



March 2, 2020

MH Ref: 1904484.00

Mr. Patrick Lucas  
 R-stud, LLC  
 PO Box 692  
 Donald, OR 97020

email: patrick@rstud.com

Dear Patrick:

**Re: CEC R-stud Wall Assembly Thermal Analysis**

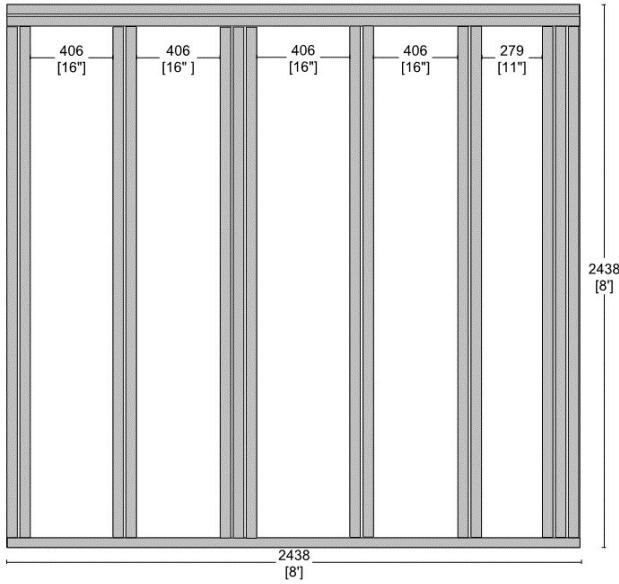
Morrison Hershfield Limited (MH) was retained by R-stud LLC (R-stud) to evaluate the thermal performance of the R-stud steel framing system for compliance with the California Energy Commission (CEC). This report is a summary of the analysis.

**BACKGROUND INFORMATION**

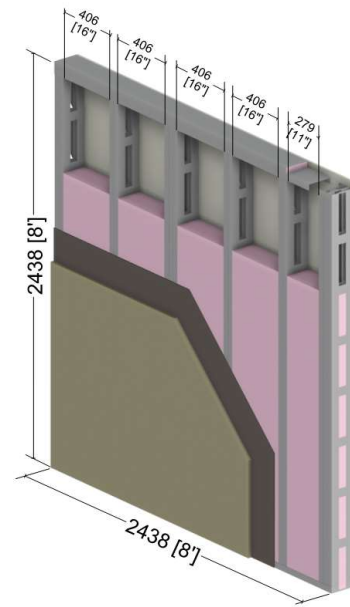
The evaluated wall assemblies are based assemblies listed in Tables 4.3.3 and 4.3.4 for metal framed walls for nonresidential and residential construction in the CEC 2019 Building Energy Efficiency Standard Joint Appendix. The wall assemblies consists of the components listed in Table 1 and have the framing configuration shown in Figure 1.

**Table 1:** Evaluated Assembly Components

Assembly	Section	Components
Without Continuous Insulation		Interior <ul style="list-style-type: none"> <li>• R-0.68 interior air film</li> <li>• 1/2 inch gypsum (R-0.45)</li> <li>• 1-1/2 inch x 4 inch or 1-1/2 inch x 6 steel R-Stud at 16 inch or 24 inch spacing (Nonresidential: 14 gauge, Residential: 18 gauge)</li> <li>• Batt insulation in stud cavity (varies, see Table 2)</li> <li>• Building paper (R-0.06)</li> <li>• 7/8 inch stucco (R-0.18)</li> <li>• R-0.17 exterior air film</li> </ul> Exterior
With Continuous Insulation		Interior <ul style="list-style-type: none"> <li>• R-0.68 interior air film</li> <li>• 1/2 inch gypsum (R-0.45)</li> <li>• 1-1/2 inch x 4 inch or 1-1/2 inch x 6 steel R-Stud at 16 inch or 24 inch spacing (Nonresidential: 14 gauge, Residential: 18 gauge)</li> <li>• Batt insulation in stud cavity (varies, see Table 2)</li> <li>• Continuous insulation (varies, see Table 2)</li> <li>• Building paper (R-0.06)</li> <li>• 3/8 inch stucco (R-0.08)</li> <li>• R-0.17 exterior air film</li> </ul> Exterior

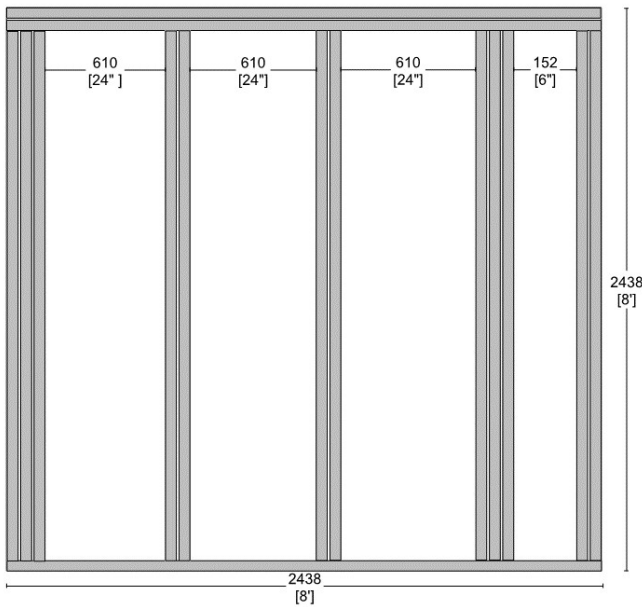


Framing Layout

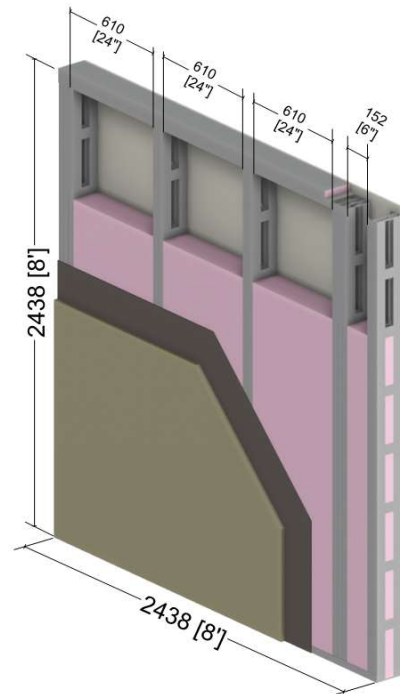


3D Layout

**Wall Configuration for Studs at 16 inch spacing**  
(25% framing factor)



Framing Layout



3D Layout

**Wall Configuration for Studs at 24 inch spacing**  
(22% framing factor)

**Figure 1:** Evaluated Metal Frame Wall Configurations

The wall assemblies were evaluated for different insulation levels as listed in Table 2. The material properties of the detail components and metal framing layouts are given in Appendix A.

**Table 2:** Insulation Scenarios

Nominal Framing Size	Application	Stud Cavity Insulation	Continuous Insulation
2x4	Nonresidential (14 gauge studs), Residential (18 gauge studs)	R-13, R-15	None, R-2, R-4, R-5, R-6, R-7, R-8
2x6	Nonresidential (14 gauge studs), Residential (18 gauge studs)	R-19, R-20, R-21	None, R-2, R-4, R-5, R-6, R-7, R-8

## THERMAL ANALYSIS

The thermal performance of the assembly scenarios were evaluated by 3D thermal modeling using the Nx software package from Siemens, which is a general purpose computer aided design (CAD) and finite element analysis (FEA) package. The thermal analysis utilized steady-state conditions, published thermal properties of materials and information provided by R-stud, and the CEC. Additional assumptions for the thermal analysis are listed in Appendix A. The analysis followed the same procedures as the previous analysis from August 30, 2019<sup>1</sup> which compared the evaluated regular stud and R-stud metal framed assemblies to the listed U-values in Table 4.3.3 of the CEC 2019 Building Energy Efficiency Standard Joint Appendix.

### CEC Assembly U-Values

The U-values of the evaluated assemblies are shown in Tables 3 and 4 for nonresidential and residential assemblies, respectively. The thermal transmittance values of scenarios with continuous insulation were determined by adding the insulation nominal thermal resistance to the effective thermal resistance of the steel frame wall assemblies determined from 3D thermal modeling. This approach assumes the thermal resistance of the continuous insulation is applied in series to the thermal resistance of the steel frame wall similar to the calculation method used by the CEC. The effective R-values of the evaluated assemblies are listed in Appendix B.

