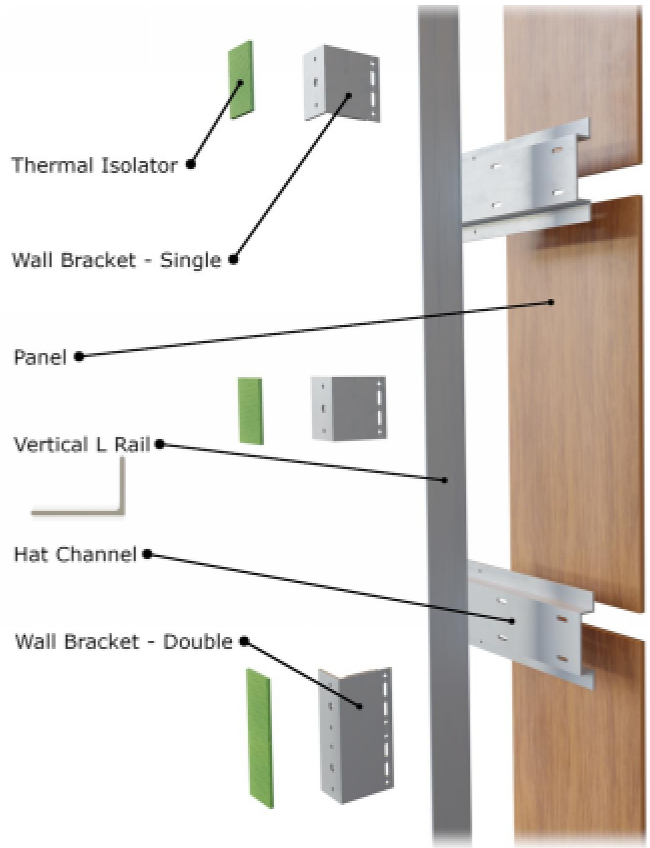
Monarch Metal Fabrication
Rain Screen Thermal Analysis



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MONARCH METAL FABRICATION

Table of Contents

Appendix

MONARCH
METAL FABRICATION

1.) Introduction

Rice Engineering Inc. has performed a thermal analysis of the rain screen support system per the request of Monarch Metal Fabrication. This analysis was performed using Berkeley Labs 2-D Therm7.7 software for various insulation thicknesses, clip depths, and with an insulated and un-insulated metal stud substrate. The purpose of this analysis was to determine the heat transfer into the building cavity due to penetrations in the building façade from the rain screen which are presented in U and R values.

Monarch Metal Fabrication rain screen system consist of an exterior panel type (HPL Phenolic Panels, Stone, Fiber Concrete, GFRC, HPL Plank Boards, Fiber Cement Panels, Hybrid Aluminum Wood Plastic Composites, Embedded GRFC, and Honeycomb Panels), a continuous aluminum panel extrusion, a continuous horizontal or vertical rail, a thermal isolator shim, and double and single clips as shown below in Figure 1-3.

Figure 1: Vertical Screen Example

Panel Components Shown:

Panel
Single Clip
Continuous vertical Rail
Panel Extrusion
Double Clip
Thermal Isolator Shim

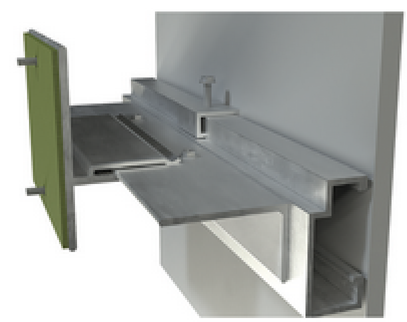

Figure 2: Horizontal Screen Clip

Figure 3: Vertical Screen Clip

2.) Modelling Inputs

The rain screen systems are comprised of a ½" thick interior gypsum, 6" x 1 5/8" steel stud with and without insulation, 5/8" thick exterior gypsum, ¼" thick Poron shim, Monarch Metal Fabrication clips, mineral wool insulation, and continuous L rail. All insulation has been assumed to be tight to the exterior gypsum. See Figure 4 and 5 for visual representation of insulation.

The various assortment of panel types that can be used with the Monarch Metal Fabrication sub framing for these rain screen systems have not been accounted for in the thermal modeling. A generic 1/16" thick painted aluminum sheet has been modeled which allows for a one-inch maximum air space at the panel to insulation interface.

All brackets, rail members, and panel attachment extrusions have been analyzed as mill finish aluminum while all fasteners have been analyzed as 300 series stainless steel. Emissivity and conductivity values of all materials come from NFRC 101/ISO 10077/ASHRAE or manufacturer data and can be found in Appendix D of this report. Exterior insulation thicknesses vary from 2" to 6" with variable clip depths, clip spacings vary from 24" to 48", and rail spacings of 16" and 32" have been analyzed as shown in the tables found in Section 3. The Poron shim used to separate the exterior gypsum from Monarch Metal Fabrication's sub framing is a key player in the thermal values. Shims with higher conductivity will directly affect the performance of rain screen systems as a whole as shown in Appendix E.

Thermal performance for commercial applications in North America are controlled by various entities. Common energy codes are the International Energy Conservation Code and ASHRAE 90.1. NFRC, ASTM and ISO standards in addition to the ASHRAE Fundamentals Handbook and various research papers from reputable sources are also available for informational purposes. There are differences in the performance requirements per building energy code which will need to be compared to the site-specific requirements of the jurisdiction which has authority over the project. It is not the intention of this report to dictate a governing code or standard.

The Therm figures shown in this package are for reference only and may not represent actual installation orientations. Due to the analysis being performed in 2D software, some profiles may have been rotated to establish a more accurate value.

Always refer to the construction documents, local codes, and local authority which has jurisdiction for the project for energy requirements.

