MORRISON HERSHFIELD

August 30, 2019 MH Ref: 1904484.00

Mr. Patrick Lucas
R-stud, LLC
PO Box 692
Donald, OR 97020 email: patrick@rstud.com

Dear Patrick:

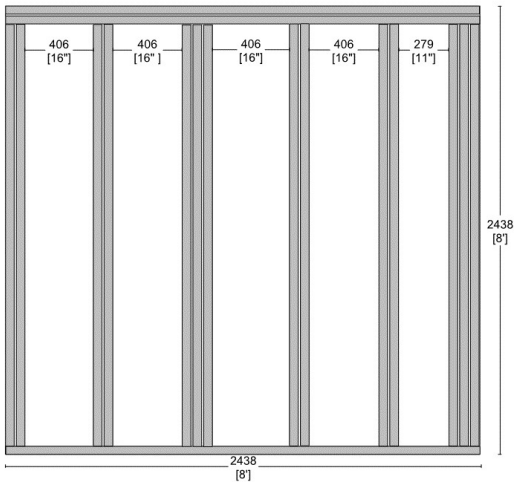
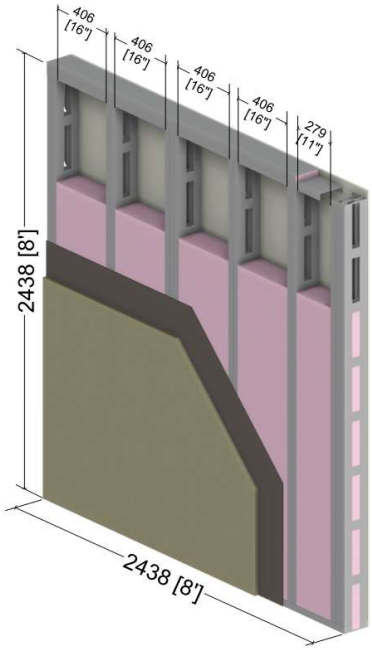
Re: R-stud Wall Assembly Thermal Analysis

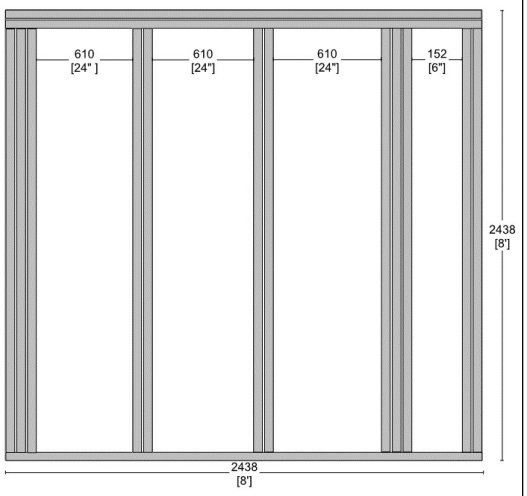
Morrison Hershfield Limited (MH) was retained by R-stud LLC (R-stud) to evaluate the thermal performance of the R-stud steel framing system for compliance with the California Energy Commission (CEC). This report is a summary of the analysis.

BACKGROUND INFORMATION

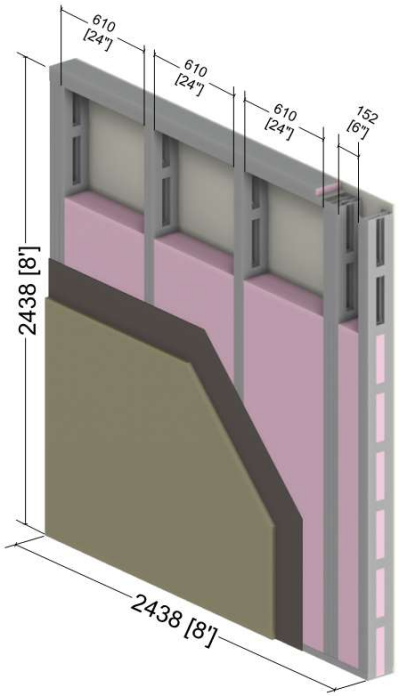
The wall configurations are based on the nonresidential metal framed wall assemblies listed in Table 4.3.3 of the CEC 2019 Building Energy Efficiency Standard Joint Appendix following the same layout as shown in Table 1.

Table 1: Evaluated Metal Frame Wall Configurations

Layout		Components
 Framing Layout	 3D Layout	• R-0.17 exterior air film • 7/8 inch stucco (R-0.18) • Building paper (R-0.06) • 1 1/2 inch x 6 inch, 14 gauge steel studs at 16 inch spacing • R-21 fiberglass batt insulation • 1/2 inch gypsum (R-0.45) • R-0.68 interior air film
Wall Configuration for Studs at 16 inch spacing (25% framing factor)		



Framing Layout

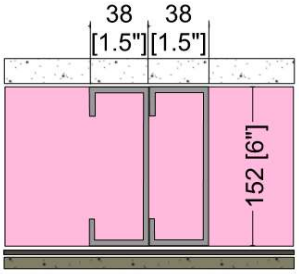


3D Layout

- R-0.17 exterior air film
- 7/8 inch stucco (R-0.18)
- Building paper (R-0.06)
- 1 1/2 inch x 6 inch, 14 gauge steel studs at 24 inch spacing
- R-21 fiberglass batt insulation
- 1/2 inch gypsum (R-0.45)
- R-0.68 interior air film

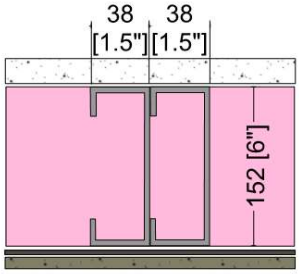
Wall Configuration for Studs at 24 inch spacing
(22% framing factor)

Four scenarios were evaluated with regular steel studs and R-studs as outlined in Figure 1. The material properties of the detail components and metal framing layouts are given in Appendix A.



