FERO THERMAL TIE™ CONNECTOR AND FAST THERMAL BRACKET™ OFFSET SHELF ANGLE SUPPORT THERMAL ANALYSIS

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Abstract

The current industry standards for building energy efficiency have led to a significant trend toward placing exterior insulation within the cavity behind anchored masonry veneers. To comply with ever changing energy standards, building designers need to consider the impact of thermal bridging caused by masonry connectors and shelf angles that penetrate this exterior insulation. This paper examines the need to address thermal bridging in the context of masonry tie and shelf angle support design and selection to achieve compliance with the International Energy Conservation Code (IECC), ASHRAE Standard 90.1, or the National Energy Code for Buildings (NECB).

After discussing the different energy code requirements for walls, this paper presents the results of three-dimensional thermal modelling that quantifies the impact of thermal bridging in typical exterior masonry veneer wall assemblies. Modelling was completed for a variety of masonry tie products with common backup wall assemblies and a variety of masonry shelf angle attachment options. The modelling included generic masonry tie and shelf angle attachment options in addition to proprietary FERO Thermal Tie™ Masonry Connectors (i.e., FERO Thermal Ties) and FERO FAST Thermal Bracket™ Offset Shelf Angle Supports – Standard (i.e., FAST Thermal Bracket Supports). Physical thermal performance testing was also completed to validate the model results for the Fast Thermal Bracket Support using a modified ASTM C177 large-scale guarded hot plate apparatus. The results demonstrate that masonry tie and shelf angle design can have a significant impact on thermal performance. This paper also presents the results of a comparative study to illustrate the impact of thermal bridging caused by comparable non-masonry cladding assemblies supported by continuous/intermittent metal Z-girts, clips, or screws.

The information presented in this paper will be of interest to design professionals who are responsible for assessing overall building energy efficiency and code compliance and selecting cladding support materials for masonry veneer wall assemblies.

Introduction

Most jurisdictions in Canada and the United States have adopted some form of a governing energy efficiency code that establishes code compliance options using either minimum insulation R-values or maximum assembly U-factors for building enclosure components (e.g., metal-framed above-grade walls, mass floors, etc.). Often the use of continuous insulation is required for above-grade wall components to meet code compliance. This insulation is commonly located on the outboard side of the wall backup structure and termed *exterior insulation*. This insulation is required per code to meet the definition of exterior insulation, or consideration for thermal bridging through this layer may be required.

Thermal bridging can be defined as the energy loss that occurs through framing, gaps, fasteners, structural elements, and any other penetrations through lower conductivity materials such as insulation. As a result, structural framing such as studs, girts, and slab edges generally need to be considered in thermal calculations for code compliance. For exterior-insulated masonry veneer wall assemblies, attachment points such as masonry ties and shelf angles may need to be considered for energy code compliance depending on the governing code and local interpretations.

Regardless of local code provisions, when the thermal impact of highly conductive metal ties and support components for masonry veneers are realized, these components can have a profound impact on the thermal performance of the wall assembly, despite their seemingly insignificant contribution to the total wall area. As demonstrated in this paper, conventional masonry ties and conventional shelf angle supports occupying less than 0.5% of the wall surface area can reduce the effective R-value of the wall assembly by 18% to over 50%. For the purposes of this paper, the effective R-value is defined as the thermal resistance of the wall assembly layers including the three-dimensional effect of standard repetitive framing and intermittent attachments or fastening, inclusive of interior and exterior air films.

This paper presents typical exterior insulation reduction factors and effective R-values for common above-grade masonry veneer walls with various tie types and serves to update a previous paper titled "FERO Rap Tie and Fast System Thermal Analysis" [1]. The thermal analysis performed to determine these values provides a comparison between typical masonry tie types and several FERO masonry tie products, including the:

→ FERO Thermal Tie™ – Holed Rap-Tie® Masonry Connector (i.e., FERO Thermal Holed Rap-Tie),

→ FERO Thermal Tie™ – Stud Shear® Masonry Connector (i.e., FERO Thermal Stud Shear Connector), and

→ FERO Thermal Tie™ – Block Shear® Masonry Connector (FERO Thermal Block Shear Connector).

The influence of the masonry shelf angle support is also presented, with a comparison between typical shelf angle support configurations and FERO's FAST Thermal Bracket Support system. The modelled thermal performance of the FERO FAST Thermal Bracket Support was validated through physical testing of the specimen at a slab edge. Design tables, located in Appendix A, are provided for FERO Thermal Ties and FAST Thermal Bracket Supports to aid designers in evaluating the effective thermal transmittance of anchored masonry veneer assemblies.

Energy Code Requirements for Walls

In the United States, most jurisdictions have adopted some version of the IECC or ASHRAE 90.1, with or without amendments, to specify the minimum required energy efficiency provisions for buildings. In Canada, energy efficiency provisions for building may be governed by either the NBC, National Energy Code for Buildings (NECB), or ASHRAE 90.1. The NBC thermal performance requirements for the building enclosure are provided for single-family housing and low-rise buildings (Part 9 buildings). The thermal performance requirements for larger (Part 3) buildings are provided by the NECB. These codes, in both Canada and the United States, allow building enclosure assemblies to demonstrate compliance with the code considering either minimum insulation R-values or maximum assembly U-factors (also considered as minimum assembly effective R-values). The NECB in Canada considers only maximum assembly U-factors (or minimum effective R-values), and energy modelling paths typically use only effective U-factor/R-value inputs. Additionally, some buildings in the United States and Canada choose to further meet more stringent energy performance requirements such as passive house or net zero levels of performance.

Insulation R-Value

Compliance using the minimum insulation R-value option allows for a minimum rated R-value of insulation to be installed between framing members and/or provided as continuous insulation (often abbreviated as "ci" by the energy code). Should the installed R-value meet the code requirements and the continuous insulation meet the code definition, additional consideration of losses due to thermal bridging is not required. Historically, most building codes have specified nominal insulation R-values to simplify the requirements for designers and builders of small buildings. However, this option leads to a significant range of actual installed thermal performance due to variability in actual framing factors and other thermal bridges.

Therefore, the use of effective R-values is a more rational measure of the true thermal performance and is often easier to conceptualize when considering thermal bridges through low-conductivity layers such as insulation. Consideration of effective R-values, rather than nominal R-values, is also becoming more common because two- and three-dimensional finite-element heat flow calculation software is readily available and used by practitioners to calculate effective R-values.

Assembly U-Factors and Continuous Insulation

An assembly's U-factor considers the degradation of the assembly's thermal performance due to thermal bridging caused by wall framing, penetrations through exterior insulation, and other high-conductivity projections through the above-grade wall enclosure. The U-factor can be thought of as the inverse of the effective R-value. It is required to be calculated or referenced from published design tables to demonstrate conformance when complying with the code using one of the following methods: the U-factor method, in which the project specific assembly U-factor is to be less than the code required value; the component analysis method, in which the area weighted performance of all enclosure components for the building is less than or equal to that defined by the code; or the enclosure performance, which is considered as part of the whole-building energy performance through a modelling approach. Compliance through a U-factor method or component analysis method is often triggered by an assembly that cannot accommodate the minimum insulation R-value or where continuous insulation is used but does not meet the code definition. Many other factors can influence the energy code compliance approach of a building, but these factors are beyond the discussion of this paper.

The definition of continuous insulation and the enforcement of this definition will vary with each adopted (and amended) code provision and authority having jurisdiction. The 2018 IECC defines continuous insulation as an "Insulating material that is continuous across all structural members without thermal bridges other than fasteners and service openings. It is installed on the interior or exterior or is integral to any opaque surface of the building envelope" [2]. The current version of ASHRAE 90.1 provides a similar definition [3]. By this definition, continuous insulation can be installed on the interior, exterior, or within the middle of the wall assembly. In most practical scenarios, continuous insulation is addressed with rigid or semi-rigid insulation exterior to the wall structure because the continuity requirement can be difficult to maintain at floor levels in multi-storey buildings when located interior or integral to the wall structure.

For exterior-insulated anchored masonry veneer wall assemblies, thermal bridging at masonry ties and shelf angle supports may need to be considered for code compliance. The IECC/ASHRAE 90.1 definition for continuous insulation above could be interpreted to classify shelf angles—and in particular, continuous shelf angles—as structural members that bridge the exterior insulation. This interpretation would therefore require that the R-value reduction at shelf angles is accounted for in code compliance procedures. Some jurisdictions may classify intermittent masonry ties as fasteners so that the remaining wall area is continuously insulated for code compliance purposes; however, others may require that masonry ties are accounted for as structural thermal bridging. In some Canadian jurisdictions, energy codes may be interpreted to allow thermal bridges to be ignored if the wall area occupied by the thermal bridge or if the thermal bridge's impact on the overall thermal performance is below a certain threshold. Since these interpretations may vary by project and jurisdiction, this paper recommends that treatment of masonry ties and shelf angles for energy code compliance is first clarified with the jurisdiction having authority.

The thermal performance requirements mandated by energy codes vary by climate zone, which are defined by such climatic features such as the annual heating degree days (HDD) and cooling degree days (CDD). Figure 1 shows the distribution of climate zones across Canada and the United States. Table 1 summarizes the thermal insulation requirements in the 2015 IECC, 2018 IECC, 2015 NECB, ASHRAE 90.1-2016, and 2015 NBC for common wall types.

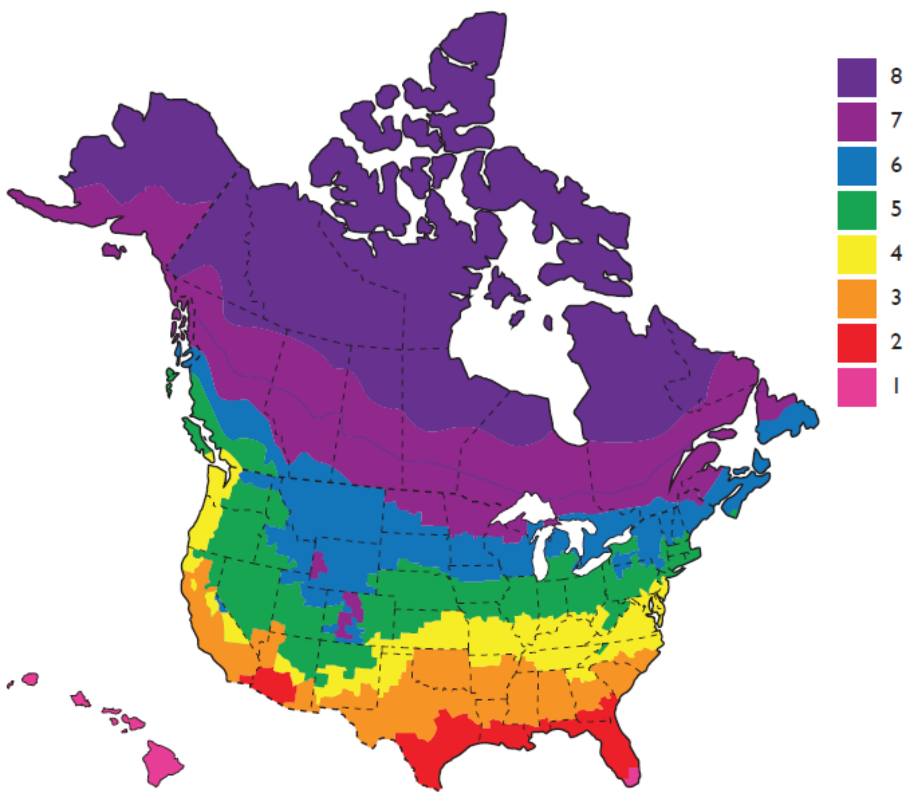


Figure 1. Climate zone map of Canada and the United States as defined by the IECC [2], ASHARE 90.1 [3], the NECB [4], and the NBC [5]

Table 1. Minimum effective R-value requirements for above-grade wall assemblies within the 2015 IECC [6], 2018 IECC [2], 2015 NECB [4], ASHRAE 90.1-2016 [3], and 2015 NBC [5] in North American climate zones

	IECC 2015 and 2018	**IECC 2015 and 2018**	**ASHRAE 90.1-2016**	**ASHRAE 90.1-2016**	**NECB 2015**	**NBC 2015 Part 9.36**
	Commercial Building*	Residential Building*	Commercial Building*	Residential Building*	All Construction Types	With and without a heat recovery ventilator
	Minimum Effective Assembly R-Values [RSI]					
Zone 1 **5000 < CDD 10°C**	(6.6, 13.0, 15.6) [1.17, 2.29, 2.75]	(6.6, 13.0, 15.6) [1.17, 2.29, 2.75]	(1.7, 8.1, 11.2) [0.30, 1.42, 1.98]	(6.6, 8.1, 11.2) [1.17, 1.42, 1.98]	N/A	N/A
Zone 2 **3500 < CDD 10°C ≤ 5000**	(6.6, 13.0, 15.6) [1.17, 2.29, 2.75]	(8.1, 15.6, 15.6) [1.43, 2.75, 2.75]	(6.6, 11.9, 11.2) [1.17, 2.10, 1.98]	(8.1, 15.6, 11.2) [1.43, 2.75, 1.98]	N/A	N/A
Zone 3 **CDD 10°C < 3500 and HDD 18°C ≤ 2000**	(8.1, 15.6, 15.6) [1.43, 2.75, 2.75]	(9.6, 15.6, 15.6) [1.69, 2.75, 2.75]	(8.1, 13.0, 11.2) [1.43, 2.29, 1.98]	(9.6, 15.6, 15.6) [1.69, 2.75, 2.75]	N/A	N/A
Zone 4† **CDD 10°C < 3500 and 2000 < HDD 18°C ≤ 3000**	(9.6, 15.6, 15.6) [1.69, 2.75, 2.75]	(9.6, 15.6, 15.6) [1.69, 2.75, 2.75]	(9.6, 15.6, 15.6) [1.69, 2.75, 2.75]	(11.1, 15.6, 15.6) [1.96, 2.75, 2.75]	18.0 [3.17]	(15.8, 15.8) [2.78, 2.78]
Zone 5 **3000 < HDD 18°C ≤ 4000**	(11.1, 15.6, 15.6) [1.96, 2.75, 2.75]	(12.5, 15.6, 15.6) [1.96, 2.75, 2.75]	(11.1, 18.2, 19.6) [1.96, 3.20, 3.45]	(12.5, 18.2, 19.6) [2.20, 3.20, 3.45]	20.4 [3.60]	(17.5, 16.9) [3.08, 2.97]
Zone 6 **4000 < HDD 18°C ≤ 5000**	(12.5, 15.6, 19.6) [2.20, 2.75, 3.45]	(14.1, 17.5, 19.6) [2.48, 3.09, 3.45]	(12.5, 20.4, 19.6) [2.20, 3.59, 3.45]	(14.1, 20.4, 19.6) [2.48, 3.59, 3.45]	23.0 [4.05]	(17.5, 16.9) [3.08, 2.97]
Zone 7a‡ **5000 < HDD 18°C ≤ 6000**	(14.1, 15.6, 19.6) [2.48, 2.75, 3.45]	(16.4, 19.2, 19.6) [2.89, 3.39, 3.45]	(14.1, 20.4, 19.6) [2.48, 3.59, 3.45]	(14.1, 23.8, 19.6) [2.48, 4.19, 3.45]	27.0 [4.76]	(17.5, 16.9) [3.08, 2.97]
Zone 7b‡ **6000 < HDD 18°C ≤ 7000**	(14.1, 15.6, 19.6) [2.48, 2.75, 3.45]	(16.4, 19.2, 19.6) [2.89, 3.39, 3.45]	(14.1, 20.4, 19.6) [2.48, 3.59, 3.45]	(14.1, 23.8, 19.6) [2.48, 4.19, 3.45]	27.0 [4.76]	(21.9, 17.5) [3.85, 3.08]
Zone 8 **7000 < HDD 18°C**	(16.4, 22.2, 27.8) [2.89, 3.91, 4.89]	(16.4, 22.2, 27.8) [2.89, 3.91, 4.89]	(20.8, 27.0, 31.3) [3.67, 4.76, 5.50]	(20.8, 27.0, 31.3) [3.67, 4.76, 5.50]	31.0 [5.46]	(21.9, 17.5) [3.85, 3.08]

* Includes mass, metal-framed, and wood-framed assemblies.

† The IECC includes Climate Zone 4 Marine (C) with the Climate Zone 5 building enclosure requirements shown above.

‡The IECC and ASHRAE 90.1 do not differentiate between Climate Zone 7a and 7b.

Masonry Support Design and Thermal Bridging

With higher effective R-values prescribed by new energy codes, the design of masonry ties and shelf angle supports is an important factor in overall energy efficiency. As will be presented in the next section, reduction of the insulation value due to thermal bridging through the masonry ties and shelf angle supports can be significant. Where masonry is used with exterior continuous insulation, stainless steel or galvanized masonry ties will penetrate the exterior insulation, as shown in Figure 2, creating a thermal bridge through the insulation and reducing the overall insulation level (referred to as thermal degradation). This is even more pronounced at each floor level and over openings and windows.

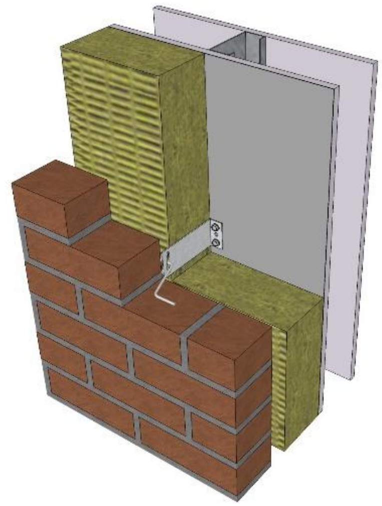


Figure 2. Standard face mount 2-inch, 16-gauge masonry tie (no punched holes)

The focus of the thermal analysis in this paper compares specific FERO Thermal Tie options and the FAST Thermal Bracket Support to other typical masonry ties and shelf angle configurations, respectively. The FERO products evaluated aim to reduce the effect of thermal bridging by using masonry ties and shelf angle supports that minimize the amount of material penetrating the insulation. The FERO Thermal Ties evaluated have large perforations through the side profile where the tie penetrates the insulation. The FAST Thermal Bracket Support evaluated uses intermittent brackets to stand off the shelf angle from the floor line structure so that only the intermittent support penetrates the insulation rather than the entire length of a large continuous shelf angle. The FAST Standard Bracket also incorporates perforations within the sides of the thermal bracket to further optimize its thermal performance.

Thermal Analysis with HEAT3 Software

Three-dimensional thermal analysis of various masonry ties and supports was performed using HEAT3 [7]. The HEAT3 software package has been well tested and validated by the building industry, and it is commonly used by practitioners to calculate the U-factors of enclosure assemblies (more so in Europe than North America due to more stringent European energy code requirements and other energy efficiency programs). Three-dimensional thermal modelling, versus two-dimensional modelling, allows for more accurate representation of discrete cladding attachment elements such as masonry ties and intermittent shelf angle brackets.

The purpose of the analysis is to assess the thermal impact and to provide data on the U-factors of several masonry tie options and shelf angle configurations. In our experience, the R-values calculated from HEAT3 tend to be conservative due to the way that surface film resistances are included in the model. Results from guarded hotbox or hot plate testing and other three-dimensional finite-element thermal modelling software packages may be more optimistic (by up to 5% to 10%) depending on the backup wall and assumed material contact resistances. When accounting for real-life construction practices (e.g., air/insulation gaps around ties, extra ties and fasteners, etc.), the conservative results from HEAT3 tend to be more realistic in our view.

Masonry Ties: Thermal Modelling Study

A series of thermal models were developed to assess the thermal bridging impact of different masonry ties through exterior insulation at common backup wall types. The intent of the models is to evaluate the difference between the FERO Thermal Tie products with perforations (see Figure 3) and equivalent masonry tie designs without the thermal efficiency created by the perforations. Four different backup wall types were modelled, including 6-inch cast-in-place (CIP) concrete, 8-inch concrete masonry units (CMU), 6-inch steel studs (uninsulated), 2 × 6 wood studs (insulated with R-21 batts) with varying levels of exterior insulation, and the following masonry tie products:

- FERO Thermal Holed Rap-Ties (face mounted) at CIP concrete, steel stud, and wood stud walls
- FERO Thermal Block Shear Connector (block tie) at CMU walls
- Standard face mounted and block ties without perforations

For all tie products, both stainless steel (i.e., SS) and galvanized steel (i.e., Galv) masonry ties were modelled. Masonry wires are attached to the ties through holes, as shown in **Error! Reference source not found.**. Modelling assumptions are described in further detail in Appendix B. Model geometry for the FERO Thermal Tie products is based on the shop drawings included in Appendix C. Model geometry for the standard masonry ties is based off of equivalent ties without punched holes.

Figure 4 through Figure 7 present the effective R-values (i.e., inverse of the modelled U-factor) and resulting percentages of thermal degradation from the masonry ties for the four backup wall assemblies. These results assume a tie spacing of 16 inches on-center horizontally by 24 inches on-center vertically, and do not include the influence of the floor line structure or shelf angle support. This results in a seemingly negligible 0.03% to 0.04% of the surface area of the insulation being penetrated by the masonry ties.

A range of exterior insulation R-values have been considered from 2- to 6-inches of nominal R-4.2/inch insulation (i.e., from R-8.4 to R-25 [RSI 1.48 to RSI 4.40]) to capture the typical range of exterior insulation values. The general trends for each masonry tie type considered are relatively consistent between the figures; however, the thermal performance for the same masonry tie can vary quite drastically with differences in backup wall configuration and material thermal conductivity. More conductive and monolithic backup wall materials including steel and concrete versus wood will encourage more heat transfer, essentially funneling more heat to the masonry ties. As a result, masonry ties cause more significant reductions in thermal performance at concrete and concrete block backup walls, followed by steel stud/gypsum, and wood-framed or mass timber walls. To convert from IP R-values to metric RSI-values, divide the values presented in the figures by a factor of 5.678.