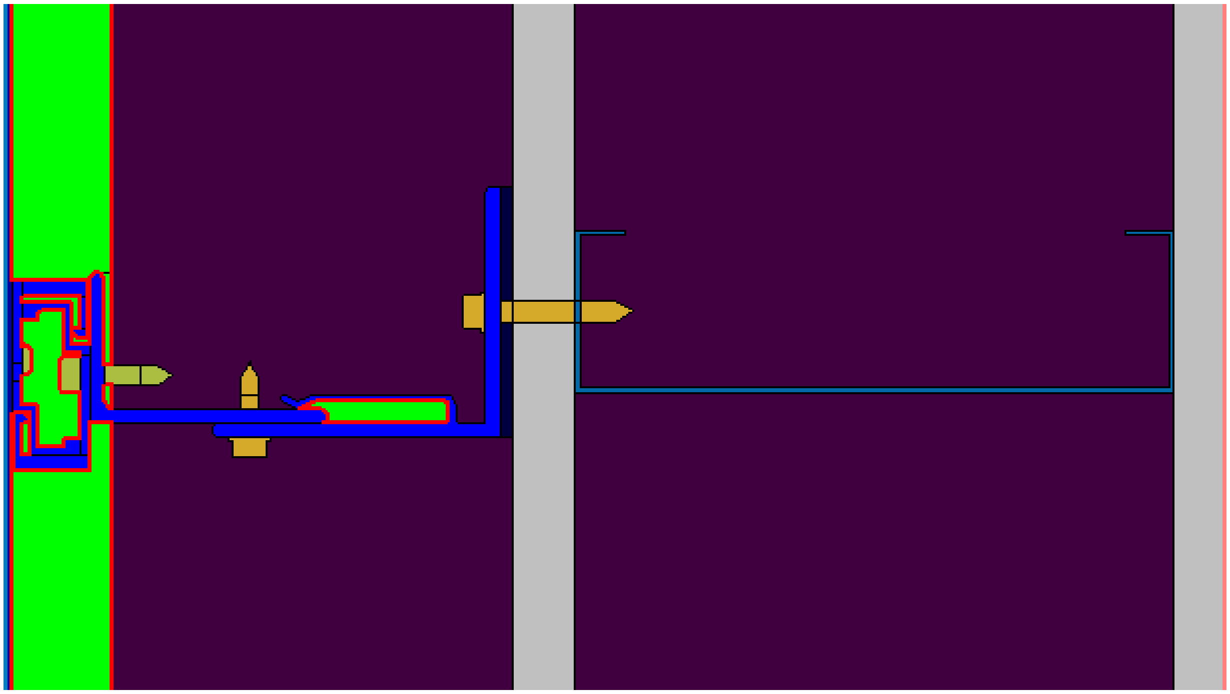

Figure 4: Therm7.7 4" Insulation with 3" Clip and Insulated Studs

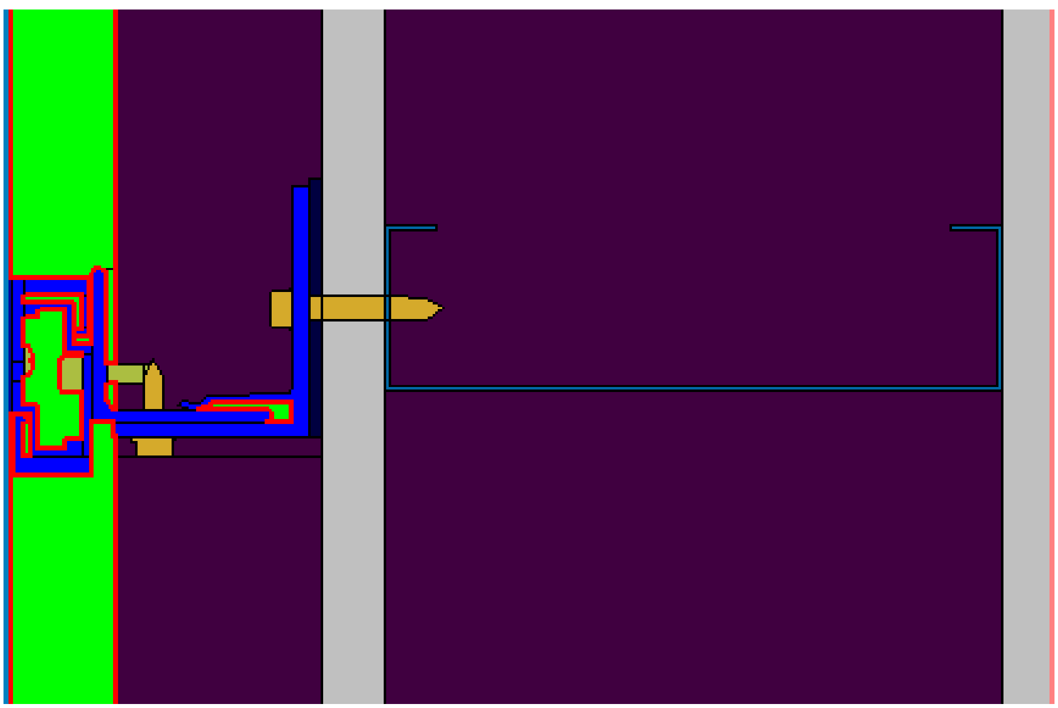

Figure 5: Therm7.7 2" Insulation with 2" Clip and Insulated Studs

*Note: 2" Insulation is the only time the 1 ¾" x 1 ½" rail is used

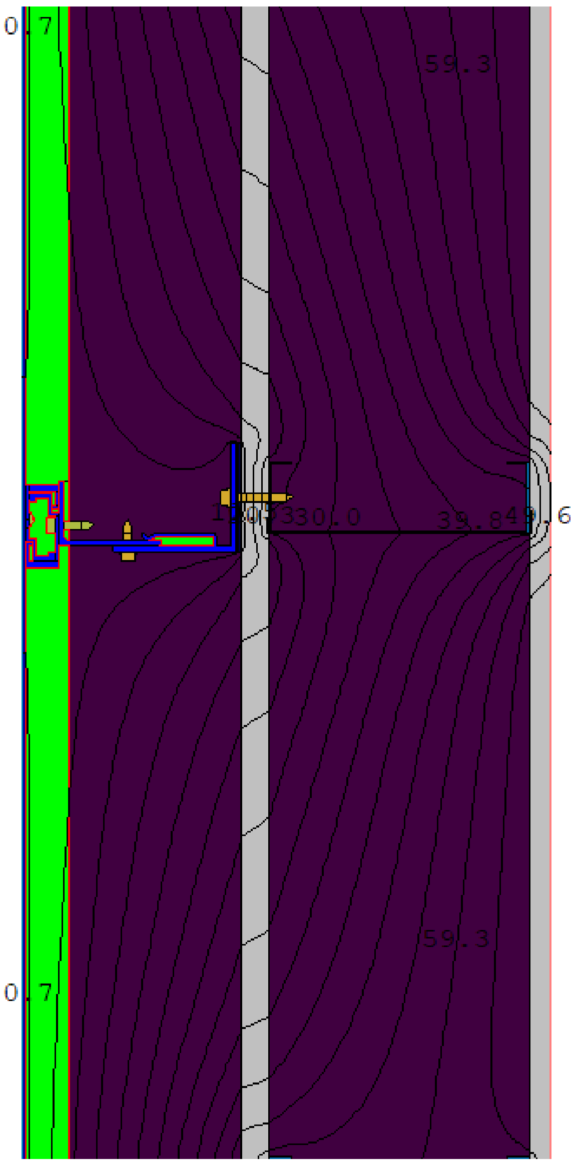

Figure 6: 4” Insulation with 3” Clip and Insulated Studs Isotherm Gradient

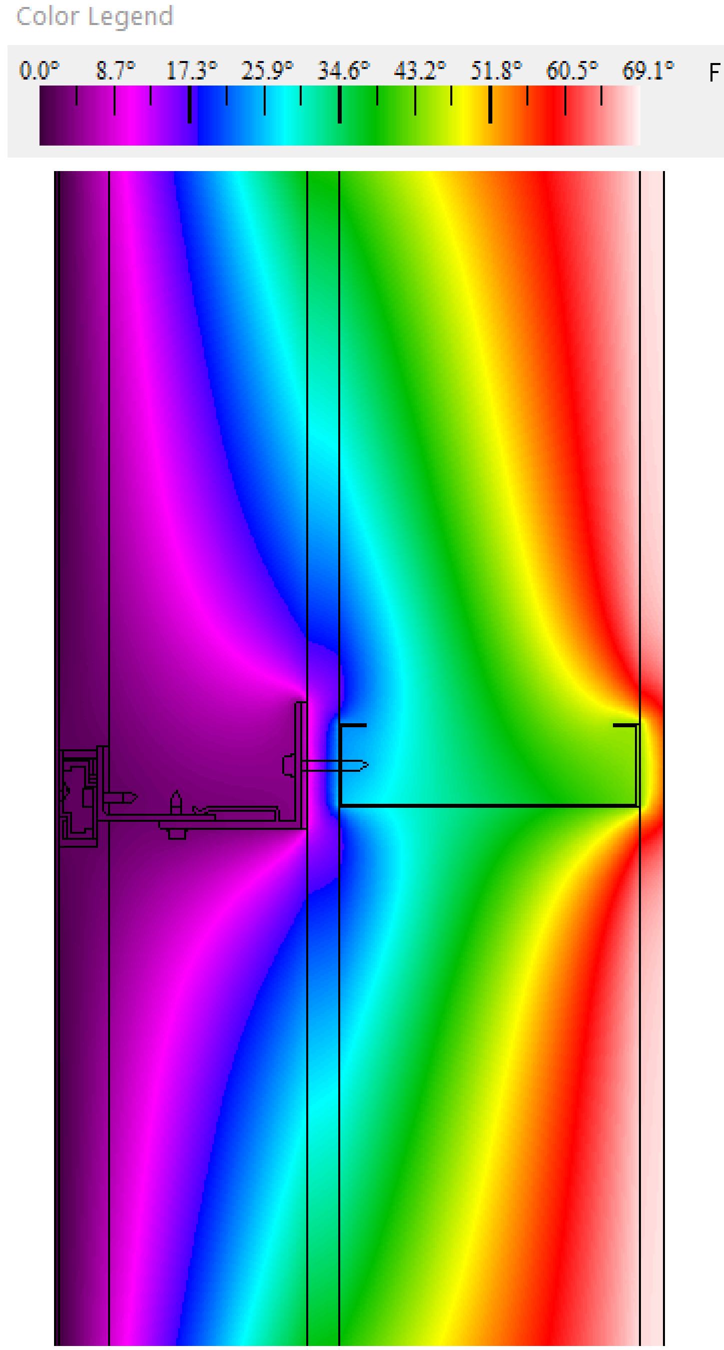

Figure 7: 4” Insulation with 3” Clip and Insulated Studs Infrared Gradient

3.) Thermal Analysis Results

The weighted assembly U values for a minimum of three clips per rail and two rails per panel have been statically analyzed as shown in Table 1 through Table 4. See Appendix A for U values in SI and R values in Imperial and SI. A sample of the calculations performed to achieve the values noted in the U and R Value tables is shown below.

CLIP SPACING OF 24" O.C.
STUD SPACING OF 16" O.C.

Inputs:

Panel:

$space\_stud := 16in$

$space\_clip := 24in$

$H := 4 \cdot space\_clip = 96in$

$W := 2 \cdot space\_stud = 32in$

Clips:

$n_{c\_short} := 2$

$n_{c\_long} := 1$

$L_{short} := 3.25in$

$L_{long} := 6.5in$

$C_{frame} := 2.94819in$

$C_{edge} := 5in$

Rail:

$n_r := 2$

$L_r := H = 96in$

$R_{frame} := 2.08731in$

$R_{edge} := 5in$

Horizontal:

$n_h := 2$

$L_h := 2in$

$H_{frame} := 2.94819in$

$H_{edge} := 5in$

Center:

$\lambda_{mw} := 0.0198 \frac{BTU}{hr \cdot ft \cdot F}$

$\lambda_{gyp} := 0.092 \frac{BTU}{hr \cdot ft \cdot F}$

$t_{mw} := 2in$

$t_{stud} := 6in$

$t_{ext} := 0.625in$

$t_{int} := 0.5in$

$U_{C\_Frame} := 0.2442 \frac{BTU}{hr \cdot ft^2 \cdot F}$ $U_{R\_Frame} := 0.0778 \frac{BTU}{hr \cdot ft^2 \cdot F}$ $U_{H\_Frame} := 0.2496 \frac{BTU}{hr \cdot ft^2 \cdot F}$

$U_{C\_Edge} := 0.0652 \frac{BTU}{hr \cdot ft^2 \cdot F}$ $U_{R\_Edge} := 0.0236 \frac{BTU}{hr \cdot ft^2 \cdot F}$ $U_{H\_Edge} := 0.0666 \frac{BTU}{hr \cdot ft^2 \cdot F}$

Calculations: *All Calculations Below This Line Are Automatic*

Clips:

$A_{C\_Frame} := (n_{c\_short} \cdot L_{short} + n_{c\_long} \cdot L_{long}) \cdot C_{frame} \cdot n_r = 76.65in^2$

$A_{C\_Edge} := (n_{c\_short} \cdot L_{short} + n_{c\_long} \cdot L_{long}) \cdot C_{edge} \cdot n_r = 130in^2$

Rail:

$A_{R\_Frame} := n_r \cdot L_r \cdot R_{frame} = 400.76in^2$