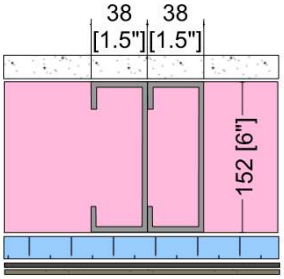
Scenario 1
Stud Spacing at 16"
with R-21 Batt

Base wall configuration at 16 inch stud spacing with:
- Standard studs with 15% knockout, or
- R-stud



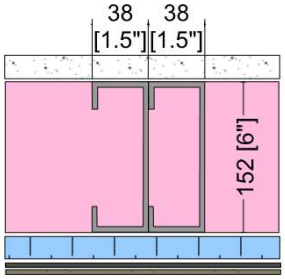
Scenario 3
Stud Spacing at 24"
With R-21 Batt

Base wall configuration at 24 inch stud spacing with:
- Standard studs with 15% knockout, or
- R-stud



Scenario 2
Stud Spacing at 16" with
R-21 Batt and R-5 Insulation

Base wall configuration at 16 inch stud spacing with:
- 3/8 inch stucco (R-0.08)
- R-5 continuous insulation
- Standard studs with 15% knockout, or
- R-stud



Scenario 4
Stud Spacing at 24" with
R-21 Batt and R-5 Insulation

Base wall configuration at 24 inch stud spacing with:
- 3/8 inch stucco (R-0.08)
- R-5 continuous insulation
- Standard studs with 15% knockout, or
- R-stud

Figure 1: Evaluated Scenarios

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.

CEC Assembly U- and R-Values

The U-values and effective R-values of the evaluated assemblies and of the CEC assemblies are shown in Table 2. 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 zone calculation method used by the CEC.

Table 2: Thermal Transmittance of the Evaluated Standard Stud and R-stud Nonresidential Wall Assemblies

Scenario		U-value Btu/h·ft²·°F (W/m²·°K)	Effective R-value ft²·hr·°F/Btu (m²·°K/W)	U-value Difference
Scenario 1 Stud Spacing at 16" with R-21 Batt	CEC – Standard Stud	0.178 (1.01)[1]	R-5.62 (0.99)	-
	Evaluated – Standard Stud (3D Modeling)	0.178 (1.01)	R-5.62 (0.99)	0%
	Evaluated – R-stud (3D Modeling)	0.141 (0.80)	R-7.09 (1.25)	21%
Scenario 2 Stud Spacing at 16" with R-21 Batt and R-5 Insulation	CEC – Standard Stud	0.094 (0.53) [1]	R-10.64 (1.87)	-
	Evaluated – Standard Stud (3D Modeling + R-5)	0.095 (0.54)	R-10.51 (1.85)	-1%
	Evaluated – R-stud (3D Modeling + R-5)	0.083 (0.47)	R-11.99 (2.11)	11%
Scenario 3 Stud Spacing at 24" with R-21 Batt	CEC – Standard Stud	0.161 (0.91) [1]	R-6.21 (1.09)	-
	Evaluated – Standard Stud (3D Modeling)	0.161 (0.92)	R-6.20 (1.09)	0%
	Evaluated – R-stud (3D Modeling)	0.135 (0.76)	R-7.43 (1.31)	16%
Scenario 4 Stud Spacing at 24" with R-21 Batt and R-5 Insulation	CEC – Standard Stud	0.089 (0.51) [1]	R-11.24 (1.98)	-
	Evaluated – Standard Stud (3D Modeling + R-5)	0.090 (0.51)	R-11.09 (1.95)	-1%
	Modeled – R-stud (3D Modeling + R-5)	0.081 (0.46)	R-12.33 (2.17)	9%

[1]Published U-values from Table 4.3.3 of the CEC 2019 Building Energy Efficiency Standards Joint Appendix

Simulated Assembly U- and R-Values

Although the zone calculation method may be used to evaluate the thermal transmittance of steel frame wall assemblies, its application is very limited. The zone calculation method may be

effective at evaluating the thermal transmittance of frame wall assemblies with only stud cavity insulation or assemblies with only continuous insulation.

For assemblies with stud cavity insulation and continuous insulation, the zone calculation method 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)[2] showed the use of continuous insulation increases the assembly effective R-value by a greater amount than the insulation nominal R-value. These assemblies should be evaluated using 2D or 3D thermal analysis as recommended by the ASHRAE Handbook of Fundamentals. The difference in effective R-value between the two methods is shown in Table 3, which lists the U-values and effective R-values of the evaluated assemblies determined by 3D thermal analysis. Example temperature profiles for each configuration are provided in Appendix B.

Table 3: Thermal Transmittance of the Evaluated 3D Thermal Models with Standard Stud and R-stud Nonresidential Wall Assemblies

Scenario		U-value Btu/h·ft²·°F (W/m²·°K)	Effective R-value ft²·hr·°F/Btu (m²·°K/W)	U-value Difference
Scenario 1 Stud Spacing at 16" with R-21 Batt	CEC – Standard Stud	0.178 (1.01)[1]	R-5.62 (0.99)	-
	Evaluated – Standard Stud (3D Modeling)	0.178 (1.01)	R-5.62 (0.99)	0%
	Evaluated – R-stud (3D Modeling)	0.141 (0.80)	R-7.09 (1.25)	21%
Scenario 2 Stud Spacing at 16" with R-21 Batt and R-5 Insulation	CEC – Standard Stud	0.094 (0.53) [1]	R-10.64 (1.87)	-
	Evaluated – Standard Stud (3D Modeling)	0.073 (0.41)	R-13.73 (2.42)	23%
	Evaluated – R-stud (3D Modeling)	0.068 (0.39)	R-14.70 (2.59)	28%
Scenario 3 Stud Spacing at 24" with R-21 Batt	CEC – Standard Stud	0.161 (0.91) [1]	R-6.21 (1.09)	-
	Evaluated – Standard Stud (3D Modeling)	0.161 (0.92)	R-6.20 (1.09)	0%
	Evaluated – R-stud (3D Modeling)	0.135 (0.76)	R-7.43 (1.31)	16%
Scenario 4 Stud Spacing at 24" with R-21 Batt and R-5 Insulation	CEC – Standard Stud	0.089 (0.51) [1]	R-11.24 (1.98)	-
	Evaluated – Standard Stud (3D Modeling)	0.073 (0.41)	R-13.73 (2.42)	23%
	Evaluated – R-stud (3D Modeling)	0.068 (0.39)	R-14.70 (2.59)	28%

