

MASONRY VENEER SUPPORT DETAILS: THERMAL BRIDGING

Michael Wilson, M.Eng, P.Eng, Graham Finch MSc, P.Eng & James Higgins Dipl.T,

RDH Building Engineering Ltd. Vancouver, BC, Canada

ABSTRACT

The use of increased levels of insulation within masonry veneer walls places increased demands on the gravity support systems including slab edge, edge-connected steel angles, and discretely connected steel angles. In addition to structural and durability criteria, designers need to assess masonry gravity support systems for thermal bridging.

This paper summarizes the essential thermal design criteria related to masonry veneer gravity support systems. The results of three-dimensional thermal modelling are presented to illustrate the impact of thermal bridging and the inherent benefits of de-coupling masonry supports from the building structure.

This paper will assist both masonry contractors and designers responsible for thermally efficient masonry veneer gravity support systems. A companion paper at this conference by Finch, Wilson, and Higgins (2013) has been prepared which specifically deals with thermal bridging issues at brick masonry veneer connectors.

INTRODUCTION

Masonry veneer support systems need to address structural capacity, deflection control, building movements, durability and thermal performance. While most of these design challenges are well understood and appreciated, meeting the thermal performance requirements are complicated, with multiple compliance paths, overlapping requirements for buildings, assemblies and attachment details, and no single point of accountability for meeting the performance requirements.

BACKGROUND

Masonry veneer cladding, supported laterally by steel or wood framing, or poured concrete is a traditional form of exterior wall construction. The thermal performance of these traditional masonry veneer wall assemblies was not a primary design consideration, and nominal R-values (IP) ranged from R-12 to R-20 (RSI 2.1-3.5), with effective R-values of R-5 to R-7 (RSI 0.9 to 1.2) accounting for thermal bridging of steel framing and slab edges.

Building codes have gradually increased thermal performance requirements and have moved towards consideration of effective R-values and the use of continuous insulation. This means that thermal bridging (energy loss) at penetrations through the insulation material must generally be accounted for in design. Some interpretations may conclude that small areas of thermal bridging can be ignored for code compliance; however the impact may be significant and influence the design of other building systems. This evolution places new demands on the design of masonry veneer support systems.

SUMMARY OF THERMAL INSULATION REQUIREMENTS IN CANADIAN BUILDING CODES

Awareness and understanding of the building code, related standards, and the various energy compliance paths is required in order to establish the context for thermal considerations and masonry veneer support systems.

In Canada there are two national model codes that specify energy efficiency provisions for buildings: the National Building Code of Canada (NBC) and the National Energy Code for Buildings (NECB), which was previously called the Model National Energy Code for Buildings (MNECB). These National Codes are adopted either with or without modifications by each of the Provinces and Territories. The City of Vancouver, BC has a modified version of the BC Building Code written into their municipal building bylaws.

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.

The Province of BC has adopted ASHRAE 90.1-2004 and Ontario has adopted a combination of ASHRAE 90.1-1989 and 2004 for large building energy code compliance. The City of Vancouver through its Building Bylaw has adopted ASHRAE 90.1-2007. Both the Province of BC and City of Vancouver are in the public review process for the adoption of ASHRAE 90.1-2010 (plus NECB 2011). The 1997 MNECB building enclosure performance requirements are often used in LEED energy simulations and the new 2011 NECB is currently undergoing review for adoption into many of the provinces.

Compliance with the building enclosure provisions of ASHRAE Standard 90.1 requires meeting some prescriptive and mandatory requirements as well as one of the three alternate building enclosure compliance paths. The three compliance paths include, in order of lowest to highest complexity and level of work required to demonstrate building project compliance: Prescriptive Building Envelope (Enclosure) Option, Building Envelope (Enclosure) Trade-off Option, or Energy Cost Budget Method.