$A_{R\_Edge} := n_r \cdot L_r \cdot R_{edge} = 960in^2$

Horizontal:

$A_{H\_Frame} := n_h \cdot n_r \cdot L_h \cdot H_{frame} = 23.59in^2$

$A_{H\_Edge} := n_h \cdot n_r \cdot L_h \cdot H_{edge} = 40in^2$

Center:

$R_{mineral\_wool} := \frac{t_{mw}}{\lambda_{mw}} = 8.42 \frac{hr \cdot ft^2 \cdot F}{BTU}$

$R_{stud} := \frac{t_{stud}}{\lambda_{mw}} = 25.25 \frac{hr \cdot ft^2 \cdot F}{BTU}$

$R_{exterior} := \frac{t_{ext}}{\lambda_{gyp}} = 0.57 \frac{hr \cdot ft^2 \cdot F}{BTU}$

$R_{interior} := \frac{t_{int}}{\lambda_{gyp}} = 0.45 \frac{hr \cdot ft^2 \cdot F}{BTU}$

$R_{center} := R_{mineral\_wool} + R_{stud} + R_{exterior} + R_{interior} = 34.69 \frac{hr \cdot ft^2 \cdot F}{BTU}$

$U_{center} := \frac{1}{R_{center}} = 0.0288 \frac{BTU}{hr \cdot ft^2 \cdot F}$

Average Values:

$A_{total} := H \cdot W = 3072in^2$ Total Area of Panel

$A_{center} := A_{total} - A_{C\_Frame} - A_{C\_Edge} - A_{R\_Frame} - A_{R\_Edge} - A_{H\_Frame} - A_{H\_Edge} = 1441in^2$

$A\_U_C := A_{C\_Frame} \cdot U_{C\_Frame} + A_{C\_Edge} \cdot U_{C\_Edge} = 0.19 \frac{BTU}{hr \cdot F}$

$A\_U_R := A_{R\_Frame} \cdot U_{R\_Frame} + A_{R\_Edge} \cdot U_{R\_Edge} = 0.37 \frac{BTU}{hr \cdot F}$

$A\_U_H := A_{H\_Frame} \cdot U_{H\_Frame} + A_{H\_Edge} \cdot U_{H\_Edge} = 0.06 \frac{BTU}{hr \cdot F}$

$A\_U_{Center} := U_{center} \cdot A_{center} = 0.29 \frac{BTU}{hr \cdot F}$

$U := \frac{A\_U_C + A\_U_R + A\_U_H + A\_U_{Center}}{A_{total}} = 0.0427 \frac{BTU}{hr \cdot ft^2 \cdot F}$

System Totals:

$U_T := U = 0.04268 \frac{BTU}{hr \cdot ft^2 \cdot F}$

$R_T := \frac{1}{U_T} = 23.43 \frac{hr \cdot ft^2 \cdot F}{BTU}$

Figure 6: U Value Calculation – Insulated Studs, 5" Insulation, 4" Clip, 16" Rail Spacing, 24" Clip Spacing.

Table 1: U Value Vertical Rail with Insulated Stud Substrate

Vertical Rail with Insulated 6" Steel Studs					
Rail Spacing (in)	Insulation Thickness (in)	Clip Depth (in)	U Value (BTU/hr*ft^2*°F)		
			24" Clip Spacing	36" Clip Spacing	48" Clip Spacing
16	2	2	0.051	0.048	0.047
	3	2	0.052	0.050	0.049
	3	3	0.052	0.050	0.049
	4	3	0.050	0.047	0.045
	4	4	0.046	0.044	0.043
	5	4	0.043	0.040	0.039
	5	5	0.046	0.043	0.041
	6	5	0.043	0.040	0.039
32	2	2	0.040	0.039	0.038
	3	2	0.040	0.039	0.039
	3	3	0.041	0.039	0.039
	4	3	0.039	0.038	0.037
	4	4	0.038	0.037	0.036
	5	4	0.036	0.034	0.034
	5	5	0.037	0.036	0.035
	6	5	0.036	0.035	0.034