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<sup>1</sup> R-stud Wall Assembly Thermal Analysis, August 30, 2019, Report Number: 1904484.00

**Table 3:** Thermal Transmittance (U-value) of R-stud Nonresidential Wall Assemblies Evaluated with Thermal Modeling and Series Calculation Method

Stud Spacing	Cavity Insulation R-value	Nominal Framing Size	U-value Btu/h ft <sup>2</sup> °F (W/m <sup>2</sup> K)						
			Base Assembly (R-0)	Rated R-value of Continuous Insulation added to Base Assembly					
				R-2	R-4	R5	R-6	R-7	R-8
16 in o.c.	R-13	2x4	0.166 (0.94)	0.126 (0.72)	0.101 (0.57)	0.091 (0.52)	0.084 (0.48)	0.077 (0.44)	0.072 (0.41)
	R-15	2x4	0.159 (0.90)	0.122 (0.69)	0.098 (0.56)	0.089 (0.51)	0.082 (0.47)	0.076 (0.43)	0.071 (0.40)
	R-19	2x6	0.145 (0.82)	0.113 (0.64)	0.092 (0.52)	0.085 (0.48)	0.078 (0.44)	0.072 (0.41)	0.067 (0.38)
	R-20	2x6	0.143 (0.81)	0.112 (0.64)	0.092 (0.52)	0.084 (0.48)	0.077 (0.44)	0.072 (0.41)	0.067 (0.38)
	R-21	2x6	0.141 (0.80)	0.111 (0.63)	0.091 (0.52)	0.083 (0.47)	0.077 (0.44)	0.071 (0.41)	0.067 (0.38)
24 in o.c.	R-13	2x4	0.160 (0.91)	0.123 (0.70)	0.099 (0.56)	0.090 (0.51)	0.082 (0.47)	0.076 (0.43)	0.071 (0.40)
	R-15	2x4	0.153 (0.87)	0.119 (0.67)	0.096 (0.55)	0.088 (0.50)	0.081 (0.46)	0.075 (0.42)	0.069 (0.39)
	R-19	2x6	0.138 (0.78)	0.109 (0.62)	0.090 (0.51)	0.082 (0.47)	0.076 (0.43)	0.071 (0.40)	0.066 (0.38)
	R-20	2x6	0.136 (0.77)	0.108 (0.61)	0.089 (0.51)	0.082 (0.46)	0.076 (0.43)	0.070 (0.40)	0.066 (0.37)
	R-21	2x6	0.135 (0.76)	0.107 (0.61)	0.088 (0.50)	0.081 (0.46)	0.075 (0.43)	0.070 (0.40)	0.065 (0.37)



**Table 4:** Thermal Transmittance (U-value) of R-stud Residential Wall Assemblies Evaluated with Thermal Modeling and Series Calculation Method

Stud Spacing	Cavity Insulation R-value	Nominal Framing Size	U-value Btu/h ft <sup>2</sup> °F (W/m <sup>2</sup> K)						
			Base Assembly (R-0)	Rated R-value of Continuous Insulation added to Base Assembly					
				R-2	R-4	R5	R-6	R-7	R-8
16 in o.c.	R-13	2x4	0.143 (0.81)	0.113 (0.64)	0.092 (0.52)	0.084 (0.48)	0.078 (0.44)	0.072 (0.41)	0.067 (0.38)
	R-15	2x4	0.137 (0.78)	0.108 (0.62)	0.089 (0.51)	0.082 (0.46)	0.076 (0.43)	0.070 (0.40)	0.066 (0.37)
	R-19	2x6	0.121 (0.69)	0.098 (0.56)	0.082 (0.47)	0.076 (0.43)	0.071 (0.40)	0.066 (0.37)	0.062 (0.35)
	R-20	2x6	0.119 (0.67)	0.097 (0.55)	0.081 (0.46)	0.075 (0.43)	0.070 (0.40)	0.065 (0.37)	0.061 (0.35)
	R-21	2x6	0.117 (0.66)	0.096 (0.54)	0.080 (0.46)	0.074 (0.42)	0.069 (0.39)	0.065 (0.37)	0.061 (0.35)
24 in o.c.	R-13	2x4	0.139 (0.79)	0.110 (0.63)	0.090 (0.51)	0.083 (0.47)	0.076 (0.43)	0.071 (0.40)	0.066 (0.38)
	R-15	2x4	0.132 (0.75)	0.106 (0.60)	0.087 (0.50)	0.080 (0.46)	0.074 (0.42)	0.069 (0.39)	0.065 (0.37)
	R-19	2x6	0.116 (0.66)	0.095 (0.54)	0.080 (0.45)	0.074 (0.42)	0.069 (0.39)	0.064 (0.37)	0.061 (0.34)
	R-20	2x6	0.114 (0.65)	0.094 (0.53)	0.079 (0.45)	0.073 (0.42)	0.068 (0.39)	0.064 (0.36)	0.060 (0.34)
	R-21	2x6	0.112 (0.64)	0.092 (0.53)	0.078 (0.44)	0.072 (0.41)	0.068 (0.38)	0.063 (0.36)	0.059 (0.34)

**Simulated Assembly U-values**

For assemblies with stud cavity insulation and continuous insulation, adding the nominal thermal resistance (R-value) of the continuous insulation to the effective R-value of the steel frame wall assembly yields very conservative values. This method underestimates the assembly effective R-value by not fully accounting for multidirectional heat flow of the steel framing. Test results from studies such as Konsy et al. (1994)<sup>2</sup> showed the use of continuous insulation increases the assembly effective R-value by a greater amount than the insulation nominal R-value. These assemblies can be evaluated using 2D or 3D thermal analysis to yield more accurate results and the entire benefit of exterior insulation. For reference, the difference in U-values between the two methods is shown in Table 5 for standard stud wall assemblies.

<sup>2</sup> Konsy, J. et al., 1994, *Thermal Performance of Steel-Frame Walls*, Oak Ridge National Laboratory



**Table 5:** Thermal Transmittance of the Evaluated 3D Thermal Models with Standard Stud Nonresidential Wall Assemblies

Scenario		U-value Btu/h·ft <sup>2</sup> ·°F (W/m <sup>2</sup> ·°K)	Effective R-value ft <sup>2</sup> ·hr·°F/Btu (m <sup>2</sup> ·°K/W)	U-value Difference
2x6 Studs at 16" o.c. with R-21 Batt	CEC – Standard Stud	0.178 (1.01) <sup>3</sup>	R-5.62 (0.99)	-
	Evaluated – Standard Stud (3D Modeling)	0.178 (1.01)	R-5.62 (0.99)	0%
2x6 Studs at 16" o.c. with R-21 Batt and <b>R-5 Exterior Insulation</b>	CEC – Standard Stud	0.094 (0.53) <sup>3</sup>	R-10.64 (1.87)	-
	Evaluated – Standard Stud (3D Modeling + R-5)	0.095 (0.54)	R-10.51 (1.85)	-1%
	Evaluated – Standard Stud (3D Modeling)	0.073 (0.41)	R-13.73 (2.42)	23%
2x6 Studs at 24" o.c. with R-21 Batt	CEC – Standard Stud	0.161 (0.91) <sup>3</sup>	R-6.21 (1.09)	-
	Evaluated – Standard Stud (3D Modeling)	0.161 (0.92)	R-6.20 (1.09)	0%
2x6 Studs at 24" o.c. with R-21 Batt and <b>R-5 Exterior Insulation</b>	CEC – Standard Stud	0.089 (0.51) <sup>3</sup>	R-11.24 (1.98)	-
	Evaluated – Standard Stud (3D Modeling + R-5)	0.090 (0.51)	R-11.09 (1.95)	-1%
	Evaluated – Standard Stud (3D Modeling)	0.068 (0.39)	R-14.72 (2.59)	24%

<sup>3</sup>Published U-values from Table 4.3.3 of the CEC 2019 Building Energy Efficiency Standards Joint Appendix

Tables 6 and 7 lists the U-values of R-stud assemblies evaluated using 3D thermal modeling. The effective R-values of the same assemblies are listed in Appendix B. Example temperature profiles for each configuration are provided in Appendix C.

