NCC Floor Insulation

Final Report

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Prepared for:	Erica Kenna & Mike Dodd Senior Project Officer ABCB
Author:	Hongsen Zhang
Reviewer:	Grace Foo, Paul Bannister
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Executive summary

DeltaQ understands that the methodology changes from a deemed fixed floor contact resistance in 2016 to a more accurate approach for varying sub-floor or soil R-value depending on geometry in 2019 may have resulted in unintended consequences for small buildings. Specifically, small buildings may require more floor insulation than was previously required for similar buildings under NCC 2016. The scope of works within this project is intended to address this issue, by reviewing the differences in floor insulation requirements between NCC2016 and NCC2019. Additionally, further clarification was sought regarding the treatment of the common floor slab adjoining a conditioned space to an unconditioned space; as well as the definition of external wall thickness.

In summary, our analysis in this report found that the increased insulation requirements for small buildings in NCC 2019 Section J1.6 does not achieve a BCR of between 1 and 1.5, with the exception of Climate Zone 7 small buildings (with floor-area-to-perimeter ratio <2.0).

A review of CIBSE Guide A and NZS 4214:2006 indicates that increasing external wall thickness has positive impact on the floor R-Value. When calculated using the CIBSE method, the floor R-Value (with soil type being clay/silt) ranges from 0.24 to 0.62 as external wall thickness is increased from 50mm to 300m, and ranges from 0.26 to 0.81 when calculated using the NZS 4214 method.

Our recommendations can be summarised as follows:

- Any small buildings with slab-on-ground without in-slab heating/cooling:
    - Any building with a floor-area-to-perimeter ratio of less than 7 without in-slab heating or cooling should have a *deemed* floor construction resistance[1] of R=2.0 (i.e. no need for additional insulation compared to NCC2016) except for overnight buildings in climate zone 7. In Climate Zone 8, the deemed floor construction resistance for the building is R=3.5. These R-values are identical to the regulated minimum total R-value requirements in Table J1.6 of the 2019 Section J for an unheated/cooled slab.
    - For overnight buildings (Building Class 2, 3, 4, 9a and 9c) in Climate Zone 7:
        - with a floor-area-to-perimeter ratio between 2.0 and 7.0, the building's floor construction resistance is *deemed* to be R=2.0.
        - with a floor-area-to-perimeter ratio of less than ratio less than or equal to 2, existing minimum floor total R-value requirements apply.

- For unconditioned spaces connected to conditioned spaces via an adjoining floor slab on ground, the unconditioned space and floor should be treated in accordance with CIBSE Guide A Section 3.5.
    - The area of the unconditioned space outside of the insulated fabric of the building should be excluded when determining the floor area and perimeter.
    - The length of the wall between the conditioned space and the unconditioned space must be included in the perimeter calculations (see Figure 19)

[1] Note that R=X is a *deemed* resistance only for Code compliance. In practice, slab on ground without insulation might not achieve these values, but it still meet NCC2019 Section J requirement.

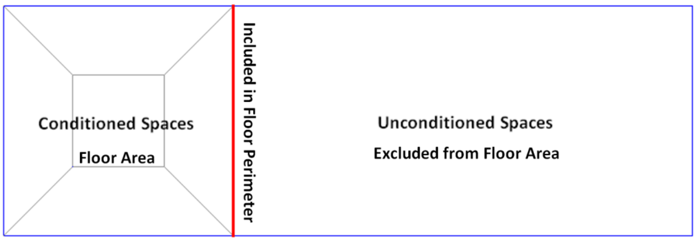


Figure 1 Floor Area and Floor Perimeter for Conditioned Spaces connected to Unconditioned Spaces

- External wall thickness plays an important role in determining soil/sub-floor thermal resistance and should be defined in accordance with CIBSE Guide A definitions (see Figure 15).
  - CIBSE Guide A specifies that the external wall thickness is the thickness of the wall surrounding the ground floor (that is, if the wall is constructed above the floor surface, its thickness is treated as 0mm).
  - AS/NZS 4214:2006 Section 5.5 does not explicitly distinguish whether the external wall surrounds the floor slab or not, which may lead to a discrepancy between external wall thickness treatments using 2019 Method 1 and 2019 Method 2 floor insulation calculations.
    - Deduction using the equation referenced in NZS 4214:2006 suggests that NZS 4214 would only be applicable for external walls that surround the floor slab, and not applicable for external walls constructed directly on top of the floor slab.
    - A BRANZ publication in 2007 [2] suggests that even when the external wall is constructed above the foundation (such that it is the foundation that surrounds the floor slab not the wall), the external wall thickness in AS4214 still uses the wall thickness in lieu of the foundation thickness.
    - We recommend that the values in Specification J1.6 Table 2b be reviewed in light of this apparent difference in treatment between NZS4214 and CIBSE Guide A.
  - In terms of the floor area and perimeter definitions, this should be defined in accordance with Example 3.4 in CIBSE Section J3.5. CIBSE Guide A indicates that it is calculated from the interior surface of the external wall surrounding the floor (see Figure 20).

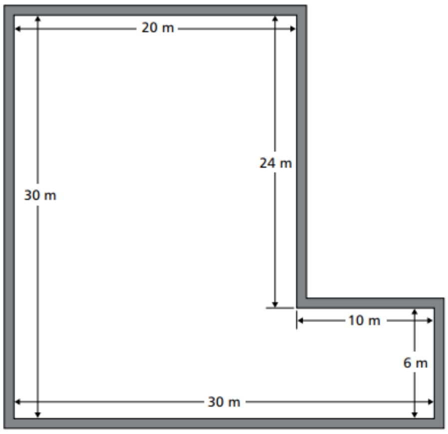


Figure 2 Example 3.4 in CIBSE Section 3.5 indicating the floor area and the floor perimeter is calculated from calculated from the interior surface of the external wall surrounding the floor

[2] https://www.buildmagazine.org.nz/index.php/articles/show/timber-aids-insulation-of-slab-on-ground-floors

Table of Contents

1 Project Objectives

This report reviews Section J1.6 and Specification J1.6 of the 2016 and 2019 National Construction Code (NCC) to:

- Determine whether it is appropriate to set a different minimum total R-value requirement for floors of small buildings, and recommend appropriate stringencies based on research findings. This is discussed in Section 2 of this report.
- Provide advice on how Specification J1.6 should be interpreted where the slab under the conditioned space connects to a larger unconditioned space (e.g. an office attached to a warehouse or a sports hall). This is discussed in Section 3 of this report.
- Improve the definition of "wall thickness" for walls joining a slab on ground, as referenced in Table 2b of Specification J1.6 of the code, considering how this applies to both lightweight and heavyweight wall constructions, and the impact of additional air gap spaces to thicken the walls. This is discussed in Section 4 of this report.

In 2016, the Deemed-to-Satisfy (DTS) pathway only allows one method of compliance – by using the Specification J1.6 common constructions and deemed R-values for different construction layers to calculate the achieved floor R-value.

In 2019, the Deemed-to-Satisfy (DTS) pathway allows two methods of compliance. Method 1 is similar to the 2016 method, where Specification J1.2 and Specification J1.6 provides some deemed R-values for different construction layers. Method 2 is a more detailed calculation using the CIBSE Guide A Section 3.5. Either Method 1 or Method 2 can be used to demonstrate compliance.

The minimum total R-value for floors requirements in the 2016 and 2019 NCC are shown in Table 1 and Table 3 respectively.

Table 1 NCC2016 Section J1.6 Floor Minimum Total R-Value requirements extracted from Table J1.6

Location	Climate Zone 1	Climate Zone 2	Climate Zone 3	Climate Zone 4	Climate Zone 5	Climate Zone 6	Climate Zone 7	Climate Zone 8
Direction of heat flow	Upwards	Downwards and upwards	Downwards and upwards	Downwards	Downwards	Downwards	Downwards	Downwards
(a) A slab on ground:								
(i) without an in-slab or in-screed heating or cooling system	NIL	NIL	NIL	NIL	NIL	NIL	1.0	2.0
(ii) with an in-slab or in-screed heating or cooling system.	1.25	1.25	1.25	1.25	1.25	1.25	1.25	2.25
(b) A suspended floor without an in-slab or in-screed heating or cooling system where the non-*conditioned space* is- (i) enclosed; and (ii) where mechanically ventilated by not more than 1.5 air changes per hour	1.0	1.0	NIL	NIL	1.0	1.0	1.5	2.5
(c) A suspended floor with an in-slab or in-screed heating or cooling system where the non-*conditioned space* is- (i) enclosed; and	1.25	1.25	1.25	1.25	1.25	1.25	1.75	2.75

(ii) where mechanically ventilated by not more than 1.5 air changes per hour								
(d) For other than (a), (b) or (c)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	3.5
Note: A subfloor space with not more than 150% of the *required* subfloor ventilation is considered enclosed.								

Table 2 NCC2019 Section J1.6 Floor Minimum Total R-Value requirements extracted from Table J1.6

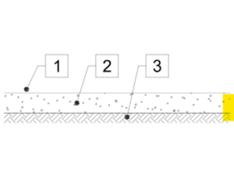
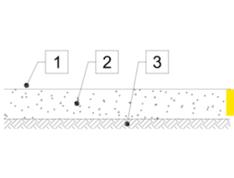
Location	**Climate zone 1 — upwards heat flow**	**Climate zones 2&3 — upwards and downwards heat flow**	**Climate zones 4,5, 6 and 7 — downwards heat flow**	**Climate zones 8 — downwards heat flow**
A floor without an in-slab heating or cooling system	2.0	2.0	2.0	3.5
A floor with an in-slab heating or cooling system	3.25	3.25	3.25	4.75

It can be seen that in 2019, the minimum total R-value requirement is simplified to a floor with and without in-slab heating/cooling systems plus a new option for practitioners to use the CIBSE Guide A Section 3.5 method to calculate floor total R-value.

The contents in Specification J1.6 between 2016 and 2019 also changed – namely:

- In 2016, Specification J1.6 presented deemed thermal performance for various floor construction types without reference to the floor geometry; and,
- In 2019, Specification J1.6 presented deemed suspended- and slab-on-ground R-values depending on the ratio of floor-area-to-floor-perimeter.

In 2016, Specification J1.6 requires the practitioner to assign a R-value of 0 to ground thermal resistance (see Figure 3) as the minimum required total R-value is already adjusted implicitly to allow for a fixed ground resistance; whereas this is a non-zero figure for practitioners in 2019.

		Total R-Value	0.33	0.38
(e) 100 mm solid concrete slab-on-ground 	1.	Indoor air film (still air)	0.11	0.16
	2.	Solid concrete (100 mm, 2400 kg/m^3)	0.07	0.07
	3.	Ground thermal resistance	-	-
		Total R-Value	0.18	0.23
(f) 150 mm solid concrete slab-on-ground 	1.	Indoor air film (still air)	0.11	0.16
	2.	Solid concrete (150 mm, 2400 kg/m^3)	0.10	0.10
	3.	Ground thermal resistance	-	-
		Total R-Value	0.21	0.26

Notes:

1. The *R-Value* of an item, other than an airspace, air film or air cavity, may be increased in proportion to the increased thickness of the item.
2. The *Total R-Value* of a form of construction may be increased by the amount that an individual item is increased.
3. For floor types (c) and (d) that are located over an internal space, the *Total R-Value* can be calculated by replacing the value for outdoor air film (R0.04) on the underside of the floor with the value for indoor air film (R0.11 for heat flow up or R0.16 for heat flow down).

Figure 3. 2016 Specification J1.6 showing Ground thermal resistance R=0.

2 Applicability of Minimum Total R-Value Requirements to Small Buildings

2.1 NCC 2016 Requirement

The calculated floor R-value excluding indoor air film resistance, R_f, for the 2016 requirements is presented in Table 4. The values in Table 4 are used for comparison in Sections 2.2.1 and 2.2.2 below.

Table 3 NCC2016 Section J1.6 Floor Minimum Total R-Value requirements extracted from Table J1.6

Location	CZ1 — upwards heat flow	CZ2&3 — upwards and downwards heat flow	CZ4,5&6 — downwards heat flow	CZ7 — downwards heat flow	CZ8 — downwards heat flow
A floor without an in-slab heating or cooling system	0	0	0	1	2

Table 4 NCC2016 Floor R-Value required excluding indoor film resistance and ground thermal resistance[3]

Location	CZ1 — upwards heat flow	CZ2&3 — upwards and downwards heat flow	CZ4,5&6 — downwards heat flow	CZ7 — downwards heat flow	CZ8 — downwards heat flow
A floor without an in-slab heating or cooling system	0	0	0	0.84[4]	1.84

2.2 Inflection Points Calculation

In terms of floor insulation requirement, one of the major differences between NCC2019 and NCC2016 is that NCC2019 takes the soil resistance into account explicitly but NCC2016 allows for this implicitly through adjustment of the minimum R-value stringency. NCC2019 has two methods to calculate the soil R-Value: one is to use Specification J1.6 (Method 1) and the other one is to use Section 3.5 of CIBSE Guide A (Method 2).

To determine if the NCC 2019 requirements inadvertently led to smaller buildings requiring more insulation, we compare the resultant floor bag-insulation R-values in 2019 to 2016 using two methods:

1. Comparison 1 (2016 vs. 2019 Method 1): Comparing values obtained using NCC 2016 Volume One Section J1.6 Specification J1.6 to NCC 2019 Volume One Section J1.6 and soil R-Values from Specification J1.6 (2019 Method 1).
2. Comparison 2 (2016 vs. 2019 Method 2): Comparing values obtained using NCC 2016 Volume One Section J1.6 Specification J1.6 to NCC 2019 Volume Section J1.6 and soil R-Value calculated in accordance with CIBSE Guide A Section 3.5 (2019 Method 2).

The inflection point is defined as the point at which the floor insulation thickness required using the NCC 2019 Methods 1 or 2 is higher than the requirements using NCC 2016 (see Section 2.1 above).

[3] Note that the NCC 2016 Specification J1.6 assumes that the ground thermal resistance is R=0, whereas NCC 2019 assumes a non-zero ground thermal resistance value.

[4] As an example, R=0.84 is calculated by subtracting 0.16 (indoor air resistance taken from Specification J1.6 construction type (e)) from R=1 (see Table 3).

2.2.1 Comparison 1: 2016 vs. 2019 Method 1

2.2.1.1 Description of Calculations

The NCC2019 Specification J1.6 provides R-Value calculation methods for sub-floor spaces and soil in contact with a floor, without need for further consideration based on sub-floor soil type. These R-Values are variable depending on the ratio of floor-area-to-floor-perimeter and wall thickness. In general, the deemed soil R-Value increases when the ratio (or implicitly, building size) and the wall thickness increase.

The floor total R-value is the sum of the sub-floor R-Value, indoor air film resistance and the floor insulation R-Value. As such, buildings with smaller ratio of floor area to floor perimeter might need higher floor insulation thickness as the minimum total R-value is fixed for each climate zone.

2.2.1.2 Results

Using the values in NCC2019 Specification J1.6, the floor construction total R-Values[5] were calculated and shown in Table 5 to Table 8. These are compared to the NCC 2016 floor construction R-values (excluding indoor air film resistance), presented in Table 4. Cells shaded in red signify ratios where the 2019 floor R-value requirements are higher than 2016.

Table 5 NCC2019 Floor R-Value required excluding indoor film resistance and ground thermal resistance in CZ1,2 & 3.

Ratio of *floor area* to floor perimeter (m)	Wall thickness of 50 mm	Wall thickness of 100 mm	Wall thickness of 150 mm	Wall thickness of 200 mm	Wall thickness of 250 mm	Wall thickness of 300 mm
1	1.49	1.39	1.39	1.29	1.19	1.09
1.5	1.29	1.19	1.19	1.09	0.99	0.89
2	1.19	1.09	0.99	0.89	0.79	0.59
2.5	0.99	0.89	0.79	0.69	0.59	0.39
3	0.89	0.69	0.59	0.49	0.39	0.19
3.5	0.69	0.59	0.39	0.29	0.19	-0.01
4	0.59	0.39	0.29	0.19	-0.01	-0.31
4.5	0.39	0.19	0.09	-0.01	-0.21	-0.51
5	0.29	0.09	-0.11	-0.21	-0.41	-0.71
5.5	0.09	-0.11	-0.21	-0.31	-0.51	-0.91
6	-0.01	-0.21	-0.41	-0.51	-0.71	-1.01
6.5	-0.11	-0.41	-0.51	-0.71	-0.91	-1.21
7	-0.31	-0.51	-0.71	-0.81	-1.11	-1.41

[5] Excluding indoor air film resistances

Table 6 NCC2019 Floor R-Value required excluding indoor film resistance and ground thermal resistance in CZ4,5 & 6.

Ratio of *floor area* to floor perimeter (m)	Wall thickness of 50 mm	Wall thickness of 100 mm	Wall thickness of 150 mm	Wall thickness of 200 mm	Wall thickness of 250 mm	Wall thickness of 300 mm
1	1.44	1.34	1.34	1.24	1.14	1.04
1.5	1.24	1.14	1.14	1.04	0.94	0.84
2	1.14	1.04	0.94	0.84	0.74	0.54
2.5	0.94	0.84	0.74	0.64	0.54	0.34
3	0.84	0.64	0.54	0.44	0.34	0.14
3.5	0.64	0.54	0.34	0.24	0.14	-0.06
4	0.54	0.34	0.24	0.14	-0.06	-0.36
4.5	0.34	0.14	0.04	-0.06	-0.26	-0.56
5	0.24	0.04	-0.16	-0.26	-0.46	-0.76
5.5	0.04	-0.16	-0.26	-0.36	-0.56	-0.96
6	-0.06	-0.26	-0.46	-0.56	-0.76	-1.06
6.5	-0.16	-0.46	-0.56	-0.76	-0.96	-1.26
7	-0.36	-0.56	-0.76	-0.86	-1.16	-1.46

Table 7 NCC2019 Floor R-Value required excluding indoor film resistance and ground thermal resistance in CZ7.

Ratio of *floor area* to floor perimeter (m)	Wall thickness of 50 mm	Wall thickness of 100 mm	Wall thickness of 150 mm	Wall thickness of 200 mm	Wall thickness of 250 mm	Wall thickness of 300 mm
1	1.44	1.34	1.34	1.24	1.14	1.04
1.5	1.24	1.14	1.14	1.04	0.94	0.84
2	1.14	1.04	0.94	0.84	0.74	0.54
2.5	0.94	0.84	0.74	0.64	0.54	0.34
3	0.84	0.64	0.54	0.44	0.34	0.14
3.5	0.64	0.54	0.34	0.24	0.14	-0.06
4	0.54	0.34	0.24	0.14	-0.06	-0.36
4.5	0.34	0.14	0.04	-0.06	-0.26	-0.56
5	0.24	0.04	-0.16	-0.26	-0.46	-0.76
5.5	0.04	-0.16	-0.26	-0.36	-0.56	-0.96
6	-0.06	-0.26	-0.46	-0.56	-0.76	-1.06
6.5	-0.16	-0.46	-0.56	-0.76	-0.96	-1.26
7	-0.36	-0.56	-0.76	-0.86	-1.16	-1.46

Table 8 NCC2019 Floor R-Value required excluding indoor film resistance and ground thermal resistance in CZ8.