Table 2: U Value Vertical Rail with Un-Insulated Stud Substrate

Vertical Rail with Un-Insulated 6" Steel Studs					
Rail Spacing (in)	Insulation Thickness (in)	Clip Depth (in)	U Value (BTU/hr*ft^2*°F)		
			24" Clip Spacing	36" Clip Spacing	48" Clip Spacing
16	2	2	0.084	0.083	0.082
	3	2	0.073	0.072	0.072
	3	3	0.074	0.073	0.073
	4	3	0.057	0.056	0.056
	4	4	0.057	0.056	0.056
	5	4	0.047	0.046	0.045
	5	5	0.048	0.046	0.456
	6	5	0.046	0.043	0.042
32	2	2	0.079	0.078	0.078
	3	2	0.073	0.072	0.072
	3	3	0.074	0.073	0.073
	4	3	0.057	0.056	0.056
	4	4	0.057	0.056	0.056
	5	4	0.046	0.046	0.045
	5	5	0.046	0.046	0.045
	6	5	0.042	0.041	0.040

Table 3: U Value Horizontal Rail with Insulated Stud Substrate

Horizontal Rail with Insulated 6" Steel Studs					
Rail Spacing (in)	Insulation Thickness (in)	Clip Depth (in)	U Value (BTU/hr*ft^2*°F)		
			24" Clip Spacing	36" Clip Spacing	48" Clip Spacing
16	2	2	0.054	0.046	0.041
	3	2	0.054	0.051	0.052
	3	3	0.055	0.053	0.053
	4	3	0.048	0.046	0.045
	4	4	0.048	0.046	0.046
	5	4	0.045	0.042	0.042
	5	5	0.048	0.045	0.044
	6	5	0.046	0.043	0.042
32	2	2	0.042	0.041	0.040
	3	2	0.042	0.041	0.041
	3	3	0.042	0.042	0.042
	4	3	0.040	0.039	0.038
	4	4	0.039	0.038	0.038
	5	4	0.038	0.037	0.036
	5	5	0.040	0.038	0.037
	6	5	0.039	0.037	0.036

Table 4: U Value Horizontal Rail with Un-Insulated Stud Substrate

Horizontal Rail with Un-Insulated 6" Steel Studs					
Rail Spacing (in)	Insulation Thickness (in)	Clip Depth (in)	U Value (BTU/hr*ft^2*°F)		
			24" Clip Spacing	36" Clip Spacing	48" Clip Spacing
16	2	2	0.108	0.107	0.107
	3	2	0.083	0.080	0.078
	3	3	0.084	0.080	0.078
	4	3	0.069	0.064	0.062
	4	4	0.069	0.064	0.062
	5	4	0.059	0.054	0.052
	5	5	0.059	0.549	0.052
	6	5	0.053	0.048	0.045
32	2	2	0.101	0.102	0.103
	3	2	0.077	0.075	0.075
	3	3	0.077	0.076	0.075
	4	3	0.061	0.059	0.059
	4	4	0.061	0.059	0.059
	5	4	0.051	0.049	0.048
	5	5	0.052	0.049	0.048
	6	5	0.045	0.043	0.041

Appendix A
Alternative U Value units and R Values

The tables in this appendix are for alternative U values as well as the R values.

Table A1: U Value Vertical Rail with Insulated Stud Substrate Alt. Units

Vertical Rail with Insulated 6" Steel Studs					
Rail Spacing (in)	Insulation Thickness (in)	Clip Depth (in)	U Value (W/m^2*K)		
			24" Clip Spacing	36" Clip Spacing	48" Clip Spacing
16	2	2	0.287	0.275	0.268
	3	2	0.293	0.282	0.277
	3	3	0.297	0.285	0.278
	4	3	0.284	0.264	0.255
	4	4	0.262	0.251	0.246
	5	4	0.242	0.225	0.221
	5	5	0.261	0.244	0.235
	6	5	0.246	0.229	0.220
32	2	2	0.225	0.219	0.216
	3	2	0.229	0.223	0.220
	3	3	0.230	0.224	0.221
	4	3	0.223	0.214	0.209
	4	4	0.213	0.207	0.205
	5	4	0.203	0.194	0.193
	5	5	0.212	0.204	0.199
	6	5	0.205	0.196	0.192

Table A2: U Value Vertical Rail with Un-Insulated Stud Substrate Alt. Units

Vertical Rail with Un-Insulated 6" Steel Studs					
Rail Spacing (in)	Insulation Thickness (in)	Clip Depth (in)	U Value (W/m^2*K)		
			24" Clip Spacing	36" Clip Spacing	48" Clip Spacing
16	2	2	0.478	0.471	0.467
	3	2	0.414	0.408	0.408
	3	3	0.420	0.412	0.414
	4	3	0.324	0.318	0.315
	4	4	0.324	0.318	0.315
	5	4	0.268	0.261	0.257
	5	5	0.270	0.262	2.589
	6	5	0.263	0.245	0.236
32	2	2	0.447	0.443	0.442
	3	2	0.413	0.411	0.410
	3	3	0.418	0.414	0.412
	4	3	0.321	0.318	0.316
	4	4	0.321	0.318	0.316
	5	4	0.263	0.259	0.257
	5	5	0.263	0.260	0.258
	6	5	0.239	0.230	0.226

Table A3: R Value Vertical Rail with Insulated Stud Substrate

Vertical Rail with Insulated 6" Steel Studs					
Rail Spacing (in)	Insulation Thickness (in)	Clip Depth (in)	R Value (hr*ft^2*°F/BTU)		
			24" Clip Spacing	36" Clip Spacing	48" Clip Spacing
16	2	2	19.759	20.657	21.137
	3	2	19.339	20.109	20.521
	3	3	19.106	19.936	20.379
	4	3	20.000	21.478	22.227
	4	4	21.654	22.599	23.100
	5	4	23.474	25.221	25.641
	5	5	21.734	23.277	24.131
	6	5	23.089	24.802	25.753
32	2	2	25.176	25.893	26.267
	3	2	24.832	25.458	25.786
	3	3	24.643	25.323	25.674
	4	3	25.471	26.532	27.093
	4	4	26.660	27.367	27.732
	5	4	27.964	29.206	29.412
	5	5	26.724	27.863	28.466
	6	5	27.724	28.927	29.560

Table A4: R Value Vertical Rail with Un-Insulated Stud Substrate

Vertical Rail with Un-Insulated 6" Steel Studs					
Rail Spacing (in)	Insulation Thickness (in)	Clip Depth (in)	R Value (hr*ft²*°F/BTU)		
			24" Clip Spacing	36" Clip Spacing	48" Clip Spacing
16	2	2	11.867	12.048	12.142
	3	2	13.717	13.908	13.908
	3	3	13.495	13.757	13.717
	4	3	17.498	17.857	18.018
	4	4	17.513	17.870	18.018
	5	4	21.182	21.772	22.075
	5	5	21.039	21.622	2.192
	6	5	21.603	23.164	24.038
32	2	2	12.694	12.798	12.850
	3	2	13.732	13.814	13.856
	3	3	13.570	13.701	13.768
	4	3	17.674	17.854	17.947
	4	4	17.680	17.864	17.953
	5	4	21.612	21.915	22.070
	5	5	21.538	21.839	21.993
	6	5	23.708	24.624	25.107

Table A5: R Value Vertical Rail with Insulated Stud Substrate Alt. Units

Vertical Rail with Insulated 6" Steel Studs					
Rail Spacing (in)	Insulation Thickness (in)	Clip Depth (in)	R Value (m²*K/W)		
			24" Clip Spacing	36" Clip Spacing	48" Clip Spacing
16	2	2	3.482	3.640	3.725
	3	2	3.408	3.544	3.616
	3	3	3.367	3.513	3.591
	4	3	3.525	3.785	3.917
	4	4	3.816	3.983	4.071
	5	4	4.137	4.445	4.519
	5	5	3.830	4.102	4.253
	6	5	4.069	4.371	4.538
32	2	2	4.437	4.563	4.629
	3	2	4.376	4.486	4.544
	3	3	4.343	4.463	4.524
	4	3	4.489	4.676	4.775
	4	4	4.698	4.823	4.887
	5	4	4.928	5.147	5.183
	5	5	4.709	4.910	5.016
	6	5	4.886	5.098	5.209