**Table 6:** Thermal Transmittance (U-value) of R-stud Nonresidential Wall Assemblies Evaluated with 3D Thermal Modeling

Stud Spacing	Cavity Insulation R-value	Nominal Framing Size	U-value Btu/h ft <sup>2</sup> °F (W/m <sup>2</sup> K)						
			Base Assembly (R-0)	Rated R-value of Continuous Insulation					
				R-2	R-4	R5	R-6	R-7	R-8
16 in o.c.	R-13	2x4	0.166 (0.94)	0.111 (0.63)	0.086 (0.49)	0.078 (0.44)	0.072 (0.41)	0.066 (0.38)	0.062 (0.35)
	R-15	2x4	0.159 (0.90)	0.106 (0.60)	0.082 (0.47)	0.075 (0.42)	0.068 (0.39)	0.063 (0.36)	0.059 (0.34)
	R-19	2x6	0.145 (0.82)	0.098 (0.56)	0.077 (0.44)	0.070 (0.40)	0.065 (0.37)	0.060 (0.34)	0.056 (0.32)
	R-20	2x6	0.143 (0.81)	0.096 (0.55)	0.076 (0.43)	0.069 (0.39)	0.064 (0.36)	0.059 (0.34)	0.055 (0.31)
	R-21	2x6	0.141 (0.80)	0.095 (0.54)	0.075 (0.42)	0.068 (0.39)	0.063 (0.36)	0.058 (0.33)	0.055 (0.31)
24 in o.c.	R-13	2x4	0.160 (0.91)	0.106 (0.60)	0.083 (0.47)	0.075 (0.43)	0.069 (0.39)	0.064 (0.36)	0.060 (0.34)
	R-15	2x4	0.153 (0.87)	0.101 (0.57)	0.079 (0.45)	0.072 (0.41)	0.066 (0.37)	0.061 (0.35)	0.057 (0.33)
	R-19	2x6	0.138 (0.78)	0.093 (0.53)	0.073 (0.41)	0.067 (0.38)	0.062 (0.35)	0.057 (0.33)	0.054 (0.30)
	R-20	2x6	0.136 (0.77)	0.091 (0.52)	0.072 (0.41)	0.065 (0.37)	0.060 (0.34)	0.056 (0.32)	0.053 (0.30)
	R-21	2x6	0.135 (0.76)	0.090 (0.51)	0.071 (0.40)	0.064 (0.37)	0.060 (0.34)	0.055 (0.31)	0.052 (0.29)

**Table 7:** Thermal Transmittance (U-value) of R-stud Residential Wall Assemblies Evaluated with 3D Thermal Modeling

Stud Spacing	Cavity Insulation R-value	Nominal Framing Size	U-value Btu/h ft <sup>2</sup> °F (W/m <sup>2</sup> K)						
			Base Assembly (R-0)	Rated R-value of Continuous Insulation					
				R-2	R-4	R5	R-6	R-7	R-8
16 in o.c.	R-13	2x4	0.143 (0.81)	0.102 (0.58)	0.081 (0.46)	0.074 (0.42)	0.068 (0.39)	0.064 (0.36)	0.060 (0.34)
	R-15	2x4	0.137 (0.78)	0.097 (0.55)	0.077 (0.44)	0.071 (0.40)	0.065 (0.37)	0.061 (0.35)	0.057 (0.32)
	R-19	2x6	0.121 (0.69)	0.088 (0.50)	0.071 (0.40)	0.065 (0.37)	0.061 (0.34)	0.057 (0.32)	0.053 (0.30)
	R-20	2x6	0.119 (0.67)	0.086 (0.49)	0.070 (0.40)	0.064 (0.37)	0.060 (0.34)	0.056 (0.32)	0.052 (0.30)
	R-21	2x6	0.117 (0.66)	0.085 (0.48)	0.069 (0.39)	0.063 (0.36)	0.059 (0.33)	0.055 (0.31)	0.052 (0.29)
24 in o.c.	R-13	2x4	0.139 (0.79)	0.098 (0.56)	0.079 (0.45)	0.072 (0.41)	0.067 (0.38)	0.062 (0.35)	0.058 (0.33)
	R-15	2x4	0.132 (0.75)	0.093 (0.53)	0.075 (0.42)	0.068 (0.39)	0.063 (0.36)	0.059 (0.34)	0.055 (0.31)
	R-19	2x6	0.116 (0.66)	0.084 (0.48)	0.068 (0.39)	0.063 (0.36)	0.058 (0.33)	0.054 (0.31)	0.051 (0.29)
	R-20	2x6	0.114 (0.65)	0.082 (0.47)	0.067 (0.38)	0.061 (0.35)	0.057 (0.32)	0.053 (0.30)	0.050 (0.29)
	R-21	2x6	0.112 (0.64)	0.081 (0.46)	0.066 (0.37)	0.060 (0.34)	0.056 (0.32)	0.053 (0.30)	0.049 (0.28)

We believe that this report meets your objectives for evaluating the thermal performance of the steel frame assemblies. If you have any questions or comments related to the above, please do not hesitate to contact the undersigned.

Yours truly,  
**MORRISON HERSHFIELD LIMITED**



Ivan Lee, P.Eng.  
*Building Science Consultant*



Katie Hay, P.Eng.  
*Building Science Consultant*





## APPENDIX A: MODELING PARAMETERS AND ASSUMPTIONS

### A.1 THERMAL MODELING ASSUMPTIONS

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

- Material properties were taken from information provided by R-stud, CEC 2019 Building Energy Efficiency Standards Joint Appendix, and ASHRAE Handbook – Fundamentals for common materials.
- Interior/exterior air films were derived from R-values listed in the CEC 2019 Building Energy Efficiency Standards Joint Appendix.
- Insulation were considered tight to steel studs.
- No solar heating impacts were included.
- Impacts of air leakage through the system was not modeled.

### A.2 BOUNDARY CONDITIONS

Table A2.1: Boundary Conditions

Boundary Location	Combined Convective and Radiation Heat Transfer Coefficient BTU/hft <sup>2</sup> °F (W/m <sup>2</sup> K)	Equivalent R-value hft <sup>2</sup> °F/BTU (m <sup>2</sup> K/W)
Exterior Wall Surfaces	5.9 (33.4)	R-0.17 (0.03)
Interior Walls	1.5 (8.35)	R-0.68 (0.12)

