Cladding Attachment Systems:

The Effects of Fasteners on Thermal Performance

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ABSTRACT – Three-dimensional thermal modeling was employed to compare effective R-values of cladding attachment systems. Particular emphasis was placed on the effects of fasteners and their connectivity with other thermal bridges. Thermal degradation attributed exclusively to fasteners ranged from 2 to 16%. When considering all bridging elements and an exterior insulation layer of three inches, the most efficient systems were Structural Insulated Sheathing (SIS) and composite z-girts. These systems achieved the true intent of the R-20 wall with effective R-values of 21.5 and 20.1, respectively. Other means for mitigating thermal degradation such as thermal isolation pads and punched engineered z-girts offered limited effectiveness.

INTRODUCTION

Code requirements for continuous insulation (C.I.) exclude fasteners when determining assembly thermal performance. The assumption has always been that fasteners play an insignificant role. This notion held true for conventional framed wall construction where the bulk of thermal bridging occurs through wood and steel studs, not fasteners [1, 2].

With the advent of exterior insulation, fasteners and cladding attachment systems now serve as the primary bridging elements within typical clear fields. These components inherently disrupt the insulation layer, providing intermittent continuity with sheathing and studs. Furthermore, the ‘cladding attachment system’ has essentially morphed into the ‘cladding fastening system’ while also achieving de facto exclusion from thermal calculations. In other words, prescriptive R-values and alternative U-factors did not account for the ill effects of these thermal bridges. What ensued was a decade of under-achieving walls where effective R-vales were only marginally better than conventional framed assemblies. This happened both knowingly and unknowingly through poor code enforcement and confusion.

> Continuous Insulation (C.I.) - insulation that is uncompressed and 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 [3].

The miscues of prescriptive C.I. were well known even as new energy codes were adopted [4, 5]. For example, from ASHRAE 1365-RP, emerged a clear depiction of thermal bridges and their magnitude of effects. Subsequent design guides followed, offering additional insights for thermal performance [6, 7]. Still, confusion persists as seemingly minor deviation from an explicit design may yield different but undetermined ratings. Furthermore, the effects of fasteners remain relegated to an ‘insignificant’ but unknown measure.

Similar uncertainties arise from a myriad of new products focused on mitigating thermal bridges. And again, their efficacies do not necessarily account for fastener-induced losses, which in some instances may actually negate claimed improvements.

Going forward, designers will be faced with more questions than answers. Prescriptive R-values and alternative U-factors offer no solutions to complex, three-dimensional heat flows through complex, three dimensional assemblies. Answers will demand what they always have – either three-dimensional thermal modeling or assembly testing. Anything short of this is guesswork or design by guide. And due to the undertaking of these endeavors, ever-greater reliance will be placed on data generated by manufacturers and their proxies.

This study offers additional clarity on the effects of fasteners and cladding attachment systems that vary in both material and form. My findings show that fasteners do matter and that certain fasteners warrant inclusion for thermal calculations and code compliance.

METHODS

Wall Assemblies

The modeled assemblies are illustrated in Figure 1. Selected wall types represent variations around the prescriptive R-20 rating, a commercial standard pertinent to many climate zones during the first decade of C.I. adoption.

Wall 1 represents a code-prescribed hybrid assembly containing R-13 in the stud cavity and R-7.5 as exterior insulation. Wall 2 depicts a common U-factor alternative for compliance with a maximum U-factor of 0.049 per ASHRAE 90.1 2016. It contains three inches of exterior polyisocyanurate and an empty stud cavity. Wall 2 also serves as the base model for comparing thermal efficiencies of cladding attachment strategies (Walls 4-6).