(a) (b)

Figure 3. Tie products: (a) FERO Thermal Holed Rap-Tie and (b) FERO Thermal Block Shear Connector

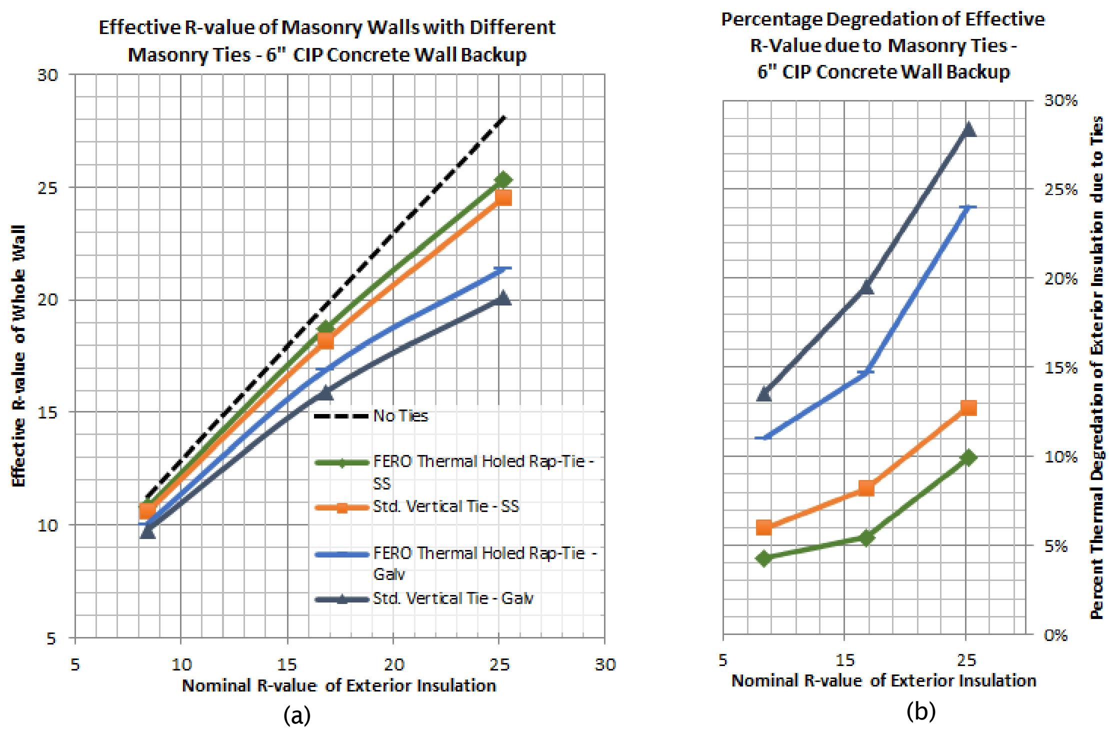


Figure 4. Effective R-value (a) and corresponding percent thermal degradation (b) of masonry walls with different masonry ties – 6-inch concrete wall backup

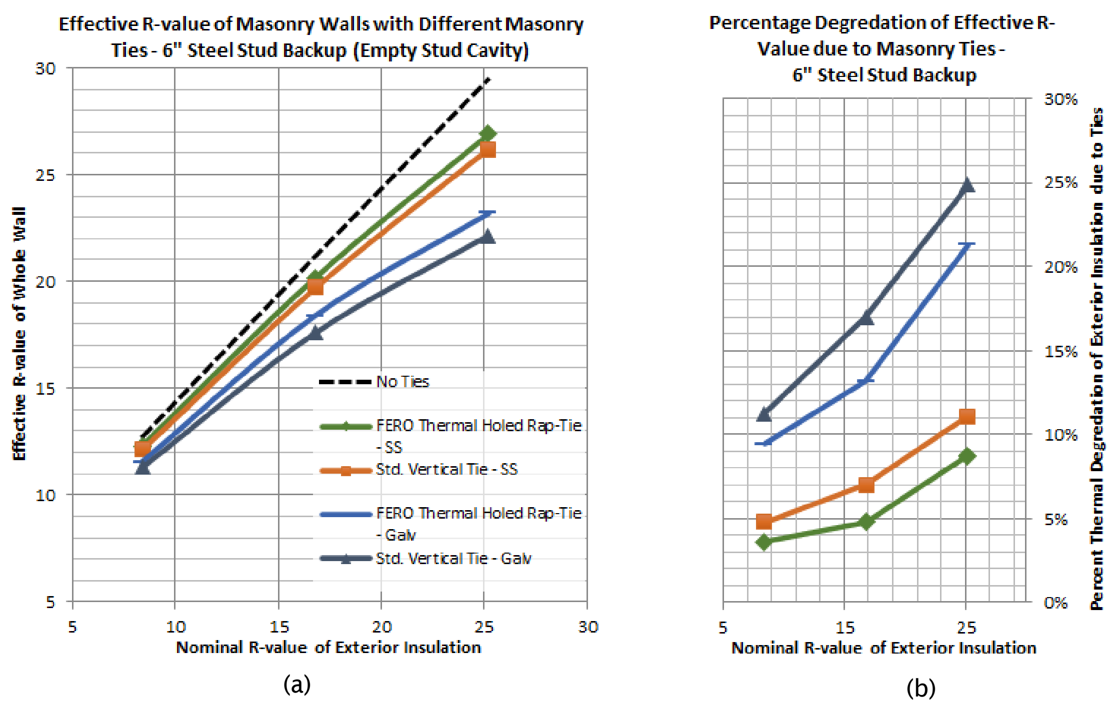
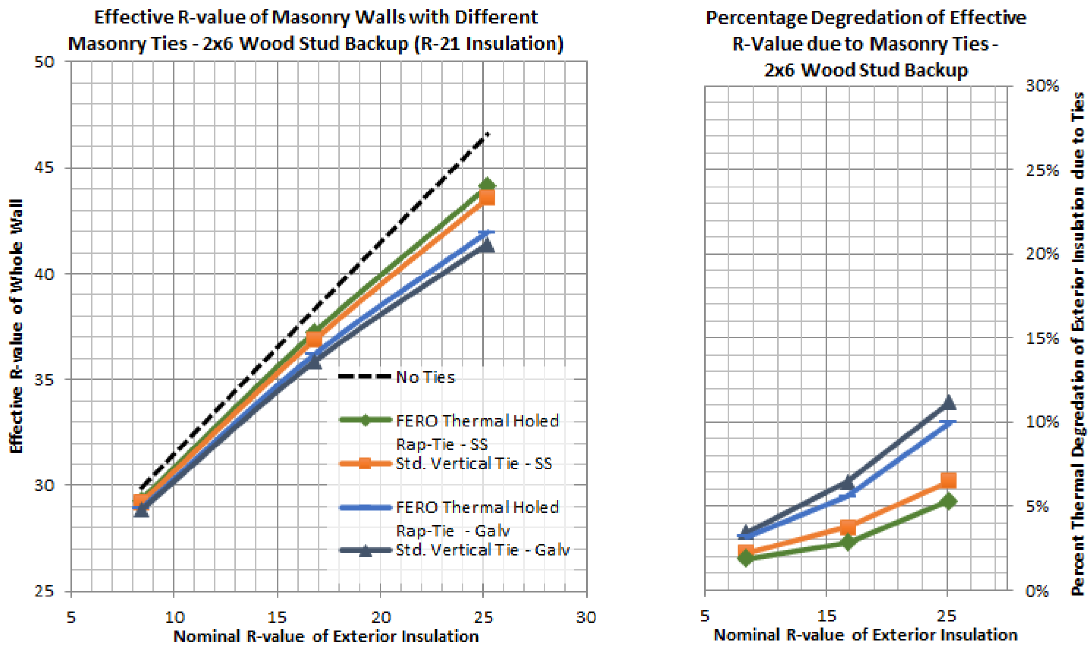
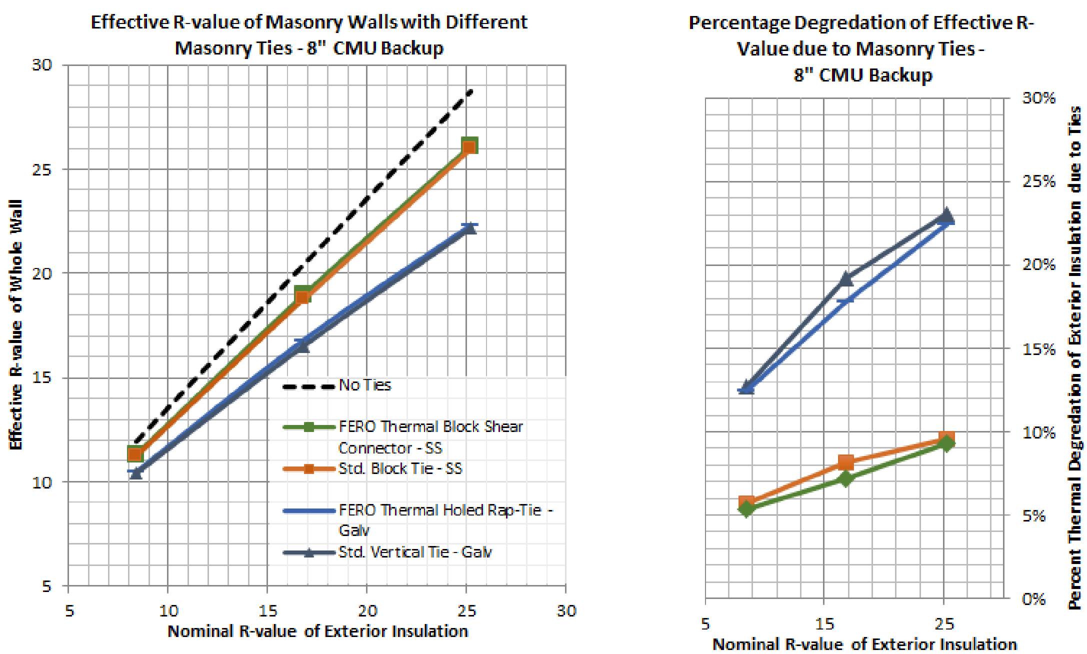


Figure 5. Effective R-value (a) and corresponding percent thermal degradation (b) of masonry walls with different masonry ties – uninsulated 6-inch steel stud wall backup



(a) (b)

Figure 6. Effective R-value (a) and corresponding percent thermal degradation (b) of masonry walls with different masonry ties – 2 × 6 wood stud wall backup (R-21 batt insulation)



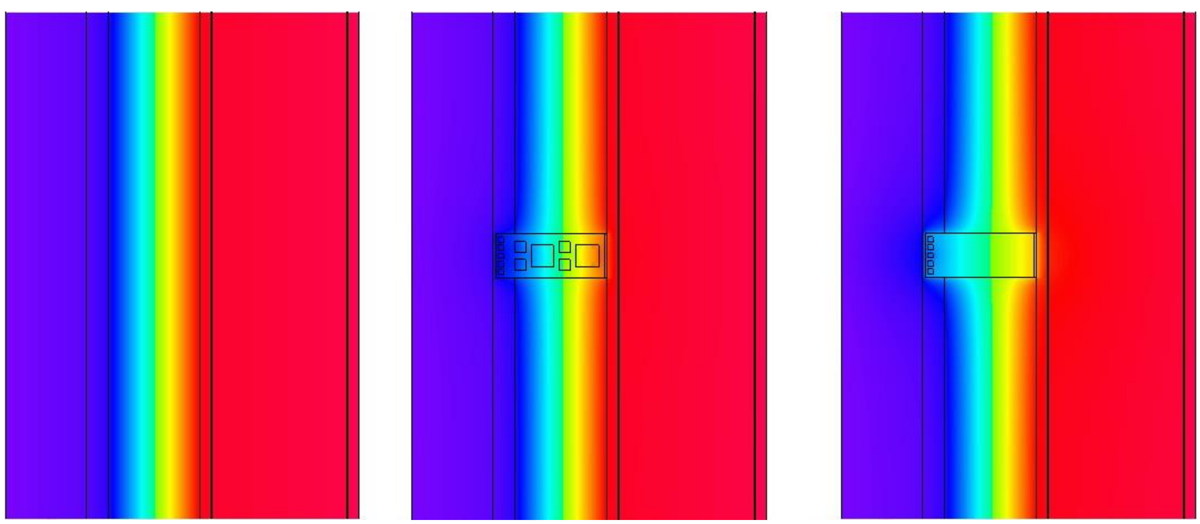
(a) (b)

Figure 7. Effective R-value (a) and corresponding percent thermal degradation (b) of masonry walls with different masonry ties – 8-inch CMU wall backup

The selection of masonry tie material and tie design can have a significant impact on the effective R-value of masonry veneer walls. The effective reduction can be anywhere from 2% to over 25%—depending on the thickness of the exterior insulation, the insulation type, and the backup wall structure—which can be an important consideration for energy code compliance.

In terms of masonry tie selection, stainless steel performs better than galvanized steel because of the metal thermal conductivity, with exterior insulation reductions in the order of 5% to 13% for stainless steel over a concrete backup wall and steel stud backup wall versus 11% to 28% for galvanized steel. These insulation reductions are less with wood framing: in the 2% to 7% range for stainless ties and 5% to 11% for galvanized ties. In addition, the FERO Thermal Ties with perforations perform better than their equivalent sized standard ties without perforations and fabricated of the same metal. The stainless steel FERO Thermal Tie with perforations produces reductions of less than 10% for all the types of backup walls, while the standard stainless steel tie produces reductions up to 13%. The difference is even more significant for galvanized steel, where the FERO Thermal Ties with perforations create between an 11% to 24% reduction for a concrete wall backup, while the standard solid tie of the same size creates a 14% to 28% reduction.

Figure 8 presents a graphical comparison of the best- and worst-case scenarios using a stainless steel FERO Thermal Tie with perforations versus a standard galvanized tie without perforations. The relative temperature gradient across the ties shows the more pronounced heat loss through the standard galvanized tie, whereas the stainless steel FERO Thermal Tie shows very little thermal variation similar to the section without a masonry tie.



(a) No ties | (b) Stainless steel FERO Thermal Tie | (c) Galvanized tie without perforations

Figure 8. Relative temperature gradient across a masonry veneer wall: (a) without masonry ties, (b) with a stainless steel FERO Thermal Holed Rap-Tie, and (c) with a standard galvanized steel masonry tie. Blue indicates a colder temperature extreme and red indicates a warmer temperature extreme

Figure 9 presents the results of the thermal impact of the other masonry tie product designs modelled. All models were completed using an uninsulated 6-inch steel stud backup wall and 4-inches of exterior mineral wool insulation.

The methods of attachment of the masonry wire to the tie through either holed or slotted openings have very similar results for both stainless steel and galvanized steel ties. The wire attachment options accommodate different backup wall types and structural needs while providing similar thermal performance. The standard masonry ties that do not use perforations create lower R-values and larger thermal degradations than FERO Thermal Ties fabricated from the same material such as stainless steel or hot-dipped galvanized steel.

Refer to Appendix A for thermal performance design tables for several FERO Thermal Tie types and standard tie performance.

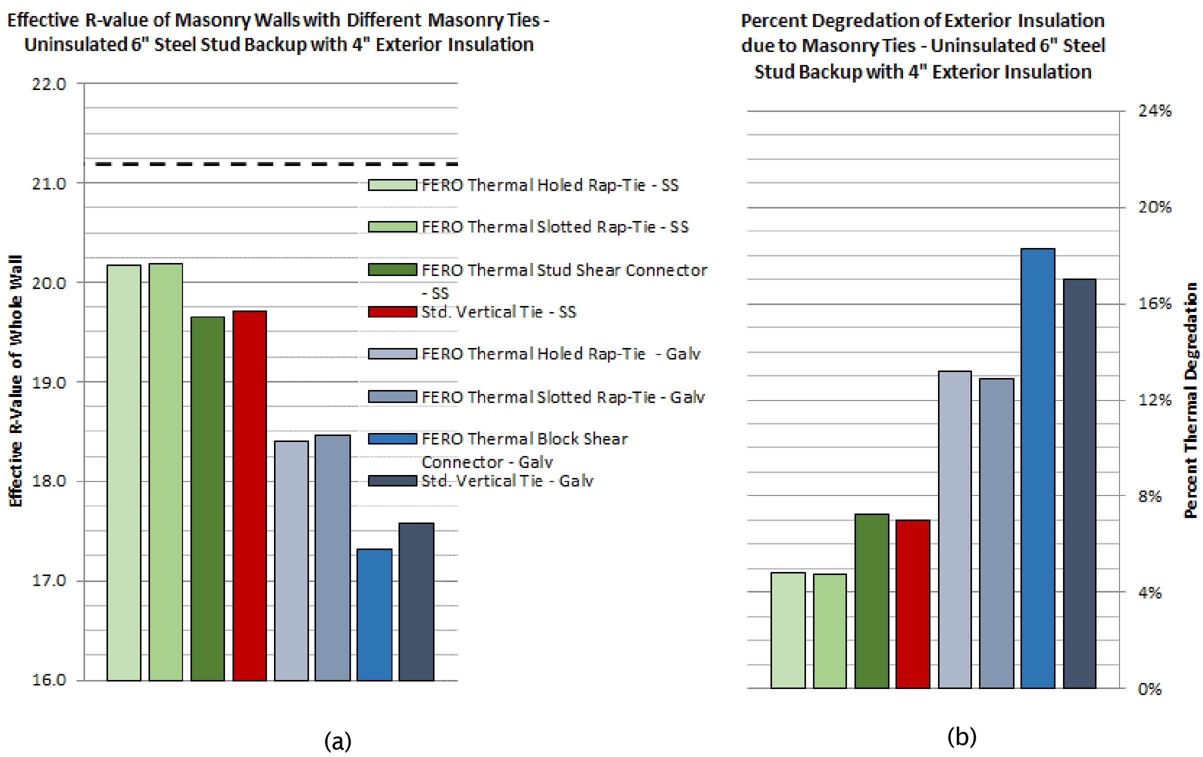


Figure 9. Effective R-value (a) and corresponding percent thermal degradation (b) of masonry walls with different masonry ties – uninsulated 6-inch steel stud wall backup

Masonry Shelf Angles: Placement and Design

Masonry shelf angles provide bearing support for masonry veneers and are typically placed at openings (e.g., over windows and doors) and at floor slab edges or other floor line structures. Although shelf angles may not necessarily be required at every floor, it is typical practice to include a shelf angle at every floor to accommodate ease of construction, alignment, and tolerance requirements. In addition to structural implications, the placement and design of masonry shelf angles also impact the overall thermal performance of the wall enclosure.

Traditionally, masonry shelf angles have been attached directly to the concrete slab edge in multi-storey concrete structure buildings with welded embed plates that are cast into the slab edge or with bolts through the slab edge. For enclosure assemblies, including the floor line structure, that do not need exterior insulation to improve the enclosure's thermal performance (e.g., more commonly in wood-frame wall construction), this method of attachment does not have a significant impact on the thermal performance. However, where exterior insulation is used, such as in steel-framed and mass backup wall and floor line structures, the shelf angle has a significant impact on the overall thermal performance of the whole wall area.

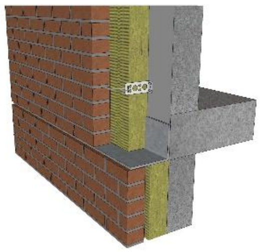
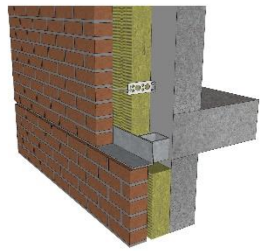
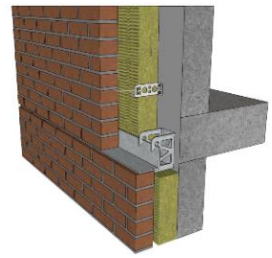
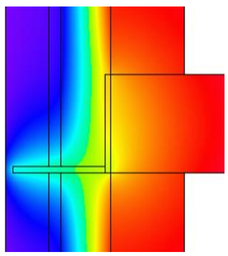
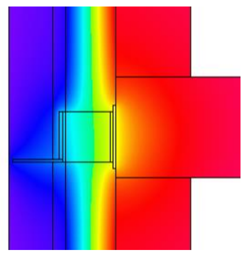
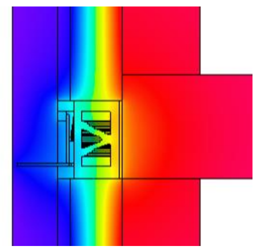
Whether the impact of the shelf angle can be ignored for energy code compliance will depend on the governed code provisions. In terms of the overall wall area, including both the floor line structure and wall area above and below, a steel plate of up to ½-inch thick might represent less than 0.5% of the surface area of the insulation, but this could degrade the effective R-value of the assembly by up to and over 50%. The analysis presented here demonstrates the importance of rigour in energy analysis and calculations, and it confirms that standing off the shelf angle from the building's structure using an intermittent support system can reduce the degree of thermal bridging at shelf angle conditions.

A thermal analysis was performed to assess the impact of continuous and stand-off masonry shelf angles. The modelling was completed using a concrete backup wall with 4 inches of exterior mineral wool insulation, representing a typical exterior insulated masonry veneer wall. Three methods of shelf angle attachment were modelled: direct to the slab edge (i.e., continuous angle); intermittent hollow structural steel (HSS) tubes; and FERO FAST Thermal Bracket Supports with perforations. These methods are summarized in Table 2. Typical construction practices include a water-resistive barrier (WRB) membrane at the slab edge condition. For this reason, a 20-mil-thick, silicone-based, liquid-applied WRB was assumed at the slab edge, adding a contact resistance of R-0.009 (0.00016 RSI) between the shelf angle support and the concrete slab edge.

When considering an 8-inch-thick slab edge with a 4-foot section of wall above and below the slab (i.e., 8-foot, 8-inch floor-to-floor height) and stainless steel FERO Thermal Holed Rap-Ties spaced at 16 inches on-center horizontally and 24 inches on-center vertically, the continuous shelf angle was shown to reduce the effective R-value of the full height assembly by 48%. Standing off the shelf angle from the slab edge outboard of the exterior insulation layer with intermittent supports spaced at 4 feet on-center was shown to dramatically improve the thermal performance; the HSS attachment contributed to a reduction in R-value of 14.8% and the FERO FAST Thermal Bracket Support resulted in a reduction of only 13.4%. Table 2 presents the results of the analysis of the influence of the shelf angle attachment methods on the effective R-value of a masonry wall.