Table A6: R Value Vertical Rail with Un-Insulated Stud Substrate Alt. Units

Vertical Rail with Un-Insulated 6" Steel Studs					
Rail Spacing (in)	Insulation Thickness (in)	Clip Depth (in)	R Value (m^2*K/W)		
			24" Clip Spacing	36" Clip Spacing	48" Clip Spacing
16	2	2	2.091	2.123	2.140
	3	2	2.417	2.451	2.451
	3	3	2.378	2.424	2.417
	4	3	3.084	3.147	3.175
	4	4	3.086	3.149	3.175
	5	4	3.733	3.837	3.890
	5	5	3.708	3.810	0.386
	6	5	3.807	4.082	4.236
32	2	2	2.237	2.255	2.265
	3	2	2.420	2.434	2.442
	3	3	2.391	2.414	2.426
	4	3	3.115	3.146	3.163
	4	4	3.116	3.148	3.164
	5	4	3.809	3.862	3.889
	5	5	3.796	3.849	3.876
	6	5	4.178	4.340	4.425

Table A7: U Value Horizontal Rail with Insulated Stud Substrate Alt. Units

Horizontal Rail with Insulated 6" Steel Studs					
Rail Spacing (in)	Insulation Thickness (in)	Clip Depth (in)	U Value (W/m^2*K)		
			24" Clip Spacing	36" Clip Spacing	48" Clip Spacing
16	2	2	0.306	0.259	0.235
	3	2	0.308	0.291	0.293
	3	3	0.315	0.302	0.298
	4	3	0.272	0.263	0.257
	4	4	0.275	0.261	0.260
	5	4	0.256	0.238	0.239
	5	5	0.274	0.256	0.249
	6	5	0.263	0.243	0.236
32	2	2	0.237	0.232	0.229
	3	2	0.240	0.235	0.233
	3	3	0.239	0.238	0.236
	4	3	0.227	0.219	0.217
	4	4	0.223	0.218	0.217
	5	4	0.213	0.208	0.205
	5	5	0.225	0.216	0.209
	6	5	0.219	0.208	0.203

Table A8: U Value Horizontal Rail with Un-Insulated Stud Substrate Alt. Units

Horizontal Rail with Un-Insulated 6" Steel Studs					
Rail Spacing (in)	Insulation Thickness (in)	Clip Depth (in)	U Value (W/m²*K)		
			24" Clip Spacing	36" Clip Spacing	48" Clip Spacing
16	2	2	0.613	0.609	0.607
	3	2	0.473	0.454	0.445
	3	3	0.474	0.455	0.445
	4	3	0.389	0.366	0.354
	4	4	0.390	0.366	0.354
	5	4	0.335	0.309	0.296
	5	5	0.336	3.118	0.297
	6	5	0.299	0.271	0.257
32	2	2	0.571	0.581	0.586
	3	2	0.435	0.428	0.425
	3	3	0.435	0.429	0.426
	4	3	0.347	0.337	0.332
	4	4	0.347	0.337	0.333
	5	4	0.290	0.279	0.274
	5	5	0.292	0.281	0.275
	6	5	0.254	0.241	0.235

Table A9: R Value Horizontal Rail with Insulated Stud Substrate

Horizontal Rail with Insulated 6" Steel Studs					
Rail Spacing (in)	Insulation Thickness (in)	Clip Depth (in)	R Value (hr*ft²*°F/BTU)		
			24" Clip Spacing	36" Clip Spacing	48" Clip Spacing
16	2	2	18.529	21.935	24.155
	3	2	18.418	19.523	19.360
	3	3	18.024	18.808	19.046
	4	3	20.880	21.581	22.097
	4	4	20.623	21.730	21.792
	5	4	22.145	23.793	23.742
	5	5	20.699	22.169	22.765
	6	5	21.579	23.398	24.068
32	2	2	23.977	24.428	24.781
	3	2	23.650	24.131	24.327
	3	3	23.695	23.889	23.994
	4	3	24.989	25.917	26.205
	4	4	25.390	26.064	26.162
	5	4	26.633	27.295	27.747
	5	5	25.211	26.286	27.110
	6	5	25.910	27.289	27.886

Table A10: R Value Horizontal Rail with Un-Insulated Stud Substrate

Horizontal Rail with Un-Insulated 6" Steel Studs					
Rail Spacing (in)	Insulation Thickness (in)	Clip Depth (in)	R Value (hr*ft²*°F/BTU)		
			24" Clip Spacing	36" Clip Spacing	48" Clip Spacing
16	2	2	9.259	9.319	9.348
	3	2	11.990	12.495	12.765
	3	3	11.962	12.475	12.749
	4	3	14.571	15.523	16.046
	4	4	14.556	15.511	16.036
	5	4	16.943	18.362	19.168
	5	5	16.866	1.820	19.117
	6	5	18.986	20.921	22.041
32	2	2	9.945	9.770	9.684
	3	2	13.057	13.247	13.344
	3	3	13.033	13.231	13.332
	4	3	16.348	16.821	17.068
	4	4	16.343	16.818	17.065
	5	4	19.539	20.313	20.725
	5	5	19.417	20.227	20.657
	6	5	22.326	23.502	24.137

Table A11: R Value Horizontal Rail with Insulated Stud Substrate Alt. Units

Horizontal Rail with Insulated 6" Steel Studs					
Rail Spacing (in)	Insulation Thickness (in)	Clip Depth (in)	R Value (m²*K/W)		
			24" Clip Spacing	36" Clip Spacing	48" Clip Spacing
16	2	2	3.265	3.865	4.257
	3	2	3.246	3.440	3.412
	3	3	3.176	3.314	3.356
	4	3	3.680	3.803	3.894
	4	4	3.634	3.829	3.840
	5	4	3.903	4.193	4.184
	5	5	3.648	3.907	4.012
	6	5	3.803	4.123	4.242
32	2	2	4.225	4.305	4.367
	3	2	4.168	4.253	4.287
	3	3	4.176	4.210	4.228
	4	3	4.404	4.567	4.618
	4	4	4.474	4.593	4.610
	5	4	4.693	4.810	4.890
	5	5	4.443	4.632	4.778
	6	5	4.566	4.809	4.914

Table A12: R Value Horizontal Rail with Un-Insulated Stud Substrate Alt. Units

Horizontal Rail with Un-Insulated 6" Steel Studs					
Rail Spacing (in)	Insulation Thickness (in)	Clip Depth (in)	R Value (m^2*K/W)		
			24" Clip Spacing	36" Clip Spacing	48" Clip Spacing
16	2	2	1.632	1.642	1.647
	3	2	2.113	2.202	2.250
	3	3	2.108	2.198	2.247
	4	3	2.568	2.736	2.828
	4	4	2.565	2.733	2.826
	5	4	2.986	3.236	3.378
	5	5	2.972	0.321	3.369
	6	5	3.346	3.687	3.884
32	2	2	1.753	1.722	1.707
	3	2	2.301	2.334	2.352
	3	3	2.297	2.332	2.349
	4	3	2.881	2.964	3.008
	4	4	2.880	2.964	3.007
	5	4	3.443	3.580	3.652
	5	5	3.422	3.564	3.640
	6	5	3.935	4.142	4.254

Appendix B
Materials and Conductivities

Table B1: Therm7.7 Materials and Conductivities Used

Therm 7.7 Materials			
Color	Material	Conductivity	
		BTU/hr*ft*°F	W/m*K
	Painted Aluminum Alloy	92.4463	160.000
	Mill Finish Aluminum Alloy	92.4463	160.000
	Air Frame Cavity	Varies	Varies
	Screw	0.3062	0.530
	Screw	0.1961	0.339
	Mineral Wool	0.0198	0.034
	Poron Shim	0.051	0.088
	Gypsum Board	0.092	0.159
	Galvanized Steel	35.8229	62.000