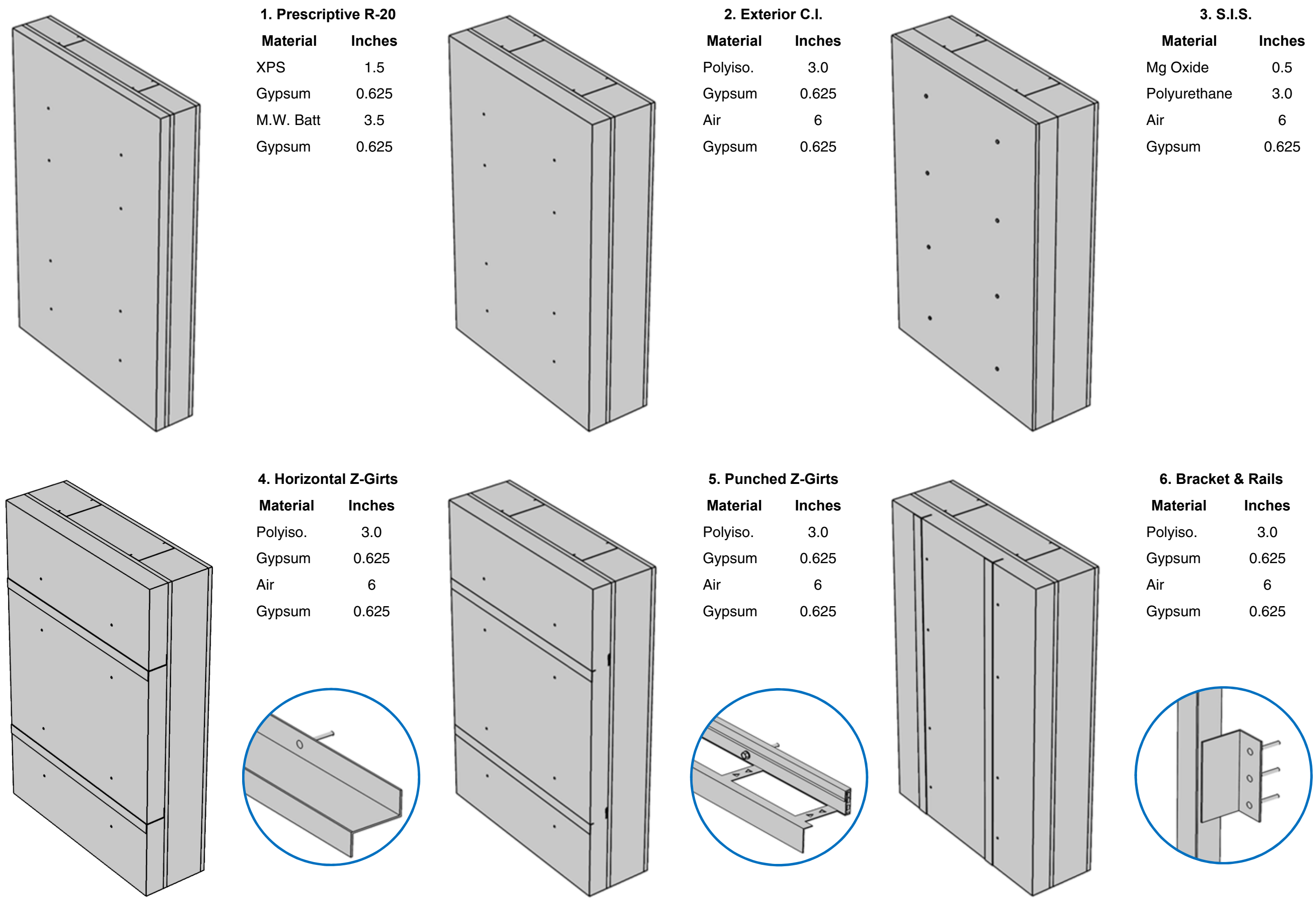

Fig. 1. Modeled wall assemblies. Geometries are shown with all corresponding components, including steel studs, fasteners, and cladding attachment systems.

Wall 3 depicts an entirely unique assembly and is referenced herein as Structural Insulated Sheathing (SIS). It includes the same 6-inch frame assembly as Wall 2; however, the gypsum sheathing and polyiso are replaced by a panel consisting of three inches of poured polyurethane foam fused to half-inch magnesium oxide.

Each model represented clear field assemblies with a uniform dimension of 32 inches (w) x 48 inches (h). Note that all wall types were modeled without exterior rainscreen cavities and cladding. This approach offers a simplified assembly while providing a common basis for comparison.

Steel studs were modeled as 16-gauge (0.0538”) with web lengths of 3.5 or 6 inches and flange lengths of 1.3 or 2 inches, respectively. The code-prescribed R-20 wall included 3.5-inch solid studs; whereas all remaining walls contained 6-inch studs configured with a single, ovate punch with a free area of 8.24 in^2.

Fasteners

Modeled fasteners reflected simplified geometries with dimensions commonly associated with their intended real-world use (Table 1, Fig. 2). Thread-less geometries were employed as is customary when modeling repetitive penetrations through three-dimensional assemblies. Sensitivity analyses showed only minor differences between threaded and unthreaded fasteners – the former requiring significantly greater computational resources while offering little additional information. Other factors such as head and shank diameter, contact resistances, and material properties played far greater roles. Likewise, plastic washers typically used with exterior insulation were not considered in the final analyses due to their limited influence.

Cladding Attachment Systems

The attachment systems included horizontal z-girts, engineered punched steel girts, and a simple bracket & rail assembly (Fig. 1). These systems were compared to Structural Insulation Sheathing (SIS) in which the panel itself, not the backup stud, serves as the cladding attachment substrate. The SIS system was modeled with either steel fasteners (3a) or stainless steel fasteners (3b).