Ratio of ***floor area*** to floor perimeter (m)	Wall thickness of 50 mm	Wall thickness of 100 mm	Wall thickness of 150 mm	Wall thickness of 200 mm	Wall thickness of 250 mm	Wall thickness of 300 mm
1	2.94	2.84	2.84	2.74	2.64	2.54
1.5	2.74	2.64	2.64	2.54	2.44	2.34
2	2.64	2.54	2.44	2.34	2.24	2.04
2.5	2.44	2.34	2.24	2.14	2.04	1.84
3	2.34	2.14	2.04	1.94	1.84	1.64
3.5	2.14	2.04	1.84	1.74	1.64	1.44
4	2.04	1.84	1.74	1.64	1.44	1.14
4.5	1.84	1.64	1.54	1.44	1.24	0.94
5	1.74	1.54	1.34	1.24	1.04	0.74
5.5	1.54	1.34	1.24	1.14	0.94	0.54
6	1.44	1.24	1.04	0.94	0.74	0.44
6.5	1.34	1.04	0.94	0.74	0.54	0.24
7	1.14	0.94	0.74	0.64	0.34	0.04

2.2.2 Comparison 2: 2016 vs. 2019 Method 2

In this section, we use the CIBSE Guide A Section 3.5 methodology to calculate the soil R-Value of the floor construction.

The 2019 floor construction R-Values[6] was calculated by deducting the soil R-value from the minimum total-R-Value requirement (in 2019 Section J Table J1.6). Then, the calculated 2019 floor construction R-Value[7] was compared to NCC2016 values (presented in Table 4).

The inflection point is defined as the point at which insulation requirements in 2019 exceed 2016 NCC code requirements (due to its floor construction R-values being higher than 2016 floor construction R-values). Cells shaded in red signify ratios where the 2019 floor R-value requirements are higher than 2016.

A detailed description of the CIBSE method is provided in Section 2.2.2.1, followed by a presentation of results in Sections 2.2.2.2 to 2.2.2.4.

2.2.2.1 Description of Calculations

CIBSE Guide A Section 3.5 provides detailed equations to calculate solid ground floor thermal transmittance, allowing the floor construction total R-Value[8] to be calculated. In simplified terms, the total R-value is determined by the thermal conductivity of soils (λ_g), characteristic dimension (B') and total equivalent thickness (d_{ef}).

[6] Excluding indoor air film resistance
[7] Excluding indoor air film resistance and soil/ground thermal resistance
[8] Including indoor air film resistance and ground thermal resistance.

Using Equation 1 and Equation 2 below, the soil R-Value is calculated by assuming the floor slab thermal resistance (R_f) is zero. Then the floor insulation required can be calculated by subtracting the soil R-Value from the 2019 minimum required floor total R-Value (see **Error! Reference source not found.**).

Under CIBSE, the floor construction total R-value is calculated using either Equation 1 or Equation 2, depending on the total equivalent thickness (d_{ef}).

For $d_{ef} < \mathrm{B}'$, the total R-Value is given by:

$$R_t = \frac{\pi B' + d_{ef}}{2\lambda_g ln\left(\frac{\pi B'}{d_{ef}} + 1\right)} \; [Equation\ 1]$$

For $d_{ef} \geq \mathrm{B}'$, the total R-Value is given by:

$$R_t = \frac{(0.457B' + d_{ef})}{\lambda_g} \; [Equation\ 2]$$

Definition of the variables in Equation 1 and Equation 2 to calculate *Rt* is described overleaf.

Thermal Conductivity of Soils (λ_g)

As shown in Table 9, different soil types have different thermal conductivity.

Table 9 Thermal Conductivity of Soils

Soil type	Thermal conductivity, λg (W/m·K)
Clay or silt	1.5
Sand or gravel	2
Homogeneous rock	3.5

Characteristic Dimension (*B'*)

The characteristic dimension is defined as:

$$B' = 2 \times Ratio\ of\ Floor\ Area\ to\ Floor\ Perimeter$$

Total Equivalent Thickness (d_{ef})

The total equivalent thickness is:

$$d_{ef} = d_w + \lambda_g(R_{si} + R_f + R_{se})$$

where:

d_{ef} – the total equivalent thickness of the floor (m)

d_w- the thickness of the wall surrounding the ground floor (m)

R_{si}- the inside surface resistance (m^2·K/W)

R_f- the thermal resistance of the floor (includes thermal resistance of any insulation layers above, below or within the floor slab plus any floor covering).

R_{se}- the external surface resistance for the outside ground floor surface

The deemed indoor air film resistance (R_{si}) is taken from Table 2b in NCC 2019 Specification J1.2 (Table 10).

Table 10 NCC2016 R-Value of Indoor Air Film

	CZ1 — upwards heat flow	CZ2&3 — upwards heat flow	CZ4, 5, 6&7 — downwards heat flow	CZ8 — downwards heat flow
Indoor Air Film resistance	0.11	0.11	0.16	0.16

2.2.2.2 Results for Clay or Silt

The results for clay or silt soil is shown in Table 11 to Table 14. The shaded cells are where the NCC 2019 Specification J1.6 method requires more insulation than the NCC 2016 requirements (calculated using the CIBSE method) – this is defined as the inflection point in this report.

Table 11 NCC2019 Floor R-Value required excluding indoor film resistance and ground thermal resistance using the CIBSE Method in CZ1,2 & 3 (Soil Type - Clay or Silt)

Ratio of *floor area* to floor perimeter (m)	Wall thickness of 50 mm	Wall thickness of 100 mm	Wall thickness of 150 mm	Wall thickness of 200 mm	Wall thickness of 250 mm	Wall thickness of 300 mm
1	1.31	1.27	1.23	1.19	1.15	1.11
1.5	1.09	1.04	1.00	0.96	0.91	0.87
2	0.89	0.83	0.78	0.73	0.69	0.64
2.5	0.69	0.63	0.57	0.52	0.47	0.42
3	0.50	0.43	0.37	0.32	0.26	0.21
3.5	0.31	0.24	0.18	0.12	0.06	0.00
4	0.13	0.05	-0.01	-0.08	-0.14	-0.20
4.5	-0.05	-0.13	-0.20	-0.27	-0.34	-0.40
5	-0.23	-0.31	-0.39	-0.46	-0.53	-0.59
5.5	-0.40	-0.49	-0.57	-0.64	-0.72	-0.78
6	-0.57	-0.66	-0.75	-0.83	-0.90	-0.97
6.5	-0.74	-0.83	-0.92	-1.01	-1.08	-1.16
7	-0.90	-1.00	-1.10	-1.18	-1.26	-1.34

Table 12 NCC2019 Floor R-Value required excluding indoor film resistance and ground thermal resistance using the CIBSE Method in CZ4,5 & 6 (Soil Type - Clay or Silt)

Ratio of *floor area* to floor perimeter (m)	Wall thickness of 50 mm	Wall thickness of 100 mm	Wall thickness of 150 mm	Wall thickness of 200 mm	Wall thickness of 250 mm	Wall thickness of 300 mm
1	1.25	1.21	1.17	1.13	1.10	1.06
1.5	1.02	0.98	0.93	0.89	0.85	0.81
2	0.81	0.76	0.71	0.67	0.62	0.58
2.5	0.60	0.55	0.50	0.45	0.40	0.35
3	0.40	0.34	0.29	0.24	0.19	0.14
3.5	0.21	0.15	0.09	0.03	-0.02	-0.08
4	0.02	-0.05	-0.11	-0.17	-0.23	-0.28
4.5	-0.17	-0.24	-0.30	-0.37	-0.43	-0.48
5	-0.35	-0.42	-0.49	-0.56	-0.62	-0.68
5.5	-0.53	-0.61	-0.68	-0.75	-0.82	-0.88
6	-0.71	-0.79	-0.86	-0.94	-1.01	-1.07
6.5	-0.88	-0.97	-1.05	-1.12	-1.19	-1.26
7	-1.05	-1.14	-1.23	-1.30	-1.38	-1.45

Table 13 NCC2019 Floor R-Value required excluding indoor film resistance and ground thermal resistance using the CIBSE Method in CZ7 (Soil Type - Clay or Silt)

Ratio of *floor area* to floor perimeter (m)	Wall thickness of 50 mm	Wall thickness of 100 mm	Wall thickness of 150 mm	Wall thickness of 200 mm	Wall thickness of 250 mm	Wall thickness of 300 mm
1	1.25	1.21	1.17	1.13	1.10	1.06
1.5	1.02	0.98	0.93	0.89	0.85	0.81
2	0.81	0.76	0.71	0.67	0.62	0.58
2.5	0.60	0.55	0.50	0.45	0.40	0.35
3	0.40	0.34	0.29	0.24	0.19	0.14
3.5	0.21	0.15	0.09	0.03	-0.02	-0.08
4	0.02	-0.05	-0.11	-0.17	-0.23	-0.28
4.5	-0.17	-0.24	-0.30	-0.37	-0.43	-0.48
5	-0.35	-0.42	-0.49	-0.56	-0.62	-0.68
5.5	-0.53	-0.61	-0.68	-0.75	-0.82	-0.88
6	-0.71	-0.79	-0.86	-0.94	-1.01	-1.07
6.5	-0.88	-0.97	-1.05	-1.12	-1.19	-1.26
7	-1.05	-1.14	-1.23	-1.30	-1.38	-1.45

Table 14 NCC2019 Floor R-Value required excluding indoor film resistance and ground thermal resistance using the CIBSE Method in CZ8 (Soil Type - Clay or Silt)

Ratio of *floor area* to floor perimeter (m)	Wall thickness of 50 mm	Wall thickness of 100 mm	Wall thickness of 150 mm	Wall thickness of 200 mm	Wall thickness of 250 mm	Wall thickness of 300 mm
1	2.75	2.71	2.67	2.63	2.60	2.56
1.5	2.52	2.48	2.43	2.39	2.35	2.31
2	2.31	2.26	2.21	2.17	2.12	2.08
2.5	2.10	2.05	2.00	1.95	1.90	1.85
3	1.90	1.84	1.79	1.74	1.69	1.64
3.5	1.71	1.65	1.59	1.53	1.48	1.42
4	1.52	1.45	1.39	1.33	1.27	1.22
4.5	1.33	1.26	1.20	1.13	1.07	1.02
5	1.15	1.08	1.01	0.94	0.88	0.82
5.5	0.97	0.89	0.82	0.75	0.68	0.62
6	0.79	0.71	0.64	0.56	0.49	0.43
6.5	0.62	0.53	0.45	0.38	0.31	0.24
7	0.45	0.36	0.27	0.20	0.12	0.05

2.2.2.3 Results for Sand or Gravel

The results for sand or gravel are shown in Table 15 to Table 18. The shaded cells are where the NCC 2019 Specification J1.6 method requires more insulation than the NCC 2016 requirements (calculated using the CIBSE method) – this is defined as the inflection point in this report.

Table 15 NCC2019 Floor R-Value required excluding indoor film resistance and ground thermal resistance using the CIBSE Method in CZ1,2 & 3 (Soil Type – Sand or Gravel)

Ratio of *floor area* to floor perimeter (m)	Wall thickness of 50 mm	Wall thickness of 100 mm	Wall thickness of 150 mm	Wall thickness of 200 mm	Wall thickness of 250 mm	Wall thickness of 300 mm
1	1.44	1.41	1.38	1.35	1.32	1.29
1.5	1.27	1.23	1.20	1.17	1.14	1.11
2	1.11	1.07	1.03	1.00	0.97	0.93
2.5	0.95	0.91	0.87	0.84	0.80	0.77
3	0.80	0.76	0.72	0.68	0.64	0.60
3.5	0.66	0.61	0.56	0.52	0.48	0.44
4	0.51	0.46	0.42	0.37	0.33	0.29
4.5	0.38	0.32	0.27	0.22	0.18	0.14
5	0.24	0.18	0.13	0.08	0.03	-0.01
5.5	0.10	0.05	-0.01	-0.06	-0.11	-0.16

6	-0.03	-0.09	-0.15	-0.20	-0.25	-0.30
6.5	-0.16	-0.22	-0.28	-0.34	-0.39	-0.45
7	-0.29	-0.36	-0.42	-0.48	-0.53	-0.59

Table 16 NCC2019 Floor R-Value required excluding indoor film resistance and ground thermal resistance using the CIBSE Method in CZ4,5 & 6 (Soil Type – Sand or Gravel)

Ratio of ***floor area*** to floor perimeter (m)	Wall thickness of 50 mm	Wall thickness of 100 mm	Wall thickness of 150 mm	Wall thickness of 200 mm	Wall thickness of 250 mm	Wall thickness of 300 mm
1	1.38	1.35	1.32	1.29	1.27	1.24
1.5	1.20	1.17	1.14	1.11	1.08	1.05
2	1.03	1.00	0.97	0.93	0.90	0.87
2.5	0.87	0.84	0.80	0.77	0.73	0.70
3	0.72	0.68	0.64	0.60	0.57	0.53
3.5	0.56	0.52	0.48	0.44	0.41	0.37
4	0.42	0.37	0.33	0.29	0.25	0.21
4.5	0.27	0.22	0.18	0.14	0.09	0.05
5	0.13	0.08	0.03	-0.01	-0.06	-0.10
5.5	-0.01	-0.06	-0.11	-0.16	-0.20	-0.25
6	-0.15	-0.20	-0.25	-0.30	-0.35	-0.40
6.5	-0.28	-0.34	-0.39	-0.45	-0.50	-0.54
7	-0.42	-0.48	-0.53	-0.59	-0.64	-0.69

Table 17 NCC2019 Floor R-Value required excluding indoor film resistance and ground thermal resistance using the CIBSE Method in CZ7 (Soil Type – Sand or Gravel)

Ratio of ***floor area*** to floor perimeter (m)	Wall thickness of 50 mm	Wall thickness of 100 mm	Wall thickness of 150 mm	Wall thickness of 200 mm	Wall thickness of 250 mm	Wall thickness of 300 mm
1	1.38	1.35	1.32	1.29	1.27	1.24
1.5	1.20	1.17	1.14	1.11	1.08	1.05
2	1.03	1.00	0.97	0.93	0.90	0.87
2.5	0.87	0.84	0.80	0.77	0.73	0.70
3	0.72	0.68	0.64	0.60	0.57	0.53
3.5	0.56	0.52	0.48	0.44	0.41	0.37
4	0.42	0.37	0.33	0.29	0.25	0.21
4.5	0.27	0.22	0.18	0.14	0.09	0.05
5	0.13	0.08	0.03	-0.01	-0.06	-0.10
5.5	-0.01	-0.06	-0.11	-0.16	-0.20	-0.25
6	-0.15	-0.20	-0.25	-0.30	-0.35	-0.40
6.5	-0.28	-0.34	-0.39	-0.45	-0.50	-0.54

7	-0.42	-0.48	-0.53	-0.59	-0.64	-0.69

Table 18 NCC2019 Floor R-Value required excluding indoor film resistance and ground thermal resistance using the CIBSE Method in CZ8 (Soil Type – Sand or Gravel)

Ratio of *floor area* to floor perimeter (m)	Wall thickness of 50 mm	Wall thickness of 100 mm	Wall thickness of 150 mm	Wall thickness of 200 mm	Wall thickness of 250 mm	Wall thickness of 300 mm
1	2.88	2.85	2.82	2.79	2.77	2.74
1.5	2.70	2.67	2.64	2.61	2.58	2.55
2	2.53	2.50	2.47	2.43	2.40	2.37
2.5	2.37	2.34	2.30	2.27	2.23	2.20
3	2.22	2.18	2.14	2.10	2.07	2.03
3.5	2.06	2.02	1.98	1.94	1.91	1.87
4	1.92	1.87	1.83	1.79	1.75	1.71
4.5	1.77	1.72	1.68	1.64	1.59	1.55
5	1.63	1.58	1.53	1.49	1.44	1.40
5.5	1.49	1.44	1.39	1.34	1.30	1.25
6	1.35	1.30	1.25	1.20	1.15	1.10
6.5	1.22	1.16	1.11	1.05	1.00	0.96
7	1.08	1.02	0.97	0.91	0.86	0.81

2.2.2.4 Results for Homogeneous Rock

The results for homogeneous rock are shown in Table 19 to Table 22. The shaded cells are where the NCC 2019 Specification J1.6 method requires more insulation than the NCC 2016 requirements (calculated using the CIBSE method) – this is defined as the inflection point in this report.

