached to post

[1]Surface temperatures are a result of steady-state conductive heat flow with constant heat transfer coefficients. Limitations are identified in final report.

Nominal (1D) vs. Assembly Performance Indicators

Base Assembly – Wall

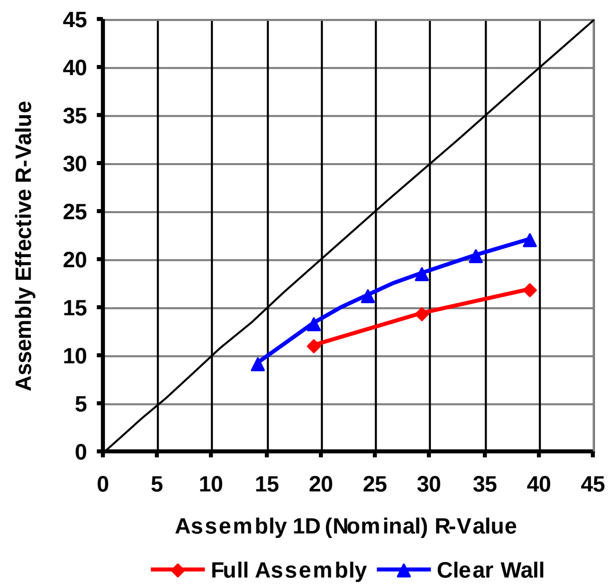
Exterior Insulation 1D R-Value (RSI)	R_{1D} ft^2·hr·^{o}F / Btu (m^2 K / W)	R_o ft^2·hr·^{o}F / Btu (m^2 K / W)	U_o Btu/ft^2 ·hr ·^{o}F (W/m^2 K)
R-5 (0.88)	R-19.2 (3.38)	R-13.4 (2.36)	0.075 (0.42)
R-15 (2.64)	R-29.2 (5.14)	R-18.5 (3.25)	0.054 (0.31)
R-25 (4.40)	R-39.2 (6.90)	R-22.1 (3.90)	0.045 (0.26)

Post Linear Transmittance

Exterior Insulation 1D R-Value (RSI)	R ft^2·hr·^{o}F / Btu (m^2 K / W)	U Btu/ft^2 ·hr ·^{o}F (W/m^2 K)	ψ Btu/ft hr ^{o}F (W/m K)
R-5 (0.88)	R-12.1 (2.13)	0.082 (0.47)	0.034 (0.060)
R-15 (2.64)	R-16.6 (2.92)	0.060 (0.34)	0.027 (0.047)
R-25 (4.40)	R-19.9 (3.49)	0.050 (0.29)	0.023 (0.040)

Beam Point Transmittance

Exterior Insulation 1D R-Value (RSI)	R ft^2·hr·^{o}F / Btu (m^2 K / W)	U Btu/ft^2 ·hr ·^{o}F (W/m^2 K)	χ Btu/hr ^{o}F (W/K)
R-5 (0.88)	R- 11.0 (1.93)	0.091 (0.52)	0.16 (0.08)
R-15 (2.64)	R- 14.4 (2.54)	0.069 (0.39)	0.16 (0.08)
R-25 (4.40)	R-16.9 (2.97)	0.059 (0.34)	0.16 (0.08)

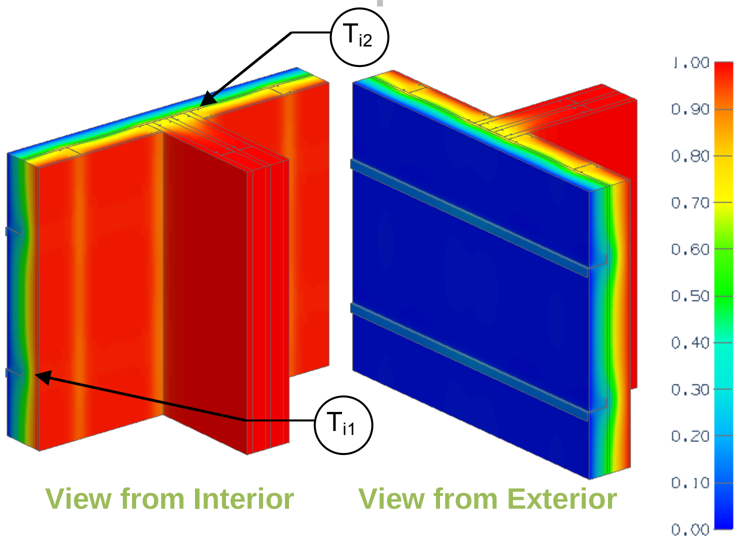


Temperature Indices

	R5	R15	R25	
T_{i1}	0.23	0.35	0.42	Min T on sheathing, along girt between studs, away from post
T_{i2}	0.58	0.71	0.76	Max T on sheathing, at studs, between z girts, away from post

Detail 13

Exterior and Interior Insulated 3 5/8″ x 1 5/8″ Steel Stud (16″ o.c) Wall Assembly with Horizontal Z-Girts (24″ o.c.) Supporting Metal Cladding – Interior Wall Intersection



Thermal Performance Indicators

Assembly 1D (Nom□nal) R-Value	R_{1D}	R- 14.2 (2.5 RSI) + exterior insulation
Transmittance / Resistance without Anomaly	U_o, R_o	"clear wall" U- and R-value, without interior wall(Detail 11)
Surface Temperature Index[1]	T_i	0 = exterior temperature 1 = interior temperature
Linear Transmittance	ψ	Incremental increase in transmittance per linear length of inner wall

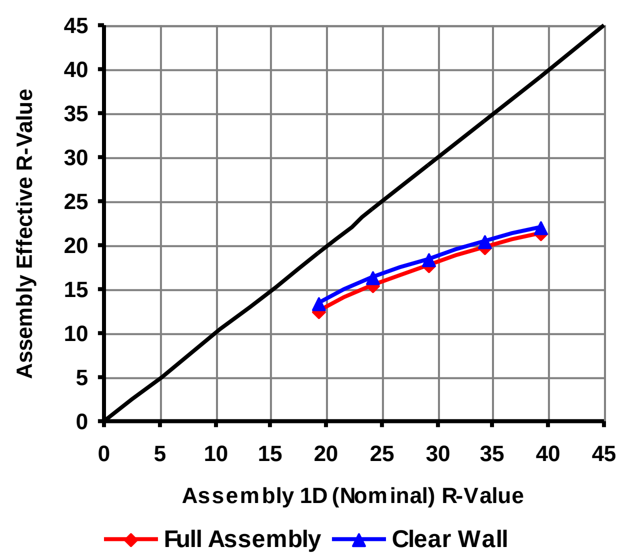
[1]Surface temperatures are a result of steady-state conductive heat flow with constant heat transfer coefficients. Limitations are identified in final report.

Nominal (1D) vs. Assembly Performance Indicators

Exterior Insulation 1D R-Value (RSI)	R_{1D} ft^2·hr·^{o}F / Btu (m^2 K / W)	R_o ft^2·hr·^{o}F / Btu (m^2 K / W)	U_o Btu/ft^2 ·hr ·^{o}F (W/m^2 K)	R ft^2·hr·^{o}F / Btu (m^2 K / W)	U Btu/ft^2 ·hr ·^{o}F (W/m^2 K)	ψ Btu/ft hr ^{o}F (W/m K)
R-5 (0.88)	R-19.2 (3.38)	R-13.4 (2.36)	0.075 (0.42)	R-12.6 (2.22)	0.079 (0.45)	0.023 (0.039)
R-10 (1.76)	R-24.2 (4.26)	R-16.3 (2.87)	0.061 (0.35)	R-15.6 (2.74)	0.064 (0.37)	0.014 (0.024)
R-15 (2.64)	R-29.2 (5.14)	R-18.5 (3.25)	0.054 (0.31)	R-17.8 (3.14)	0.056 (0.32)	0.010 (0.017)
R-20 (3.52)	R-34.2 (6.02)	R-20.5 (3.61)	0.049 (0.28)	R-19.8 (3.49)	0.050 (0.29)	0.008 (0.014)
R-25 (4.40)	R-39.2 (6.90)	R-22.1 (3.90)	0.045 (0.26)	R-21.4 (3.77)	0.047 (0.27)	0.007 (0.013)

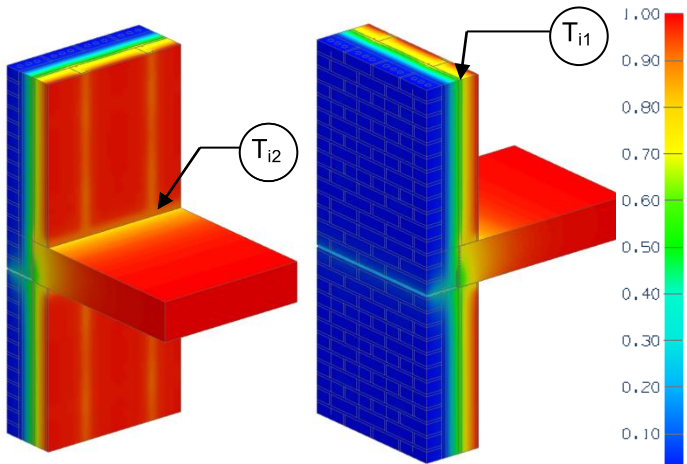
Temperature Indices

	R5	R10	R15	R20	R25	
T_{i1}	0.27	0.29	0.33	0.37	0.39	Min T on sheathing, along girt between studs, away from interior wall intersection
T_{i2}	0.55	0.68	0.73	0.76	0.78	Max T on sheathing, at studs, between z girts, at the acoustic wall intersection



Detail 14

Exterior and Interior Insulated Wall Assembly with Shelf Angle & Brick Ties Supporting Brick Veneer – Slab Intersection



View from Interior   View from Exterior

Thermal Performance Indicators

Assembly 1D (Nominal) R-Value	R_{1D}	R- 15.33 (2.698 RSI) + exterior insulation
Transmittance / Resistance without Anomaly	U_o, R_o	"clear wall" U- and R-value without slab and shelf angle
Surface Temperature Index[1]	T_i	0 = exterior temperature 1 = interior temperature
Linear Transmittance	ψ	Incremental increase in transmittance per linear length of shelf angle and slab

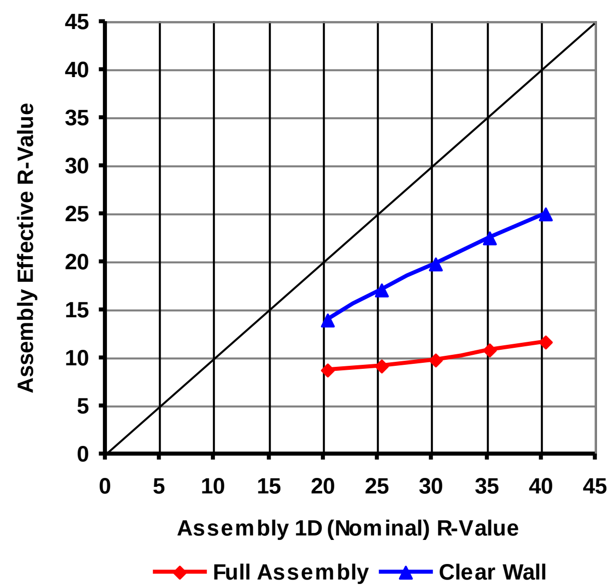
[1]Surface temperatures are a result of steady-state conductive heat flow with constant heat transfer coefficients. Limitations are identified in final report.

Nominal (1D) vs. Assembly Performance Indicators

Exterior Insulation 1D R-Value (RSI)	R_{1D} ft^2·hr·^{o}F / Btu (m^2 K / W)	R_o ft^2·hr·^{o}F / Btu (m^2 K / W)	U_o Btu/ft^2 ·hr ·^{o}F (W/m^2 K)	R ft^2·hr·^{o}F / Btu (m^2 K / W)	U Btu/ft^2 ·hr ·^{o}F (W/m^2 K)	ψ Btu/ft hr ^{o}F (W/m K)
R-5 (0.88)	R-20.3 (3.58)	R-13.9 (2.45)	0.072 (0.41)	R-8.7 (1.53)	0.115 (0.65)	0.268 (0.464)
R-10 (1.76)	R-25.3 (4.46)	R-17.1 (3.00)	0.059 (0.33)	R-9.3 (1.63)	0.108 (0.61)	0.305 (0.528)
R-15 (2.64)	R-30.3 (5.34)	R-19.8 (3.48)	0.051 (0.29)	R-9.9 (1.74)	0.101 (0.58)	0.314 (0.544)
R-20 (3.52)	R-35.3 (6.22)	R-22.4 (3.95)	0.045 (0.25)	R-10.9 (1.92)	0.092 (0.52)	0.291 (0.504)
R-25 (4.40)	R-40.3 (7.10)	R-24.9 (4.39)	0.040 (0.23)	R-11.6 (2.04)	0.086 (0.49)	0.286 (0.496)

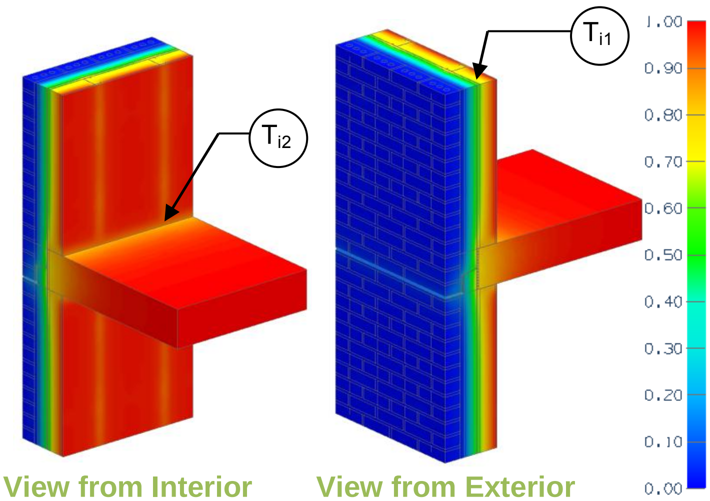
Temperature Indices

	R5	R15	R25	
T_{i1}	0.39	0.59	0.66	Min T on sheathing cavity centre away from slab
T_{i2}	0.66	0.71	0.77	Max T on sheathing, at slab, at steel studs



Detail 15

Exterior and Interior Insulated Wall Assembly with Spaced Shelf Angle & Brick Ties Supporting Brick Veneer – Slab Intersection



View from Interior View from Exterior

Thermal Performance Indicators

Assembly 1D (Nominal) R-Value	R_{1D}	R- 15.33 (2.698 RSI) + exterior insulation
Transmittance / Resistance without Anomaly	U_o, R_o	"clear wall" U- and R-value without slab and shelf angle
Surface Temperature Index[1]	T_i	0 = exterior temperature 1 = interior temperature
Linear Transmittance	ψ	Incremental increase in transmittance per linear length of shelf angle and slab

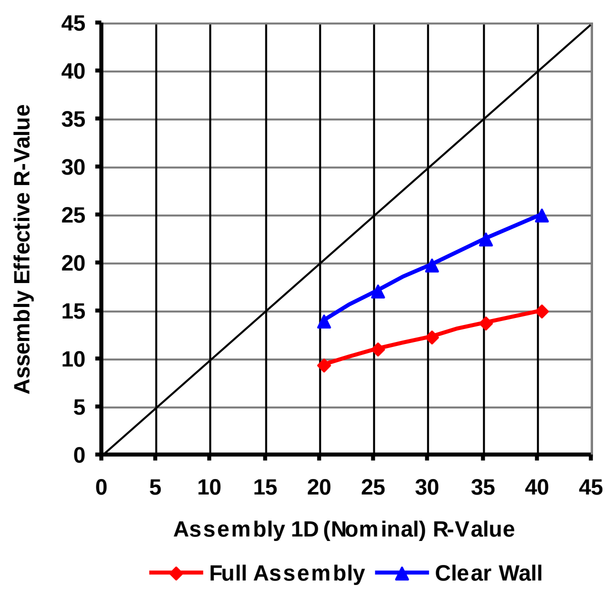
[1]Surface temperatures are a result of steady-state conductive heat flow with constant heat transfer coefficients. Limitations are identified in final report.