Masonry veneer supports are addressed in the various codes and standards in the following manner:

- NBC (Part 9 or low rise buildings): Code requirements are related to nominal insulation R-values. Nominal insulation R-values do not account for losses due to thermal bridging. Until such time that the nominal insulation R-values includes requirements for continuous insulation (ci) the basic design criteria for masonry veneer supports will not vary from traditional considerations. It is important to note that the December 2012 changes to Part 9.36 thermal insulation requirements within the 2010 NBC, similar to that within the new 2011 NECB (replacing the older 1997 MNECB) require effective R-values to be considered, and therefore will affect masonry veneer support design in the future.
- NECB and ASHRAE 90.1 Prescriptive Compliance path (Part 3 or high rise buildings). In addition to minimum nominal R-value requirements for insulation, the standard also

provides the option for maximum assembly U-values (minimum R-values). The determination of an assembly U-value requires the calculation of an effective assembly R-value accounting for type of framing and degree of thermal bridging. The use of effective R-values is a more rational measure of the true thermal performance of an assembly. The use of effective R-values rather than nominal R-values in building and energy codes is 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. Depending on the wall type and climatic zone in consideration, traditional masonry veneer wall assemblies will not satisfy the prescriptive requirements of ASHRAE 90.1 and the design criteria for masonry veneer supports will be affected.

- NECB and ASHRAE 90.1 Building Envelope Trade Off and Energy Cost Budget. In most situations, the distribution of opaque wall and fenestration area does not satisfy the basic limitations governing the use of the prescriptive compliance path. The prescriptive compliance path is generally only available for buildings with a fenestration area less than 40 to 50% of the overall wall area. Overall building compliance requires demonstration that the “proposed design” achieves the same energy performance as a “base-line” building that would otherwise be compliant with the standard. With respect to the design criteria for masonry veneer supports, this means that the design needs to address thermal conductance, and the impact of thermal bridging becomes an important factor. The addition of “continuous insulation” also increases the importance of structural consideration as the masonry support is typically located further outboard of the building structure increasing eccentric loads and bending forces on supporting plates and angles.

THERMAL DESIGN CRITERIA

As indicated in the previous section, the thermal design criteria are going to vary with the overall building energy compliance path. Using larger buildings as the example explored in this paper, Figure 1 summarizes the minimum effective R-values currently required by NECB and ASHRAE 90.1-2010 (Part 3), within the six different Canadian Climate Zones.

| Climate Zone – By Zone and HDD(°C) | NECB 2011 - Above Grade Walls (All Construction Types) | ASHRAE 90.1-2010 – Above Grade Walls Residential Building (Mass Concrete, Wood- Frame, Steel-Frame) |
|--|---|---|
| | Minimum Effective Assembly R-value [RSI] | Minimum Effective Assembly R-values [RSI] |
| Zone 4 - <3000 HDD | 18.0 [3.17] | (9.6, 11.2, 15.6) [1.69, 1.97, 2.75] |
| Zone 5 - 3000 – 3999 HDD | 20.4 [3.59] | (11.1, 15.6, 15.6) [1.95, 2.75, 2.75] |
| Zone 6 - 4000 – 4999 HDD | 23.0 [4.05] | (12.5, 19.6, 15.6) [2.20, 3.45, 2.75] |
| Zone 7a - 5000 – 5999 HDD | 27.0 [4.76] | (14.1, 19.6, 15.6) [2.48, 3.45, 2.75] |
| Zone 7b - 6000 – 6999 HDD | 27.0 [4.76] | (14.1, 19.6, 15.6) [2.48, 3.45, 2.75] |
| Zone 8 - >7000 HDD | 31.0 [5.46] | (14.1, 27.8, 15.6) [2.48, 3.45, 2.75] |

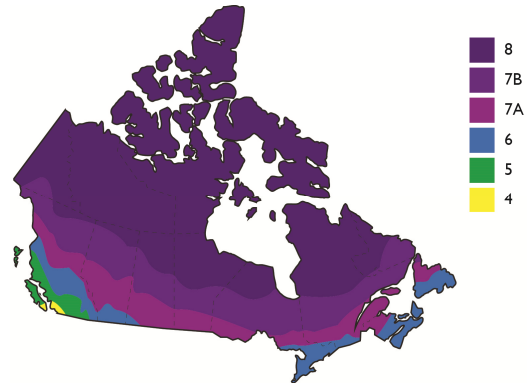


Figure 1: Minimum Effective R-Value Requirements for Building Enclosure Assemblies within 2011 NECB and ASHRAE 90.1-2010 in Canadian NECB and ASHRAE 90.1 Climate Zones (Note that ASHRAE 90.1 includes Climate Zone 4, Lower Mainland and Victoria, BC with Climate Zone 5 in Canada)