Table 19 NCC2019 Floor R-Value required excluding indoor film resistance and ground thermal resistance using the CIBSE Method in CZ1,2 & 3 (Soil Type – Homogeneous Rock)

Ratio of *floor area* to floor perimeter (m)	Wall thickness of 50 mm	Wall thickness of 100 mm	Wall thickness of 150 mm	Wall thickness of 200 mm	Wall thickness of 250 mm	Wall thickness of 300 mm
1	1.60	1.59	1.57	1.56	1.54	1.53
1.5	1.50	1.48	1.47	1.45	1.43	1.42
2	1.40	1.38	1.36	1.35	1.33	1.31
2.5	1.30	1.28	1.27	1.25	1.23	1.21
3	1.21	1.19	1.17	1.15	1.13	1.11
3.5	1.12	1.10	1.08	1.06	1.04	1.02
4	1.03	1.01	0.99	0.97	0.95	0.92
4.5	0.95	0.92	0.90	0.88	0.85	0.83
5	0.86	0.84	0.81	0.79	0.77	0.74
5.5	0.78	0.75	0.73	0.70	0.68	0.66

6	0.70	0.67	0.64	0.62	0.59	0.57
6.5	0.62	0.59	0.56	0.53	0.51	0.48
7	0.54	0.51	0.48	0.45	0.42	0.40

Table 20 NCC2019 Floor R-Value required excluding indoor film resistance and ground thermal resistance using the CIBSE Method in CZ4,5 & 6 (Soil Type – Homogeneous Rock)

Ratio of *floor area* to floor perimeter (m)	Wall thickness of 50 mm	Wall thickness of 100 mm	Wall thickness of 150 mm	Wall thickness of 200 mm	Wall thickness of 250 mm	Wall thickness of 300 mm
1	1.55	1.54	1.52	1.51	1.49	1.48
1.5	1.44	1.43	1.41	1.40	1.38	1.36
2	1.34	1.32	1.31	1.29	1.27	1.26
2.5	1.24	1.22	1.20	1.19	1.17	1.15
3	1.14	1.12	1.10	1.09	1.07	1.05
3.5	1.05	1.03	1.01	0.99	0.97	0.95
4	0.96	0.94	0.91	0.89	0.88	0.86
4.5	0.87	0.84	0.82	0.80	0.78	0.76
5	0.78	0.75	0.73	0.71	0.69	0.67
5.5	0.69	0.67	0.64	0.62	0.60	0.58
6	0.60	0.58	0.56	0.53	0.51	0.49
6.5	0.52	0.49	0.47	0.45	0.42	0.40
7	0.44	0.41	0.38	0.36	0.34	0.31

Table 21 NCC2019 Floor R-Value required excluding indoor film resistance and ground thermal resistance using the CIBSE Method in CZ7 (Soil Type – Homogeneous Rock)

Ratio of *floor area* to floor perimeter (m)	Wall thickness of 50 mm	Wall thickness of 100 mm	Wall thickness of 150 mm	Wall thickness of 200 mm	Wall thickness of 250 mm	Wall thickness of 300 mm
1	1.55	1.54	1.52	1.51	1.49	1.48
1.5	1.44	1.43	1.41	1.40	1.38	1.36
2	1.34	1.32	1.31	1.29	1.27	1.26
2.5	1.24	1.22	1.20	1.19	1.17	1.15
3	1.14	1.12	1.10	1.09	1.07	1.05
3.5	1.05	1.03	1.01	0.99	0.97	0.95
4	0.96	0.94	0.91	0.89	0.88	0.86
4.5	0.87	0.84	0.82	0.80	0.78	0.76
5	0.78	0.75	0.73	0.71	0.69	0.67
5.5	0.69	0.67	0.64	0.62	0.60	0.58
6	0.60	0.58	0.56	0.53	0.51	0.49
6.5	0.52	0.49	0.47	0.45	0.42	0.40

7	0.44	0.41	0.38	0.36	0.34	0.31

Table 22 NCC2019 Floor R-Value required excluding indoor film resistance and ground thermal resistance using the CIBSE Method in CZ8 (Soil Type – Homogeneous Rock)

Ratio of ***floor area*** to floor perimeter (m)	Wall thickness of 50 mm	Wall thickness of 100 mm	Wall thickness of 150 mm	Wall thickness of 200 mm	Wall thickness of 250 mm	Wall thickness of 300 mm
1	3.05	3.04	3.02	3.01	2.99	2.98
1.5	2.94	2.93	2.91	2.90	2.88	2.86
2	2.84	2.82	2.81	2.79	2.77	2.76
2.5	2.74	2.72	2.70	2.69	2.67	2.65
3	2.64	2.62	2.60	2.59	2.57	2.55
3.5	2.55	2.53	2.51	2.49	2.47	2.45
4	2.46	2.44	2.41	2.39	2.38	2.36
4.5	2.37	2.34	2.32	2.30	2.28	2.26
5	2.28	2.25	2.23	2.21	2.19	2.17
5.5	2.19	2.17	2.14	2.12	2.10	2.08
6	2.10	2.08	2.06	2.03	2.01	1.99
6.5	2.02	1.99	1.97	1.95	1.92	1.90
7	1.94	1.91	1.88	1.86	1.84	1.81

2.3 Summary of Inflection Point Calculation Results

Table 23 to Table 25 summarises the inflection points for different soil types in each climate zone. The same results are presented graphically in Figure 4 to Figure 6**.** Inflection points at the point at which 2019 insulation requirements are higher than NCC 2016 requirements.

Table 23 Inflection Points of Floor Area to Floor Perimeter Ratio (Soil Type – Clay or Silt)

Inflection Point of Floor Area to Floor Perimeter Ratio		**Wall thickness of 50 mm**	**Wall thickness of 100 mm**	**Wall thickness of 150 mm**	**Wall thickness of 200 mm**	**Wall thickness of 250 mm**	**Wall thickness of 300 mm**
CZ1 to 3	2019 Method 1	5.5	5	4.5	4	3.5	3
	2019 Method 2	4	4	3.5	3.5	3.5	3.5
CZ4 to 6	2019 Method 1	5.5	5	4.5	4	3.5	3
	2019 Method 2	4	3.5	3.5	3.5	3	3
CZ7	2019 Method 1	2.5	2	2	1.5	1.5	1
	2019 Method 2	1.5	1.5	1.5	1.5	1.5	1
CZ8	2019 Method 1	4	3.5	3	3	2.5	2
	2019 Method 2	3	3	2.5	2.5	2.5	2.5

Table 24 Inflection Points of Floor Area to Floor Perimeter Ratio (Soil Type – Sand or Gravel)

Inflection Point of Floor Area to Floor Perimeter Ratio		Wall thickness of 50 mm	Wall thickness of 100 mm	Wall thickness of 150 mm	Wall thickness of 200 mm	Wall thickness of 250 mm	Wall thickness of 300 mm
CZ1 to 3	2019 Method 1	5.5	5	4.5	4	3.5	3
	2019 Method 2	5.5	5.5	5	5	5	4.5
CZ4 to 6	2019 Method 1	5.5	5	4.5	4	3.5	3
	2019 Method 2	5	5	5	4.5	4.5	4.5
CZ7	2019 Method 1	2.5	2	2	1.5	1.5	1
	2019 Method 2	2.5	2	2	2	2	2
CZ8	2019 Method 1	4	3.5	3	3	2.5	2
	2019 Method 2	4	4	3.5	3.5	3.5	3.5

Table 25 Inflection Points of Floor Area to Floor Perimeter Ratio (Soil Type – Homogeneous Rock)

Inflection Point of Floor Area to Floor Perimeter Ratio		Wall thickness of 50 mm	Wall thickness of 100 mm	Wall thickness of 150 mm	Wall thickness of 200 mm	Wall thickness of 250 mm	Wall thickness of 300 mm
CZ1 to 3	2019 Method 1	5.5	5	4.5	4	3.5	3
	2019 Method 2	>7	>7	>7	>7	>7	>7
CZ4 to 6	2019 Method 1	5.5	5	4.5	4	3.5	3
	2019 Method 2	>7	>7	>7	>7	>7	>7
CZ7	2019 Method 1	2.5	2	2	1.5	1.5	1
	2019 Method 2	4.5	4.5	4	4	4	4
CZ8	2019 Method 1	4	3.5	3	3	2.5	2
	2019 Method 2	>7	>7	>7	>7	6.5	6.5

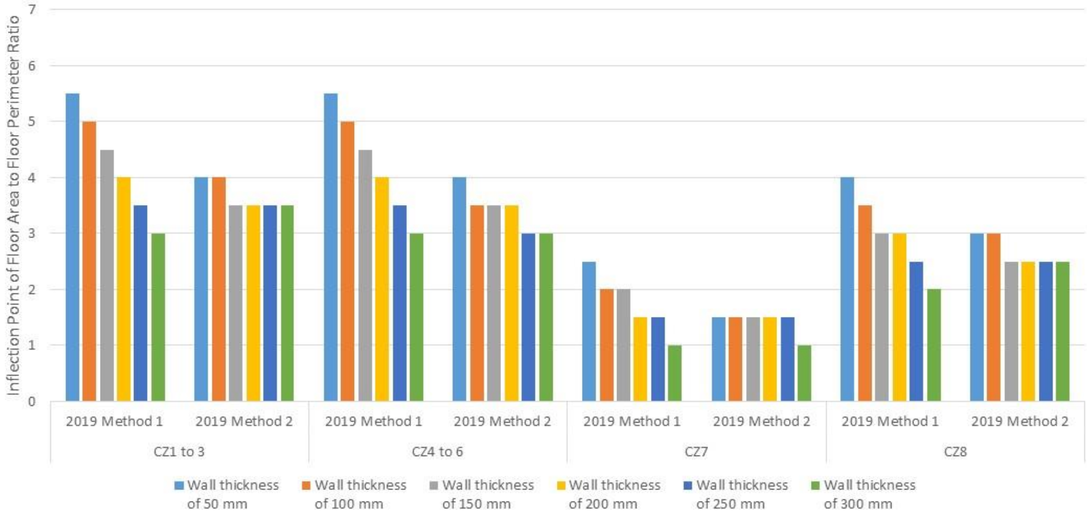


Figure 4 Inflection Points of Floor Area to Floor Perimeter Ratio (Soil Type – Clay or Silt)

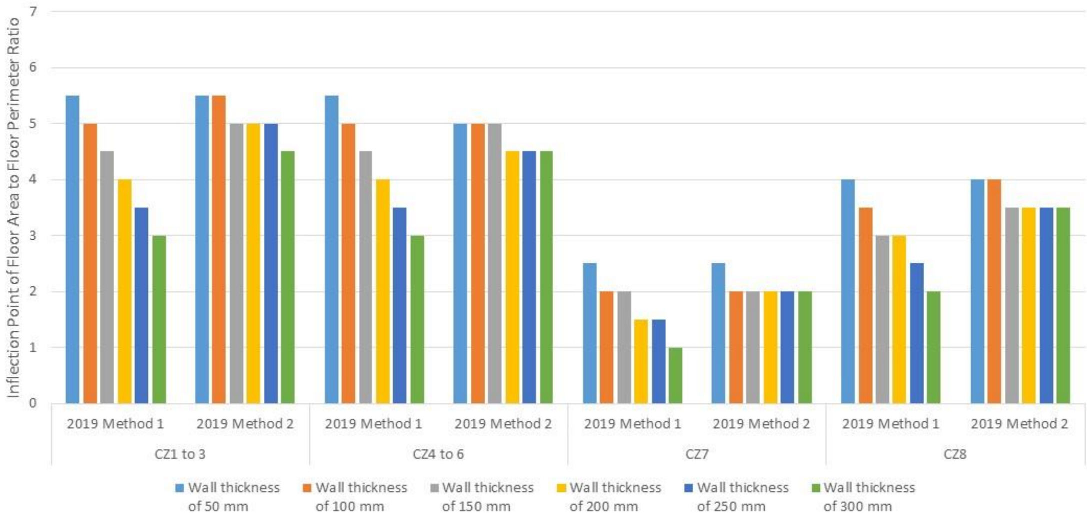


Figure 5 Inflection Points of Floor Area to Floor Perimeter Ratio (Soil Type – Sand or Gravel)

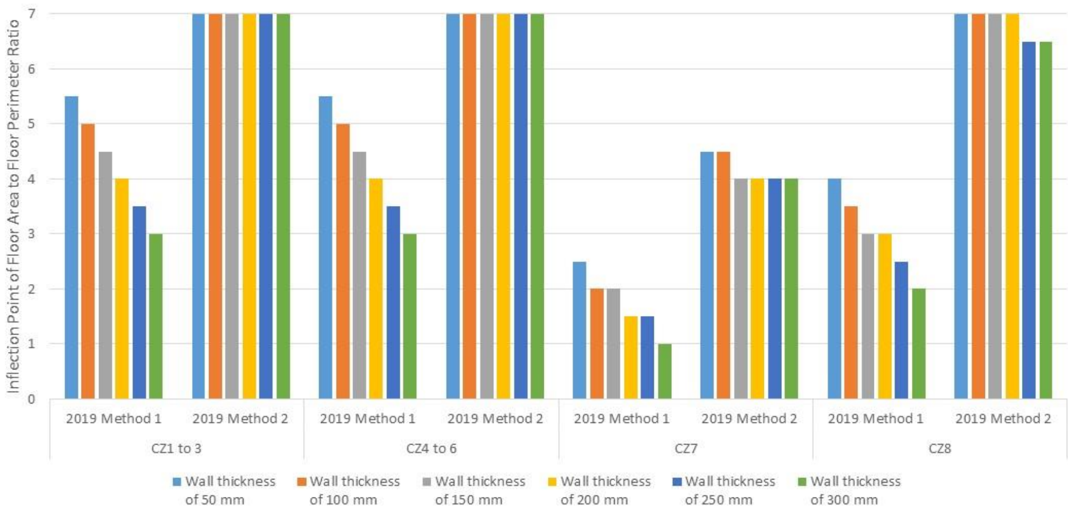


Figure 6 Inflection Points of Floor Area to Floor Perimeter Ratio (Soil Type – Homogeneous Rock)

2.4 Energy Simulation

An energy simulation was conducted to enable the benefit-to-cost ratio of installing additional insulation in small buildings to be calculated in Section 2.5. Section 2.4 describes the energy simulation results.

2.4.1 Overview

Based on the summary of results presented in Section 2.3, the inflection points range from a ratio[9] of 1 to 5.5 in 2019 Method 1, depending on wall thickness and climate zone. We used the midpoint ratio of 3.0, as the ratio of floor area to floor perimeter in the simulation. For a 144m² building, this is equivalent to a perimeter length of 48m. The ratio of 3.0 represents the lowest ratio in climate zones 1 to 6 (corresponding to an external wall thickness of 300mm) when calculated using 2019 Method 1. For sake of comparison, we have also presented some examples of how the ratio changes with building area and perimeter length in Table 26 – this is calculated for a square building.

The analysis was conducted for three building archetypes – a daytime building (Class 5 Office), an overnight building (Class 3 Motel) and a retail building (Class 6 Shop). Description of the modelling parameters and building geometry is provided in Appendix A below.

Table 26. Floor area to perimeter ratio and its physical representations in small building size. The shaded row represents the modelled building size.

Floor area to perimeter ratio	length (m)	width (m)	Area (m^2)	Perimeter Length (m)
1	4	4	16	16
1.5	6	6	36	24
2.0	8	8	64	32
2.5	10	10	100	40
3.0	*12*	*12*	*144*	*48*
3.5	14	14	196	56
4.0	16	16	256	64
4.5	18	18	324	72
5.0	20	20	400	80
5.5	22	22	484	88
6.0	24	24	576	96
6.5	26	26	676	104
7.0	28	28	784	112

2.4.2 Energy Simulation Results

The dynamic thermal simulations performed in IES <VE> give the cooling, heating and total HVAC energy consumption as shown in Table 27, Table 28 and Table 29. Overall, the simulation results show that floor insulation impact on the HVAC energy is very marginal (all <1% difference and <220kWh/year difference).

In general, thicker floor insulation is required across the climate zones 1 to 6. The execption is Climate Zone 7, where the required insulation thickness required in 2019 is less than the required insulation thickness in 2016 (see Appendix A Section A4.5 for more details). This is the reason why a '*Negative Cost'* result is observed for climate zone 7 in the BCR results (Section 2.6).

[9] Ratio of floor area to floor perimeter

2.4.2.1 Class 5 Office

For small office buildings, the majority of climate zones exhibit lower heating energy requirements but increased cooling energy. This is because floor insulation is beneficial to saving heating energy but reduces the opportunity for "free cooling", largely occurring from the heat transfer between the conditioned zone and the ground.

A few additional observations can be made for the office model:

a) For small office buildings, NCC2019 models in Climate Zone 2 to 6 use less heating energy but more cooling energy. This is because floor insulation is beneficial to saving heating energy but reduces the opportunity for "free cooling", largely occurring from the heat transfer between the conditioned zone and the ground.
b) Overall NCC2019 models save energy compared with NCC2016 models in Climate Zone 3, 4 and 6 because the heating saving in these areas exceeds the extra cooling caused by the additional floor insulation.
c) In Climate Zone 7, NCC2016 floor modelling has more insulation than NCC2019 modelling. NCC2016 uses more cooling energy but less heating energy. Overall NCC2016 modelling saves energy.
d) Climate Zone 1 is an exception. NCC2019 modelling has more floor insulation but uses more cooling. This is because the ground temperature in Climate Zone 1 is very warm, acting as a heating source to the building. As such, increased floor insulation reduces heat transfer from the ground to the conditioned zones and then saves cooling energy. This applicable to the motel and shop models as well (see discussion in the sub-sections below).

Table 27: Simulation Results for Office Modelling

Climate Zone	Scenario	Cooling Energy (kWh)	Heating Energy (kWh)	Total Energy (kWh)	Total Energy Difference (kWh)	Total Energy Difference (%)
CZ1	NCC2019 Floor	7,283	-	7,283	-24	-0.32%
	NCC2016 Floor	7,307	-	7,307		
CZ2	NCC2019 Floor	3,927	205	4,132	16	0.38%
	NCC2016 Floor	3,900	216	4,116		
CZ3	NCC2019 Floor	6,112	382	6,494	-4	-0.06%
	NCC2016 Floor	6,101	397	6,498		
CZ4	NCC2019 Floor	2,430	1,012	3,442	-6	-0.18%
	NCC2016 Floor	2,400	1,048	3,448		
CZ5	NCC2019 Floor	2,680	390	3,070	24	0.78%
	NCC2016 Floor	2,643	403	3,046		
CZ6	NCC2019 Floor	1,616	1,114	2,729	-9	-0.32%
	NCC2016 Floor	1,583	1,155	2,738		
CZ7	NCC2019 Floor	1,795	1,546	3,340	4	0.13%
	NCC2016 Floor	1,812	1,524	3,336		

2.4.2.2 Class 3 Motel

Motels are overnight operation buildings.

Relatively speaking, motels are heating energy intensive, particularly when compared to small office buildings. As a result, the energy savings from reduced heating requirements consistently exceeds the extra cooling energy caused by the additional floor insulation in Climate Zone 2 to 7. In Climate Zone 1, the ground temperature is usually warm. So additional insulation saves cooling energy.

The energy simulation results show that from an energy consumption perspective, floor insulation is always beneficial to reduce energy usage for small motels.

Table 28: Simulation Results for Motel Modelling

Climate Zone	Scenario	Cooling Energy (kWh)	Heating Energy (kWh)	Total Energy (kWh)	Total Energy Difference (kWh)	Total Energy Difference (%)
CZ1	NCC2019 Floor	5,816	-	5,816	-40	-0.67%
	NCC2016 Floor	5,855	-	5,855		
CZ2	NCC2019 Floor	1,951	1,255	3,206	-55	-1.69%
	NCC2016 Floor	1,895	1,367	3,261		
CZ3	NCC2019 Floor	3,456	1,154	4,610	-97	-2.05%
	NCC2016 Floor	3,437	1,270	4,707		
CZ4	NCC2019 Floor	1,088	3,222	4,310	-192	-4.26%
	NCC2016 Floor	1,053	3,449	4,501		
CZ5	NCC2019 Floor	1,086	2,217	3,303	-70	-2.06%
	NCC2016 Floor	1,039	2,334	3,372		
CZ6	NCC2019 Floor	466	3,530	3,996	-218	-5.18%
	NCC2016 Floor	433	3,781	4,214		
CZ7	NCC2019 Floor	552	4,440	4,992	101	2.06%
	NCC2016 Floor	566	4,326	4,892		

2.4.2.3 Class 6 Retail

On the contrary, small shops have high lighting load. Therefore, small shops are cooling energy dominated. Consequently, the extra cooling demand incurred by installing additional floor insulation typically exceeds the heating energy saved.