Table B2: Sample Effective K Value for Thermal Bridging Screws*

Cross Section	Material	Conductivity (W/mK)	Depth (m)	Conductivity (Btu/h-ft-F)	Depth (in)	R (m2K/W)	R (h-ft-F/Btu)
1	Air Cavity - Default is 0.024 W/mK	0.024	0.00530352	0.014	0.2088	0.2190	14.9143
2	Aluminum Alloy - Mill Finish	159.893	0.00562864	92.446	0.2216	0.0000	0.0024
3	Air Cavity - Default is 0.024 W/mK	0.024	0.00250	0.014	0.0983	0.1031	7.0214
4	Mineral Wool	0.034	0.00000	0.020	0.43	0.0000	21.7172
5		0.000	0	0.000	0	0.0000	0.0000
6		0.000	0	0.000	0	0.0000	0.0000
7		0.000	0	0.000	0	0.0000	0.0000
			0.01343		**0.9587**	**0.3222**	**43.6553**
			Dt		**Dt**	**Rt**	**Rt**
	Calculated conductivity		Metric		Inch-Pounds		
			Kn = Dt/Rt		Kn = Dt/Rt		
		Kn=	0.0417		0.02		
			(W/m*K)		(Btu/hr*F)		
	Other conductivities required		SI Units		IP Units		
		Stainless steel:					
		Kb=	14.30		8.2628		
			(W/mK)		(Btu/h*ft*F)		
	Calculate the fraction of bolt to no bolt:						
		Bolt head width:					
		Wb=	10.5		0.4139		
		Bolt spacing:					
		Sb=	304.8		12		
	Fraction of thermal bridging:						
		Fb=	0.034		0.034		
			3.4	%	3.4	%	
	Fraction of non thermal bridging:						
		Fn=	0.966		0.966		
			96.6	%	96.6	%	
		New keff in Therm:	(Fb*Kb+Fn*Kn)				
		keff=	0.53		0.30620097		
			(W/mK)		(Btu/h*ft*F)		

* Procedure outlined in NFRC Simulation Manual

Appendix C
Therm7.7 Profiles

Due to the number of models required for a 2D analysis, only a portion of the profiles are shown for informational purposes only. Available information is available upon request.

The three model profiles shown in Figures C1-C3 have been performed for insulated and un-insulated studs as well as each insulation thickness and clip depth.

