TO	**Mr. Len Anastasi**	**21332.000**
EMAIL	**len@exo-tec.biz**	**EXO-TEC Assembly and**
	1 Kiddie Drive, Suite 215	**Bracket Modeling**
	Avon, MA 02322	

DATE April 8, 2019

REGARDING **Stand-Off MPV Bracket Three-Dimensional Thermal Modeling Report**

Dear Mr. Anastasi,

RDH Building Science Inc. (RDH) is pleased to provide EXO-TEC Companies with this report for three-dimensional (3D) thermal modeling of your proprietary Stand-Off MPV Bracket for fastening metal panel veneer cladding systems. The purpose of this report is to present and summarize the simulated effective thermal performance results.

Introduction

It is widely understood that traditional methods of attaching cladding through exterior insulated wall assemblies can cause significant thermal bridging, thereby reducing the effective thermal performance of the overall wall assembly. EXO-TEC has developed an intermittent cladding support bracket known as the Stand-Off MPV Bracket to reduce thermal bridging through the insulation. See images of bracket in Figure 1. Intermittent clip systems, like the Stand-Off MPV Bracket, can reduce thermal bridging through exterior insulation when compared to more conventional solutions such as continuous vertical or horizontal Z-girts.
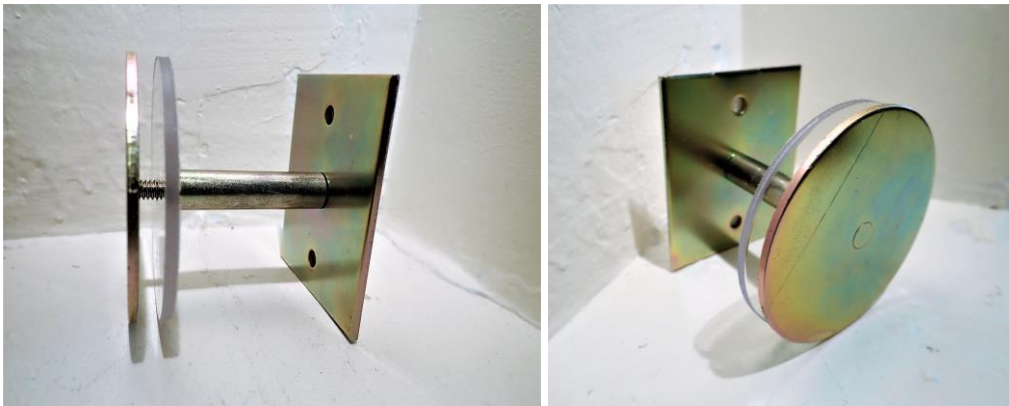

Figure 1: Photographs of the 2" Stand-Off MPV Bracket

RDH Building Science Inc. (RDH) was retained by EXO-TEC to perform three-dimensional thermal modeling of the Stand-Off MPV Bracket. Our experience with modeling of similar systems has shown 3D thermal modeling to be the most effective means of accurately simulating the thermal performance of intermittent clips. This approach provides thermal performance values suitable for use in building energy use calculations.

Thermal modelling was conducted to determine clear-field effective R-values of several Stand-Off MPV bracket wall assemblies. Other performance attributes of the wall assemblies including air, water, acoustic, and fire performance were not evaluated.

Stand-Off MPV Bracket

The wall assembly assessed in this report is an exterior insulated steel frame wall as shown in Figure 2.

— ½" Drywall

— Steel frame cavity (no insulation)

— ½" Exterior sheathing

— Stand-Off MPV Bracket (2", 3", or 4"), and (Rolled- or stainless-steel)

— Insulation (Varies with clip depth), and (mineral wool, XPS, or polyisocyanurate)