Table 29: Simulation Results for Shop Modelling

Climate Zone	Scenario	Cooling Energy (kWh)	Heating Energy (kWh)	Total Energy (kWh)	Total Energy Difference (kWh)	Total Energy Difference (%)
CZ1	NCC2019 Floor	14,759	0	14,760	-9	-0.06%
	NCC2016 Floor	14,768	0	14,768		
CZ2	NCC2019 Floor	9,135	204	9,339	34	0.37%
	NCC2016 Floor	9,091	214	9,305		
CZ3	NCC2019 Floor	12,391	486	12,877	7	0.05%
	NCC2016 Floor	12,367	503	12,871		
CZ4	NCC2019 Floor	5,891	1,147	7,038	19	0.27%
	NCC2016 Floor	5,836	1,183	7,019		
CZ5	NCC2019 Floor	6,521	404	6,925	45	0.65%
	NCC2016 Floor	6,462	418	6,880		
CZ6	NCC2019 Floor	4,401	1,256	5,657	13	0.24%
	NCC2016 Floor	4,345	1,298	5,644		
CZ7	NCC2019 Floor	4,924	1,760	6,684	-10	-0.15%

	NCC2016 Floor	4,960	1,734	6,694		

2.4.2.4 Simulation Result Summary

In summary, the simulation results show that –

a) In climate zones 2 to 7, the need for additional floor insulation typically leads to lower heating energy but higher cooling energy. Whether it saves overall HVAC energy or not depends on the internal load, operation pattern of the building and ambient temperature.
b) In Climate Zone 1, the ground temperature is relatively high. The heat is transferred from the ground to the conditioned spaces through the floor. As such, installing additional floor insulation reduces cooling energy.
c) Overall, the floor insulation impact on HVAC energy is very marginal for all buildings.

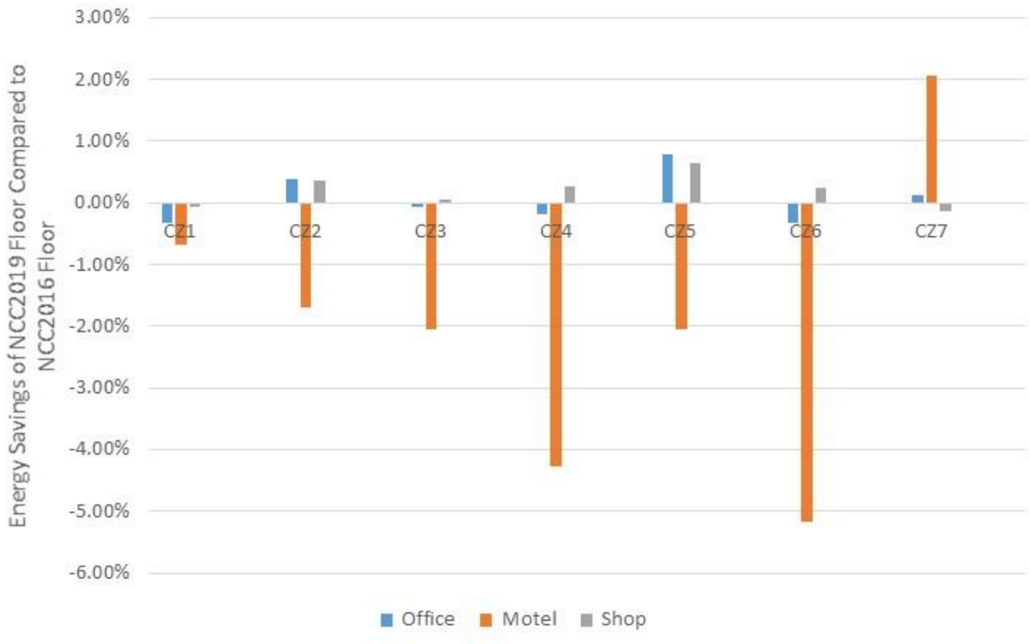


Figure 7 Energy Savings of NCC2019 Floor Compared to NCC2016 Floor

2.5 Cost Benefit Analysis

2.5.1 Methodology

Using the NCC 2016 floor as the base case, benefit-to-cost ratios (BCRs) were calculated for NCC 2019 compliant floors. The BCR calculations was repeated for varying floor insulation thickness for the three building archetypes for climate zones 1 to 8 respectively.

The lifetime of the building envelope was set to 40 years with a discount rate of 7%. As the lifetime of individual pieces of equipment were often much less than 40 years, their replacement was considered across the 40-year period.

2.5.2 Benefit Cost Ratio

The benefit cost analysis requires use of the incremental cost between NCC2016 floor models and NCC2019 floor models or cost benefit analysis models.

Three costs are required in order to carry out a benefit cost analysis:

1. Incremental floor insulation and incremental split unit construction costs for the building.

2. Split AC unit operational costs associated with energy consumption.

3. Lifecycle replacement costs i.e. split AC unit replacements – these costs are considered as a part of operational costs.

The benefit cost ratio can be expressed in the following relationship:

$$Benefit\ Cost\ Ratio = \frac{-\ Incremental\ Operational\ Cost}{Incremental\ Construction\ Cost}$$

Three main results are expected from the benefit cost ratio analysis:

- 'Negative Cost' will be displayed when the incremental construction cost in 2019 relative to 2016 floor constructions is negative.
- A result between zero and one identifies a situation that is beneficial on an energy basis, but not economically viable over the lifetime of the analysis.
- A result greater than one identifies a scenario that is both economically viable and has a positive impact on energy performance.
- A negative BCR result indicates that the operational cost for the 2019 requirement is higher than 2016 requirements.

2.5.2.1 Floor Insulation Pricing

Table 30 shows the pricing for Kooltherm K3 floorboard insulation we have sourced from Kingspan.

The floor insulation cost regression equation was then developed based the information in Table 30. This gives:

$$Floor\ Insulation\ Cost\ (\$/m^2) = 4.5854 \times R - Value^2 + 2.3731 \times R - Value + 18.469$$

Table 30: Kingspan Kooltherm K3 Floorboard Pricing

Conductivity (W/m·K)	Thickness (mm)	R-Value (m·K/W)	Price ($/m2)
0.023	25	1.087	26.5
0.023	40	1.739	36.5
0.021	50	2.381	45.3

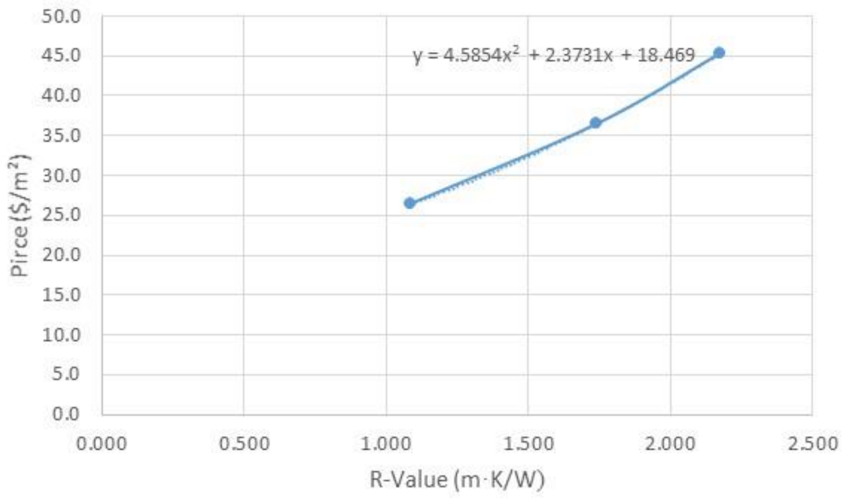


Figure 8 Floor Insulation Cost Variation with R-Value

2.5.2.2 *Split Unit Pricing*

Table 31 shows the pricing for split units we have sourced from the website https://www.luxeairconditioning.com.au.

The split unit cost regression equation was then developed based the information in Table 31. This gives:

$$Split\ Unit\ Cost\ (\$) = 480 \times Split\ Unit\ Size + 1630$$

Table 31: Split Unit Pricing

System	Split Unit Size (kW)	Price ($)
High end brand	4	3,550
High end brand	6	4,510
High end brand	8	5,470
High end brand	10	6,430
High end brand	12	7,390

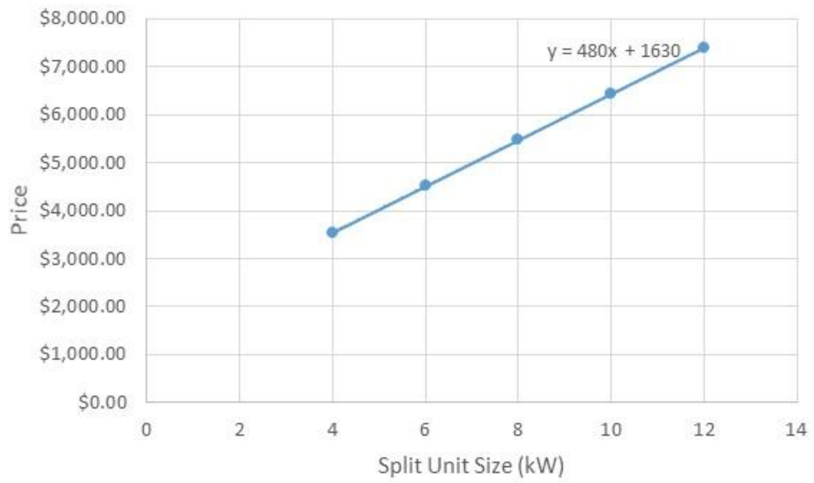


Figure 9 Split Unit Cost Variation with Split Unit Size

2.6 Cost Benefit Analysis Results

Based on the above methodology, we used NCC2016 floor models as the base case to calculate Benefit Cost Ratios (BCRs) for NCC2019 floor models and a number of cost benefit analysis models with various floor insulation thickness for each building type in each climate zone. The BCR results are shown in Table 32, Table 33 and Table 34. Note that the red shaded values are the BCRs for current NCC2019 compliance levels; and, where the cell is blank, it means that the BCR was not calculated for that particular insulation thickness.

A few observations can be made:

- The results show that most of the BCRs are between 0 and 1. This means additional floor insulation is beneficial to the operational cost, but not economically viable over the lifetime of the analysis.
- A small number of the BCRs are below zero. This means that additional floor insulation leads to either higher energy consumption or increased split AC unit lifecycle replacement costs.
- Buildings or climate zones that are heating-dominant usually display a higher BCR. The biggest BCRs (0.42 to 0.8) occur in the motel models in Climate Zone 7. This is because floor insulation has more impact on heating energy. Overall, we have calculated the insulation thickness ranging from 4mm to 100mm, but none of the BCR results are above 1. This means additional floor insulation is not economically viable in all above cases.

Table 32: BCR Results for Office Models

Insulation Thickness	4mm	7mm	8mm	14mm	16mm	20mm	25mm	50mm	100mm
CZ1	0		0		-0.01		-0.02		
CZ2	0.01		0		-0.01		-0.02		
CZ3	0.01		0		-0.02		-0.04		
CZ4		0.02		0.04		0.04	0.05	0.04	
CZ5	-0.01	-0.01		-0.03			-0.04		
CZ6		0.02		0.03			0.03	0.02	0.01
CZ7				Negative Cost			0	0.02	0.01

Table 33: BCR Results for Motel Models

Insulation Thickness	7mm	8mm	14mm	16mm	20mm	22mm	23mm	25mm	27mm	30mm	50mm	75mm	100mm
CZ1		0.03		0.06				0.08			0.08		0.05
CZ2		0.03		0.04				0.05			0.04		
CZ3		0.07		0.11				0.14			0.14	0.11	
CZ4	0.1		0.17					0.23			0.24	0.2	
CZ5	0.02		0.04					0.05			0.05	0.04	
CZ6	0.08		0.13					0.18			0.2	0.18	
CZ7			Negative Cost			0.8	0.78	0.73	0.69	0.65	0.42		

Table 34: BCR Results for Shop Models

Insulation Thickness	4mm	7mm	8mm	14mm	16mm	23mm	25mm	50mm	100mm
CZ1	0.01		0.01		0.01		0.01		
CZ2	0		-0.01		-0.03		-0.05		
CZ3	0.01		0		-0.02		-0.03		
CZ4	0	0		-0.01			-0.03		
CZ5	-0.01	-0.02		-0.05			-0.08		
CZ6	0	-0.01		-0.02			-0.04		
CZ7				Negative Cost		-0.29	-0.21	-0.08	-0.04

2.6.1 Additional Simulation Test for a Small Building with Ratio <3.0

Our initial analysis in Section 2.6 was conducted based on a building with area to perimeter ratio of 3.0. Most of the BCRs calculated for a ratio of 3.0 were found to be less than 1. As shown in Table 2b of NCC2019 Specification J1.6, higher ratios result in higher soil R-Value. Consequently, heat transfer through the floor reduces with higher ratio – therefore the floor insulation will have a lower impact on energy consumption and lead to lower BCRs. Conversely, a smaller building (i.e. one with a small floor-area-to-perimeter ratio) will incur higher heat transfer from the floor edge. In this case, floor insulation could have a higher impact on reducing energy consumption and therefore lead to higher BCRs.

Table 35: Table 2b of NCC2019 Specification J1.6

Ratio of *floor area* to floor perimeter (m)	Wall thickness of 50 mm	Wall thickness of 100 mm	Wall thickness of 150 mm	Wall thickness of 200 mm	Wall thickness of 250 mm	Wall thickness of 300 mm
1	0.4	0.5	0.5	0.6	0.7	0.8
1.5	0.6	0.7	0.7	0.8	0.9	1
2	0.7	0.8	0.9	1	1.1	1.3
2.5	0.9	1	1.1	1.2	1.3	1.5
3	1	1.2	1.3	1.4	1.5	1.7
3.5	1.2	1.3	1.5	1.6	1.7	1.9
4	1.3	1.5	1.6	1.7	1.9	2.2
4.5	1.5	1.7	1.8	1.9	2.1	2.4
5	1.6	1.8	2	2.1	2.3	2.6
5.5	1.8	2	2.1	2.2	2.4	2.8
6	1.9	2.1	2.3	2.4	2.6	2.9
6.5	2	2.3	2.4	2.6	2.8	3.1
7	2.2	2.4	2.6	2.7	3	3.3

2.6.1.1 Office Building

To better understand if our observations found for a building with ratio of 3.0 is still valid for one that is smaller, we conducted a test analysis for a smaller office model in Climate Zone 6 (heating-driven) with a floor area to perimeter ratio of 2 (8m × 8m floor plate).

As shown in Table 36, the BCR results are slightly better than the previous models, but still well below 1. This further confirms that additional floor insulation is not economically viable for small office buildings in most cases.

Table 36: BCR Results for Office Models with Floor Area to Perimeter Ratio of 2 and 3 in Climate Zone 6

Insulation Thickness	7mm	14mm	25mm	28mm	50mm	75mm	100mm
Floor Area to Perimeter Ratio = 3	0.02	0.03	0.03	NC	0.02	NC	0.01
Floor Area to Perimeter Ratio = 2	NC	0.04	NC	0.05	0.04	0.03	0.02

2.6.1.2 *Motel Building*

Conversely, Table 33 shows that the BCRs for a motel in Climate Zone 7 is relatively close to 1. Therefore, it is possible that it may be cost-beneficial to increase floor insulations for an overnight building in climate zone 7 for a smaller building than that initially modelled. The motel model was repeated using a floor area to floor perimeter ratio of 2.0. The calculated BCR for NCC2019 is 1.05 as shown in Table 37. This means that for buildings that operate overnight, with a floor-area-to-perimeter-ratio of 2.0 in Climate Zone 7, the minimum R-Value (R=2.0) for floors specified in NCC2019 Section J is cost beneficial.

Table 37: BCR Results for Motel Models with Floor Area to Perimeter Ratio of 2 in Climate Zone 7

Insulation Thickness:	28mm (Equivalent to R2 in NCC2019)
BCR	1.05

2.6.2 Sensitivity Analysis for Edge Insulation

We note that the work discussed in Section 2.6.2 was not included within the contracted scope – we conducted this additional analysis on a goodwill basis to better understand the sensitivity of the conclusions derived in previous sections floor insulation type. As such it does not cover all climate zones and building types.

The floor construction modelled assumes a consistent layer of floor insulation is applied to the whole slab (between the ground and slab). This is consistent with previous modelling conducted for the NCC2019 Section J revision work, though we note that the NZS4214 states that application of floor insulation in this manner is only expected if ground water is less than 1m below ground.

In Australia, it is also common practice for builders to apply only vertical edge insulation surrounding the floor perimeter or horizontal edge insulation , rather than insulating the entire slab. We note that most energy and thermal simulation software including IES<VE>, is unable to adequately model vertical/horizontal edge insulation configuration without complex adjustments to HVAC zoning and creation of new construction layers to mimic this construction method. As such, we have kept to a similar convention used for prior analysis used in the initial section J revision work.

Theoretically, edge only insulation have much larger impact on heating than the impact on cooling. To test this, we conducted a sensitivity analysis by recalculating the BCR for the office model in Climate Zone 5 and the motel model in Climate Zone 6&7 (both with floor area to perimeter ratios of 3.0), this time by disregarding cooling energy improvements and only accounting for heating energy. The results are shown in Table 38 to Table 40 and Figure 10 to Figure 12.. Note that the shaded values are the BCRs for NCC2019 models.

Table 38 indicates that the edge only floor insulation has minimal impact on the BCR compared with the entire floor simulation results for daytime operation buildings. The BCRs are still well below 1.

Table 39 and Table 40 show that the edge only floor insulation can improve the BCRs for overnight operation buildings as the heating energy is relatively large. However, additional floor insulation can only be economically justified for these buildings in Climate Zone 7 (see Figure 10).

