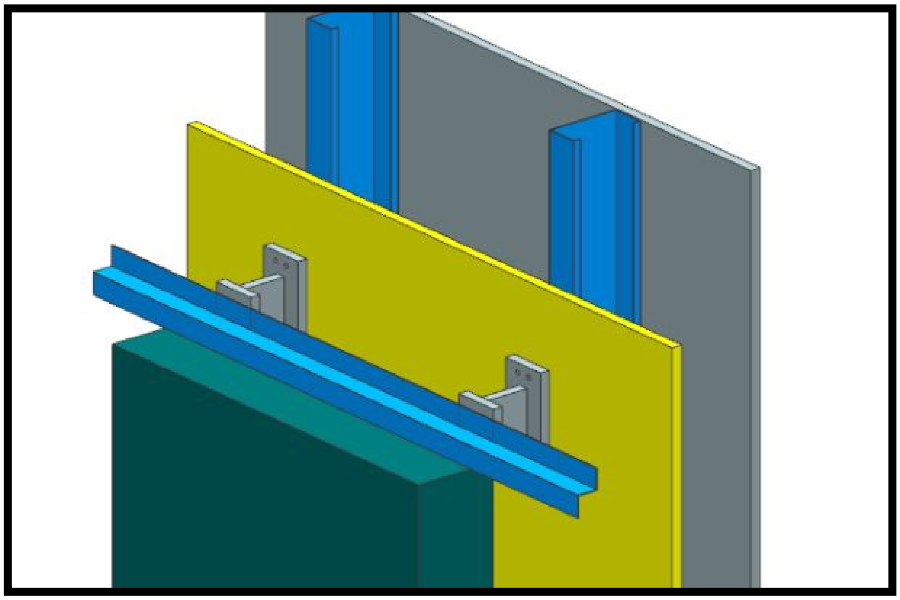
REPORT

Thermal and Structural Performance of the Thermal Assembly Clip (TAC) System



Presented to:

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1. INTRODUCTION

The Thermal Assembly Clip (TAC) system is for attaching lightweight cladding systems to different types of backup walls. Morrison Hershfield was contracted to evaluate the thermal and structural performance of this system for various scenarios.

The clips of the TAC system are attached to a structural back-up wall, which support horizontal Z-girts and cladding system. More details of the components evaluated and the detailed drawings can be found in Appendix A.

2. MODELING PROCEDURES

Modeling was done using the Nx software package from Siemens, which is a general purpose computer aided design (CAD) and finite element analysis (FEA) package. The thermal solver and modeling procedures utilized for this study were extensively calibrated and validated for ASHRAE Research Project 1365-RP "Thermal Performance of Building Envelope Details for Mid- and High-Rise Construction (1365-RP)[1]. The thermal transmittance (U-Value) or "effective R-value" was determined using the methodology presented in 1365-RP and is summarized in Appendix B.

3. STRUCTURAL ANALYSIS

Structural analysis for dead and wind loads was performed on the TAC system, the fasteners and the cladding. The clip system was analyzed for the attachment to four types of backup walls: steel stud backup wall, wood stud backup wall, concrete wall, and concrete block wall. The clip was analyzed for a maximum cladding dead load of 5 pounds per square foot.

The allowable force on the clip itself was determined to occur with a wind load of 40 psf with a tributary area of 1150 square inches (32" x 36"), and a 60 psf wind load with a tributary area of 856 square inches (32" x 26"). However, for some of the scenarios the governing factor was found to be the pull-out of the fasteners connecting the clip to the backing wall. It should be noted that the fastener used for concrete and concrete hollow block wall was a 3/16" diameter Hilti KWIK-CON II+ fastener. This fastener requires a minimum spacing of 28.6 mm. Therefore, for the clip to be used on a concrete substrate the spacing of the pre-drilled holes in the flanges should be increased to 28.6 mm or greater.

The fasteners connecting the cladding to the outstretched flange of the clip shall be (2) #12-14 coarse-threaded self-drilling screws with a minimum #3 drill point. The entire thickness of the outstretched flange shall be screwed through. Table 1 gives a summary of the maximum spacing values for the different scenarios. The spacing indicated is the centre to centre spacing of the adjacent clips. The strength and stiffness of the cladding in spanning the indicated horizontal and vertical spacing between the clips/girts must be confirmed by the end user. Strength, stiffness and local failure (at the fasteners) of the

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

backup walls must be confirmed by the end user. Sufficient corrosion protection of the fasteners must also be specified by the end user to match the application. For example, proprietary coating systems, such as DT2000 or equivalent performance, are recommended for fasteners within the cavity of rain-screen wall assemblies.

Table 1: Maximum Tributary Area and Girt Spacing from Structural Analysis

	Maximum Unfactored Wind Load	Maximum Tributary Area (in^2) per Clip	Horizontal Spacing (in)	Maximum Vertical Spacing (in)	Additional Information
Steel Stud Backup Wall	20 psf	1840	16	115	• Min. 18 gauge steel studs • Studs spaced at 16" o.c. • Fasteners: #12-24 self-drilling screw (min. 3 threads into stud)
			32	57	
	30 psf	1429	16	89	
			32	44	
	40 psf	1168	16	73	
			32	36	
	50 psf	988	16	61	
			32	30	
	60 psf	856	16	53	
			32	26	
Wood Stud Backup Wall	20 psf	1840	16	115	• Wood studs: 2 x 4 at 16" o.c. • Fasteners: ¼" diameter – 3 ½" long screws into 2 x 4
			32	57	
	30 psf	1429	16	89	
			32	44	
	40 psf	1168	16	73	
			32	36	
	50 psf	988	16	61	
			32	30	
	60 psf	856	16	53	
			32	26	
Concrete Wall	20 psf	1737	24	72	• Fasteners: Hilti Kwik-Con II+ 3/16" diameter anchor with 1 ¾" embedment or equivalent
			36	48	
	30 psf	1384	24	57	
			36	38	
	40 psf	1151	24	48	
			36	32	
	50 psf	985	24	41	
			36	27	
	60 psf	856	24	35	
			36	24	
Concrete Block	20 psf	996	24	41	• Fasteners: Hilti Kwik-Con II+ 3/16" diameter anchor with 1"embedment
			30	33	
	30 psf	787	24	32	
			30	26	
	40 psf	650	24	27	
			30	22	
	50 psf	554	24	23	
			30	18	
	60 psf	483	24	20	
			30	16	

4. THERMAL ANALYSIS

The following section provides U-Value results for both the clear field area and an assembly including a typical floor slab detail. For effective assembly R-Values please see Appendix C.

4.1 Clear Field Thermal Performance

Thermal analysis was conducted on four different clip sizes. The four clip sizes accommodate 3”, 4”, 5”, and 6” of external insulation. Drawings for these systems, including dimensions and material properties are shown in Appendix A.

Each of the clip sizes was modeled with 16” horizontal clip spacing and three vertical clip spacings: 24”, 36” and 48”. The spacings were chosen to accommodate a range of different cladding modules and structural loadings (see Table 1). Semi-rigid mineral wool, R-4.2 per inch (RSI-0.74 per 25 mm), was modeled outboard the exterior sheathing with 90 mm steel studs in the back-up wall spaced at 16” o.c.. A sensitivity analysis using other insulation types and clips spacings can be found in section 5 of this report. Table 2 shows the clear field U-values of the four clip sizes and clip spacing arrangements (Effective R-values are given in Table C1).

Table 2: Clear Field Thermal Transmittance for Exterior Insulation and a Steel Stud Backup Wall

Clip Size in	**Exterior Insulation Nominal R-Value** hr·ft²·°F/BTU (m²K/W)	**Assembly U-Value** BTU/hr·ft²·°F (W/m²K)		
		24” Vertical Clip Spacing	36” Vertical Clip Spacing	48” Vertical Clip Spacing
3	12.6 (2.22)	0.066 (0.374)	0.065 (0.371)	0.065 (0.370)
4	16.8 (3.0)	0.052 (0.295)	0.052 (0.293)	0.051 (0.291)
5	21.0 (3.7)	0.043 (0.244)	0.042 (0.241)	0.042 (0.240)
6	25.2 (4.4)	0.036 (0.206)	0.036 (0.205)	0.036 (0.204)

The “effective R-value” of the TAC system for all the assemblies are all over 97% effective compared to the overall nominal thermal resistances. As with all types of thermal bridging, the assembly is less effective with increasing insulation. However, here the diminishing returns are minor due to the efficiency of this clip. The results show that increasing the vertical spacing from 24 to 48 inches results in no more than a 3% reduction in the U-value (R-0.3 gain).

