Thermal bridging – calculations and impacts

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ABSTRACT

This paper presents an overview of methods for calculating the Total R-value (RT) of opaque constructions (e.g., walls, roofs and suspended floors), with specific consideration of thermal bridging due to penetration or compression of the insulation by metal frames and rails.

The impact of thermal bridging is highly non-linear: a small bridge can have a substantial impact on the overall heat transfer through the building envelope. It is therefore important for building simulators to take thermal bridging into account when establishing the layers in the model, in order for the model to provide an accurate representation of the facade.

However, the 2016 National Construction Code (NCC 2016) makes no direct reference to thermal bridging calculations. Accordingly, these calculations appear to be rarely applied in practice. A more detailed assessment of thermal bridging impacts shows that common construction methods (such as cold-framed steel walls) would not comply with the NCC 2016 RT requirements.

Simplified methods of calculating RT are compared for a common metal-framed wall arrangement, with examples of their application. The NCC 2019, to be released in February, is expected to include requirements for designers and certifiers to consider thermal bridging. Thermal bridging effects will be incorporated into a new Façade Calculator that is being produced to help designers understand energy efficiency requirements for glazing and opaque constructions set out in Section J1.5 of the Code. This paper provides some background on the topic and a summary of how thermal bridging is treated under various calculation standards.

1. INTRODUCTION

In Australia, thermal bridging across the facade is rarely considered by designers, building performance modellers, builders or certifiers. There are a number of probable reasons:

- Thermal short circuits account for only a tiny proportion of the facade area. It is easy to dismiss a problem that seems small.
- Thermal bridging is almost invisible in the NCC 2016. There is no requirement to assess thermal bridging when calculating RT: while the NCC requires insulation to comply with Australian/New Zealand Standard: 4859 Part 1 – 2002, "Materials for the thermal insulation of buildings, Part 1 – General criteria and technical provisions" (AS 4859.1)[1], there is no requirement for the overall thermal performance of the construction to be calculated in accordance with AS 4859.1. However, more explicit requirements around the treatment of thermal bridging are expected to be included in the NCC 2019, which will be released in February 2019.
- The assessment of thermal bridging can be complex, requiring 2D or 3D heat-flow modelling or in-situ measurements for accurate results. While a number of international standards provide simplified methods, these are of limited applicability, and produce inconsistent results. For users who are unfamiliar with these methods, they are also time-consuming and expensive to implement.
- Documents that Australian specifiers are likely to refer to when calculating the R-value of the structure do not provide adequate examples of thermal bridging. For example, Specification J1.5 of the NCC 2016 does not identify thermal bridging at all. Although AIRAH DA09 tables 24–35 incorporate thermal bridging by timber frames, there are no examples of the more severe impacts of thermal bridging across metal frames.
- The relatively mild climate prevailing in most large Australian population centres during much of the year means that the energy impact of thermal bridging may be relatively small, particularly in buildings types that are driven by internal load. However, this impact will become more important as the building code stringency is ratcheted up in future.
- Thermal bridging calculations are not generally built in to thermal simulation packages.

In this context, it's not surprising that – in our experience – manufacturers and specifiers generally work on the basis of "simple, unbridged" R-value when assessing the thermal performance of structures.

However, building simulators are well-placed to assess the scope and impacts of thermal bridging, since it can be "pre-processed" and fed into the simulation when construction layers are defined.

The overview of calculation methods provided in this paper will assist simulators to fill this gap. Further assistance will be available through the NCC 2019 Façade Calculator, to be released later this year.

2. SUMMARY OF SIMPLIFIED CALCULATION METHODS

2.1 Thermal Bridging in New Zealand Standard: 4214 – 2006, "Methods of Determining the total thermal resistance of parts of buildings"

2.1.1 Overview

NZS 4214 forms the key focus of this paper because the 2019 revision of the NCC will closely align with it in regards to the assessment of RT. Moreover, NZS 4214 is already enshrined within Australian standards, since it is referenced by Clause K2 of AS 4859.1, which requires assessors to use it when calculating the total thermal resistance of building elements "(e.g., thermal bridging and compression of insulation under roofs, joists etc.)".

