# NCC 2025 Energy Efficiency - Advice on the technical basis

## Initial Measures Development: Building Envelope Report

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Measures investigated in this report include:

- Roof insulation
- Wall insulation
- Glazing
- Vertical shading
- Cool roofs

[Draft regulation text shown in this report was originally provided to the ABCB for consideration and further development. It may not reflect final provisions for public comment. The draft regulation below also may not reflect any changes following feedback received from the ABCB or various industry stakeholders.]

## Table of Contents

1 Introduction ..... 6
1.1 Project Context ..... 6
2 Roof Insulation ..... 7
2.1 Background and context ..... 7
2.2 Methodology ..... 7
2.3 Constructions ..... 7
2.3.1 Construction details – roof insulation ..... 7
2.3.2 Construction details – ceiling insulation ..... 11
2.3.3 Capital Costs ..... 13
2.4 Simulation Results ..... 15
2.5 Benefit-Cost Analysis ..... 18
2.5.1 Roof insulation ..... 18
2.5.2 Ceiling insulation ..... 19
2.6 Discussion ..... 21
2.6.1 Roof insulation vs ceiling insulation ..... 21
2.6.2 Stringency ..... 22
2.7 Proposed Measures ..... 23
3 Wall Insulation ..... 24
3.1 Background and context ..... 24
3.2 Methodology ..... 24
3.2.1 Construction summary ..... 24
3.3 Simulation Methodology and Results ..... 29
3.4 Economic analysis ..... 32
3.5 Discussion ..... 34
3.5.1 Minimum R-Value for walls with less than 20% glazing ..... 34
3.5.2 Minimum R-Value for walls with more than 20% glazing ..... 35
3.6 Treatment of unconditioned spaces within the building envelope. ..... 41
3.6.1 Introduction ..... 41
3.6.2 Discussion ..... 41
3.6.3 Proposed Code text ..... 42
4 Glazing ..... 43
4.1 Background and context ..... 43

4.2 Methodology ... 43
4.2.1 SDA analysis ... 44
4.2.2 Underlying archetypes ... 45
4.3 Derivation of revised solar admittance requirements ... 45
4.3.1 Maximum solar admittance – initial analysis ... 45
4.3.2 Base case – glazing selections ... 48
4.3.3 Simulation Methodology ... 49
4.3.4 Additional SHGC analyses ... 49
4.3.5 U value Stringency ... 56
4.4 Discussion ... 59
4.4.1 Window-wall total system U value ... 59
4.5 Proposed Measures ... 60
4.5.1 Stringency 1&2 ... 60
4.5.2 Stringency 3 ... 61
5 Vertical Shading ... 63
5.1.1 Background and context ... 63
5.1.2 Methodology ... 63
5.2 Proposed Measures ... 65
6 Cool Roofs ... 69
6.1 Background and context ... 69
6.1.1 How cool roofs work ... 69
6.2 Methodology ... 70
6.2.1 Data collection and review ... 70
6.2.2 Cool Roof Products ... 70
6.2.3 Simulation Methodology ... 71
6.2.4 Cost information ... 72
6.2.5 Simulation Results ... 73
6.2.6 Economic analysis ... 75
6.3 Discussion ... 76
6.3.1 Microclimate impact ... 76
6.3.2 As supplied versus post-applied ... 77
6.4 Proposed Measures ... 77
6.4.1 Rationale ... 77
6.4.2 TSR vs SRI ... 77
6.4.3 Weathered vs new solar performance ... 77