Nominal (1D) vs. Assembly Performance Indicators

Exterior Insulation 1D R-Value (RSI)	R_{1D} ft^2·hr·^{o}F / Btu (m^2 K / W)	R_o ft^2·hr·^{o}F / Btu (m^2 K / W)	U_o Btu/ft^2 ·hr ·^{o}F (W/m^2 K)	R ft^2·hr·^{o}F / Btu (m^2 K / W)	U Btu/ft^2 ·hr ·^{o}F (W/m^2 K)	ψ Btu/ft hr ^{o}F (W/m K)
R-5 (0.88)	R-20.3 (3.58)	R-13.9 (2.45)	0.072 (0.41)	R-9.4 (1.65)	0.072 (0.61)	0.217 (0.376)
R-10 (1.76)	R-25.3 (4.46)	R-17.1 (3.00)	0.059 (0.33)	R-11.1 (1.95)	0.059 (0.51)	0.197 (0.341)
R-15 (2.64)	R-30.3 (5.34)	R-19.8 (3.48)	0.051 (0.29)	R-12.6 (2.17)	0.051 (0.46)	0.189 (0.326)
R-20 (3.52)	R-35.3 (6.22)	R-22.4 (3.95)	0.045 (0.25)	R-13.8 (2.43)	0.045 (0.41)	0.174 (0.301)
R-25 (4.40)	R-40.3 (7.10)	R-24.9 (4.39)	0.040 (0.23)	R-15.0 (2.64)	0.040 (0.38)	0.165 (0.290)

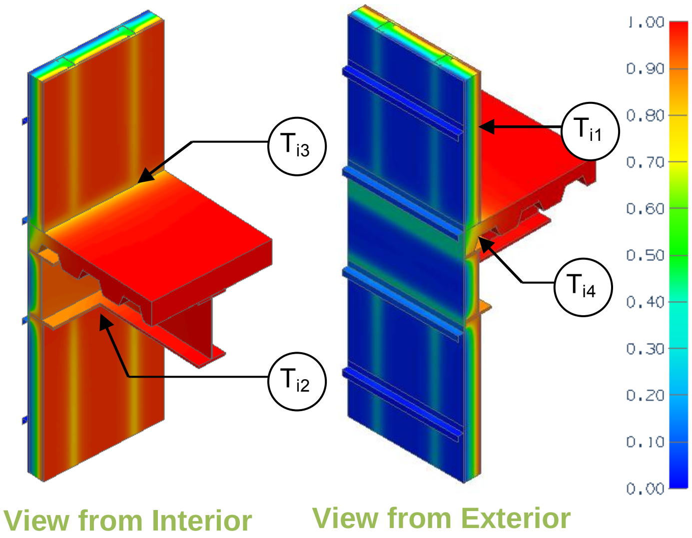
Temperature Indices

	R5	R15	R25	
T_{i1}	0.39	0.59	0.69	Min T on sheathing, cavity centre away from slab
T_{i2}	0.72	0.79	0.83	Max T on sheathing, at slab, at steel studs



Detail 16

Exterior and Interior Insulated 3 5/8″ x 1 5/8″ Steel Stud (16″ o.c) Wall Assembly with Horizontal Z-Girts (24″ o.c.) Supporting Metal Cladding – Structural Steel Framed Floor Intersection, No Exterior Insulation



Thermal Performance Indicators

Assembly 1D (Nominal) R-Value	R_{1D}	R- 14.21 (2.50 RSI) + exterior insulation
Transmittance / Resistance without Anomaly	U_o, R_o	"clear wall" U- and R-value, without slab and I-Beam (Detail 11)
Surface Temperature Index¹	T_i	0 = exterior temperature 1 = interior temperature
Linear Transmittance	ψ	Incremental increase in transmittance per linear length of the slab and I-Beam

¹Surface temperatures are a result of steady-state conductive heat flow with constant heat transfer coefficients. Limitations are identified in final report.

Nominal (1D) vs. Assembly Performance Indicators

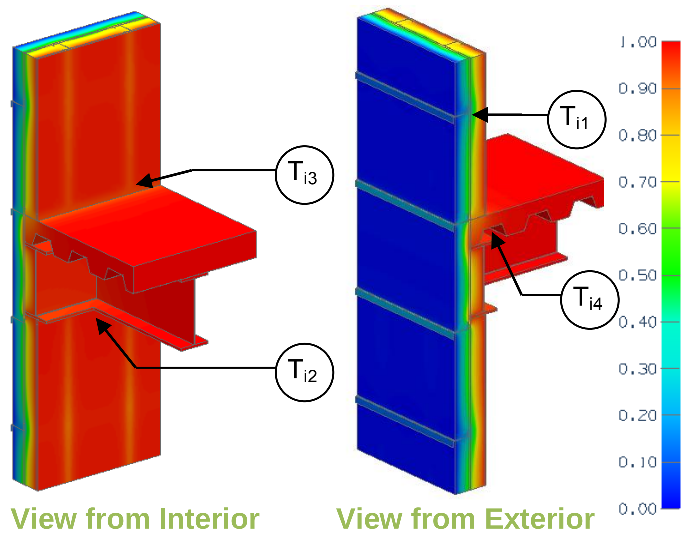
Exterior Insulation 1D R-Value (RSI)	R_{1D} ft²·hr·°F / Btu (m² K / W)	R_o ft²·hr·°F / Btu (m² K / W)	U_o Btu/ft² ·hr ·°F (W/m² K)	R ft²·hr·°F / Btu (m² K / W)	U Btu/ft² ·hr ·°F (W/m² K)	ψ Btu/ft hr °F (W/m K)
R-0 (0)	R-14.2 (2.50)	R-9.2 (1.62)	0.109 (0.62)	5.9 (1.04)	0.170 (0.96)	0.487 (0.842)

Temperature Indices

T_{i1}	0.07	Min T on sheathing, along girt between studs, away from slab
T_{i2}	0.71	Max T on sheathing, at I-Beam intersection
T_{i3}	0.79	Min T on floor, at gypsum and steel studs
T_{i4}	0.81	Min T on ceiling, at corrugated steel, away from I-Beam

Detail 17

Exterior and Interior Insulated 3 5/8″ x 1 5/8″ Steel Stud (16″ o.c) Wall Assembly with Horizontal Z-Girts (24″ o.c.) Supporting Metal Cladding – Structural Steel Framed Floor Intersection



View from Interior   View from Exterior

Thermal Performance Indicators

Assembly 1D (Nomi□al) R-Value	R_{1D}	R- 14.21 (2.50 RSI) + Exterior Insulation
Transmittance / Resistance without Anomaly	U_o, R_o	“clear wall” U- and R-value, without slab and I-Beam (Detail 11)
Surface Temperature Index[1]	T_i	0 = exterior temperature 1 = interior temperature
Linear Transmittance	ψ	Incremental increase in transmittance per linear length of the□slab and I-Beam

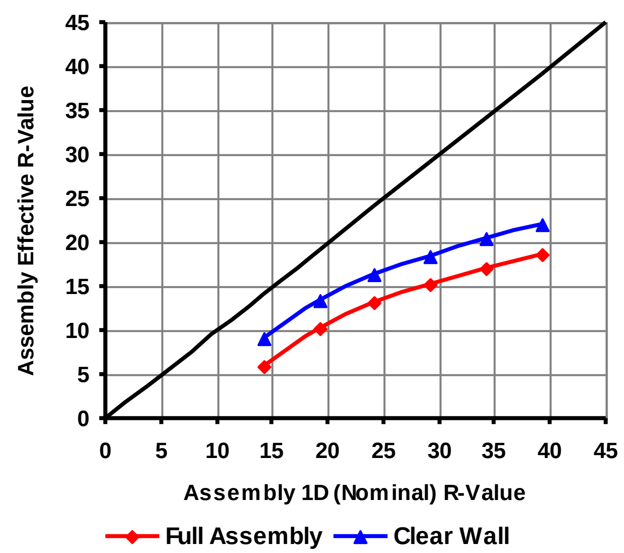
[1]Surface temperatures are a result of steady-state conductive heat flow with constant heat transfer coefficients. Limitations are identified in final report.

Nominal (1D) vs. Assembly Performance Indicators

Exterior Insulation 1D R-Value (RSI)	R_{1D} ft^2·hr·^{o}F / Btu (m^2 K / W)	R_o ft^2·hr·^{o}F / Btu (m^2 K / W)	U_o Btu/ft^2 ·hr ·^{o}F (W/m^2 K)	R ft^2·hr·^{o}F / Btu (m^2 K / W)	U Btu/ft^2 ·hr ·^{o}F (W/m^2 K)	ψ Btu/ft hr ^{o}F (W/m K)
R-0 (0)	R-14.2 (2.50)	R-9.2 (1.62)	0.109 (0.62)	R-5.9 (1.04)	0.170 (0.96)	0.487 (0.842)
R-5 (0.88)	R-19.2 (3.38)	R-13.4 (2.36)	0.075 (0.42)	R-10.3 (1.82)	0.097 (0.55)	0.177 (0.306)
R-10 (1.76)	R-24.2 (4.26)	R-16.3 (2.87)	0.061 (0.35)	R-13.1 (2.30)	0.077 (0.44)	0.121 (0.210)
R-15 (2.64)	R-29.2 (5.14)	R-18.5 (3.25)	0.054 (0.31)	R-15.2 (2.68)	0.066 (0.37)	0.093 (0.162)
R-20 (3.52)	R-34.2 (6.02)	R-20.5 (3.61)	0.049 (0.28)	R-17.1 (3.00)	0.059 (0.33)	0.079 (0.137)
R-25 (4.40)	R-39.2 (6.90)	R-22.1 (3.90)	0.045 (0.26)	R-18.7 (3.28)	0.054 (0.30)	0.067 (0.117)

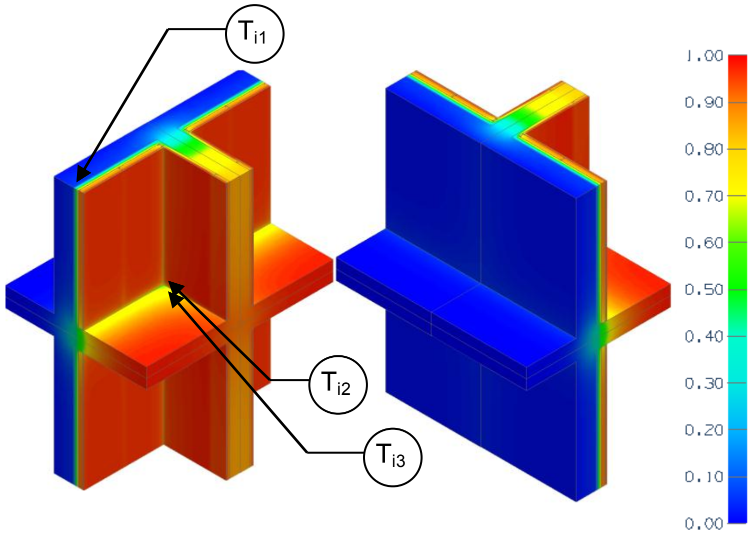
Temperature Indices

	R5	R10	R15	R20	R25	
T_{i1}	0.21	0.28	0.33	0.36	0.39	Min T on sheathing, along girt between studs, away from slab
T_{i2}	0.89	0.92	0.94	0.95	0.95	Max T on sheathing, at I-Beam intersection
T_{i3}	0.89	0.91	0.93	0.93	0.94	Min T on floor, at gypsum and steel studs
T_{i4}	0.94	0.96	0.96	0.97	0.97	Min T on ceiling, at corrugated sheet, away from I-Beam



Detail 18

Interior Insulated Concrete Mass Wall with 1 5/8″ Steel Stud (16″ o.c.) Supporting Interior Finish – Insulated Interior Wall and Non-insulated Slab Intersection



View from Interior View from Exterior

Thermal Performance Indicators

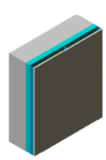
Assembly 1D (Nominal) R-Value	R_{1D}	Nominal thermal resistance of exterior wall
Transmittance / Resistance without Anomaly	U_o, R_o	“clear wall” U- and R-value of just concrete wall and steel stud assembly
Transmittance / Resistance	U_s R_s U_i R_i	U and R values for s = concrete wall + slab i = concrete wall + interior wall
Surface Temperature Index¹	T_i	0 = exterior temperature 1 = interior temperature
Linear Transmittance	ψ_s, ψ_i	Incremental increase in transmittance per linear length of s = slab i = interior wall
Point Transmittance	χ	Incremental increase in transmittance for inner w□ll and slab intersection

¹Surface temperatures are a result of steady-state conductive heat flow with constant heat transfer coefficients. Limitations are identified in final report.