NZS 4214 provides a relatively simple way to evaluate thermal bridging, which is summarised below.

Clause 5.7.1 of NZS 4214 states that the thermal performance of a bridged layer is assessed by assuming isotherms exist at the inner and outer surfaces of the section of the construction containing all bridged and inhomogeneous layers. The placement of the isotherms across the whole section of the structure containing the inhomogeneous layers (i.e., collectively) is a key conceptual difference between NZS 4214 and other methods.

Heat transfer between these isotherms is in proportion to the conductance and relative areas of the components within, i.e., with total resistance across the bridged layers assessed as follows:

$$R_b = \frac{1}{\left(\frac{f_1}{R_1} + \frac{f_2}{R_2} + \cdots \frac{f_n}{R_n}\right)} \qquad (1)$$

Where

R_b is the thermal resistance of the bridged portion of the structure, and

f_n is the fractional cross-sectional area of each portion of the bridged plane – assessed in the plane perpendicular to the direction of the heat transfer, and

R_n is the thermal resistance for the portion of the bridged layers in the region corresponding to f_n.

The thermal resistance of the air films and homogenous (unbridged) layers in the structure is subsequently added to R_b, to calculate the total thermal resistance.

The total R-value is then calculated by adding the R-values associated with the homogeneous section of the structure and the surface films to R_b.

Where an air layer is located adjacent to a bridged layer, the bridged section must be considered as extending (outwards or inwards through the structure) to include this layer.

NZS 4214 does not provide an explicit method for adjusting the thermal resistance (or thermal conduction values) calculated due to penetration of the insulation by fastenings or gaps between adjacent insulation layers.

Clause 5.7.3 of NZS 4214 provides a specific method for dealing with bridging of metal frame elements, e.g., in walls and roofs, firstly transforming them into an "equivalent rectangle", and adding contact resistances where the frame contacts incompressible surfaces (such as the external cladding or internal wall lining). The R-value of the equivalent rectangle is calculated as follows:

$$R_{eq} = \frac{l_{frame}}{k_{eq}} \qquad (2)$$

Where

l_{frame} is the depth of the frame, and,

$$K_{eq} = K_{frame} \times \frac{\textit{web BMT}}{\textit{flange width}} \qquad (3)$$

Where

K_{frame} is the thermal conductivity of the framing material (generally steel),

web BMT is the base metal thickness of the part of the frame that penetrates the insulation (typically 1–2.5 mm) and

flange width is the face width of the frame, perpendicular to the direction of heat transfer and parallel to the insulation and wall-facing materials.

2.1.2 Example 1 – Metal-framed walls in NZS 4214

We have calculated the construction total R-value for the arrangement illustrated in plan view in Figure 1.

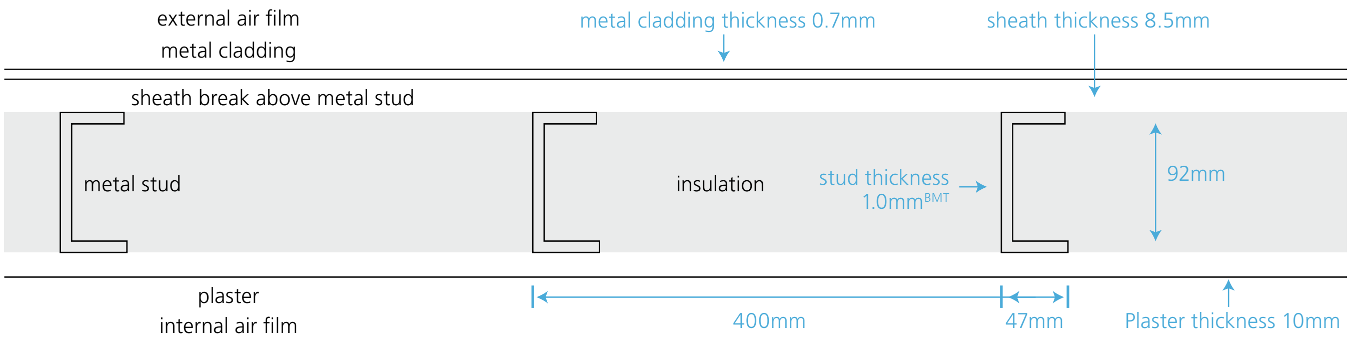

Figure 1: Plan view through metal-framed wall.