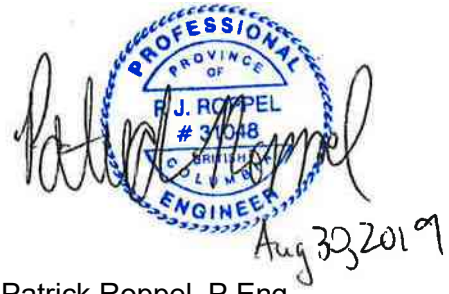
[1]Published U-values from Table 4.3.3 of the CEC 2019 Building Energy Efficiency Standards Joint Appendix

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.

[2] Konsy, J. et al., 1994, *Thermal Performance of Steel-Frame Walls*, Oak Ridge National Laboratory

Yours truly,
MORRISON HERSHFIELD LIMITED

Ivan Lee, P.Eng.
Building Science Consultant



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

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:

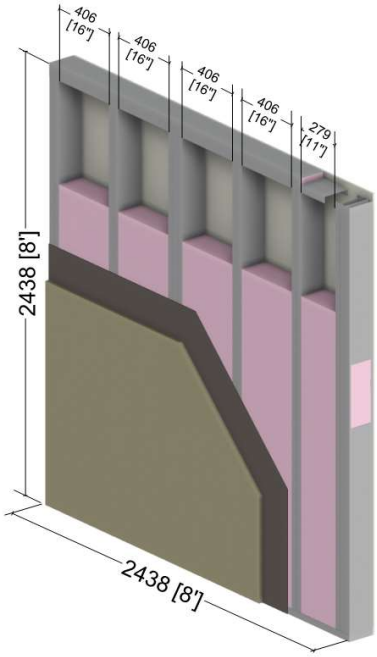
- Material properties were taken from information provided by R-stud, CEC 2019 Building Energy Efficiency Standards Joint Appendix, and ASHRAE Handbook – Fundamentals for common materials.
- Interior/exterior air films were derived from R-values listed in the CEC 2019 Building Energy Efficiency Standards 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

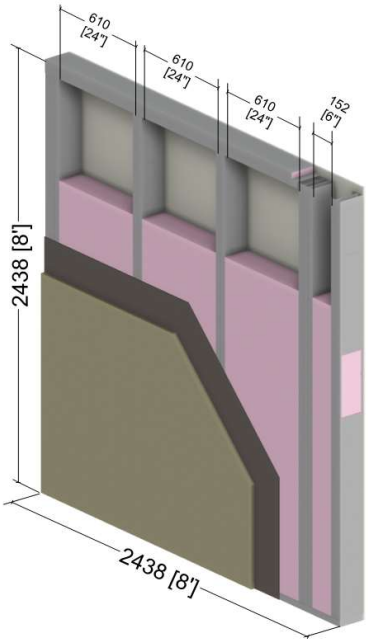
Table A2.1: Boundary Conditions

Boundary Location	Combined Convective and Radiation Heat Transfer Coefficient BTU/hft^2^{o}F (W/m^{2}K)	Equivalent R-value hft^2^{o}F/BTU (m^{2}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)