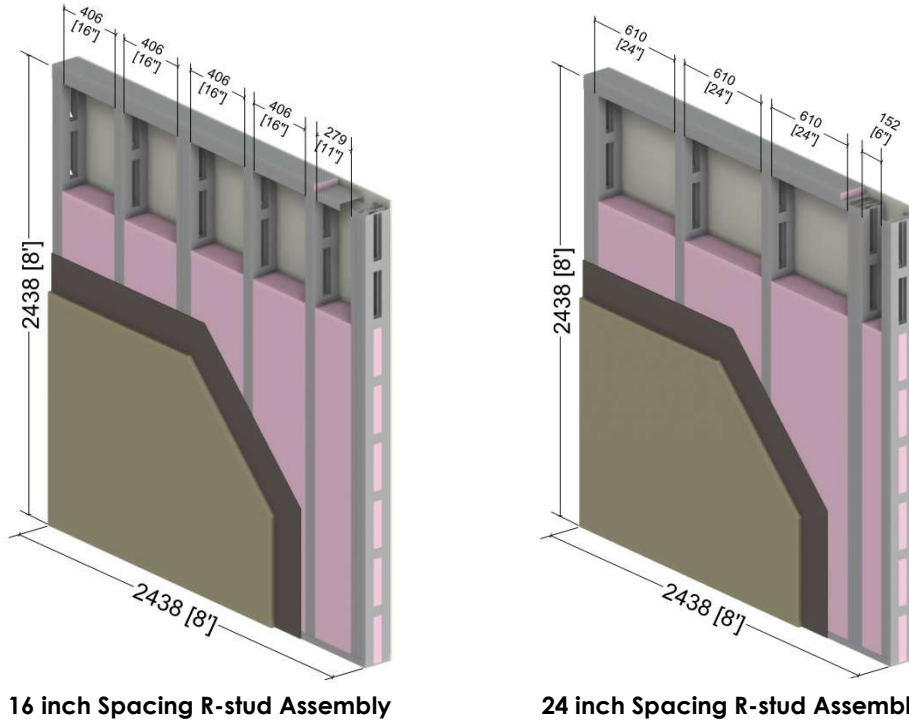
### A.3 TEMPERATURE INDEX

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

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

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

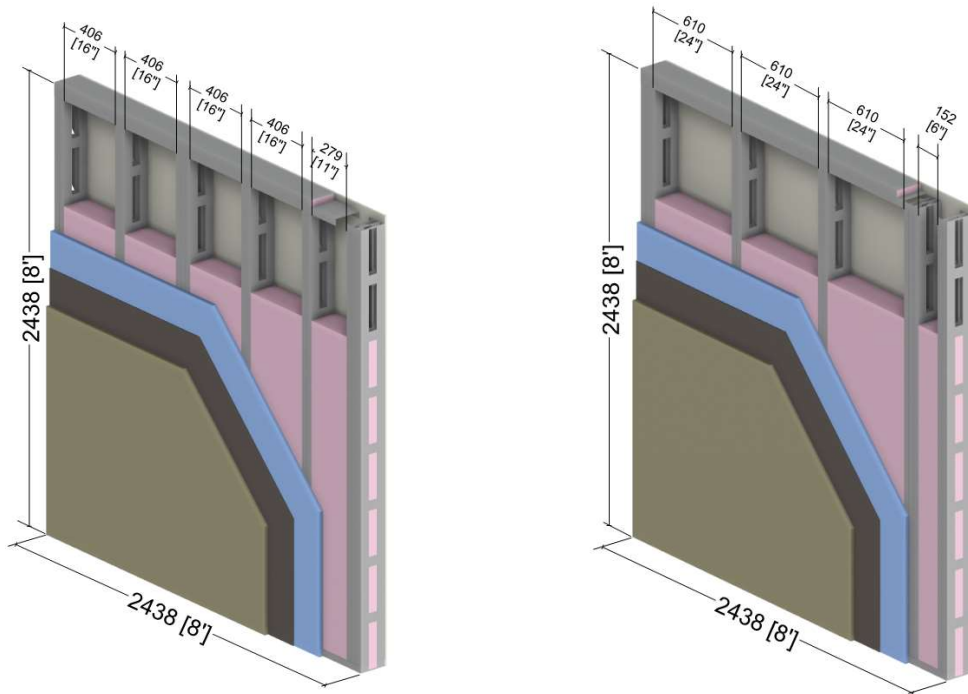
### A.4 MATERIAL PROPERTIES



**Figure A4.1:** Evaluated Geometry of Assemblies without Continuous Insulation

**Table A4.1:** Material Properties of Assemblies without Continuous Insulation

Component	Material	Thickness Inches (mm)	Thermal Conductivity BTU in / ft <sup>2</sup> hr °F (W/m K)	Nominal Resistance ft <sup>2</sup> hr °F/BTU (m <sup>2</sup> K/W)
Interior Air Film	-	-	-	R-0.17 (0.03 RSI)
Drywall	Gypsum	1/2 (13)	1.1 (0.16)	R-0.45 (0.08 RSI)
Stud	Galvanized Steel	14 gauge or 18 gauge	430 (62)	-
Cavity	Fiberglass Batt	4 to 6 (102 to 152)	varies	R-13 to R-21 (2.29 RSI to 3.70 RSI)
Membrane	Building Paper	-	-	R-0.06 (0.01 RSI)
Exterior Finish	Stucco	7/8 (22)	4.86 (0.70)	R-0.18 (0.03 RSI)
Exterior Air Film	-	-	-	R-0.68 (0.12 RSI)



16 inch Spacing Assembly with R-stud

24 inch Spacing Assembly with R-stud

**Figure A4.2:** Evaluated Geometry of Assemblies with Continuous Insulation

**Table A4.2:** Material Properties of Assemblies of with R-5 Continuous Insulation

Component	Material	Thickness Inches (mm)	Thermal Conductivity BTU in / ft <sup>2</sup> hr °F (W/m K)	Nominal Resistance ft <sup>2</sup> hr °F/BTU (m <sup>2</sup> K/W)
Interior Air Film	-	-	-	R-0.17 (0.03 RSI)
Drywall	Gypsum	1/2 (13)	1.1 (0.16)	R-0.45 (0.08 RSI)
Stud	Galvanized Steel	14 gauge or 18 gauge	430 (62)	-
Cavity	Fiberglass Batt	4 to 6 (102 to 152)	varies	R-13 to R-21 (2.29 RSI to 3.70 RSI)
Insulation	varies	varies	varies	R-2 to R-8 (0.35 RSI to 0.88 RSI)
Membrane	Building Paper	-	-	R-0.06 (0.01 RSI)
Exterior Finish	Stucco	3/8 (10)	4.86 (0.70)	R-0.08 (0.01 RSI)
Exterior Air Film	-	-	-	R-0.68 (0.12 RSI)

## APPENDIX B: ASSEMBLY EFFECTIVE R-VALUES

**Table B.1:** Effective R-value of R-stud Nonresidential Wall Assemblies Evaluated with Thermal Modeling and Series Calculation Method

Stud Spacing	Cavity Insulation R-value	Nominal Framing Size	Effective R-value h ft <sup>2</sup> °F/Btu (m <sup>2</sup> K/W)						
			Base Assembly (R-0)	Rated R-value of Continuous Insulation added to Base Assembly					
				R-2	R-4	R5	R-6	R-7	R-8
16 in o.c.	R-13	2x4	R-6.0 (RSI-1.06)	R-7.9 (RSI-1.40)	R-9.9 (RSI-1.75)	R-10.9 (RSI-1.93)	R-11.9 (RSI-2.10)	R-12.9 (RSI-2.28)	R-13.9 (RSI-2.45)
	R-15	2x4	R-6.3 (RSI-1.11)	R-8.2 (RSI-1.44)	R-10.2 (RSI-1.79)	R-11.2 (RSI-1.97)	R-12.2 (RSI-2.15)	R-13.2 (RSI-2.32)	R-14.2 (RSI-2.50)
	R-19	2x6	R-6.9 (RSI-1.22)	R-8.8 (RSI-1.55)	R-10.8 (RSI-1.90)	R-11.8 (RSI-2.08)	R-12.8 (RSI-2.26)	R-13.8 (RSI-2.43)	R-14.8 (RSI-2.61)
	R-20	2x6	R-7.0 (RSI-1.23)	R-8.9 (RSI-1.57)	R-10.9 (RSI-1.92)	R-11.9 (RSI-2.10)	R-12.9 (RSI-2.27)	R-13.9 (RSI-2.45)	R-14.9 (RSI-2.62)
	R-21	2x6	R-7.1 (RSI-1.25)	R-9.0 (RSI-1.58)	R-11.0 (RSI-1.94)	R-12.0 (RSI-2.11)	R-13.0 (RSI-2.29)	R-14.0 (RSI-2.46)	R-15.0 (RSI-2.64)
24 in o.c.	R-13	2x4	R-6.2 (RSI-1.10)	R-8.1 (RSI-1.43)	R-10.1 (RSI-1.79)	R-11.1 (RSI-1.96)	R-12.1 (RSI-2.14)	R-13.1 (RSI-2.31)	R-14.1 (RSI-2.49)
	R-15	2x4	R-6.5 (RSI-1.15)	R-8.4 (RSI-1.48)	R-10.4 (RSI-1.83)	R-11.4 (RSI-2.01)	R-12.4 (RSI-2.19)	R-13.4 (RSI-2.36)	R-14.4 (RSI-2.54)
	R-19	2x6	R-7.2 (RSI-1.27)	R-9.1 (RSI-1.61)	R-11.1 (RSI-1.96)	R-12.1 (RSI-2.14)	R-13.1 (RSI-2.31)	R-14.1 (RSI-2.49)	R-15.1 (RSI-2.67)
	R-20	2x6	R-7.3 (RSI-1.29)	R-9.2 (RSI-1.63)	R-11.2 (RSI-1.98)	R-12.2 (RSI-2.15)	R-13.2 (RSI-2.33)	R-14.2 (RSI-2.51)	R-15.2 (RSI-2.68)
	R-21	2x6	R-7.4 (RSI-1.31)	R-9.3 (RSI-1.64)	R-11.3 (RSI-2.00)	R-12.3 (RSI-2.17)	R-13.3 (RSI-2.35)	R-14.3 (RSI-2.52)	R-15.3 (RSI-2.70)

**Table B.2:** Effective R-value of R-stud Residential Wall Assemblies Evaluated with Thermal Modeling and Series Calculation Method