Table 1: Wall construction layers.

Layer description	Depth (mm)	Layer k-value, W/m-K	Layer R-value, m^2-K/W
External surface film			0.04
Metal cladding	0.7mm	47.5	Approx 0
R0.25 thermal break (sheath-type) on metal frame/nogging	8.5mm	0.034	0.25
Fibreglass-type insulation batts bridged by metal frame	Frame: 92mm Insulation: 92mm	Frame: 47.5 Insulation: 0.04	Frame: 0.061 Insulation: 2.5
Plasterboard	10mm	0.170	0.0588
Internal surface film	n/a	n/a	0.12

The calculation also assumes that the frame height is 3,200mm and that horizontal elements are located at vertical spacings of 800mm (i.e., four horizontal elements in total). The fractional area of the surface of the studs is therefore 0.17 (based on exposed flange area perpendicular to the direction of the heat transfer). Fractional area of the insulation between the studs is 0.83.

Point thermal bridging by the screws used to fasten the cladding to the metal frame was not considered and fastenings are therefore not illustrated, but was observed by Trethowen et al[2] to be insignificant in terms of the overall thermal performance of the structure.

Properties of the layers used in the calculation are described in Table 1.

Surface film resistance is as per clause K5 of AS 4859.1.

In addition to the resistances listed in Table 1, we have applied a contact resistance of 0.03 m^2-K/W between the metal frame and the inner surface of the thermal break sheath. A second contact resistance of 0.03 m^2-K/W exists between the metal frame and the outer surface of the wall lining. This is in line with Clause 5.7.4 of NZS 4214, and with the "standard default" identified by Trethowen et al[3].

The following interpretations have also been made and are highlighted here as uncertainties in the application of the standard:

- Inclusion of the thermal break sheath within the "inhomogeneous" layer section. While the NZS 4214 method clearly requires strip-type thermal breaks to be included with other non-homogeneous layers in R_b, the application of the same approach to a (homogeneous) sheath break is less clear. Thermal resistance diagrams conceptualising the two alternative approaches – where R_b is defined with and without the sheath thermal break in the bridged layers – are shown in Figure 2. Including the thermal break within the bridged section reduces heat transfer through the steel frame, i.e., by effectively assuming that no lateral heat transfer occurs within the thermal break sheath. While the standard provides no specific guidance or examples around sheath-type thermal breaks, it seems plausible to assume that they would perform at least as well as strip-type breaks. This approach also seems to have been taken in the National Association of Steel Framed Housing in its N11 House Insulation Guide[4] (NASH N11), which shows that for all steel-framed constructions, sheath-type thermal breaks perform at least as well as strip-type breaks used in constructions that are otherwise identical. We have therefore used the approach illustrated on the left-hand side of Figure 2.
- An additional contact resistance may exist between the metal cladding and the thermal break sheath. However, since any additional contact resistance would occur between two homogeneous layers and is not part of the bridged layer, its impact on overall performance is minimal (i.e., in the order of R-0.03 m^2-K/W or less).

The basic calculation process is then applied as follows:

- The steel frame members are firstly transformed into "equivalent rectangles" of face width 47mm and depth 92mm and equivalent thermal resistance R_{eq} = 0.091 m^2/K-W, which is calculated based on equation (2) and (3)
- R_{eq} or the total resistance for Path 1 is increased to 0.401 m^2-K/W by adding the resistance of the thermal break (0.25 m^2-K/W) and the two associated contact resistances (i.e., 0.03 m^2-K/W each).
- The thermal resistance for Path 2 is calculated based on the resistance of the break plus insulation.
- The thermal resistance across all the bridged layers is then calculated using equation (1), applying the area proportions of 0.17 to Path 1 and 0.83 to Path 2.
- Total thermal resistance of the structure is found by adding the internal and external air films and the thermal resistance of the internal wall lining. Thermal resistance of the vapour barrier or other membranes is ignored in this example.