Nominal (1D) vs. Assembly Performance Indicators

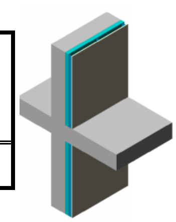
Base Assembly – Wall

R_{1D} ft²·hr·°F / Btu (m² K / W)	R_o ft²·hr·°F / Btu (m² K / W)	U_o Btu/ft² ·hr ·°F (W/m² K)
R-13.9 (2.44)	R-13.5 (2.37)	0.074 (0.42)



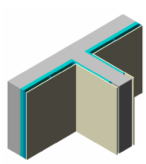
Slab Linear Transmittance

R_s ft²·hr·°F / Btu (m² K / W)	U_s Btu/ft² ·hr ·°F (W/m² K)	ψ_s Btu/ft hr °F (W/m K)
R-7.0 (1.22)	0.144 (0.82)	0.465 (0.805)



Interior Wall Linear Transmittance

R_i ft²·hr·°F / Btu (m² K / W)	U_i Btu/ft² ·hr ·°F (W/m² K)	ψ_i Btu/ft hr °F (W/m K)
R-8.6 (1.52)	0.116 (0.66)	0.262 (0.454)



Intersection Point Transmittance

R ft²·hr·°F / Btu (m² K / W)	U Btu/ft² ·hr ·°F (W/m² K)	χ² Btu/ft hr °F (W/K)
R-6.1 (1.07)	0.164 (0.93)	-0.29 (-0.16)

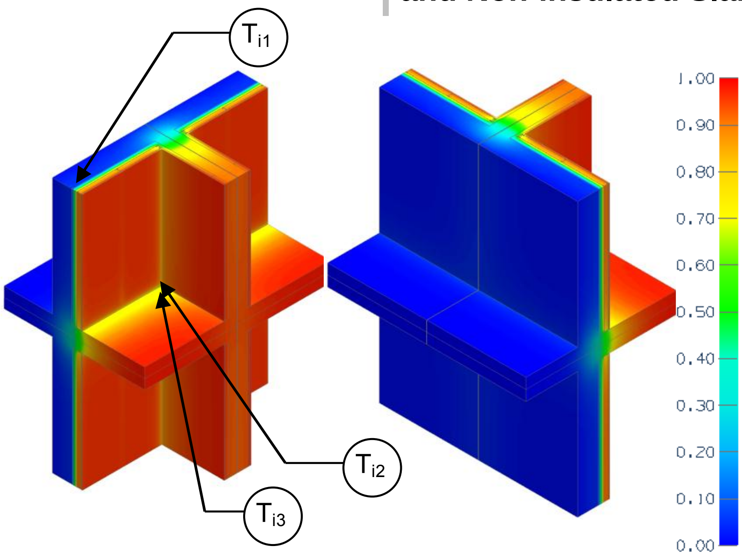
²Values are negative for a correction factor. See section 6 for clarification

Temperature Indices

T_{i1}	0.06	Min T on concrete wall between studs, away from wall and slab
T_{i2}	0.34	Max T on concrete wall, at corner intersection
T_{i3}	0.57	Min T on interior surface, at corner intersection

Detail 19

Interior Non-insulated Concrete Mass Wall with 1 5/8″ Steel Stud (16″ o.c.) Supporting Interior Finish – Non-Insulated Interior Wall and Non-insulated Slab Intersection



View from Interior View from Exterior

Thermal Performance Indicators

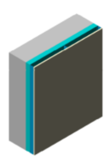
Assembly 1D (Nominal) R-Valu	R_{1D}	Nominal thermal resistance of exterior wall
Transmittance / Resistance without Anomaly	U_o, R_o	"clear wall" U- and R-value of just concrete wall and steel stud assembly
Transmittance / Resistance	U_s R_s U_i R_i	U and R-values for s = concrete wall + slab i = concrete wall + interior wall
Surface Temperature Index[1]	T_i	0 = exterior temperature 1 = interior temperature
Linear Transmittance	ψ_s, ψ_i	Incremental increase in transmittance per linear length of s = slab i = interior wall
Point Transmittance	χ	Incremental increase in transmittance for inner wall and slab intersection

[1]Surface temperatures are a result of steady-state conductive heat flow with constant heat transfer coefficients. Limitations are identified in final report.

Nominal (1D) vs. Assembly Performance Indicators

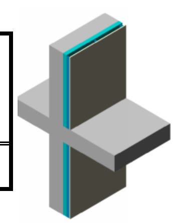
Base Assembly – Wall

R_{1D} ft²·hr·°F / Btu (m² K / W)	R_o ft²·hr·°F / Btu (m² K / W)	U_o Btu/ft² ·hr ·°F (W/m² K)
R-13.9 (2.44)	R-13.5 (2.37)	0.074 (0.42)



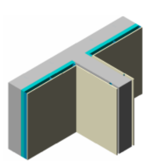
Slab Linear Transmittance

R_s ft²·hr·°F / Btu (m² K / W)	U_s Btu/ft² ·hr ·°F (W/m² K)	ψ_s Btu/ft hr °F (W/m K)
R-7.0 (1.22)	0.144 (0.82)	0.465 (0.805)



Interior Linear Transmittance

R_i ft²·hr·°F / Btu (m² K / W)	U_i Btu/ft² ·hr ·°F (W/m² K)	ψ_i Btu/ft hr °F (W/m K)
R-7.4 (1.30)	0.135 (0.77)	0.385 (0.666)



Intersection Point Transmittance

R ft²·hr·°F / Btu (m² K / W)	U Btu/ft² ·hr ·°F (W/m² K)	χ[2] Btu/ft hr °F (W/K)
R-4.4 (0.77)	0.228 (1.30)	-0.48 (-0.25)

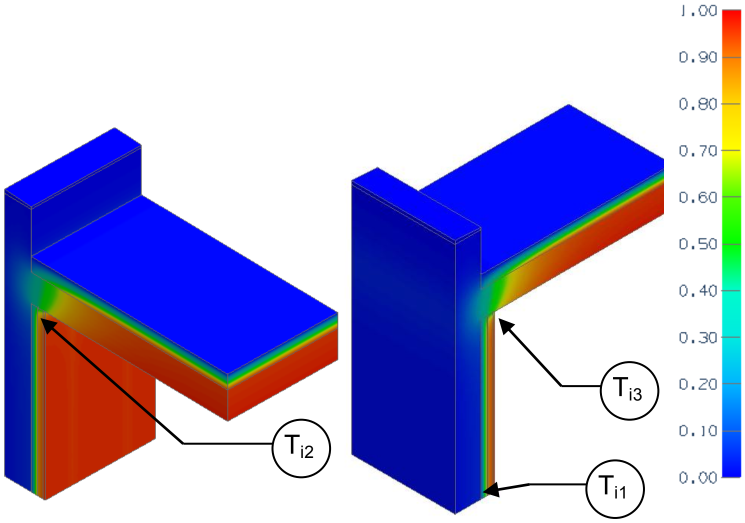
[2]Values are negative for a correction factor. See section 6 for clarification

Temperature Indices

T_{i1}	0.06	Min T on concrete wall, between studs, away from wall and slab
T_{i2}	0.35	Max T on concrete wall, at corner intersection
T_{i3}	0.59	Min T on interior surface, at corner intersection

Detail 20

Interior Insulated Concrete Mass Wall with 1 5/8″ Steel Stud (16″ o.c) Supporting Interior Finish – Concrete Parapet & Roof Intersection



View from Interior View from Exterior

Thermal Performance Indicators

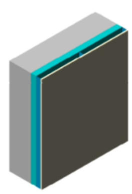
Assembly 1D (Nominal) R-Value	R_{1Dr}, R_{1Dw}	Two base assemblies : r = roof w = wall
Transmittance / Resistance without Anomaly	U_{or} R_{or} U_{ow} R_{ow}	"clear field" U- and R-values. Separate values presented for the two base assemblies
Surface Temperature Index[1]	T_i	0 = exterior temperature 1 = interior temperature
Linear Transmittance	ψ	Incremental increase in transmittance per linear length of parapet

[1]Surface temperatures are a result of steady-state conductive heat flow with constant heat transfer coefficients. Limitations are identified in final report.

Nominal (1D) vs. Assembly Performance Indicators

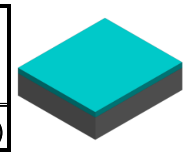
Base Assembly – Wall

R_{1D} ft²·hr·°F / Btu (m² K / W)	R_{ow} ft²·hr·°F / Btu (m² K / W)	U_{ow} Btu/ft² ·hr ·°F (W/m² K)
R-13.9 (2.44)	R-13.5 (2.37)	0.074 (0.42)



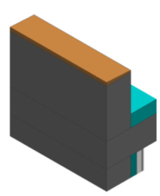
Base Assembly – Roof

R_{1D} ft²·hr·°F / Btu (m² K / W)	R_{or} ft²·hr·°F / Btu (m² K / W)	U_{or} Btu/ft² ·hr ·°F (W/m² K)
R-21.4 (3.77)	R-21.4 (3.77)	0.047 (0.27)



Parapet Linear Transmittance

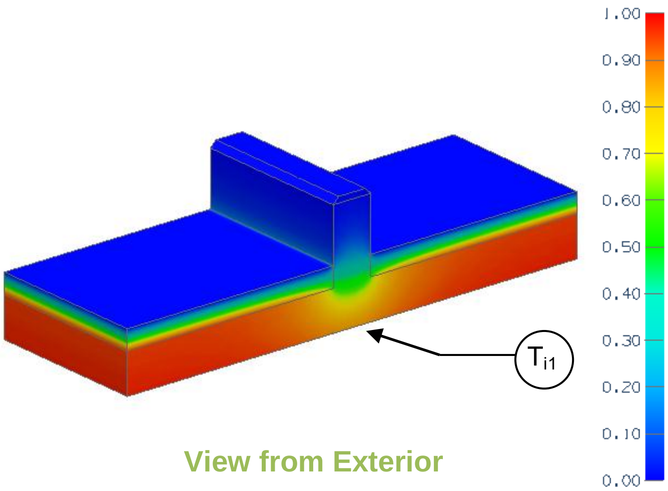
R ft²·hr·°F / Btu (m² K / W)	U Btu/ft² ·hr ·°F (W/m² K)	ψ Btu/ft hr °F (W/m K)
R-8.94 (1.57)	0.112 (0.64)	0.449 (0.777)



Temperature Indices

T_{i1}	0.06	Min T on concrete wall, between studs, away from ceiling
T_{i2}	0.27	Max T on concrete wall, at wall/roof intersection
T_{i3}	0.59	Min T on interior ceiling, at gypsum board, between studs

Detail 21 | Insulated Concrete Slab – Concrete Curb or Wall Intersection



View from Exterior

Thermal Performance Indicators

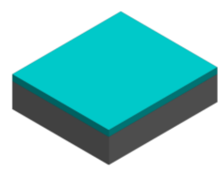
Assembly 1D (Nominal) R-Value	R_{1D}	R- 1.40 (0.25 RSI) + Insulation
Transmittance / Resistance without Anomaly	U_o, R_o	"clear wall" U- and R-value, without concrete anomaly
Surface Temperature Index[1]	T_i	0 = exterior temperature 1 = interior temperature
Linear Transmittance	ψ	Incremental increase in transmittance per linear length of concrete anomaly

[1]Surface temperatures are a result of steady-state conductive heat flow with constant heat transfer coefficients. Limitations are identified in final report.

Nominal (1D) vs. Assembly Performance Indicators

Base Assembly – Roof

Exterior Insulation 1D R-Value (RSI)	R_{1D} ft^2·hr·^{o}F / Btu (m^2 K / W)	R_o ft^2·hr·^{o}F / Btu (m^2 K / W)	U_o Btu/ft^2 ·hr ·^{o}F (W/m^2 K)
R-20 (3.52)	R-21.4 (3.77)	R-21.4 (3.77)	0.047 (0.27)



Concrete Anomaly Linear Transmittance

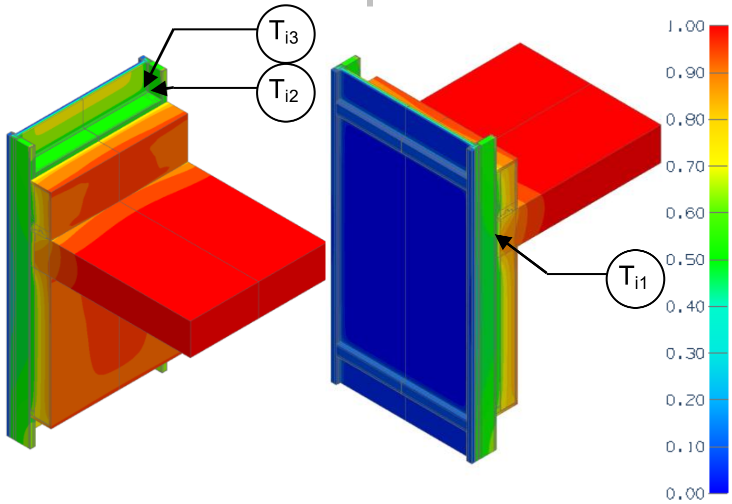
R ft^2·hr·^{o}F / Btu (m^2 K / W)	U Btu/ft^2 ·hr ·^{o}F (W/m^2 K)	ψ Btu/ft hr ^{o}F (W/m K)
R-8.8 (1.54)	0.114 (0.65)	0.536 (0.927)

Temperature Indices

T_{i1}	0.82	Min T on concrete, at center of anomaly

Detail 22

Conventional Curtain Wall System with Insulated Spandrel Panel and 3 5/8″ x 1 5/8″ Steel Stud (16″ o.c) – Slab Intersection & No Interior Insulation in Stud Cavity



View from Interior

View from Exterior

Thermal Performance Indicators

Assembly 1D (Nominal) R-Value	R_{1D}	Nominal thermal resistance of spandrel section + backup wall
Spandrel Transmittance/ Resistance	U_s, R_s	U- and R Value for Spandrel section only[2]
Surface Temperature Index[1]	T_i	0 = exterior temperature 1 = interior temperature

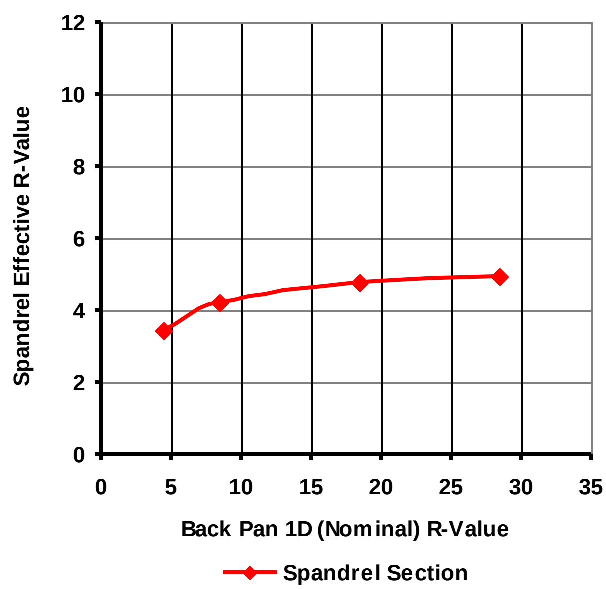
[1]Surface temperatures are a result of steady-state conductive heat flow with constant heat transfer coefficients. Limitations are identified in final report.