Table 38: BCR Results for Office Model in CZ5 (Sensitivity Analysis for Edge Insulation)

Insulation Thickness	4mm	7mm	14mm	25mm
CZ5_Initial Findings	-0.01	-0.01	-0.03	-0.04
CZ5_Heating Only	0	0.01	0.01	0.02

Figure 10 BCR Results for Office Model in CZ5 (Sensitivity Analysis for Edge Insulation)

Table 39: BCR Results for Motel Models in CZ6 (Sensitivity Analysis for Edge Insulation)

Insulation Thickness	7mm	14mm	25mm	50mm	75mm
CZ6_Initial Findings	0.08	0.13	0.18	0.2	0.18
CZ6_Heating Only	0.17	0.29	0.41	0.46	0.38

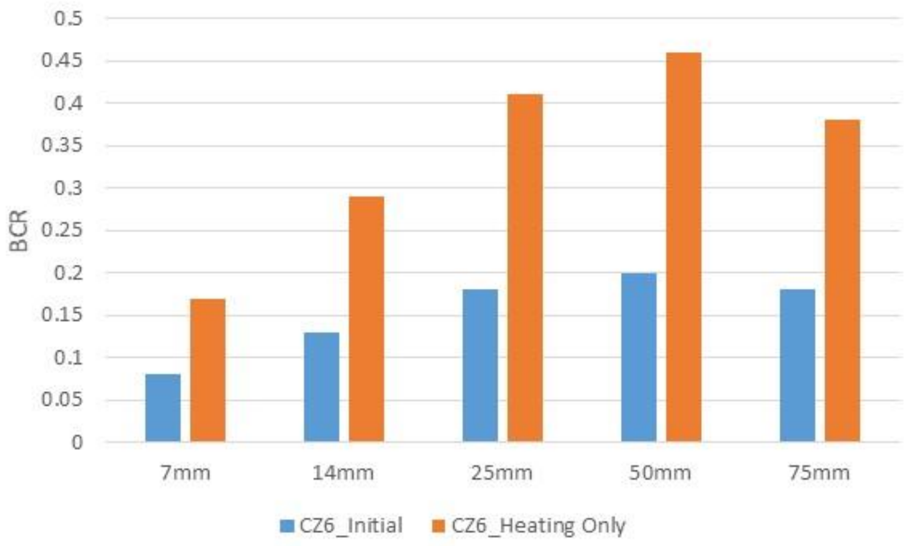


Figure 11 BCR Results for Motel Models in CZ6 (Sensitivity Analysis for Edge Insulation)

Table 40: BCR Results for Motel Models in CZ7 (Sensitivity Analysis for Edge Insulation)

Insulation Thickness	14mm	22mm	25mm	30mm	50mm
CZ7_Initial	Negative Cost	0.8	0.73	0.65	0.42
CZ7_Heating Only	Negative Cost	2.49	2.08	1.7	0.3

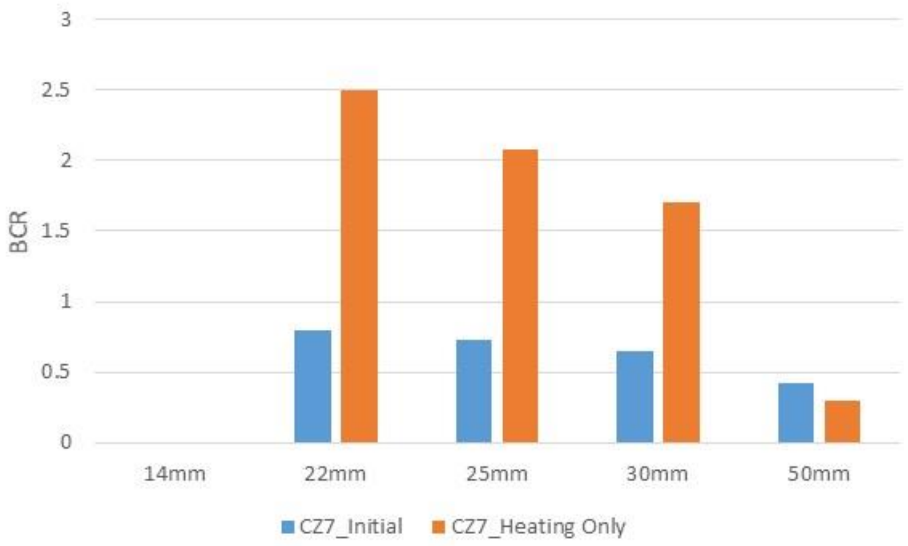


Figure 12 BCR Results for Motel Models in CZ7 (Sensitivity Analysis for Edge Insulation)

3 A Smaller Conditioned Space Connected to a Larger Unconditioned Space

3.1 Background

For a building with a smaller conditioned space connected to a larger unconditioned space, we understand the ABCB has received multiple technical enquiries from practitioners seeking clarity on how the ratio of floor area to floor perimeter ratio should be defined.

3.2 Treatment in CIBSE Guide A

CIBSE Guide A Section 3.5 indicates that the area of the unconditioned space outside of the insulated fabric of the building should be excluded when determining the floor area and perimeter. However, the length of the wall between the conditioned space and the unconditioned space must be included in the perimeter calculations. At time of writing, we have not seen any relevant information in other documents such as ASHRAE 90.1.

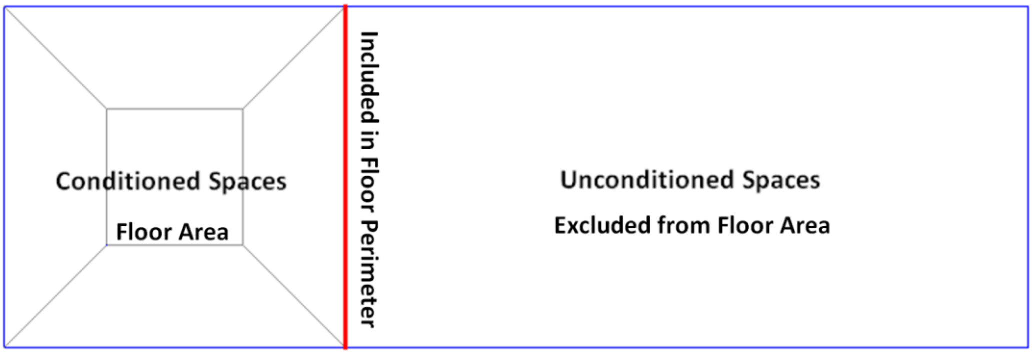


Figure 13 Floor Area and Floor Perimeter for Conditioned Spaces connected to Unconditioned Spaces

The CIBSE method treats the unconditioned space as outdoor area. In this scenario, the temperature in the unconditioned space is likely to be somewhere between the temperature within the conditioned space and outdoor temperature. In terms of material properties, soil temperature is relatively stable, and concrete is highly conductive. Therefore, the treatment by the CIBSE method for the unconditioned space to be treated as outdoor area is theoretically reasonable.

3.3 Simulation Test

To confirm the above theoretical analysis, we used simulation software to test the floor heat transfer impact in this case. We developed two types of models using IES<VE> (Figure 14), which adopts a finite difference approach to the solution of the heat diffusion equation in the heat conduction calculation.

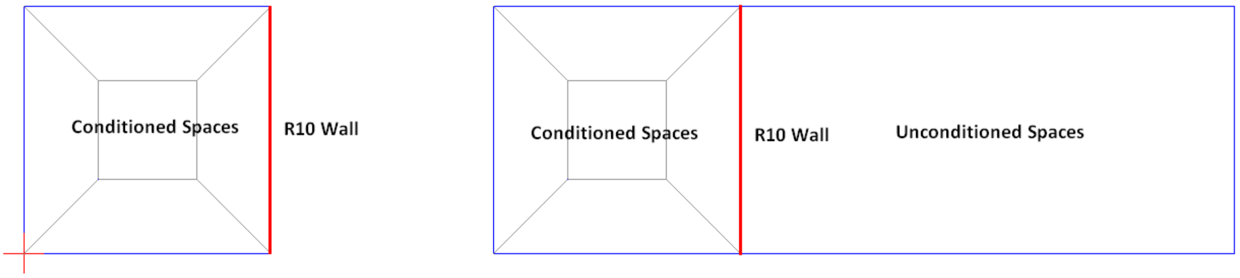


Figure 14 Models to Test the Heat Transfer through the Floor in a Conditioned Space and an Unconditioned Space

The first model is one without an unconditioned space but has a R=10 (R10) external wall. The second model is one with an unconditioned space attached to the conditioned spaces, with a R10 wall between the conditioned spaces and the unconditioned space. The R10 wall eliminates heat transfer through the wall between the conditioned and unconditioned space. As such, the only difference between the two models is the heat transfer through the ground floor.

We tested a number of infiltration rates and finally selected 1 ACH. Through trial and error, the ACH=1 infiltration rate is one that results in the unconditioned space temperature being at a value between the conditioned space temperature and the ambient temperature. We conducted the simulation using the building types of office and motel in Climate Zone 2, 5 and 7.

The simulation results are shown in Table 41 and Table 42. The energy consumption difference between the models with a big unconditioned space and the models without a big unconditioned space is minimal (<10kWh/year with relative energy difference <1%). Therefore, the methodology described in CIBSE Guide A Section 3.5 is confirmed by the simulation.

Table 41: Simulation Test Results for Office Modelling with/without a Big Unconditioned Space

Climate Zone	Scenario	Cooling Energy (kWh)	Heating Energy (kWh)	Total Energy (kWh)	Total Energy Difference (kWh)	Total Energy Difference (%)
CZ2	Big Unconditioned Space	3,661	157	3,818	-5.6	-0.15%
	Normal Model	3,665	158	3,824		
CZ5	Big Unconditioned Space	2,552	309	2,861	3.9	0.14%
	Normal Model	2,548	309	2,857		
CZ7	Big Unconditioned Space	1,711	1,254	2,965	2.4	0.08%
	Normal Model	1,708	1,255	2,963		

Table 42: Simulation Test Results for Motel Modelling with/without a Big Unconditioned Space

Climate Zone	Scenario	Cooling Energy (kWh)	Heating Energy (kWh)	Total Energy (kWh)	Total Energy Difference (kWh)	Total Energy Difference (%)
CZ2	Big Unconditioned Space	1,895	870	2,765	5	0.18%
	Normal Model	1,888	873	2,760		
CZ5	Big Unconditioned Space	1,076	1,631	2,707	1.7	0.06%
	Normal Model	1,070	1,635	2,705		
CZ7	Big Unconditioned Space	525	3,642	4,167	-3.6	-0.09%
	Normal Model	521	3,649	4,170		

3.4 Summary

The analysis conducted indicates that an adjoining floor slab should only be included in the floor area to perimeter ratio calculations to the extent of the surface of the wall in contact with the floor slab. The floor slab within the conditioned space should be treated as if it is non-existent.

4 Impact of External Wall Thickness

4.1 Background

The ABCB seeks to improve the definition of "wall thickness" for walls joining a slab on ground, as referenced in Table 2b of Specification J1.6 of the Code, by considering how this applies to both lightweight and heavyweight wall constructions, and/or the impact of additional air gap spaces to thicken the walls.

4.2 Literature Review

4.2.1 CIBSE Guide A

In order to understand how the wall thickness impacts on the floor total R-Value, we firstly review CIBSE Guide A Section 3.5. As discussed in Section 2.2.2.1, under CIBSE Guide A Section 3.5 the floor construction total R-Value is calculated by the thermal conductivity of soils (λ_g), characteristics dimension (*B'*) and total equivalent thickness (d_{ef}). The thicker the wall surrounding the ground floor is, the larger the total equivalent thickness is. According to Equation 1 and Equation 2 in Section 2.2.2.1, a larger total equivalent thickness value results in a higher floor total R-Value. Figure 15 shows where the external wall thickness (d_w) is measured for the wall surrounding the floor. If the wall sits on the floor rather than surrounding the floor, $d_w=0$.

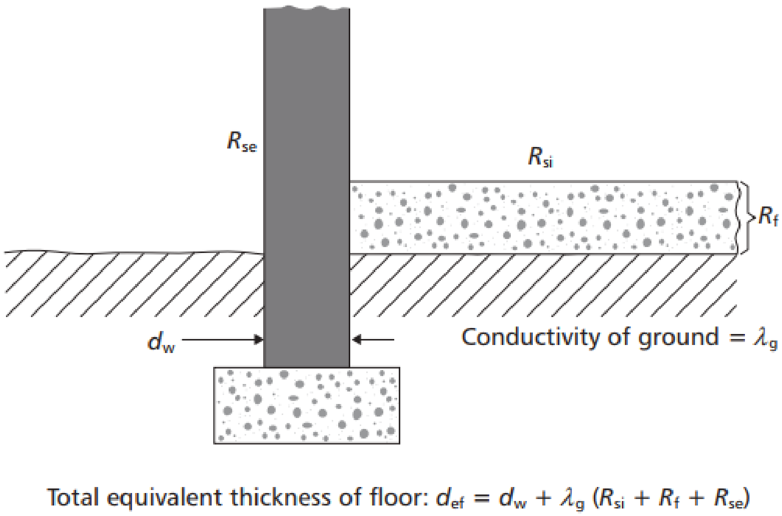


Figure 15 External Wall Thickness (d_w) in CIBSE Section J3.5

In terms of the floor area, Example 3.4 in CIBSE Section J3.5 indicates it is calculated from the interior surface of the external wall surrounding the floor.

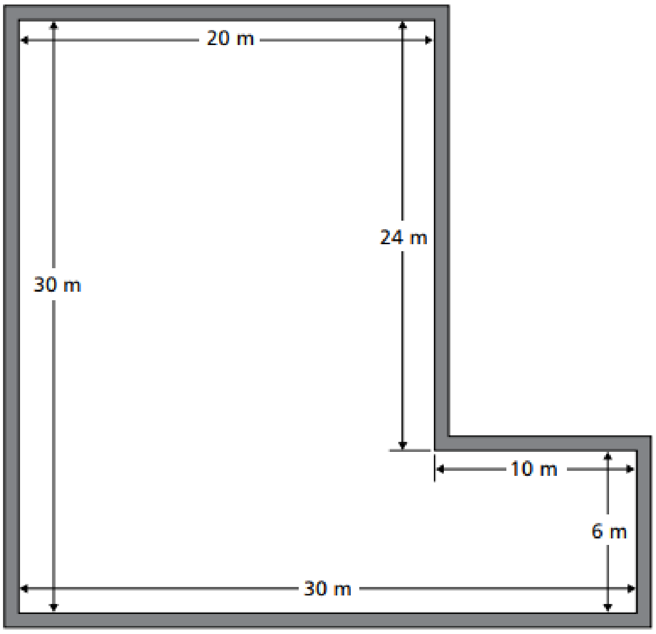


Figure 16 Example 3.4 in CIBSE Section J3.5 indicating the floor area and the floor perimeter is calculated from calculated from the interior surface of the external wall surrounding the floor

4.2.2 NZS 4214:2006

The treatment of external wall thickness as adopted by NZS 4214:2006 was also examined. We understand that the deemed values provided in the 2019 Section J Specification J1.6 was derived using the NZS 4214.

Section 5.5.2.1 in NZS 4214 indicates that for insulated slab-on-ground floors, the total R-Value is the sum of the thermal resistance of the insulation and the thermal resistance of the un-insulated floor. Section 5.5.1 describes how to calculate the R-Value of the un-insulated slab-on-ground floors, which is:

$$R = \frac{\pi l x}{2k\, ln\left[(1+x)\left(1+\frac{1}{x}\right)^{x}\right]} \quad \text{[Equation 3]}$$

where,

$$x = \frac{2 \times L \times a}{l \times (L+a)} = \frac{2 \times A}{l \times P} \quad \text{[Equation 4]}$$

and,

A – the floor area (m²)
P – the total floor perimeter (m)
a – the half-width of floor (m)
L – the half-length of floor (m)
l – the external wall thickness (m)
k – the soil conductivity (W/m·K)
R - the floor plus ground thermal resistance and does not include surface resistances or floor coverings (m·K/W) (un-insulated)

According to Equation 3 and 4, increasing external wall thickness has a positive impact on the floor R-Value.

NZS 4214:2006 does not explicitly specify where/how the external wall thickness should be defined (the standard only says '*external wall* thickness' but based on a deduction using Equation 3 and 4, we assume that this formula would only be applicable for external walls that are constructed to surround the floor slab rather directly sitting on the floor slab. It can be seen from Equation 3 that NZS 4214 only applies to a ground floor surrounded by an external wall, because if the external wall directly sits on the floor, l will be zero (0mm). When substituted into Equation 3, this will result in floor R-Value of zero which is not reasonable.

Further analysis of this treatment was also found in a 2007 BRANZ article in Build Magazine[10]. Figure 17 shows that the external wall is defined as 90mm and 140mm, despite the foundation thickness of 120mm being the actual material that surrounds the floor slab. Therefore, while the NZS4214 is unlikely to be applicable for external walls constructed directly above the floor slab, the NZS4214 does not appear to strictly define the external wall thickness as the actual material width adjacent to the floor slab. This nuance in treatment poses a small level of discrepancy with the CIBSE Guide A definition discussed in Section 4.2.1.