Table 2 shows that shelf angles supported with intermittent HSS section supports or brackets result in an effective R-value of approximately R-16, compared to an effective R-value of R-9 for the continuous shelf angle case. A comparison of these values to current prescriptive energy code requirements for the mass wall types shown in Table 1 (i.e., generally in the R-10 to R-20 (RSI 1.76 to 3.52) or higher range) demonstrates that there are few climate zones where the continuous shelf angle would meet these requirements. The significant thermal bridging through the continuous shelf angle also heightens the effect of depreciating returns when adding additional exterior insulation, meaning that it is extremely difficult to attain R-values close to R-16 (RSI 2.38) if conventional continuous shelf angles are relied upon for bearing support. Therefore, to prescriptively comply with current energy codes, the use of intermittently supported and thermally improved shelf angles may be necessary.

Table 2. Summary of effective R-values and corresponding thermal degradation of masonry walls with different shelf angle support configurations – concrete wall backup with 4 inches of mineral wool insulation and stainless steel FERO Thermal Holed Rap-Ties spaced at 16 inches on-center horizontally and 24 inches on-center vertically

	Continuous Angle	**HSS Section**	**FERO FAST Thermal Bracket Support**
Illustration of the Modelled Wall and Floor Line Assembly			
Relative Temperature Gradient at the Slab Edge Condition*			
Assembly R-Value Without Masonry Support Penetrations	R-19.6 (RSI 3.45)		
Effective Assembly R-Value	R-9.63 (RSI 1.70)	R-15.8 (RSI 2.79)	R-16.1 (RSI 2.83)
Thermal Degradation: Shelf Angle Support	48.0%	15.7%	13.4%
Thermal Degradation: Masonry Ties	5.4%		
Combined Thermal Degradation: Shelf Angle Support and Masonry Ties	50.8%	20.3%	18.1%

**Blue indicates a colder temperature extreme and red indicates a warmer temperature extreme*

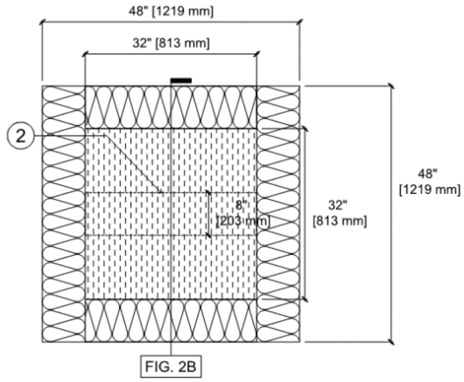
Physical Thermal Testing and Model Verification

To validate the thermal modelling results of the FERO FAST Thermal Bracket Support, physical thermal testing was performed using a modified ASTM C177 compliant large-scale guarded hot plate apparatus to measure the heat flow across a FERO FAST Thermal Bracket Support [8], [9]. The test apparatus consists of a top cold plate and multiple bottom hot plates that impose a temperature differential, and thus heat flow, across a horizontal test specimen. The apparatus accommodates a 48-inch square specimen assembly and measures heat flow over a 16-inch square area at the center of the apparatus using the metered hot plate, called the meter plate. The heat flow is determined by measuring the power input to the meter plate, which is guarded at the sides and below with guard plates. The guard plates are maintained at the same hot temperature as the meter plate to ensure that all heat from the meter plate is directed upward through the specimen. While hot plate testing is not typically used to measure nonhomogeneous specimens (i.e., thermally bridged components), the modified ASTM C177 compliant test apparatus and the methods used for this study have been previously validated for measuring heat flow across thermally bridged specimens [10].

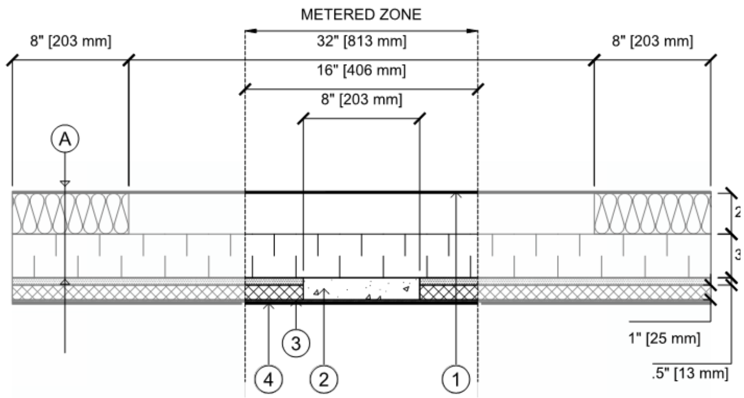
Two specimen assemblies were tested by the guarded hot plate apparatus, as shown schematically in Figure 10. Both test specimen assemblies were mocked-up with a slab edge condition using a 1-1/2-inch-thick, 8-inch-wide concrete paver to approximate a concrete floor slab. One of the assemblies includes continuous insulation while the other assembly includes a FERO FAST Standard bracket to bridge the exterior insulation for comparison. The FERO FAST Thermal Bracket Support was attached using a threaded rod grouted into the concrete paver. Extruded polystyrene (XPS) insulation measuring 1 inch thick covered by a 1/2-inch-thick fiberglass mat-faced gypsum sheathing board was used to approximate a simplified wall assembly above and below the floor slab. The assemblies were exterior insulated with 3 inches of mineral wool insulation.

An air cavity was provided between the mineral wool insulation and the cold plate filled at the perimeter with an 8-inch-wide band of fiberglass batt guard insulation to limit lateral heat flow in the cavity space. For simplicity of construction, a masonry veneer was not included in either mock-up. Polyethylene foam gaskets were used where rigid materials were in contact with the hot and cold plates to approximate typical air film resistances and to encourage more uniform temperatures at the plates.

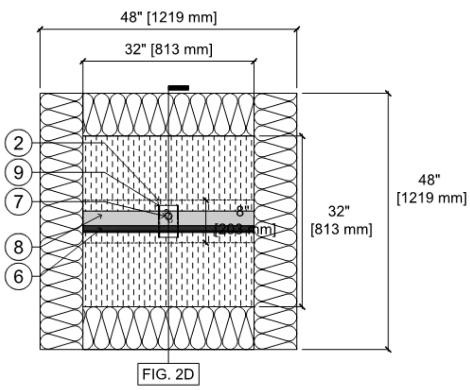
To determine the validity of the thermal modelling results discussed in the previous section, the metered areas of the above tested assemblies were recreated in HEAT3. The conductivity of concrete varies significantly based on its composition, and the composition of the concrete paver tested was unknown. For this reason, the conductivity of the concrete paver was inferred from the test results of the assembly with continuous insulation, where the conductivities of the remaining materials were estimated with a relatively high degree of confidence. Using a conductivity value of 0.58 Btu/hr·ft°F (1.0 W/m·K) for the concrete paver resulted in good agreement (1.5% difference) between the modelled and tested heat flow for the assembly with continuous insulation.



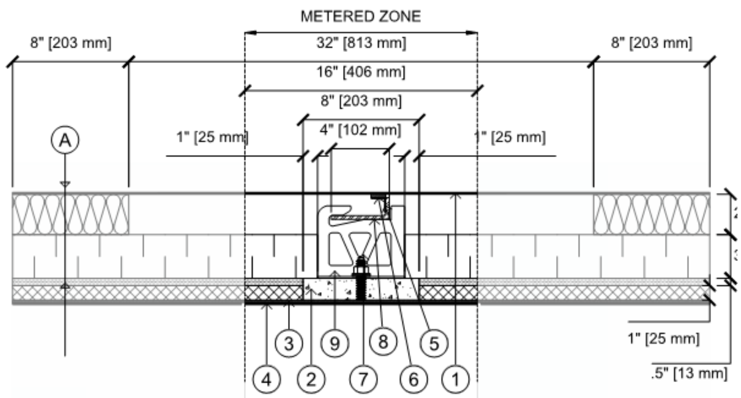
(a)



(b)



(c)



(d)

LEGEND:

1. COLD PLATE
2. CONCRETE PAVER
3. POLYETHYLENE FOAM
4. METER (HOT) PLATE
5. SMALL STEEL ANGLE
6. POLYETHYLENE FOAM
7. THREADED ROD WITH SQUARE WASHER, ROUND WASHER, AND NUT
8. SHELF ANGLE
9. FERO FAST THERMAL BRACKET SUPPORT

ASSEMBLY A (TOP TO BOTTOM):

- COLD PLATE
- FIBERGLASS BATT INSULATION
- MINERAL WOOL INSULATION
- FIBERGLASS MAT FACED GYPSUM SHEATHING
- XPS INSULATION
- POLYETHYLENE FOAM
- GUARD (HOT) PLATE

Figure 10 Schematic of the tested assemblies: (a) plan view with continuous insulation, (b) section with continuous insulation, (c) plan view with bracket, and (d) section with bracket. Plans and sections are not to scale.

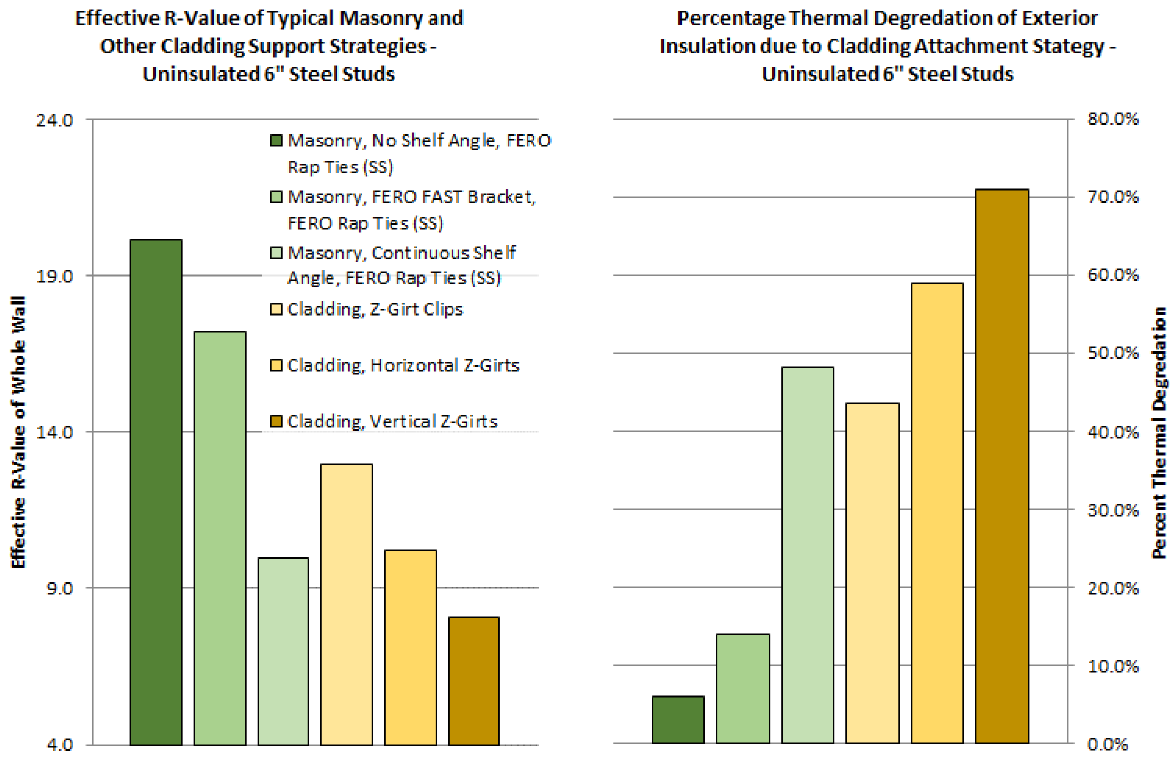
Contact resistances can significantly impact the modelled heat flow where highly conductive materials are in contact [11], [3]. For this reason, a contact resistance of R-0.06 (0.011 RSI) was included between the FERO FAST Standard bracket and the concrete, and a value of R-0.01 (0.0018 RSI) was included at the points of contact between the bracket to calibrate the model. Similar values have been used by others at concrete-to-steel and steel-to-steel interfaces, respectively [11]. Including the above contact resistances and the inferred conductivity of the concrete paver resulted in excellent agreement (0.1% difference) between the modelled and metered heat flow for the assembly with the FERO FAST Standard bracket.

It should be noted that the FERO FAST Thermal Bracket Support was tested in direct contact with the concrete paver. In most practical field applications, the shelf angle support is installed over a WRB membrane rather than directly to the concrete slab edge. For this reason, the concrete paver contact resistance was not included in the models discussed in the previous section of this paper or in the design table results shown in Appendix A. Instead, the resistance synonymous with a 20-mil (0.51 mm), silicone-based, liquid-applied WRB membrane was used behind the bracket. The R-0.009 (0.00016 RSI) resistance provided by the WRB is significantly lower than the concrete paver R-0.06 (0.011 RSI) contact resistance use for model calibration. Therefore, the modeled results in Appendix A for shelf angle supports consider a WRB membrane and are both conservative as well as applicable to a wide range of real-world installations. Note that the resistance provided by the WRB membrane was not included for masonry tie models when producing the Appendix A tie design tables because including the WRB membrane was found to have a negligible impact (less than 1%) on the modelled performance.

Comparison of Masonry to Other Cladding Systems

A final analysis was performed to compare anchored masonry veneer cladding to other cladding systems supported through exterior insulation. Claddings such as metal panel, fiber cement panels, stucco, thin cultured stone, and thin masonry, etc., with exterior insulation are typically supported by systems such as continuous girts, intermittent clips, long screws, and other systems. These structural elements penetrate the exterior insulation and are typically larger cross sectionally than masonry ties and designed to carry gravity and live loads from the claddings. Historically, the use of continuous metal Z-girts was the most common cladding attachment method used throughout construction markets in Canada and the United States; however, in recent years the use of more thermally efficient systems has become more common.

Figure 11 presents three masonry veneer conditions, including stainless steel FERO Thermal Holed-Rap Ties, stainless steel FERO Thermal Holed Rap-Ties with the FERO FAST Thermal Bracket Support, and stainless steel FERO Thermal Holed Rap-Ties with a continuous shelf angle. These three anchored masonry veneer wall assemblies are compared to exterior insulated wall assemblies with three configurations: continuous 18-gauge Z-girts in a horizontal orientation; continuous 18-gauge Z-girts in a vertical orientation; and intermittent 6-inch-tall, 18-gauge clips. The backup wall assembly for this analysis is an uninsulated 6-inch steel stud wall with gypsum sheathing and gypsum interior finish. The results for CIP and CMU backup walls would be similar to that shown in Figure 11. The results for wood stud walls would show improvement over these more conductive backup wall structures, as previously shown for the masonry tie analysis.



(a) (b)

Figure 11. a) Effective R-value and b) corresponding percent thermal degradation of typical masonry veneer and other cladding support strategies using 4 inches of exterior insulation over uninsulated 6-inch steel studs

As demonstrated by this comparative analysis of other cladding support systems, masonry veneers have the potential to be one of the most thermally efficient cladding systems if the thermal performance of masonry supports is adequately addressed. The results demonstrate that where effective R-value targets are in the R-10 to R-20 (RSI 2.64 to 3.52) range, 4 inches (or less, depending on the backup wall structure and locality) of exterior insulation may be sufficient for masonry walls supported using stainless steel ties and a stand-off shelf angle supports, whereas many other systems would require considerably more insulation to produce these results.

Thermal degradation through the masonry ties can be reduced to less than 6% using stainless steel FERO Holed Rap Ties. With the use of FERO FAST Thermal Bracket Supports, exterior insulation reductions of 14% are expected for 4 inches of exterior insulation over an uninsulated 6-inch steel stud backup wall. This is significantly better than the reductions of approximately 44% to over 70% that can be seen with continuous Z-girts and Z-girt clips used to support other cladding systems. This reduction supports the use of anchored masonry veneers over exterior insulated walls without compromising thermal performance.

Conclusion

The effective R-values of several different masonry ties over different backup wall structures (e.g., concrete, steel stud, and wood frame) were modelled using a three-dimensional finite-element computer software program. The results show that the selection of tie material and tie design can have a significant impact on the effective R-value of masonry walls, and R-value reductions from 2% to almost 29% can be expected. The use of stainless steel FERO Thermal Ties or galvanized masonry ties with perforations results in the lowest insulation reductions (i.e., between 5% and 24%) compared to standard masonry ties without holes (i.e., between 5% and 28%) over concrete or steel stud backup walls, and lower for wood-frame backup walls.

The thermal impact of the design of masonry veneer shelf angles was also shown to be significant. Direct-attached masonry shelf angles perform quite poorly from a thermal standpoint, with exterior insulation R-value reductions of over 50% for 4 inches of exterior insulation using stainless ties over a 6-inch concrete backup wall. Shelf angles supported outside of the exterior insulation with intermittent HSS or thermal bracket supports have more tolerable insulation reductions in the order of 18% to 19% for the same wall, as shown by computer modelling validated by physical thermal testing.

For anchored masonry veneer walls, effective R-values in the range of R-10 to R-20 (RSI 1.76 to 3.52) can be achieved with 3 to 6 inches of exterior insulation, depending on masonry tie selection and the backup wall construction, provided that stand-off shelf angles are intermittently supported. This generally means that compliance with the current and future prescriptive energy code requirements in North America requires the use of intermittently supported and thermally improved shelf angle supports.

It was shown that masonry veneer claddings have the potential to perform very well from a thermal standpoint and will outperform many other exterior insulated cladding assemblies. Typical exterior insulation R-value reductions for well-designed anchored masonry veneer walls will be in the order of 14% for 4 inches of exterior insulation, whereas continuous girt systems will have reductions in the 60% to 70% or more range. This means that less exterior insulation can be used, and thinner masonry walls can be constructed to achieve the same performance as other less thermally efficient cladding supports.

This paper demonstrates that thermal efficiency must be addressed as part of the material selection and design process of exterior-insulated masonry veneer wall assemblies. The use of stand-off shelf angles and stainless or galvanized masonry ties with perforations can minimize the thermal degradation of the wall, and masonry veneer wall assemblies can be one of the more thermally efficient wall assemblies available.

Designers are encouraged to reference the design tables provided in Appendix A to determine the effective thermal performance of various anchored masonry veneer wall assemblies.

References

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The FERO family of Masonry Wall Connectors, as installed, may fall within the scope of one or more issued Patents or pending patent applications, according to the applicable installation type. Those patents include US 8,051,621; US 8,555,595; US 8,893,452 and corresponding Canadian Patents CA 2 566 552; CA 2 700 636; and CA 2 804 542.

The FERO FAST family of masonry supports, as installed may fall within the scope of one or more US or foreign patents or patent applications. Those patents include US 9,316,004; US 9,447,585; US 10, 323,419; US 10,294,676; US 11,041,315; US 11,162,265 and other pending applications.
Other US and Foreign Patents Pending.

Appendix A: Thermal Design Tables

Use of the Design Tables

Designers may wish to consider the effective R-value of an anchored masonry wall assembly to confirm project-specific conformance with energy codes, energy efficiency standards, or energy and thermal performance targets. An accurate effective R-value for exterior insulated masonry walls can be difficult to obtain through conventional calculation methods due to the irregular geometry and discrete thermal bridging at anchor points. Thus, the tables provided in this appendix present effective R-values, linear transmittance, and point transmittance values derived from three-dimensional thermal modelling for exterior-insulated masonry veneer walls and floor line conditions. Tabulated values include a variety of different masonry tie and shelf angle configurations to aid in the design process. The modelled performance of the FERO FAST Thermal Bracket Support has been validated by physical thermal testing. Where a U-factor is needed, taking the inverse of the effective R-value will provide this value.

Modelling results consider four backup wall structures, including:

- 2 × 6 wood stud walls framed at 16 inches on-center with 1/2-inch-thick interior gypsum board, R-21 batt insulation in cavities, and 1/2-inch-thick fiberglass-reinforced exterior-grade gypsum sheathing
- 6-inch, 18-gauge steel stud walls framed at 16 inches on-center with 1/2-inch-thick interior gypsum board, no cavity insulation, and 1/2-inch-thick fiberglass-reinforced exterior-grade gypsum sheathing
- 6-inch cast-in-place (CIP) concrete walls
- 8-inch concrete masonry unit (CMU) walls with fully grouted cores

For each backup wall structure, three thicknesses of exterior insulation are considered: 2 inches, 4 inches, and 6 inches, with a thermal resistance value of R-4.2/inch and R-6/inch. This R-value range covers the lower and upper bound R-values of the insulation types commonly used for exterior insulation. For insulation types that have a thermal resistance value that exceeds R-4.2/inch and is less than R-6/inch, the effective R-value design table values can be linearly interpolated using the equation below, within an accuracy of 1%. Linear and point transmittance values can similarly be interpolated.

$$R_{eff} = \frac{R_{nom} - R_{4.2,nom}}{R_{6,nom} - R_{4.2,nom}}\left(R_{6,eff} - R_{4.2,eff}\right) + R_{4.2,eff}$$

Where:

- R_{eff} is the effective R-value for the assembly to be estimated by interpolation
- R_{nom} is the nominal R-value of the assembly to be estimated by interpolation
- $R_{4.2,nom}$ is the nominal R-value of the lower range in the design table (i.e., R-4.2/inch exterior insulation)
- $R_{6,nom}$ is the nominal R-value of the upper range in the design table (i.e., R-6/inch exterior insulation)
- $R_{4.2,eff}$ is the effective R-value of the lower range in the design table (i.e., R-4.2/inch exterior insulation)

→ $R_{6,eff}$ is the effective R-value of the upper range in the design table (i.e., R-6/inch exterior insulation)

The design tables include effective R-values for above-grade walls that account for thermal bridging at anchored masonry ties (refer to Table A1 through Table A4) and for floor line conditions that account for thermal bridging at shelf angle supports (refer to Table A5 through Table A8). The effective R-values for wood and steel stud framed walls from Table A1 and Table A2 are only valid when used with the accompanying floor line R-value from Table A5 and Table A6. R-values reported for the framed walls capture vertical studs, and the effective R-values reported for the floor line conditions account for the added heat loss through horizontal framing members (i.e., top and bottom plates/tracks) directly above and below the floor line condition.