[2]Half width of upper transom to half width of lower transom

Back Pan Insulation vs. Assembly Performance Indicators

Back Pan Insulation 1D R-Value (RSI)	R_{1D} ft²·hr·°F / Btu (m² K / W)	R_s ft²·hr·°F / Btu (m² K / W)	U_s Btu/ft² ·hr ·°F (W/m² K)
R-1 (0.18)[3]	R-4.4 (0.77)	R-3.4 (0.60)	0.292(1.66)
R-5 (0.88)	R-8.4 (1.47)	R-4.2 (0.74)	0.238 (1.35)
R-15 (2.64)	R-18.4 (3.23)	R-4.8 (0.84)	0.210 (1.19)
R-25 (4.40)	R-28.4 (4.99)	R-5.0 (0.87)	0.202 (1.15)

[3] This value represents no insulation in the back pan.

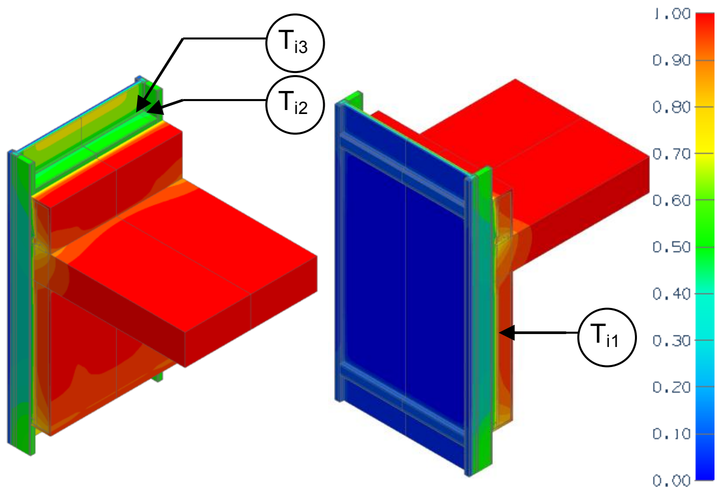


Temperature Indices

	R1	R5	R15	R25	
T_{i1}	0.44	0.52	0.57	0.59	Min T on Back Pan, at concrete slab and mullion intersection
T_{i2}	0.52	0.55	0.56	0.57	Min T on interior frame, at vertical to horizontal mullion intersection
T_{i3}	0.46	0.47	0.48	0.48	Min T on interior window, at bottom corner

Detail 23

Conventional Curtain Wall System with Insulated Spandrel Panel and 3 5/8″ x 1 5/8″ Steel Stud (16″ o.c) – Slab Intersection & Spray Foam Insulation in Stud Cavity



View from Interior View from Exterior

Thermal Performance Indicators

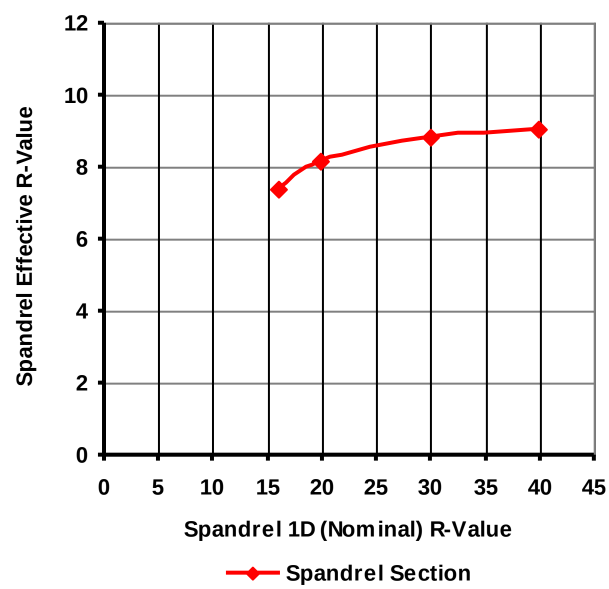
Assembly 1D (Nominal) R-Value	R_{1D}	Nominal thermal resistance of spandrel section + backup wall
Spandrel Transmittance/ Resistance	U_s, R_s	U- and R-Value for Spandrel section only[2]
Surface Temperature Index[1]	T_i	0 = exterior temperature 1 = interior temperature

[1]Surface temperatures are a result of steady-state conductive heat flow with constant heat transfer coefficients. Limitations are identified in final report.
[2]Half width of upper transom to half width of lower transom

Back Pan Insulation vs. Assembly Performance Indicators

Back Pan Insulation 1D R-Value (RSI)	R_{1D} ft^2·hr·^{o}F / Btu (m^2 K / W)	R_s ft^2·hr·^{o}F / Btu (m^2 K / W)	U_s Btu/ft^2 ·hr ·^{o}F (W/m^2 K)
R-1 (0.18)[3]	R-15.91 (2.80)	R-7.40 (1.30)	0.135 (0.77)
R-5 (0.88)	R-19.91 (3.50)	R-8.18 (1.44)	0.122 (0.69)
R-15 (2.64)	R-29.91 (5.26)	R-8.83 (1.55)	0.113 (0.64)
R-25 (4.40)	R-39.91 (7.02)	R-9.07 (1.60)	0.110 (0.63)

[3]This value represents no insulation in the back pan.

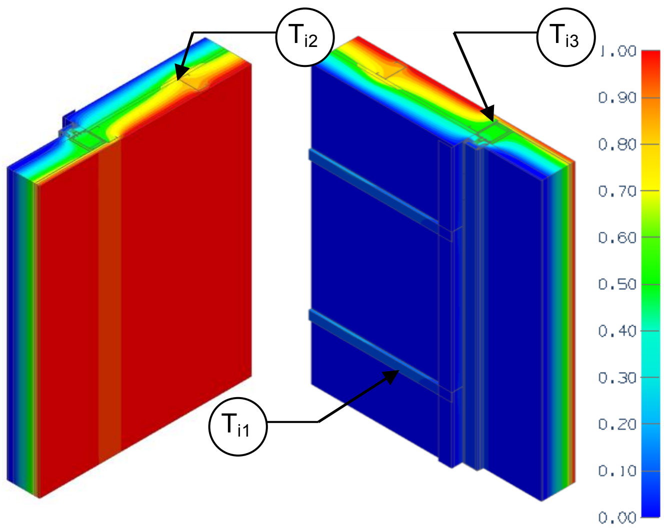


Temperature Indices

	R1	R5	R15	R25	
T_{i1}	0.22	0.31	0.37	0.39	Min T on Back Pan, at the mullion, the between slab and bottom transom
T_{i2}	0.45	0.47	0.48	0.49	Min T on interior frame, at vertical to horizontal mullion intersection
T_{i4}	0.41	0.42	0.43	0.43	Min T on interior window, at bottom corner

Detail 24

Exterior and Interior Insulated 3 5/8″ x 1 5/8″ Steel Stud (16″ o.c) Wall Assembly with Horizontal Z-Girts (24″ o.c.) Supporting Metal Cladding – Conventional Curtain Wall Intersection



View from Interior   View from Exterior

Thermal Performance Indicators

Assembly 1D (Nominal) R-Value	R_{1Dw} R_{1Dcw}	Nominal thermal resistance of two base assemblies: w = wall (Detail 11) cw = curtain wall
Transmittance / Resistance without Anomaly	U_{ow} R_{ow} U_{ocw} R_{ocw}	"clear wall" U- and R-value for the two base assemblies
Surface Temperature Index[1]	T_i	0 = exterior temperature 1 = interior temperature
Linear Transmittance	ψ	Incremental increase in transmittance per linear length of transition joint

[1]Surface temperatures are a result of steady-state conductive heat flow with constant heat transfer coefficients. Limitations are identified in final report.

Back Pan Insulation vs. Assembly Performance Indicators

Base Assembly – Wall

Exterior Insulation 1D R-Value (RSI)	R_{1D} ft²·hr·°F / Btu (m² K / W)	R_o ft²·hr·°F / Btu (m² K / W)	U_o Btu/ft² ·hr ·°F (W/m² K)
R-5 (0.88)	R-19.2 (3.38)	R-13.4 (2.36)	0.075 (0.42)
R-15 (2.64)	R-29.2 (5.14)	R-18.5 (3.25)	0.054 (0.31)
R-25 (4.40)	R-39.2 (6.90)	R-22.1 (3.90)	0.045 (0.26)

Base Assembly – Curtain Wall

R_{1Dcw}[2] ft²·hr·°F / Btu (m² K / W)	R_{ocw} ft²·hr·°F / Btu (m² K / W)	U_{ocw} Btu/ft² ·hr ·°F (W/m² K)
R-18.3 (3.22)	R-4.4 (0.78)	0.226 (1.29)

[2] R-15 back pan insulation

Transition Joint Linear Transmittance

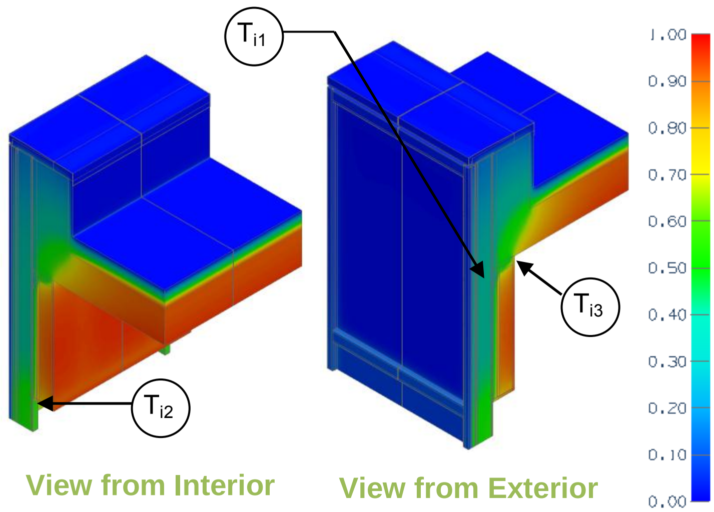
Exterior Insulation 1D R-Value (RSI)	R ft²·hr·°F / Btu (m² K / W)	U Btu/ft² ·hr ·°F (W/m² K)	ψ Btu/ft hr °F (W/m K)
R-5 (0.88)	R-6.5 (1.14)	0.154 (0.88)	0.088 (0.151)
R-15 (2.64)	R-7.1 (1.25)	0.140 (0.80)	0.088 (0.151)
R-25 (4.40)	R-7.4 (1.30)	0.135 (0.77)	0.089 (0.155)

Temperature Indices

	R5	R15	R25	
T_{i1}	0.19	0.26	0.32	Min T on sheathing, along girt between studs, close to curtain wall
T_{i2}	0.66	0.78	0.82	Max T on sheathing, at studs, between z girts, away from curtain wall
T_{i3}	0.52	0.53	0.54	Min T on air cavity behind curtain wall, at mullion panel

Detail 25

Conventional Curtain Wall System with Insulated Spandrel Panel and 3 5/8″ x 1 5/8″ Steel Stud (16″ o.c.) – Concrete Parapet, Roof Intersection & Spray Foam Insulation in Stud Cavity



Thermal Performance Indicators

Assembly 1D (Nominal) R-Value	R_{1Dr}, R_{1Ds}	Two base assemblies : r = insulated roof s = curtain wall spandrel
Transmittance / Resistance without Anomaly	U_{or} R_{or} U_{os} R_{os}	"clear field" R- and U-values. Separate values presented for the two base assemblies
Surface Temperature Index¹	T_i	0 = exterior temperature 1 = interior temperature
Linear Transmittance	ψ	Incremental increase in transmittance per linear length of parapet

¹Surface temperatures are a result of steady-state conductive heat flow with constant heat transfer coefficients. Limitations are identified in final report.

Nominal (1D) vs. Assembly Performance Indicators

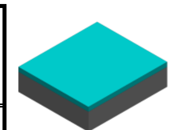
Base Assembly – Spandrel Panel Section

Back Pan Insulation 1D R-Value (RSI)	R_{1Ds} ft²·hr·°F / Btu (m² K / W)	R_{os} ft²·hr·°F / Btu (m² K / W)	U_{os} Btu/ft² ·hr ·°F (W/m² K)
R-1 (0.18)	R-15.9 (2.80)	R-7.4 (1.30)	0.135 (0.77)
R-5 (0.88)	R-19.9 (3.50)	R-8.2 (1.44)	0.122 (0.69)
R-15 (2.64)	R-29.9 (5.26)	R-8.8 (1.55)	0.113 (0.64)
R-25 (4.40)	R-39.9 (7.02)	R-9.1 (1.60)	0.110 (0.63)

[2] This value represents no insulation in the back pan.

