

Calculating the Total R-Value

J1.2



Flat (horizontal) steel framed roof with a thermal break

This case study shows how to calculate the Total R-Value for a Class 7 single-storey storage facility with a flat steel framed roof system in a climate zone 6 location. The case study shows how to calculate the Total R-Value, including thermal breaks, in accordance with the J1.2 Thermal construction Deemed-to-Satisfy (DTS) Provisions in NCC Volume One Section J Energy efficiency.

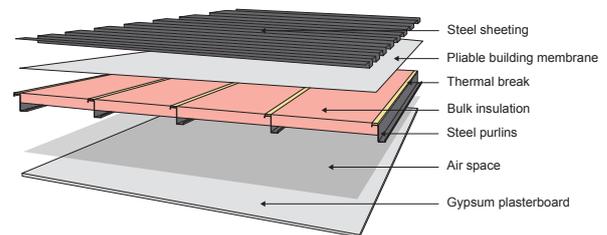


Figure 1 Illustration of a flat roof system with a steel frame and thermal break

Scenario

A Class 7 storage facility is located in climate zone 6. The flat roof system consists of 3 mm thick steel sheeting, a pliable building membrane, 175 mm thick bulk insulation with a nominal R-Value of 4.2 (m².K/W) supported by mesh, a 243 mm non-reflective, unventilated air space (heat flow direction is down), and 13 mm thick gypsum plasterboard. The insulation layer is bridged by Z200-19 section purlins at 1200 mm centres. There is a 12 mm thick by 79 mm wide (the width of the purlin flange) thermal break between the purlins and the steel sheeting.

It is assumed that the Z200-19 purlins span 8000 mm (i.e. 8 m) and supporting purlins are located at each end, filling the air space between the Z200-19 purlins and the gypsum plasterboard. For the purpose of this case study, only the space between the supporting purlins will be analysed. Figure 1 illustrates this roof system.

Construction material and layer properties

Table 1 below outlines the construction material and layer properties in this abovementioned roof system. Known properties include thickness, thermal conductivity and R-Value.

Table 1 Construction material and layer properties (climate zone 6 – downward heat flow)
(From the outside (top of the table) to the inside (bottom of the table))

Layer	Material	Thickness (mm)	Thermal conductivity $\frac{W}{m.K}$	R-Value $\frac{m^2.K}{W}$
Exterior surface resistance	Air films – moving air (assuming wind speed of greater than 3 m/s and not more than 7 m/s)	n.a.	n.a.	0.030
Layer 1	Steel sheeting	3	47.5	0.000063
Layer 2	Pliable building membrane	<1	negligible	negligible
Layer 3	Thermal break	12	0.024	0.500
Layer 3 (continued)	Steel purlins (Z200-19)	203	47.5	0.004
Layer 3 (continued)	Bulk insulation	175	0.042	4.200
Layer 3 (continued)	Unventilated, non-reflective air space	243	n.a.	0.220
Layer 4	Gypsum plasterboard	13	0.17	0.076
Interior surface resistance	Air films – still air	n.a.	n.a.	0.160

Note: Thermal conductivity and R-Values are as per NCC Specification J1.2 or for specific products, from manufacturer and supplier data. Layer 3 is the thermal bridge.

Total R-Value calculation

This method of calculating Total R-Value is as outlined in New Zealand Standard (NZS) 4214 'Methods of determining the total thermal resistance of parts of buildings'.

In general, the R-Value of a material is determined by dividing the thickness of the material (in metres) by the thermal conductivity (in W/m.K). The Total R-Value is the sum of the thermal resistance of each layer, surface air film resistance, and any bridged layers.

Using the information provided in Table 1, we know the thicknesses, thermal conductivity, and R-Values, of the individual materials and layers involved in this roof system. Now, let's look at their individual resistance values.