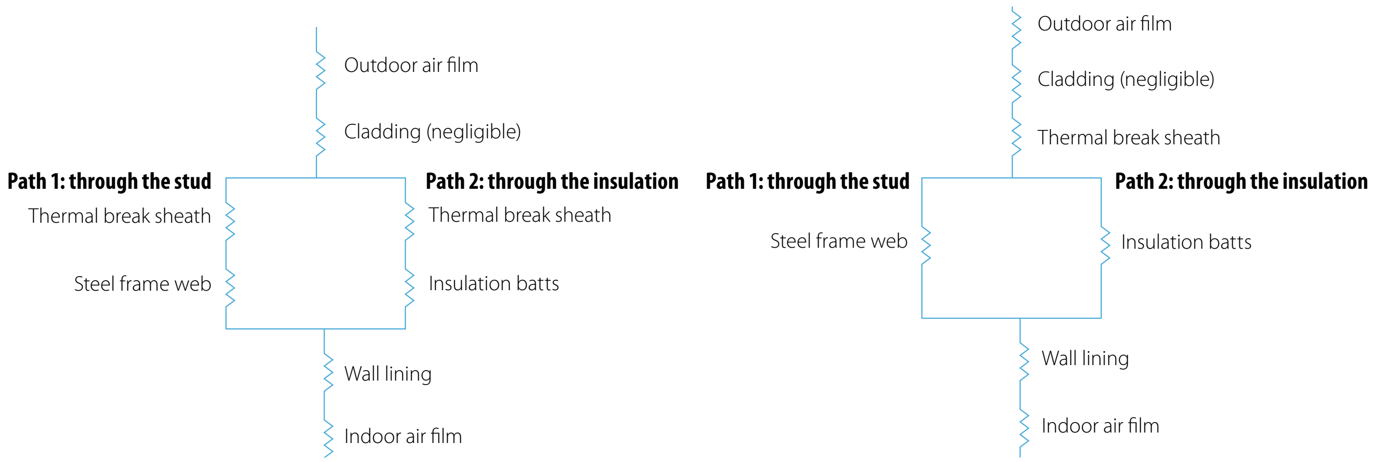

Figure 2: Different concepts of heat-flow pathways through the metal-framed wall. The diagram on the left was used for the calculation (i.e., isotherms for the bridged layers were drawn outside the thermal break sheath, even though it is a homogeneous material).

2.1.3 Application of the example across a greater range of insulation thicknesses

For the NCC 2019, we have applied this method to develop a series of nomograms that present RT for several types of insulation products. This will allow simulators to assess the installed performance of thinner insulation products as well as thicker products that are compressed during installation to fit within the 92mm frame depth. Web BMT, frame spacing and frame depth can also be varied as parameters to the calculations.

This work is similar to work originally presented by NASH N11, except that it has been adapted for use with the Australian NCC and provides more visibility of the assumptions made with regards to framing detail.

In preparing these calculations, we have assumed that:

- Where the insulation is shallower than the stud depth, an air layer remains between the inner surface of the insulation and the outer surface of the wall lining. We assumed that the insulation is pushed all the way to the "back" (outside) of the frame, i.e., with no additional air layer behind the insulation. For air layers ≥ 13mm, the thermal resistance is interpolated from Table E3 of NZS 4214, based on a 6K temperature difference across the air space. Table E3 does not cover airspaces shallower than 13mm. In this case, Annex B.2 of International Standard: ISO 6946, 2007, "Building components and building elements – thermal resistance and thermal transmittance – calculation method" (ISO 6946) was used, also assuming a mean gap temperature of 18°C and a temperature difference of 6K. The air layer insulation is included in Path 2 of Figure 2, but not Path 1.
- Performance of compressed insulation is derated at 50% of the compression ratio. This is in line with Appendix C2 of NZS 4214, which identifies no limits in relation to the application of this adjustment. The compression examples in NZS 4214 are in the order of a few percent, but we have applied this correction to compression by up to around 40% of the original thickness (i.e., from 150mm to 92mm).