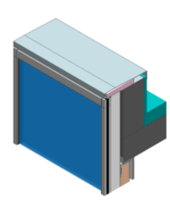
Base Assembly – Roof

R_{1Dr} ft²·hr·°F / Btu (m² K / W)	R_{or} ft²·hr·°F / Btu (m² K / W)	U_{or} Btu/ft² ·hr ·°F (W/m² K)
R-21.4 (3.77)	R-21.0 (3.77)	0.047 (0.27)



Parapet Linear Transmittance

Back Pan Insulation 1D R-Value (RSI)	R ft²·hr·°F / Btu (m² K / W)	U Btu/ft² ·hr ·°F (W/m² K)	ψ Btu/ft hr °F (W/m K)
R-1 (0.18)	R-6.6 (1.16)	0.151 (0.86)	0.426 (0.738)
R-5 (0.88)	R-7.0 (1.23)	0.143 (0.81)	0.404 (0.699)
R-15 (2.64)	R-7.4 (1.30)	0.136 (0.77)	0.384 (0.664)
R-25 (4.40)	R-7.5 (1.32)	0.134 (0.76)	0.380 (0.657)

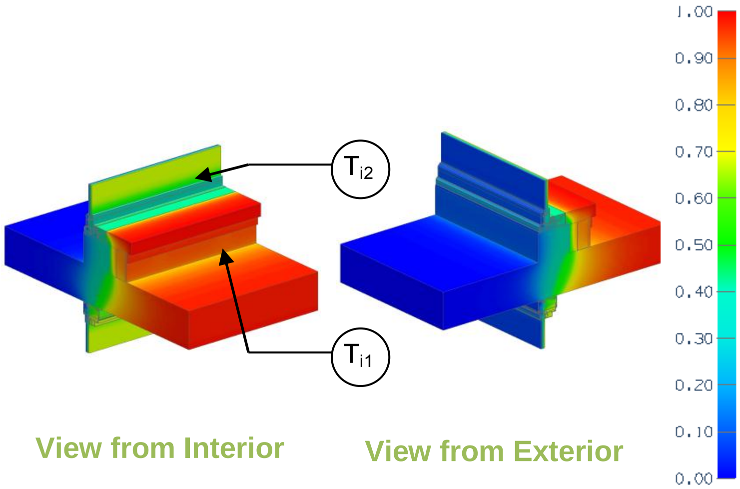


Temperature Indices

	R1	R5	R15	R25	
T_{i1}	0.26	0.34	0.38	0.39	Min T on Back Pan, at the mullion, the between slab and bottom transom
T_{i2}	0.47	0.51	0.53	0.53	Min T on interior frame, at mullion transom corner
T_{i3}	0.60	0.64	0.65	0.66	Min T ceiling, at gypsum/ceiling intersection, adjacent to curtain wall anchor

Detail 26

Interior Insulated Concrete Curb at Sliding Door Sill and Window Head – Slab Intersection



Thermal Performance Indicators

Transmittance / Resistance[1]	U, R	U- and R-value
Surface Temperature Index[2]	T_i	0 = exterior temperature 1 = interior temperature

[1] Projected distance from bottom of slab to top of curb
[2] Surface temperatures are a result of steady-state conductive heat flow with constant heat transfer coefficients. Limitations are identified in final report.

Thermal Transmittance

Sliding Door with Curb

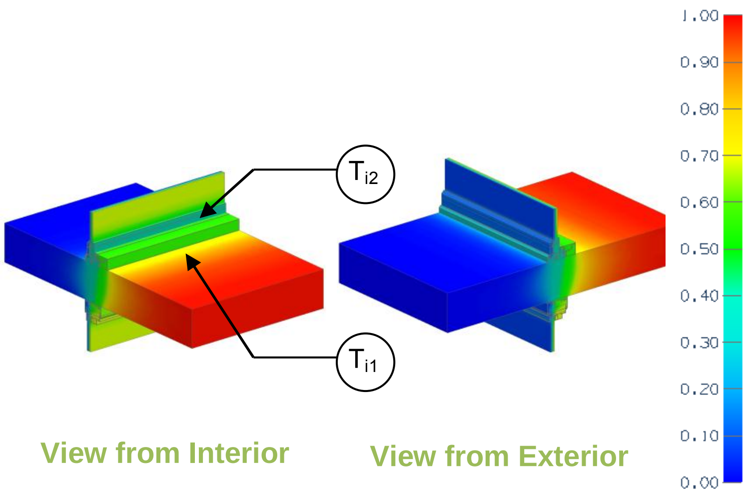
R $ft^2 \cdot hr \cdot {}^oF$ / Btu (m^2 K / W)	U Btu/$ft^2 \cdot hr \cdot {}^oF$ (W/m^2 K)
R-1.6 (0.29)	0.618 (3.509)

Temperature Indices

T_{i1}	0.83	Min T on interior concrete, at gypsum, at studs
T_{i2}	0.44	Min T on glass, at gaskets

Detail 27

Non- Insulated Sliding Door Sill and Window Head – Slab Intersection



Thermal Performance Indicators

Transmittance / Resistance[1]	U, R	U- and R-value
Surface Temperature Index[2]	T_i	0 = exterior temperature 1 = interior temperature

[1] Projected distance from bottom of slab to top of curb
[2] Surface temperatures are a result of steady-state conductive heat flow with constant heat transfer coefficients. Limitations are identified in final report.

Thermal Transmittance

Sliding Door without Curb

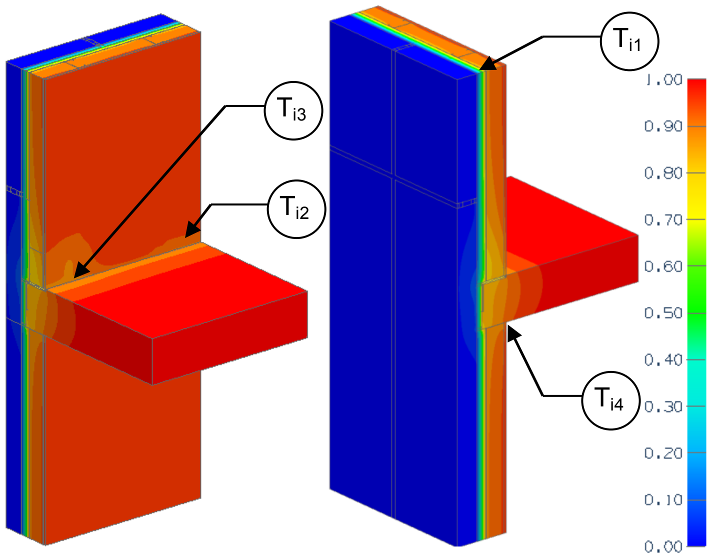
R $ft^2 \cdot hr \cdot {}^oF$ / Btu (m^2 K / W)	U Btu/$ft^2 \cdot hr \cdot {}^oF$ (W/m^2 K)
R-1.2 (0.22)	0.807 (4.59)

Temperature Indices

T_{i1}	0.58	Min T on interior concrete, at frame
T_{i2}	0.48	Min T on glass, at gaskets

Detail 28

Precast Wall Assembly with 3 5/8″ x 1 5/8″ Steel Stud (16″ o.c) and Rigid Insulation Outboard of Studs – Slab Intersection



View from Interior   View from Exterior

Thermal Performance Indicators

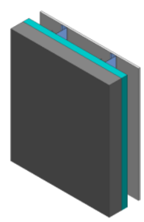
Assembly 1D (Nominal) R-Value	R_{1D}	Nominal thermal resistance of wall
Transmittance / Resistance without Anomaly	U_o, R_o	"clear wall" U- and R-value, without slab and anchor connections
Surface Temperature Index[1]	T_i	0 = exterior temperature 1 = interior temperature
Linear Transmittance	ψ	Incremental increase in transmittance per linear length of slab

[1]Surface temperatures are a result of steady-state conductive heat flow with constant heat transfer coefficients. Limitations are identified in final report.

Nominal (1D) vs. Assembly Performance Indicators

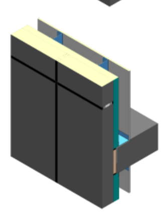
Base Assembly – Wall

R_{1D} ft^2·hr·^{o}F / Btu (m^2 K / W)	R_o ft^2·hr·^{o}F / Btu (m^2 K / W)	U_o Btu/ft^2 ·hr ·^{o}F (W/m^2 K)
R-12.8 (2.25)	R-12.2 (2.15)	0.082 (0.47)



Slab Linear Transmittance[2]

R ft^2·hr·^{o}F / Btu (m^2 K / W)	U Btu/ft^2 ·hr ·^{o}F (W/m^2 K)	ψ Btu/ft hr ^{o}F (W/m K)
R-8.7 (1.54)	0.115 (0.65)	0.218 (0.377)



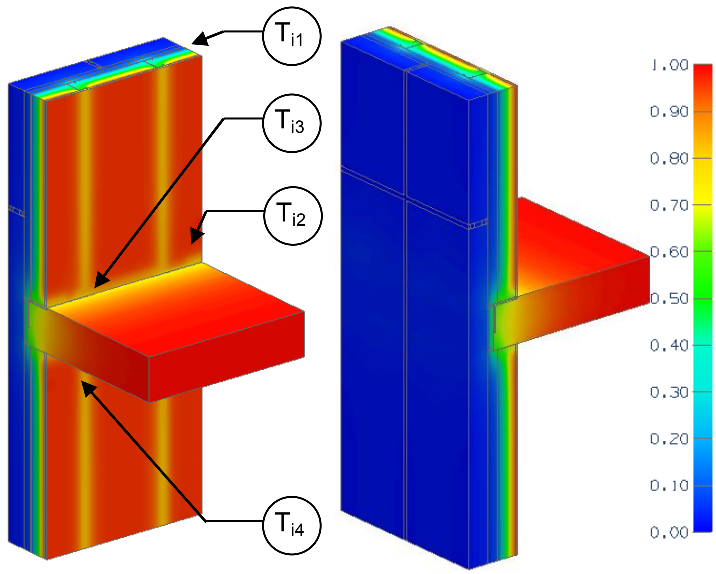
[2] Panel edges (caulked joints between panels) had negligible linear transmittance effects so values not presented

Temperature Indices

T_{i1}	0.04	Min T on concrete wall, between studs, away from slab
T_{i2}	0.31	Max T on concrete wall, at slot anchor connection
T_{i3}	0.80	Min T on floor, at gypsum and gravity anchor
T_{i4}	0.87	Min T on ceiling, at gypsum and studs

Detail 29

Precast Wall Assembly with 3 5/8″ x 1 5/8″ Steel Stud (16″ o.c) and Insulation in Stud Cavity – Slab Intersection



View from Interior   View from Exterior

Thermal Performance Indicators

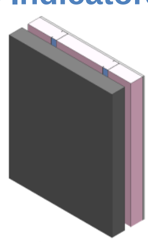
Assembly 1D (Nominal) R-Value	R_{1D}	Nominal thermal resistance of wall
Transmittance / Resistance without Anomaly	U_o, R_o	"clear wall" U- and R-value, without slab and anchor connections
Surface Temperature Index[1]	T_i	0 = exterior temperature 1 = interior temperature
Linear Transmittance	ψ	Incremental increase in transmittance per linear length of slab

[1]Surface temperatures are a result of steady-state conductive heat flow with constant heat transfer coefficients. Limitations are identified in final report.

Nominal (1D) vs. Assembly Performance Indicators

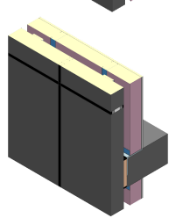
Base Assembly – Wall

R_{1D} ft^2·hr·°F / Btu (m^2 K / W)	R_o ft^2·hr·°F / Btu (m^2 K / W)	U_o Btu/ft^2 ·hr ·°F (W/m^2 K)
R-14.5 (2.55)	R-8.5 (1.49)	0.118 (0.67)



Slab Linear Transmittance[2]

R ft^2·hr·°F / Btu (m^2 K / W)	U Btu/ft^2 ·hr ·°F (W/m^2 K)	ψ Btu/ft hr °F (W/m K)
R-6.2 (1.09)	0.161 (0.91)	0.286 (0.495)



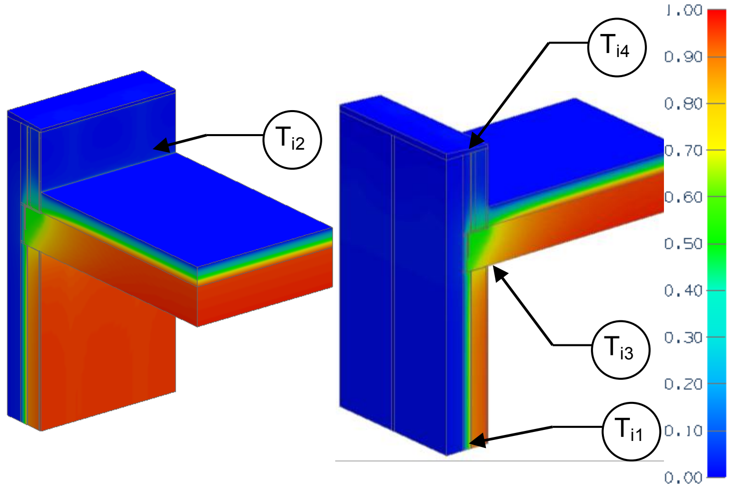
[2] Panel edges (caulked joints between panels) had negligible linear transmittance effects so values not presented

Temperature Indices

T_{i1}	0.05	Min T on concrete wall, between studs, away from slab
T_{i2}	0.23	Max T on concrete wall, at slot anchor
T_{i3}	0.73	Min T on floor, at gypsum and studs
T_{i4}	0.75	Min T on ceiling, at gypsum and studs

Detail 30

Precast Wall Assembly with 3 5/8″ x 1 5/8″ Steel Stud (16″ o.c) and Rigid Insulation Outboard of Studs – Parapet & Roof Intersection



View from Interior

View from Exterior

Thermal Performance Indicators

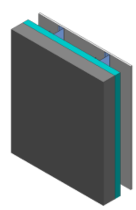
Assembly 1D (Nominal) R-Value	R_{1Dr}, R_{1Dw}	Two base assemblies : r = roof w = wall
Transmittance / Resistance without Anomaly	U_{or} R_{or} U_{ow} R_{ow}	“clear field” U- and R-values. Separate values presented for the two base assemblies
Surface Temperature Index[1]	T_i	0 = exterior temperature 1 = interior temperature
Linear Transmittance	ψ	Incremental increase in transmittance per linear length of parapet

[1]Surface temperatures are a result of steady-state conductive heat flow with constant heat transfer coefficients. Limitations are identified in final report.