As an example of how to use Table 2, look at the chart and find the U-values that are lower than the ASHRAE 90.1-2010 Maximum U-value for climate zones 4C to 8 which is equal to 0.064 (0.363). One can see that the 4” clip size meets this standard for all three spacings.

The temperature distribution for the 4” clip size with clips spaced 16” apart horizontally and 24” apart vertically is found in Appendix C. The surface temperatures are presented using temperature indices as defined in Appendix B.

4.2 Slab Edge Linear Transmittance

A slab edge detail was evaluated with the clips fastened to the slab as well as directly beneath it to the steel stud wall; this is to allow movement between the slab and the wall. Drawings for this detail including material properties are found in Appendix A.

This detail was modeled in the same manner as the previous section for four clip sizes and three vertical clip spacings. Table 3 summarizes the thermal performance values (U-values) for a 9 foot floor to ceiling height including an 8 inch thick slab. Effective R-Values are given in Table C2. Linear transmittance values are also provided, which allow the overall U-value to be calculated for any floor to ceiling height. More information on utilizing linear transmittance is provided in Appendix B.

Adding a slab (which includes adding extra clips at the slab edge) increases the overall U-value by approximately 2-3% (a max. R-0.7 reduction) compared to the clear field U-value for a 9 foot floor to ceiling height. The U-value of the assembly was hardly affected by vertical spacing.

The linear transmittance values are also not significantly impacted by the vertical clip spacing (at 24 inches, the clips are well isolated from the slab); therefore a single linear transmittance can represent any vertical clip spacing. There is a slight decrease in linear transmittance from the 3 inch clip to the 6 inch clip. It is reasonable to assign a single linear transmittance value of 0.02 BTU/hr·ft·^{o}F (W/m K) to the slab edge for the thermal clip systems because the differences do not equate to significant difference in overall heat flow. The temperature distribution for the scenario composed of the 4” clip size with 24” vertical and 16” horizontal clip spacing with the addition of a slab edge and extra clips can be found in Appendix D.

Table 3: Overall Thermal Transmittance including the effects of an insulated slab edge and extra clips for 9 foot floor to ceiling height

Clip Size in	**Exterior Insulation Nominal R-Value** hr·ft²·°F/BTU (m²K/W)	**Assembly U-Value with Slab Edge** BTU/hr·ft²·°F (W/m²K)			**Ψ Slab Edge Linear Transmittance** BTU/hr·ft·°F (W/mK)
		24" Vertical Spacing	36" Vertical Spacing	48" Vertical Spacing	
3	12.6 (2.22)	0.068 (0.39)	0.067 (0.38)	0.067 (0.38)	0.017 (0.029)
4	16.8 (2.96)	0.053 (0.30)	0.053 (0.30)	0.052 (0.30)	0.009 (0.016)
5	21.0 (3.70)	0.044 (0.25)	0.043 (0.25)	0.043 (0.25)	0.008 (0.014)
6	25.2 (4.44)	0.037 (0.21)	0.037 (0.21)	0.037 (0.21)	0.008 (0.014)

4.3 Impact of Batt Insulation in Steel Stud Cavity

The stud cavities did not have any insulation in the scenarios presented in the previous sections. The impact of adding R-12 batt insulation to the stud cavity was analyzed for the clear wall scenarios presented in section 4.1. The thermal transmittance values are summarized in Table 4. Effective R-values are given in Table C3.

Table 4: Clear Field Thermal Transmittance with Batt Insulation in the Stud Cavity

Clip Length in	Exterior Insulation Nominal R-Value hr·ft²·°F/BTU (m²K/W)	Assembly U-Value with interior insulation BTU/hr·ft²·°F (W/m²K)		
		24" Vertical Spacing	36" Vertical Spacing	48" Vertical Spacing
3	12.6 (2.22)	0.047 (0.266)	0.046 (0.263)	0.046 (0.262)
4	16.8 (2.96)	0.040 (0.225)	0.039 (0.221)	0.039 (0.219)
5	21.0 (3.70)	0.034 (0.192)	0.033 (0.190)	0.033 (0.189)
6	25.2 (4.44)	0.030 (0.169)	0.029 (0.167)	0.029 (0.167)

Table 5: Minimum temperature indices for interior face of sheathing, with and without batt for 24" vertical and 16" horizontal clip spacing

Clip Length	Without Batt Insulation	With R12 Batt Insulation in Stud cavity
3	0.87	0.55
4	0.90	0.63
5	0.92	0.67
6	0.93	0.71

Adding batt insulation to the steel stud cavity is often considered when design constraints (cost or overall wall thickness) exist to meet specific building envelope thermal transmittance targets. Here, adding R-12 batt insulation increases the overall effective R-value by approximately R-6.3. One can see that adding batt insulation in the stud cavity is not as effective as adding insulation to the exterior for a clip system. Furthermore, the condensation resistance of the assembly will be greatly reduced. Table 5 summarizes the temperature indices (see appendix B for definition) for the three clip systems with and without batt insulation in the stud cavity for 24" clip spacing. The significance of this is that split insulated assemblies have marginal condensation resistance compared to fully exterior insulated assembly[2]. The temperature distribution profile for the 4" system with a 24" vertical and 16" horizontal clip spacing with R-12 batt insulation in the steel stud cavity is found in Appendix D.

5. SENSITIVITY ANALYSIS

A sensitivity analysis of the modeled systems was performed to allow designers to interpolate the thermal performance values for others insulation levels and clip spacing.

5.1 Insulation Type

The previous analysis assumed semi-rigid insulation (R 4.2 / inch) for the exterior insulation. Other conductivities were evaluated to allow the thermal transmittance values for the thermal clip system to be utilized for other types of insulation. In order to characterize the range of exterior insulation values, the modeled assemblies in section 4.1 were re-calculated using a low end of R-3.5 per inch (RSI-0.62 per inch) to a high end of R-6.5 per inch (RSI-1.14 per inch).

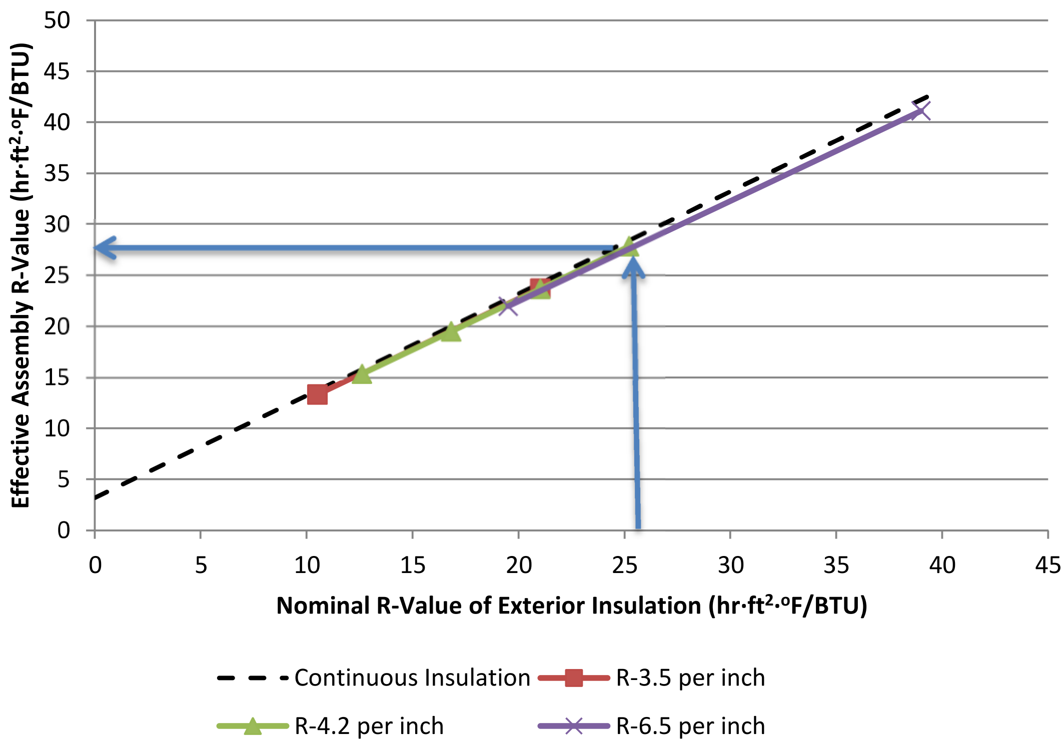

Figure 1: *Effective Assembly R-Value vs Nominal Insulation R-Value for a variety of insulation materials for 48 in clip spacing*

[2] A thorough discussion on how to evaluate condensation resistance using temperature indices is available upon request

Figure 1 shows the graphical results for effective assembly R-Values with a clip spacing of 48" vertically and 26" horizontally with no batt insulation when varying the insulation materials. The case of continuous exterior insulation as assumed in energy standard ASHRAE 90.1-2007 is also graphed as a reference.