Stud Spacing	Cavity Insulation R-value	Nominal Framing Size	Effective R-value h ft <sup>2</sup> °F/Btu (m <sup>2</sup> K/W)						
			Base Assembly (R-0)	Rated R-value of Continuous Insulation added to Base Assembly					
				R-2	R-4	R5	R-6	R-7	R-8
16 in o.c.	R-13	2x4	R-7.0 (RSI-1.23)	R-8.9 (RSI-1.56)	R-10.9 (RSI-1.91)	R-11.9 (RSI-2.09)	R-12.9 (RSI-2.27)	R-13.9 (RSI-2.44)	R-14.9 (RSI-2.62)
	R-15	2x4	R-7.3 (RSI-1.29)	R-9.2 (RSI-1.62)	R-11.2 (RSI-1.98)	R-12.2 (RSI-2.15)	R-13.2 (RSI-2.33)	R-14.2 (RSI-2.50)	R-15.2 (RSI-2.68)
	R-19	2x6	R-8.3 (RSI-1.46)	R-10.2 (RSI-1.79)	R-12.2 (RSI-2.14)	R-13.2 (RSI-2.32)	R-14.2 (RSI-2.50)	R-15.2 (RSI-2.67)	R-16.2 (RSI-2.85)
	R-20	2x6	R-8.4 (RSI-1.48)	R-10.3 (RSI-1.82)	R-12.3 (RSI-2.17)	R-13.3 (RSI-2.34)	R-14.3 (RSI-2.52)	R-15.3 (RSI-2.70)	R-16.3 (RSI-2.87)
	R-21	2x6	R-8.5 (RSI-1.50)	R-10.4 (RSI-1.84)	R-12.4 (RSI-2.19)	R-13.4 (RSI-2.37)	R-14.4 (RSI-2.54)	R-15.4 (RSI-2.72)	R-16.4 (RSI-2.89)
24 in o.c.	R-13	2x4	R-7.2 (RSI-1.27)	R-9.1 (RSI-1.60)	R-11.1 (RSI-1.95)	R-12.1 (RSI-2.13)	R-13.1 (RSI-2.30)	R-14.1 (RSI-2.48)	R-15.1 (RSI-2.66)
	R-15	2x4	R-7.6 (RSI-1.33)	R-9.5 (RSI-1.67)	R-11.5 (RSI-2.02)	R-12.5 (RSI-2.20)	R-13.5 (RSI-2.37)	R-14.5 (RSI-2.55)	R-15.5 (RSI-2.72)
	R-19	2x6	R-8.6 (RSI-1.52)	R-10.5 (RSI-1.85)	R-12.5 (RSI-2.21)	R-13.5 (RSI-2.38)	R-14.5 (RSI-2.56)	R-15.5 (RSI-2.73)	R-16.5 (RSI-2.91)
	R-20	2x6	R-8.8 (RSI-1.55)	R-10.7 (RSI-1.88)	R-12.7 (RSI-2.23)	R-13.7 (RSI-2.41)	R-14.7 (RSI-2.58)	R-15.7 (RSI-2.76)	R-16.7 (RSI-2.94)
	R-21	2x6	R-8.9 (RSI-1.57)	R-10.8 (RSI-1.90)	R-12.8 (RSI-2.26)	R-13.8 (RSI-2.43)	R-14.8 (RSI-2.61)	R-15.8 (RSI-2.79)	R-16.8 (RSI-2.96)

**Table B.3:** Effective R-value of R-stud Nonresidential Wall Assemblies Evaluated with 3D Thermal Modeling

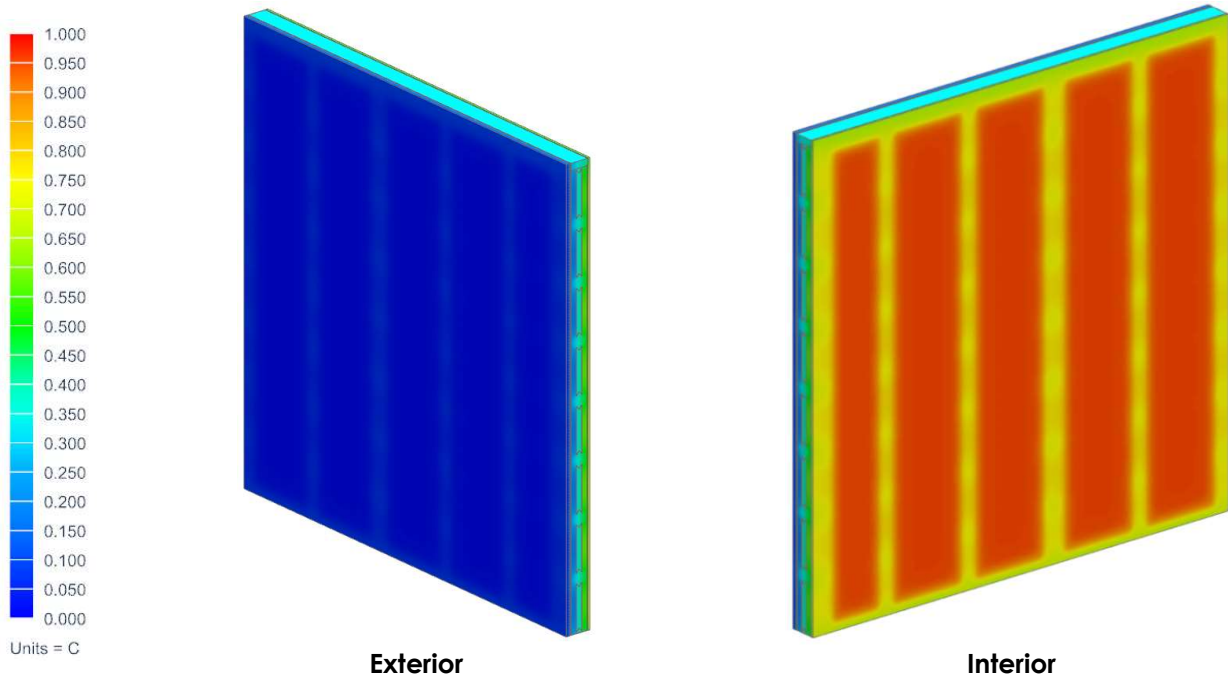
Stud Spacing	Cavity Insulation R-value	Nominal Framing Size	Effective R-value h ft <sup>2</sup> °F/Btu (m <sup>2</sup> K/W)						
			Base Assembly (R-0)	Rated R-value of Continuous Insulation					
				R-2	R-4	R5	R-6	R-7	R-8
16 in o.c.	R-13	2x4	R-6.0 (RSI-1.06)	R-9.0 (RSI-1.59)	R-11.6 (RSI-2.05)	R-12.8 (RSI-2.26)	R-14.0 (RSI-2.46)	R-15.1 (RSI-2.66)	R-16.2 (RSI-2.86)
	R-15	2x4	R-6.3 (RSI-1.11)	R-9.5 (RSI-1.67)	R-12.2 (RSI-2.14)	R-13.4 (RSI-2.36)	R-14.6 (RSI-2.57)	R-15.8 (RSI-2.78)	R-16.9 (RSI-2.98)
	R-19	2x6	R-6.9 (RSI-1.22)	R-10.2 (RSI-1.80)	R-13.0 (RSI-2.29)	R-14.3 (RSI-2.51)	R-15.5 (RSI-2.72)	R-16.7 (RSI-2.93)	R-17.8 (RSI-3.14)
	R-20	2x6	R-7.0 (RSI-1.23)	R-10.4 (RSI-1.83)	R-13.2 (RSI-2.33)	R-14.5 (RSI-2.55)	R-15.7 (RSI-2.77)	R-16.9 (RSI-2.98)	R-18.1 (RSI-3.18)
	R-21	2x6	R-7.1 (RSI-1.25)	R-10.5 (RSI-1.85)	R-13.4 (RSI-2.36)	R-14.7 (RSI-2.59)	R-15.9 (RSI-2.81)	R-17.2 (RSI-3.02)	R-18.3 (RSI-3.23)
24 in o.c.	R-13	2x4	R-6.2 (RSI-1.10)	R-9.4 (RSI-1.66)	R-12.1 (RSI-2.12)	R-13.3 (RSI-2.34)	R-14.4 (RSI-2.54)	R-15.6 (RSI-2.74)	R-16.7 (RSI-2.94)
	R-15	2x4	R-6.5 (RSI-1.15)	R-9.9 (RSI-1.74)	R-12.7 (RSI-2.23)	R-13.9 (RSI-2.45)	R-15.1 (RSI-2.67)	R-16.3 (RSI-2.88)	R-17.5 (RSI-3.08)
	R-19	2x6	R-7.2 (RSI-1.27)	R-10.8 (RSI-1.90)	R-13.7 (RSI-2.41)	R-15.0 (RSI-2.64)	R-16.3 (RSI-2.86)	R-17.5 (RSI-3.08)	R-18.6 (RSI-3.28)
	R-20	2x6	R-7.3 (RSI-1.29)	R-11.0 (RSI-1.93)	R-13.9 (RSI-2.45)	R-15.3 (RSI-2.69)	R-16.5 (RSI-2.91)	R-17.8 (RSI-3.13)	R-19.0 (RSI-3.34)
	R-21	2x6	R-7.4 (RSI-1.31)	R-11.2 (RSI-1.96)	R-14.2 (RSI-2.50)	R-15.5 (RSI-2.73)	R-16.8 (RSI-2.96)	R-18.0 (RSI-3.18)	R-19.3 (RSI-3.39)