Nominal (1D) vs. Assembly Performance Indicators

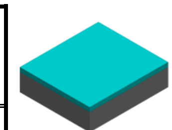
Base Assembly – Wall

R_{1D} ft^2·hr·^{o}F / Btu (m^2 K / W)	R_{ow} ft^2·hr·^{o}F / Btu (m^2 K / W)	U_{ow} Btu/ft^2 ·hr ·^{o}F (W/m^2 K)
R-12.8 (2.25)	R-12.2 (2.15)	0.082 (0.47)



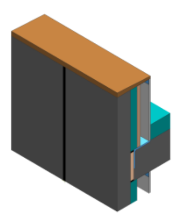
Base Assembly – Roof

R_{1D} ft^2·hr·^{o}F / Btu (m^2 K / W)	R_{or} ft^2·hr·^{o}F / Btu (m^2 K / W)	U_{or} Btu/ft^2 ·hr ·^{o}F (W/m^2 K)
R-21.4 (3.77)	R-21.4 (3.77)	0.047 (0.27)



Parapet Linear Transmittance[2]

R ft^2·hr·^{o}F / Btu (m^2 K / W)	U Btu/ft^2 ·hr ·^{o}F (W/m^2 K)	ψ Btu/ft hr ^{o}F (W/m K)
R-9.1 (1.60)	0.110 (0.63)	0.334 (0.579)



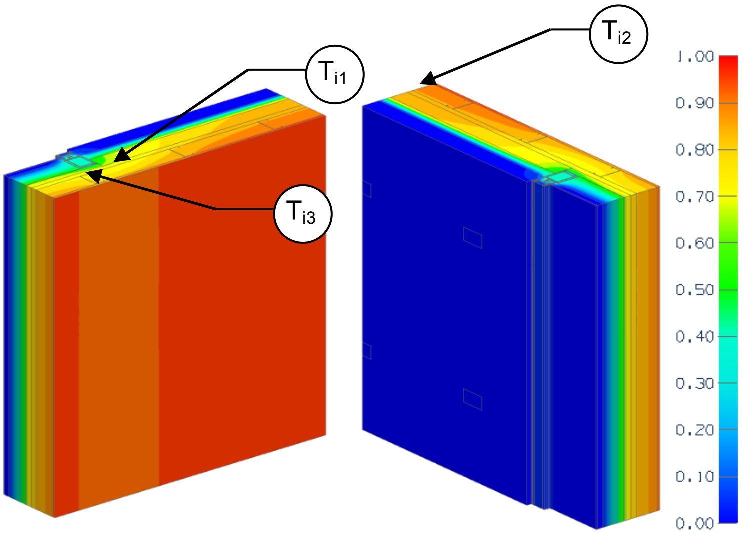
[2] Panel edges (caulked joints between panels) had negligible linear transmittance effects so values not presented

Temperature Indices

T_{i1}	0.04	Min T on concrete wall, between studs, away from roof
T_{i2}	0.16	Max T on concrete wall, at slot anchor
T_{i3}	0.73	Min T on ceiling, at gypsum board, at studs
T_{i4}	0.01	Min T on concrete parapet, at wood blocking

Detail 31

Precast Sandwich Panel Wall Assembly with 3 5/8″ Steel Stud (16″ o.c.) – Curtain Wall Transition



View from Interior   View from Exterior

Thermal Performance Indicators

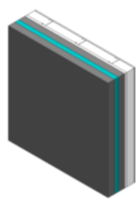
Assembly 1D (Nominal) R-Value	R_{1D}	Nominal thermal resistance of two base assemblies: w = concrete wall cw = curtain wall
Transmittance / Resistance without Anomaly	U_{ow} R_{ow} U_{ocw} R_{ocw}	"clear wall" U- and R-value for the two base assemblies
Surface Temperature Index¹	T_i	0 = exterior temperature 1 = interior temperature
Linear Transmittance	ψ	Incremental increase in transmittance per linear length of transition joint

¹Surface temperatures are a result of steady-state conductive heat flow with constant heat transfer coefficients. Limitations are identified in final report.

Nominal (1D) vs. Assembly Performance Indicators

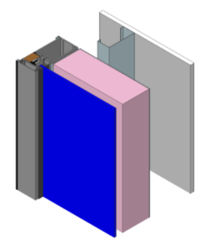
Base Assembly – Wall

R_{1Dw} ft^2·hr·°F / Btu (m^2 K / W)	R_{ow} ft^2·hr·°F / Btu (m^2 K / W)	U_{ow} Btu/ft^2 ·hr ·°F (W/m^2 K)
R-13.1 (2.30)	R-12.6 (2.22)	0.079 (0.45)



Base Assembly – Curtain Wall[2]

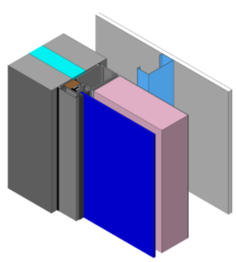
R_{1Dcw} ft^2·hr·°F / Btu (m^2 K / W)	R_{ocw} ft^2·hr·°F / Btu (m^2 K / W)	U_{ocw} Btu/ft^2 ·hr ·°F (W/m^2 K)
R-19.2 (3.38)	R-5.7 (1.01)	0.175 (0.99)



[2] R-15 back pan insulation

Transition Joint Linear Transmittance

R ft^2·hr·°F / Btu (m^2 K / W)	U Btu/ft^2 ·hr ·°F (W/m^2 K)	ψ Btu/ft hr °F (W/m K)
R-8.0 (1.41)	0.125 (0.71)	0.082 (0.142)

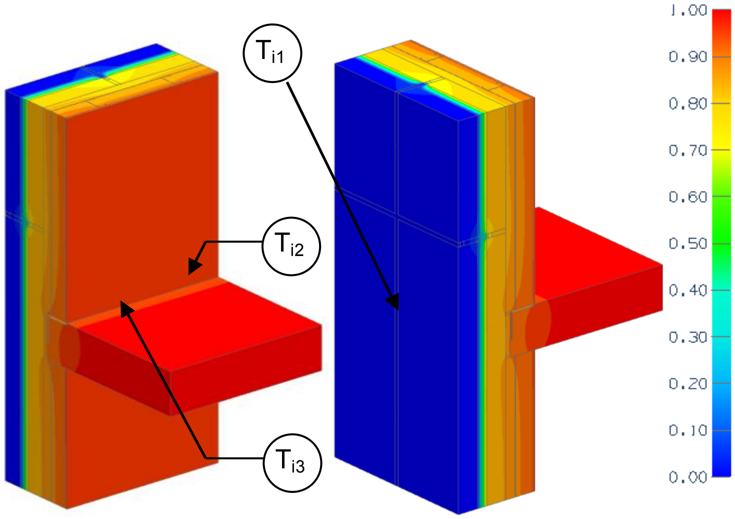


Temperature Indices

T_{i1}	0.62	Min T on interior concrete wall, at mullion
T_{i2}	0.83	Max T on interior concrete wall, away from mullion
T_{i3}	0.43	Min T in air cavity, at mullion

Detail 32

Precast Sandwich Panel Wall Assembly with 3 5/8″ Steel Stud (16″ o.c.) – Slab Intersection



View from Interior View from Exterior

Thermal Performance Indicators

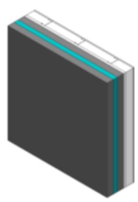
Assembly 1D (Nominal) R-Value	R_{1D}	Nominal Thermal Resistance of wall
Transmittance / Resistance without Anomaly	U_o, R_o	"clear wall" U- and R-value without slab
Surface Temperature Index[1]	T_i	0 = exterior temperature 1 = interior temperature
Linear Transmittance	ψ_j, ψ_s	Incremental increase in transmittance per linear length of j = panel joint s = slab

[1]Surface temperatures are a result of steady-state conductive heat flow with constant heat transfer coefficients. Limitations are identified in final report.

Nominal (1D) vs. Assembly Performance Indicators

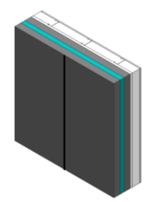
Base Assembly – Wall

R_{1D} ft^2·hr·^{o}F / Btu (m^2 K / W)	R_o ft^2·hr·^{o}F / Btu (m^2 K / W)	U_o Btu/ft^2 ·hr ·^{o}F (W/m^2 K)
R-13.1 (2.30)	R-12.6 (2.22)	0.079 (0.45)



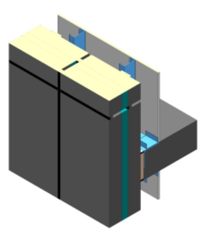
Panel Joint Linear Transmittance

R_j ft^2·hr·^{o}F / Btu (m^2 K / W)	U_j Btu/ft^2 ·hr ·^{o}F (W/m^2 K)	ψ_j Btu/ft hr ^{o}F (W/m K)
R-11.7 (2.05)	0.086 (0.49)	0.026 (0.046)



Slab Linear Transmittance

R_p ft^2·hr·^{o}F / Btu (m^2 K / W)	U_p Btu/ft^2 ·hr ·^{o}F (W/m^2 K)	ψ_p Btu/ft hr ^{o}F (W/m K)
R-8.8 (1.54)	0.114 (0.65)	0.118 (0.205)

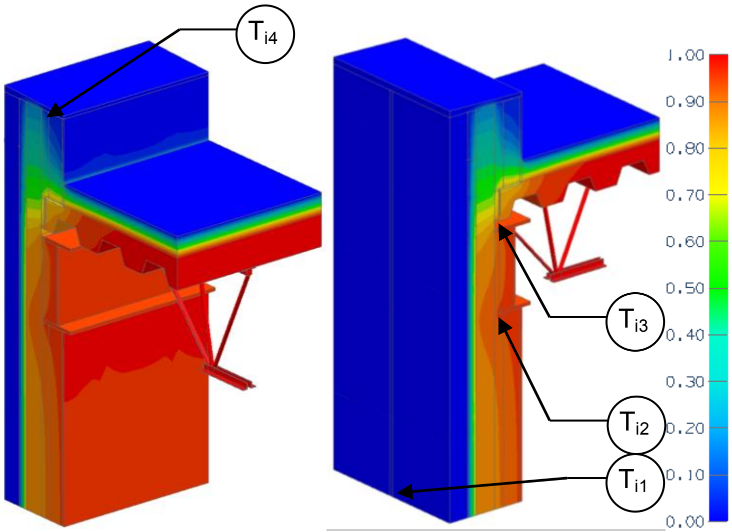


Temperature Indices

T_{i1}	0.73	Min T on interior concrete wall, at panel joints, at slab
T_{i2}	0.82	Max T on concrete wall, at slot anchor
T_{i3}	0.92	Min T in interior surface, at floor/gypsum intersection and anchor

Detail 33

Precast Sandwich Panel Wall Assembly with 3 5/8″ Steel Stud (16″ o.c.) – Steel Roof Deck with Open Web Steel Joist & Parapet Intersection



View from Interior　　View from Exterior

Thermal Performance Indicators

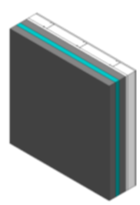
Assembly 1D (Nominal) R-Value	R_{1Dr}, R_{1Dw}	Nominal Thermal resistance for two base assemblies: r = roof w = wall
Transmittance / Resistance without Anomaly	U_{ow}, R_{ow} U_{or} , R_{or}	"clear wall" U- and R-value of base assemblies
Surface Temperature Index¹	T_i	0 = exterior temperature 1 = interior temperature
Linear Transmittance	ψ_j, ψ_p	Incremental increase in transmittance per linear length of j = panel joint p = parapet

¹Surface temperatures are a result of steady-state conductive heat flow with constant heat transfer coefficients. Limitations are identified in final report.

Nominal (1D) vs. Assembly Performance Indicators

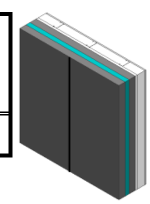
Base Assembly –Wall

R_{1Dw} ft²·hr·°F / Btu (m² K / W)	R_{ow} ft²·hr·°F / Btu (m² K / W)	U_{ow} Btu/ft² ·hr ·°F (W/m² K)
R-13.1 (2.30)	R-12.6 (2.22)	0.079 (0.45)



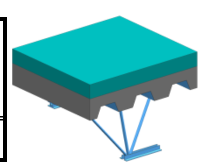
Panel Joint Linear Transmittance

R_j ft²·hr·°F / Btu (m² K / W)	U_j Btu/ft² ·hr ·°F (W/m² K)	ψ_j Btu/ft hr °F (W/m K)
R-11.7(2.05)	0.086 (0.49)	0.026 (0.046)



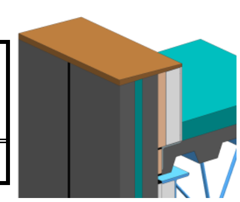
Base Assembly – Roof

R_{1Dr} ft²·hr·°F / Btu (m² K / W)	R_{or} ft²·hr·°F / Btu (m² K / W)	U_{or} Btu/ft² ·hr ·°F (W/m² K)
R-21.2 (3.74)	R-21.0 (3.69)	0.048 (0.27)



Parapet Linear Transmittance

R_p ft²·hr·°F / Btu (m² K / W)	U_p Btu/ft² ·hr ·°F (W/m² K)	ψ_p Btu/ft hr °F (W/m K)
R-8.2 (1.43)	0.123 (0.70)	0.375 (0.650)

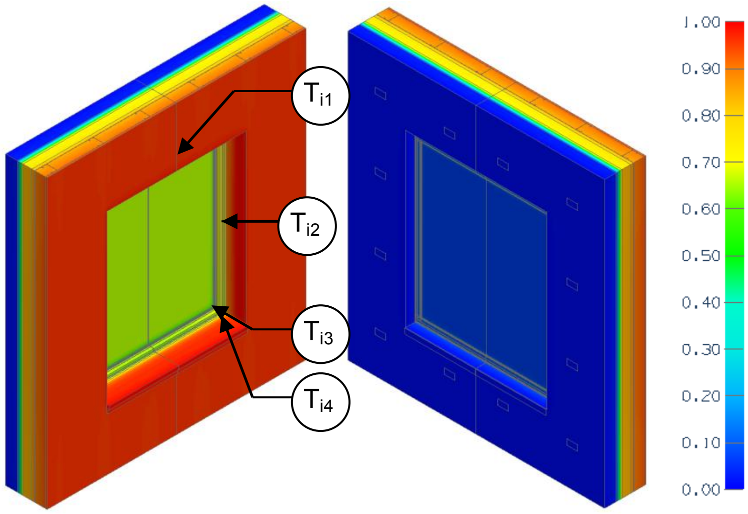


Temperature Indices

T_{i1}	0.82	Min T on concrete wall, at panel joint, away from roof
T_{i2}	0.89	Max T on concrete wall, below Ibeam
T_{i3}	0.77	Min T in interior surface, on concrete, away from joist
T_{i4}	0.19	Min T on concrete parapet, and panel edge and wood block

Detail 34

Precast Sandwich Panel Wall Assembly with 3 5/8″ Steel Stud (16″ O.C.) – Window Intersection



View from Interior View from Exterior

Thermal Performance Indicators

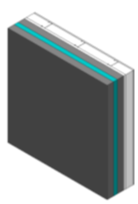
Assembly 1D (Nominal) R-Value	R_{1D}	Nominal thermal resistance wall
Transmittance / Resistance without Anomaly	U_o, R_o	"clear wall" U- and R-value, without slab and anchor connections
Surface Temperature Index[1]	T_i	0 = exterior temperature 1 = interior temperature
Linear Transmittance	ψ	Incremental increase in transmittance per linear length of glazing transition
Point Transmittance	χ	Incremental increase in transmittance from glazing transition

[1]Surface temperatures are a result of steady-state conductive heat flow with constant heat transfer coefficients. Limitations are identified in final report.