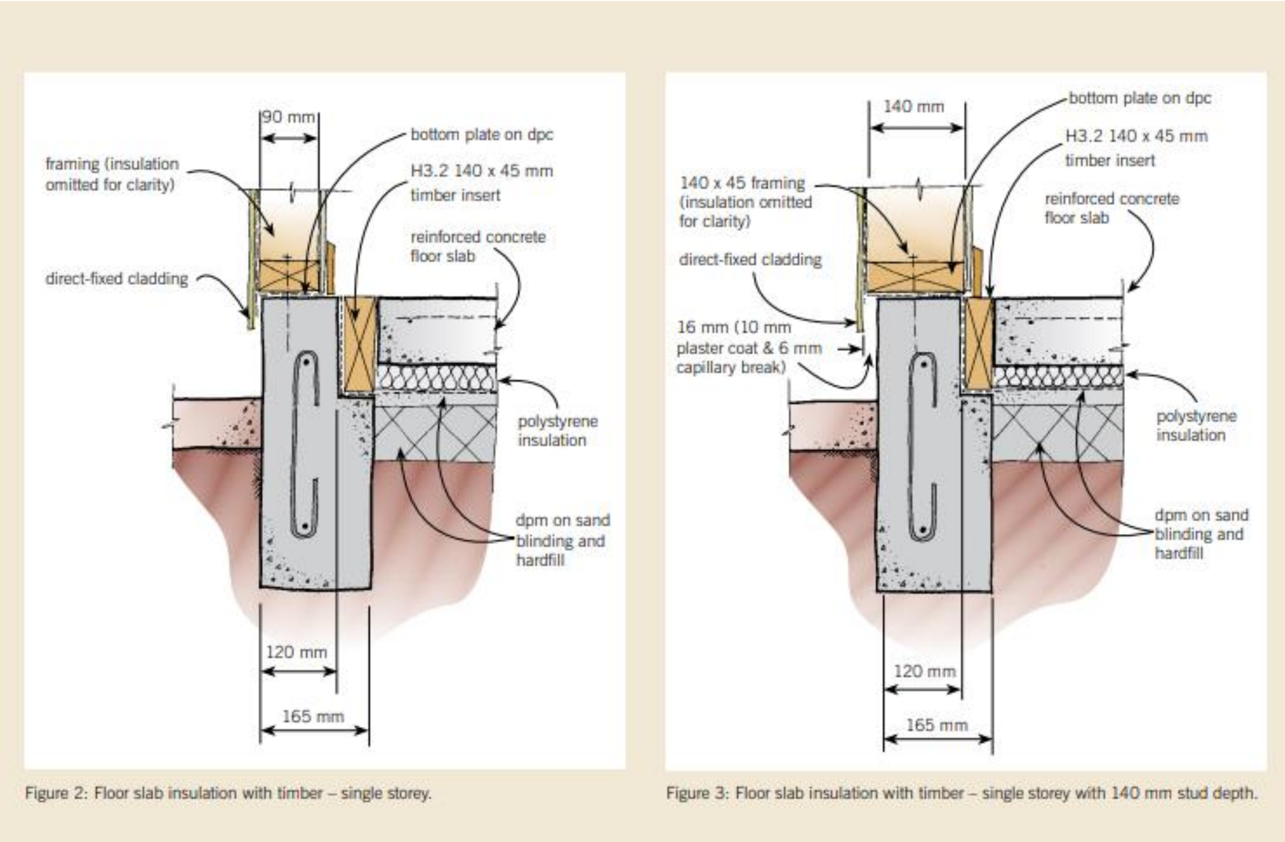


Figure 17. External wall thickness definitions as defined by Ian Cox-Smith (BRANZ) in Build Magazine (page 105, BUILD June/July 2007 – accessed: https://www.buildmagazine.org.nz/assets/PDF/B100-103-InsulateSlab.pdf)

[10] https://www.buildmagazine.org.nz/index.php/articles/show/timber-aids-insulation-of-slab-on-ground-floors

4.3 Analysis

4.3.1 Impact of changing external wall thickness on floor R-value

Based on the equations in CIBSE Guide A Section 3.5 and NZS 4214:2006 Section 5.51, we can calculate the soil R-Value for a range of external wall thickness and floor area to floor perimeter ratio. The results for clay or silt soils are shown in Table 43 and Table 44.

Table 43: R-Value of soil (clay or silt) in contact with a floor calculated by CIBSE method

Ratio of *floor area* to floor perimeter (m)	Wall thickness of 50 mm	Wall thickness of 100 mm	Wall thickness of 150 mm	Wall thickness of 200 mm	Wall thickness of 250 mm	Wall thickness of 300 mm
1	0.52	0.58	0.63	0.68	0.72	0.76
1.5	0.71	0.78	0.84	0.89	0.94	0.99
2	0.89	0.97	1.04	1.10	1.15	1.20
2.5	1.06	1.15	1.23	1.29	1.35	1.41
3	1.23	1.33	1.41	1.48	1.55	1.61
3.5	1.39	1.50	1.59	1.67	1.74	1.80
4	1.55	1.67	1.76	1.85	1.92	1.99
4.5	1.70	1.83	1.93	2.02	2.11	2.18
5	1.86	1.99	2.10	2.20	2.28	2.36
5.5	2.01	2.15	2.27	2.37	2.46	2.54
6	2.16	2.31	2.43	2.54	2.63	2.72
6.5	2.31	2.46	2.59	2.71	2.81	2.90
7	2.45	2.62	2.75	2.87	2.98	3.07

Table 44: R-Value of soil (clay or silt) in contact with a floor calculated by NZS 4214 method

Ratio of *floor area* to floor perimeter (m)	Wall thickness of 50 mm	Wall thickness of 100 mm	Wall thickness of 150 mm	Wall thickness of 200 mm	Wall thickness of 250 mm	Wall thickness of 300 mm
1	0.45	0.52	0.58	0.63	0.67	0.71
1.5	0.62	0.71	0.78	0.84	0.89	0.94
2	0.78	0.89	0.97	1.04	1.10	1.15
2.5	0.93	1.06	1.16	1.24	1.30	1.36
3	1.08	1.23	1.34	1.42	1.50	1.56
3.5	1.23	1.39	1.51	1.60	1.69	1.76
4	1.38	1.55	1.68	1.78	1.87	1.95
4.5	1.52	1.71	1.85	1.96	2.05	2.13
5	1.66	1.87	2.01	2.13	2.23	2.32
5.5	1.80	2.02	2.17	2.30	2.40	2.50
6	1.94	2.17	2.33	2.46	2.57	2.67
6.5	2.07	2.32	2.49	2.63	2.74	2.85
7	2.21	2.47	2.65	2.79	2.91	3.02

The absolute difference in soil R-value calculated using CIBSE Guide A and NZS 4214 ranges between 0.4 and 0.24. When the same results are presented visually, Figure 18 shows that using the CIBSE formula leads to a marginally higher soil R-value compared to using the AS4214 formula in all cases.

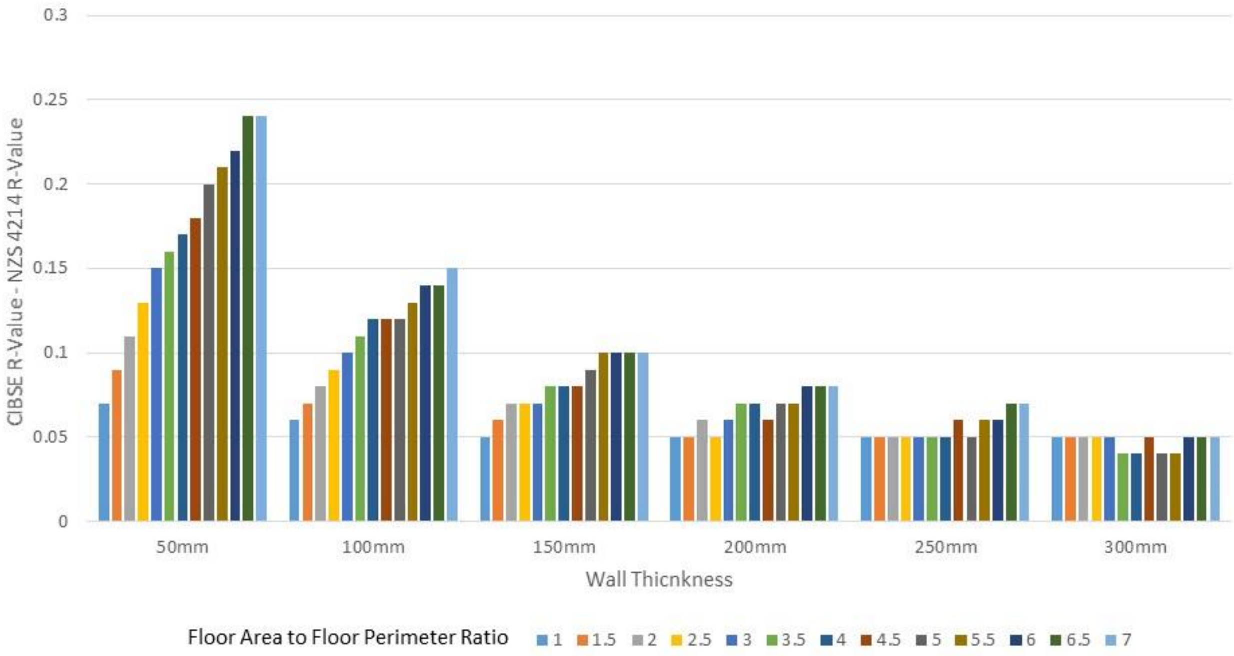


Figure 18 R-Value Differences between CIBSE Guide A and NZS 4214

Table 45 shows that the soil (clay or silt) R-Value difference between 50mm wall and 300mm wall ranges from 0.24 to 0.62 calculated by CIBSE Guide A method and from 0.26 to 0.81 calculated by NZS 4214 method depending on floor area to floor perimeter ratio.

Table 45: Soil (clay or silt) R-Value difference between 50mm wall and 300mm wall

Ratio of floor area to floor perimeter (m)	CIBSE Guide A	NZS 4214
1	0.24	0.26
1.5	0.28	0.32
2	0.31	0.37
2.5	0.35	0.43
3	0.38	0.48
3.5	0.41	0.53
4	0.44	0.57
4.5	0.48	0.61
5	0.5	0.66
5.5	0.53	0.7
6	0.56	0.73
6.5	0.59	0.78
7	0.62	0.81

4.3.2 Impact of heavyweight and lightweight external wall constructions on floor R-value

The soil R-Value for three practical wall types – one being heavy weight wall and the other two being light weight walls – was calculated using the CIBSE and NZS 4214 methods. The constructions are listed in Table 46, Table 47 and Table 48.

Table 46: Heavyweight Wall

Material	Thickness (mm)
Concrete	150
Insulation	40 (R1.14)
Plasterboard	13
Total	203

Table 47: Single Stud Lightweight Wall

Material	Thickness (mm)
Cladding	16
Airspace	50
Stud+Insulation	35 (R1)
Plasterboard	13
Total	114

Table 48: Double Stud Lightweight Wall

Material	Thickness (mm)
Cladding	16
Airspace	50
Stud+Insulation	35 (R1)
Airspace	20
Shaftliner Track[11]	25
Airspace	20
Stud+Insulation	35 (R1)
Plasterboard	13
Total	214

The soil R-Values for these three wall types are listed in Table 49 and Table 50 calculated by CIBSE method and NZS 4214 respectively.

[11] This material provides fire and acoustic resistance.

Table 49: R-Value of soil (clay or silt) calculated by CIBSE method for three wall types

Ratio of *floor area* to floor perimeter (m)	Single Stud Lightweight Wall (114mm)	Heavyweight Wall (203mm)	Double Stud Lightweight Wall (214mm)
1	0.60	0.68	0.69
1.5	0.80	0.90	0.91
2	0.99	1.10	1.11
2.5	1.17	1.30	1.31
3	1.35	1.49	1.50
3.5	1.52	1.67	1.69
4	1.69	1.85	1.87
4.5	1.86	2.03	2.05
5	2.02	2.20	2.22
5.5	2.19	2.38	2.40
6	2.35	2.54	2.57
6.5	2.50	2.71	2.73
7	2.66	2.88	2.90

Table 50: R-Value of soil (clay or silt) calculated by NZS 4214 method for three wall types

Ratio of *floor area* to floor perimeter (m)	Single Stud Lightweight Wall (114mm)	Heavyweight Wall (203mm)	Double Stud Lightweight Wall (214mm)
1	0.54	0.63	0.64
1.5	0.73	0.84	0.85
2	0.92	1.05	1.06
2.5	1.09	1.24	1.25
3	1.26	1.43	1.44
3.5	1.43	1.61	1.63
4	1.59	1.79	1.81
4.5	1.75	1.96	1.98
5	1.91	2.13	2.16
5.5	2.07	2.30	2.33
6	2.22	2.47	2.50
6.5	2.37	2.63	2.66
7	2.52	2.80	2.83

4.4 Summary

The analysis shows that regardless of method used, external wall thickness has a significant impact on soil R-Value, and up to 0.1 to 0.3 R-value difference between a thinner wall and thicker wall depending on the floor area to floor perimeter ratio.

5 Conclusion

In summary, our analysis in this report found that the increased insulation requirements for small buildings in NCC 2019 Section J1.6 does not achieve a BCR of between 1 and 1.5, with the exception of Climate Zone 7 small buildings (floor-area-to-perimeter ratio <2.0).

A review of CIBSE Guide A and NZS 4214:2006 indicates that increasing external wall thickness has positive impact on the floor R-Value. When calculated using the CIBSE method, the floor R-Value (with soil type being clay/silt) ranges from 0.24 to 0.62 as external wall thickness is increased from 50mm to 300m, and ranges from 0.26 to 0.81 when calculated using the NZS 4214 method.

Our recommendations can be summarised as follows:

- Small buildings floor insulation dispensation:
    - Any building with a floor-area-to-perimeter ratio of less than 7 should have a deemed floor construction resistance of R=X[12] where X is the minimum total R-value in Table J1.6 for a floor without in-slab heating or cooling (i.e. no need for additional insulation compared to NCC2016) except for overnight buildings in climate zone 7.

Table 51: NCC2019 Section J1.6 Floor Minimum Total R-Value requirements extracted from Table J1.6

Location	Climate zone 1 — upwards heat flow	Climate zones 2&3 — upwards and downwards heat flow	Climate zones 4,5, 6 and 7 — downwards heat flow	Climate zones 8 — downwards heat flow
A floor without an in-slab heating or cooling system	2.0	2.0	2.0	3.5
A floor with an in-slab heating or cooling system	3.25	3.25	3.25	4.75

-
    - For overnight buildings (Building Class 2, 3, 4, 9a and 9c) in climate zone 7 with a floor-area-to-perimeter ratio between 2.0 and 7.0, the building's floor construction resistance is deemed to be R=2.0.
    - For overnight buildings (Building Class 2, 3, 4, 9a and 9c) in climate zone 7 with a floor-area-to-perimeter ratio of less than ratio less than or equal to 2, existing minimum floor total R-value requirements apply.

- For unconditioned spaces connected to conditioned spaces via an adjoining floor slab on ground, the unconditioned space and floor should be treated in accordance with CIBSE Guide A Section 3.5.
    - The area of the unconditioned space outside of the insulated fabric of the building should be excluded when determining the floor area and perimeter.
    - The length of the wall between the conditioned space and the unconditioned space must be included in the perimeter calculations (see Figure 19)

[12] Note that R=X is a deemed resistance only. In practice, slab on ground without insulation might not achieve these values, but it still meet NCC2019 Section J requirement.

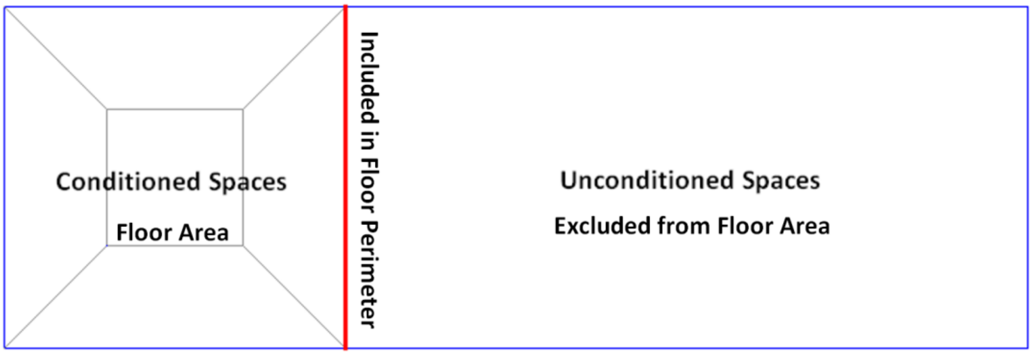


Figure 19 Floor Area and Floor Perimeter for Conditioned Spaces connected to Unconditioned Spaces

- External wall thickness plays an important role in determining soil/sub-floor thermal resistance and should be defined in accordance with CIBSE Guide A definitions.
  - CIBSE Guide A specifies that the external wall thickness is the thickness of the wall surrounding the ground floor (that is, if the wall is constructed above the floor surface, its thickness is treated as 0mm).
  - AS/NZS 4214:2006 Section 5.5 does not make this distinction of whether the external wall surrounds the floor slab or not, which may lead to a discrepancy between external wall thickness treatments using 2019 Method 1 and 2019 Method 2 floor insulation calculations.
    - Deduction of the equation referenced in NZS 4214:2006 suggests that it would only be applicable for external walls that surround the floor slab, and not applicable for external walls constructed on top of the floor slab.
    - A BRANZ publication in 2007[13] suggests that even when the external wall is constructed above the foundation (such that it is the foundation that surrounds the floor slab not the wall), the external wall thickness in AS4214 still uses the wall thickness in lieu of the foundation thickness.
    - We recommend that the values in Specification J1.6 Table 2b be reviewed in light of this apparent difference in treatment between NZS 4214 and CIBSE Guide A.
  - In terms of the floor area and perimeter definitions, this should be defined in accordance with Example 3.4 in CIBSE Section J3.5. CIBSE Guide A indicates that it is calculated from the interior surface of the external wall surrounding the floor (see Figure 20).

[13] https://www.buildmagazine.org.nz/index.php/articles/show/timber-aids-insulation-of-slab-on-ground-floors

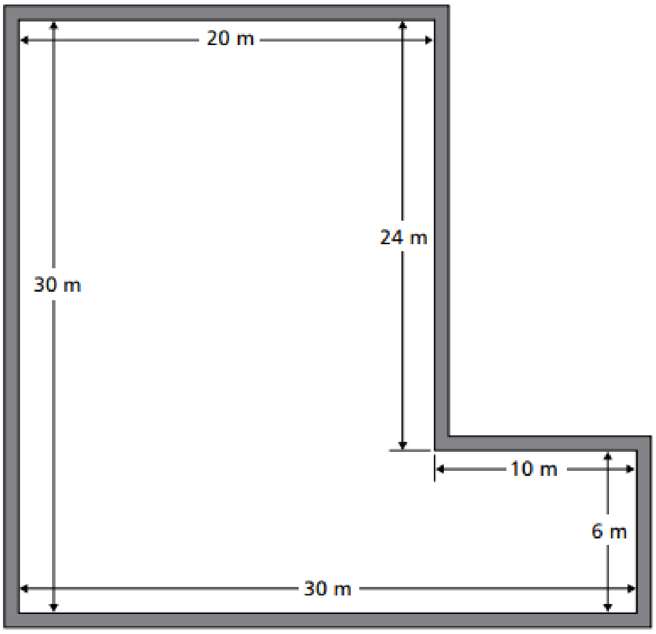


Figure 20 Example 3.4 in CIBSE Section 3.5 indicating the floor area and the floor perimeter is calculated from calculated from the interior surface of the external wall surrounding the floor

Appendix A Simulation Model Description

A.1 Overview

A.1.1 Building Type

As discussed with ABCB, we modelled three building types – office (Class 5), shop (Class 6) and motel (Class 3) to represent daytime or overnight operation with different internal loads.

A.1.2 Modelling Scenarios

In order to do the cost benefit analysis for the floor insulation, we developed the following simulation scenarios for all three building types and across Climate Zone 1 to 7:

- NCC2019 Floor Models: We developed the models based on NCC2019 Section J deemed-to-satisfy provisions.

- NCC2016 Floor Models: These models are the same as the NCC2019 scenarios, but the floor construction was changed to meet NCC2016 Section J deemed-to-satisfy provisions. These scenarios are the base cases in the cost benefit analysis.