**Table B.4:** Effective R-value of R-stud Residential Wall Assemblies Evaluated with 3D Thermal Modeling

Stud Spacing	Cavity Insulation R-value	Nominal Framing Size	Effective R-value h ft <sup>2</sup> °F/Btu (m <sup>2</sup> K/W)						
			Base Assembly (R-0)	Rated R-value of Continuous Insulation					
				R-2	R-4	R5	R-6	R-7	R-8
16 in o.c.	R-13	2x4	R-7.0 (RSI-1.23)	R-9.8 (RSI-1.73)	R-12.3 (RSI-2.17)	R-13.5 (RSI-2.37)	R-14.6 (RSI-2.57)	R-15.7 (RSI-2.77)	R-16.8 (RSI-2.96)
	R-15	2x4	R-7.3 (RSI-1.29)	R-10.3 (RSI-1.82)	R-12.9 (RSI-2.28)	R-14.1 (RSI-2.49)	R-15.3 (RSI-2.70)	R-16.4 (RSI-2.89)	R-17.6 (RSI-3.09)
	R-19	2x6	R-8.3 (RSI-1.46)	R-11.4 (RSI-2.01)	R-14.1 (RSI-2.48)	R-15.3 (RSI-2.69)	R-16.5 (RSI-2.90)	R-17.6 (RSI-3.10)	R-18.8 (RSI-3.30)
	R-20	2x6	R-8.4 (RSI-1.48)	R-11.6 (RSI-2.04)	R-14.3 (RSI-2.52)	R-15.6 (RSI-2.74)	R-16.7 (RSI-2.95)	R-17.9 (RSI-3.16)	R-19.1 (RSI-3.36)
	R-21	2x6	R-8.5 (RSI-1.50)	R-11.8 (RSI-2.07)	R-14.5 (RSI-2.56)	R-15.8 (RSI-2.78)	R-17.0 (RSI-3.00)	R-18.2 (RSI-3.21)	R-19.3 (RSI-3.41)
24 in o.c.	R-13	2x4	R-7.2 (RSI-1.27)	R-10.2 (RSI-1.79)	R-12.7 (RSI-2.24)	R-13.9 (RSI-2.44)	R-15.0 (RSI-2.64)	R-16.1 (RSI-2.84)	R-17.2 (RSI-3.04)
	R-15	2x4	R-7.6 (RSI-1.33)	R-10.7 (RSI-1.89)	R-13.4 (RSI-2.36)	R-14.6 (RSI-2.57)	R-15.8 (RSI-2.78)	R-16.9 (RSI-2.98)	R-18.1 (RSI-3.18)
	R-19	2x6	R-8.6 (RSI-1.52)	R-12.0 (RSI-2.10)	R-14.7 (RSI-2.59)	R-16.0 (RSI-2.81)	R-17.2 (RSI-3.03)	R-18.4 (RSI-3.23)	R-19.5 (RSI-3.44)
	R-20	2x6	R-8.8 (RSI-1.55)	R-12.2 (RSI-2.14)	R-15.0 (RSI-2.64)	R-16.3 (RSI-2.87)	R-17.5 (RSI-3.08)	R-18.7 (RSI-3.29)	R-19.9 (RSI-3.50)
	R-21	2x6	R-8.9 (RSI-1.57)	R-12.4 (RSI-2.18)	R-15.3 (RSI-2.69)	R-16.6 (RSI-2.92)	R-17.8 (RSI-3.14)	R-19.0 (RSI-3.35)	R-20.2 (RSI-3.56)

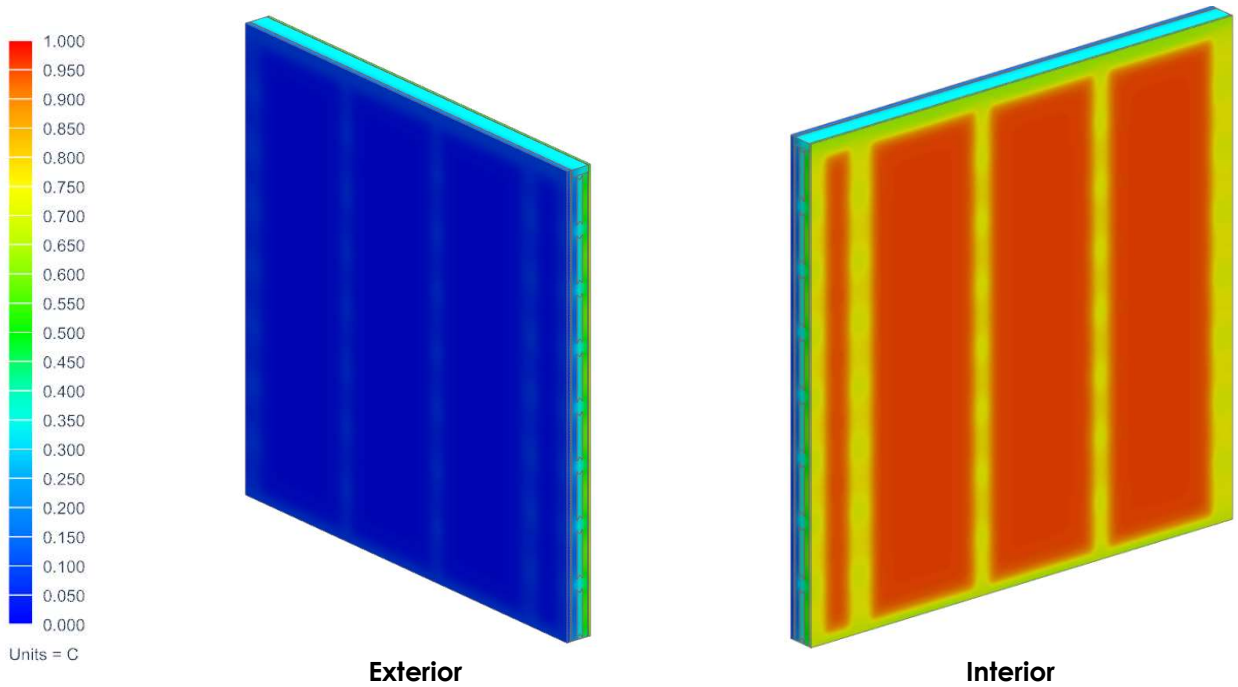
## APPENDIX C: SIMULATED TEMPERATURE PROFILES

Simulated temperature profiles of representative scenarios with and without continuous insulation are shown below. The temperature profiles were evaluated using a temperature index with 0 representing the exterior temperature and 1 representing the interior temperature as described in section A.3 of Appendix A.