An example nomogram showing the performance of the wall described in Figure 1 for a varied range of insulation depths is illustrated in Figure 3. The orange line on Figure 3 shows the expected in-situ RT for fibreglass insulation of a nominal (uncompressed) k-value of 0.04 W/m-K and arbitrary thickness from 50mm to 150mm (nominal R-1.25 m^2-K/W to R3.75 m^2-K/W). Figure 3 also shows calculated performance for a range of off-the-shelf insulation products with rated (uncompressed) k-values of 0.035W/m-K to 0.05W/m-K and thickesses of 70mm to 140mm.

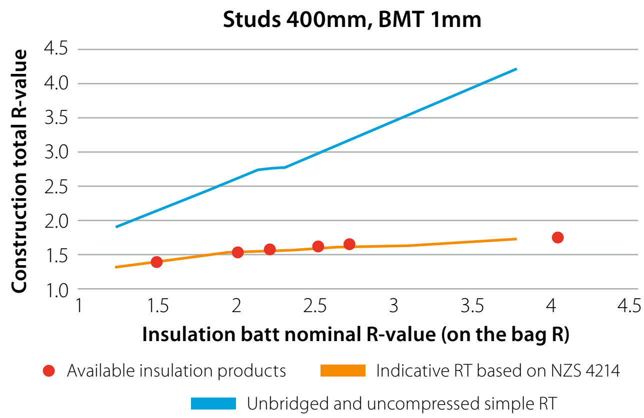

Figure 3: Metal framed wall total R-value, calculated according to NZS 4214 for a range of insulation thicknesses and compared with the unbridged R-values. Note the "kick" in the unbridged graph occurs at the point where the thickness of the insulation fully fills the gap in the frame so that there is no air layer inside the insulation.

An example nomogram showing the impact of changing the frame geometry is illustrated in Figure 4.

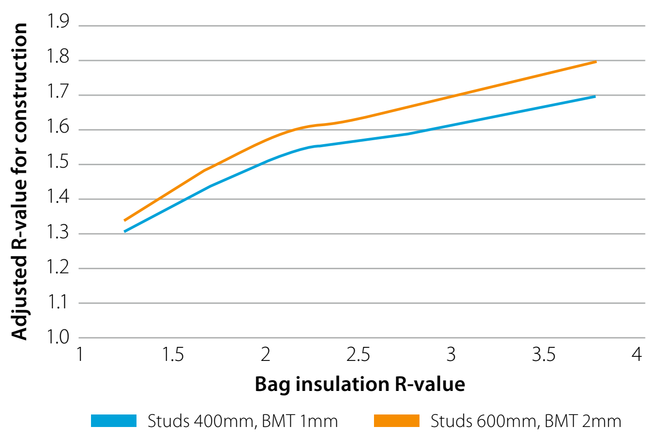

Figure 4: Metal framed wall total R-value, calculated according to NZS 4214 for a range of insulation thicknesses and two different frame geometries.

3. COMPARISON WITH ISO 6946

3.1 Overview

ISO 6946:2007 provides a different method for assessing the heat flow across bridged insulation layers. This is generally more conservative than NZS 4214, so may be useful when simulators run “off-axis scenarios”. ISO 6946 is also useful because it provides methods for adjusting for point thermal bridging by screws or other fastenings and small gaps between poorly installed insulation batts.

Thermal bridging is dealt with by calculating RT as the average of R_{min} and R_{max}.

$$R_T = \frac{R_{min} + R_{max}}{2} \qquad (4)$$

Where

R_{min} is calculated by placing isotherms at the inner and outer surface of each thermally inhomogeneous layer. The R_{min} of the construction is then found by adding the thermal resistance of all homogenous layers and the surface air films to the equivalent thermal resistance of the inhomogeneous layers; and

R_{max} is calculated by placing isotherms at the inner and outer surface of the overall construction and the heat transfer through the construction is then assessed using a similar process to Equation (1).