The results show that the thickness of the insulation (and length of the clip) for a given nominal thermal resistance is largely independent of the effective R-value. Therefore, the results can be characterized by the R-value of the exterior insulation and can be applied to any material. The results from Table 2 can be re-arranged and additional R-values can be interpolated with the results from the sensitivity analysis. The U-value results are presented in Table 6. Effective R-Values are given in Table C.4.

As an example of how to use Table 6, look at a design that uses the 4" clip size with exterior closed cell polyurethane sprayfoam and 48" vertical clip spacing. Four inches of sprayfoam (R-6.5 per inch) is equivalent to an exterior insulation nominal value of R-26 (RSI-4.58). Interpolating from Table 6, results in an assembly U-value of approximately U-0.035 (USI-0.202). The answer can also be interpolated from the graph in Figure 1. One can follow the blue arrows to determine the effective R-value to be about R 27.5. This translates to a U-value of 0.036, which is very close to the interpolated value from the table.

Table 6: Clip System Thermal Performance Per Exterior Insulation Level

Exterior Insulation Nominal R-Value hr·ft^2·°F/BTU (m^{2}K/W)	**Assembly U-Value** BTU/hr·ft^2·°F (W/m^{2}K)		
	24" Clip Spacing	36" Clip Spacing	48" Clip Spacing
15 (2.64)	0.057 (0.321)	0.057 (0.321)	0.056 (0.320)
20 (3.52)	0.045 (0.253)	0.044 (0.252)	0.044 (0.251)
25 (4.40)	0.037 (0.209)	0.037 (0.207)	0.036 (0.206)
30 (5.28)	0.031 (0.178)	0.031 (0.176)	0.031 (0.175)
35 (6.16)	0.027 (0.154)	0.027 (0.153)	0.027 (0.152)
40 (7.04)	0.024 (0.137)	0.024 (0.135)	0.024 (0.135)

5.2 Clip Spacing

Several vertical clip spacings were analyzed for the 4" clip size with exterior insulation. The U-value results are presented in Table 7. Effective R-values are given in Table C.5.

Table 7: 4" Clip Thermal Transmittance for Alternative Vertical Clip Spacing

Exterior Insulation Nominal R-Value hr·ft²·°F/BTU (m²K/W)	Assembly U-Value BTU/hr·ft²·°F (W/m²K)				
	16" Hor., 12" Vert. Clip Spacing	16" Hor., 24" Vert. Clip Spacing	16" Hor., 36" Vert. Clip Spacing	16" Hor., 48" Vert. Clip Spacing	32" Hor., 24" Vert. Clip Spacing
16.8 (2.96)	0.053 (0.303)	0.052 (0.296)	0.052 (0.292)	0.051 (0.291)	0.051 (0.287)

There is less than an R-1 difference in the effective R-value over the range clip spacing range that was evaluated. Increasing the spacing of the clips has a diminishing return but is essentially negligible when increasing the spacing past 36 inches. Doubling the horizontal clip spacing with a constant vertical spacing of 24 inches increases the R-value by approximately R-0.5. This shows that horizontal clip spacing has a similar effect as vertical clip spacing because this (R-0.5) is comparable to doubling the vertical spacing from 12 inches to 24 inches while keeping the horizontal spacing constant at 16".

6. CONCLUSION

From this report, the following conclusions can be made:

- For clear field exterior insulated scenarios, the clip system assembly U-values range between 0.036 BTU/hr·ft^2·°F - 0.066 BTU/hr·ft^2·°F (0.204 W/m^{2}K - 0.374 W/m^{2}K).
- Including extra clips at the slab edge, increases the U-value of the wall, at most, 2-3%.
- With the inclusion of interior R-12 batt, the clear wall thermal resistance gains approximately an effective R-6.3. This means that the batt insulation is only 52.5% effective.
- The insulation type and thickness have a negligible effect on the thermal resistance of for the same nominal R-value of insulation. The results can be used for any type of insulation as long as the nominal R-value of the insulation is known.
- The clip spacing has a small effect on the thermal performance under 36" vertical spacing. Higher than 36", the increase in thermal resistance is negligible.

Overall, the TAC system is structurally and thermally efficient allowing it to meet energy standards with less insulation than competing methods for the structural attachment of lightweight cladding.