Solid horizontal z-girts were spaced vertically at 24 inches (Wall 4). Variants of this attachment system included: 16-gauge steel (4a); 0.1 inch steel (4b); 0.1 inch aluminum (4c); and 0.1 inch composite plastic (4d).

The engineered punched steel girt (Wall 5) represents a modified version of a manufactured girt product. Its complex punched geometry is intended as a partial thermal break. In this study, the girt was modeled as 16-gauge steel and spaced vertically at 24 inches.

Brackets and rails were modeled as 0.1 inch steel without consideration for additional fasteners at bracket-rail interfaces. This system included two variants. The 6a variant contained brackets directly against the backup gypsum sheathing; whereas 6b incorporated a quarter-inch thermal isolation pad behind the bracket. Attachment was modeled with three Type B fasteners.

Table 1. Fastener quantity, dimensions and placement.

Type	Use	Quantity and Placement	Diameter – inch (mm) Head	Shank
A	Gypsum Sheathing	8 fasteners 8” o.c.	0.3 (7.6)	0.152 (3.9)
A	Interior Gypsum	6 fasteners 16” o.c.	0.3 (7.6)	0.152 (3.9)
B	Solid Girts	4 fasteners 2 per girt	0.45 (11.4)	0.25 (6.4)
B	Brackets	12 fasteners 3 per bracket	0.45 (11.4)	0.25 (6.4)
C	Punched Girts	4 fasteners 2 per girt	0.5[1] (12.7)	0.242 (6.1)
D	Exterior Insulation[2]	8 fasteners variable	0.3 (7.3)	0.152 (3.9)
E	SIS Panel[3]	8 fasteners 12” o.c.	0.42 (10.7)	0.20 (5.1)

[1] Diameter at flange.
[2] Length of insulation fastener varied based on insulation thickness.
[3] Fasteners reflect worst-case scenario intended for 16 ga and ¼” steel; Type D fasteners are typically used for lighter gauge steel .

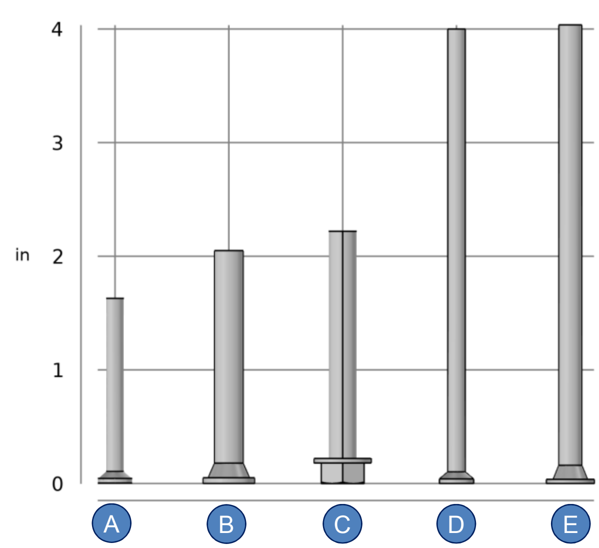

Fig. 2. Modeled fasteners.

Computational Modeling

Simulations were performed using COMSOL Multiphysics 5.4, a computational software package utilizing Finite Element Analysis. In this study, the software was employed to assess steady-state, conductive heat flows through the selected three-dimensional assemblies.

Assembly components were treated as solids with the corresponding thicknesses and thermal conductivities reported in Table 2.

Boundary Layers and Contact Resistances

Boundary layers were modeled as convective heat fluxes with exterior and interior temperatures of 32 °F and 70 °F, respectively. Both boundary conditions incorporated the heat transfer coefficient of 8.3 W/m^2·°K (1.5 Btu/hr·ft^2·°F). The selected exterior coefficient was reduced from values typically employed in order to represent a semi-enclosed rainscreen cavity.

The software's 'Thermal Contact' feature was used to simulate contact resistances between key assembly components. A contact resistance of 0.01 m^2·°K/W (0.057 h·ft2·°F/Btu) was applied to interfaces between cavity insulation and gypsum panels. Air voids within stud cavities were simulated as solids, therefore, the same resistance was applied to interfaces between air and gypsum panels. Interfaces between steel studs and gypsum received a contact resistance of 0.03 m^2·°K/W (0.17 h·ft2·°F/Btu). Resistances were not applied to interfaces at exterior insulation or cladding attachment systems.

Preliminary analyses revealed varying effects of contact resistances when applied to interfaces between fasteners and exterior insulation. These interfaces were most relevant for fastener shanks in direct contact with magnesium oxide panels. Based on these findings, and consideration for fastener shanks being narrower than threaded portions, a contact resistance was warranted. The applied thermal contact was 0.03 m^2·°K/W.