While ISO 6946 does not apply to bridging by linear metal elements, approaches adapting ISO 6946 to metal framing have been published by the UK Building Research Establishment[5] and the Steel Construction Institute[6]. The basic approach to calculating R_{min} and R_{max} is unchanged.

However, the overall RT is now weighted towards either R_{min} or R_{max}, depending on the ratio of these two values and the frame geometry and spacing.

In particular, RT, is calculated as:

$$R_T = pR_{max} + (1 - p)R_{min} \qquad (5)$$

Where p is found in equation 4:

Contact resistances are not considered in this approach.

Equivalent rectangles are not used: the heat flow through the bridged layers is calculated directly based on the conductivity and cross-sectional area of the web of the steel frame that penetrates the insulation.

$$p = 0.8\left[\frac{R_{min}}{R_{max}}\right] + 0.44 - 0.1\left[\frac{Flange\ width}{40}\right] - 0.2\left[\frac{600}{stud\ spacing}\right] - 0.04\left[\frac{frame\ web\ depth}{100}\right] \quad (6)$$

3.2 Example: Metal framed wall

Applying this concept to the wall arrangement illustrated in Figure 1, the calculation of R_{min} is similar as per the right-hand-side concept drawing in Figure 2, i.e., with the thermal break layer considered separately than the bridged frame. For the geometry described in Figure 1, the bridged layer R-values used to calculate R_{min} are as described in Table 2:

Table 2: Bridged layer calculations, ISO 6946

Path Description	Depth (mm)	Layer k-value, W/m-K	Layer R-value, m^2-K/W	Area proportion, web (1 mm BMT)
Insulation	92mm	0.04	2.3	99.6%
Stud web	92mm	47.5	0.00194	0.374%

Applying equation (1) across the bridged layer, the thermal resistance across this layer is 0.0422m²/K-W. Adding the surface film, thermal break and lining resistance produces R_{min} 0.641m²/K-W.

To find R_{max}, the area proportions identified in Table 2 are applied across the entire structure, so that the R-value for heat flowing through the stud pathway is 0.369m²/K-W and through the insulation pathway is 2.52m²/K-W and R_{max} is 2.465m²/K-W.

Applying equation (6), p is 0.194.

Applying equation (5), RT is 1.20m²/K-W. This compares with 1.56m²/K-W for the NZS 4214 method and a simple, unbridged R-value of 2.77m²/K-W.

4. CONCLUSION

Thermal bridging by metal frames and rails can significantly decrease the performance of opaque building elements, such as walls and roofs. However, calculation of thermal bridging impacts is generally outside the scope of most building simulators.

This paper summarises a simple method that simulators or other design team members can use to assess thermal bridging by metal frames and rails using techniques defined in NZS 4214. Simulators can then adjust the thickness of insulation layers to match the simulated R-value with the bridged RT calculation output. This should be determined from NZS 4214. If adjustment due to point bridges or gaps in the insulation is required, ISO 6946 or an appropriate adaptation should be referenced. A series of nomograms is also being produced for the NCC 2019, which will help simulators to easily evaluate thermal bridging impacts when establishing opaque constructions in the model. ▮

REFERENCES

1 Ibid., Clause J1.2, p406.

2 Trethowen, H. and Cox-Smith, I. "Contact Resistance in a Steel-framed Wall, J. Thermal Insul and Bldg Envs, Volume 20 – October 1996, pp. 132 – 143.

3 Ibid, p 140.

4 Pearse-Danker, H. and Rundle G, N-11 House Insulation Guide, v2.2, National Association of Steel Framed Housing

5 Doran S and Gorgolewski M, "U-values for light steel-frame construction", BRE and Department of Transport, Local Governemnt And Regions, Digest No. 465. pp1 - 12

6 Gorgolewski, Metal cladding: U-value calculation Technical Information Sheet, SCI P312, The Steel Construction Institute.

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