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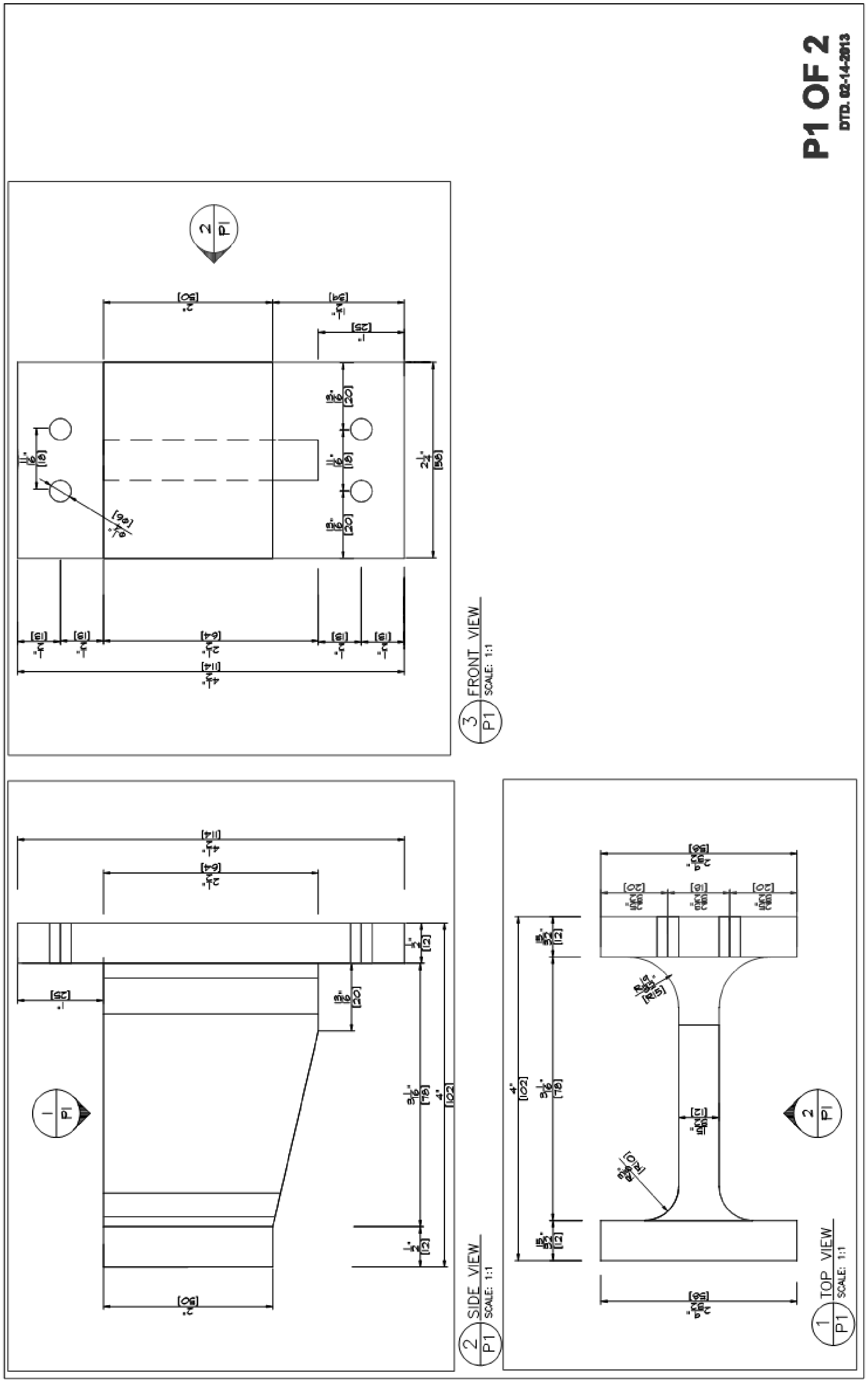
APPENDIX A – CLIP SYSTEM DETAILS AND MATERIAL PROPERTIES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TOP VIEW
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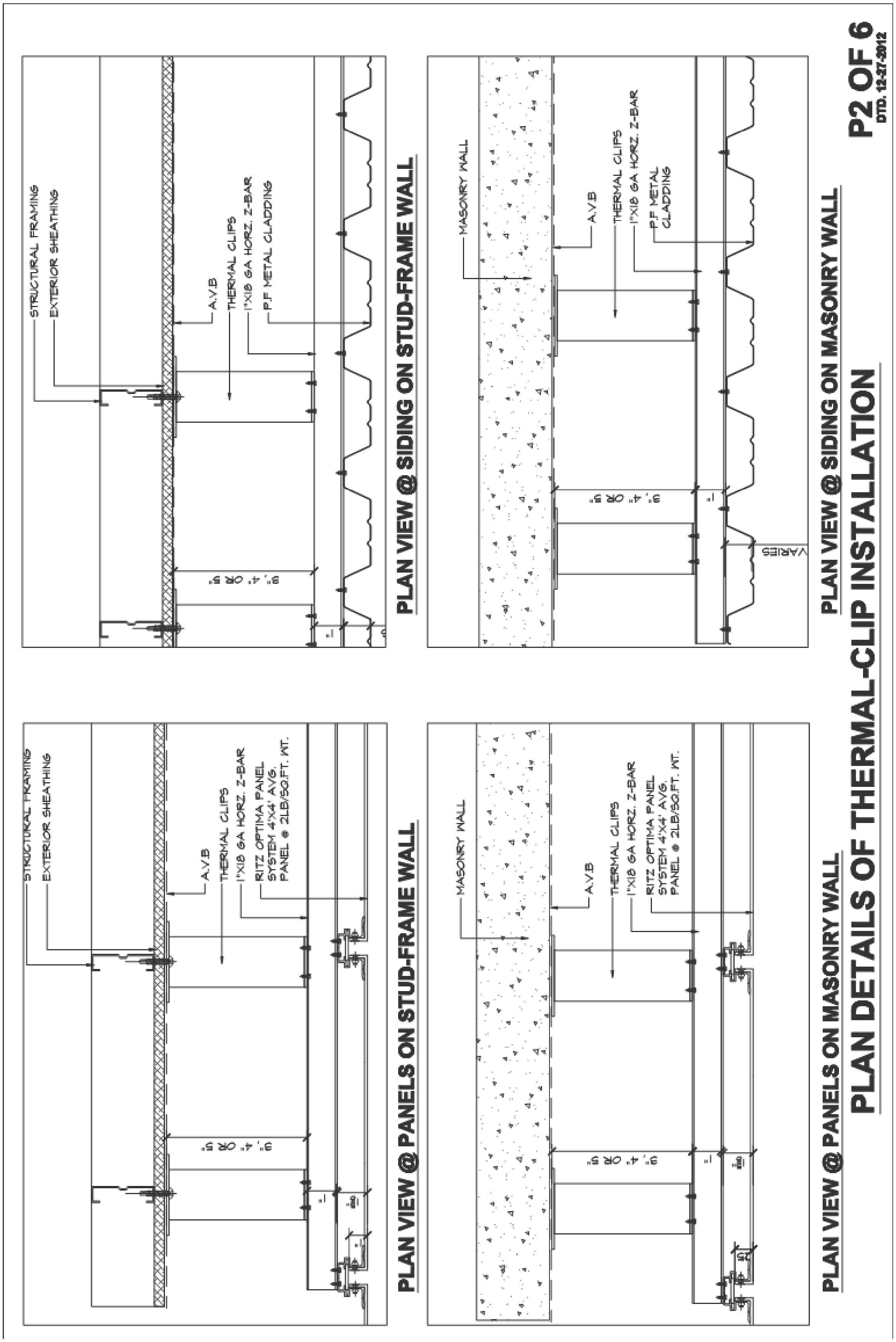
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EXTERIOR SHEATHING
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3", 4" OR 5"
PLAN VIEW @ PANELS ON STUD-FRAME WALL
STRUCTURAL FRAMING
EXTERIOR SHEATHING
A.V.B
THERMAL CLIPS
1"X18 GA HORZ. Z-BAR
P.F METAL CLADDING
3", 4" OR 5"
PLAN VIEW @ SIDING ON STUD-FRAME WALL
MASONRY WALL
A.V.B
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RITZ OPTIMA PANEL SYSTEM 4'X4' AVG. PANEL @ 2LB/SQ.FT. WT.
3", 4" OR 5"
PLAN VIEW @ PANELS ON MASONRY WALL
MASONRY WALL
A.V.B
THERMAL CLIPS
1"X18 GA HORZ. Z-BAR
P.F METAL CLADDING
3", 4" OR 5"
VARIES