A significant portion of the significantly populated regions of British Columbia fall into zone 4 and 5, and the above effective R-value requirements will impose limitations on the use of traditional masonry veneer wall assemblies. In fact, the use of traditional (no insulation placed in the air space) masonry veneer wall assemblies will be limited to buildings that achieve compliance through the building enclosure trade off or energy cost budget at the expense of other more thermally effective assemblies. Masonry veneer assemblies exceed the above effective R-value requirements when 3 to 4 inches of continuous insulation is added to the wall assembly and support details are designed to minimize thermal bridging at shelf angles thus maximizing overall wall thermal performance.

Without considering thermal losses at shelf-angles or connectors, a masonry veneer wall assembly can be designed to satisfy all the above requirements with an effective R-value ranging from R-10 to R-20 (RSI 2.1-3.5) depending on the amount of insulation and type of construction.

IMPACT OF THERMAL BRIDGING

While the leg of a steel shelf angle at every floor may not appear to be a significant issue, the fact that it is attached to the concrete slab edge and is cutting through the exterior insulation generally results in an effective R-value reduction in the order of 40% for the full height wall assembly. It is such a substantial reduction, that even adding thicker amounts of exterior insulation cannot overcome the thermal bridging effect, necessitating a design change to the shelf angle support.

Design should ideally minimize the use of shelf angles and maximize thermal performance, recognizing that most applications require discrete and intermittent support of the masonry veneer, such as those shown in Figure 2. The impact of thermal bridging at shelf angles can be

reduced with alternate masonry shelf angle support strategies such as stand-off plates and other proprietary components. All of these strategies involve decoupling the direct connection of the shelf angle from the slab edge, allowing for continuous insulation behind the shelf angle, and some optimized connection from the shelf angle back to the supporting structure.

Figure 2 presents a series of sketches of the “traditional” approach, representing common shelf angle support details that can be considered “baseline” conditions within the context of the comparative analysis presented in this paper. The common features and characteristics of the baseline masonry support details include:

- 3 ½” clay brick,
- 1” minimum airspace (ventilated),
- 4” semi-rigid mineral fibre insulation (R-4.2/inch, R-16.8 (RSI 2.96) nominal)
- Connectors: 16 gauge x 2” tall x 4.5” deep stainless steel slotted L-bracket with 0.19” wire ties, spaced at 16” horizontally and 24” vertically
- 8” reinforced concrete or 5 1/2” steel stud backup wall, steel studs with 5 1/2” fibreglass insulation (R-3.6/inch, R-20 (RSI 3.52) nominal),
- Interior finish