To provide greater flexibility in the evaluation of thermal bridging at anchored masonry veneer points, Table A9 through Table A12 provide linear transmittance values (i.e., Psi-values) and point transmittance values (i.e., Chi values) to account for thermal bridging at shelf angle supports and masonry ties respectively. The linear transmittance and point transmittance values represent the additional heat flow lost through these thermal bridges and can be used to calculate the U-factor of the entire wall elevation using the following equation:

$$U = \left[\frac{\sum(\psi \cdot L) + \sum(\chi \cdot n)}{\text{Wall Area}} + \frac{1}{R_{\text{w/o penetrations}}} \right]$$

Where:

→ Ψ is the linear transmittance value of the shelf angle support

→ L is the length of shelf angle within the representative area

→ χ is the point transmittance value for the masonry tie

→ n is the number of masonry ties included in the representative wall area

→ Wall Area is the area of a representative section of the wall elevation in question

→ $R_{w/o\ penetrations}$ is the R-value of the wall elevation in question without penetrations through the exterior insulation

Effective R-Value Design Tables: FERO Thermal Ties and Standard Masonry Ties

Table A1: Effective R-value of wood stud walls between wood-framed floor lines

WOOD STUD WALLS	2×6 Wood Stud Walls with R-21 Batt Insulation, R-4.2/inch – R-6/inch Exterior Insulation								
Tie Type	Exterior Insulation Thickness	Rated R-Value of Insulation Alone, Cavity + Exterior (RSI)	Effective R-Value (RSI)						
			Without Masonry Tie Penetrations	With Masonry Tie Penetrations* @ 16" × 24" o.c.		With Masonry Tie Penetrations* @ 16" × 16" o.c.		With Masonry Tie Penetrations* @ 24" × 24" o.c.	
				Stainless Steel	Galvanized Steel	Stainless Steel	Galvanized Steel	Stainless Steel	Galvanized Steel
FERO Thermal Holed Rap-Tie	2"	21 + 8.4-12 (3.7+1.5-2.1)	29.8-33.5 (5.3-5.9)	29.3-32.6 (5.2-5.7)	28.9-32.0 (5.1-5.6)	29.1-32.2 (5.1-5.7)	28.5-31.3 (5.0-5.5)	30.4-33.8 (5.4-6.0)	30.1-33.4 (5.3-5.9)
	4"	21+ 16.8-24 (3.7+3.0-4.2)	38.3-45.5 (6.7-8.0)	37.2-43.7 (6.6-7.7)	36.2-41.9 (6.4-7.4)	36.7-42.8 (6.5-7.5)	35.2-40.3 (6.2-7.1)	38.5-45.2 (6.8-8.0)	37.8-43.9 (6.7-7.7)
	6"	21+ 25.2-36 (3.7+4.4-6.34)	46.6-57.4 (8.2-10.1)	44.1-52.9 (7.8-9.3)	42.0-49.3 (7.4-8.7)	43.0-51.0 (7.6-9.0)	40.0-46.2 (7.0-8.1)	45.8-55.2 (8.1-9.7)	44.2-52.6 (7.8-9.3)
FERO Thermal Stud Shear Connector	2"	21 + 8.4-12 (3.7+1.5-2.1)	29.8-33.5 (5.3-5.9)	27.4-30.4 (4.8-5.3)	24.6-26.9 (4.3-4.7)	26.3-29.0 (4.6-5.1)	22.7-24.5 (4.0-4.3)	29.0-32.2 (5.1-5.7)	26.9-29.5 (4.7-5.2)
	4"	21+ 16.8-24 (3.7+3.0-4.2)	38.3-45.5 (6.7-8.0)	34.9-40.8 (6.2-7.2)	30.7-34.9 (5.4-6.1)	33.5-38.7 (5.9-6.8)	27.9-31.3 (4.9-5.5)	36.8-43.1 (6.5-7.6)	33.6-38.5 (5.9-6.8)
	6"	21+ 25.2-36 (3.7+4.4-6.34)	46.6-57.4 (8.2-10.1)	42.0-50.3 (7.4-8.9)	36.1-41.7 (6.4-7.4)	40.0-47.4 (7.0-8.3)	32.4-36.7 (5.7-6.5)	44.2-53.3 (7.8-9.4)	39.7-46.6 (7.0-8.2)
Standard Vertical Tie	2"	21 + 8.4-12 (3.7+1.5-2.1)	29.8-33.5 (5.3-5.9)	29.2-32.4 (5.1-5.7)	28.8-31.9 (5.1-5.6)	28.9-31.9 (5.1-5.6)	28.4-31.1 (5.0-5.5)	30.3-33.7 (5.3-5.9)	30.1-33.3 (5.3-5.9)
	4"	21+ 16.8-24 (3.7+3.0-4.2)	38.3-45.5 (6.7-8.0)	36.9-43.1 (6.5-7.6)	35.8-41.4 (6.3-7.3)	36.2-41.9 (6.4-7.4)	34.8-39.6 (6.1-7.0)	38.3-44.8 (6.7-7.9)	37.5-43.5 (6.6-7.7)
	6"	21+ 25.2-36 (3.7+4.4-6.34)	46.6-57.4 (8.2-10.1)	43.6-52.0 (7.7-9.2)	41.4-48.5 (7.3-8.5)	42.2-49.7 (7.4-8.7)	39.3-45.1 (6.9-7.9)	45.4-54.5 (8.0-9.6)	43.8-51.9 (7.7-9.1)

*For horizontal and vertical spacing, respectively.

Table A2: Effective R-value of steel stud walls between concrete floor lines

STEEL STUD WALLS	6" Steel 16 ga Stud Walls (No Cavity Insulation), R-4.2/inch – R-6/inch Exterior Insulation								
Tie Type	Exterior Insulation Thickness	Rated R-Value of Insulation Alone, Cavity + Exterior (RSI)	Effective R-Value (RSI)						
			Without Masonry Tie Penetrations	With Masonry Tie Penetrations* @ 16" × 24" o.c.		With Masonry Tie Penetrations* @ 16" × 16" o.c.		With Masonry Tie Penetrations* @ 24" × 24" o.c.	
				Stainless Steel	Galvanized Steel	Stainless Steel	Galvanized Steel	Stainless Steel	Galvanized Steel
FERO Thermal Holed Rap-Tie	2"	0 + 8.4-12 (0+1.5-2.1)	12.7-16.4 (2.2-2.9)	12.3-15.5 (2.2-2.7)	11.5-14.2 (2.0-2.5)	12.1-15.1 (2.1-2.7)	11.0-13.4 (1.9-2.4)	12.5-15.8 (2.2-2.8)	11.9-14.9 (2.1-2.6)
	4"	0+ 16.8-24 (0+3.0-4.2)	21.2-28.4 (3.7-5.0)	20.2-26.5 (3.6-4.7)	18.4-23.3 (3.2-4.1)	19.7-25.6 (3.5-4.5)	17.3-21.4 (3.0-3.8)	20.5-27.1 (3.6-4.8)	19.3-24.8 (3.4-4.4)
	6"	0+ 25.2-36 (0+4.4-6.34)	29.5-40.3 (5.2-7.1)	26.9-35.4 (4.7-6.2)	23.2-29.0 (4.1-5.1)	25.8-33.3 (4.5-5.9)	21.0-25.5 (3.7-4.5)	27.7-36.9 (4.9-6.5)	25.0-32.0 (4.4-5.6)
FERO Thermal Stud Shear Connector	2"	0 + 8.4-12 (0+1.5-2.1)	12.7-16.4 (2.2-2.9)	12.1-15.1 (2.1-2.7)	11.1-13.5 (2.0-2.4)	11.7-14.5 (2.1-2.6)	10.4-12.4 (1.8-2.2)	12.3-15.5 (2.2-2.7)	11.6-14.3 (2.0-2.5)
	4"	0+ 16.8-24 (0+3.0-4.2)	21.2-28.4 (3.7-5.0)	19.7-25.5 (3.5-4.5)	17.3-21.5 (3.1-3.8)	19.0-24.3 (3.3-4.3)	15.9-19.2 (2.8-3.4)	20.2-26.5 (3.6-4.7)	18.5-23.5 (3.3-4.1)
	6"	0+ 25.2-36 (0+4.4-6.34)	29.5-40.3 (5.2-7.1)	26.7-35.1 (4.7-6.2)	22.7-28.3 (4.0-5.0)	25.6-33.0 (4.5-5.8)	20.4-24.6 (3.6-4.3)	27.6-36.7 (4.9-6.5)	24.6-31.4 (4.3-5.5)
Standard Vertical Tie	2"	0 + 8.4-12 (0+1.5-2.1)	12.7-16.4 (2.2-2.9)	12.1-15.2 (2.1-2.7)	11.3-13.8 (2.0-2.4)	11.8-14.7 (2.1-2.6)	10.7-12.9 (1.9-2.3)	12.4-15.6 (2.2-2.8)	11.8-14.6 (2.1-2.6)
	4"	0+ 16.8-24 (0+3.0-4.2)	21.2-28.4 (3.7-5.0)	19.7-25.6 (3.5-4.5)	17.6-22.0 (3.1-3.9)	19.0-24.4 (3.4-4.3)	16.2-19.7 (2.9-3.5)	20.2-26.5 (3.6-4.7)	18.7-23.8 (3.3-4.2)
	6"	0+ 25.2-36 (0+4.4-6.34)	29.5-40.3 (5.2-7.1)	26.2-34.1 (4.6-6.0)	22.1-27.3 (3.9-4.8)	24.8-31.7 (4.4-5.6)	19.7-23.6 (3.5-4.1)	27.2-36.0 (4.8-6.3)	24.1-30.6 (4.3-5.4)

*For horizontal and vertical spacing, respectively.

Table A3: Effective R-value of CIP concrete walls between concrete floor lines

CIP CONCRETE WALLS			6" CIP Concrete Walls, R-4.2/inch – R-6/inch Exterior Insulation						
Tie Type	Exterior Insulation Thickness	Rated R-Value of Insulation Alone, Cavity + Exterior (RSI)	Effective R-Value (RSI)						
			Without Masonry Tie Penetrations	With Masonry Tie Penetrations* @ 16" × 24" o.c.		With Masonry Tie Penetrations* @ 16" × 16" o.c.		With Masonry Tie Penetrations* @ 24" × 24" o.c.	
				Stainless Steel	Galvanized Steel	Stainless Steel	Galvanized Steel	Stainless Steel	Galvanized Steel
FERO Thermal Holed Rap-Tie	2"	8.4-12 (1.5-2.1)	11.3–14.9 (2.0–2.6)	10.8–14.0 (1.9–2.5)	10.0–12.7 (1.8–2.2)	10.6–13.6 (1.9–2.4)	9.5–11.8 (1.7–2.1)	11.0–14.3 (1.9–2.5)	10.4–13.3 (1.8–2.3)
	4"	16.8-24 (3.0-4.2)	19.8–27.1 (3.5–4.8)	18.7–25.0 (3.3–4.4)	16.9–21.7 (3.0–3.8)	18.2–24.0 (3.2–4.2)	15.7–19.7 (2.8–3.5)	19.0–25.6 (3.4–4.5)	17.7–23.2 (3.1–4.1)
	6"	25.2-36 (4.4-6.34)	28.1–38.9 (4.9–6.9)	25.3–33.6 (4.5–5.9)	21.4–26.8 (3.8–4.7)	24.1–31.5 (4.2–5.5)	19.1–23.2 (3.4–4.1)	26.2–35.2 (4.6–6.2)	23.2–29.9 (4.1–5.3)
Standard Vertical Tie	2"	8.4-12 (1.5-2.1)	11.3–14.9 (2.0–2.6)	10.6–13.6 (1.9–2.4)	9.8–12.2 (1.7–2.1)	10.3–13.1 (1.8–2.3)	9.1–11.2 (1.6–2.0)	10.8–14.0 (1.9–2.5)	10.2–13.0 (1.8–2.3)
	4"	16.8-24 (3.0-4.2)	19.8–27.1 (3.5–4.8)	18.2–24.0 (3.2–4.2)	15.9–20.1 (2.8–3.5)	17.4–22.7 (3.1–4.0)	14.5–17.8 (2.6–3.1)	18.7–24.9 (3.3–4.4)	17.0–21.9 (3.0–3.9)
	6"	25.2-36 (4.4-6.34)	28.1–38.9 (4.9–6.9)	24.5–32.2 (4.3–5.7)	20.1–24.8 (3.5–4.4)	23.0–29.6 (4.1–5.2)	17.6–21.0 (3.1–3.7)	25.6–34.1 (4.5–6.0)	22.2–28.2 (3.9–5.0)

*For horizontal and vertical spacing, respectively.

Table A4: Effective R-value of CMU walls between concrete floor lines

CMU CONCRETE WALLS			8" CMU Walls, R-4.2/inch – R-6/inch Exterior Insulation				
Tie Type	Exterior Insulation Thickness	Rated R-Value of Insulation Alone, Cavity + Exterior (RSI)	Effective R-Value [RSI]				
			Without Masonry Tie Penetrations	With Masonry Tie Penetrations* @ 16" × 24" o.c.		With Masonry Tie Penetrations* @ 16" × 16" o.c.	
				Stainless Steel	Galvanized Steel	Stainless Steel	Galvanized Steel
FERO Thermal Block Shear Connector	2"	8.4-12 (1.5-2.1)	11.9–15.6 (2.1–2.7)	11.3–14.4 (2.0–2.5)	10.5–12.9 (1.8–2.3)	11.0–13.8 (1.9–2.4)	9.8–11.9 (1.7–2.1)
	4"	16.8-24 (3.0-4.2)	20.4–27.7 (3.6–4.9)	19.0–24.8 (3.3–4.4)	16.8–21.1 (3.0–3.7)	18.3–23.6 (3.2–4.2)	15.4–18.9 (2.7–3.3)
	6"	25.2-36 (4.4-6.34)	28.8–39.6 (5.1–7.0)	26.1–34.5 (4.6–6.1)	22.3–28.0 (3.9–4.9)	24.9–32.4 (4.4–5.7)	20.1–24.4 (3.5–4.3)
Standard Block Tie	2"	8.4-12 (1.5-2.1)	11.9–15.6 (2.1–2.7)	11.3–14.3 (2.0–2.5)	10.4–12.9 (1.8–2.3)	11.0–13.8 (1.9–2.4)	9.8–11.8 (1.7–2.1)
	4"	16.8-24 (3.0-4.2)	20.4–27.7 (3.6–4.9)	18.8–24.5 (3.3–4.3)	16.5–20.6 (2.9–3.6)	18.0–23.2 (3.2–4.1)	15.1–18.3 (2.7–3.2)
	6"	25.2-36 (4.4-6.34)	28.8–39.6 (5.1–7.0)	26.0–34.3 (4.6–6.0)	22.1–27.7 (3.9–4.9)	24.8–32.2 (4.4–5.7)	19.9–24.1 (3.5–4.2)

*For horizontal and vertical spacing, respectively.

Effective R-Value Design Tables: FERO FAST Thermal Bracket Support

Table A5: Effective R-value of wood floor lines

WOOD-FRAMED FLOOR LINE		R-4.2/in - R-6/in Exterior Insulation	
Exterior Insulation Thickness	Rated R-Value of Insulation Alone, Cavity + Exterior (RSI)	Effective R-Value [RSI]	
		Without Shelf Angle Penetrations	FERO FAST Thermal Bracket Support
2"	21 + 8.4-12 (3.7+1.5-2.1)	20.3–23.7 (3.57–4.18)	17.4–19.3 (3.07–3.41)
4"	21 + 16.8-24 (3.7+3.0-4.2)	28.7–35.3 (5.06–6.22)	21.1–23.7 (3.71–4.17)
6"	21 + 25.2-36 (3.7+4.4-6.34)	36.8–47.4 (6.47–8.35)	23.8–26.6 (4.20–4.68)

Table A6: Effective R-value of concrete floor lines with steel stud walls above and below

CONCRETE FLOOR LINE		at Steel Stud Walls, R-4.2/in - R-6/in Exterior Insulation	
Exterior Insulation Thickness	Rated R-Value of Insulation Alone, Cavity + Exterior (RSI)	Effective R-Value (RSI)	
		Without Shelf Angle Penetrations	FERO FAST Thermal Bracket Support
2"	8.4-12 (1.5-2.1)	10.2–13.6 (1.79–2.40)	4.6–5.0 (.82–.89)
4"	16.8-24 (3.0-4.2)	18.4–25.6 (3.24–4.51)	6.1–6.5 (1.07–1.14)
6"	25.2-36 (4.4-6.34)	26.6–37.5 (4.69–6.60)	7.2–7.6 (1.27–1.35)

Table A7: Effective R-value of concrete floor lines with CIP concrete walls above and below

CONCRETE FLOOR LINE		at CIP Walls, R-4.2/in - R-6/in Exterior Insulation	
Exterior Insulation Thickness	Rated R-Value of Insulation Alone, Cavity + Exterior (RSI)	Effective R-Value (RSI)	
		Without Shelf Angle Penetrations	FERO FAST Thermal Bracket Support
2"	8.4-12 (1.5-2.1)	10.4–13.8 (1.83–2.43)	4.6–4.8 (.81–.85)
4"	16.8-24 (3.0-4.2)	18.3–25.1 (3.21–4.42)	5.9–6.3 (1.03–1.10)
6"	25.2-36 (4.4-6.34)	26.0–36.2 (4.58–6.37)	6.7–7.1 (1.18–1.25)

Table A8: Effective R-value of concrete floor lines with CMU walls above and below

CONCRETE FLOOR LINE		at CMU Walls, R-4.2/in - R-6/in Exterior Insulation	
Exterior Insulation Thickness	Rated R-Value of Insulation Alone, Cavity + Exterior (RSI)	Effective R-Value (RSI)	
		Without Shelf Angle Penetrations	FERO FAST Thermal Bracket Support
2"	8.4-12 (1.5-2.1)	10.3–13.7 (1.81–2.41)	4.7–5.1 (.83–.90)
4"	16.8-24 (3.0-4.2)	18.2–25.0 (3.21–4.40)	6.1–6.5 (1.08–1.15)
6"	25.2-36 (4.4-6.34)	26.0–36.1 (4.58–6.36)	7.0–7.3 (1.23–1.29)

Linear and Point Transmittance Values: FERO Thermal Ties and FERO FAST Thermal Bracket Support

Table A9: Linear and point transmittance values for wood stud walls and wood-framed floor line conditions

WOOD STUD WALLS	2x6 Wood Stud Walls with R-21 Batt Insulation, R-4.2/inch – R-6/inch Exterior Insulation							
Exterior Insulation Thickness	Rated R-Value of Insulation Alone, Cavity + Exterior (RSI)	Chi-Value Btu/°F·hr (W/K)						Psi-Value Btu/ft·°F·hr (W/m·K)
		FERO Thermal Holed Rap-Tie		FERO Thermal Stud Shear Connector		Standard Vertical Tie (Without Perforations)		FERO FAST Thermal Bracket Support
		Stainless Steel	Galvanized Steel	Stainless Steel	Galvanized Steel	Stainless Steel	Galvanized Steel	
2"	21 + 8.4-12 (3.7+1.5-2.1)	.0017-.0021 (.0009-.0011)	.0029-.0037 (.0015-.0019)	.0080-.0082 (.0042-.0043)	.0189-.0195 (.010-.0103)	.0020-.0026 (.0010-.0014)	.0031-.0040 (.0017-.0021)	.005-.006 (.009-.011)
4"	21 + 16.8-24 (3.7+3.0-4.2)	.0020-.0025 (.0010-.0013)	.0041-.0051 (.0021-.0027)	.0067-.0069 (.0035-.0036)	.0172-.0178 (.0091-.0094)	.0027-.0034 (.0014-.0018)	.0048-.0059 (.0025-.0031)	.008-.009 (.015-.016)
6"	21 + 25.2-36 (3.7+4.4-6.34)	.0032-.0039 (.0017-.0021)	.0063-.0076 (.0033-.0040)	.0063-.0065 (.0033-.0035)	.0166-.0174 (.0088-.0092)	.0039-.0048 (.0021-.0025)	.0071-.0085 (.0038-.0045)	.010-.011 (.017-.019)

Table A10: Linear and point transmittance values for steel stud walls and concrete floor line conditions

STEEL STUD WALLS	6" Steel 16 ga Stud Walls (No Cavity Insulation), R-4.2/inch – R-6/inch Exterior Insulation							
Exterior Insulation Thickness	Rated R-Value of Insulation Alone, Cavity + Exterior (RSI)	Chi-Value Btu/°F·hr (W/K)						Psi-Value Btu/ft·°F·hr (W/m·K)
		FERO Thermal Holed Rap-Tie		FERO Thermal Stud Shear Connector		Standard Vertical Tie (Without Perforations)		FERO FAST Thermal Bracket Support
		Stainless Steel	Galvanized Steel	Stainless Steel	Galvanized Steel	Stainless Steel	Galvanized Steel	
2"	0 + 8.4-12 (0+1.5-2.1)	.0079-.0091 (.0042-.0048)	.0219-.0245 (.0116-.0129)	.0121-.0136 (.0064-.0072)	.0314-.0350 (.0166-.0185)	.0106-.0120 (.0056-.0063)	.0267-.0298 (.0141-.0157)	.078-.083 (.135-.144)
4"	0+ 16.8-24 (0+3.0-4.2)	.0064-.0069 (.0034-.0036)	.0190-.0205 (.010-.0108)	.0098-.0106 (.0052-.0056)	.0281-.030 (.0148-.0158)	.0095-.0102 (.0050-.0054)	.0258-.0276 (.0136-.0146)	.073-.076 (.127-.132)
6"	0+ 25.2-36 (0+4.4-6.34)	.0087-.0091 (.0046-.0048)	.0244-.0257 (.0129-.0135)	.0092-.0097 (.0049-.0051)	.0269-.0281 (.0142-.0148)	.0113-.0119 (.0060-.0063)	.0299-.0314 (.0158-.0166)	.067-.069 (.116-.120)