- Cost Benefit Analysis Models: These models are the same as the NCC2019 scenarios, but the floor insulation was adjusted to test the cost benefit ratio with various floor insulation thickness.

A.2 Geometry

Screenshots of the models used are given in Figure 21 and Figure 22. Note that the office model and the motel model share the same building geometry but differ in the internal loads such as equipment, occupancy and lighting densities.

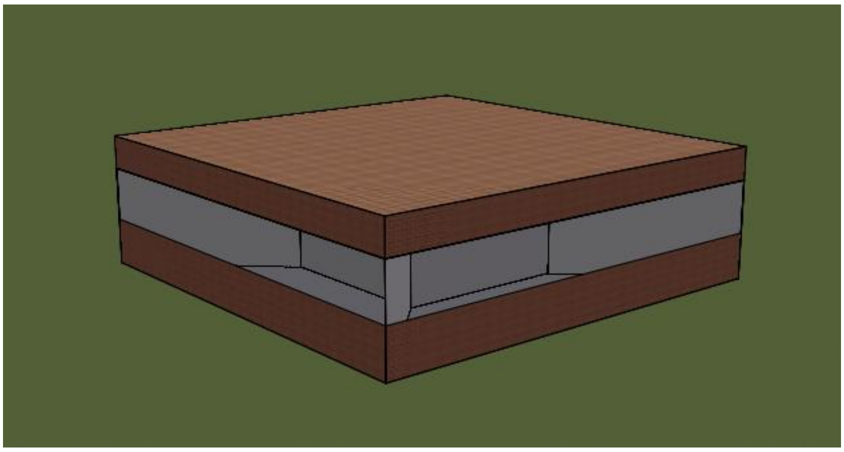


Figure 21: Geometry of the Office Model and the Motel Model

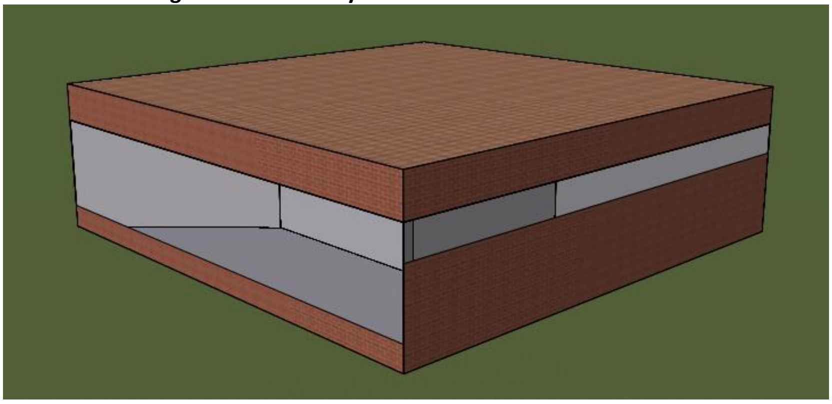


Figure 22: Geometry of the Shop Model

The key parameters in the simulation geometry are:

- Single level
- 12mx12m floor plate
- 2.7m conditioned space height
- 0.9m ceiling space height
- 4 perimeter zones and 1 centre zones
- Window to wall ratio (WWR) for the office and motel: 40%
- WWR for the shop model: 60% on the North and South façade to represent the display windows and 20% on the East and West façade to represent normal windows. The average WWR is still 40%.

A.3 Locations & Weather Files

The following centres and weather files were used to represent Australian climate zones 1 to 7 (climate zone 8 was omitted from the analysis due to its relatively low population and to reduce the computational time):

Table 52: Simulation weather file and location summary.

Climate Zone	Centre	State/Territory	Weather File
1	Darwin	NT	AUS_NT.Darwin.941200_IWEC.epw
2	Brisbane	QLD	Brisbane_IWEC.fwt
3	Alice Springs	NT	AUS_ALICE-SPRINGS-AP_943260_IW2.EPW
4	Wagga Wagga	NSW	AUS_WAGGA-WAGGA-AMO_949100_IW2.EPW
5	Sydney	NSW	SydneyIWEC.fwt
6	Melbourne	VIC	MelbourneIWEC.fwt
7	Canberra	ACT	AUS_ACT.Canberra.949260_IWEC.epw

A.4 Construction

A.4.1 Building Envelope Provisions

NCC2019 Section J provisions make is a reference to the entire façade (wall-glazing construction) U-Value and solar admittance (SHGC x WWR) on an aspect-by-aspect basis. Table 53 and Table 54 below presents these provisions.

Table 53: Façade parameters used for the daytime operating buildings showing maximum U-Value and SHGC x WWR.

	East		North		South		West	
	U_Total	SHGC x WWR	U_Total	SHGC x WWR	U_Total	SHGC x WWR	U_Total	SHGC x WWR

CZ1	2.0	0.12	2.0	0.12	2.0	0.12	2.0	0.12
CZ2	2.0	0.13	2.0	0.13	2.0	0.13	2.0	0.13
CZ3	2.0	0.16	2.0	0.16	2.0	0.16	2.0	0.16
CZ4	2.0	0.13	2.0	0.13	2.0	0.13	2.0	0.13
CZ5	2.0	0.13	2.0	0.13	2.0	0.13	2.0	0.13
CZ6	2.0	0.13	2.0	0.13	2.0	0.13	2.0	0.13
CZ7	2.0	0.13	2.0	0.13	2.0	0.13	2.0	0.13
CZ8	2.0	0.20	2.0	0.20	2.0	0.42	2.0	0.36

Table 54: Façade parameters used for overnight operating buildings showing maximum U-Value and SHGC x WWR.

	East		North		South		West	
	U_Total	SHGC x WWR	U_Total	SHGC x WWR	U_Total	SHGC x WWR	U_Total	SHGC x WWR
CZ1	1.1	0.07	1.1	0.07	1.1	0.10	1.1	0.07
CZ2	2.0	0.10	2.0	0.10	2.0	0.10	2.0	0.10
CZ3	1.1	0.07	1.1	0.07	1.1	0.07	1.1	0.07
CZ4	1.1	0.07	1.1	0.07	1.1	0.07	1.1	0.07
CZ5	2.0	0.10	2.0	0.10	2.0	0.10	2.0	0.10
CZ6	1.1	0.07	1.1	0.07	1.1	0.07	1.1	0.07
CZ7	1.1	0.07	1.1	0.07	1.1	0.08	1.1	0.07
CZ8	0.9	0.08	0.9	0.08	0.9	0.08	0.9	0.08

The stringency for display glazing is defined as follows:

Table 55: Façade parameters used for the façade with display glazing showing glazing U-Value and SHGC requirements.

All Façades (East, North, South, West)	U_Total	SHGC x WWR
CZ1-CZ8	5.8	0.81

For façades with window to wall rations (WWRs) greater than 20%, the wall construction minimum R-Value is 1.0 and for WWRs less than 20%, the wall insulation requirement is as described in Table 56 below.

Table 56: Wall insulation requirements for facades with a total glazing area less than 20%.

	Daytime	Overnight
	R-Value (m^2K/W)	R-Value (m^2K/W)
Climate Zone 1	2.4	3.3
Climate Zone 2	1.4	1.4
Climate Zone 3	1.4	3.3
Climate Zone 4	1.4	2.8
Climate Zone 5	1.4	1.4
Climate Zone 6	1.4	2.8
Climate Zone 7	1.4	2.8
Climate Zone 8	1.4	3.8

A.4.2 Glazing Construction

The glazing constructions took the following process:

1. When a 40% WWR, for example, was selected for a NCC2019 model, the glass SHGC value was determined by dividing the SHGC x WWR provision by the WWR value. For a north facing, daytime operating façade in Climate Zone 1, the maximum SHGC value works out as:

$$SHGC = \frac{SHGC * WWR}{WWR} = \frac{0.12}{0.4} = 0.3$$

2. Any glass construction with a SHGC value of less than 0.3 can be chosen and within the window of compliance.

3. In this example, WWR is 40% which is greater than 20%. So the minimum R-Value of the wall is 1.

4. The maximum U-Value of the glazing required to achieve a façade U-Value defined by the stringency was then calculated using the façade U-Value, wall U-Value and WWR. For a north facing, daytime operating façade in Climate Zone 1 works out to be:

$$U_{window} = \frac{U_{facade} - U_{wall} \times (1 - WWR_{window})}{WWR_{wall}}$$

$$U_{window} = \frac{2 - 1 \times (1 - 0.4)}{0.4} = 3.5$$

A.4.3 Roof Construction

Colourbond roof was used in all the simulation scenarios.

A.4.4 Ceiling

The ceiling was modelled as plasterboard with glass fibre insulation. The insulation thickness was adjusted to achieve the R-Value requirement in NCC2019 Section J.

Table 57: Ceiling R-Value Requirement

	Ceiling
	R-Value (m^2K/W)
Climate Zone 1	3.7
Climate Zone 2	3.7
Climate Zone 3	3.7
Climate Zone 4	3.7
Climate Zone 5	3.7
Climate Zone 6	3.2
Climate Zone 7	3.7
Climate Zone 8	4.8

A.4.5 Ground Floor Construction

The ground floor construction was modelled as shown in Table 58.

Table 58: Floor Construction

	Description
Ground Floor	8mm Carpet 150mm Concrete Insulation 1692mm Clay

Table 2b in NCC2019 Specification J1.6 listed the R-Value of soil in contact with a floor for different ration of floor area to floor perimeter and different wall thickness. In this study, the ratio was selected as three and the wall used in the simulation was around 100mm. So the soil R-Value is 1.2. 1692mm soil used in the simulation was to make up soil R-Value of 1.2.

Table 2b R-Value of soil in contact with a floor

Ratio of *floor area* to floor perimeter (m)	Wall thickness of 50 mm	Wall thickness of 100 mm	Wall thickness of 150 mm	Wall thickness of 200 mm	Wall thickness of 250 mm	Wall thickness of 300 mm
1.0	0.4	0.5	0.5	0.6	0.7	0.8
1.5	0.6	0.7	0.7	0.8	0.9	1.0
2.0	0.7	0.8	0.9	1.0	1.1	1.3
2.5	0.9	1.0	1.1	1.2	1.3	1.5
3.0	1.0	1.2	1.3	1.4	1.5	1.7
3.5	1.2	1.3	1.5	1.6	1.7	1.9
4.0	1.3	1.5	1.6	1.7	1.9	2.2
4.5	1.5	1.7	1.8	1.9	2.1	2.4
5.0	1.6	1.8	2.0	2.1	2.3	2.6
5.5	1.8	2.0	2.1	2.2	2.4	2.8
6.0	1.9	2.1	2.3	2.4	2.6	2.9
6.5	2.0	2.3	2.4	2.6	2.8	3.1

Table J1.6 in NCC2019 Section J listed the minimum total R-Value requirement for floors:

Location	**Climate zone 1 — upwards heat flow**	**Climate zones 2&3 — upwards and downwards heat flow**	**Climate zones 4,5, 6 and 7 — downwards heat flow**	**Climate zones 8 — downwards heat flow**
A floor without an in-slab heating or cooling system	2.0	2.0	2.0	3.5
A floor with an in-slab heating or cooling system	3.25	3.25	3.25	4.75

Note to Table J1.6: For the purpose of calculating the *Total R-Value* of a floor, the sub-floor and soil *R-Value* must be calculated in accordance with Specification J1.6 or Sectoin 3.5 of CIBSE Guide A.

Then the minimum ground floor insulation R-Value required to achieve the minimum total R-Value defined by the stringency was calculated using the minimum total R-Value and the R-Values of soil, indoor air film, 150mm concrete and 8mm carpet. The results are listed in Table 59.

Table 59: Ground Floor Insulation R-Value Requirement in NCC2019 Floor Modelling

	R-Value					
	Total	Soil	150mm Concrete	8mm Carpet	Indoor Air Film	Insulation
Climate Zone 1	2	1.2	0.107	0.133	0.11	0.45
Climate Zone 2	2	1.2	0.107	0.133	0.11	0.45
Climate Zone 3	2	1.2	0.107	0.133	0.11	0.45
Climate Zone 4	2	1.2	0.107	0.133	0.16	0.40
Climate Zone 5	2	1.2	0.107	0.133	0.16	0.40
Climate Zone 6	2	1.2	0.107	0.133	0.16	0.40
Climate Zone 7	2	1.2	0.107	0.133	0.16	0.40

The slab on ground total R-Value requirement in NCC2016 is listed in the table below.

Table J1.6 FLOORS — MINIMUM TOTAL R-VALUE

Location	Climate zone							
	1	2	3	4	5	6	7	8
Direction of heat flow	Upwards	Downwards and upwards		Downwards				
(a) A slab on ground: (i) Without an in-slab or in-screed heating or cooling system	Nil	Nil	Nil	Nil	Nil	Nil	1.0	2.0
(ii) With an in-slab or in-screed heating or cooling system	1.25	1.25	1.25	1.25	1.25	1.25	1.25	2.25

We then can calculate the floor insulation R-Value similarly. Note that the soil resistance was not taken into consideration in NCC2016.

Table 60: Ground Floor Insulation R-Value Requirement in NCC2016 Floor Modelling

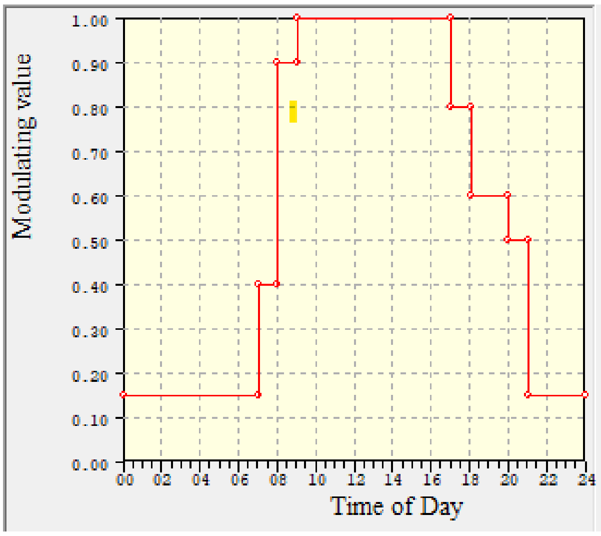
	R-Value				
	Total	150mm Concrete	8mm Carpet	Indoor Air Film	Insulation
Climate Zone 1	Nil	0.107	0.133	0.11	Nil
Climate Zone 2	Nil	0.107	0.133	0.11	Nil
Climate Zone 3	Nil	0.107	0.133	0.11	Nil
Climate Zone 4	Nil	0.107	0.133	0.16	Nil
Climate Zone 5	Nil	0.107	0.133	0.16	Nil
Climate Zone 6	Nil	0.107	0.133	0.16	Nil
Climate Zone 7	1	0.107	0.133	0.16	0.60

Note that in Climate Zone 7 NCC2016 requires higher floor insulation R-Value than NCC2019.

A.5 Internal Load Parameters and Schedules

The following parameters have been used in the representation of internal loads as per Specification JVc in NCC 2019.

- Lighting power density
  - The lighting power density was modelled to be 4.5W/m^2 for office, 14W/m^2 for shop and 5W/m^2 for motel.
- Equipment load
  - The equipment load was modelled to be 11W/m^2 for office, 5W/m^2 for shop and 160W/room for motel.
- Occupancy density
  - The occupancy density was modelled to be 10m^2/person for office, 3m^2/person for shop and 15m^2/person for motel. The sensible and latent heat gain was set as 75W/person and 55W/person respectively.
- Infiltration
  - We used 0.7 ACH when the HVAC is not operating and 0.35 ACH at all other times. These values are in accordance with Specification JVb of NCC2019.
- Schedules
  - The hours of operation of the lighting, occupancy, equipment and HVAC for the retail and serviced apartment was shown in Figure 23 to Figure 42.



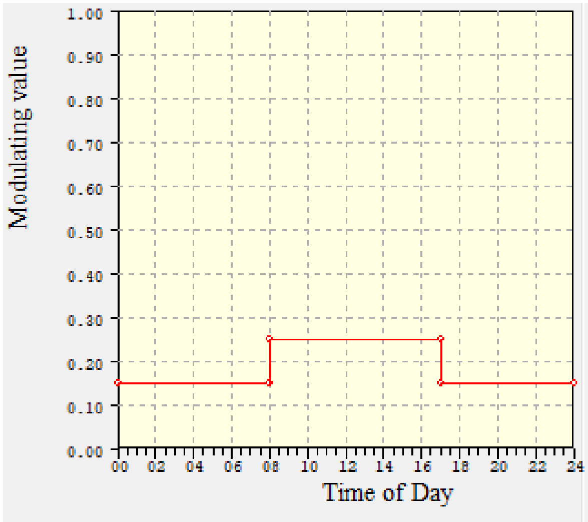
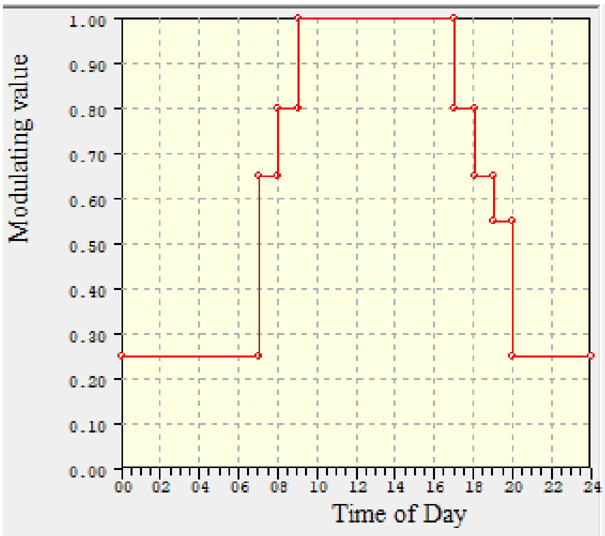