— Airspace

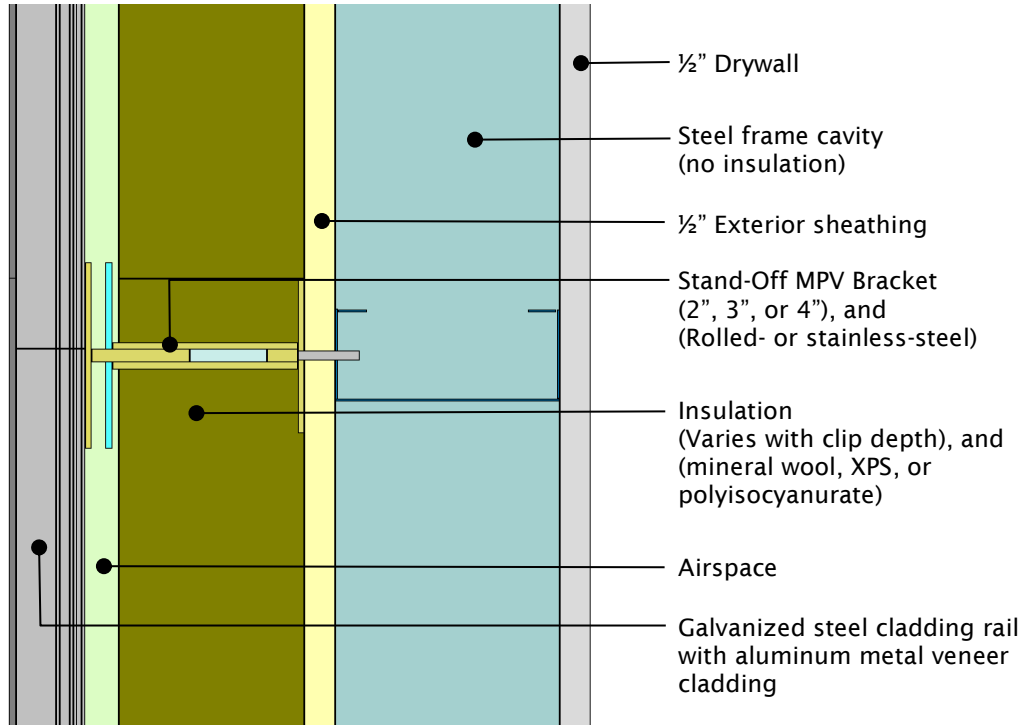— Galvanized steel cladding rail with aluminum metal veneer cladding

Figure 2: Plan view of a typical bracket model – showing the 3-inch rolled-steel Stand-Off MPV Bracket with 3-inch mineral wool insulation, airspace, galvanized steel cladding attachment rail, and aluminum metal veneer cladding.

Per your request, RDH simulated a total of 72 combinations of the Stand-Off MPV Bracket including variations in the parameters summarized in Table 1.

Table 1: Thermal Simulation Parameters	
Parameter	**Variations**
Clip	Intermittent Stand-Off MPV Bracket
Clip Material	Rolled steel (RS) and stainless steel (SS)
Backup Wall[1]	18 ga. steel-frame wall without cavity insulation
Ext. Insulation Thickness	2", 3", and 4"
Ext. Insulation Material	Mineral wool (MW), extruded polystyrene (XPS), and polyisocyanurate foam (PIC)
Fastener Material	Galvanized steel (GS)
Horizontal Spacing	16"
Vertical Spacing	24", 32", 42", and 48"

[1] a vertical 3 5/8" steel stud was modelled; however the results are considered applicable to other un-insulated steel stud sizes in the range of 2 ½" to 6".

Simulated Results

A summary of the effective R-value results for all 72 simulations is provided in Table 2. The remaining sections of this report discuss the simulation methodology and results for the Stand-Off MPV Bracket in further detail, including a comparison of the Stand-Off MPV Bracket to other intermittent clip systems available on the market. A complete summary of the simulation output and calculated results are presented in Appendix B.

Table 2: *Effective R-values of the rolled steel (RS) and stainless-steel (SS) EXO-TEC MPV Stand-Off Bracket at various insulation types, depths, and bracket spacings for a Steel Framed Wall (No Cavity Insulation).*

			Exterior Insulation Thickness								
	Spacing		2"			3"			4"		
Clip	Hor.	Vert.	MW	XPS	PIC	MW	XPS	PIC	MW	XPS	PIC
Rolled-Steel (RS)	16"	24	9.9	10.9	11.6	12.9	14.2	15.2	15.7	17.4	18.7
		32	10.4	11.4	12.3	13.5	15.0	16.2	16.7	18.6	20.0
		42	10.7	11.8	12.7	14.1	15.7	17.0	17.4	19.5	21.2
		48	10.8	12.0	13.0	14.3	16.0	17.3	17.7	19.9	21.6
Stainless-Steel (SS)	16"	24	10.8	12.1	13.0	14.4	16.2	17.6	18.0	20.3	22.1
		32	11.1	12.4	13.4	14.8	16.7	18.2	18.5	21.0	22.9
		42	11.2	12.6	13.6	15.1	17.0	18.6	18.9	21.5	23.5
		48	11.3	12.7	13.8	15.2	17.2	18.8	19.0	21.7	23.8

Abbreviations

Several abbreviations are used throughout the report to aid in the presentation of the results. The abbreviations are summarized in the table below:

Table 1: Abbreviations used in this report	
Abbreviation	**Explanation**
Al	Aluminum
GS	Galvanized-steel
Low K	Low thermal conductivity
MW	Mineral wool (R4.2/in)
PIC	Polyisocyanurate (R-5.6/in)
RS	Rolled-steel
SS	Stainless-steel
XPS	Extruded polystyrene (R-5/in)

Thermal Simulation

Thermal modeling was performed using HEAT3 version 9.01. HEAT3 is a three-dimensional finite element thermal analysis software tool commonly used by the building industry to analyze building assemblies in three dimensions which two-dimensional analysis tools (such as THERM) cannot accurately analyze. It allows for the more detailed analysis of building assemblies including the impact of thermal bridging through walls and other penetrations.