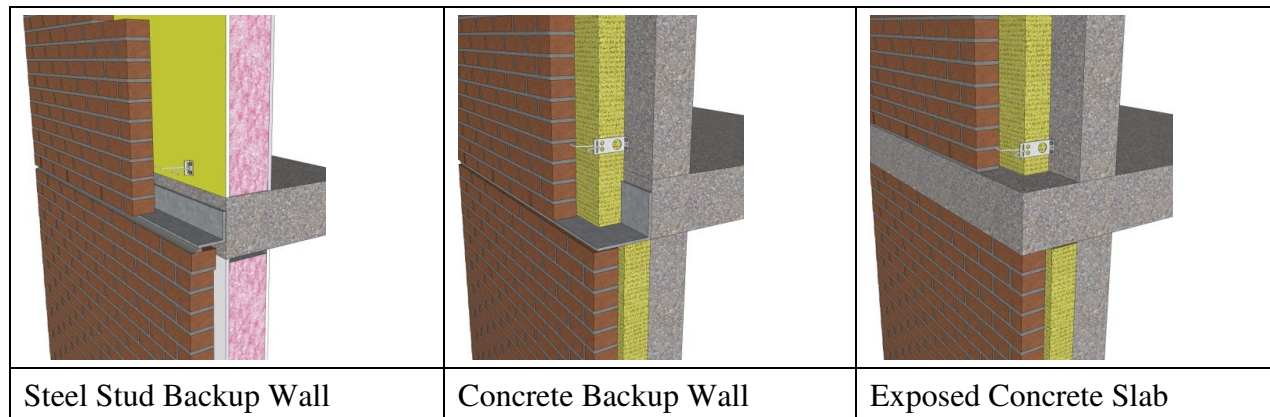


Figure 2: Typical “Baseline” Masonry Veneer Support Details

Replacing the concrete backup wall component in the above assemblies with either infill concrete block or un-insulated steel stud framing with gypsum sheathing does not impact the resulting R-values. Options with additional insulation (4 inches or more), which would generally be sufficient to meet current energy code requirements, are not presented as additional structural design consideration are required for both gravity and lateral supports.

ANALYSIS OF BASELINE MASONRY VENEER SUPPORT DETAILS

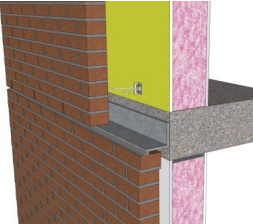
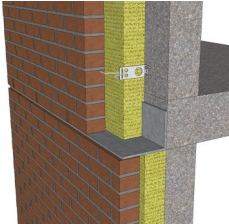
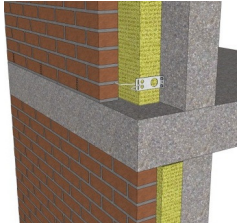
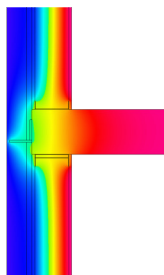
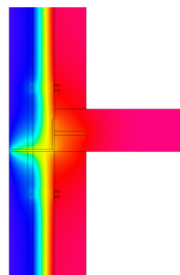
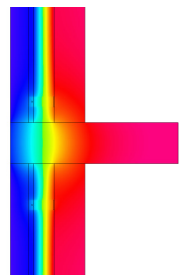
Three-dimensional thermal modelling for each wall assembly and slab edge detail was performed using the finite element program HEAT3 (www.blocon.se). The HEAT3 software package has been well tested and validated by the building industry and is commonly used to calculate effective R-values for enclosure assemblies.

For each baseline detail, the effective R-value for an 8’-8” high masonry wall (8” slab, 8’-0” floor-ceiling) including the thermal bridging through the standard brick ties and shelf angle detail is calculated. It should be noted that a shorter height wall (i.e. area below a window) would have a lower effective R-value due to the larger area weighting of the shelf angle area. As the U-value

and linear transmittance psi-values are also provided, effective R-values for different height walls can also be determined.

The nominal R-value for the poured concrete backup wall, accounting for all materials and surface conditions (ignoring thermal bridging) is R-19.6 (RSI 3.45). Accounting for the effect of thermal bridging through optimized stainless steel brick ties, the effective R-value is R-17.7 (RSI 3.11), an R-value reduction of approximately 10%. A companion paper at this conference by Finch, Wilson, and Higgins (2013) provides additional information related to the impact of variations in the masonry veneer design. Use of galvanized or solid masonry connectors can increase the thermal loss in the above wall assembly by another 5% to 7%. Table 1 contains a summary of the analysis of all baseline masonry veneer support details.

Table 1: Summary of Nominal and Effective R-Values and U-Values for Baseline Masonry Shelf Angle Support Options Showing Impact of Thermal Bridging