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PLAN DETAILS OF THERMAL-CLIP INSTALLATION
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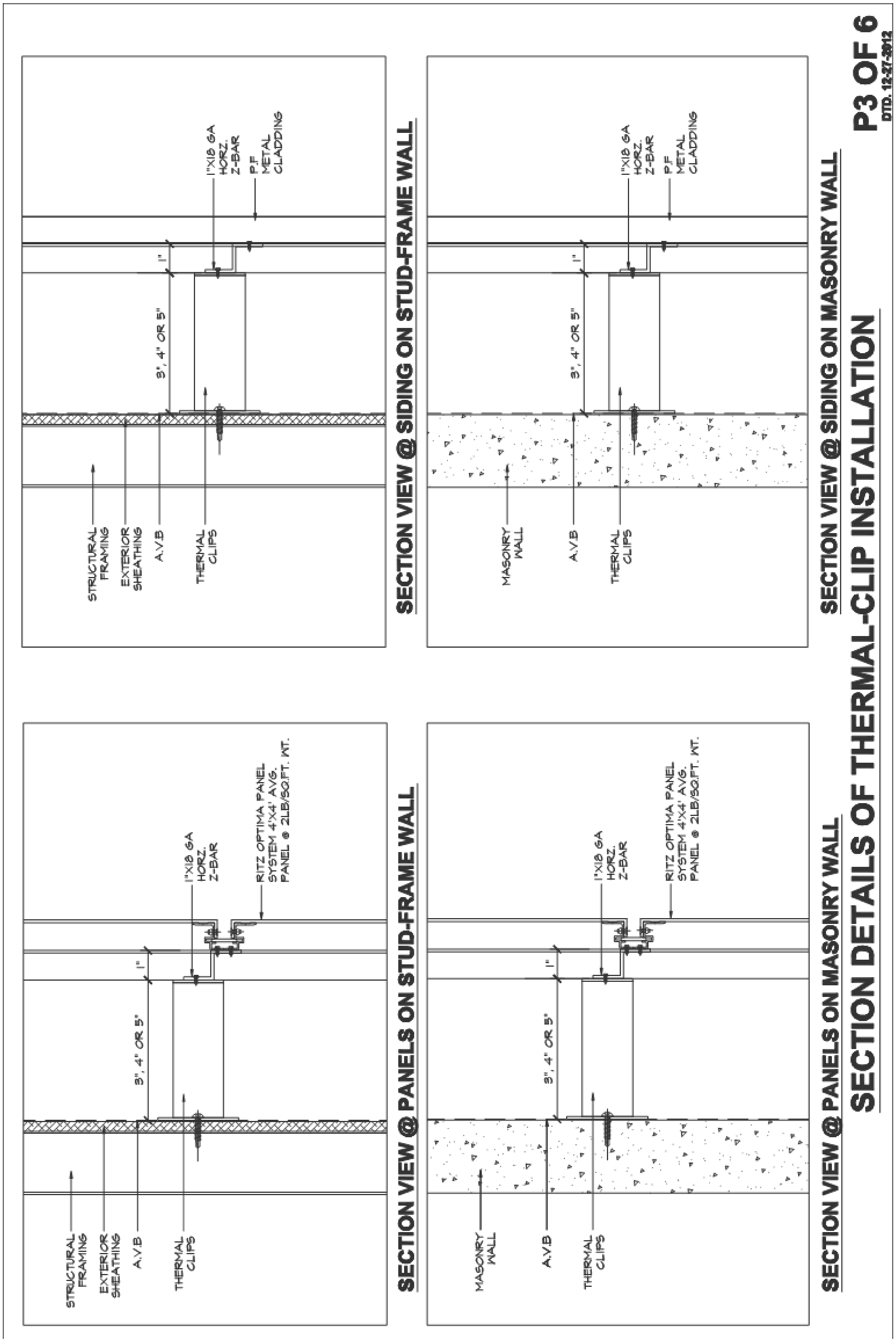
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MASONRY WALL
A.V.B
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MASONRY WALL
A.V.B
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3", 4" OR 5"
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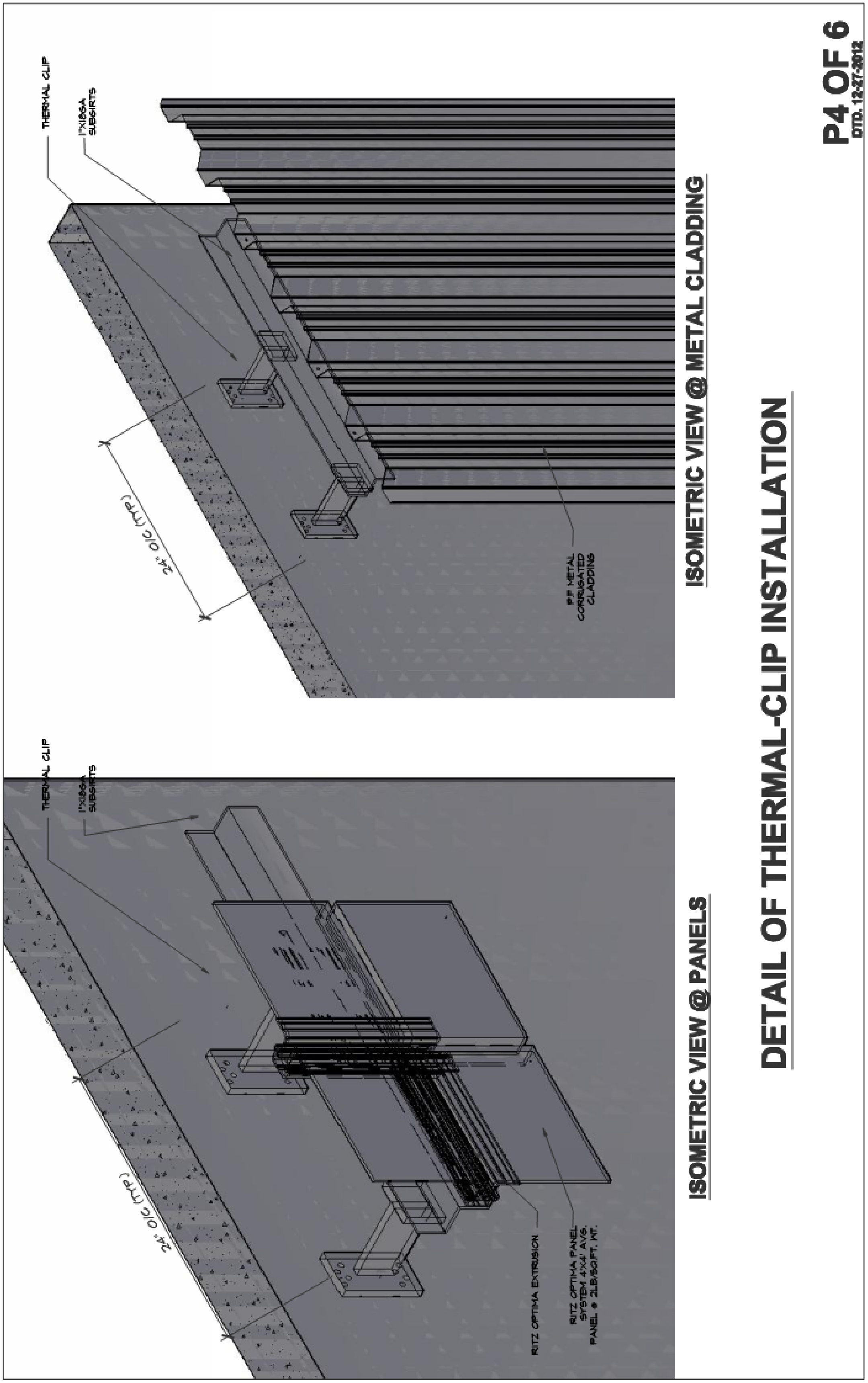
THERMAL CLIP
1"X18GA SUBGIRTS
24" O/C (TYP.)
P.F. METAL CORRUGATED CLADDING
ISOMETRIC VIEW @ METAL CLADDING
THERMAL CLIP
1"X18GA SUBGIRTS
24" O/C (TYP.)
RITZ OPTIMA EXTRUSION
RITZ OPTIMA PANEL SYSTEM 4'X4' AVG. PANEL @ 2LB/SQ.FT. WT.
ISOMETRIC VIEW @ PANELS
DETAIL OF THERMAL-CLIP INSTALLATION
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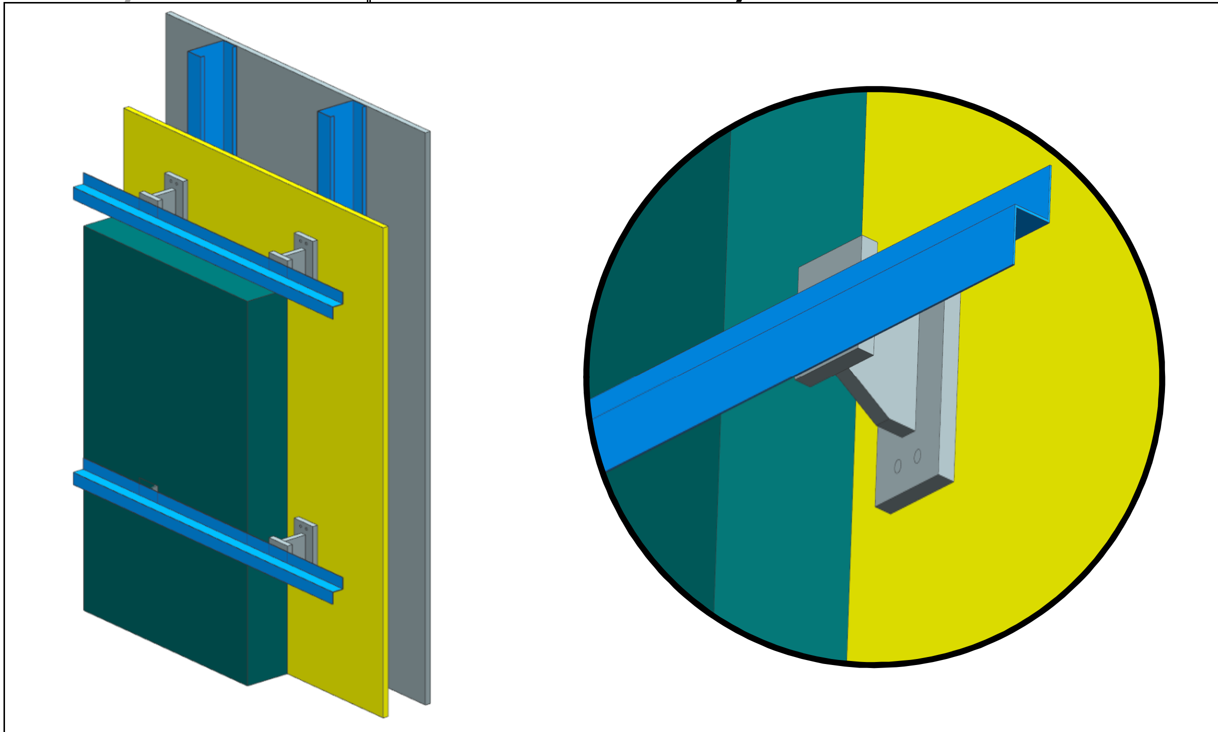
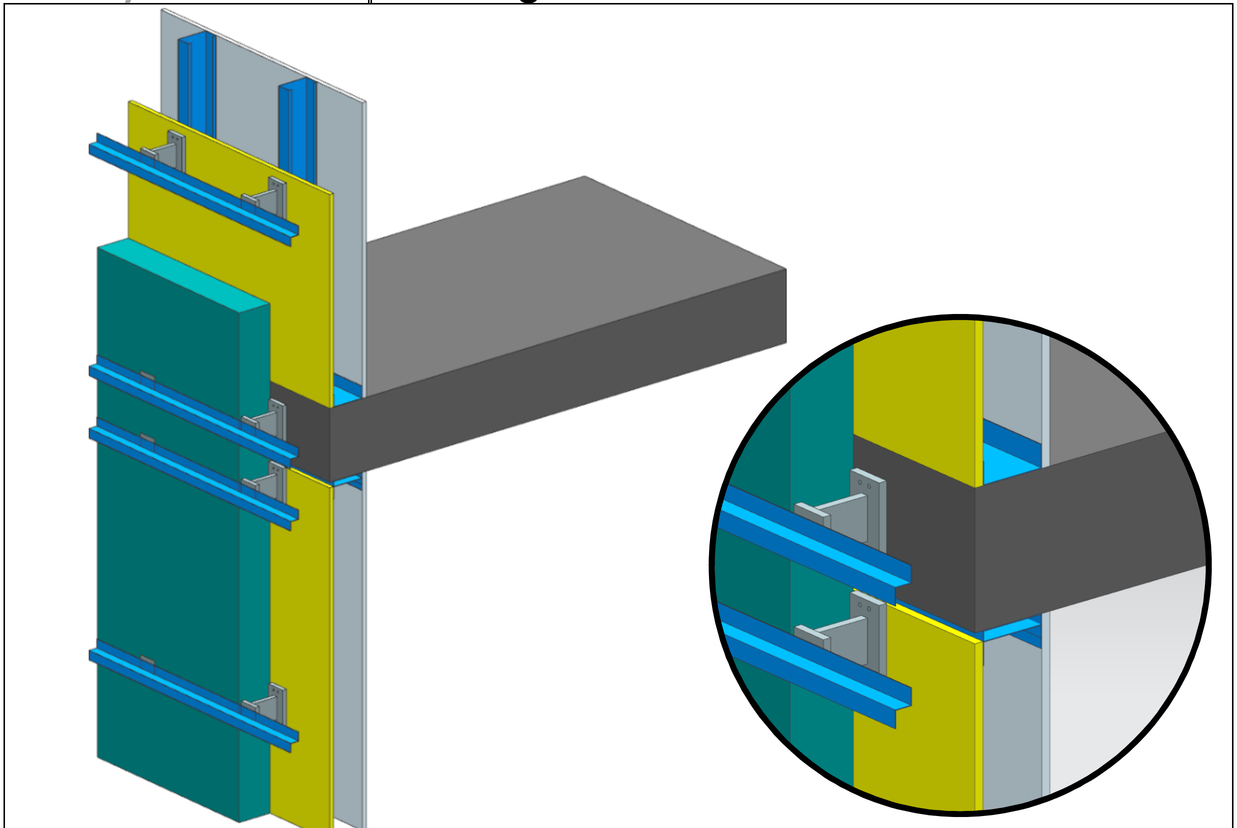
TAC System | **Clear Wall Assembly**