Exterior surface air film resistance (R-Value)

$R = 0.030 \text{ m}^2 \cdot \text{K/W}$

Layer 1 - 3 mm steel sheeting resistance (assumed flat) (R-Value)

$R = 0.000063 \text{ m}^2 \cdot \text{K/W}$ – treated as negligible.

Layer 2 – Pliable building membrane resistance (R-Value)

The pliable building membrane is applied to the outside of the building frame to provide weather protection and reduce the risk of condensation forming inside the building frame. As the pliable building membrane is less than 1 mm in thickness, the R-Value is considered negligible in this case study.

Layer 3 – Thermal break, insulation, air space and steel – calculating the thermal bridge resistance (R-Value)

Layer 3 consists of insulation and an air space that is bridged by steel purlins. As per NZS 4214, a bridged layer is never bounded by an air space (including when a membrane is in place); therefore, the airspace is included within the thermally bridged layer. There is a thermal break between the exterior sheeting and the steel purlins.

Layer 3 is split into regions so that each region has only one set of stacked 'layers' within it. There are two regions within Layer 3. Region 1 contains an air space layer and a bulk insulation layer. Region 2 contains the thermal break layer, a steel purlin layer and an air space layer. Figure 2 illustrates the bridged layer regions in this case study.

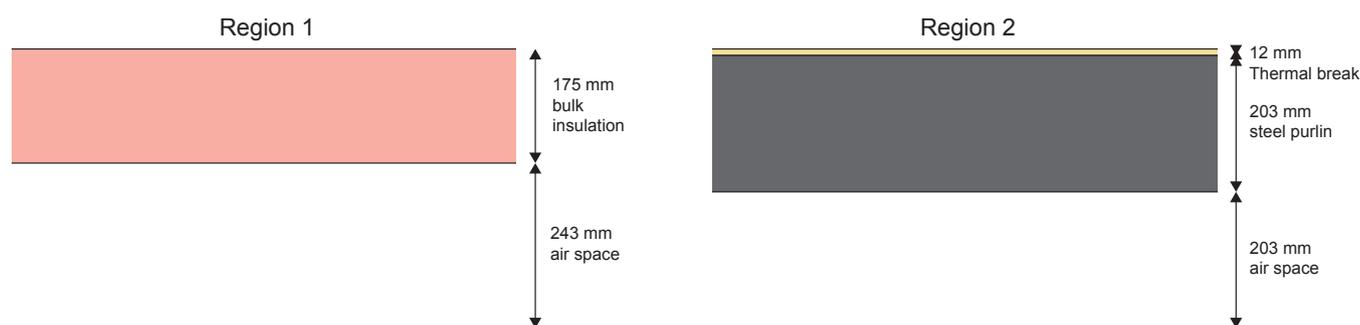


Figure 2 Bridged layer regions

Let's go through the steps of calculating the overall thermal resistance of this layer taking into account the 'thermal bridge' effect of the steel frame.

The overall rate of heat transfer through the bridged layer is proportional the area-weighted average of the heat transfer rate through each region. In steps 1 and 2, we calculate the thermal resistance and the area of each region, which together determine the rate of heat transfer through each region. In step 3, we calculate the total thermal resistance of the bridged layer, which is just the inverse of the overall rate of heat transfer through the layer.

Step 1

Calculate the thermal resistance of each region (using the R-Values in Table 1).

Region 1 (R_1) - insulation

$$R_1 = 4.420 \text{ m}^2.\text{K/W}$$

(i.e. $4.20 \text{ m}^2.\text{K/W}$ (insulation) + $0.220 \text{ m}^2.\text{K/W}$ (airspace))

Region 2 (R_2) – steel frame and thermal break

To determine the thermal resistance of the steel frame (R_s), the steel frame can be transformed into an equivalent rectangular shape (see Figure 3).