Nominal (1D) vs. Assembly Performance Indicators

Base Assembly – Wall

R_{1D} ft^2·hr·^{o}F / Btu (m^2 K / W)	R_o ft^2·hr·^{o}F / Btu (m^2 K / W)	U_o Btu/ft^2 ·hr ·^{o}F (W/m^2 K)
R-13.1 (2.30)	R-12.6 (2.22)	0.079 (0.45)



Window Point and Linear Transmittance

R ft^2·hr·^{o}F / Btu (m^2 K / W)	U Btu/ft^2 ·hr ·^{o}F (W/m^2 K)	χ^2 Btu/ hr ^{o}F (W/K)	ψ^3 Btu/ft hr ^{o}F (W/m K)
R-10.9 (1.92)	0.091 (0.52)	0.501 (0.265)	0.028 (0.048)

[2]The point transmittance for this specific sizing of window only. See material sheets for dimensions

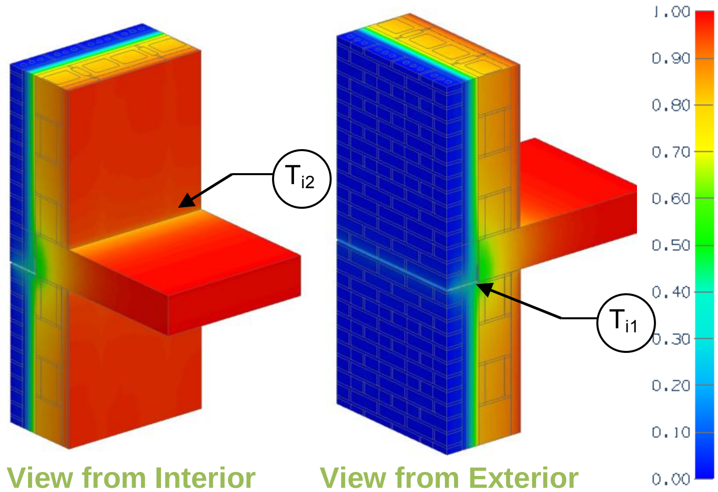
[3]For linear transmittance, use window perimeter for length

Temperature Indices

T_{i1}	0.82	Min T on concrete wall, centered above window head
T_{i2}	0.86	Max T on concrete wall, at steel stud and window frame
T_{i3}	0.59	Min T on window frame, at bottom corner
T_{i4}	0.56	Min T on window glass, in lower corner

Detail 35

Exterior Insulated Concrete Block Wall Assembly with Shelf Angle & Brick Ties Supporting Brick Veneer – Slab Intersection



Thermal Performance Indicators

Assembly 1D (Nominal) R-Value	R_{1D}	R- 5.59 (0.98 RSI) + exterior insulation
Transmittance / Resistance without Anomaly	U_o, R_o	"clear wall" U- and R-value without slab and shelf angle
Surface Temperature Index[1]	T_i	0 = exterior temperature 1 = interior temperature
Linear Transmittance	ψ	Incremental increase in transmittance per linear length of shelf angle and slab

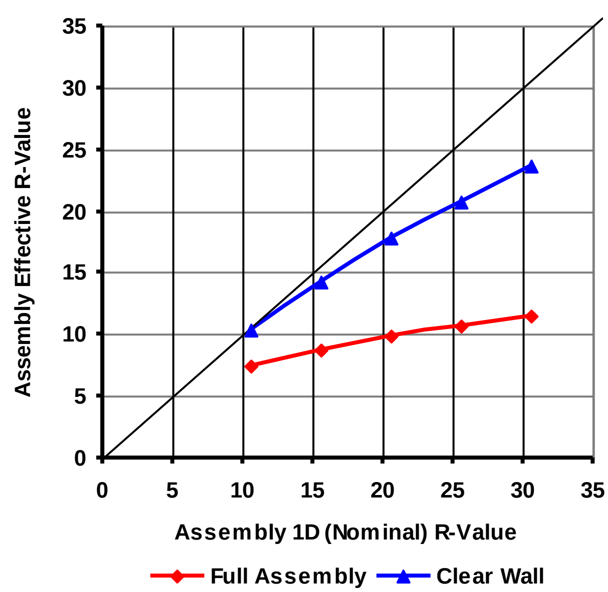
[1]Surface temperatures are a result of steady-state conductive heat flow with constant heat transfer coefficients. Limitations are identified in final report.

Nominal (1D) vs. Assembly Performance Indicators

Exterior Insulation 1D R-Value (RSI)	R_{1D} ft²·hr·°F / Btu (m² K / W)	R_o ft²·hr·°F / Btu (m² K / W)	U_o Btu/ft² ·hr ·°F (W/m² K)	R ft²·hr·°F / Btu (m² K / W)	U Btu/ft² ·hr ·°F (W/m² K)	ψ Btu/ft hr °F (W/m K)
R-5 (0.88)	R-10.6 (1.86)	R-10.4 (1.83)	0.096 (0.55)	R-7.4 (1.30)	0.135 (0.77)	0.236 (0.408)
R-10 (1.76)	R-15.6 (2.74)	R-14.2 (2.50)	0.070 (0.40)	R-8.8 (1.56)	0.113 (0.64)	0.258 (0.446)
R-15 (2.64)	R-20.6 (3.62)	R-17.8 (3.13)	0.056 (0.32)	R-9.9 (1.75)	0.101 (0.57)	0.268 (0.464)
R-20 (3.52)	R-25.6 (4.50)	R-20.8 (3.66)	0.048 (0.27)	R-10.8 (1.90)	0.093 (0.53)	0.270 (0.467)
R-25 (4.40)	R-30.6 (5.38)	R-23.7 (4.17)	0.042 (0.24)	R-11.5 (2.03)	0.087 (0.49)	0.268 (0.463)

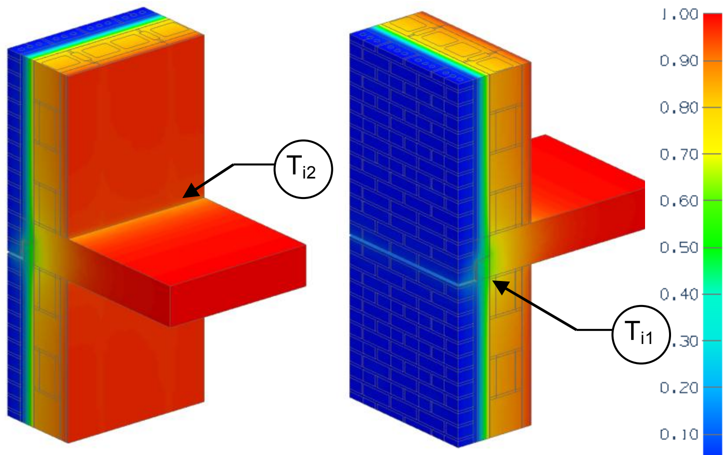
Temperature Indices

	R5	R15	R25	
T_{i1}	0.47	0.51	0.57	Min T on exterior face of concrete blocks at air-filled blocks, at bottom of slab
T_{i2}	0.82	0.84	0.86	Min T on interior surfaces, at floor/gypsum intersection, at studs



Detail 36

Exterior Insulated Concrete Block Wall Assembly with Spaced Shelf Angle & Brick Ties Supporting Brick Veneer – Slab Intersection



View from Interior   View from Exterior

Thermal Performance Indicators

Assembly 1D (Nominal) R-Value	R_{1D}	R- 5.59 (0.98 RSI) + exterior insulation
Transmittance / Resistance without Anomaly	U_o, R_o	"clear wall" U- and R-value without slab and shelf angle
Surface Temperature Index[1]	T_i	0 = exterior temperature 1 = interior temperature
Linear Transmittance	ψ	Incremental increase in transmittance per linear length of shelf angle and slab

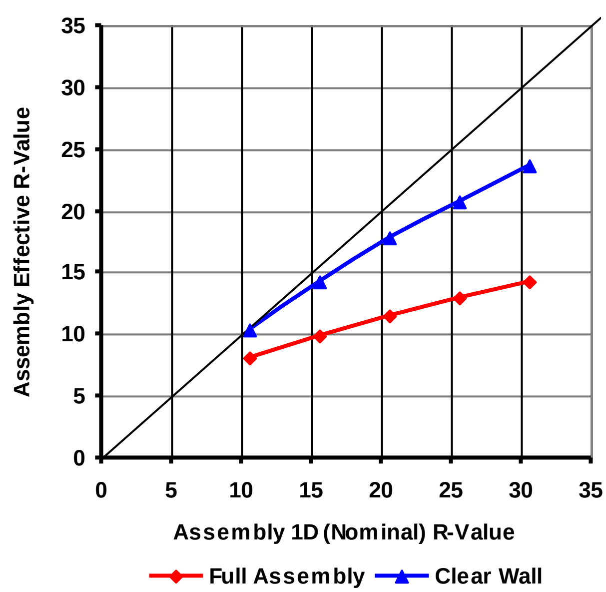
[1]Surface temperatures are a result of steady-state conductive heat flow with constant heat transfer coefficients. Limitations are identified in final report.

Nominal (1D) vs. Assembly Performance Indicators

Exterior Insulation 1D R-Value (RSI)	R_{1D} ft^2·hr·^{o}F / Btu (m^2 K / W)	R_o ft^2·hr·^{o}F / Btu (m^2 K / W)	U_o Btu/ft^2 ·hr ·^{o}F (W/m^2 K)	R ft^2·hr·^{o}F / Btu (m^2 K / W)	U Btu/ft^2 ·hr ·^{o}F (W/m^2 K)	ψ Btu/ft hr ^{o}F (W/m K)
R-5 (0.88)	R-10.6 (1.86)	R-10.4 (1.83)	0.096 (0.55)	R-8.1 (1.42)	0.124 (0.70)	0.167 (0.289)
R-10 (1.76)	R-15.6 (2.74)	R-14.2 (2.50)	0.070 (0.40)	R-9.9 (1.74)	0.101 (0.57)	0.186 (0.322)
R-15 (2.64)	R-20.6 (3.62)	R-17.8 (3.13)	0.056 (0.32)	R-11.5 (2.02)	0.087 (0.49)	0.186 (0.322)
R-20 (3.52)	R-25.6 (4.50)	R-20.8 (3.66)	0.048 (0.27)	R-12.9 (2.27)	0.078 (0.44)	0.178 (0.307)
R-25 (4.40)	R-30.6 (5.38)	R-23.7 (4.17)	0.042 (0.24)	R-14.3 (2.51)	0.070 (0.40)	0.168 (0.290)

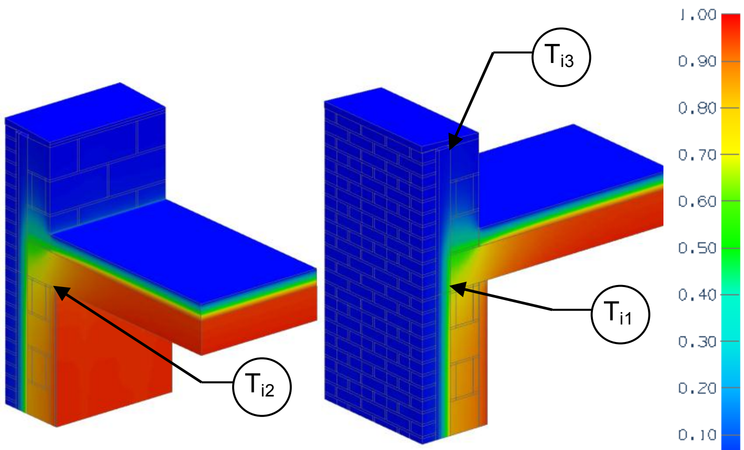
Temperature Indices

	R5	R15	R25	
T_{i1}	0.54	0.58	0.64	Min T on exterior face of concrete blocks, at air-filled blocks, at bottom of slab
T_{i2}	0.84	0.87	0.89	Min T on interior surfaces, on floor/gypsum intersection, at studs



Detail 37

Exterior Insulated Concrete Block Wall Assembly with Masonry Ties Supporting Brick Veneer – Parapet & Roof Intersection



View from Interior   View from Exterior

Thermal Performance Indicators

Assembly 1D (Nominal) R-Value	R_{1Dr}, R_{1Dw}	Two base assemblies : r = roof w = wall
Transmittance / Resistance without Anomaly	U_{or} R_{or} U_{ow} R_{ow}	"clear field" U- and R-values. Separate values presented for the two base assemblies
Surface Temperature Index[1]	T_i	0 = exterior temperature 1 = interior temperature
Linear Transmittance	ψ	Incremental increase in transmittance per linear length of parapet

[1]Surface temperatures are a result of steady-state conductive heat flow with constant heat transfer coefficients. Limitations are identified in final report.