Component	Thickness Inches (mm)	Conductivity BTU/hr ·ft· °F (W/mK)	Nominal Resistance hr· ft^2· °F/BTU (m^{2}K/W)
Interior Film	-	-	R-0.7 (RSI-0.12)
Gypsum Board	½" (13)	0.09 (0.16)	R-0.5 (RSI-0.08)
Air in Stud Cavity	3 5/8" (92)	-	R-0.9 (RSI-0.16)
3 5/8" x 1 5/8" Steel Studs	18 gauge	36 (62)	-
Exterior Sheathing	½" (13)	0.10 (0.16)	R-0.5 (RSI-0.08)
Exterior Insulation (Mineral Wool)	3" to 6" (76 to 152)	0.020 (0.034)	R-12.6 to R-25.2 (RSI-2.22 to RSI-4.44)
Fibre reinforced plastic (FRP) Clip	-	0.204 (.346)	-
Bolts	1/4"diameter (6 diameter)	29(50)	-
Horizontal Girts	18 gauge	36 (62)	-
Generic Cladding with ½" (13mm) vented air space is incorporated into exterior heat transfer coefficient			
Exterior Film	-	-	R-0.7 (RSI-0.12)

TAC System | Slab Edge Detail



Component	Thickness Inches (mm)	Conductivity BTU/hr ·ft· °F (W/mK)	Nominal Resistance hr· ft²· °F/BTU (m²K/W)
Interior Film	-	-	R-0.6 to R-0.9 (RSI-0.11 to RSI-0.16)
Gypsum Board	½” (13)	0.09 (0.16)	R-0.5 (RSI-0.08)
Air in Stud Cavity	3 5/8” (92)	-	R-0.9 (RSI-0.16)
3 5/8” x 1 5/8” Steel Studs	18 gauge	36 (62)	-
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Fibre reinforced plastic (FRP) Clip	-	0.204 (.346)	-
Bolts	1/4” diameter (6 diameter)	29(50)	-
Horizontal Girts	18 gauge	36 (62)	-
Generic Cladding with ½” (13mm) vented air space is incorporated into exterior heat transfer coefficient			
Concrete Slab	8 (203)	1.04 (1.8)	-
Exterior Film	-	-	R-0.7 (RSI-0.12)

APPENDIX B – ASHRAE 1365-RP METHODOLOGY

B.1 General Modeling Approach

For this report, a steady-state conduction model was used. Air cavities were assumed to have an effective thermal conductivity which includes the effects of cavity convection. Interior/exterior air films were taken from Table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundaments depending on surface orientation. From the calibration in 1365-RP, contact resistances between materials were modeled. The temperature difference between interior and exterior was modeled as a dimensionless temperature index between 0 and 1 (see Appendix B.3). These values, along with other modeling parameters, are given in ASHRAE 1365-RP, Chapter 5.

B.2 Thermal Transmittance

The methodology presented in ASHRAE 1365-RP separates the thermal performance of assemblies and details in order to simplify heat loss calculations. For the assemblies, a characteristic area is modeled and the heat flow through that area is found. To find the effects of thermal bridges in details (such as slab edges), the assembly is modeled with and without the detail. The difference in heat loss between the two models is then prescribed to that detail. This allows the thermal transmittances to be divided into three categories: clear field, linear and point transmittances.

The clear field transmittance is the heat flow from the wall or roof assembly, including uniformly distributed thermal bridges that are not practical to account for on an individual basis, such as structural framing, brick ties and cladding supports. This is treated the same as in standard practice, defined as a U-value, Uo (heat flow per area). For a specific area of opaque wall, this can be converted into an overall heat flow per temperature difference, Qo.

The linear transmittance is the additional heat flow caused by details that can be defined by a characteristic length, L. This includes slab edges, corners, parapets, and transitions between assemblies. The linear transmittance is a heat flow per length, and is represented by psi (Ψ).

The point transmittance is the heat flow caused by thermal bridges that occur only at single, infrequent locations. This includes building components such as pipe penetrations and intersections between linear details. The point transmittance is a single additive amount of heat, represented by chi (χ).

With these thermal quantities the overall heat flow can be found simple by adding all the components together, as given in equation 1.

$$Q = \Sigma\, Q_{thermalbridge} + Q_o = \Sigma\left(\Psi \cdot L\right) + \Sigma\left(\chi\right) + Q_o \qquad \text{EQ 1}$$

Equation 1 gives the overall heat flow for a given building size. For energy modeling, or comparisons to standards and codes, often it is more useful to present equation 1 as a heat flow per area. Knowing that the opaque wall area is A_{total}, and $U=Q/At_{otal}$, equation 2 can be derived.

$$U = \frac{\Sigma\left(\Psi \cdot L\right) + \Sigma\left(\chi\right)}{A_{Total}} + U_o \qquad \text{EQ 2}$$

Since the linear and point transmittances are simply added amounts of heat flow, they can be individually included or excluded depending on design requirements. The clear field analysis for R100, R125 and R150 clip systems is shown in Section 3.1. The linear transmittance analysis for the Engineered Assemblies clip system slab edge detail is shown in Section 3.2. For this report, no point transmittance details were analyzed.