6.4.4 Non-metal roofs ..... 78
6.4.5 Proposed code text ..... 78
7 Appendix A: Glazing ..... 80
7.1 Daylight Analysis ..... 80
7.1.1 Daylight Metrics ..... 80
7.1.2 What is an appropriate level of daylight? ..... 80
7.1.3 Daylight modelling ..... 84
7.2 Glazing analysis: NCC2022 base case definition ..... 88
7.2.1 Overall process and outcomes ..... 88
7.2.2 Glazing properties calculation ..... 90
7.2.3 NCC2022 compliant base case glazing selections for glazing analysis ..... 92
7.3 Glazing Cost Information ..... 99
8 Appendix B: Wall Insulation ..... 101
8.1 Cost Information ..... 101
9 Appendix C: Roof Insulation ..... 103
9.1 Cost Information ..... 103
10 Appendix D: Thermal bridging ..... 104
10.1 Introduction ..... 104
10.2 Interpretation of UoW results ..... 105
10.2.1 Potentially significant thermal bridges ..... 106
10.2.2 Discussion ..... 107
10.3 Recommendations ..... 108
10.3.1 Proposed Code Text: Definitions ..... 108
10.3.2 Proposed Code Text: J4 D3. ..... 108
10.3.3 Proposed Code Text S34C3 ..... 108
11 Appendix E: Simulation Models ..... 110
11.1 Medium Office C5OM ..... 110
11.1.1 General Layout ..... 110
11.1.2 HVAC ..... 111
11.1.3 Schedules and Internal Loads ..... 111
11.2 Aged Care/Small Hospital C9C/C9AS ..... 111
11.2.1 General Layout ..... 111
11.2.2 HVAC ..... 112
11.2.3 Schedules and Internal Loads ..... 112
11.3 Simplified Single Storey ..... 113

11.3.1 General Layout ..... 113
11.3.2 HVAC ..... 114
11.3.3 Schedules and Internal Loads ..... 114

# 1 Introduction

Section J of the National Construction Code (Volume One) is undergoing a cyclic review of both stringency and coverage. This report records the analyses for the initial measures development for NCC 2025 pertaining to building envelope measures.

## 1.1 Project Context

Section J of the National Construction Code (Volume One) last underwent a significant review for the 2019 edition. Since then, technologies have advanced in some areas, creating the opportunity for enhanced stringency. Furthermore, external pressures on Code from factors such as net zero targets at the Australian and state government level have added to this ambition.

# 2 Roof Insulation

## 2.1 Background and context

Roof insulation is regulated in NCC2022 under J4D4 (1) which requires the following Total R-Values:

a) in climate zones 1, 2, 3, 4 and 5, R3.7 for a downward direction of heat flow;
b) in climate zone 6, R3.2 for a downward direction of heat flow; and
c) in climate zone 7, R3.7 for an upward direction of heat flow; and
d) in climate zone 8, R4.8 for an upward direction of heat flow.

The purpose of the current analysis is to test the opportunity for increased stringency in NCC 2025.

## 2.2 Methodology

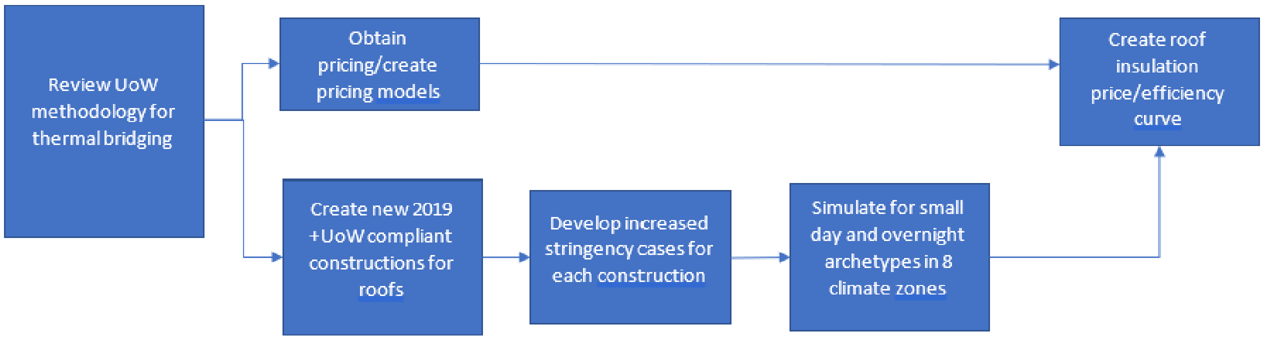



Figure 1. Methodology flowchart, roof insulation[1].