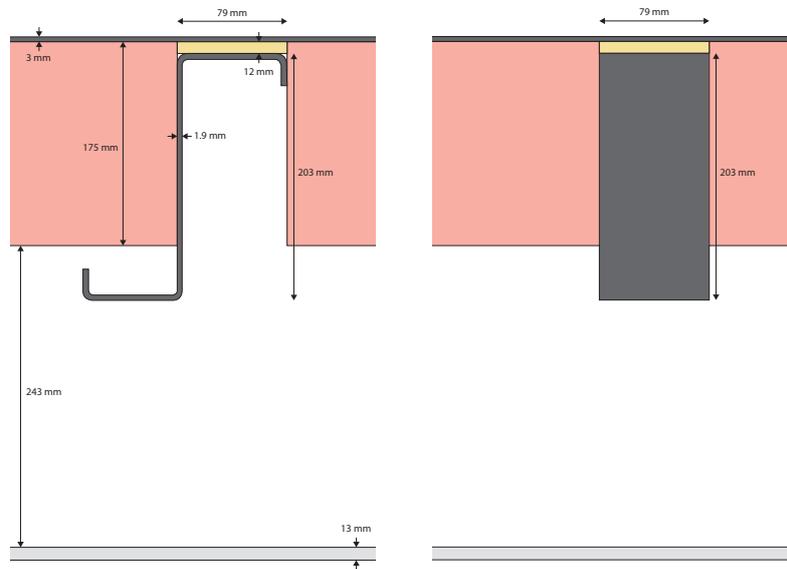


Figure 3 Equivalent rectangular steel frame transformation

The modified thermal resistance calculated as per equation 9 of NZS 4214, shown below.

$$R_s = \frac{a \times l}{d \times k_m} + R_{c1} + R_{c2}$$

- Where:
- R_s is the steel frame thermal resistance ($\text{m}^2.\text{K/W}$)
 - a is flange width (m)
 - l is the total thickness (depth) (m)
 - d is the web thickness (m)
 - k_m is the thermal conductivity of metal (W/m/K)
 - R_{c1} is the contact resistance between the steel frame and the thermal break ($\text{m}^2.\text{K/W}$)
 - R_{c2} is the contact resistance between the steel frame and any adjacent material below the frame it ($\text{m}^2.\text{K/W}$)

R_{c1} and R_{c2} are the contact resistances between metal frame and adjacent facing due to imperfect contact between them. R_{c1} is assumed to be $0.03 \text{ m}^2.\text{K/W}$ (NZS 4214 specifies a value of usually less than $0.03 \text{ m}^2.\text{K/W}$, which is equivalent to a gap of about 1 mm). In this case, R_{c2} is set to zero, because it is assumed most of this beam is not in contact with another material.

Using the dimensions for this configuration (described in the introduction):

$$R_s = \frac{0.079 \times 0.203}{0.0019 \times 47.5} + 0.03 + 0$$

$$= 0.208 \text{ m}^2.\text{K/W}$$

Now, we can calculate the R-Value for Region 2:

$$R_2 = 0.500 + 0.208 + 0.220 \text{ m}^2.\text{K}/\text{W}$$

$$= 0.928 \text{ m}^2.\text{K}/\text{W}$$

Step 2

Next, the area fraction for each region is calculated. The area fraction is the ratio of the cross-section area, at right angles to the direction of heat flow, occupied by each region. For this case study, one repeated section of the roof will be examined to determine the fraction of each region in the layer as per Figure 4.

Region 1 area fraction

$$f_1 (\text{region 1}) = \frac{\text{Cross section area of region 1}}{\text{Total cross section area}}$$

$$f_1 (\text{region 1}) = \frac{(1200 \times 8000) - (79 \times 8000)}{1200 \times 8000}$$

$$f_1 (\text{region 1}) = 0.934$$

Region 2 area fraction

$$f_2 (\text{region 2}) = \frac{\text{Cross section area of region 2}}{\text{Total cross section area}}$$