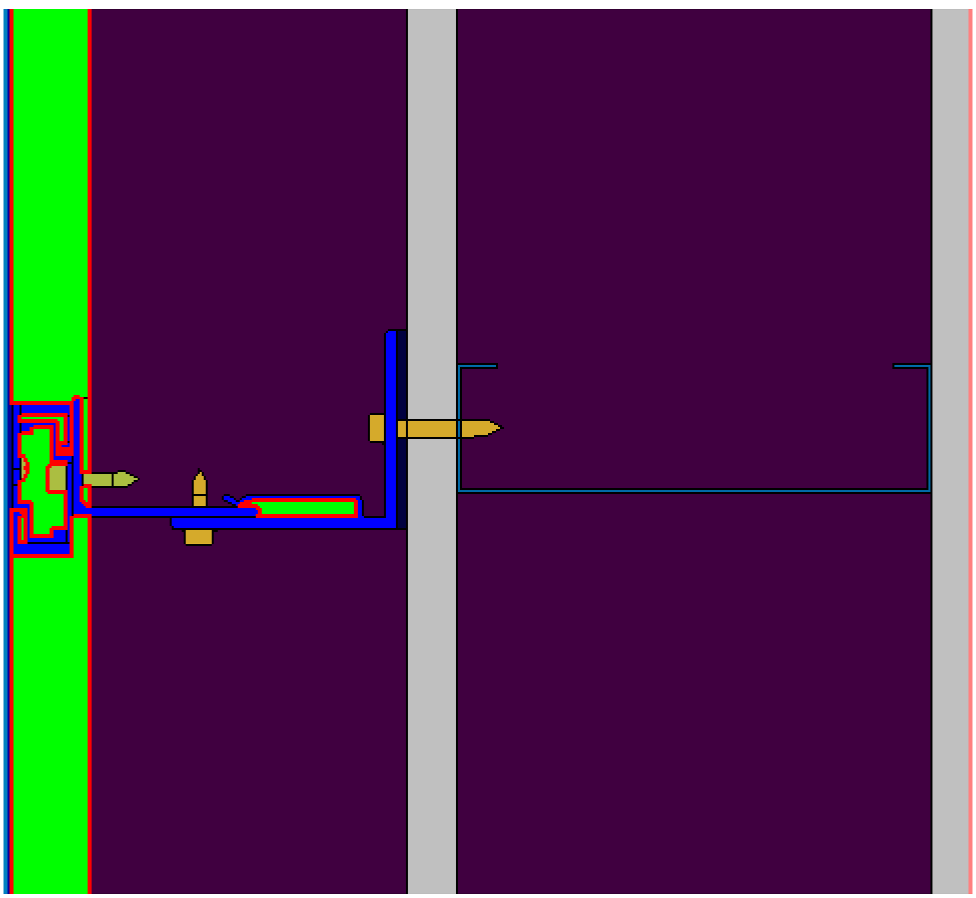

Figure C1: Therm7.7 Profile: Clips, Rail, Horizontal

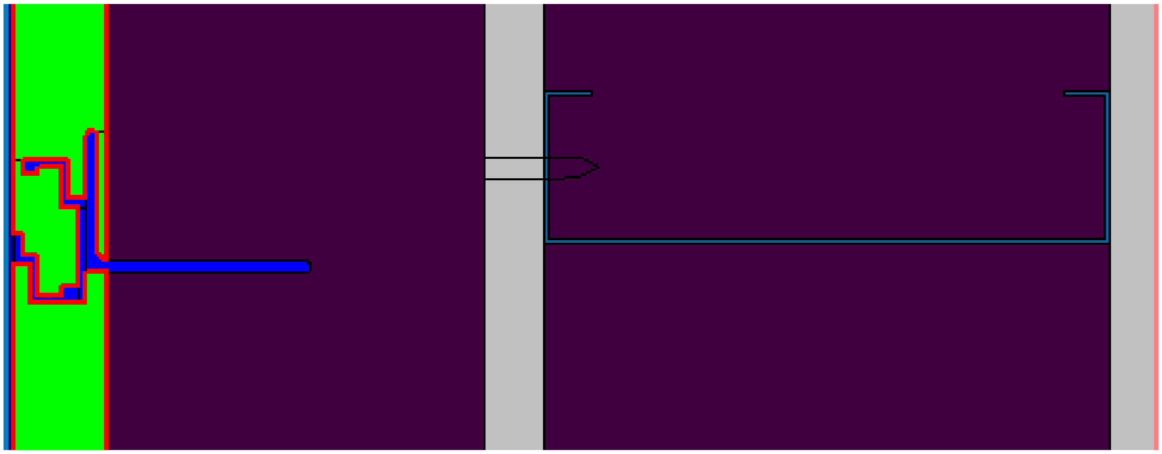

Figure C2: Therm7.7 Continuous Profile: Rail

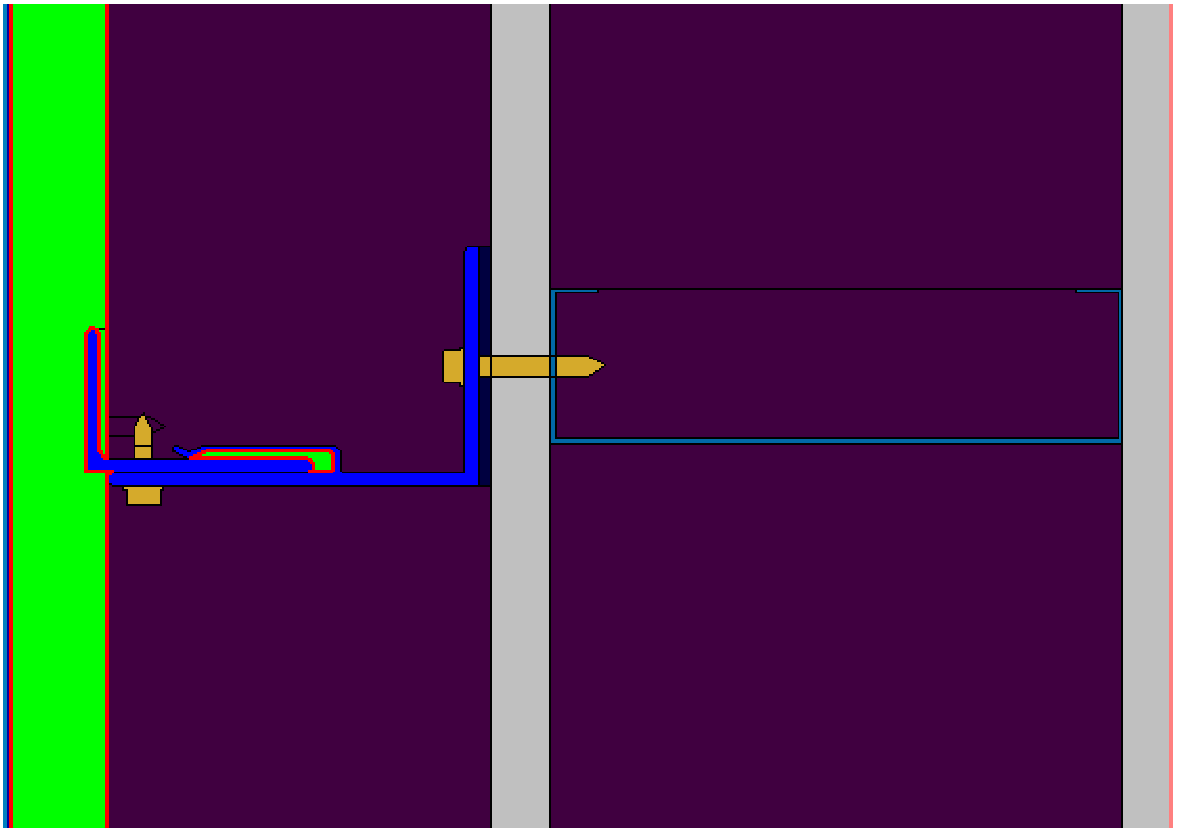

Figure C3: Therm7.7 Profile: Clips, Rail

Appendix D
Reference Material

Table D1: NFRC 101 Partial Table A.1 Thermophysical Properties of Solid Materials

Name	Conductivity k			Source[2]	Emissivity ε
	W/m•K	Btu/hr•ft•F	Btu•in/hr•ft²•°F	-	-
Timbers					
Coniferous woods (Softwoods)	0.140	0.081	0.971	4,8	0.9
Deciduous woods (Hardwoods)	0.160	0.092	1.109	4,,8	0.9
Note: Values are for 12% moisture content. This value may be applied to products of any moisture content for the purposes of this document.					
Wood based panels					
Fiberboard	0.110	0.064	0.763	8	0.9
Particleboard, Plywood	0.240	0.139	1.664	1	0.9
Metals					
Aluminum alloys (mill finish)	160.000	92.446	1109.357	1,4,8, 16, 17	0.05
Aluminum alloys (anodized)	160.000	92.446	1109.357	1,4,8, 16, 17	0.8
Aluminum alloys (painted)	160.000	92.446	1109.357	1,4,8, 16, 17	0.9
Steel (plated)	50.000	28.890	346.674	1, 13	0.05
Steel (rolled, ground)	50.000	28.890	346.674	1, 13	0.1
Steel (rolled, ground, plated)	50.000	28.890	346.674	1	0.2
Steel Stainless (oxidized)	17.000	9.822	117.869	1	0.8
Steel Stainless (buffed)	17.000	9.822	117.869	1	0.2
Steel-galvanized sheet (0.14%C)	62.0	35.823	429.876	8	0.2
Glazing Materials					
Glass (Plate or Float)	1.000	0.578	6.933	1,4,8	0.84
Glass mosaic	1.200	0.693	8.320	1	0.84
Glass-Flint (lead), Pyrex	1.400	0.809	9.707	3	0.84
Glass-Quartz	1.400	0.809	9.707	1	0.90
Plexiglass (PMMA) / Lucite	0.200	0.116	1.387	8	0.90

Table D2: ASHRAE Handbook of Fundamentals Partial Table 3 Properties of Solids

Material Description	Specific Heat, J/(kg·K)	Density, kg/m^3	Thermal Conductivity, W/(m·K)	Emissivity Ratio	Emissivity Surface Condition
Aluminum (alloy 1100)	896[b]	2 740[a]	221[a]	0.09[a] 0.20[a]	Commercial sheet Heavily oxidized
Aluminum bronze (76% Cu, 22% Zn, 2% Al)	400[a]	8 280[a]	100[a]		
Asbestos: Fiber	1050[b]	2 400[a]	0.170[a]		
Insulation	800[f]	580[b]	0.16[b]	0.93[b]	"Paper"
Ashes, wood	800[f]	640[b]	0.071[b] (50)		
Asphalt	920[b]	2 110[b]	0.74[b]		
Bakelite	1500[b]	1 300[a]	17[a]		
Bell metal	360[f] (50)				
Bismuth tin	170*		65.0*		
Brick, building	800[b]	1 970[a]	0.7[b]	0.93*	

Table D3: NFRC 100 Table 4-2 Boundary Conditions

Boundary Condition	Radiation Model	Convective Film Coefficient Boundary Tilt = 90° W/m^2K ($Btu/h·ft^2·°F$)	Tilt = 20° W/m^2K ($Btu/h·ft^2·°F$)
NFRC 100-2001 Exterior	Blackbody	26.00 (4.578)	26.00 (4.578)
Interior Aluminum Frame (convection only)	Automatic Enclosure Model	3.29 (0.579)	4.65 (0.819)
Interior Thermally Broken Frame (convection only)	Automatic Enclosure Model	3.00 (0.528)	4.09 (0.720)