Thermal modeling was carried out in general conformance with the ASHRAE Handbook Fundamentals. Per industry standard modeling practices, the following assumptions have been made:

→ Steady-state heat flow

→ Isotropic and temperature independent thermal conductivities

RDH notes that the thermal conductivity of polyisocyanurate has been shown to be temperature dependent. The National Roofing Contractors Association (NRCA) has performed extensive testing on the long-term thermal resistance (LTTR) of polyisocyanurate (PIC) at different temperatures and recommends a design value of R-5.0/in in heating dominated climates and R-5.6/in in cooling dominated climates. Other industry references such as ASHRAE Handbook Fundamentals, present LTTR values for PIC between R-5.6/in and R-6.5/in, with additional variance between brands. The thermal simulations performed for this report assume a nominal PIC thermal resistance of R-5.6/in. A design team looking to follow the NRCA recommendations regarding PIC design thermal resistance values, can use the results for the extruded polystyrene (XPS), which is R-5/in.

Baseline Models

A baseline model without the Stand-Off MPV Bracket was created for each type of insulation and insulation thickness to quantify the thermal bridging impact of the bracket. An example is shown in Figure 3.
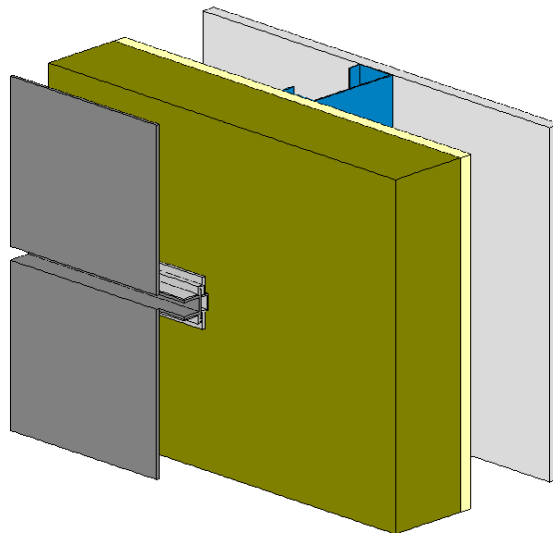

Figure 3: *3D Thermal modelling output of a baseline model consisting of an uninsulated steel frame wall and 3-inches of exterior mineral wool insulation.*

Stand-Off MPV Bracket Models

Using the baseline model, the 2-inch, 3-inch, and 4-inch Stand-Off MPV Brackets were modelled to determine the effective R-value of the rolled- and stainless-steel bracket wall assemblies at various depths, insulation types and thicknesses. An example of the model is shown in Figure 4.
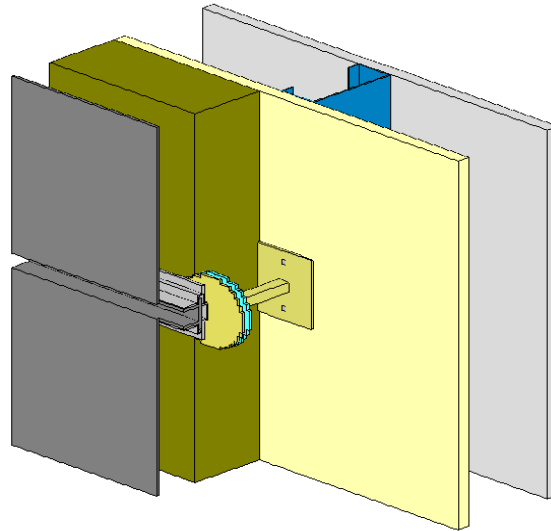

Figure 4: Cut-away 3D thermal modeling output of EXO-TEC's Stand-Off MPV Bracket for a 3-inch bracket, and 3-inches of exterior mineral wool insulation.