Table A11: Linear and point transmittance values for CIP concrete walls and concrete floor line conditions

CIP CONCRETE WALLS	6" CIP Concrete Walls, R-4.2/inch – R-6/inch Exterior Insulation					
Exterior Insulation Thickness	Rated R-Value of Insulation Alone, Cavity + Exterior (RSI)	Chi-Value Btu/°F·hr (W/K)				Psi-Value Btu/ft·°F·hr (W/m·K)
		FERO Thermal Holed Rap-Tie		Standard Vertical Tie (Without Perforations)		FERO FAST Thermal Bracket Support
		Stainless Steel	Galvanized Steel	Stainless Steel	Galvanized Steel	
2"	8.4-12 (1.5-2.1)	.0106-.0119 (.0056-.0063)	.0293-.0321 (.0154-.0169)	.0150-.0167 (.0079-.0088)	.0371-.0405 (.0196-.0196)	.081-.089 (.140-.154)
4"	16.8-24 (3.0-4.2)	.0077-.0082 (.0041-.0043)	.0232-.0244 (.0122-.0129)	.0121-.0128 (.0064-.0067)	.0327-.0345 (.0173-.0182)	.077-.080 (.133-.138)
6"	25.2-36 (4.4-6.34)	.0105-.0108 (.0055-.0057)	.030-.0310 (.0158-.0163)	.0139-.0144 (.0073-.0076)	.0377-.0390 (.0199-.0206)	.073-.076 (.127-.131)

Table A12: Linear and point transmittance values for CMU walls and concrete floor line conditions

CMU CONCRETE WALLS	8" CMU Walls, R-4.2/inch – R-6/inch Exterior Insulation					
Exterior Insulation Thickness	Rated R-Value of Insulation Alone, Cavity + Exterior (RSI)	Chi-Value Btu/°F·hr (W/K)				Psi-Value Btu/ft·°F·hr (W/m·K)
		FERO Thermal Block Shear Connector		Standard Block Tie (Without Perforations)		FERO FAST Thermal Bracket Support
		Stainless Steel	Galvanized Steel	Stainless Steel	Galvanized Steel	
2"	8.4–12 (1.5-2.1)	.0127–.0144 (.0067–.0076)	.0317–.0353 (.0167–.0186)	.0134–.0152 (.0071–.0080)	.0325–.0362 (.0172–.0191)	.077–.082 (.134–.142)
4"	16.8-24 (3.0-4.2)	.0102–.0112 (.0054–.0059)	.0282–.0301 (.0149–.0159)	.0116–.0125 (.0061–.0066)	.0309–.0329 (.0163–.0174)	.072–.076 (.125–.131)
6"	25.2-36 (4.4-6.34)	.0095–.0099 (.0050–.0052)	.0267–.0279 (.0141–.0147)	.0098–.0103 (.0052–.0054)	.0277–.0289 (.0146–.0152)	.070–.072 (.121–.125)

Appendix B: Thermal Modelling Assumptions

Modelling Assumptions

Thermal modelling for this document was performed using HEAT3. HEAT3 is a three-dimensional finite-element thermal analysis software tool commonly used by the building industry to analyze building enclosure assemblies in three dimensions. It allows for a more detailed analysis of conductive heat flow than two-dimensional tools, including the impact of fasteners, masonry ties, discrete clips, and other construction realities. Modelling can be used to determine effective R-values, point transmittance, and linear transmittance values from the heat flow measured through the building enclosure assembly.

The boundary conditions and the material conductivities used for modelling are provided in Table B1 and Table B2, respectively. Additional modelling assumptions include the following:

→ All thermal modelling and resulting R-values are for standard wall assemblies, including the floor line where applicable, but do not account for additional framing and resulting heat flow around penetrations (e.g., windows and doors), at parapets, or other exterior wall transitions.

→ All air spaces, including vented air spaces behind masonry cladding, are assigned R-values based on values given for unventilated plain air spaces in the ASHRAE Handbook – Fundamentals [12]. This approach is consistent with numerous studies showing that air cavities, including vented air cavities, provide measurable resistance to heat flow. However, some energy codes may require air cavities to be treated differently or neglected entirely from the R-value determination of an assembly. Consult the local energy code and the authority having jurisdiction for requirements.

→ Steel studs are not modelled with conduit cutouts in the web of the stud.

→ A 20-mil (0.51 mm), silicone-based, liquid-applied WRB membrane was included at floor line conditions.

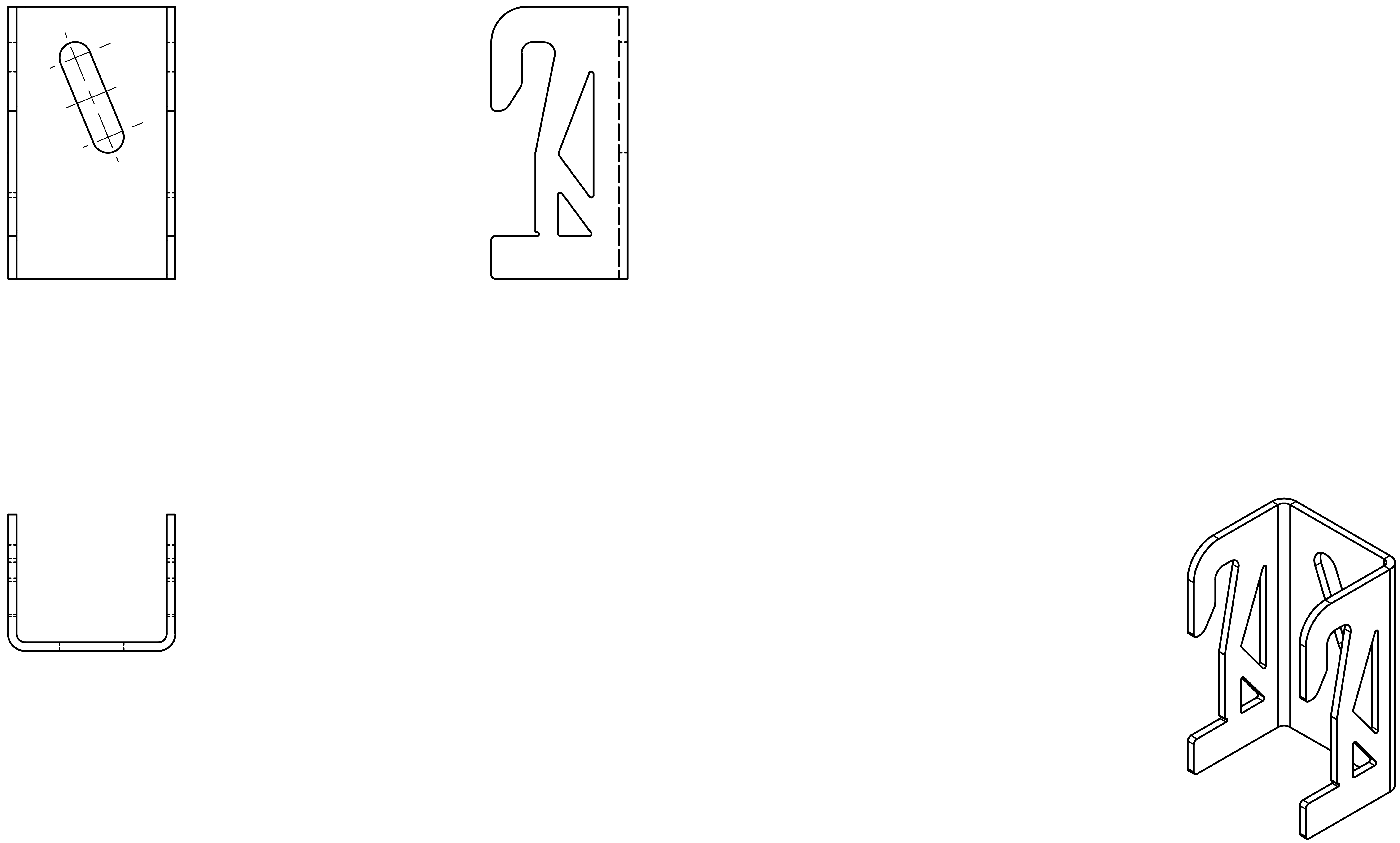
Table B1: Boundary conditions used for modelling

Model Boundary Conditions				
Location	RSI (m^2K/W)	Temperature (°C)	ΔT (°C)	Source
Interior Air Film	0.12	21.0	39.0	ASHRAE 90.1-2016 (RSI) [3] and NFRC 100 [13] (Temperature)
Exterior Air Film	0.03	-18		

Table B2: Material conductivities used for modelling

Material Thermal Conductivity			
Material	Conductivity (W/mK)	Source	Additional Notes
Clay Masonry	0.800	ASHRAE Handbook of Fundamentals 2017 [12]	Assuming a density between 1760 and 1920 kg/m^3
Steel - Galvanized Sheet (0.14%C)	62.0	NFRC 101 – 2017 [13]	
Steel - Stainless	17.0	NFRC 101 – 2017 [13]	
Steel - Carbon (Mild)	45.3	ASHRAE Handbook of Fundamentals 2017 [12]	Assuming a density of 7830 kg/m^3
Wood – (Spruce, Pine, Fur)	0.12	ASHRAE Handbook of Fundamentals 2017 [12]	Assuming a density between 390 and 500 kg/m^3
Cast-in-Place Concrete	2.50	ASHRAE Handbook of Fundamentals 2017 [12]	Assuming normal-weight concrete
Concrete Masonry Unit	1.153	ASHRAE Handbook of Fundamentals 2017 [12]	Assuming normal-weight aggregate and fully grouted cores
Mineral Wool	0.034	ASHRAE Handbook of Fundamentals 2017 [12]	R-4.2/inch
Closed-Cell Spray Polyurethane Foam Insulation	0.024	ASHRAE Handbook of Fundamentals 2017 [12]	R-6/inch
Masonry Air Space	0.147	ASHRAE Handbook of Fundamentals 2017 [12]	Based on 25 mm ASHRAE Air Space (Hor,T = 10, e = .8) R0.965
2" FERO Thermal Bracket Support Air Space	0.45	ASHRAE Handbook of Fundamentals 2017 [12]	Linear interpolation for 72 mm ASHRAE Air Space (Hor,T = 10, e = .8) R-0.924
4" FERO Thermal Bracket Support Air Space	0.75	ASHRAE Handbook of Fundamentals 2017 [12]	Linear interpolation for 122 mm ASHRAE Air Space (Hor,T = 10, e = .8) R-0.924
6" FERO Thermal Bracket Support Air Space	1.04	ASHRAE Handbook of Fundamentals 2017 [12]	Linear interpolation for 172 mm ASHRAE Air Space (Hor,T = 10, e = .8) R-0.939
Stud Wall Air Space	0.574	ASHRAE Handbook of Fundamentals 2017 [12]	Based on 92 mm ASHRAE Air Space (Hor,T = 10, e = .8) R-0.91
Plywood Sheathing (Douglas Fir)	0.093	ASHRAE Handbook of Fundamentals 2017 [12]	Assuming a density of 460 kg/m3
Exterior Gypsum Sheathing	0.129	GP DensGlass Sheathing Technical Data Sheet [14]	
Interior Gypsum Wallboard	0.160	ASHRAE Handbook of Fundamentals 2017 [12]	Assuming a density of 640 kg/m^3
Silicone	0.32	NFRC 101 – 2017 [13]	

Appendix C: FERO Shop Drawings



FAST STANDARD D3"

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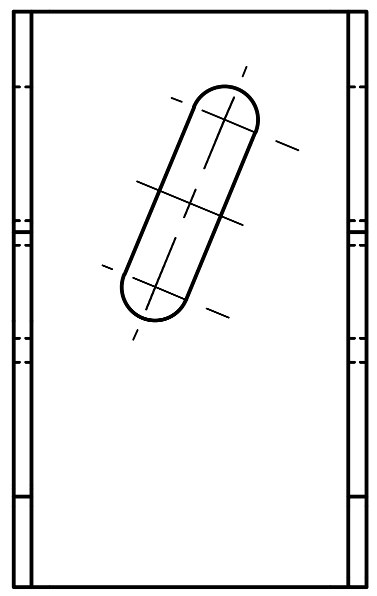
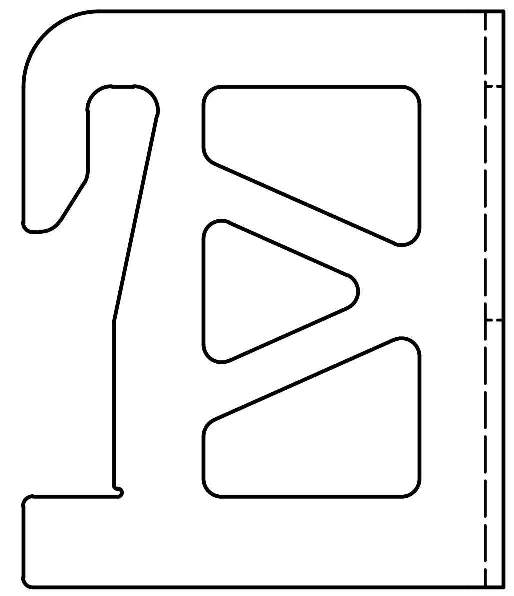
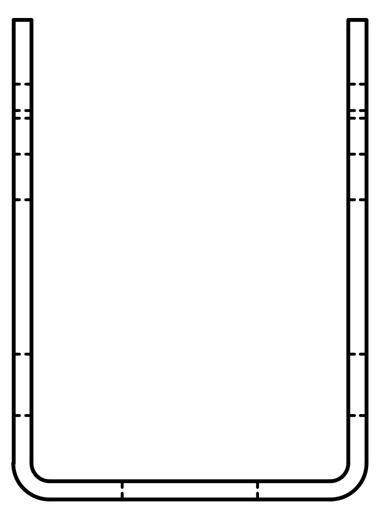
Title:

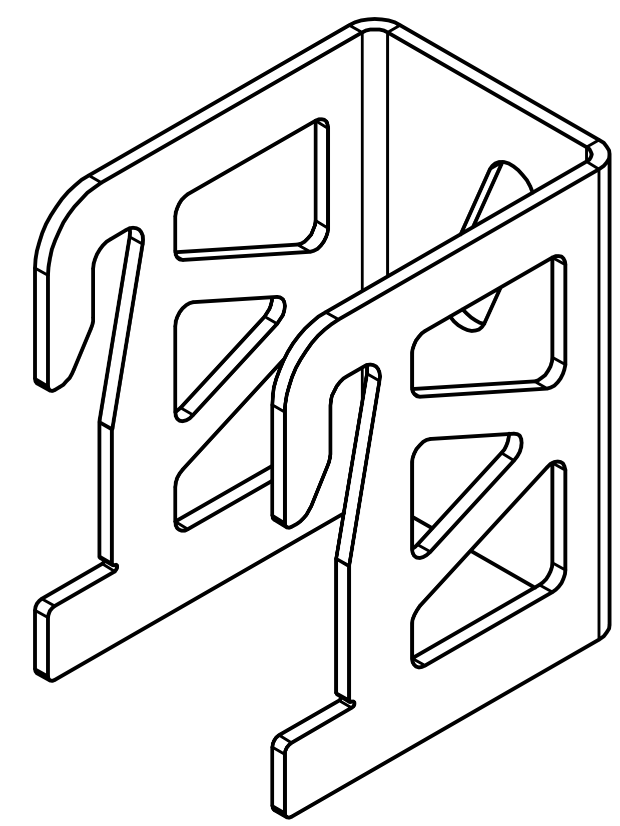
FAST Thermal Bracket™

Offset Shelf Angle Support









FAST STANDARD D5"

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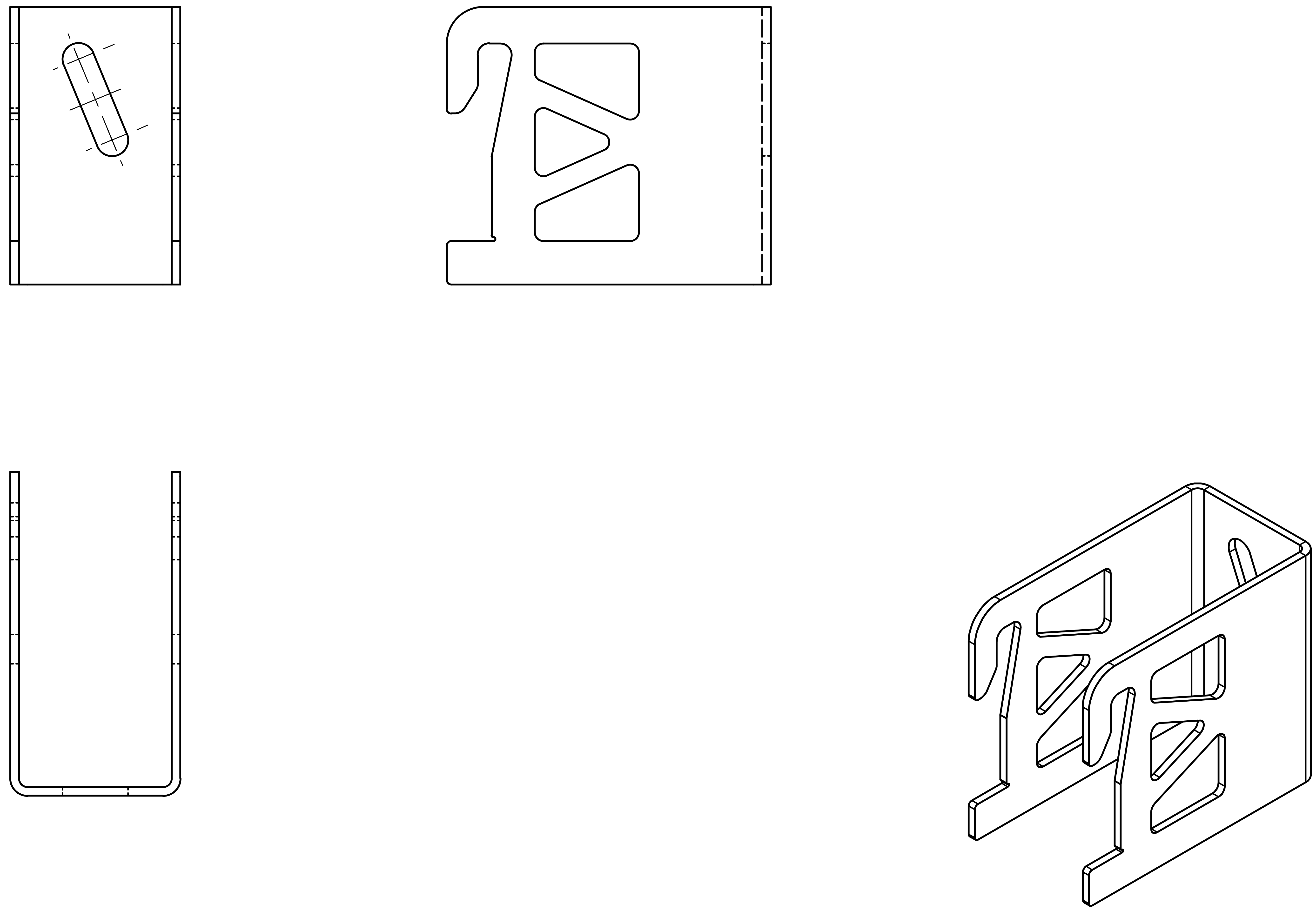
Title:

FAST Thermal Bracket™
Offset Shelf Angle Support



FAST STANDARD D7"

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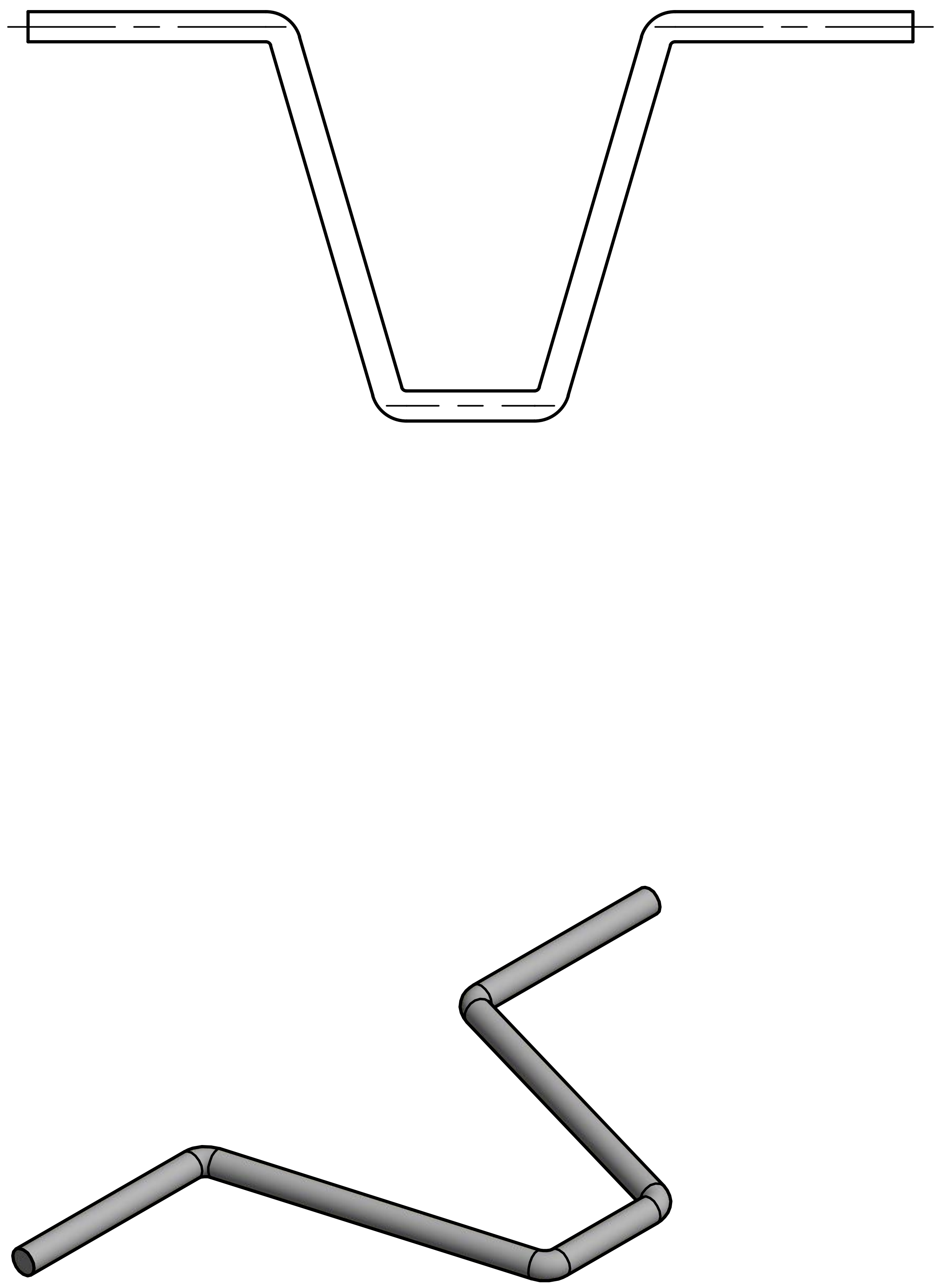
Title:

FAST Thermal Bracket™ Offset Shelf Angle Support



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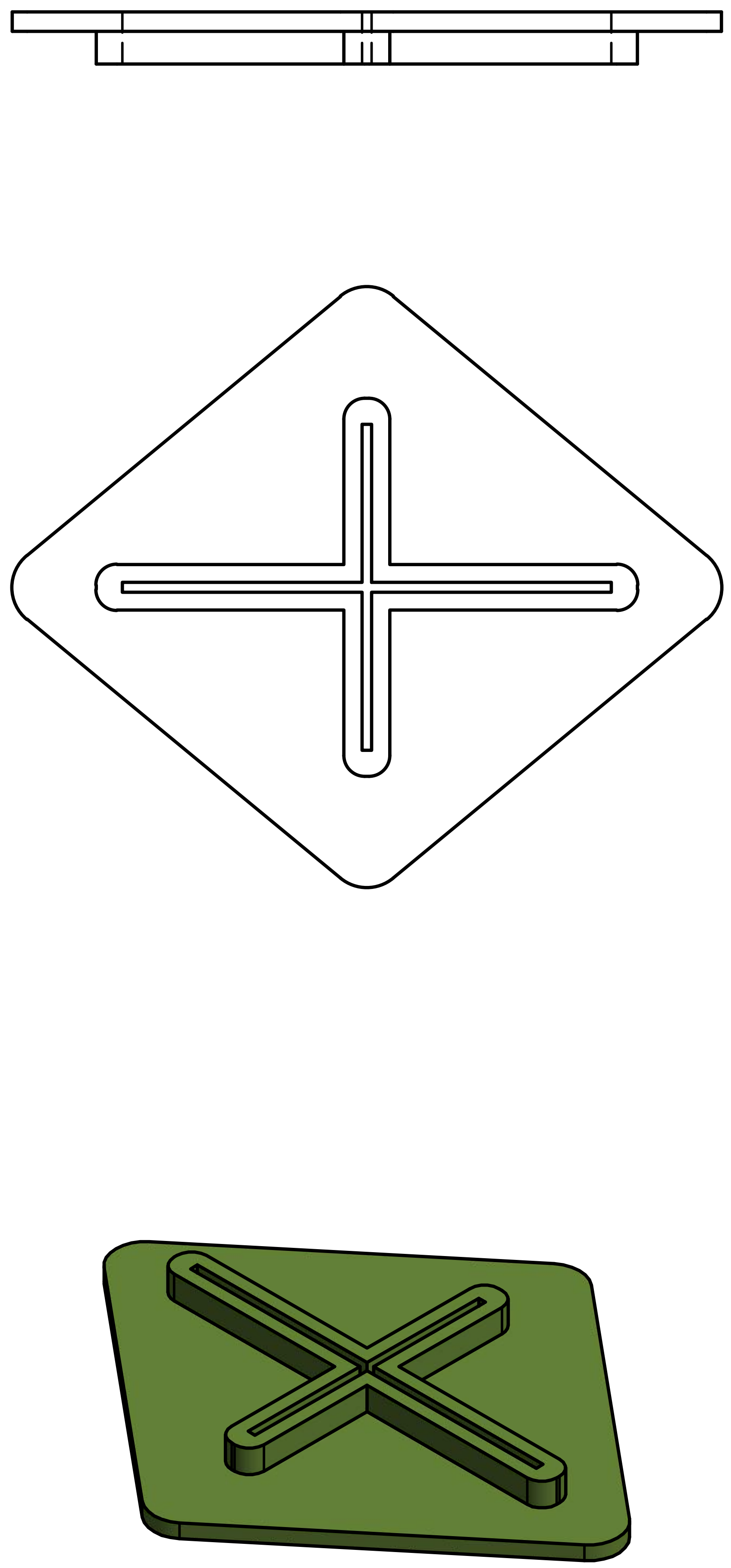

DIAMOND INSULATION SUPPORT

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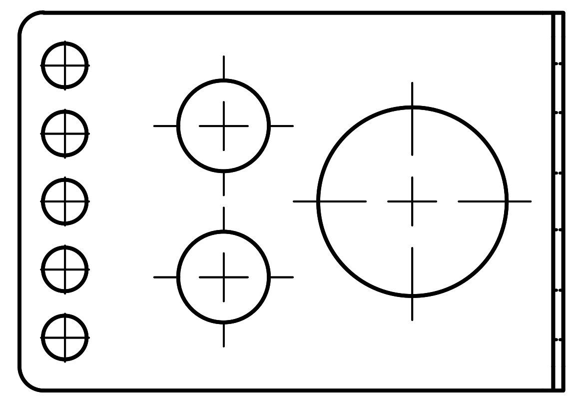
Title:

FERO Thermal Tie™ Masonry Connectors



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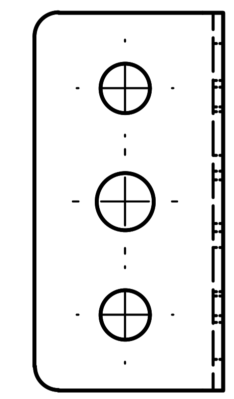

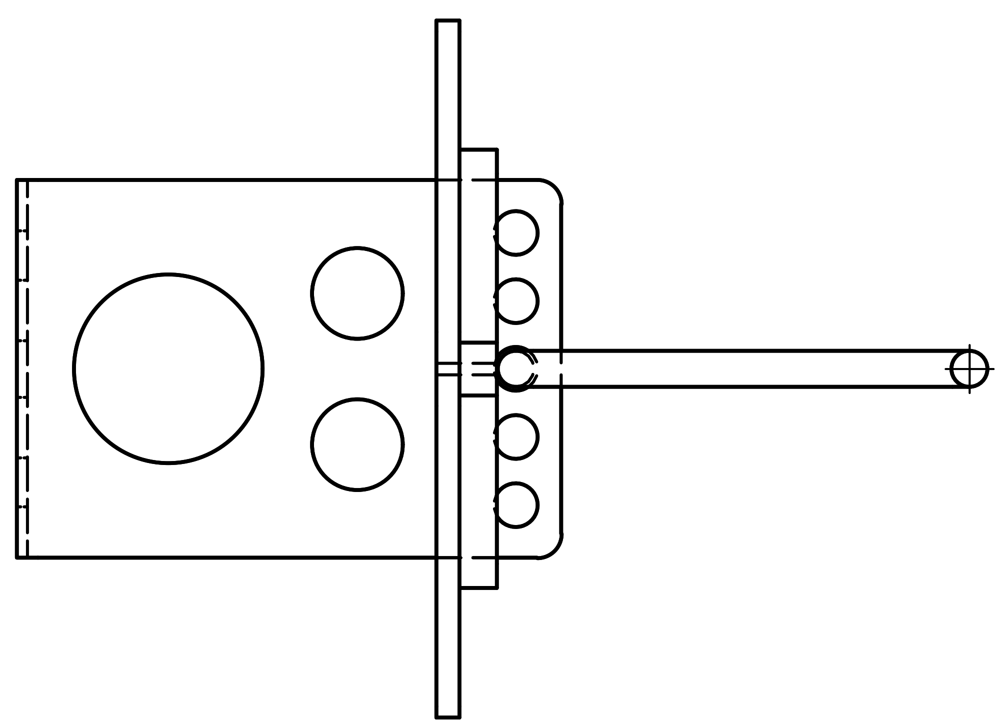

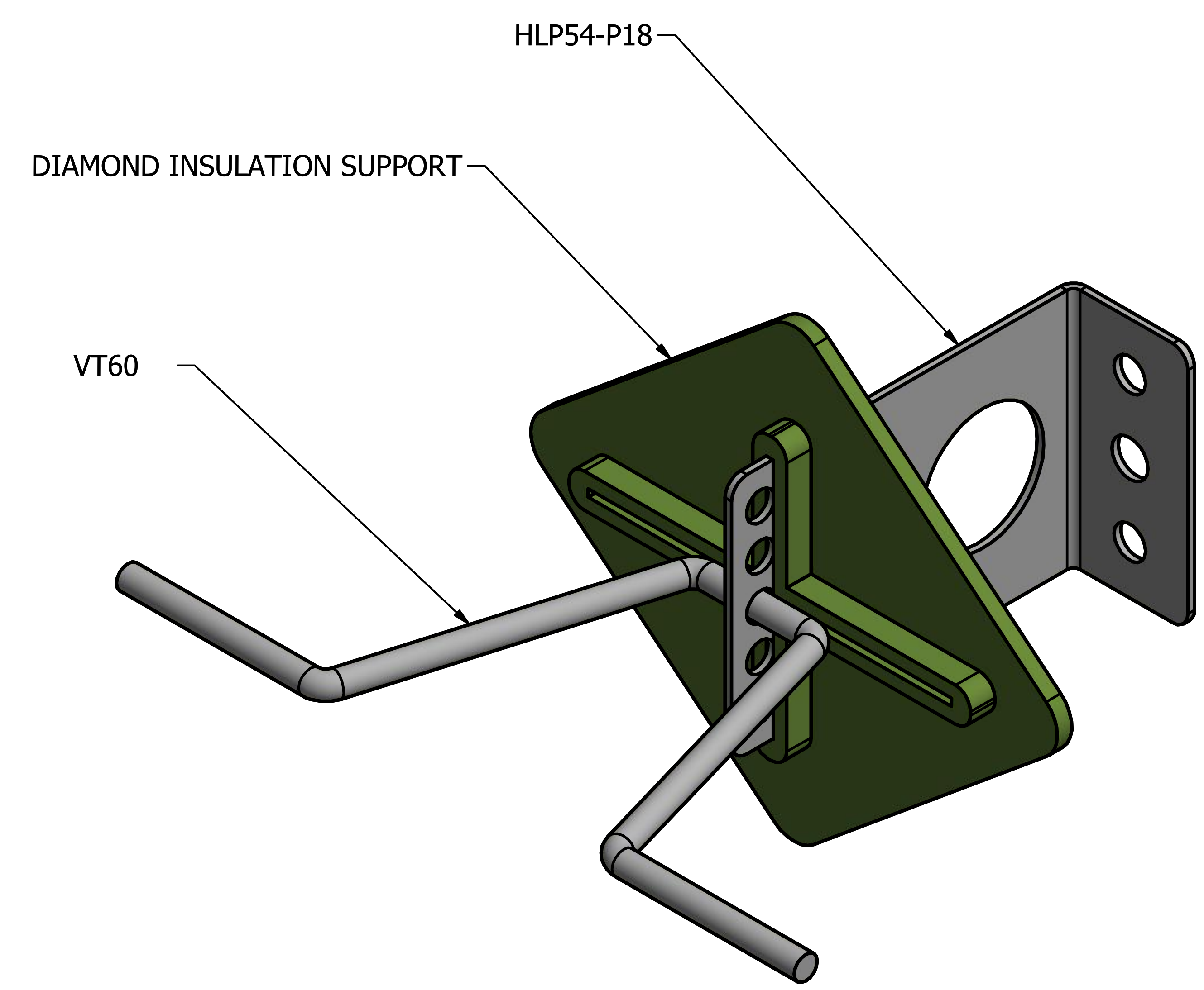

Rap Tie for 2" Insulation

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Title:

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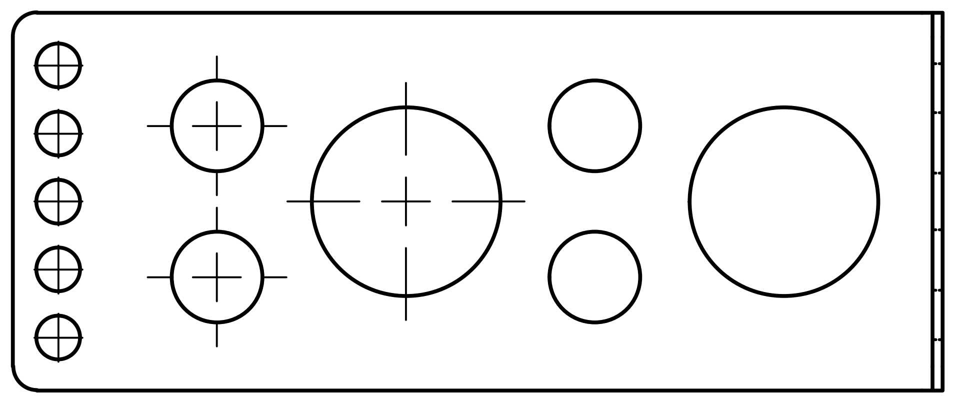

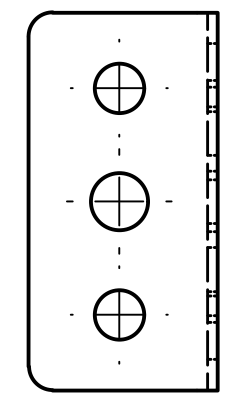

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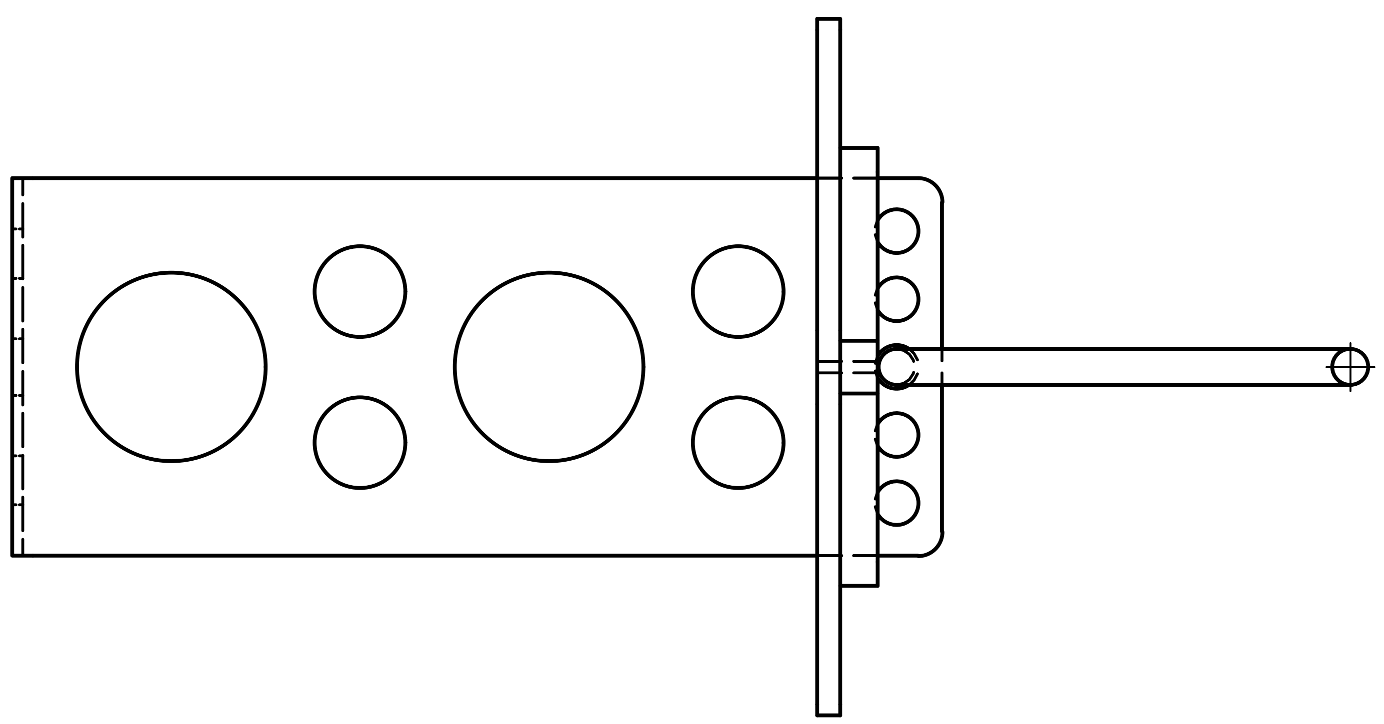

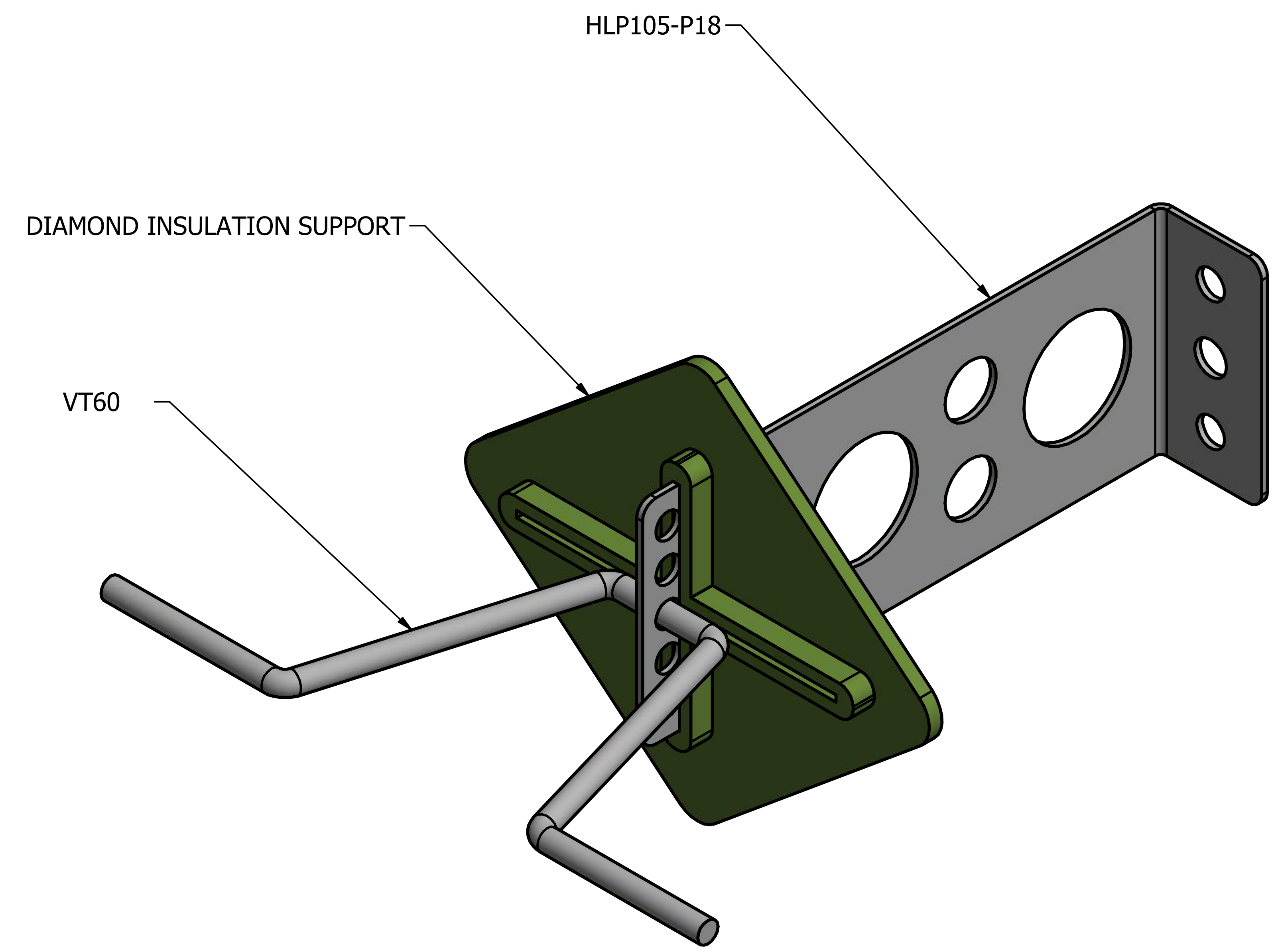

Rap Tie for 4" Insulation

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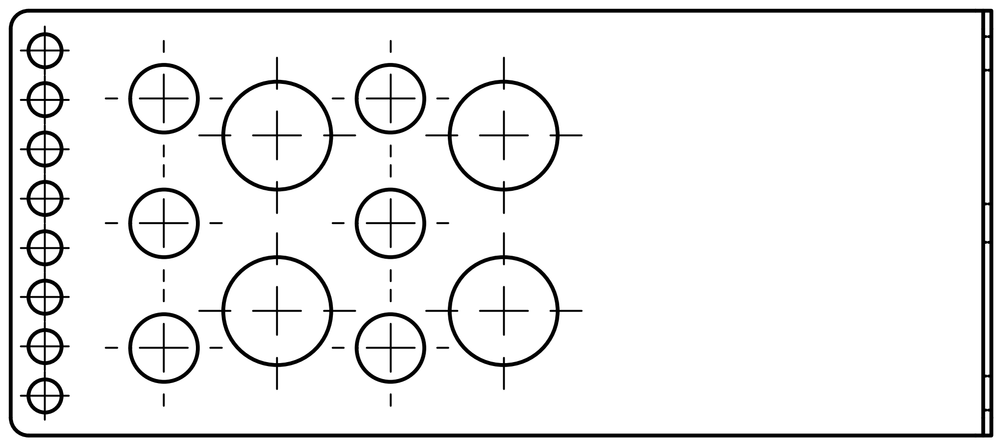
Title:

FERO Thermal Tie™ Masonry Connectors



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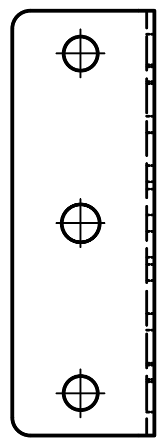

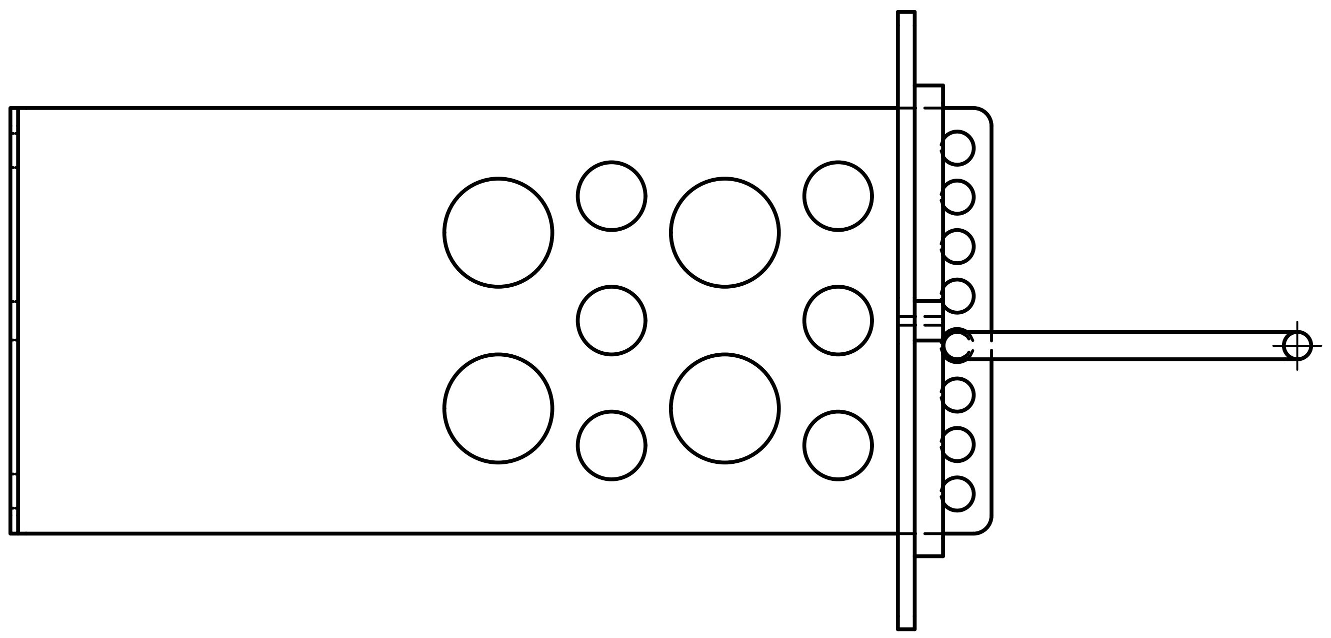

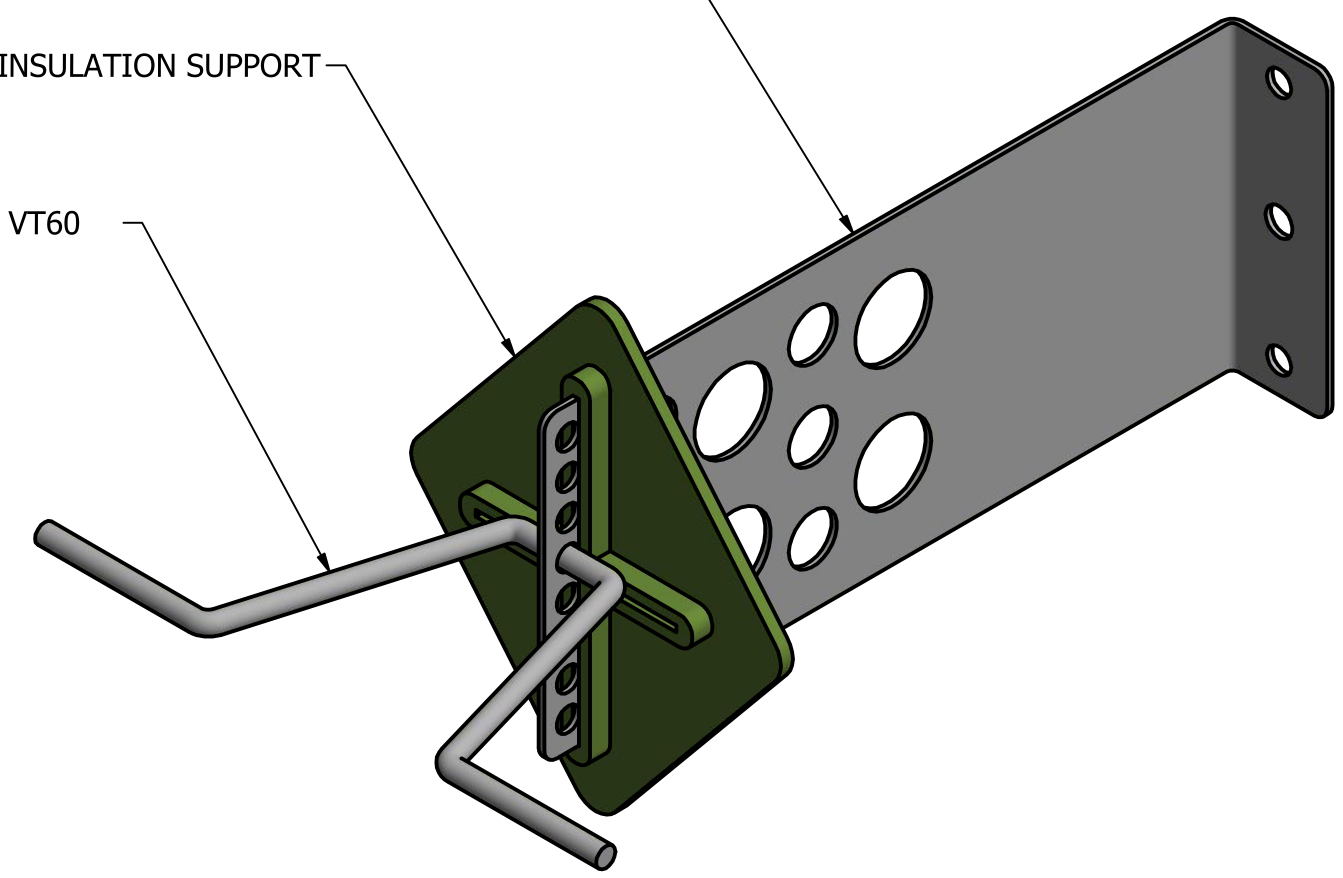

Heavy Duty Rap Tie for 6" Insulation

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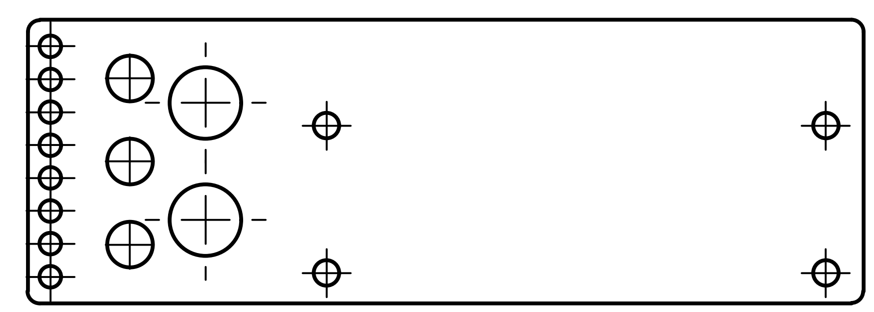
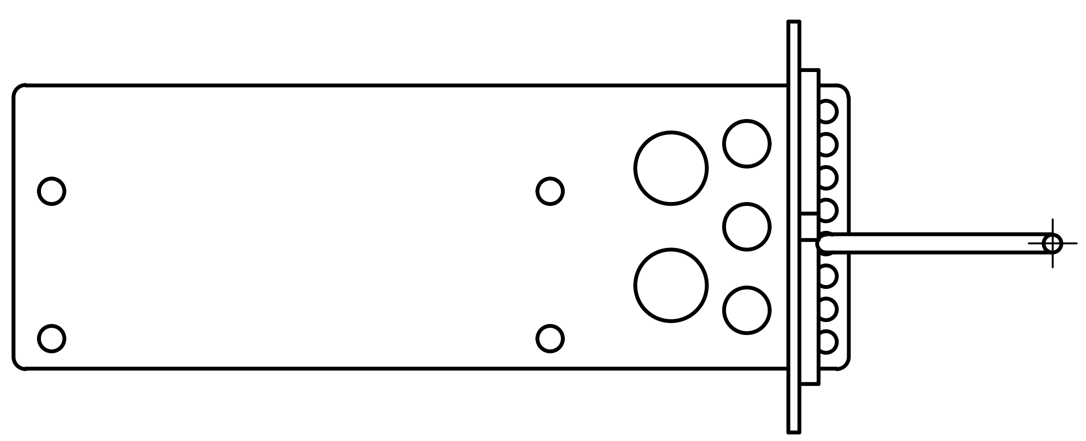
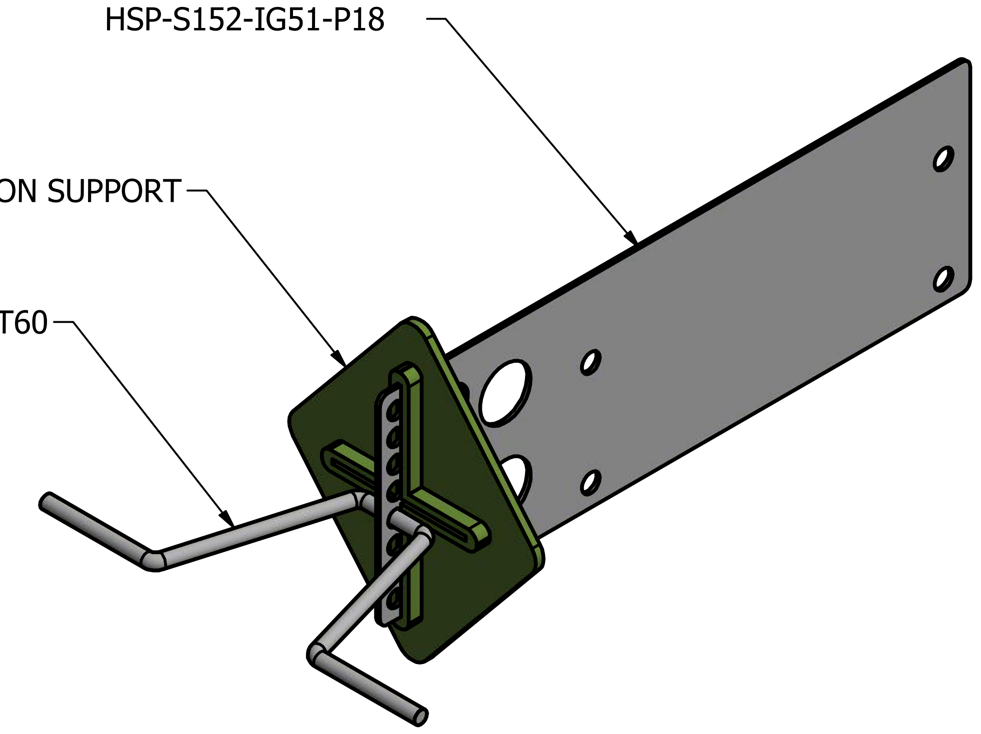
Title:

FERO Thermal Tie™ Masonry Connectors

HSP-S152-IG51-P18







Stud Tie for 2" Insulation

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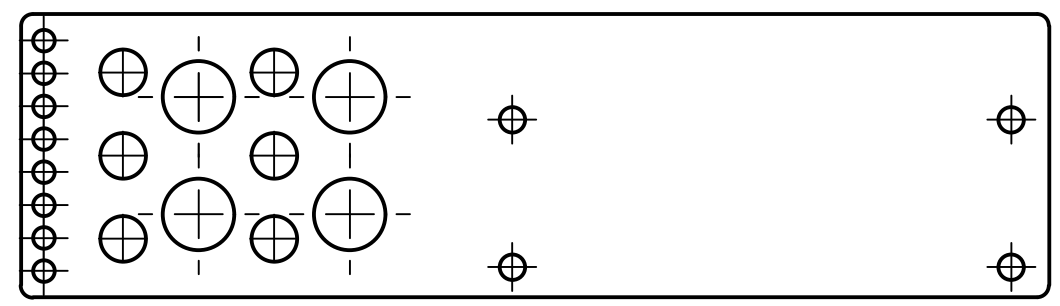
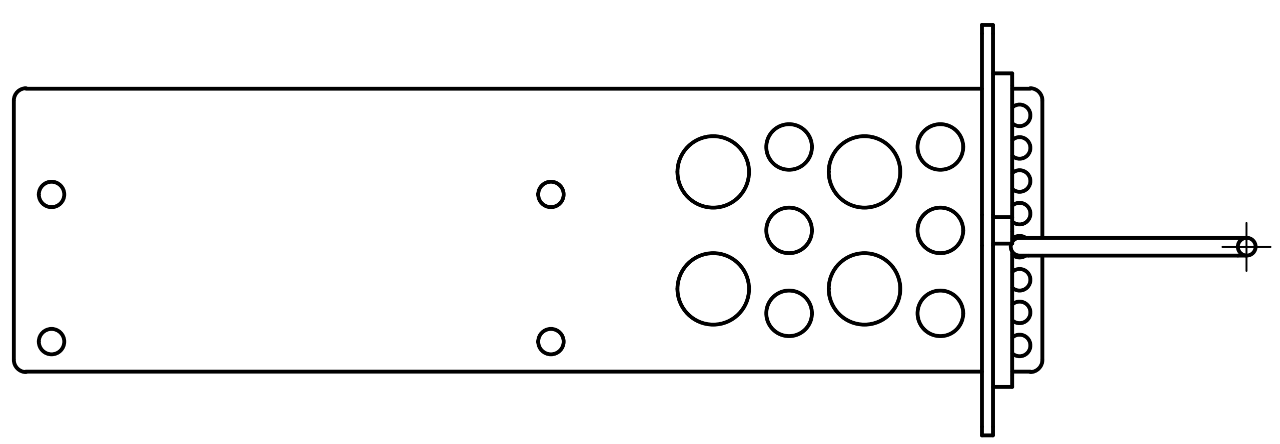
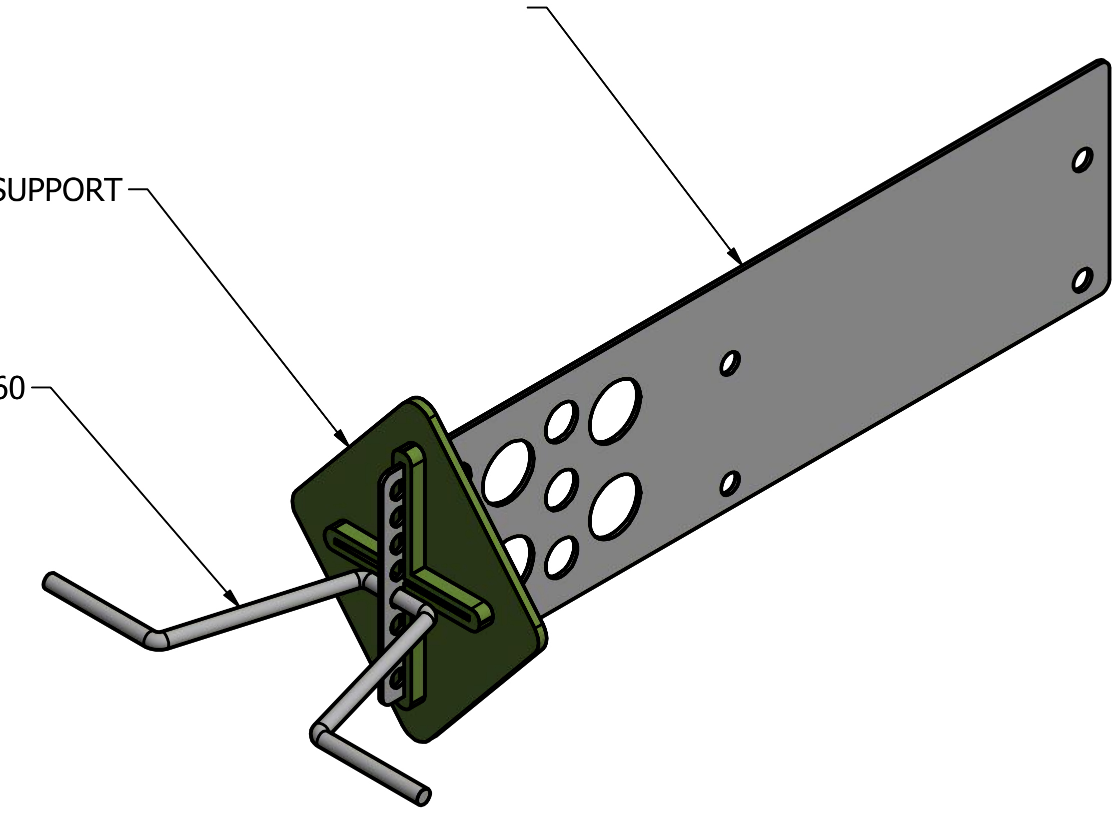
Title:

FERO Thermal Tie™
Masonry Connectors

HSP-S152-IG102-P18







Stud Tie for 4" Insulation

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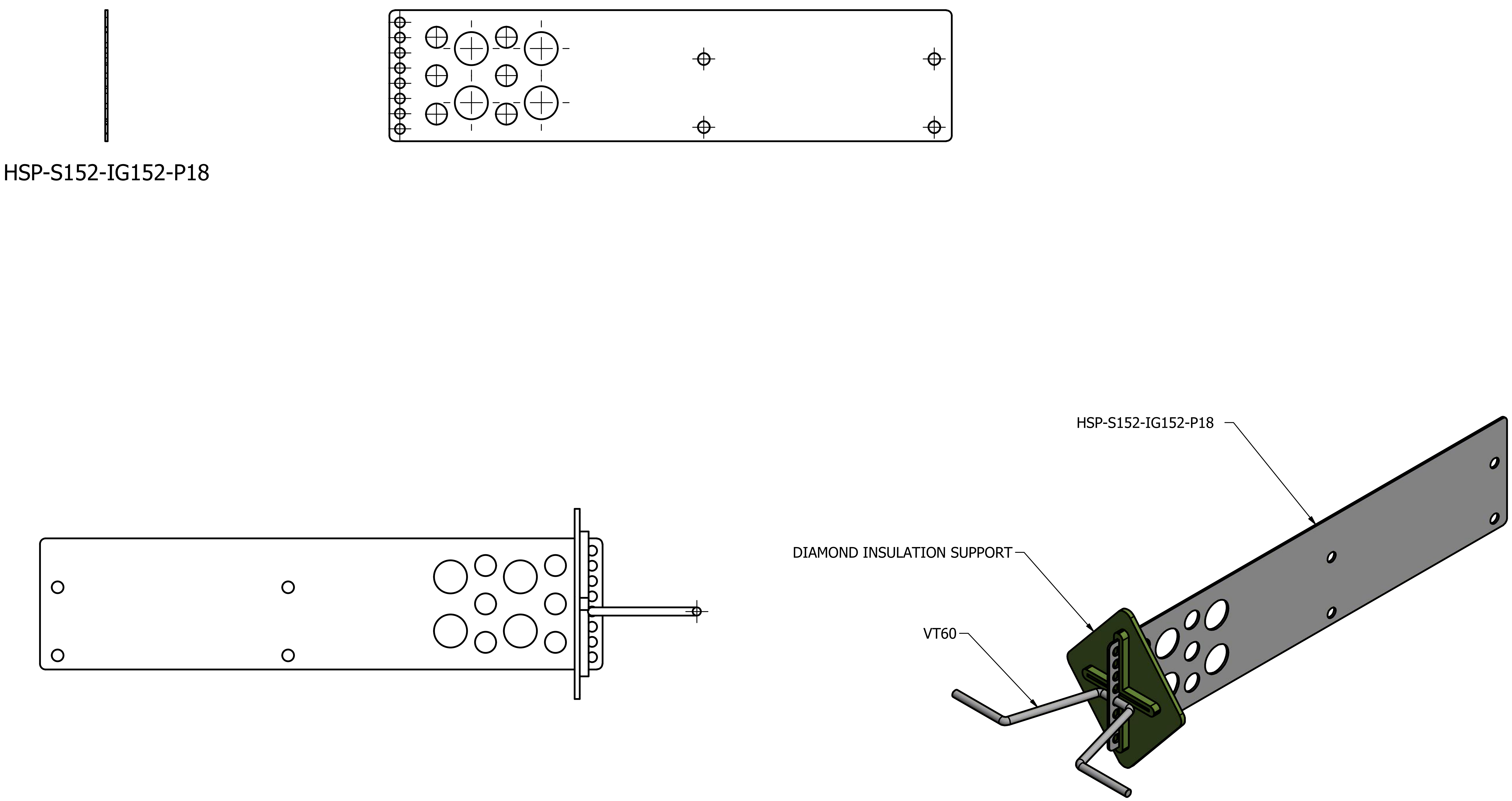
Title:

FERO Thermal Tie™ Masonry Connectors



Stud Tie for 6" Insulation

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Title:

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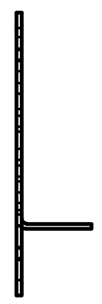

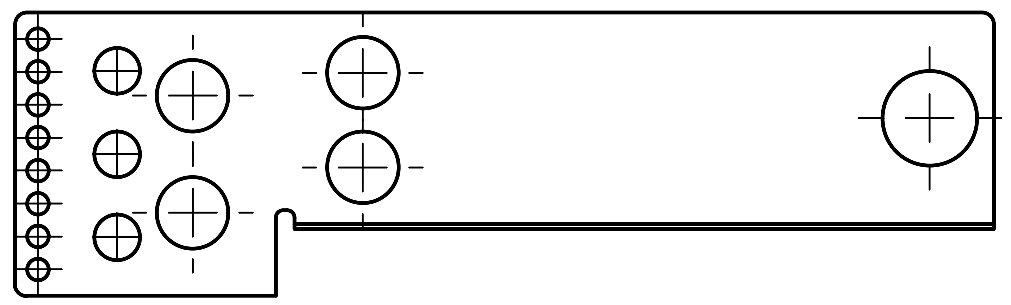

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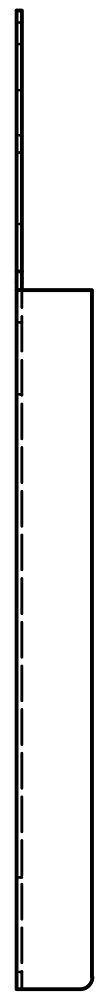

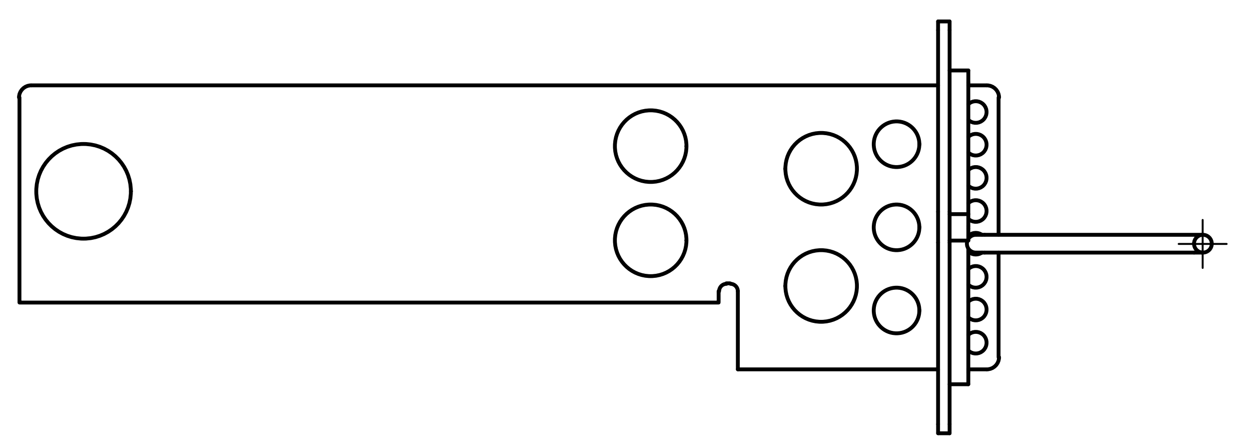

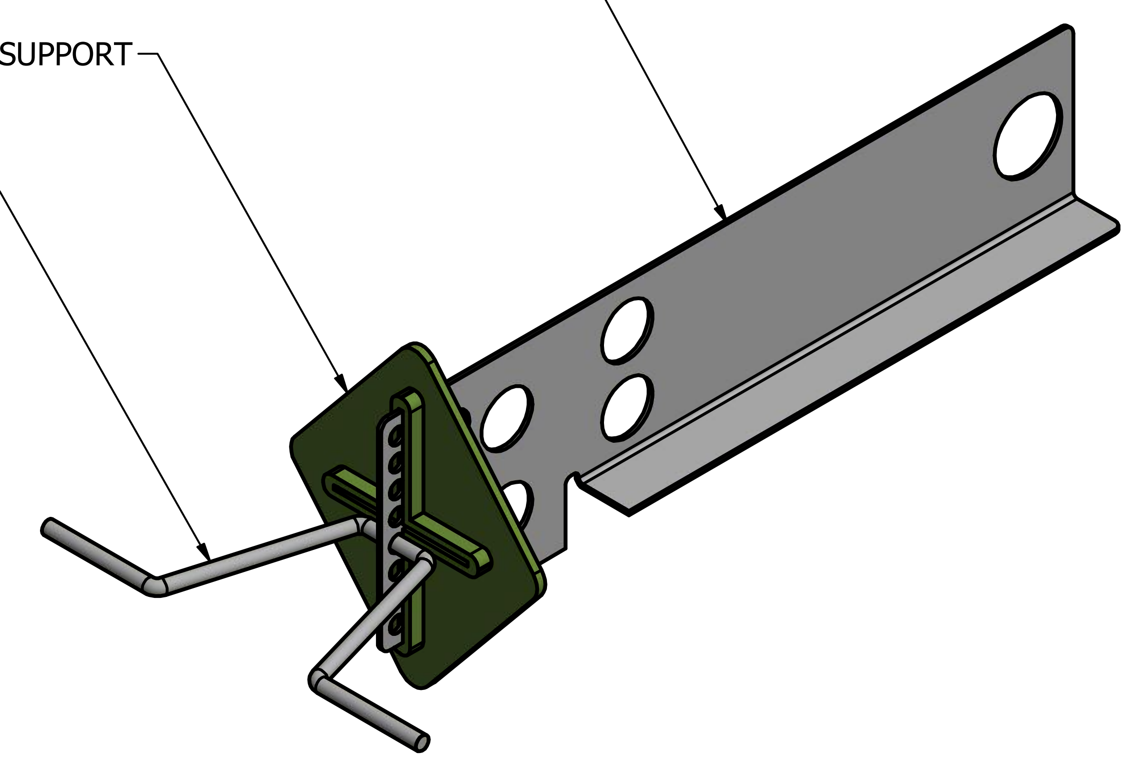

Block Tie for 2" Insulation

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Title:

FERO Thermal Tie™

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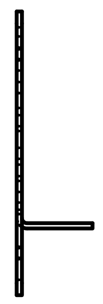

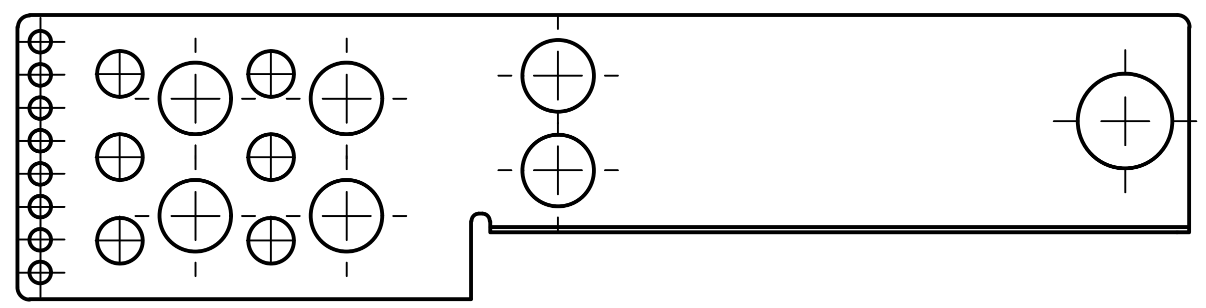

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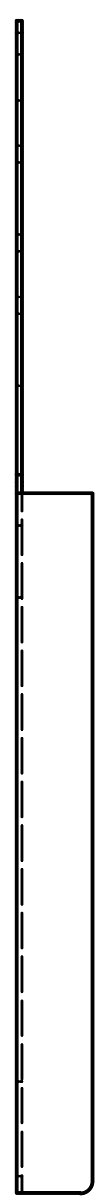

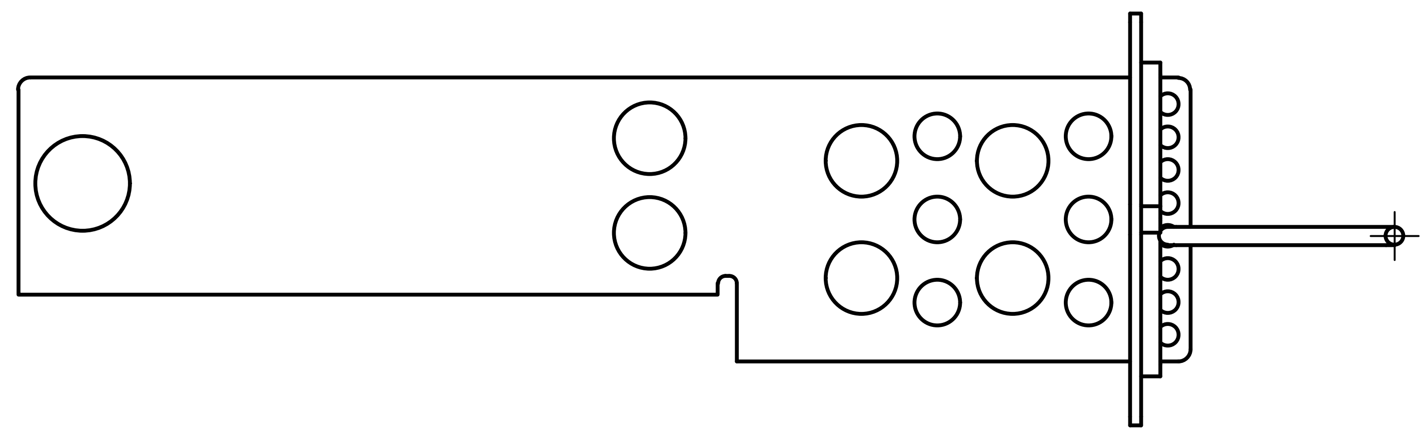

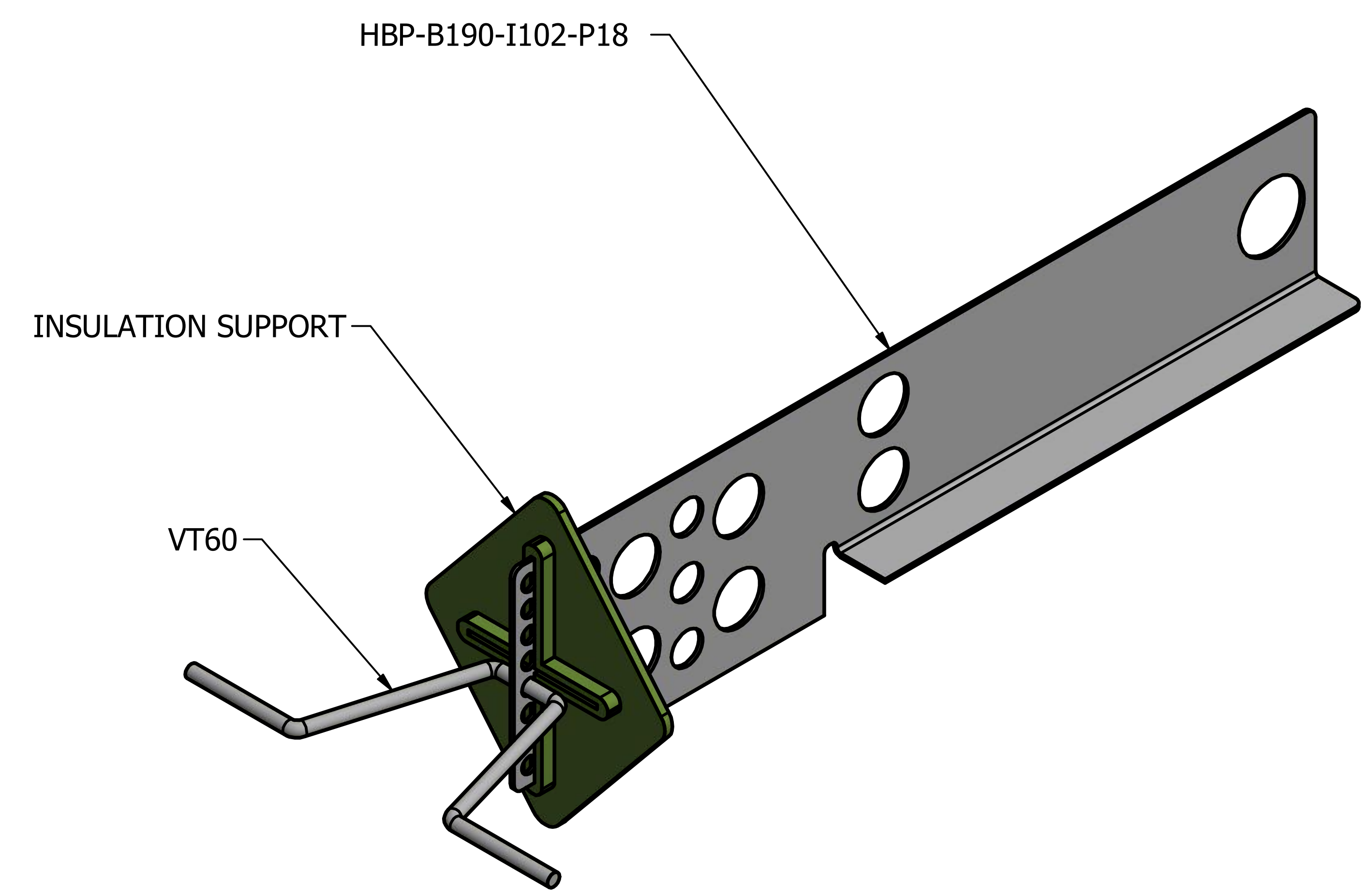

Block Tie for 4" Insulation

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Title:

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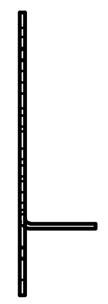

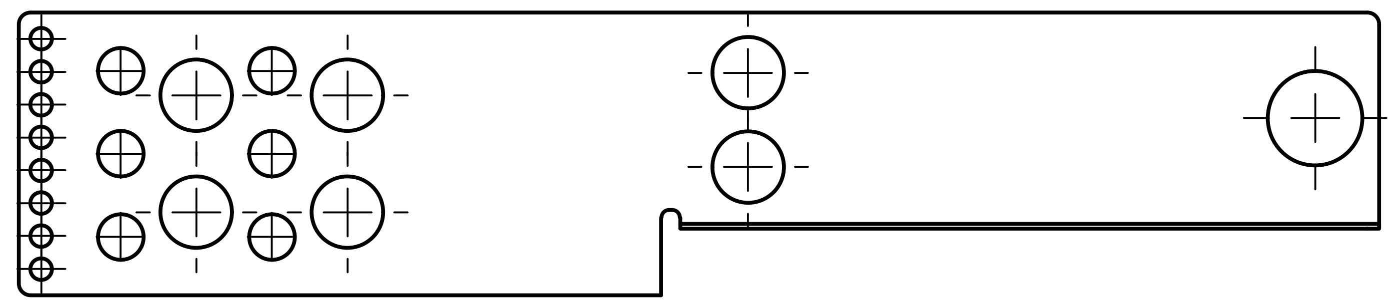

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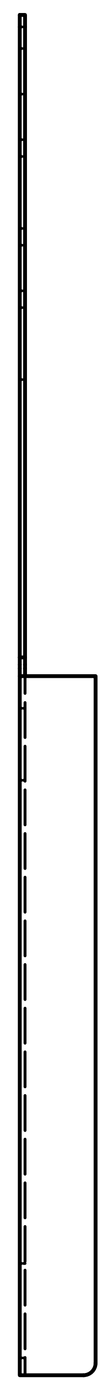

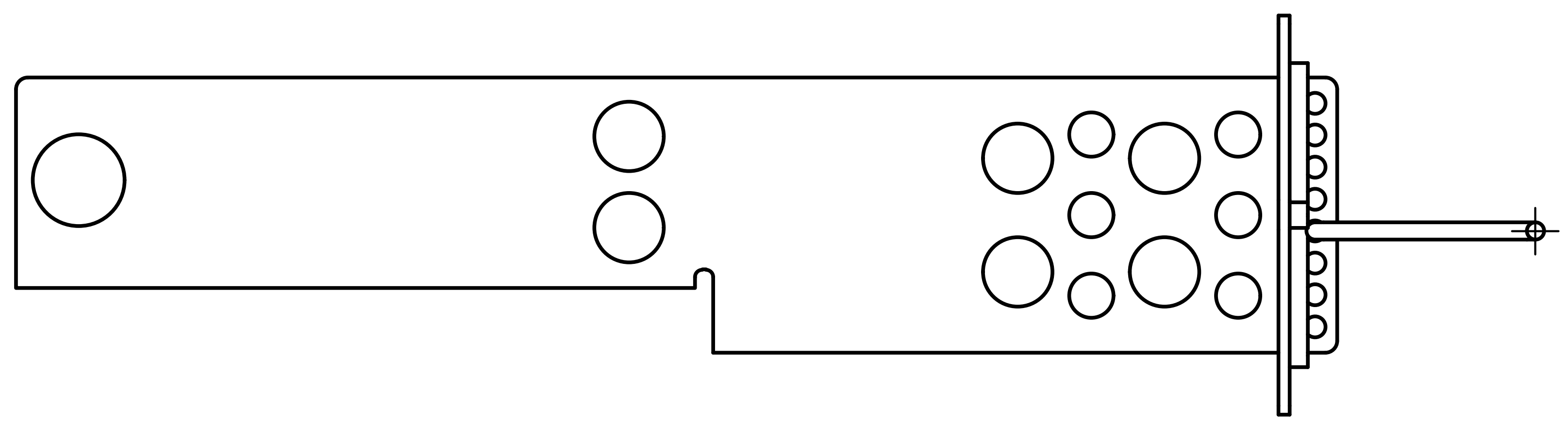

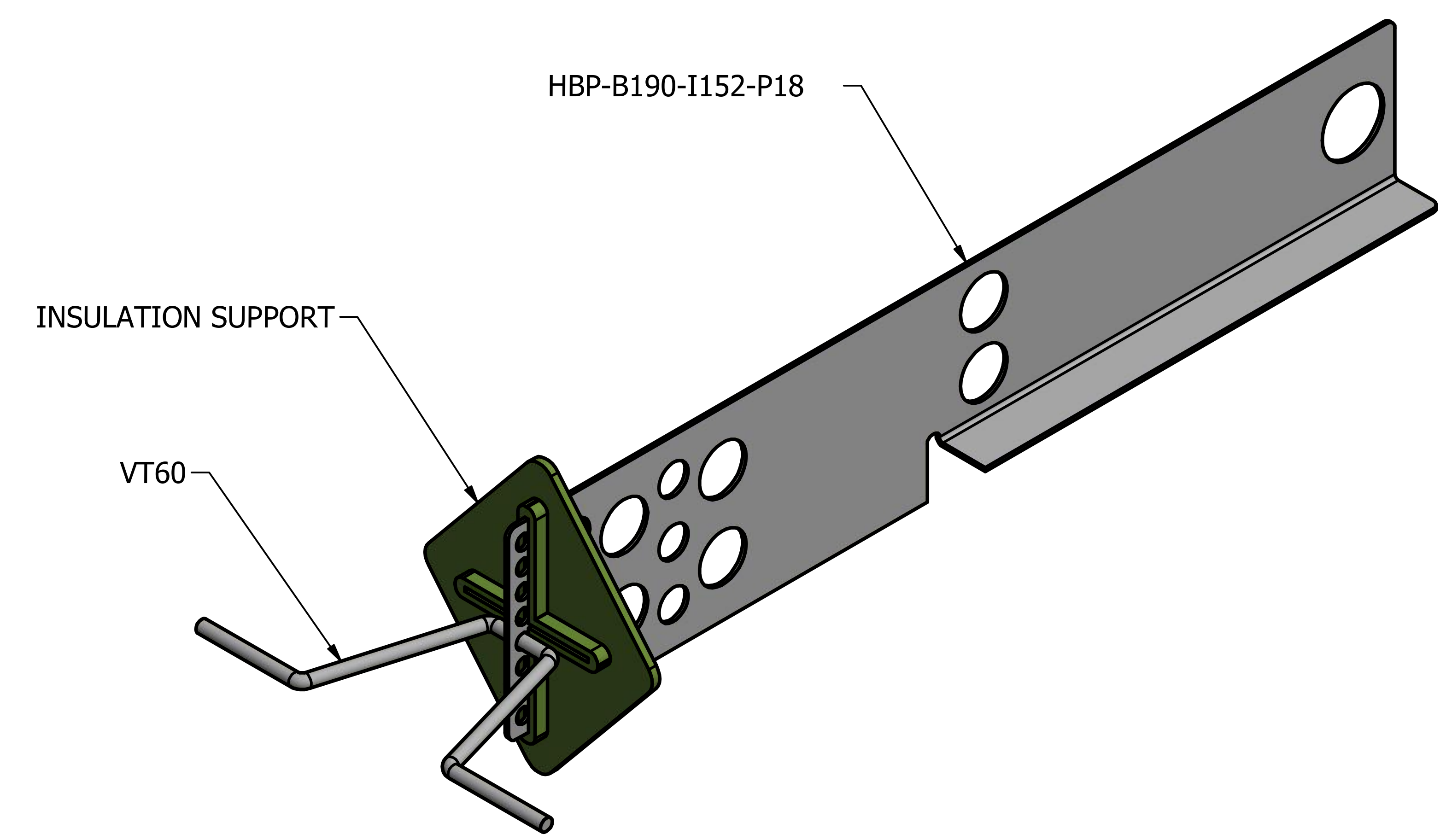

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