## 2.3 Constructions

Two constructions were considered for the analysis, being an insulated roof structure and an insulated ceiling.

### 2.3.1 Construction details – roof insulation

The metal framing for all roof systems typically assumes the following:

- 1.15bmt (base metal thickness) for 150mm purlins
- 0.75bmt for 35mm top hats
- 0.75bmt for steel profiled decks

The assumption is based on typical metal framework and its arrangement that is being used as an integral part of many light-weight roof cladding systems. The impact of solely changing base metal

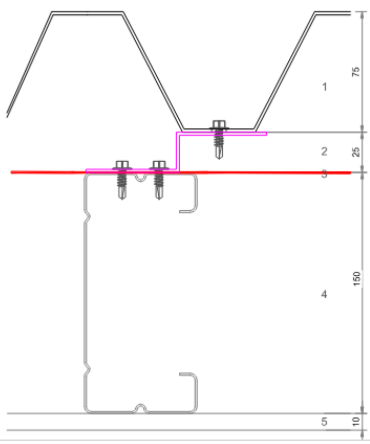
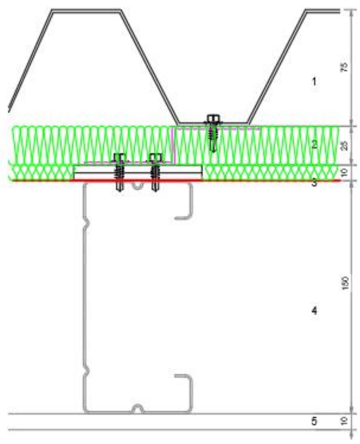
[1] The UoW report referred to in the chart is: Green, A, Kempton, L, Beltrame, S, Pickup, C, Kokogiannakis, G, Heffernan,
E & Cooper, P, 2021, Thermal bridging energy impacts modelling, Sustainable Buildings Research Centre, University of Wollongong, Australia

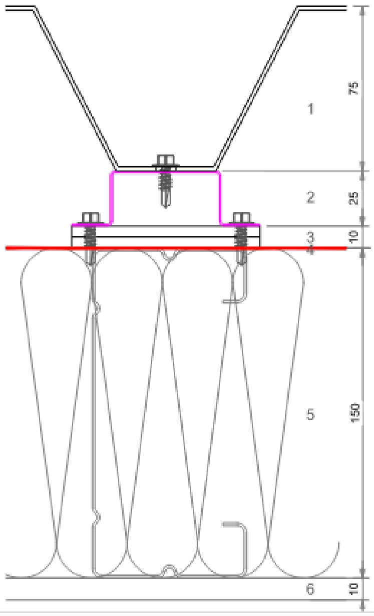
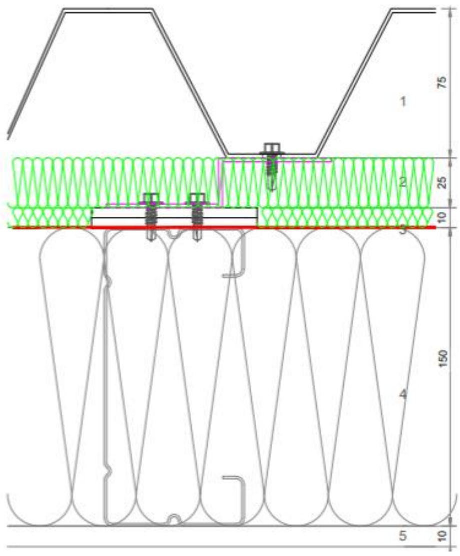
thickness does not greatly impact the thermal performance of the overall system but by its nature, having thicker metal framework is expected to result in poorer thermal performance.