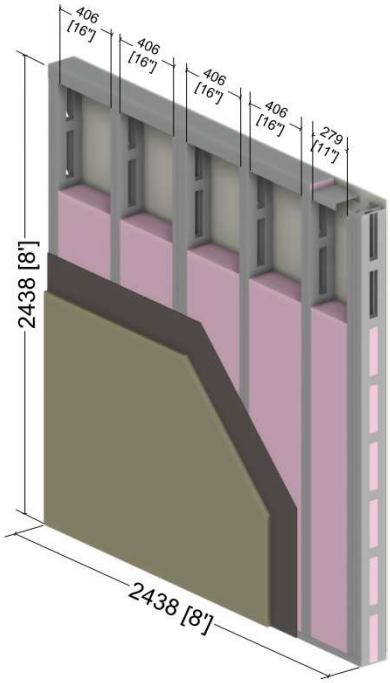
A.3 MATERIAL PROPERTIES



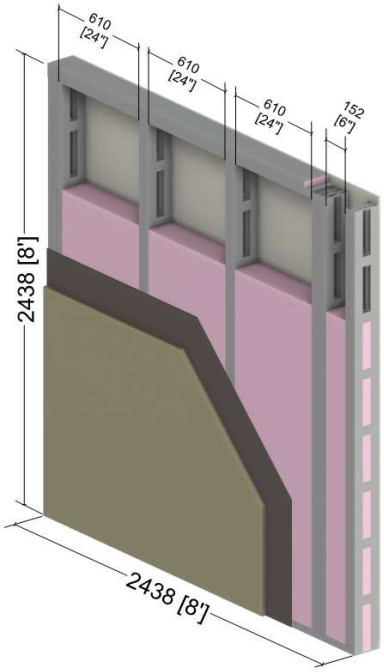
16 inch Spacing Standard Stud Assembly



24 inch Spacing Standard Assembly



16 inch Spacing R-stud Assembly

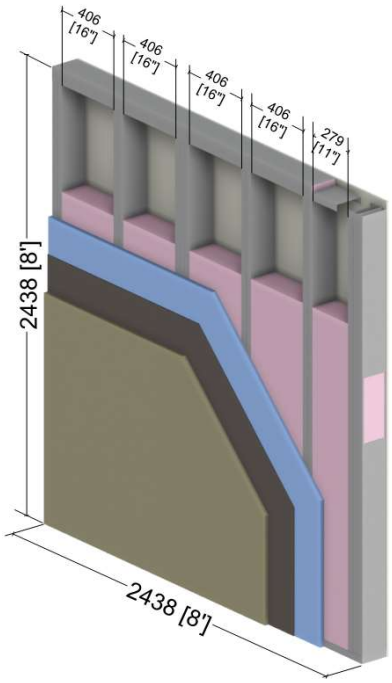


24 inch Spacing R-stud Assembly

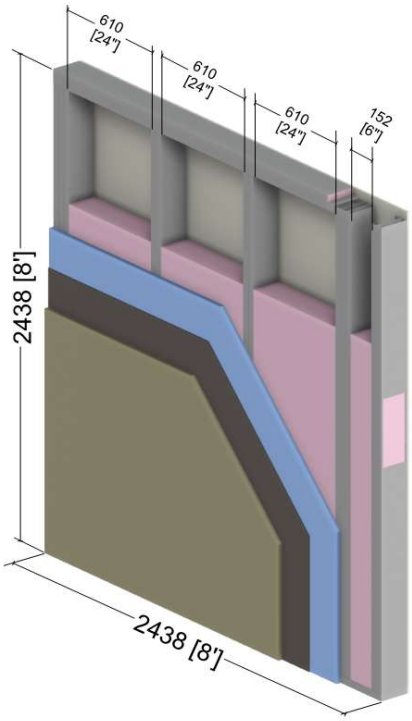
Figure A3.1: Evaluated Geometry of Assemblies without Continuous Insulation

Table A3.1: Material Properties of Assemblies without Continuous Insulation

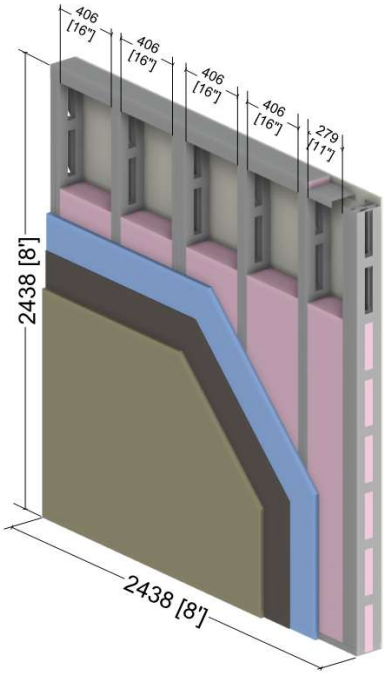
Component	Material	Thickness Inches (mm)	Thermal Conductivity BTU in / ft² hr °F (W/m K)	Nominal Resistance ft² hr °F/BTU (m ²K/W)
Interior Air Film	-	-	-	R-0.17 (0.03 RSI)
Drywall	Gypsum		1.1 (0.16)	R-0.45 (0.08 RSI)
Stud	Galvanized Steel	14 gauge	430 (62)	-
Cavity	Fiberglass Batt (R-21)	6 (152)	0.28 (0.041)	R-21 (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)
Overall Assembly 1D				R-22.5 (3.97 RSI)



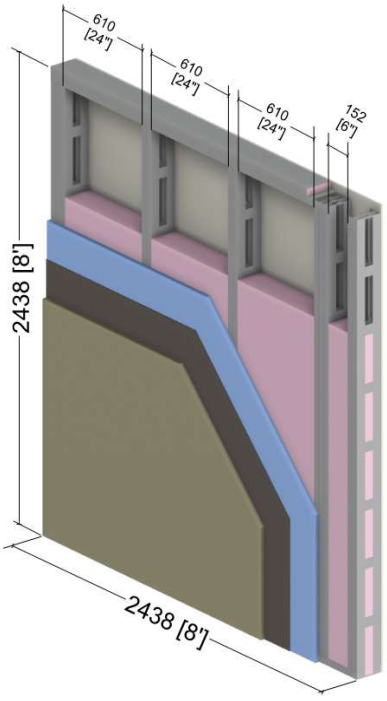
16 inch Spacing Assembly with Standard Stud



24 inch Spacing Assembly with Standard Stud



16 inch Spacing Assembly with R-stud



24 inch Spacing Assembly with R-stud

Figure A3.2: Evaluated Geometry of Assemblies with R-5 Continuous Insulation

Table A3.2: Material Properties of Assemblies of with R-5 Continuous Insulation

Component	Material	Thickness Inches (mm)	Thermal Conductivity BTU in / ft² hr °F (W/m K)	Nominal Resistance ft² hr °F/BTU (m ²K/W)
Interior Air Film	-	-	-	R-0.17 (0.03 RSI)
Drywall	Gypsum		1.1 (0.16)	R-0.45 (0.08 RSI)
Stud	Galvanized Steel	14 gauge	430 (62)	-
Cavity	Fiberglass Batt (R-21)	6 (152)	0.28 (0.041)	R-21 (3.70 RSI)
Insulation	XPS	1 (25)	0.20 (0.029)	R-5 (0.88 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)
Overall Assembly 1D				R-27.5 (4.8 RSI)