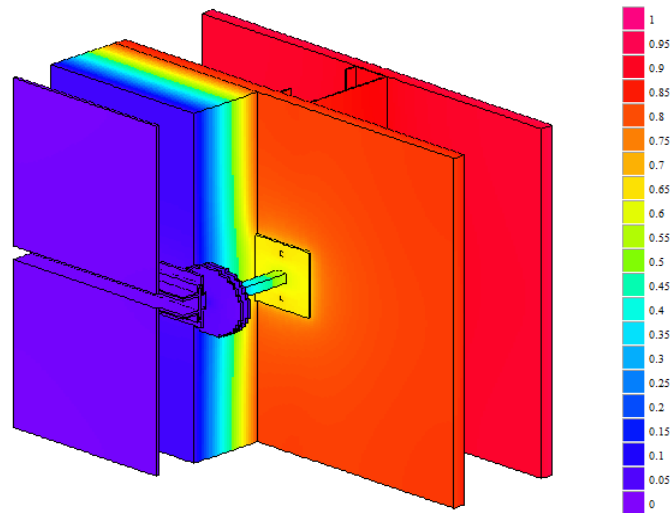An example of the temperature gradient output is shown in Figure 5.

Figure 5: Cut-away 3D Thermal modeling output of EXO-TEC's Stand-Off MPV Bracket for a 3-inch bracket and 3-inces of exterior mineral wool insulation showing the temperature gradient across the assembly.

The thermal simulations were performed at a temperature difference of 1.8 °F (1 °C). This resulted in the simulated temperatures output equaling the Temperature Index (I). Temperature Index is useful metric commonly used by industry to express surface

temperatures. Temperature Index is a ratio of a surface temperature over the change in temperature across the assembly (Equation 1).

$$I = \frac{T_s - T_e}{T_i - T_e} \tag{1}$$

Where,

T_s, is the surface thermal temperature of interest in ˚F

T_i, is the interior air temperature in ˚F

T_e, is the exterior air temperature in ˚F

I, is the Temperature Index

It can be shown that the Temperature Index is independent of the interior and exterior air temperatures, assuming standard modelling assumptions. Therefore, Equation 1 can be rearranged to solve for a specific surface temperature at a different interior and exterior design temperatures.

Thermal Bridging due to Brackets (Point Thermal Transmittances)

The building science and construction industry are familiar with effective thermal resistance (R) and thermal transmittance (U) values. However, using effective R- and U-values to describe an assembly implicitly assumes a spacing for the thermal bridging elements. For assemblies including intermittent clips like the wall assemblies presented in this report, use of effective R-values can create confusion when comparing different systems with different spacing. Furthermore, results presented as effective R-values cannot readily be extended to project specific spacing requirements.

The effective U-value of an assembly containing thermal bridges can, in a general sense, be predicted using the following equation:

$$U = \frac{\sum(\Psi_i \cdot L) + \sum(\chi_i \cdot n)}{A_{Total}} + U_0 \tag{1}$$

Where,

U, is the thermal conductance in Btu/hr·ft^2·˚F, including thermal bridging;

U_0, is the "clear-field" thermal conductance assuming no systemic thermal bridging in Btu/hr·ft^2·˚F;

A_{total}, is the area by which the heat flows through in ft^2;

Ψ, is the linear thermal transmittance value in Btu/hr·ft·˚F;

L, is the length of linear thermal bridge in ft;

χ, is the point thermal transmittance value in Btu/hr·˚F; and

n, is the number of point thermal bridges.

In addition to determining effective R-values for the Stand-Off MPV Bracket, RDH calculated Chi-values for each variation in depth, bracket material, and insulation type. Figure 6 presents the Chi-values (point thermal transmittances) for the Stand-Off MPV Bracket. The Chi-values ranged between 0.016 and 0.046 Btu/hr·°F. Tabulated results are presented in Appendix B.
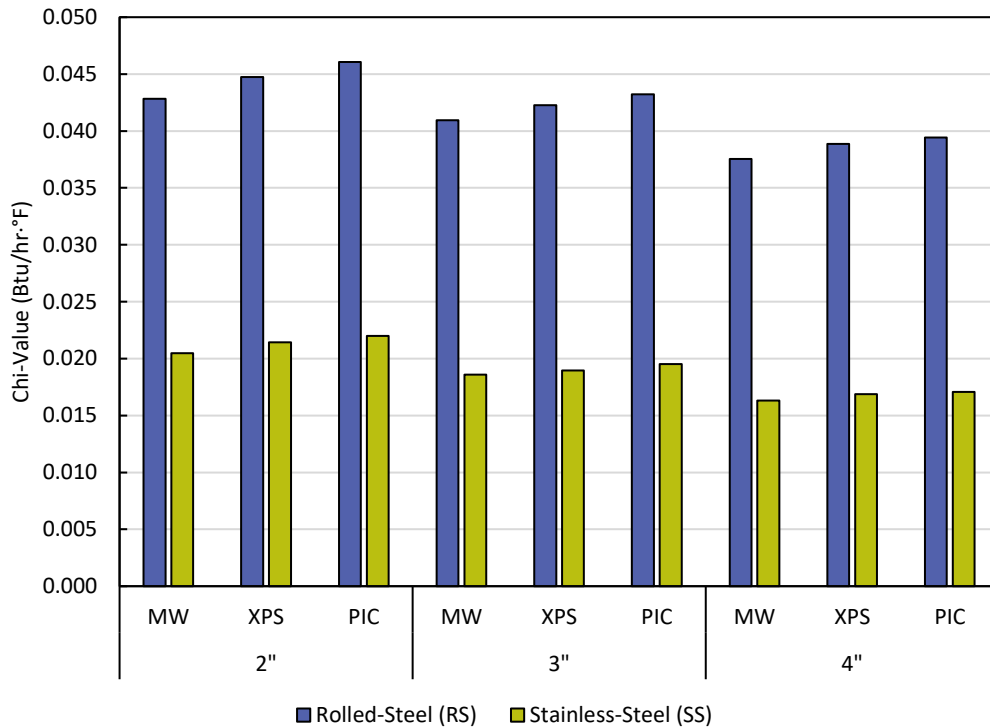