B.2 Temperature Index

For condensation concerns, the thermal model can also provide surface temperatures of assembly components to help locate potential areas of risk. In order to be applicable for any climate (varying indoor and outdoor temperatures), the temperatures can been non-dimensionalized into a temperature index, T_i, as shown below in Equation 3.

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

The index is the ratio of the surface temperature relative to the interior and exterior temperatures. The temperature index has a value between 0 and 1, where 0 is the exterior temperature and 1 is the interior temperature. If T_i is known, Equation 3 can be rearranged for $T_{surface}$.

Example temperature profiles for the assemblies and details modeled in this report are shown in Appendix C.

APPENDIX C – EFFECTIVE ASSEMBLY R-VALUES

Table C1: Clear Field Thermal Transmittance

Clip Length in	Exterior Insulation Nominal R-Value hr·ft²·°F/BTU (m²K/W)	Assembly R-Value hr·ft²·°F/BTU (m²K/W)		
		24" Vertical Clip Spacing	36" Vertical Clip Spacing	48" Vertical Clip Spacing
3	12.6 (2.22)	15.1 (2.67)	15.3 (2.69)	15.4 (2.71)
4	16.8 (3.0)	19.2 (3.39)	19.4 (3.42)	19.5 (3.44)
5	21.0 (3.7)	23.3 (4.10)	23.5 (4.15)	23.7 (4.17)
6	25.2 (4.4)	27.6 (4.86)	27.7 (4.88)	27.8 (4.90)

Table C2: Overall Thermal Transmittance including the effects of an insulated slab edge for 9 foot floor to ceiling height

Clip Length in	Exterior Insulation Nominal R-Value hr·ft²·°F/BTU (m²K/W)	Assembly R-Value with Slab Edge hr·ft²·°F/BTU (m²K/W)			Ψ Slab Edge Linear Transmittance BTU/hr·ft·°F (W/mK)
		24" Vertical Spacing	36" Vertical Spacing	48" Vertical Spacing	
3	12.6 (2.22)	14.7 (2.59)	14.9 (2.62)	14.9 (2.63)	0.017 (0.029)
4	16.8 (2.96)	18.8 (3.31)	19.0 (2.62)	19.1 (3.36)	0.009 (0.016)
5	21.0 (3.70)	22.8 (4.02)	23.1 (4.06)	23.2 (4.08)	0.008 (0.014)
6	25.2 (4.44)	26.9 (4.74)	27.0 (4.76)	27.1 (4.78)	0.008 (0.014)

Table C3: Clear Field Thermal Transmittance with Batt Insulation in the Stud Cavity

Clip Length in	**Exterior Insulation Nominal R-Value** hr·ft²·°F/BTU (m²K/W)	**Assembly R-Value with interior insulation** hr·ft²·°F/BTU (m²K/W)		
		24" Vertical Spacing	36" Vertical Spacing	48" Vertical Spacing
3	12.6 (2.22)	21.4 (3.77)	21.6 (3.80)	21.7 (3.82)
4	16.8 (2.96)	25.5 (4.49)	25.7 (4.53)	25.9 (4.56)
5	21.0 (3.70)	29.5 (5.20)	29.9 (5.26)	30.0 (5.29)
6	25.2 (4.44)	33.6 (5.91)	34.0 (5.99)	34.1 (6.01)

Table C4: Clip System Thermal Performance Per Exterior Insulation Level

Exterior Insulation Nominal R-Value hr·ft²·°F/BTU (m²K/W)	**Assembly U-Value** BTU/hr·ft²·°F (W/m²K)		
	24" Clip Spacing	36" Clip Spacing	48" Clip Spacing
15 (2.64)	17.7 (3.11)	17.7 (3.11)	17.7 (3.12)
20 (3.52)	22.4 (3.95)	22.5 (3.97)	22.6 (3.98)
25 (4.40)	27.2 (4.78)	27.4 (4.82)	27.5 (4.84)
30 (5.28)	31.9 (5.62)	32.2 (5.67)	32.4 (5.70)
35 (6.16)	36.6 (6.45)	37.1 (6.53)	37.3 (6.57)
40 (7.04)	41.4 (7.29)	41.9 (7.38)	42.2 (7.43)

Table C5: 4” Clip Thermal Transmittance for Alternative Vertical Clip Spacing

Exterior Insulation Nominal R-Value hr·ft^2·°F/BTU (m^{2}K/W)	**Assembly U-Value** BTU/hr·ft^2·°F (W/m^{2}K)				
	16” Hor., 12” Vert. Clip Spacing	16” Hor., 24” Vert. Clip Spacing	16” Hor., 36” Vert. Clip Spacing	16” Hor., 48” Vert. Clip Spacing	32” Hor., 24” Vert. Clip Spacing
16.8 (2.96)	18.7 (3.30)	19.2 (3.39)	19.4 (3.42)	19.5 (3.44)	19.8 (3.48)

APPENDIX D – EXAMPLE SIMULATED TEMPERATURE DISTRIBUTION

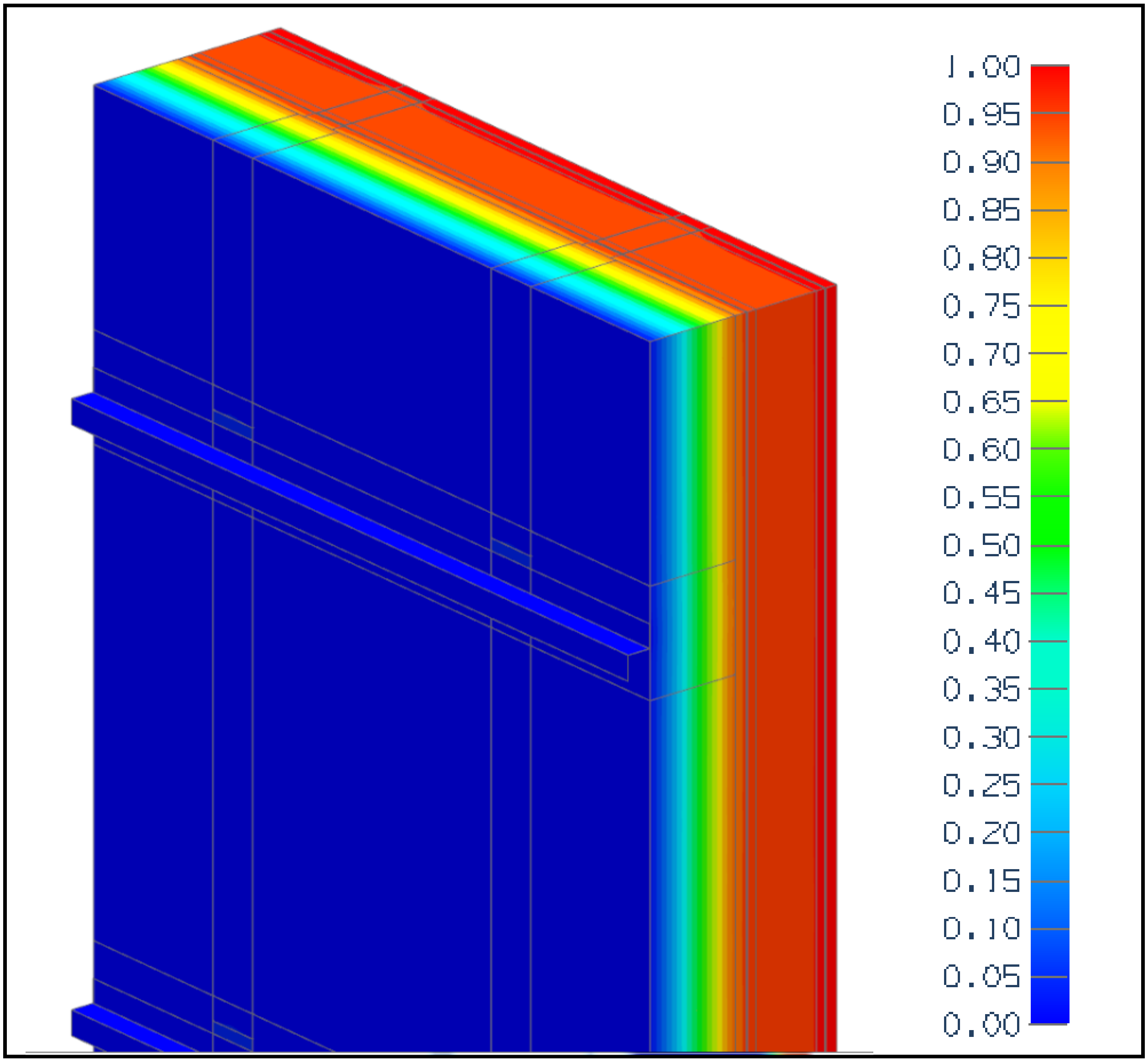

Figure D1: *Temperature profile for 4" clip size with clips spaced vertically at 24 inches*