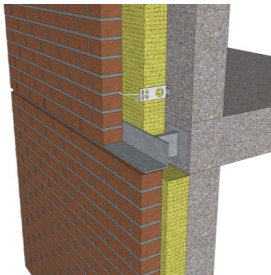
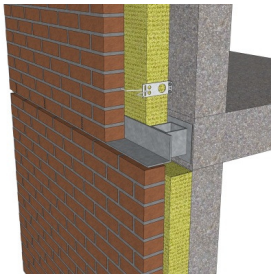
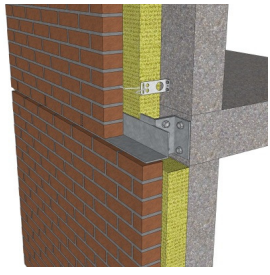
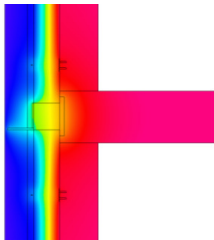
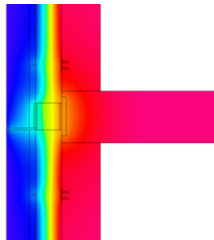
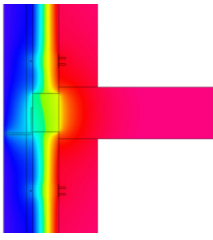
| | Steel Stud Backup | Poured Concrete Backup | Exposed Slab Edge |
|------------------------------------|---|--|---|
| |  |  |  |
| |  |  |  |
| Nominal Insulation R-Value/U-Value | R-20 (RSI 3.52) U-0.05 (USI 0.284) | R-16.8 (RSI 2.95) U-0.060 (USI 0.339) | R-16.8 (RSI 2.95) U-0.060 (USI 0.339) |
| Effective Assembly R-Value/U-Value | R-7.3 (RSI 1.29) U-0.137 (USI 0.777) | R-10.5 (RSI 1.84) U-0.096 (USI 0.543) | R-9 (RSI 1.58) U-0.112 (USI 0.634) |
| Effective Reduction | 63.5% | 37.5% | 46.4% |
| Linear Transmission | - | $\psi = 0.339$ IP (0.586 SI) | $\psi = 0.478$ IP (0.827 SI) |

Without addressing the shelf angle connection to reduce the impact of thermal bridging, a range of 40% to 60% R-value reduction (for the level of insulation provided) can be expected for the above baseline assemblies. Such large reductions in thermal performance make it nearly impossible to support their use in any application in modern building construction seeking to comply with current energy codes. The only “baseline” option that provides an opportunity to improve overall thermal effectiveness is the poured concrete backup model with continuous insulation (recall an un-insulated steel stud backup wall or a CMU backup wall could be substituted for the poured concrete backup wall with no significant implications to the analysis).

ANALYSIS OF ALTERNATE MASONRY VENEER SUPPORT DETAILS

The standard approach to improve the thermal effectiveness of the traditional steel shelf angle is to “stand-off” the angle with a knife plates, structural section, or overlapping angles. Reductions in overall wall assembly thermal values are reduced to approximately 15% (for the provided insulation thickness) when the design accommodated moving the shelf angle away from the slab edge using one of several common approaches. Table 2 provides a summary of the comparative analysis carried out for three alternative support details.

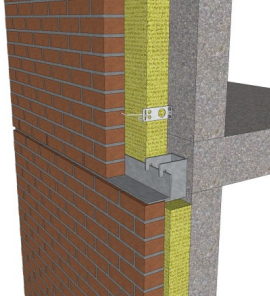
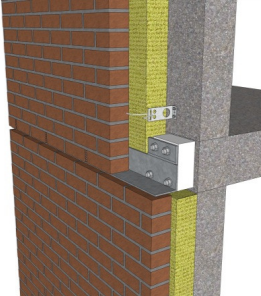
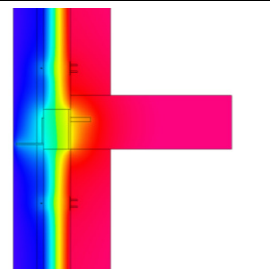
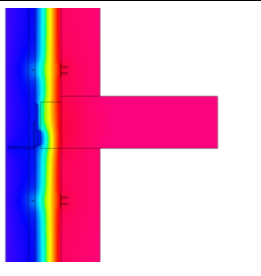
Table 2: Summary of Nominal and Effective R-Values and U-Values for Typical Stand-Off Modifications to the Baseline Masonry Shelf Angle Support Options Showing Impact of Thermal Bridging