Figure 6: Chi-value of the Stand-Off MPV Bracket

The following general observations were made:

→ Stainless-steel brackets had lower Chi-values compared to rolled-steel brackets. The difference in Chi-value ranged between 52% - 57%.

→ Increased insulation thickness resulted in lower Chi-values (less thermal bridging). The difference in Chi-value between 2" and 4" of insulation of the same type ranged between 10% -22%.

→ Insulation with higher thermal resistance value resulted in higher Chi-values (more thermal bridging). The difference in Chi-value between mineral wool and polyisocyanurate of the same thickness ranged between 4% - 7%.

Stand-Off MPV Bracket Comparison to 2D Simulations

EXO-TEC previously had the Stand-Off MPV Bracket modelled using THERM, which is a 2D simulation tool. Figure 8 compares the 2D and 3D simulation results.
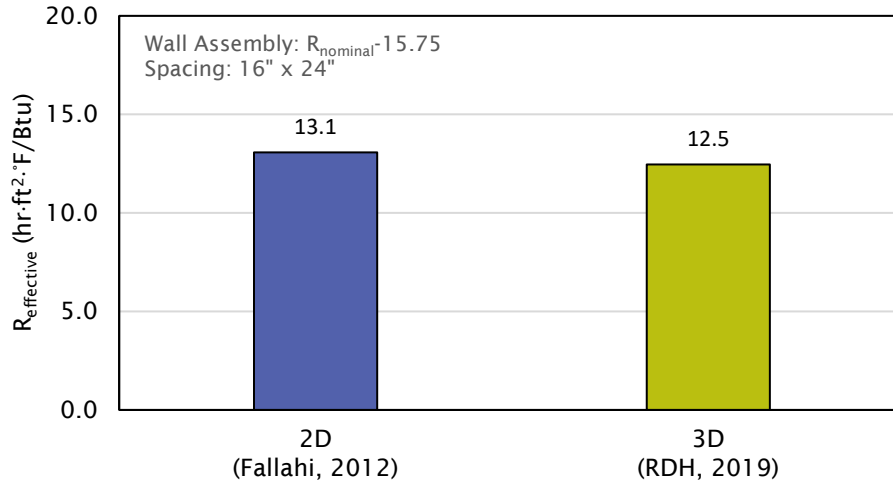
The 2D simulation predicted an effective R-value 5% higher than the 3D simulations performed in this report.

Conclusion

Thermal modeling of the intermittent MPV stand-off bracket was performed. A total of 72 combinations of the MPV bracket were simulated including variations in bracket material, bracket depth, insulation material, and bracket spacing. Based on these simulations, the MPV stand-off bracket system was found to perform similarly to other intermittent clips on the market, with the stainless-steel bracket option providing improved thermal performance.

We trust that this report meets your needs at this time. Please do not hesitate to contact the authors of this report with questions regarding this report.

Yours truly,

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Building Scientist
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RDH Building Science Inc.

Daniel Haaland | M.A.Sc., P.Eng.
Reviewed by

encl.   Appendix A: Materials and Boundary Conditions
Appendix B: Thermal Model Results Tables
Appendix C: Stand-Off MPV Bracket Drawings

References

ASHRAE. (2017). *Handbook Fundamentals.* Atlanta: American Society of Heating, Refrigerating and Air Conditioning Engineers.

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Appendix A

Material and Boundary Condition

Standard thermal conductivity values were assumed based on NFRC 101 and ASHRAE Handbook Fundamentals 2017. Material conductivities and their reference are shown in Table A.1.