Effective R-Values

Effective R-values were derived from total heat fluxes utilizing the software's 'Derived Values' and 'Surface Integration' features. Thermal efficiencies reflected comparisons between assemblies lacking all thermal bridges (i.e. one-dimensional assemblies) to those containing one or more bridging elements. The term 'total effective R-value' was used to reference thermal performance of assemblies containing all modeled components.

Table 2. Material thickness and thermal conductivity.

Material Type	Material	Thickness Inches (mm)	Conductivity Btu / hr ft °F (W/m K)
Insulation	Extruded Polystyrene[1]	1.5 (38)	0.017 (0.029)
	Mineral Wool Batt[1]	3.5 (89)	0.022 (0.039)
	Polyisocyanurate	3.0 (76)	0.014 (0.024)
	Polyurethane[2]	3.0 (76)	0.012[2] (0.020[2])
Panels	Gypsum Sheathing	0.625 (15.9)	0.094 (0.163)
	Interior Gypsum	0.625 (15.9)	0.094 (0.163)
	Magnesium Oxide	0.5 (12.7)	0.167 (0.288)
Studs	3.5 Inch Stud	0.0538 (1.4)	35.8 (62)
	6 inch Stud	0.0538 (1.4)	35.8 (62)
Girts	Steel: 16-gauge	0.0538 (1.4)	35.8 (62)
	Steel: 0.1 inch	0.1 (2.5)	35.8 (62)
	Aluminum	0.1 (2.5)	116 (201)
	Composite Plastic	0.1 (2.5)	0.145 (0.25)
Isolation Pads	Fiber-Reinforced Resin	0.25 (6.4)	0.116 (0.20)
Fasteners	Steel	-	24.9 (43)
	Stainless Steel	-	9.37 (16.2)
Air	Stud Cavity	6.0 (152)	0.555 (0.96)
	Punched Girt Voids	0.15 (3.81)	0.029 (0.05)

[1] Thermal conductivity reflects values adjusted to achieve corresponding R-13 and R-7.5 ratings for the prescription R-20 wall.

[2] Thermal conductivity reflects a total mean value derived from third-party test results. Multiple samples of poured polyurethane foam were tested at mean test temperatures of 20 °F, 55 °F, and 75 °F.

RESULTS & DISCUSSION

In this study, I compared performance ratings of cladding attachment systems for walls configured with typical fasteners. I begin by ranking the different strategies on the basis of total effective R-values (Fig. 3). These plots offer unique perspectives by illustrating only the highly-conductive bridges that interconnect and span the respective thermal gradients. In other words, these are the components that drive thermal degradation. As compared to other wall components, fasteners represent a much smaller surface area, and they therefore play a much smaller role. But their precise contributions vary and should not be arbitrarily dismissed on the basis of size, type, or material properties.

In Figure 4, I present thermal plots and effective R-values associated with key wall components. These data are then conveyed graphically in Figure 5 for a simple comparison of total effective R-values. Lastly, I delve into the specific contributions of the two main fastener types: insulation fasteners and girt/bracket fasteners (Fig. 6).

Code Reference Walls

As expected, the prescriptive R-20 wall did not achieve true R-20 performance, though this benchmark is often sought when co-mingling the intent of prescriptive R-values with U-factor alternatives. This assembly has a one-dimensional ‘nominal’ effective R-value of 23.0, which is ultimately reduced to 18.0 and 17.6 with studs and fasteners, respectively. Its thermal efficiency of 77% is notably better than conventional steel-framed walls (51%, R-11.1). Nonetheless, further reduction is expected with the addition of cladding fasteners or cladding attachment systems.

The exterior C.I. wall served as the base assembly for evaluating cladding attachment systems and their variants. It has a one-dimensional R-value of 21.5. Unlike the prescriptive hybrid wall, thermal performance was not notably degraded by metal studs (Fig 4.2). This is due to its entire insulation layer being outboard of the framed assembly. The 4% loss was due almost exclusively to insulation fasteners. Although this high efficiency is impressive, it is also purely hypothetical as the thick insulation layer requires options for cladding attachment. Attachment systems, or the cladding fasteners themselves, will further reduce thermal performance.

Structural Insulated Sheathing

The SIS system emerged as the best performing assembly. Its high performance is attained by maximizing insulation continuity while limiting highly-conductive elements to just fasteners. When considering all fasteners, the effective R-value of 21.5 matched the one-dimensional R-value for the C.I reference wall (Figs. 4.2).