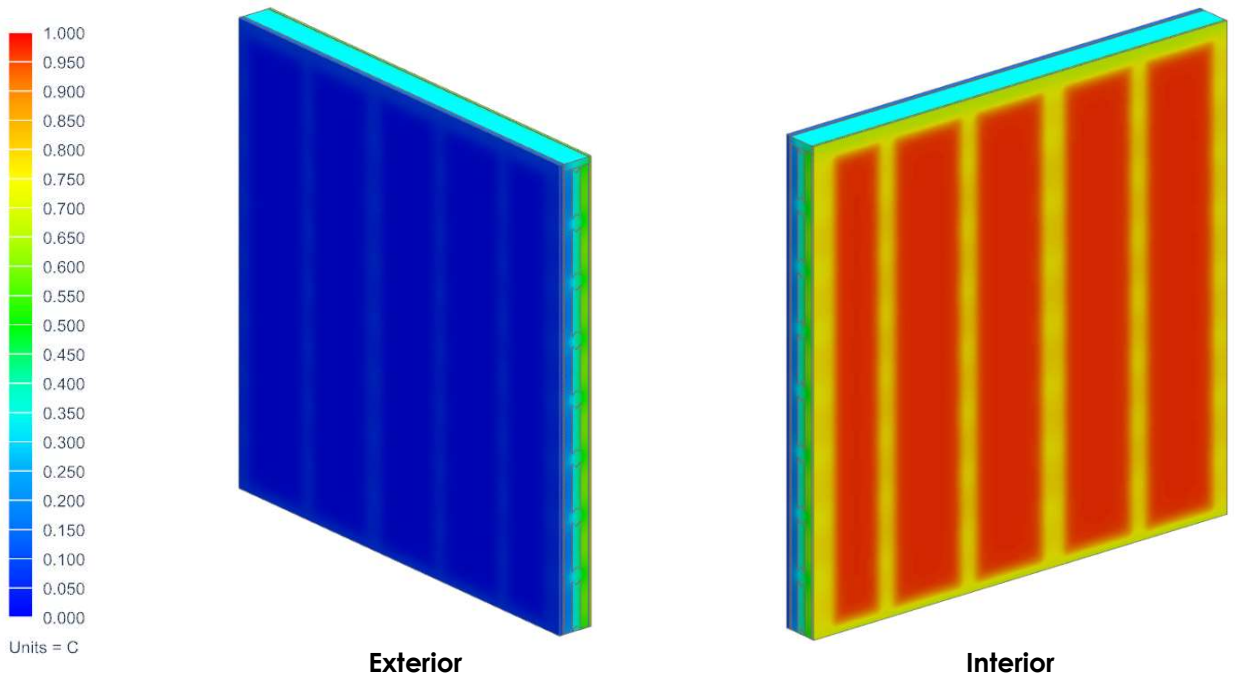


**Figure C1.1:** Interior Insulated 2x4 R-stud Nonresidential Assembly with R-13 Batt at 16 inch spacing: Isometric view from exterior and interior

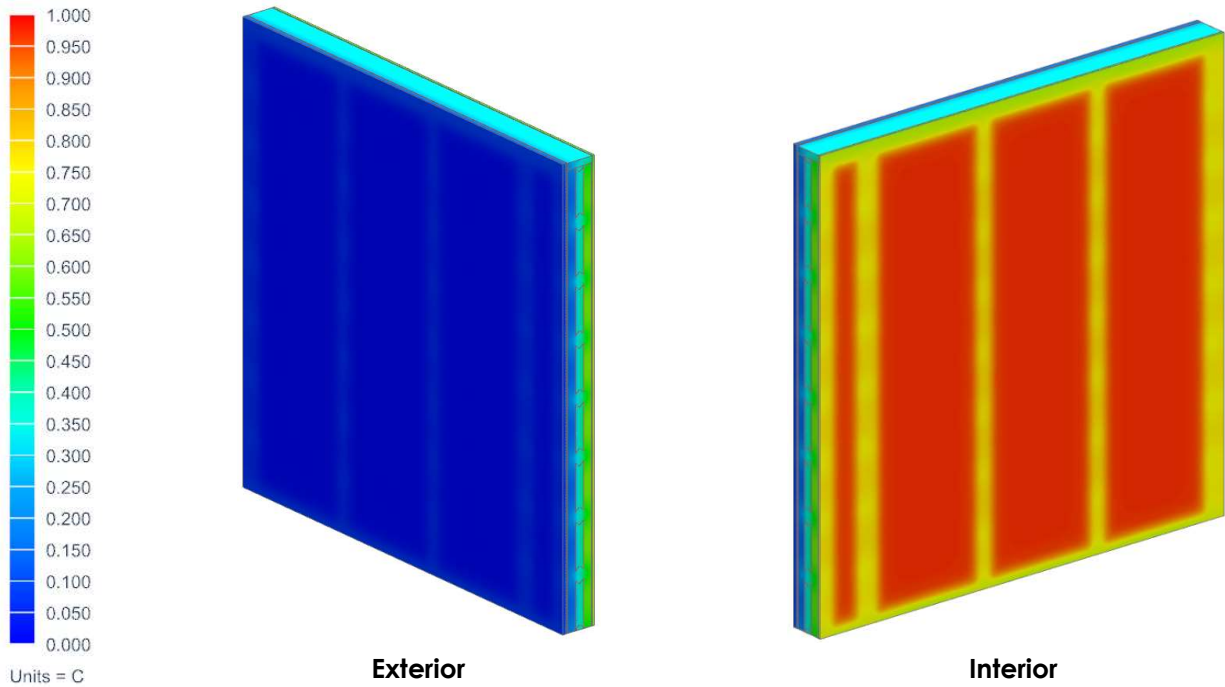




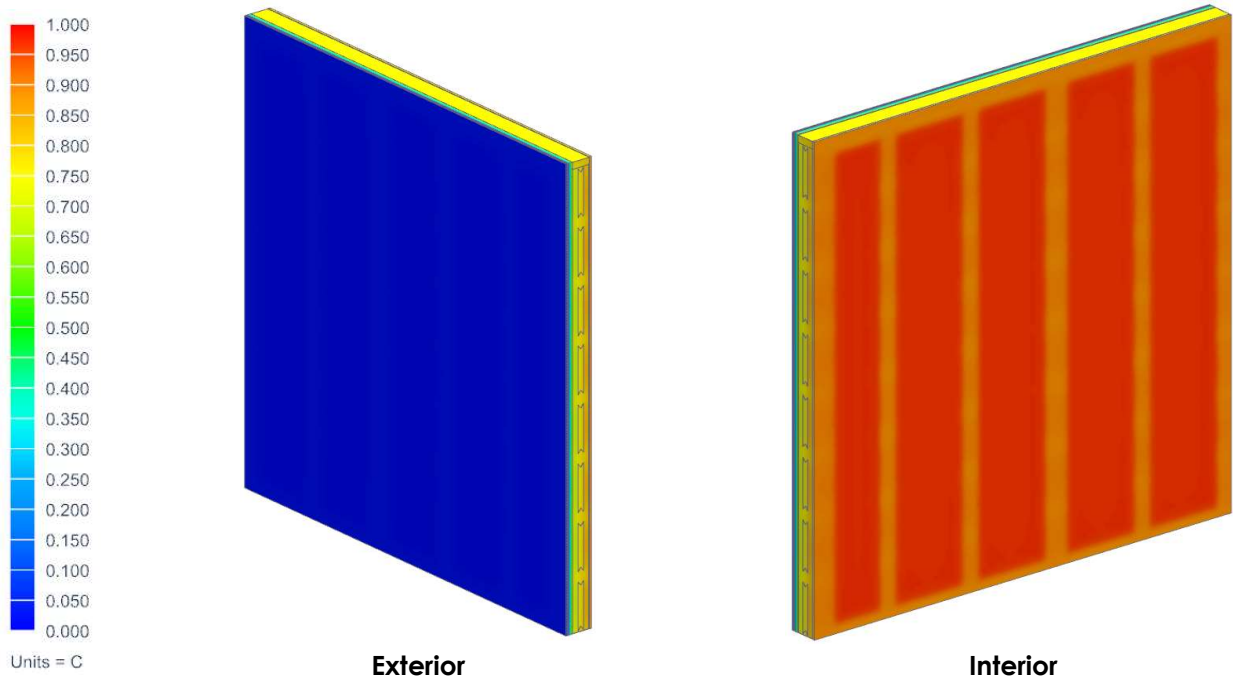
**Figure C1.2:** Interior Insulated 2x4 R-stud Nonresidential Assembly with R-13 Batt at 24 inch spacing: Isometric view from exterior and interior