TABLE A.1	MATERIAL CONDUCTIVITIES FOR THE CALIBRATED MODELING RESULTS	
Material	Conductivity (Btu/hr·°F·ft)	Reference
Air Space	varies	(ASHRAE, 2017)
Aluminum Cladding	92.446	(NFRC, 2010)
Exterior Gypsum	0.074	(Georgia-Pacific, 2017)
Extruded Polystyrene	0.017	(ASHRAE, 2017)
Galvanized-Steel	35.838	(NFRC, 2010)
Interior Gypsum	0.092	(NFRC, 2010)
Mineral Wool (R-4.2/in)	0.020	(ROCKWOOL, 2018)
MPV stand-off bracket, Rolled-Steel[1]	28.889	(NFRC, 2010)
MPV stand-off bracket, Stainless-Steel	9.822	(NFRC, 2010)
Polycarbonate	0.116	(NFRC, 2010)
Polyisocyanurate	0.015	(NRCA, 2014)

[1] zinc & yellow chromate plated per the manufacturer's specifications.

Table A.2 lists the boundary condition temperatures and air film thermal resistance values for the thermal models.

TABLE A.2	BOUNDARY CONDITIONS	
Material	Temperature (°F)	Resistance (ft²·°F·hr/Btu)
Interior, NFRC 100	33.8	0.68
Exterior, NFRC 100	32.0	0.17

Appendix B

Simulation Results

Table B1: Effective U-values (Btu/ft2 ·°F ·hr) of rolled-steel (RS) and stainless-steel (SS) EXO-TEC MPV Stand-Off Bracket at various insulation types, depths, and bracket spacings for a steel framed wall (No Cavity Insulation).

| | Spacing | | Exterior Insulation Thickness | | | | | | | | |
| | | | 2" | | | 3" | | | 4" | | |
Clip	Hor.	Vert.	MW	XPS	PIC	MW	XPS	PIC	MW	XPS	PIC
Rolled-Steel (RS)	16	24	0.1006	0.0916	0.0858	0.0777	0.0704	0.0658	0.0636	0.0574	0.0536
		32	0.0966	0.0874	0.0815	0.0739	0.0665	0.0617	0.0600	0.0538	0.0499
		42	0.0937	0.0844	0.0784	0.0712	0.0637	0.0588	0.0575	0.0512	0.0473
		48	0.0926	0.0832	0.0772	0.0701	0.0625	0.0577	0.0565	0.0502	0.0462
Stainless-Steel (SS)	16	24	0.0922	0.0829	0.0768	0.0693	0.0617	0.0569	0.0556	0.0492	0.0452
		32	0.0903	0.0809	0.0748	0.0676	0.0599	0.0551	0.0541	0.0476	0.0436
		42	0.0889	0.0794	0.0733	0.0664	0.0587	0.0538	0.0530	0.0465	0.0425
		48	0.0884	0.0789	0.0727	0.0659	0.0582	0.0532	0.0525	0.0460	0.0420

Table B2: Effective R-values (ft2 ·°F ·hr/ Btu) of rolled steel (RS) and stainless-steel (SS) EXO-TEC MPV Stand-Off Bracket at various insulation types, depths, and bracket spacings for a steel framed wall (No Cavity Insulation).

| | Spacing | | Exterior Insulation Thickness | | | | | | | | |
| | | | 2" | | | 3" | | | 4" | | |
Clip	Hor.	Vert.	MW	XPS	PIC	MW	XPS	PIC	MW	XPS	PIC
Rolled-Steel (RS)	16"	24	9.9	10.9	11.6	12.9	14.2	15.2	15.7	17.4	18.7
		32	10.4	11.4	12.3	13.5	15.0	16.2	16.7	18.6	20.0
		42	10.7	11.8	12.7	14.1	15.7	17.0	17.4	19.5	21.2
		48	10.8	12.0	13.0	14.3	16.0	17.3	17.7	19.9	21.6
Stainless-Steel (SS)	16"	24	10.8	12.1	13.0	14.4	16.2	17.6	18.0	20.3	22.1
		32	11.1	12.4	13.4	14.8	16.7	18.2	18.5	21.0	22.9
		42	11.2	12.6	13.6	15.1	17.0	18.6	18.9	21.5	23.5
		48	11.3	12.7	13.8	15.2	17.2	18.8	19.0	21.7	23.8