Nominal (1D) vs. Assembly Performance Indicators

Base Assembly – Wall

Exterior Insulation 1D R-Value (RSI)	R_{1D} $ft^2{\cdot}hr{\cdot}{}^oF$ / Btu (m^2 K / W)	R_{ow} $ft^2{\cdot}hr{\cdot}{}^oF$ / Btu (m^2 K / W)	U_{ow} Btu/ft^2 ·hr ·^oF (W/m^2 K)
R-5 (0.88)	R-10.6 (1.86)	R-10.4 (1.83)	0.096 (0.55)
R-15 (2.64)	R-20.6 (3.62)	R-17.8 (3.13)	0.056 (0.32)
R-25 (4.40)	R-30.6 (5.38)	R-23.7 (4.17)	0.042 (0.24)

Base Assembly – Roof

R_{1D} $ft^2{\cdot}hr{\cdot}{}^oF$ / Btu (m^2 K / W)	R_{or} $ft^2{\cdot}hr{\cdot}{}^oF$ / Btu (m^2 K / W)	U_{or} Btu/ft^2 ·hr ·^oF (W/m^2 K)
R-21.4 (3.77)	R-21.4 (3.77)	0.047 (0.27)

Parapet Linear Transmittance

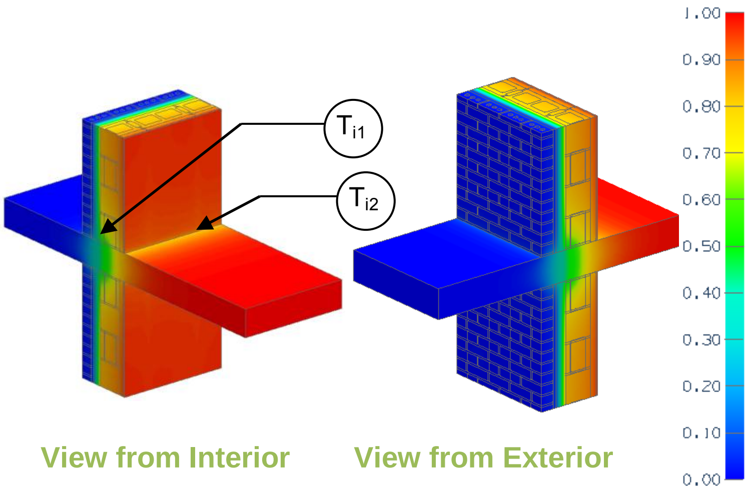
Exterior Insulation 1D R-Value (RSI)	R $ft^2{\cdot}hr{\cdot}{}^oF$ / Btu (m^2 K / W)	U Btu/ft^2 ·hr ·^oF (W/m^2 K)	ψ Btu/ft hr ^oF (W/m K)
R-5 (0.88)	10.0 (1.8)	0.100 (0.57)	0.238 (0.412)
R-15 (2.64)	12.2 (2.1)	0.082 (0.47)	0.180 (0.311)
R-25 (4.40)	13.1 (2.3)	0.076 (0.43)	0.236 (0.408)

Temperature Indices

	R5	R15	R25	
T_{i1}	0.57	0.66	0.68	Min T on exterior face of concrete block wall, at roof/gypsum intersection and air filled blocks
T_{i2}	0.78	0.81	0.82	Min T on interior surfaces, at ceiling/gypsum intersection, at studs
T_{i3}	0.01	0.01	0.01	Min T on concrete block parapet, at wood block and air filled concrete blocks

Detail 38

Exterior Insulated Concrete Block Wall Assembly with Masonry Ties Supporting Brick Veneer – Balcony Slab Intersection



View from Interior View from Exterior

Thermal Performance Indicators

Assembly 1D (Nominal) R-Value	R_{1D}	R- 5.59 (0.98 RSI) + exterior insulation
Transmittance / Resistance without Anomaly	U_o R_o	“clear wall” U- and R-value without slab
Surface Temperature Index[1]	T_i	0 = exterior temperature 1 = interior temperature
Linear Transmittance	ψ	Incremental increase in transmittance per linear length of slab

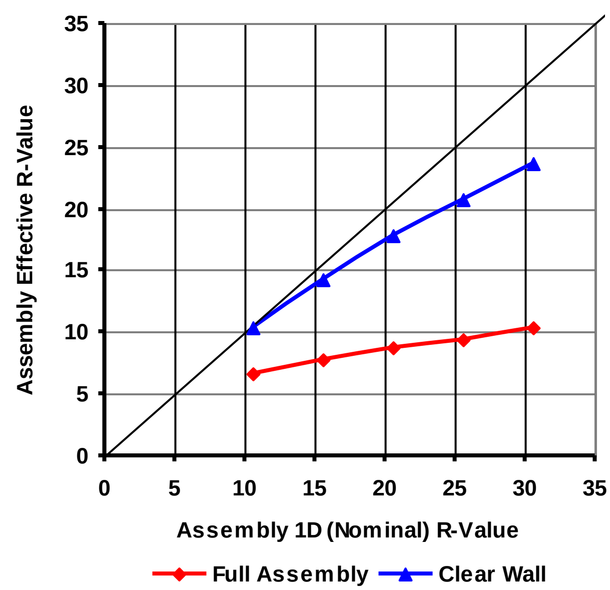
[1]Surface temperatures are a result of steady-state conductive heat flow with constant heat transfer coefficients. Limitations are identified in final report.

Nominal (1D) vs. Assembly Performance Indicators

Exterior Insulation 1D R-Value (RSI)	R_{1D} ft^2·hr·°F / Btu (m^2 K / W)	R_o ft^2·hr·°F / Btu (m^2 K / W)	U_o Btu/ft^2 ·hr ·°F (W/m^2 K)	R ft^2·hr·°F / Btu (m^2 K / W)	U Btu/ft^2 ·hr ·°F (W/m^2 K)	ψ Btu/ft hr °F (W/m K)
R-5 (0.88)	R-10.6 (1.86)	R-10.4 (1.83)	0.096 (0.55)	R-6.64 (1.17)	0.151 (0.86)	0.327 (0.565)
R-10 (1.76)	R-15.6 (2.74)	R-14.2 (2.50)	0.070 (0.40)	R-7.77 (1.37)	0.129 (0.73)	0.350 (0.606)
R-15 (2.64)	R-20.6 (3.62)	R-17.8 (3.13)	0.056 (0.32)	R-8.71 (1.53)	0.155 (0.65)	0.352 (0.609)
R-20 (3.52)	R-25.6 (4.50)	R-20.8 (3.66)	0.048 (0.27)	R-9.43 (1.66)	0.106 (0.60)	0.348 (0.603)
R-25 (4.40)	R-30.6 (5.38)	R-23.7 (4.17)	0.042 (0.24)	R-10.43 (1.84)	0.096 (0.54)	0.322 (0.558)

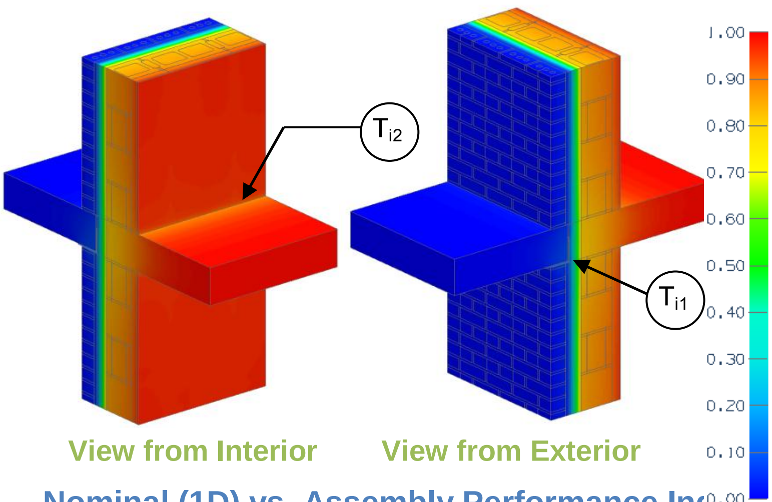
Temperature Indices

	R5	R15	R25	
T_{i1}	0.42	0.49	0.55	Min T on exterior face of concrete blocks, at top of slab, at air filled blocks
T_{i2}	0.78	0.82	0.83	Min T on interior surfaces, at floor/gypsum intersection, at studs



Detail 39

Exterior Insulated Concrete Block Wall Assembly with Masonry Ties Supporting Brick Veneer – Angle Supported Slab & Slab Intersection



View from Interior   View from Exterior

Thermal Performance Indicators

Assembly 1D (Nominal) R-Value	R_{1D}	R- 5.59 (0.98 RSI) + Exterior Insulation
Transmittance / Resistance without Anomaly	U_o, R_o	“clear wall” U- and R-value without balcony slab
Surface Temperature Index[1]	T_i	0 = exterior temperature 1 = interior temperature
Linear Transmittance	ψ	Incremental increase in transmittance per linear length of slab

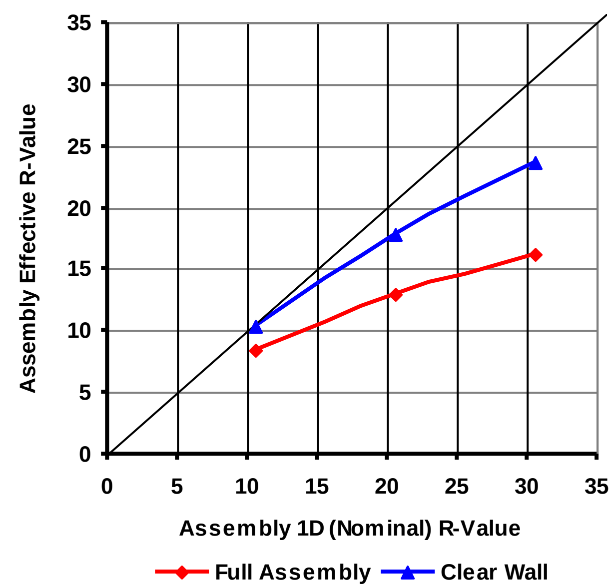
[1]Surface temperatures are a result of steady-state conductive heat flow with constant heat transfer coefficients. Limitations are identified in final report.

Nominal (1D) vs. Assembly Performance Indicators

Exterior Insulation 1D R-Value (RSI)	R_{1D} ft²·hr·°F / Btu (m² K / W)	R_o ft²·hr·°F / Btu (m² K / W)	U_o Btu/ft² ·hr ·°F (W/m² K)	R ft²·hr·°F / Btu (m² K / W)	U Btu/ft² ·hr ·°F (W/m² K)	ψ Btu/ft hr °F (W/m K)
R-5 (0.88)	R-10.6 (1.86)	R-10.4 (1.83)	0.096 (0.55)	R-8.4 (1.47)	0.120 (0.68)	0.140 (0.243)
R-15 (2.64)	R-20.6 (3.62)	R-17.8 (3.13)	0.056 (0.32)	R-13.0 (2.28)	0.077 (0.44)	0.126 (0.218)
R-25 (4.40)	R-30.6 (5.38)	R-23.7 (4.17)	0.042 (0.24)	R-16.2 (2.84)	0.062 (0.35)	0.118 (0.205)

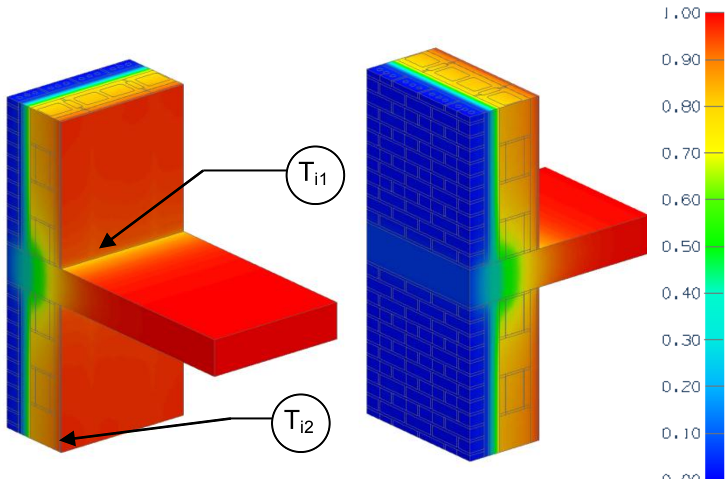
Temperature Indices

	R5	R15	R25	
T_{i1}	0.55	0.65	0.70	Min T on exterior face of concrete blocks, at bottom of slab, at slab angle supports
T_{i2}	0.85	0.89	0.91	Min T on interior surfaces, at floor/gypsum intersection, at studs



Detail 40

Exterior Insulated Concrete Block Wall Assembly with Masonry Ties Supporting Brick Veneer – Balcony Slab Intersection



View from Interior View from Exterior

Thermal Performance Indicators

Assembly 1D (Nominal) R-Value	R_{1D}	R- 5.59 (0.98 RSI) + exterior insulation
Transmittance / Resistance without Anomaly	U_o R_o	"clear wall" U- and R-value without slab
Surface Temperature Index[1]	T_i	0 = exterior temperature 1 = interior temperature
Linear Transmittance	ψ	Incremental increase in transmittance per linear length of slab

[1]Surface temperatures are a result of steady-state conductive heat flow with constant heat transfer coefficients. Limitations are identified in final report.

Nominal (1D) vs. Assembly Performance Indicators

Exterior Insulation 1D R-Value (RSI)	R_{1D} ft^2·hr·°F / Btu (m^2 K / W)	R_o ft^2·hr·°F / Btu (m^2 K / W)	U_o Btu/ft^2 ·hr ·°F (W/m^2 K)	R ft^2·hr·°F / Btu (m^2 K / W)	U Btu/ft^2 ·hr ·°F (W/m^2 K)	ψ Btu/ft hr °F (W/m K)
R-5 (0.88)	R-10.6 (1.86)	R-10.4 (1.83)	0.096 (0.55)	R-6.5 (1.14)	0.154 (0.88)	0.348 (0.602)
R-10 (1.76)	R-15.6 (2.74)	R-14.2 (2.50)	0.070 (0.40)	R-7.6 (1.34)	0.131 (0.75)	0.367 (0.636)
R-15 (2.64)	R-20.6 (3.62)	R-17.8 (3.13)	0.056 (0.32)	R-8.5 (1.50)	0.117 (0.67)	0.368 (0.636)
R-20 (3.52)	R-25.6 (4.50)	R-20.8 (3.66)	0.048 (0.27)	R-9.2 (1.61)	0.109 (0.62)	0.367 (0.636)
R-25 (4.40)	R-30.6 (5.38)	R-23.7 (4.17)	0.042 (0.24)	R-9.9 (1.75)	0.101 (0.57)	0.351 (0.607)

Temperature Indices

	R5	R15	R25	
T_{i1}	0.39	0.48	0.53	Min T on exterior face of concrete blocks, at top of slab, at air filled blocks
T_{i2}	0.77	0.81	0.83	Min T on interior surfaces, at floor/gypsum intersection, at studs