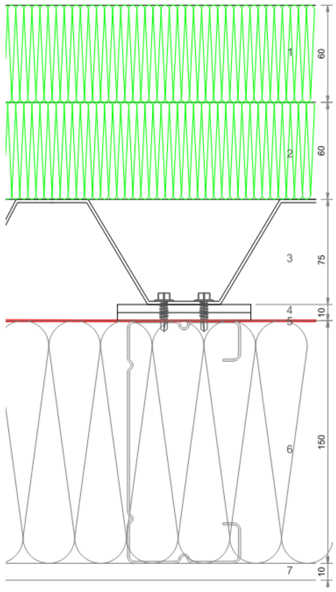
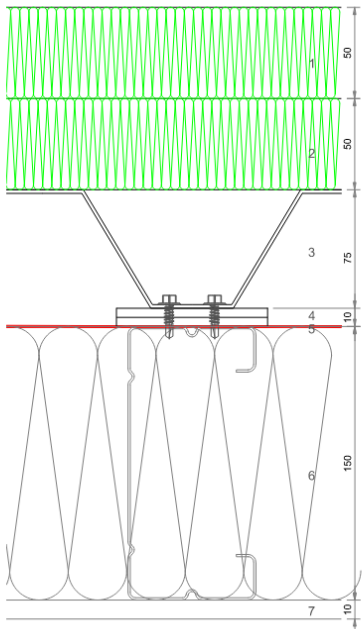
Roof construction R-Values were calculated using the Speckel software, which provides a fast and user-friendly method for AS/NZS 4859.2 compliant calculations for built up constructions.

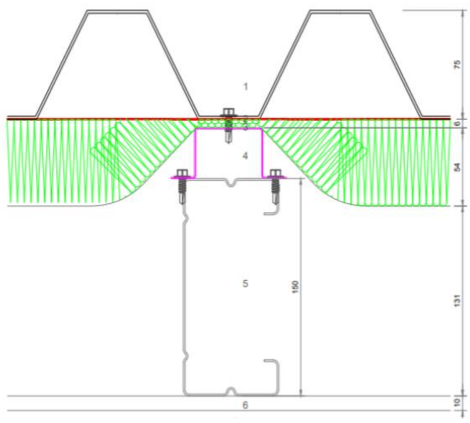
Table 1 provides a summary of the roof build-up for each case.

Table 1. Roof build-up for each case

| Case Number | Description | Summer-Calculated R-value ($m^2.K°/W$) | Winter - Calculated R-value ($m^2.K°/W$) | Configuration |
|---|---|---|---|---|
| **1** | 1. Metal cladding<br>2. 25mm z-angle 0.75bmt + ventilated air<br>3. Pliable building membrane (reflective roof sarking).<br>4. 150mm purlin<br>5. Internal lining 10mm plaster board | 1.14 | 1.75 | At 10 degrees angle<br> |
| **2** | 1. Metal cladding<br>2. 25mm z-angle 0.75bmt + 35mm external roof insulation (stone wool)<br>3. Thermal break 10mm<br>4. Pliable building membrane (reflective roof sarking)<br>5. 150mm purlin<br>6. Internal lining 10mm plaster board | 1.78 | 2.4 |  |

| Case Number | Description | Summer-Calculated R-value (m².K°/W) | Winter - Calculated R-value (m².K°/W) | Configuration |
|---|---|---|---|---|
| **3** | 1. Metal cladding<br>2. 25mm top hat 0.75bmt + ventilated air<br>3. Thermal break 10mm<br>4. Pliable building membrane (reflective roof sarking)<br>5. 150mm purlin, roof insulation of 150mm (fibreglass or equivalent)<br>6. Internal lining 10mm plaster board | 2.74 | 3.34 | At 10 degrees angle<br> |
| **4** | 1. Metal cladding<br>2. 25mm z-angle 0.75bmt + 35mm external roof insulation (stone wool)<br>3. Thermal break 10mm<br>4. Pliable building membrane (reflective roof sarking)<br>5. 150mm purlin, roof insulation of 150mm (fibreglass or equivalent)<br>6. Internal lining 10mm plaster board | 3.38 | 3.99 | At 10 degrees angle<br> |