| | Knife Plate | HSS Structural Section | Overlapping Angles |
|------------------------------------|---|---|---|
| |  |  |  |
| |  |  |  |
| | shelf angle: 4"x4"x1/4" outside of insulation. 4"x4"x3/4" stand-off knife plates welded to embed plates at 48" o.c. | shelf angle 4"x4"x1/4" outside insulation. 4"x4"x1/4" HSS tube welded to embed plates at 48" o.c. | shelf angle 4"x4"x1/4" outside insulation. 2-6"x4"x5/16" angles bolted to slab edge at 48" o.c. |
| Nominal Insulation R-Value/U-Value | R-16.8 (RSI 2.95) U-0.060 (USI 0.339) | R-16.8 (RSI 2.95) U-0.060 (USI 0.339) | R-16.8 (RSI 2.95) U-0.060 (USI 0.339) |
| Effective Assembly R-Value/U-Value | R-14.8 (RSI 2.6) U-0.068 (USI 0.384) | R-14.8 (RSI 2.6) U-0.068 (USI 0.385) | R-15.0 (RSI 2.64) U-0.067 (USI 0.379) |
| Effective Reduction | 16.4% | 16.5% | 15.3% |
| Linear Transmission | $\psi = 0.096$ IP (0.166 SI) | $\psi = 0.097$ IP (0.168 SI) | $\psi = 0.089$ IP (0.153 SI) |

Proprietary connections, such as the cast-in 4-bolt stainless steel bolt thermal break, result in reductions in the 7% range. Table 3 provides a summary of the analysis undertaken on two proprietary shelf angle connections. Like most thermal bridging scenarios, this percentage R-value reduction is not linear, and increases with thicker insulation levels. Another way of looking at these shelf angle details is in terms of an effective R-value for the 8" slab area as compared to the centre of wall (R-17.7 (RSI 3.12) in this wall case). This can be calculated using the linear thermal transmittance values, and works out to approximately R-1.8 (RSI 0.32) for the

direct attached angle (and R-0.9 (RSI 0.16) for exposed slab edge), up to R-5 (RSI 0.88) range for stand-off supports and R-9 (RSI 1.59) for proprietary thermal break connections.

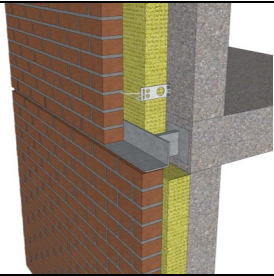
Table 3: Summary of Nominal and Effective R-Values and U-values for Propriety Masonry Shelf Angle Support Options Showing Impact of Thermal Bridging

| | Standoff Bracket | 4-Bolt Cast-In |
|------------------------------------|---|--|
| |  |  |
| |  |  |
| | shelf angle 4"x4"x1/4" outside insulation. Proprietary clip is 1/4" thick steel, 4"x4"x1/4" 6 "lg C-section. Non-welded connection. . | Shelf angle 4"x4"x1/4" outside insulation. Pre-manufactured cast-in place thermal break connection with 4 stainless steel bolts attached to 7"x7"x 3/8" plate. |
| Nominal Insulation R-Value/U-Value | R-16.8 (RSI 2.95) U-0.060 (USI 0.339) | R-16.8 (RSI 2.95) U-0.060 (USI 0.339) |
| Effective Assembly R-Value/U-Value | R-14.9 (RSI 2.62) U-0.067 (USI 0.381) | R-16.4 (RSI 2.9) U-0.061 (USI 0.345) |
| Effective Reduction | 16.4% | 7% |
| Linear Transmission | $\psi = 0.091$ IP (0.158 SI) | $\psi = 0.037$ IP (0.064 SI) |

The 16% to 7% reduction in thermal R-value that is possible for shelf angle stand-off designs is a significant improvement over traditional masonry support systems. The stainless steel masonry veneer connections account for approximately 5% of the above thermal reductions. Regardless of the representative surface area of the masonry support shelf angle (less than 1% of the weighted wall area), the impact of the thermal bridging on the effective R-value is significant.

In addition to the decoupled design for shelf angle attachment, an analysis was conducted to examine the effect of the spacing of the intermittent stand-off connections. Table 4 shows a comparison of different spacing for knife plate connection from 12" o.c. to 72" o.c. with 4" of exterior continuous insulation.