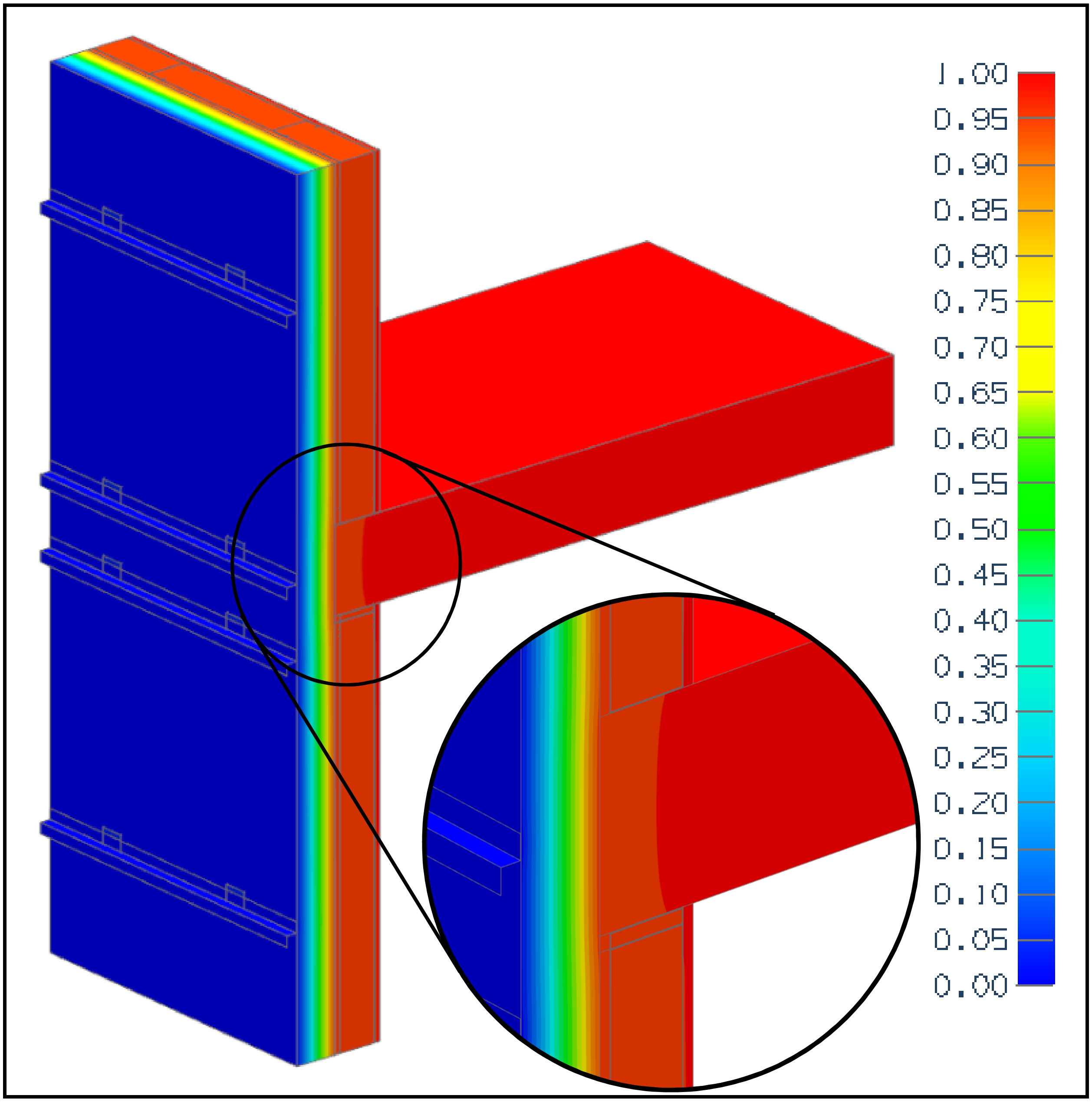

Figure D2: *Temperature profile for 4" clip size with clips spaced 24 in o.c. with extra clips at a concrete slab edge*

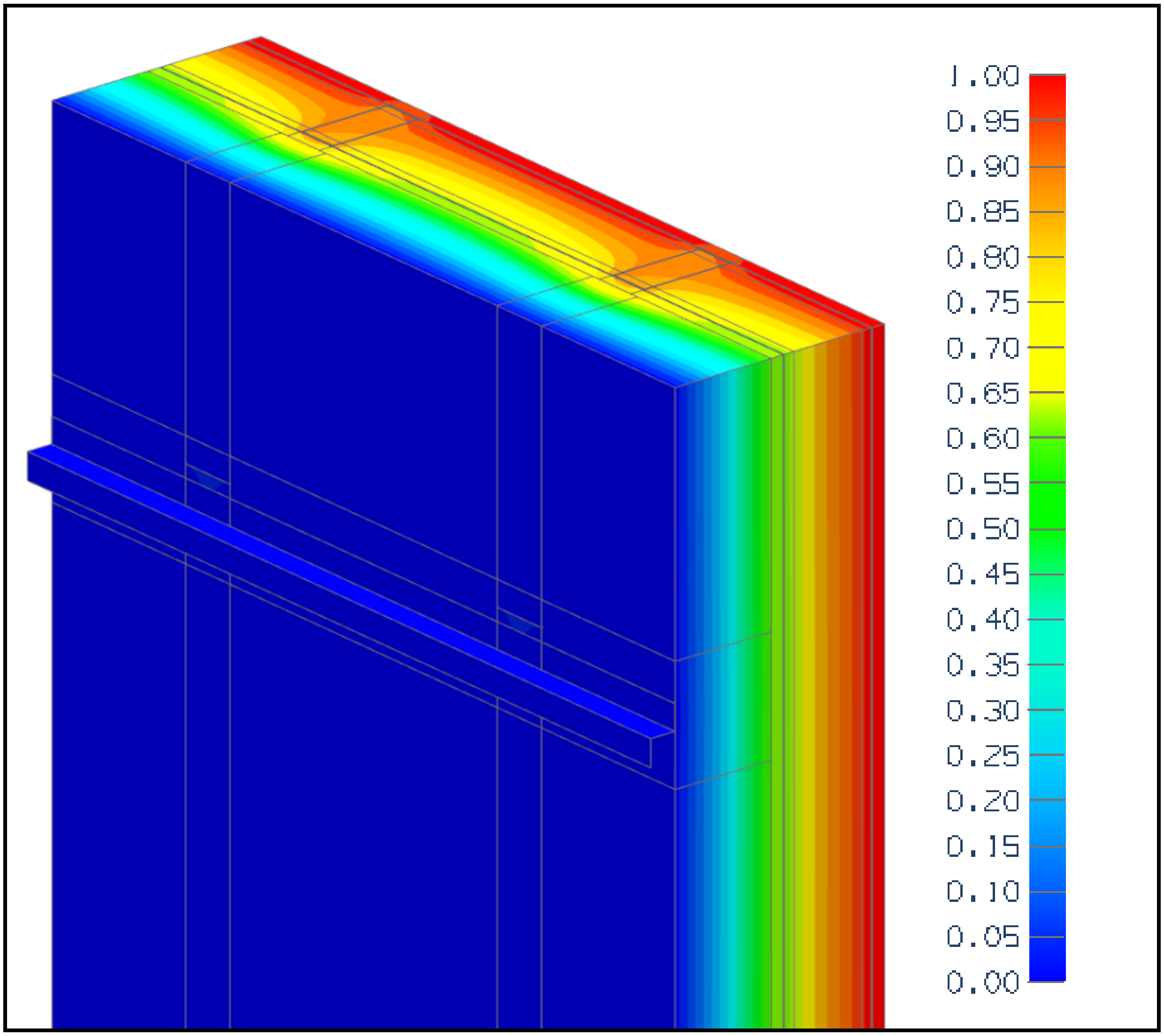

Figure D3: *Temperature Distribution for the 4" clip size with R12 interior insulation and clips vertically spaced at 24 inch.*