Table B3: Chi-values (Btu/hr ·°F) of rolled steel (RS) and stainless-steel (SS) EXO-TEC MPV Stand-Off Bracket at various insulation types, depths, and bracket spacings for a steel framed wall (No Cavity Insulation).
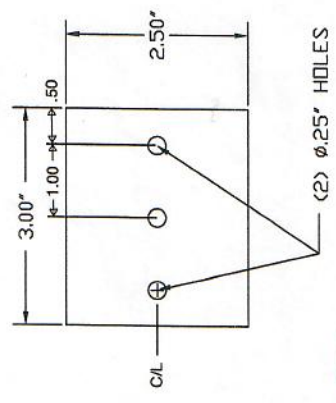
| | Spacing | | Exterior Insulation Thickness | | | | | | | | |
| | | | 2" | | | 3" | | | 4" | | |
Clip	Hor.	Vert.	MW	XPS	PIC	MW	XPS	PIC	MW	XPS	PIC
Rolled-Steel (RS)	16	24	0.0428	0.0447	0.0461	0.0409	0.0423	0.0432	0.0375	0.0389	0.0394
		32									
		42									
		48									
Stainless-Steel (SS)	16	24	0.0205	0.0214	0.0220	0.0186	0.0190	0.0195	0.0163	0.0169	0.0171
		32									
		42									
		48									

Appendix C

Stand-Off MPV Bracket Drawings

SHOP PRINT

BASE PLATE

-BASE PLATE
.104 S.S.
3.000 x 2.500
17412

3.00"
2.50"
1.00
.50
(2) Ø.25" HOLES
C/L

Ø.251
FH4-0420-08
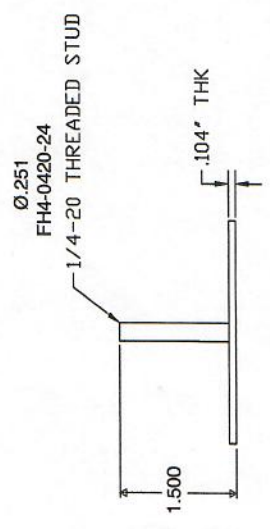1/4-20 THREADED STUD
.104" THK
.500
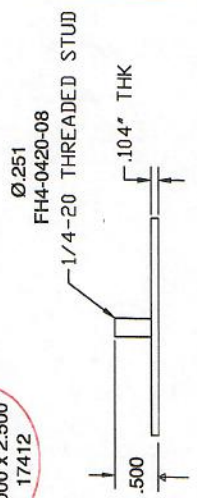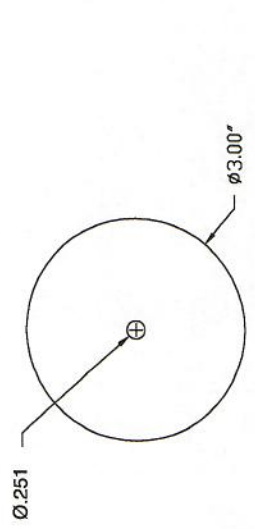
BASE PLATE

P/N #5: BASE PLATE – CRS
MATERIAL: CRS
FINISH: YELLOW ZINC

P/N #6: BASE PLATE – SS
MATERIAL: 304-2B SS
FINISH: NONE

INSULATION RETAINER

-RETAINER
.125 LEXAN
Ø3.000
17413

Ø3.000
Ø.203
1/4-20 TAPPED
(CUT-TAP)