Fastener-induced loss of 13% was due largely to shank interfaces with the thermally-isolated magnesium oxide. This was improved to 8.7% with stainless steel fasteners. These effects were further compensated by the panel’s poured polyurethane foam which has a higher R-value when compared to polyisocyanurate. Furthermore, no appreciable loss is expected by cladding fasteners since the SIS panel serves as the attachment substrate, not the back-up studs.

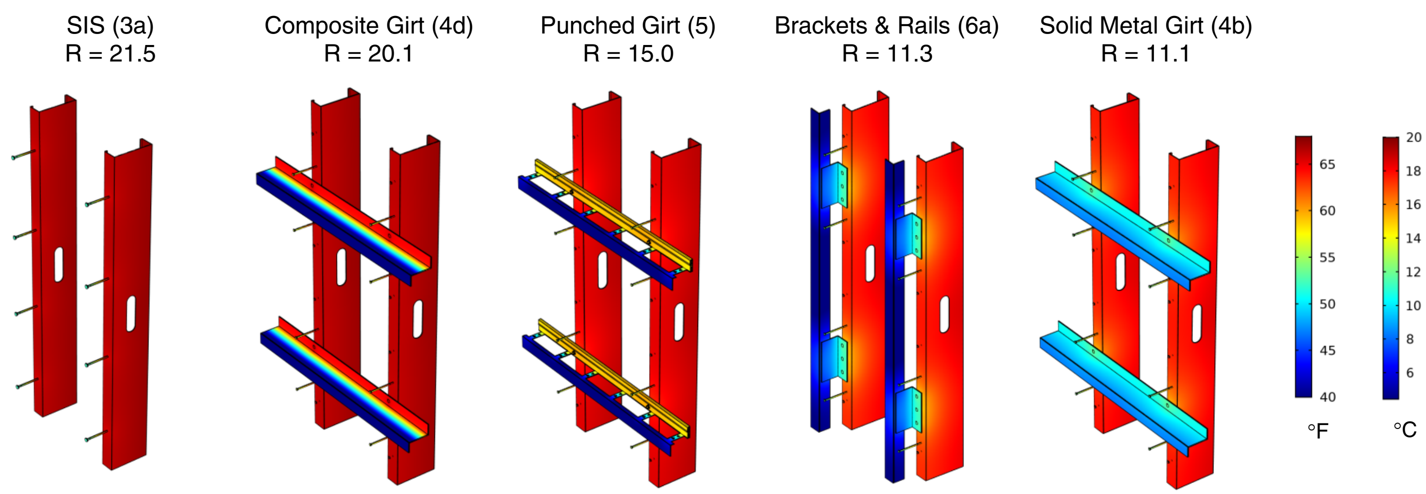

Fig. 3. Surface temperatures of primary bridging elements. Plots represent a common temperature range of 40-68 °F (4.4-20 °C). Total effective R-values represent all modeled components.

