

Calculating the Total R-Value

Solid concrete on a steel framed wall

J1.2



This case study shows how to calculate the Total R-Value for a Class 6 shop with an external wall system consisting of solid concrete wall with a steel wall frame, in a climate zone 3 location. The case study shows how to calculate the Total System 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.

Scenario

A Class 6 shop is located in climate zone 3. A wall component consists of 100 mm solid concrete, a 62 mm ventilated, non reflective air space, a pliable building membrane, 90 mm thick bulk insulation with a nominal R-Value of 2.5 (m².K/W), and 13 mm thick gypsum plasterboard. The insulation layer sits within a steel frame and is bridged by the 92 x 33.5 x 0.75 mm steel framing studs at 600 mm centres, central noggings, wall tracks and head tracks. The wall is 3 m tall. Figure 1 illustrates this wall system.

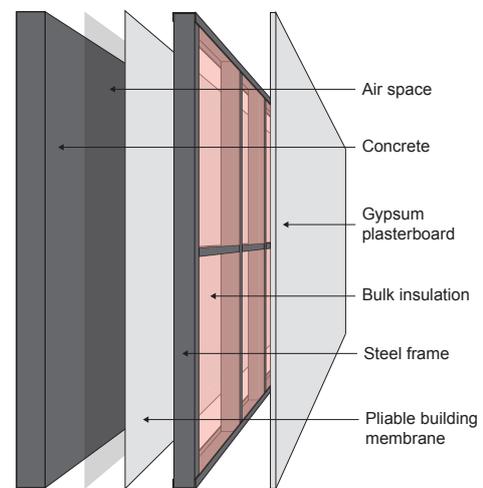


Figure 1 Illustration of a wall system with solid concrete exterior and steel wall frame

Construction material and layer properties

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

Table 1 Construction material and layer properties (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	Solid concrete	100	1.44	0.069
Layer 2	Pliable building membrane	<1	negligible	negligible
Layer 3	Ventilated ¹ , non-reflective air space	60	n.a.	0.094
Layer 3 (continued)	Steel framing studs	92	47.5	0.002
Layer 3 (continued)	Bulk insulation	90	0.036	2.500
Layer 4	Gypsum plasterboard	13	0.17	0.076
Interior surface resistance	Air films – still air	n.a.	n.a.	0.120

Notes: ¹This air space is considered slightly ventilated, so its R-Value is based on a derating of the resistance of an unventilated cavity by a factor of 0.45 as per the requirements of NZS 4214. Other 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, 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 wall system. Now, let's look at their individual resistance values.

Exterior surface air film resistance (R-Value)

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

Layer 1 - 100 mm concrete resistance (R-Value)

As the air space adjacent to the concrete is ventilated, the thermal resistance of the concrete shall be derated by a factor of 0.45 as per NZS 4214.

$$R = 0.069 - (0.069 \times 0.45) \text{ m}^2.\text{K/W}$$

$$R = 0.038 \text{ m}^2.\text{K/W}$$

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

The pliable building membrane is applied to the outside of the building frame for consistency with common practice to 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 study².

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

Layer 3 consists of a ventilated air space and insulation that is bridged by a steel frame. As per NZS 4214, a bridged layer is never bounded by an air space (including when a membrane is place); therefore, the airspace is included within the thermally bridged layer. However, as the air space is ventilated, its resistance is derated by 45% before being combined with the bridged layer.

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 an air space layer and a steel frame layer. Figure 2 illustrates the bridged layer regions in this case study.

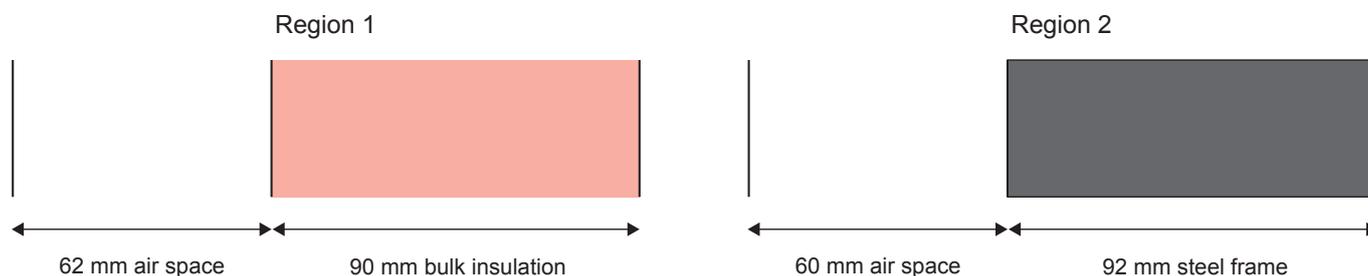


Figure 2 Bridged layer regions

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.

²Note: For users of the ABCB Façade Calculator, it is not recommended that pliable membranes be included in a wall build up as they have negligible thermal resistance.