ROGERS CORPORATION

PORON® Urethane Foams

Product Data Sheet

PORON® 4701-60 Very Firm

PROPERTY	TEST METHOD	VALUE		
PHYSICAL				
Density, lb. / ft^3 (kg /m^3)	ASTM D 3574-95, Test A	15 (240)	20 (320)	25 (400)
Tolerance, %		**± 10**		
Thickness, inches (mm)		0.125 - 0.250 (3.18 – 6.35)	0.031 - 0.188 (0.79 – 4.78)	0.031 - 0.093 (0.79 – 2.36)
Tolerance, %		**± 10**		**± 15**
Standard Color (Code)		Black (04)		
Compression Force Deflection, psi (kPa) **Typical psi (kPa)**	0.2" / min. Strain Rate Force Measured @ 25% Deflection	18 - 50 (124 - 345) **36 (249)**	25 - 85 (172 - 586) **62 (428)**	50 - 130 (345 - 896) **93 (643)**
Hardness, Durometer, Shore "O", **Shore "A"**	ASTM D 2240-97	42 **30**	55 **42**	63 **53**
Compression Set, % max.	ASTM D 3574-95 Test D @ 73°F (23°C)	5		
	ASTM D 3574-95 Test D @ 158°F (70°C)	10		
	ASTM D 3574-95 Test J/Test D autoclaved 5 hrs @ 250°F (121°C)	10		
Dimensional Stability, % max. change	22 hrs @ 176°F (80°C) in a forced-air oven	± 5		
Tensile Strength, Min. psi (kPa), **Typical psi (kPa)**	ASTM D 3574-75 Test E	135 (931) **170 (1175)**	200 (1382) **275 (1901)**	250 (1724) **380 (2627)**
Tensile Elongation, % min., **Typical**	ASTM D 3574-75 Test E	50 **75**	45 **75**	50 **75**
Tear Strength, Min. pli (kN/m), **Typical pli (kN/m)**	ASTM D 264-91 Die C	12 (2.1) **19 (3.3)**	17 (3.0) **25 (4.4)**	19 (3.3) **30 (5.3)**
ELECTRICAL AND THERMAL				
Dielectric Constant, K' ("DK")	ASTM D 150 measurements at 72°F (22°C) relative humidity 50% for 24 hrs.	1.60		
Dielectric Strength, volts/mil	ASTM D 149-97a	50		
Dissipation Factor, tan D ("DF")	ASTM D 150-98	0.05		
Volume Resistivity, ohm-cm	ASTM D 257-99	7 x 10^{12}		
Surface Resistivity, ohm/sq.	ASTM D 257-99	3 x 10^{12}		
Thermal Conductivity, W/m-C (BTU-in./hr/ft^2-F)	ASTM C 518-98	-	0.088 (0.61)	-
Coefficient of Thermal Expansion		2.3 - 3.1 x 10^{-4} in./in./°C		

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Figure D1: Poron Shim Properties

Appendix E
Comparative Shim Review

As the shim is the last defense of exterior temperatures penetrating the building face, the lower the conductivity of shim, the better the system will perform. The purpose of this comparative analysis is to show how different common shim materials used in the industry can affect the performance.

U-Factors

	U-factor Btu/h-ft2-F
Edge	0.0675
Frame	0.2519

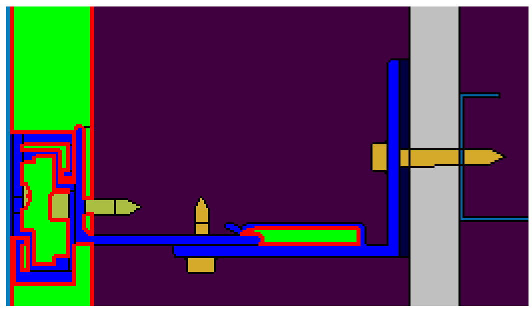

Figure E1: Therm7.7 4” Insulation with 3” Clip and Insulated Studs – Poron 4701-60 Shim (Conductivity of Poron = 0.0508 BTU/hr*ft*F)

U-Factors

	U-factor Btu/h-ft2-F
Edge	0.0700
Frame	0.2620

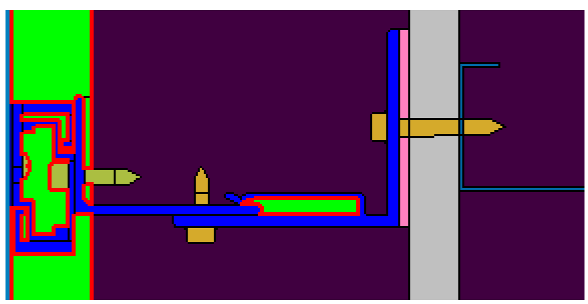

Figure E2: Therm7.7 4” Insulation with 3” Clip and Insulated Studs – Polyamide 6.6 Shim (Conductivity of Polyamide 6.6 = 0.1733 BTU/hr*ft*F)

U-Factors

	U-factor Btu/h-ft2-F
Edge	0.0691
Frame	0.2583

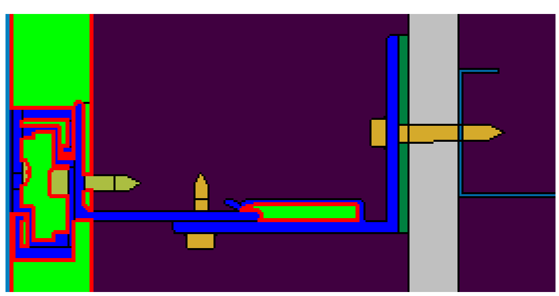

Figure E3: Therm7.7 4” Insulation with 3” Clip and Insulated Studs – Polyvinylchloride Shim (Conductivity of Polyamide 6.6 = 0.0982 BTU/hr*ft*F)

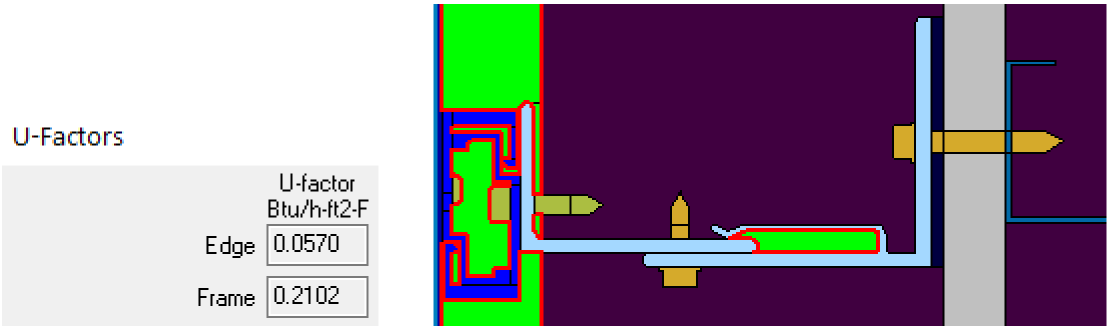

Figure E4: Therm7.7 4" Insulation with 3" Clip and Insulated Studs – Poron 4701-60 Shim (Conductivity of Poron = 0.0508 BTU/hr*ft*F) Note that clip and rail are stainless steel in this model. (Conductivity = 9.8224 BTU/hr*ft*F)

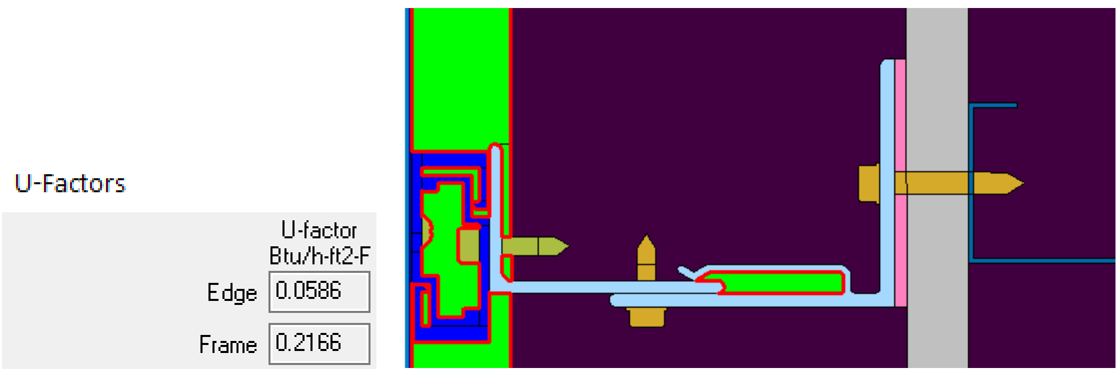

Figure E5: Therm7.7 4" Insulation with 3" Clip and Insulated Studs – Polyamide 6.6 Shim (Conductivity of Polyamide 6.6 = 0.1733 BTU/hr*ft*F) Note that clip and rail are stainless steel in this model. (Conductivity = 9.8224 BTU/hr*ft*F)

Due to the shim choice of Monarch Metal Fabrication's rainscreen framing system, even though aluminum rails and clips are used, there is only a negative 2%-5% difference in U and R value if the rails and clips were stainless steel when using the Polyamide 6.6 Shim. This comparison was only performed on the above insulation thickness and clip length though the results are expected to be similar for all configurations.