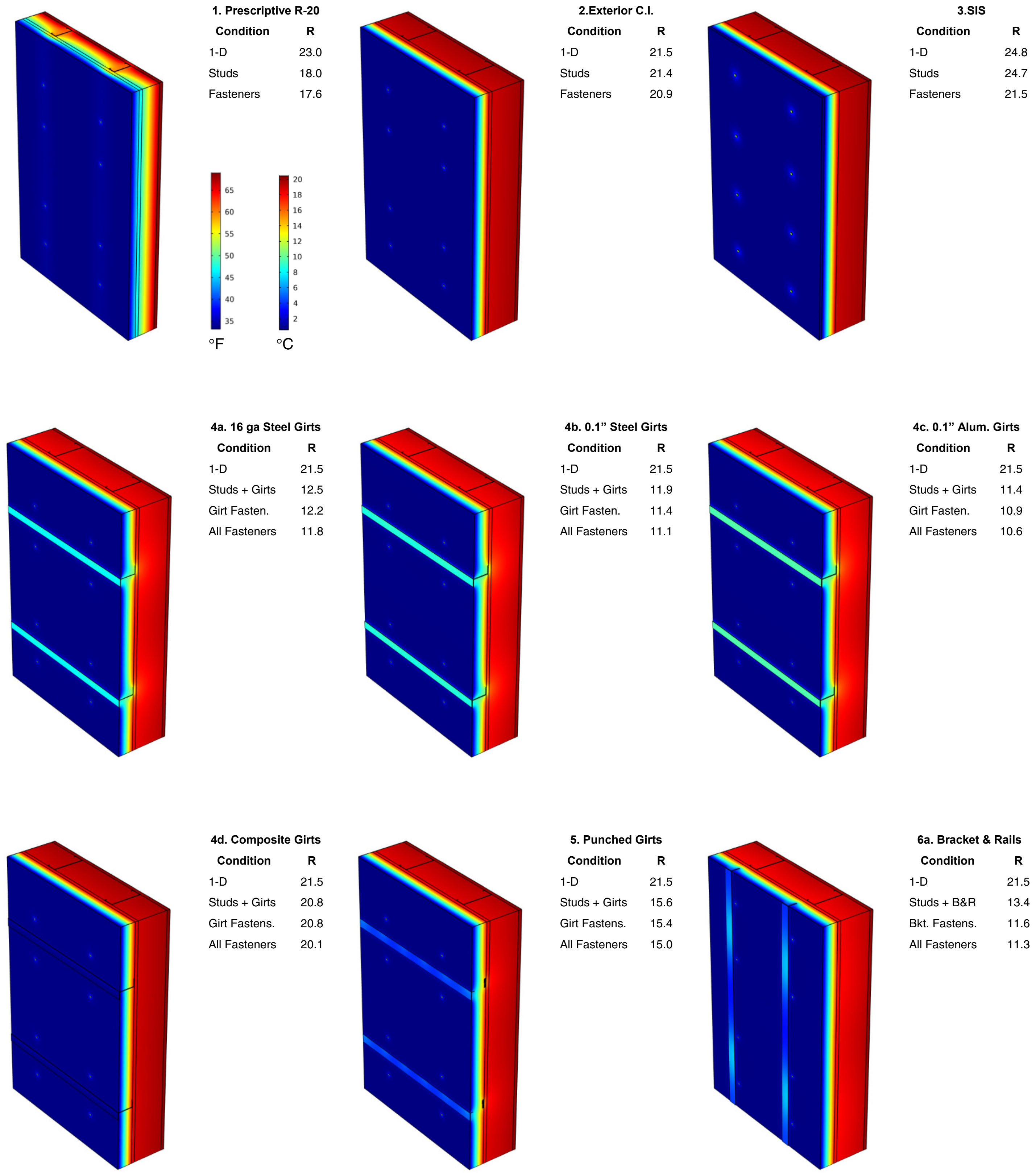

Fig. 4. Thermal performances of wall assemblies. Reported efficiencies represent walls configured with all components.

Composite Z-Girts

The composite z-girt offered another highly efficient system, achieving a total effective R-value of 20.1. This strategy relies on a low-conductive composite material that spans the entire insulation layer thereby creating a true thermal break. In this case, fasteners made little difference. The head and shank of girt fasteners interface discretely with a low-conductive girt and polyiso foam – materials that are not thermally isolated but rather part of the thermal gradient itself. Thermal loss of just 3% was split evenly between the studs and fasteners. As with the SIS system, cladding fasteners do not connect directly to the studs; therefore no further degradation is expected.

Metal Z-Girts and Bracket & Rails

The remaining wall types, including metal horizontal z-girts, engineered punched girts, and bracket & rail system failed to match the R-18 rating of the prescriptive R-20 wall. They also failed to comply with the maximum U-factor of 0.060 (R-16.7), a threshold pertinent to many climate zones during the early adoption of exterior insulation.

Solid metal z-girts were collectively the poorest performers (Figs. 4, 5). Their efficiencies ranged from 49% for aluminum girts to 55% for 16-gauge steel. Factors such as girt thickness and composition clearly made a difference but perhaps not as substantially as often assumed. For example, losses attributed to fasteners were greater than those resulting from girt properties.

The bracket & rail system ranked slightly higher than solid metal z-girts based on simulations with a common thickness of 0.1 inch. This relationship also holds true when both were modeled at 16-gauge thickness. Interestingly, the use of thermal isolation pads yielded only minor improvement (Fig. 5), The 0.25-inch pads act essentially as large washers, having limited impact at bracket interfaces while remaining unchanged at the twelve modeled fasteners. In fact, it is not possible to meet U-0.060 performance without removing the brackets altogether. Moreover, gains attributed to isolation pads were negated by the effects of fasteners. In other words, the effective R-value of the bracket system with studs was essentially the same as the thermally-isolated system with fasteners.

The most efficient of these systems was the punched girt. This strategy achieved an R-15 rating when considering all components. It also offered a significant improvement over solid steel girts modeled as either 16-gauge or 0.1 inch (Figs. 4, 5). Still, its use in mitigating thermal bridges appears limited without additional measures such as thermal isolation or a two-piece web with mid-span break.