Table 4: Summary of Nominal and Effective R-Values and U-values for Knife Plate Supported Masonry Shelf Angle Support Demonstrating Impact of Knife Plate Spacing on Thermal Bridging

| | Knife Plate | | | | | |
|--|--|---|---|---|--|--|
| |  | | | | | |
| | shelf angle: 4"x4"x1/4". 4"x4"x1/4" knife plates at 12" o.c. | shelf angle: 4"x4"x1/4". 4"x4"x3/8" knife plates at 24" o.c. | shelf angle: 4"x4"x1/4". 4"x4"x1/2" knife plates at 36" o.c. | shelf angle: 4"x4"x1/4". 4"x4"x3/4" knife plates at 48" o.c. | shelf angle: 4"x4"x5/16". 4"x4"x3/4" knife plates at 60" o.c. | shelf angle: 4"x4.5"x3/8". 4"x4.5"x3/4"knife plates at 72" o.c. |
| Nominal Insulation R-Value/U- Value | R-16.8 (RSI 2.95) U-0.060 (USI 0.339) | | | | | |
| Effective Assembly R-Value/U- Value | R-12.5 (RSI 2.2) U-0.080 (USI 0.454) | R-13.7 (RSI 2.42) U-0.073 (USI 0.414) | R-14.4 (RSI 2.55) U-0.069 (USI 0.393) | R-14.8 (RSI 2.6) U-0.068 (USI 0.384) | R-15.1 (RSI 2.66) U-0.066 (USI 0.376) | R-15.4 (RSI 2.7) U-0.065 (USI 0.370) |
| Effective Reduction | 29.1% | 22.3% | 18.2% | 16.4% | 14.5% | 13.1% |
| Linear Transmission | $\psi = 0.202$ IP (0.349 SI) | $\psi = 0.141$ IP (0.244 SI) | $\psi = 0.109$ IP (0.188 SI) | $\psi = 0.096$ IP (0.166 SI) | $\psi = 0.083$ IP (0.144 SI) | $\psi = 0.074$ IP (0.128 SI) |

The different spacing of the knife plate stand-off support produces reductions from 30% at 12" down to 13% at 72". Even the worst performing support spacing (12") has a lower reduction on the overall thermal performance than a directly attached shelf angle. Increased spacing beyond 36" to 48" does not gain significant thermal effectiveness. Any reduced impact of thermal bridging gained by spacing beyond 48" may however be lost if additional anchors or increases in plate/section thickness is required. Under rigorous analysis an optimum balance between structural requirements and thermal efficiency could be defined for each different stand-off support systems.

CONCLUSION

Building energy efficiency requirements within Canadian Energy and Building Codes have increased to the point where the use of exterior insulation within masonry walls is becoming common. The use of exterior insulation reduces thermal bridges through major structural elements such as infill framing, shear walls, columns and floor slab edges however thermal bridges still exist at all penetrations through the exterior insulation. This paper assessed the significance of the thermal bridge that occurs at the penetration through the exterior insulation at the masonry veneer shelf angle support.

While the relative area of the masonry support angle is relatively small compared to the exterior insulation (less than 1% of the surface area), the impact on the effective R-value of the wall is very significant. Traditional construction approaches where the shelf angle is bolted directly to the slab edge, or the masonry is supported directly on an exposed concrete slab edge result in effective R-value reductions in the 40% range. This means that prescriptive compliance with energy code requirements will be limited to very mild climates and buildings with non-prescriptive compliance will require a “trade-off” with other more thermally effective assemblies.

In order to comply with energy performance requirements, the use of alternate shelf angle support strategies where the shelf angle is supported intermittently outside of the exterior insulation are necessary. The use of intermittent supporting knife plates, HSS tubes, angle brackets and proprietary brackets are much more thermally efficient, and effective insulation reductions for whole wall assemblies are improved to approximately 11%. Drawing on the companion paper by Finch, Wilson, and Higgins (2013) the combined thermal bridge impact of de-coupled shelf angle support and stainless steel masonry veneer connectors’ results in a total R-value reduction of 16%.

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