APPENDIX B: SIMULATED TEMPERATURE PROFILES

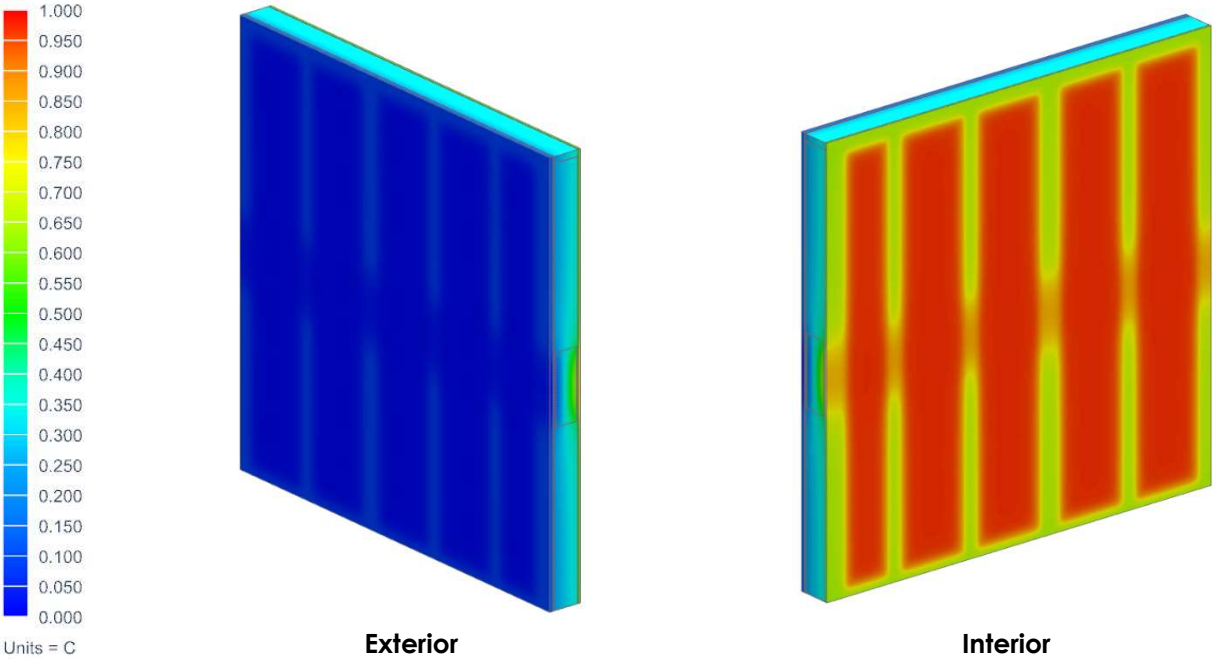


Figure B1.1: Interior Insulated Standard Stud Assembly with R-21 Batt at 16 inch spacing: Isometric view from exterior and interior

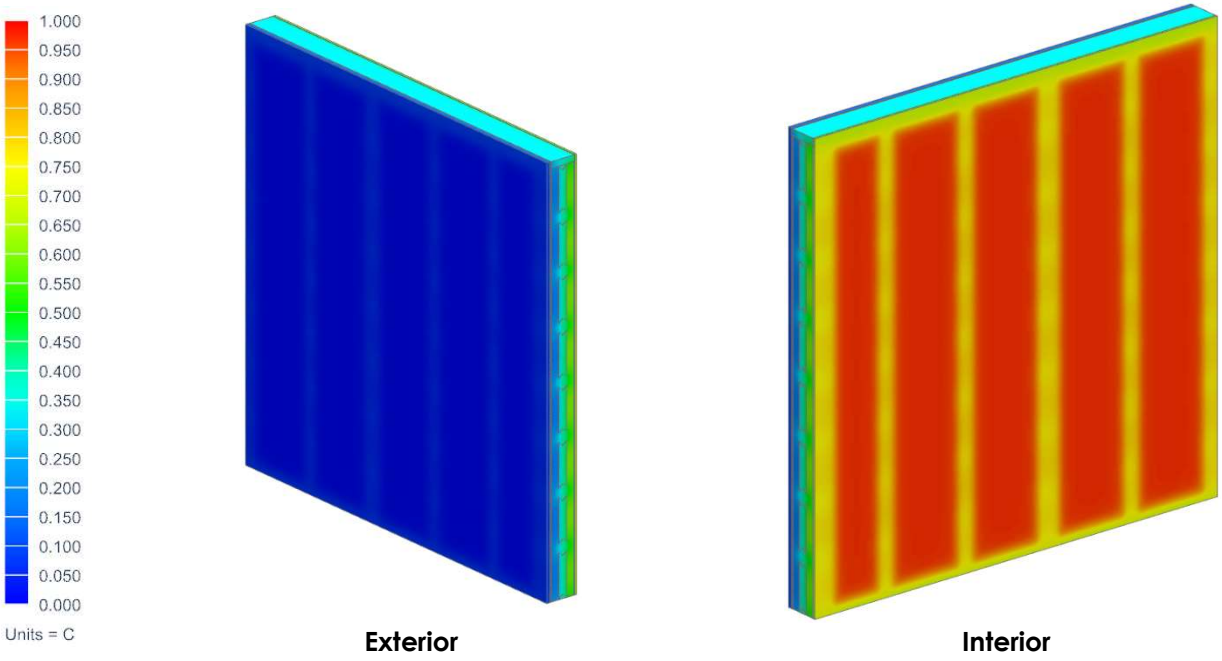


Figure B1.2: Interior Insulated R-stud Assembly with R-21 Batt at 16 inch spacing: Isometric view from exterior and interior