$$f_2 (\text{region 2}) = \frac{79 \times 8000}{1200 \times 8000}$$

$$f_2 (\text{region 2}) = 0.066$$

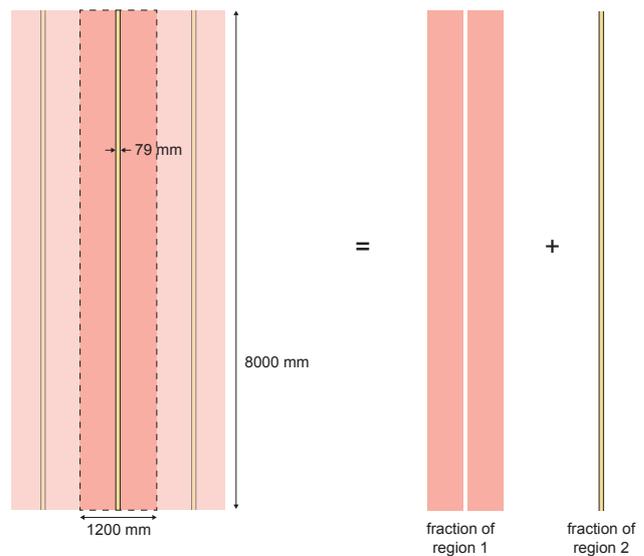


Figure 4 Area fractions

Or given there are only 2 regions:

$$f_2 = 1 - f_1$$

$$f_2 = 1 - 0.934$$

$$f_2 = 0.066$$

Step 3

Lastly, the total resistance of the layer is calculated as per equations 5 and 6 of NZS 4214.

$$\frac{1}{R_b} = \frac{f_1}{R_1} + \frac{f_2}{R_2} = \frac{0.934}{4.420} + \frac{0.066}{0.928} = 0.282$$

$$R_b = \frac{1}{\left(\frac{1}{R_b}\right)} = \frac{1}{0.282}$$

$$R_b = 3.54 \text{ m}^2.\text{K}/\text{W} \quad (\text{Total resistance (R-Value) of Layer 3 – thermal break, insulation and steel frame})$$

Layer 4 - 13 mm gypsum plaster board resistance (R-Value)

$$R = 0.076 \text{ m}^2.\text{K}/\text{W}$$

Interior surface resistance (R-Value)

$$R = 0.160 \text{ m}^2.\text{K}/\text{W}$$

Calculating total thermal resistance (Total R-Value)

You can now calculate the total thermal resistance (Total R-Value). This is the sum of all the layers, the surface layers and any bridge layers (i.e. Layer 3).

Total R-Value = $0.030 + 3.540 + 0.076 + 0.160$

Total R-Value = $3.806 \text{ m}^2\cdot\text{K/W}$

Further considerations

The calculated Total R-Value is representative of a roofing system where the steel frame and insulation batts are consistent with the area fractions used in this case study. Other areas, such as on the edge of the roof supported by purlins, would have a different Total R-Value as the fraction of steel would be different due to the additional framing. The area calculation could be carried out for the entire roof to account for this in an overall value.

This case study assumes that the insulation is sized to fit the frame with no compression and no gaps. Compression may result in moisture issues and aesthetic issues, and reduced thermal performance. The R-Value of compressed insulation should be derated in line with NZS 4214. Gaps around the edge of the insulation would also reduce the performance of the insulation.

This example includes contact resistances, which are not included in the Total R Value calculation in the NCC Façade Calculator Tool. No contact resistance exists where the steel frame is not joined to an incompressible facing material (for example when the frame directly faces an airgap). The treatment of contact resistances in steel-framed wall systems is covered in Section 5.7.4 of NZS 4214 (2006).

This case study assumes that the insulation is sized to fit between the framing elements with no gaps. Gaps around the edge of the insulation would also reduce the performance of the wall.

Want to know more?

The ABCB has developed a range of detailed case studies showing how to calculate Total R-Values with thermal bridges for different wall and roof constructions. They are freely available through the ABCB website (www.abcb.gov.au).