.125" THK
LEXAN
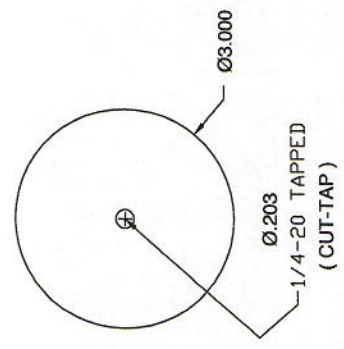
INSULATION RETAINER

P/N #3: INSULATION RETAINER
MATERIAL: LEXAN (POLY CARB)
FINISH: NONE

TOP PLATE

TOP PLATE
.104 S.S.
Ø3.000
17411

Ø3.00"
Ø.251
FH4-0420-24
1/4-20 THREADED STUD
.104" THK
1.500

TOP PLATE

P/N #1: TOP PLATE – CRS
MATERIAL: CRS
FINISH: YELLOW ZINC
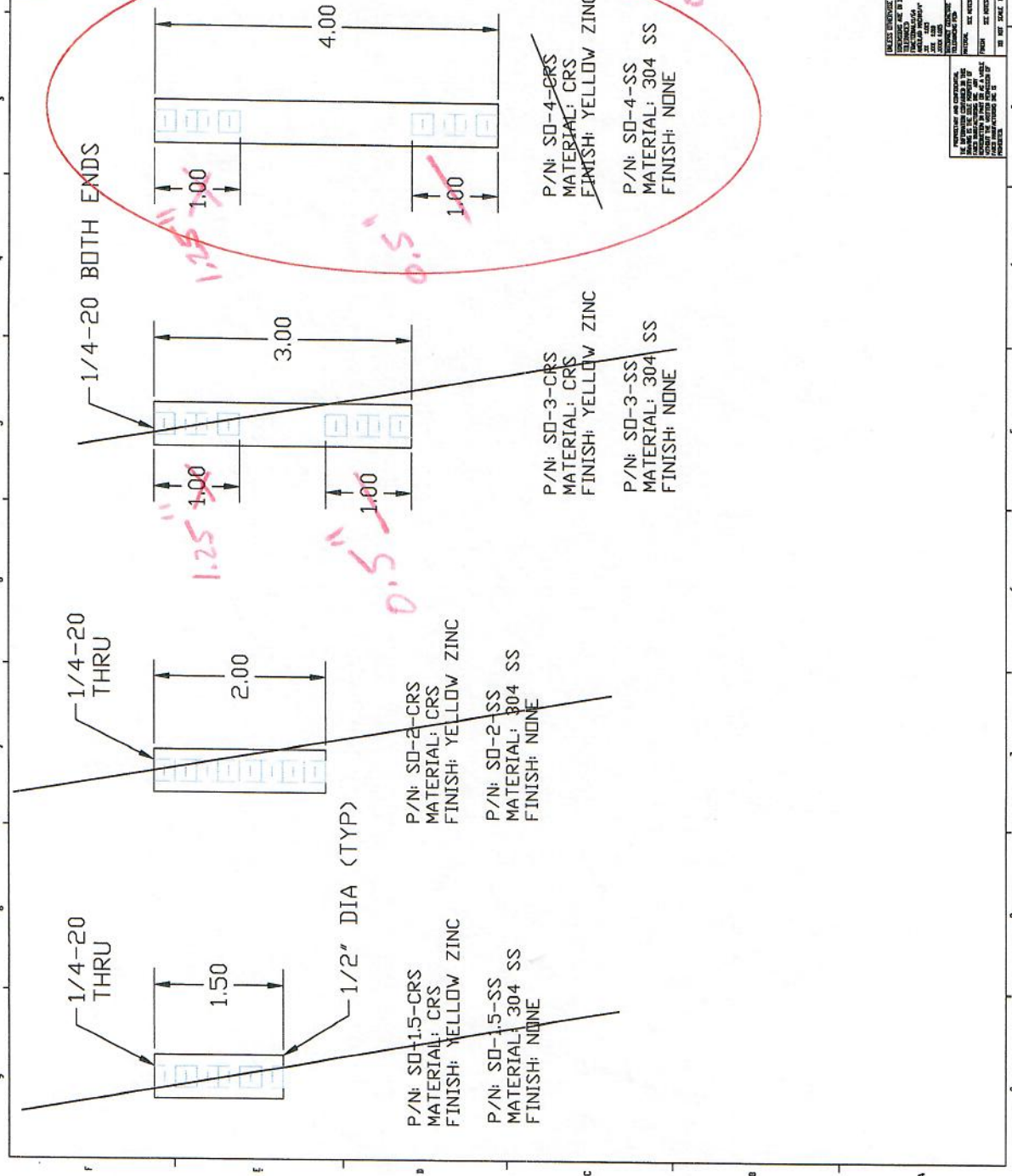
P/N #2: TOP PLATE – SS
MATERIAL: 304-2B SS
FINISH: NONE

A077

LLA

6.00

1.00

P/N: SO-6-CRS
MATERIAL: CRS
FINISH: YELLOW ZINC

P/N: SO-6-SS
MATERIAL: 304 SS
FINISH: NONE

1.00

1.25"

O.5"

4.00

1.00

P/N: SO-4-CRS
MATERIAL: CRS
FINISH: YELLOW ZINC

P/N: SO-4-SS
MATERIAL: 304 SS
FINISH: NONE

1.00

1.25"

O.5"

1/4-20 BOTH ENDS

3.00

1.00

1.00

P/N: SO-3-CRS
MATERIAL: CRS
FINISH: YELLOW ZINC

P/N: SO-3-SS
MATERIAL: 304 SS
FINISH: NONE

1.25"

O.5"

1/4-20
THRU

2.00

P/N: SO-2-CRS
MATERIAL: CRS
FINISH: YELLOW ZINC

P/N: SO-2-SS
MATERIAL: 304 SS
FINISH: NONE

1/4-20
THRU

1.50

1/2" DIA (TYP)

P/N: SO-1.5-CRS
MATERIAL: CRS
FINISH: YELLOW ZINC

P/N: SO-1.5-SS
MATERIAL: 304 SS
FINISH: NONE

FABCO MANUFACTURING INC.
14 REMOZZILE AVE. MADISON, WI 53749
TEL (700)-562-9039 Fax (700)-562-9700

TEE STANDOFFS

TEE BACKPARTS

SHT 1 OF 1

REV 1