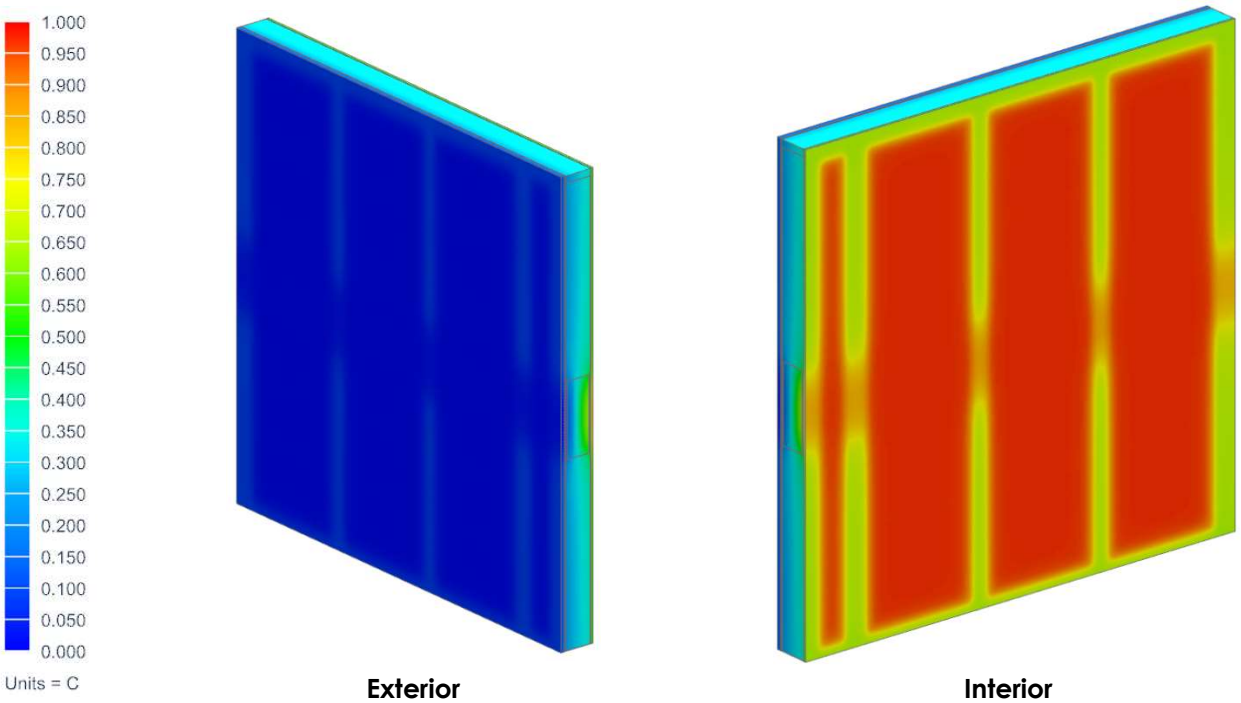


Figure B1.3: Interior Insulated Standard Stud Assembly with R-21 Batt at 24 inch spacing: Isometric view from exterior and interior

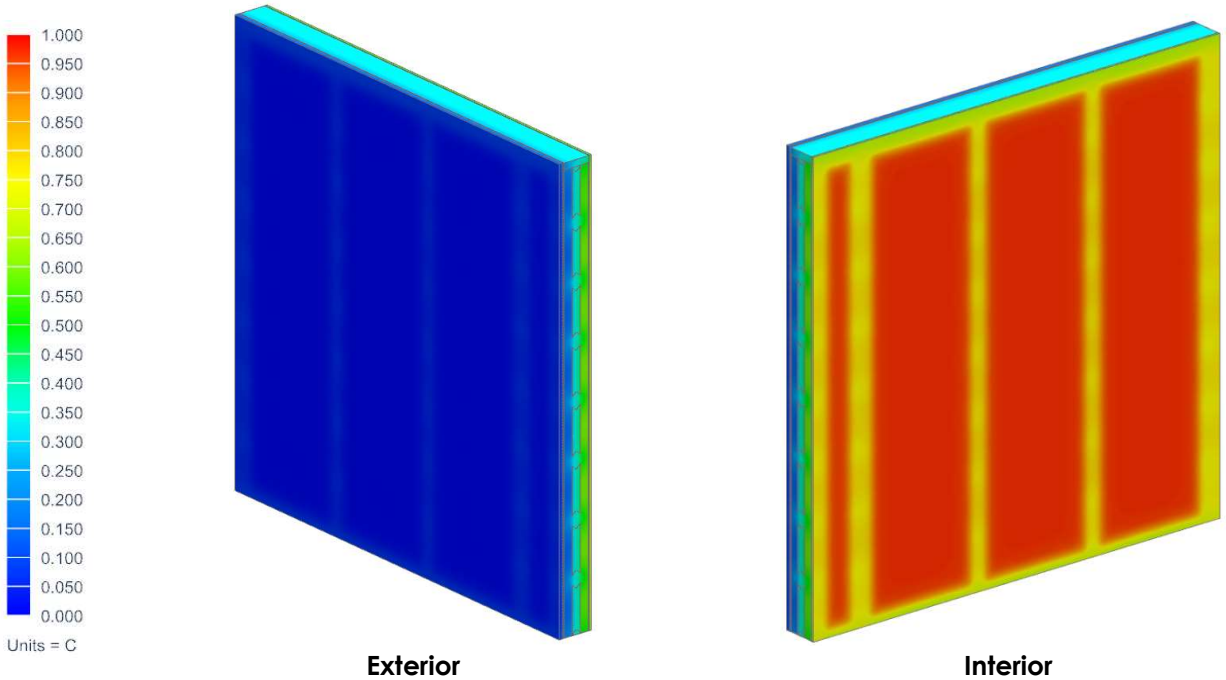


Figure B1.4: Interior Insulated R-stud Assembly with R-21 Batt at 24 inch spacing: Isometric view from exterior and interior