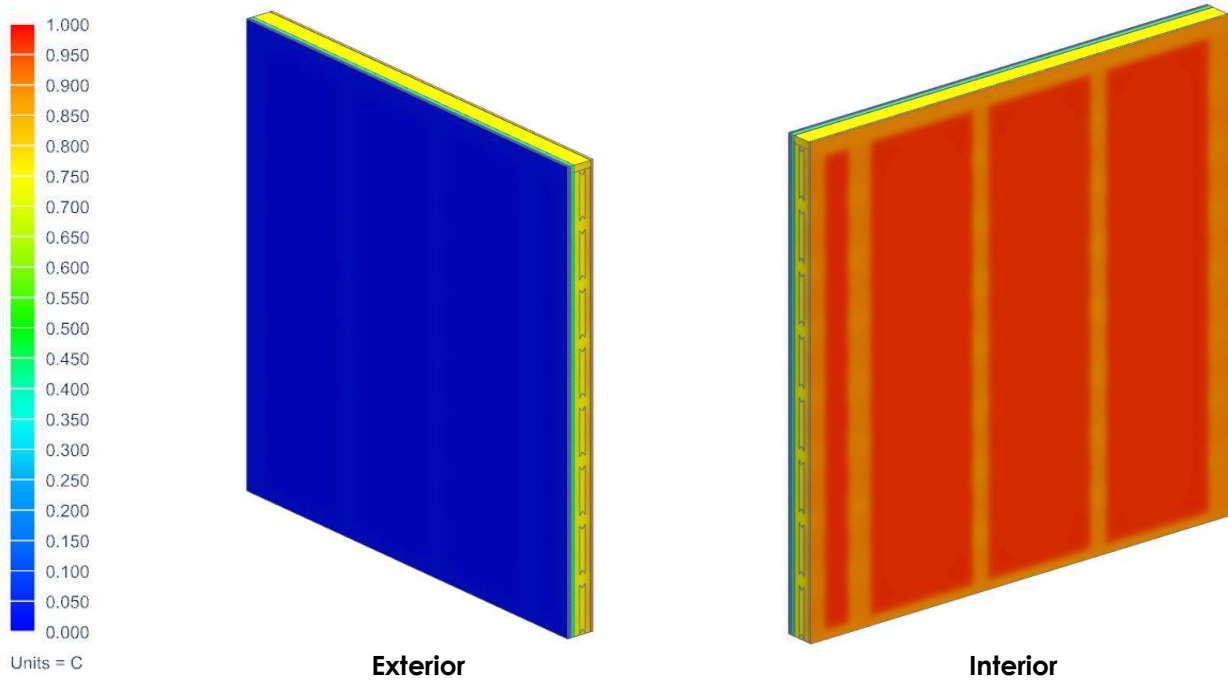
**Figure C1.3:** Interior Insulated 2x6 R-stud Nonresidential Assembly with R-21 Batt at 16 inch spacing: Isometric view from exterior and interior



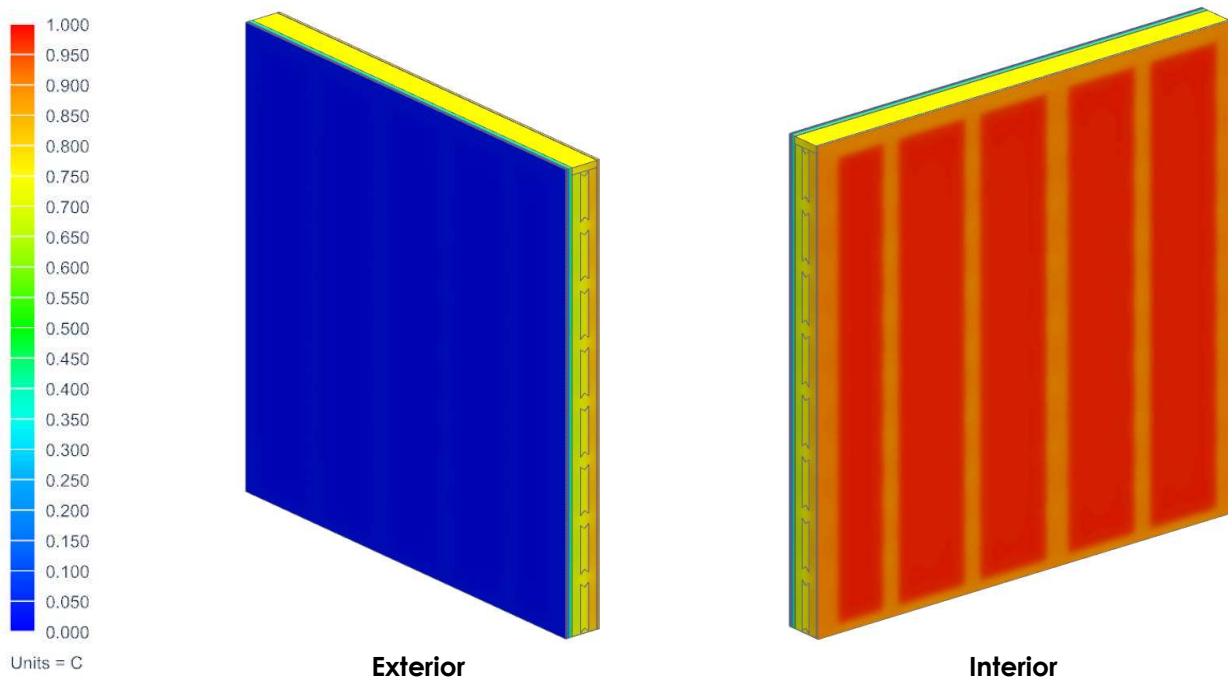
**Figure C1.4:** Interior Insulated 2x6 R-stud Nonresidential Assembly with R-21 Batt at 24 inch spacing: Isometric view from exterior and interior



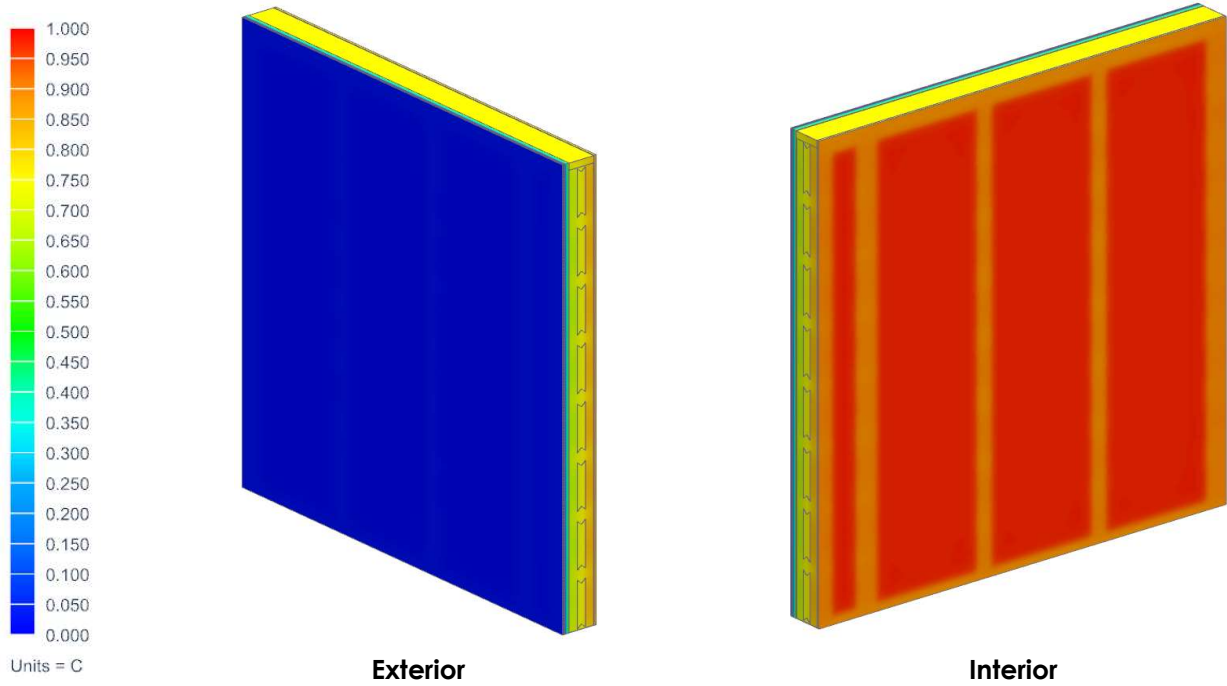
**Figure C1.5:** Exterior and Interior Insulated 2x4 R-stud Nonresidential Assembly with R-13 Batt and R-5 Continuous Insulation at 16 inch spacing: Isometric view from exterior and interior



**Figure C1.6:** Exterior and Interior Insulated 2x4 R-stud Nonresidential Assembly with R-13 Batt and R-5 Continuous Insulation at 24 inch spacing: Isometric view from exterior and interior



**Figure C1.7:** Exterior and Interior Insulated 2x6 R-stud Nonresidential Assembly with R-21 Batt and R-5 Continuous Insulation at 16 inch spacing: Isometric view from exterior and interior



**Figure C1.8:** Exterior and Interior Insulated 2x6 R-stud Nonresidential Assembly with R-21 Batt and R-5 Continuous Insulation at 24 inch spacing: Isometric view from exterior and interior