Figure 23 Office weekday lighting schedule

Figure 24 Office weekend lighting schedule



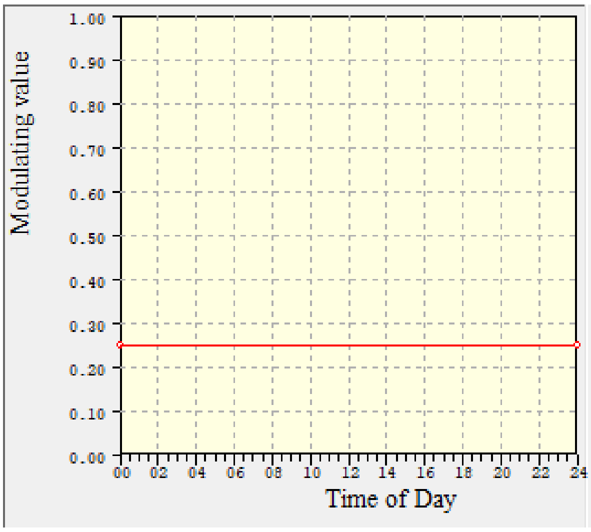


Figure 25 Office weekday equipment schedule

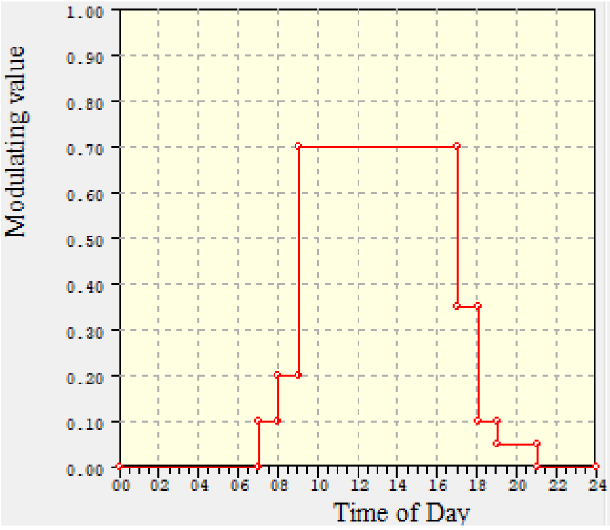


Figure 26 Office weekend equipment schedule

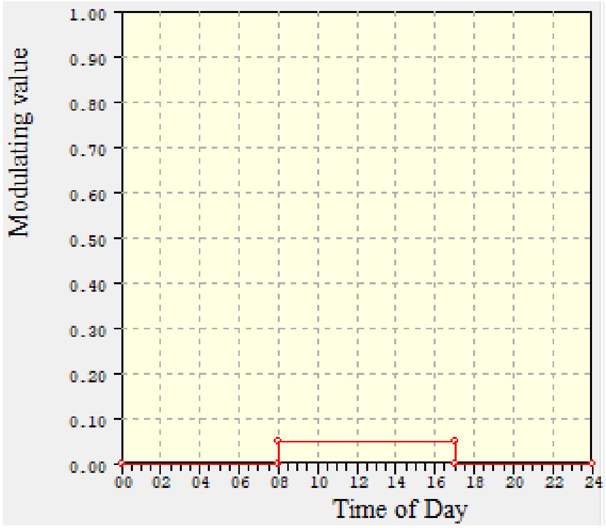


Figure 27 Office weekday occupancy schedule

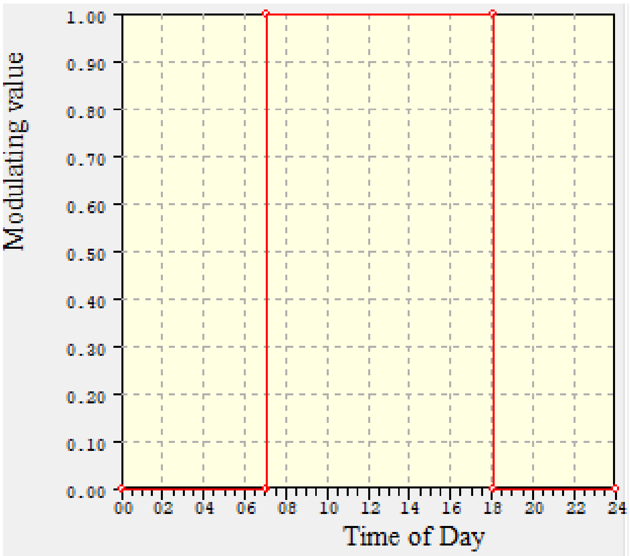


Figure 28 Office weekend occupancy schedule

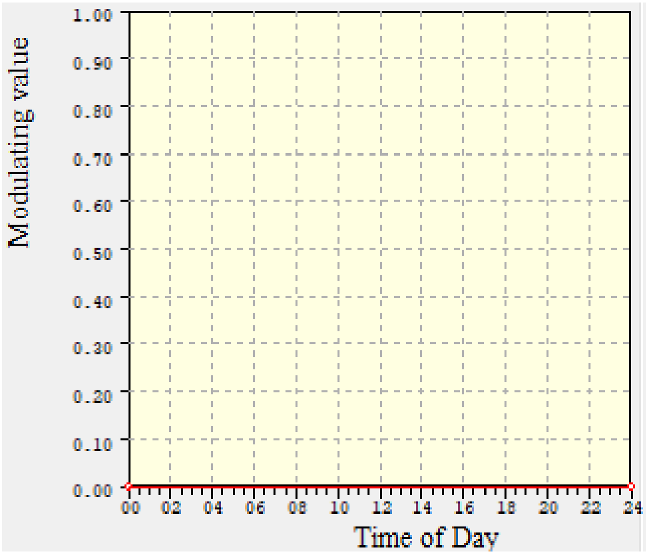


Figure 29 Office weekday HVAC schedule

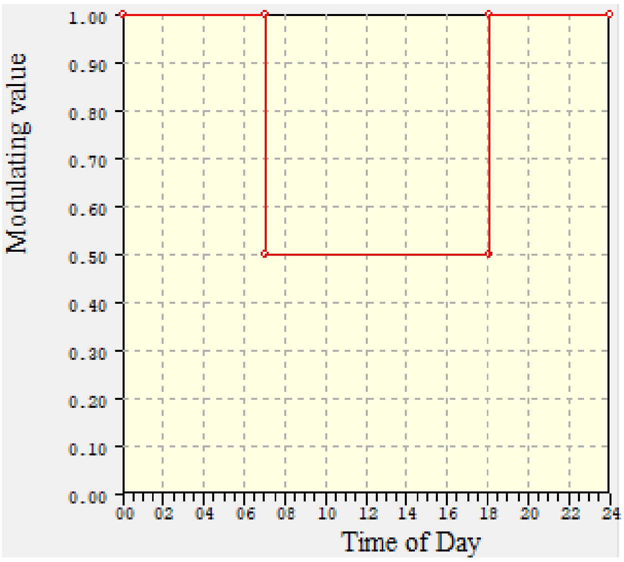


Figure 30 Office weekend HVAC schedule

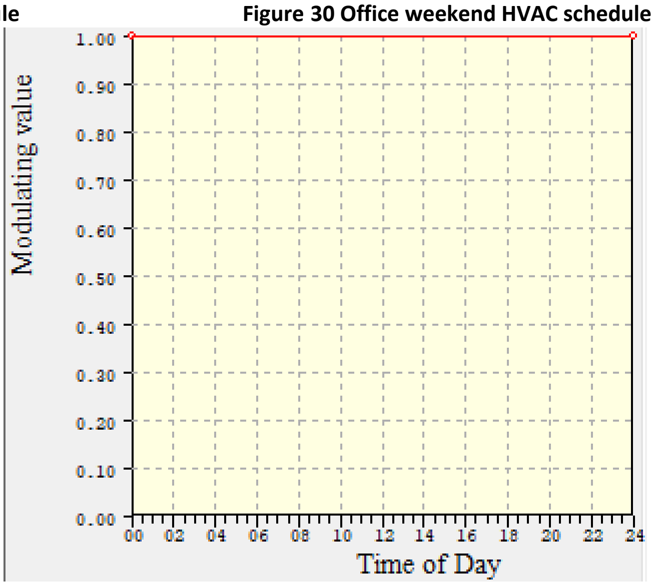
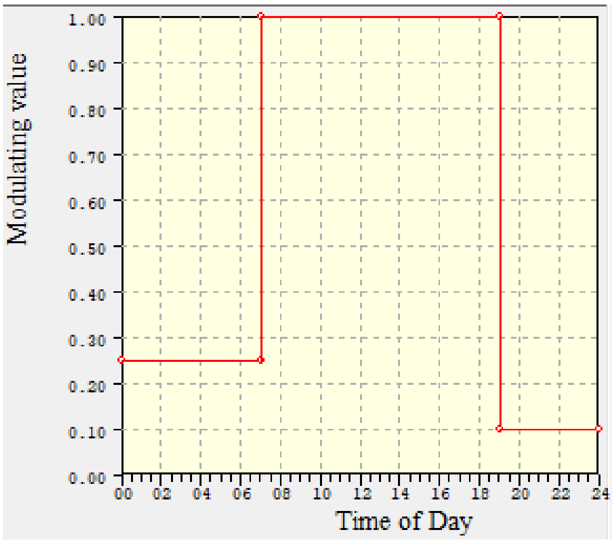


Figure 31 Office weekday Infiltration schedule **Figure 32 Office weekend Infiltration schedule**



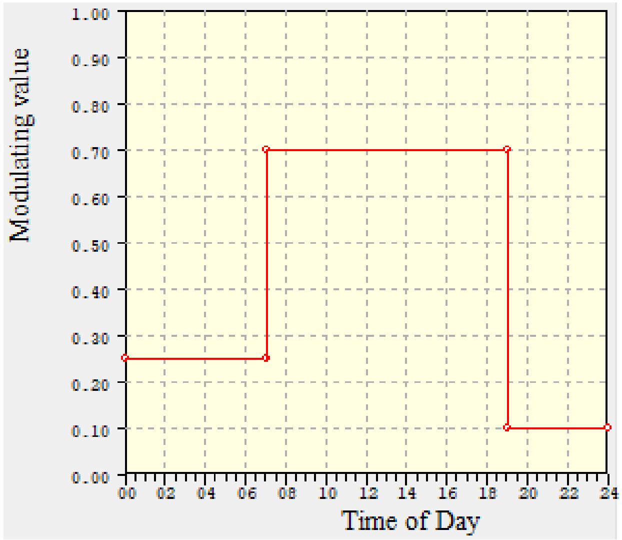
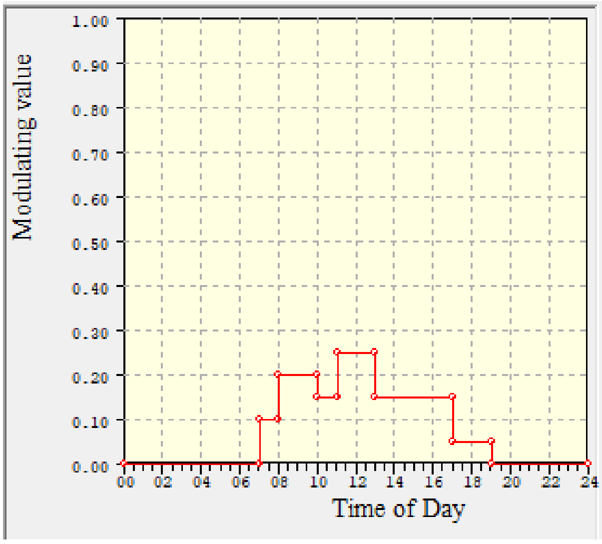


Figure 33 Shop daily lighting schedule **Figure 34 Shop daily equipment schedule**



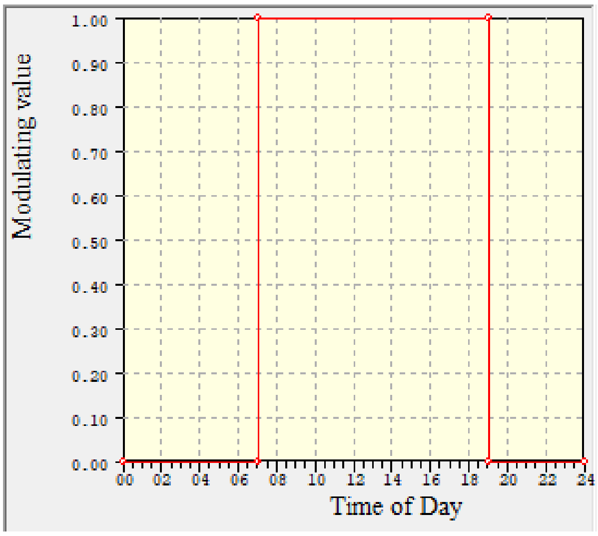


Figure 35 Shop daily occupancy schedule

Figure 36 Shop daily HVAC schedule

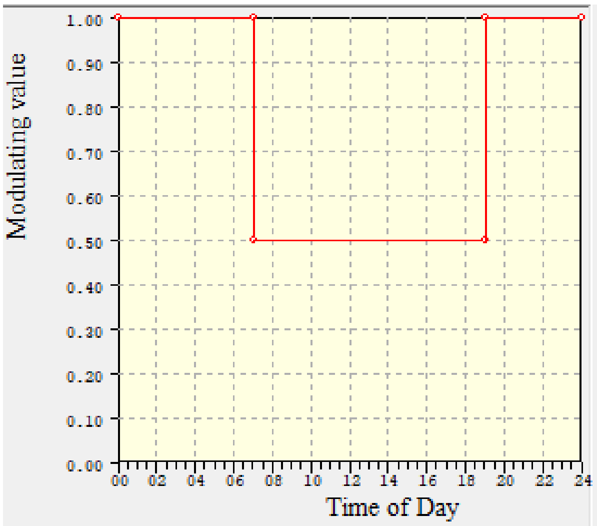
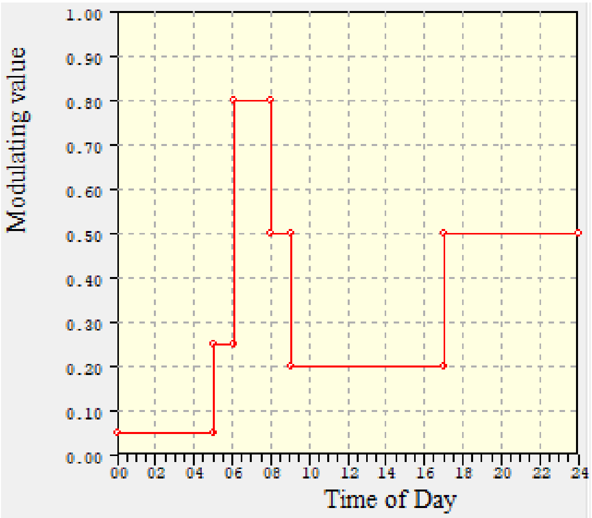


Figure 37 Shop daily infiltration schedule



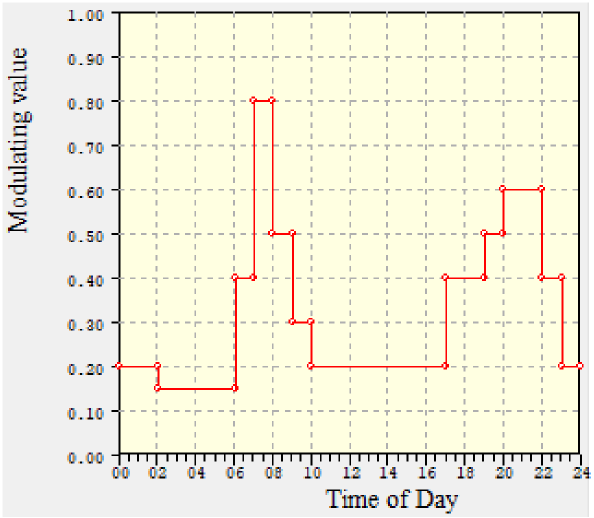
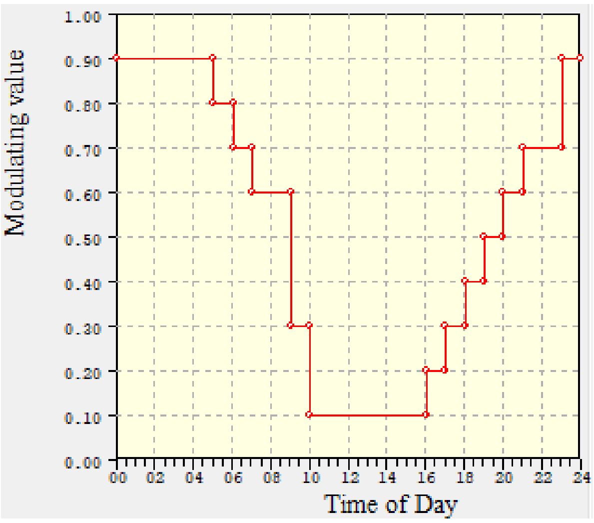


Figure 38 Motel daily lighting schedule

Figure 39 Motel daily equipment schedule



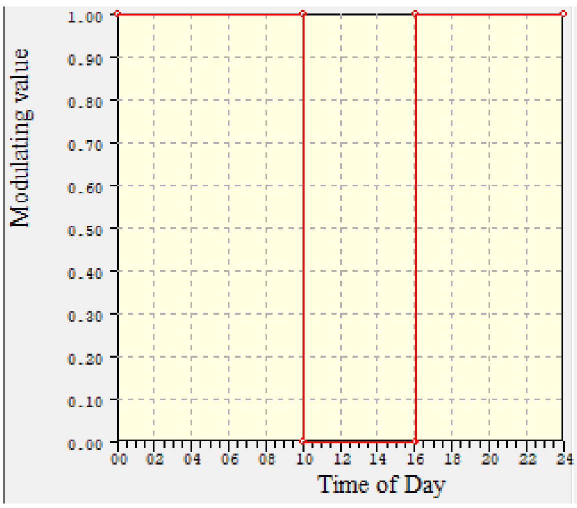


Figure 40 Motel daily occupancy schedule

Figure 41 Motel daily HVAC schedule

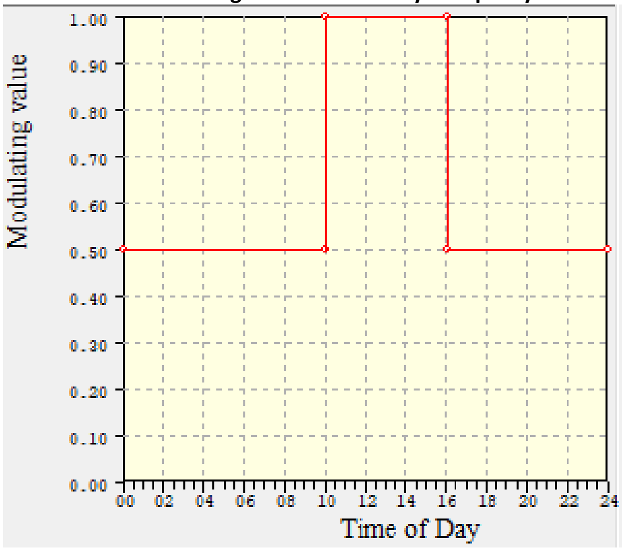


Figure 42 Motel daily infiltration schedule

A.6 HVAC

Split units were modelled to provide heating and cooling. As per Section J of NCC 2019 and MEPS, the cooling efficiency was modelled to be 2.6 and the heating efficiency was modelled to be 2.8.

The heating and cooling setpoints were set as 21°C and 24°C respectively.