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

$$R_1 = 2.594 \text{ m}^2.\text{K/W}$$

(i.e. 0.094 $\text{m}^2.\text{K/W}$ (ventilated and non-reflective air space (derated)) + 2.500 $\text{m}^2.\text{K/W}$ (insulation))

Region 2 (R_2) – steel frame

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)

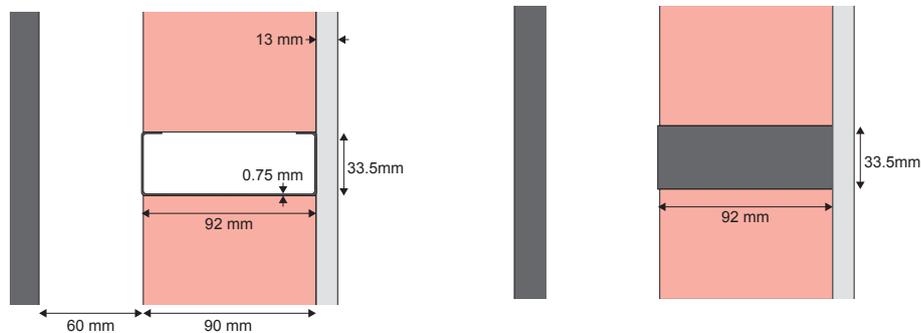


Figure 3 Equivalent rectangular steel frame transformation

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 plasterboard lining ($\text{m}^2.\text{K/W}$).

R_{c2} is the contact resistance between the steel frame and the pliable insulation membrane ($\text{m}^2.\text{K/W}$)

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). R_{c2} assumed to be zero.

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

$$R_s = \frac{0.0335 \times 0.092}{0.00075 \times 47.5} + 0.03 + 0$$

$$= 0.117 \text{ m}^2.\text{K/W}$$

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

$$R_2 = 0.094 + 0.117 \text{ m}^2.\text{K/W}$$

$$= 0.211 \text{ m}^2.\text{K/W}$$

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 wall will be examined to determine the fraction of each region in the layer as per Figure 4 below.

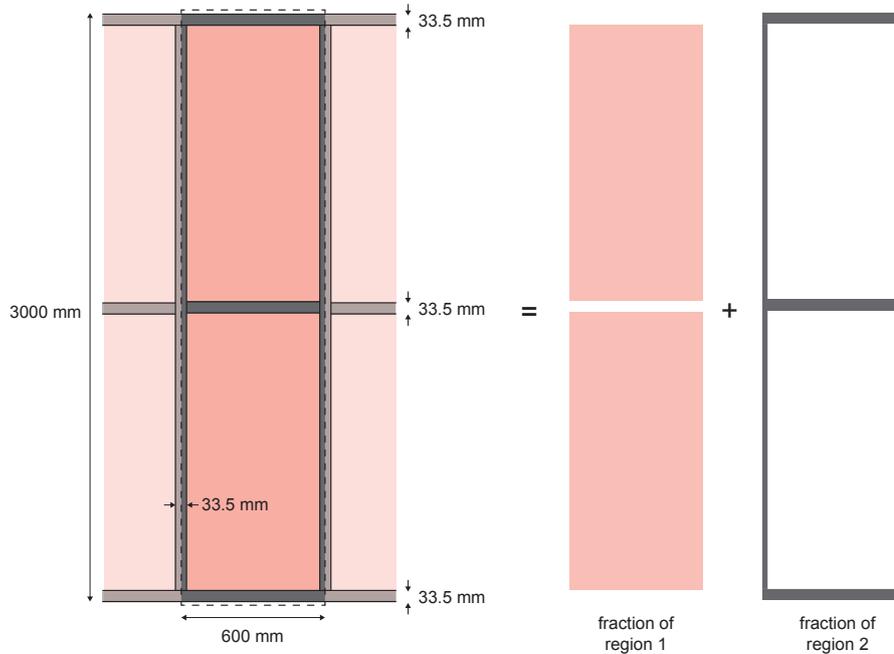


Figure 4 Area fractions

Region 1 area fraction

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

$$f_1 = \frac{(600 \times 3000) - ((3000 \times 33.5) + (600 - 33.5) \times 33.5 \times 3)}{600 \times 3000}$$

$$f_1 = 0.91$$

Region 2 area fraction

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

$$f_2 = \frac{(3000 \times 33.5) + ((600 - 33.5) \times 33.5 \times 3)}{600 \times 3000}$$

$$f_2 = 0.09$$

Or given there are only 2 regions:

$$f_2 = 1 - f_1$$

$$f_2 = 1 - 0.91$$

$$f_2 = 0.09$$

Step 3

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

$$\frac{1}{R_b} = \frac{f_1}{R_1} + \frac{f_2}{R_2} = \frac{0.91}{2.594} + \frac{0.09}{0.211} = 0.778$$

$$R_b = \frac{1}{\left(\frac{1}{R_b}\right)} = \frac{1}{0.778}$$

$$R_b = 1.28 \text{ m}^2.\text{K/W} \quad (\text{Total resistance (R-Value) of Layer 3 – insulation and steel frame})$$

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

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

Interior surface air film resistance (R-Value)

$$R = 0.120 \text{ m}^2.\text{K/W}$$

Calculating the 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).

$$\text{Total R-Value} = 0.030 + 0.038 + 1.28 + 0.076 + 0.120$$

$$\text{Total R-Value} = 1.544 \text{ m}^2.\text{K/W}$$

Further considerations

The calculated Total R-Value is representative of an external wall 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 wall, or areas that may include doors and windows, 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 wall to account for this in an overall value.

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).