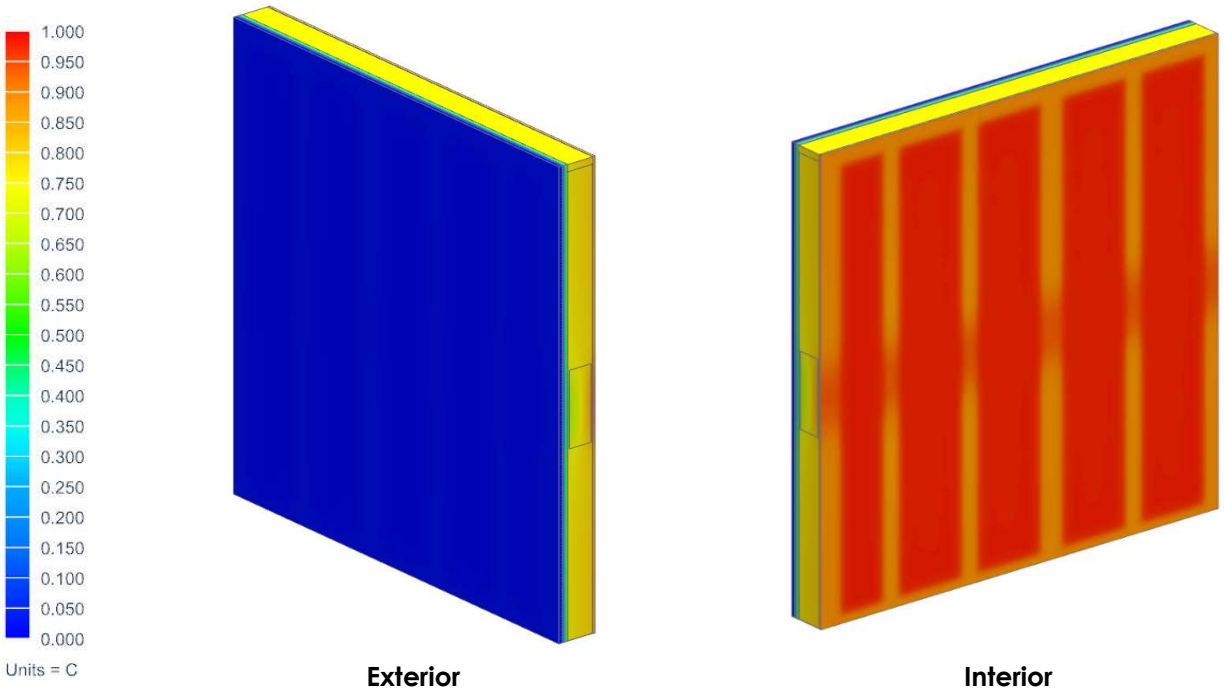


Figure B1.5: Exterior and Interior Insulated Standard Stud Assembly with R-21 Batt and R-5 Continuous Insulation at 16 inch spacing: Isometric view from exterior and interior

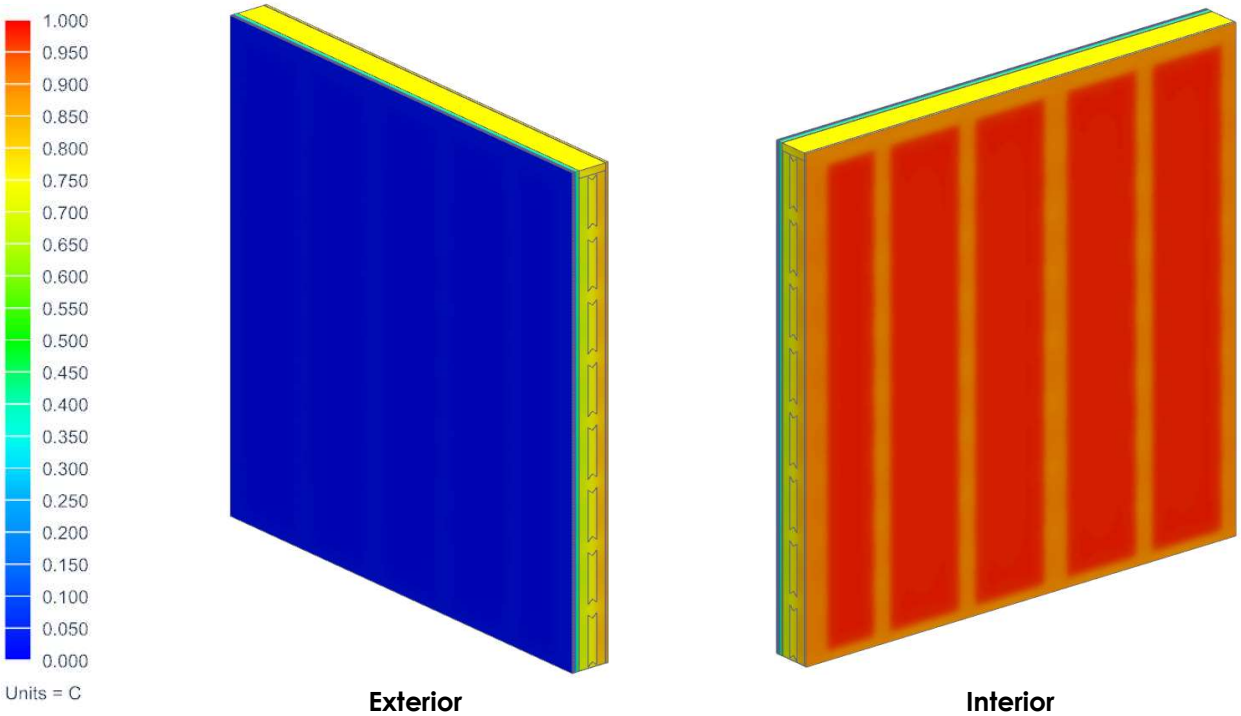


Figure B1.6: Exterior and Interior Insulated R-stud Assembly with R-21 Batt and R-5 Continuous Insulation at 16 inch spacing: Isometric view from exterior and interior