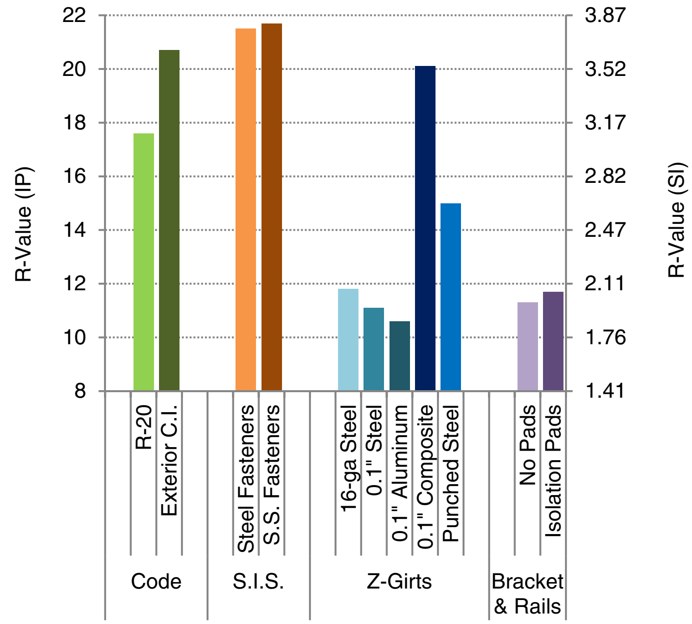

Fig.5. Total effective R-values of fully-configured assemblies.

The Effects of Fasteners

Thermal degradation resulting from fasteners varied on the basis of fastener type, quantity, and cladding attachment system. In Figure 6, I illustrate these effects for modeled assemblies and their corresponding variants. These data are expressed on the basis of fastener type. Total losses may be obtained by combining the delineated components.

Losses associated with gypsum fasteners were negligible, ranging from 0.03% for the C.I. reference wall to 0.5% for the prescriptive R-20 assembly. Walls configured with cladding attachment systems revealed similar losses. Therefore, and for the purpose of clarity, gypsum and insulation fasteners were consolidated in Figure 6.

Insulation fasteners were typically associated with 2 to 3% loss in thermal efficiency. The SIS fasteners represented an exception with reported losses of 8 to 13%. Part of this discrepancy relates to dimensional differences as SIS fasteners (Type E, Table 1) were slightly larger than gypsum and polyiso fasteners (Type A, Table 1). More relevant is the fact that shanks and heads of SIS fasteners interface with the thermally isolated magnesium oxide panel. This results in disproportionally higher heat fluxes at fastener penetrations. As previously noted, these effects were offset by the highly continuous and thermally-efficient insulation layer. The resulting trade-off yields a net benefit that is readily achieved in real-world applications.

The effects of girt fasteners were also determined by material properties, fastener quantity, and girt geometry. Thermal degradation showed a sequential increase on the basis of thermal conductivity and girt thickness (Fig. 6). This loss ranged from 2.8% for 16-gauge steel to 4.6% for 0.1 inch aluminum girts. When the same fastener was used for attaching a composite girt, the loss was a mere 0.02%. This reduction is attributed to interfaces between the composite girt and low-conductive materials on the warm side of the thermal gradient. Likewise, punched girts offered a unique compartmentalized isolation strip that reduced the fastener's overall effect.

Losses due to bracket fasteners were driven largely by fastener quantity. Specifically, the presence of three fasteners acted synergistically, causing more than a three-fold loss when compared to a single fastener with solid metal girts (Fig 6).

SUMMARY

My findings confirm what was already known. Thermal efficiencies of modern walls are determined by large pieces of metal that traverse the exterior insulation layer. Reduce these highly conductive materials whether by material type or component geometry, and you effectively improve performance. Remove them altogether, as with Structural Insulated Sheathing, and you effectively achieve the true intent of continuous insulation.

If large thermal bridges matter, then it stands to reason that smaller ones, such as fasteners, matter less. This is not to say that the effects of fasteners are insignificant. From this study, I show that fasteners do have consequences. Those having the greatest influence include: 1) fasteners that span the outer insulation layer (2-13% loss); 2) fasteners that bridge metal attachment systems to metal studs (1-4% loss); and 3) multiple fasteners at a given attachment point (13-16% loss).

Skeptics might dismiss even this magnitude of effects. After all, fastener-induced losses pale in comparison to those caused by attachment systems, fenestrations and other bridging elements. Although true, it is also irrelevant. The exclusion of fasteners from thermal calculations has largely reflected omission by diminished returns – small gains from large efforts. It has also reflected a matter of practicality. Fastener effects simply could not be measured without assembly testing or the benefits of three-dimensional thermal modeling.

I argue for the inclusion of fasteners because their effects are real and quantifiable. With thermal modeling, we have the ability to consider virtually any set of conditions, any set of components – empirically and systematically. If the technology is there to measure all thermal bridges, why not use it to gain insight? Why not use it to achieve a better, truer picture of how the whole system works? Fasteners are an inherent part of our tested assemblies. Their inclusion in thermal analyses, and ultimately their contribution to U-factor alternatives, seems quite relevant.

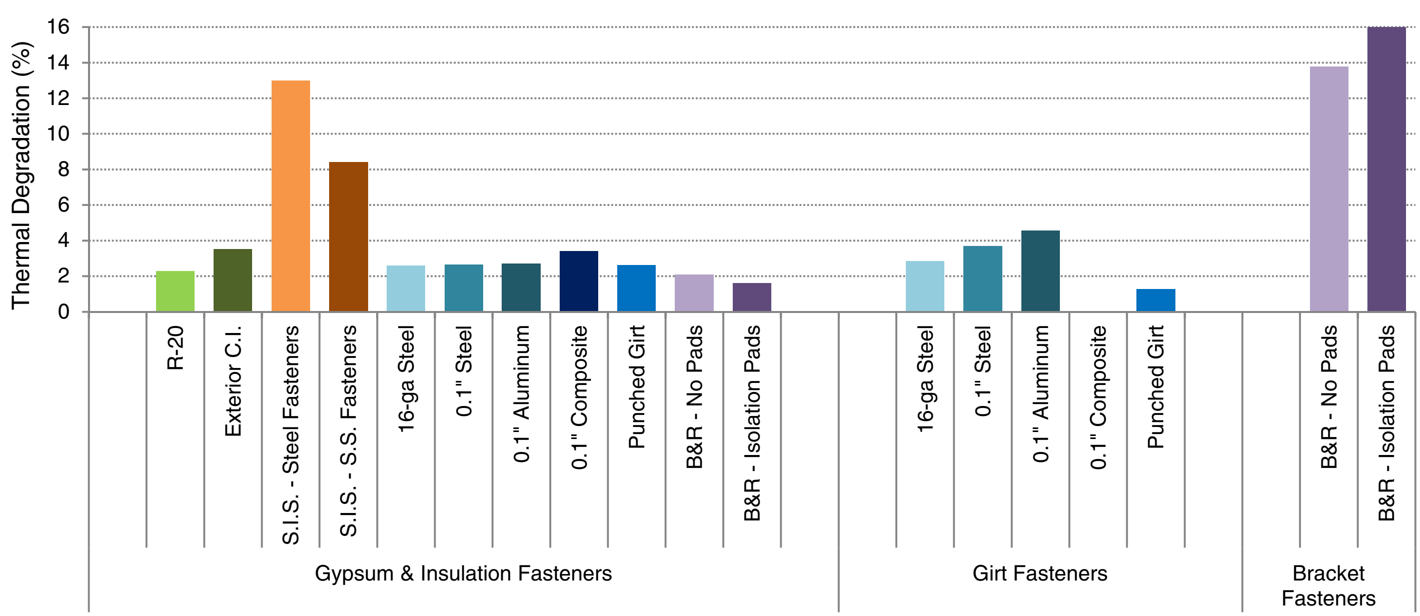

Fig. 6. The effects of fastener type on thermal degradation.

Lastly, if we do not include fasteners in our analyses, how do we know their effects? Here, I have examined just a handful of conditions yielding some very interesting outcomes. There are countless others waiting to be explored. And what about future innovations – those not yet conceived? As currently written, the code seems content with exclusion, inviting virtually any contrived system to become a fastener much as our cladding attachment system morphed into the cladding fastening system. Why not simply close the fastener loophole once and for all?

REFERENCES

[1] Enermodal Engineering Ltd, (1996). ASHRAE Research Project 785-RP – Building Insulation System Thermal Anomalies‖, Final Report, ASHRAE Research Project 785-RP.

[2] Christensen, D. (2010). Thermal Impact of Fasteners in High-Performance Wood-Framed Walls. Thermal Performance of the Exterior Envelopes of Whle Buildings XI International Conference. December 5-9, 2010.

[3] ASHRAE. (2016). ASHRAE 90.1 Energy Standard for Buildings Except Low-Rise Residential Buildings. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc.

[4] Lawton M, Roppel P, Fookes D, Teasdale A, Schoonhoven D. (2008). Real R-value of exterior insulated wall assemblies. BEST 1 Conference Proceedings. Building Enclosure Science & Technology. Minneapolis, Minnesota, June 10-12, 2008.

[5] Morrison Hershfield Ltd. (2011). ASHRAE 1365-RP Thermal Performance of Building Envelope Construction Details for Mid- and High-Rise Buildings. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc.

[6] RDH Building Science (2018). Cladding attachment Solutions for Exterior-Insulated commercial Walls.

[7] Morrison Hershfield Ltd. (2020). Building Envelope Thermal Bridging Guide, Version 1.4.

FUNDING

This research was partially funded by MaxLife Industries.