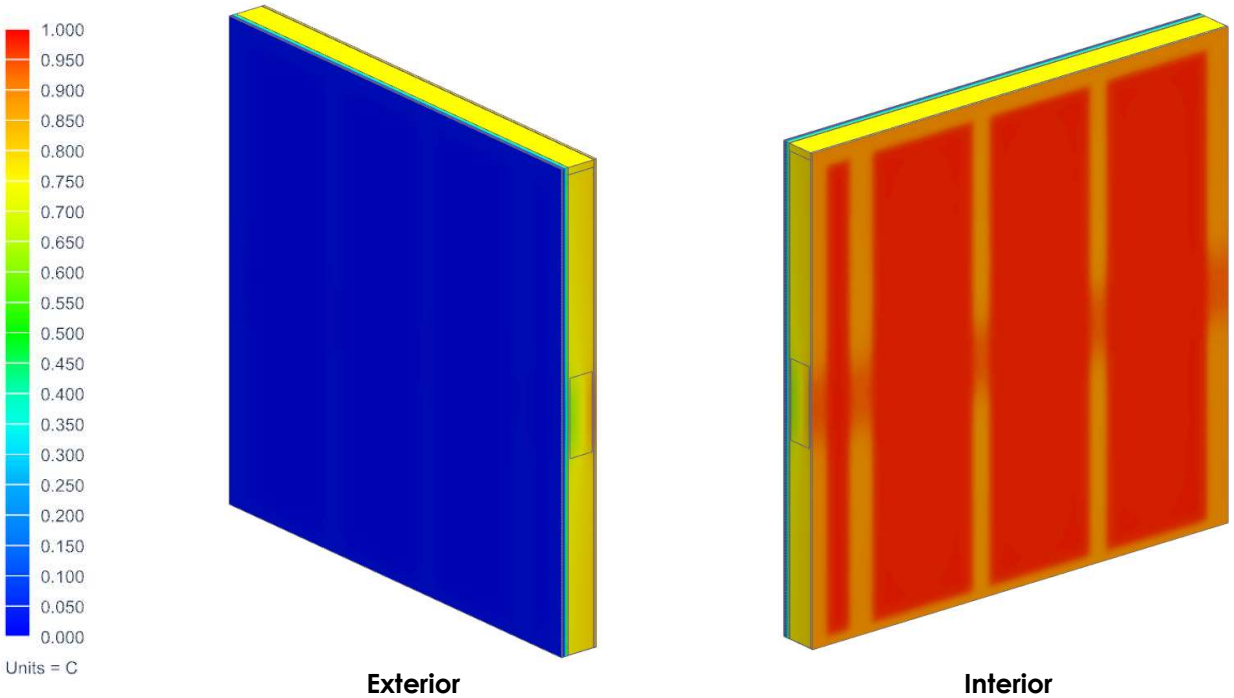


Figure B1.7: Exterior and Interior Insulated Standard Stud Assembly with R-21 Batt and R-5 Continuous Insulation at 24 inch spacing: Isometric view from exterior and interior

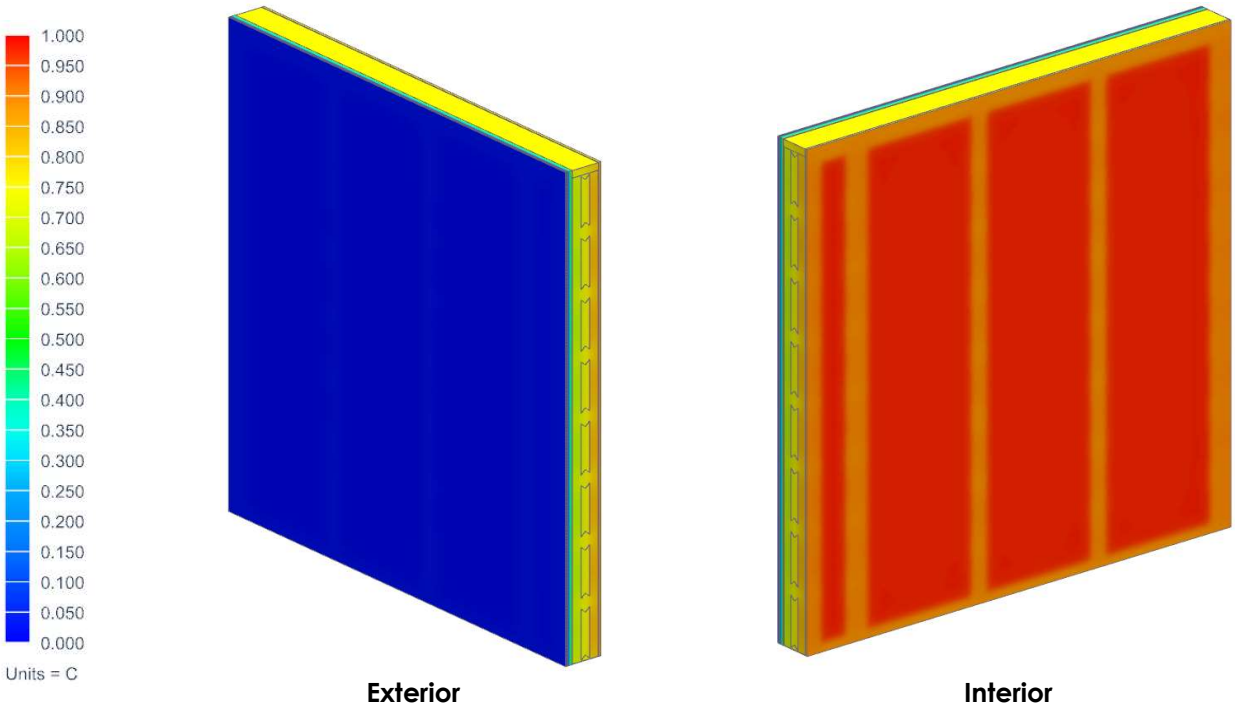


Figure B1.8: Exterior and Interior Insulated R-stud Assembly with R-21 Batt and R-5 Continuous Insulation at 24 inch spacing: Isometric view from exterior and interior