| Case Number | Description | Summer- Calculated R-value (m².K°/W) | Winter - Calculated R-value (m².K°/W) | Configuration |
|---|---|---|---|---|
| **5** | 1. External roof insulation (stone wool) 60mm<br>2. External roof insulation (stone wool) 30 – 60mm<br>3. Steel decking system +non-ventilated air gap<br>4. Thermal Break 10mm<br>5. Pliable building membrane (non-reflective roof sarking)<br>6. 150mm purlin, roof insulation of 150mm (fibreglass or equivalent)<br>7. Internal lining 10mm plaster board | 3.99 | 4.02 | At 10 degrees angle<br><br> |
| **6** | 1. External roof insulation (stone wool) 50mm<br>2. External roof insulation (stone wool) 30 – 50mm<br>3. Steel decking system +non-ventilated air gap<br>4. Thermal break 10mm<br>5. Pliable building membrane (non-reflective roof sarking)<br>6. 150mm purlin, roof insulation of 150mm (fibreglass or equivalent)<br>7. Internal lining 10mm plaster board | 5.06 | 5.08 | At 10 degrees angle<br><br> |

| Case Number | Description | Summer- Calculated R-value (m².K°/W) | Winter - Calculated R-value (m².K°/W) | Configuration |
|---|---|---|---|---|
| **7a/b** | 1. External metal cladding.<br>2. Pliable building membrane (roof sarking)<br>3. Compressed insulation (Glass wool insulation) of R1.3 (7a), R3 (7b), compressed at battens<br>4. 35mm top hat battens<br>5. 150mm purlin<br>6. 10mm Internal lining | 7a:1.76<br>7b:1.96 | 7a:2.37<br>7b:2.57 | At 10 degrees angle  |

The recommended material for the external insulation is stone wool, in which it presents excellent performance in both weather-resistance and combustibility resistance. By the sub-framing configuration within the external cavity, two options of external insulation configuration have been proposed. An additional external insulation greatly enhances the thermal performance of the total roof configuration as seen on the table.

R-value calculation for all roof types is in accordance with NCC 2022, which refers to AS/NZS 4859.2 and adopts the methodology of NZS 4214 for thermal bridging effects per each layer. Thermal breaks, assumed to be 0.2 R-value, are also introduced at the pliable building membrane to minimise thermal bridging effects.

### 2.3.2 Construction details – ceiling insulation

Ceiling insulation cases were developed based on batts applied to a fixed plaster ceiling with 450mm spaced joists (35mm*90mm).  The general arrangement for the construction is shown in Figure 2 and Figure 3 below.

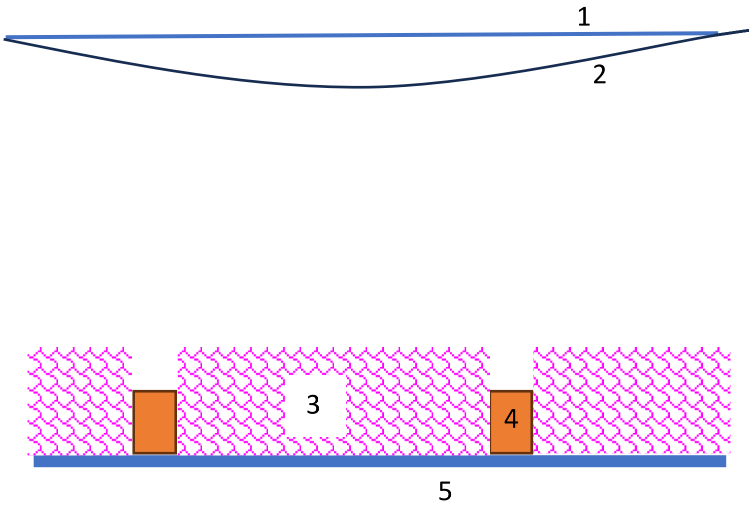



Figure 2. Ceiling insulation schematic – batts between joists. Key: 1. Metal roof. 2. Reflective sarking. 3. Fibreglass insulation 4. Ceiling joists. 5. 12mm plasterboard

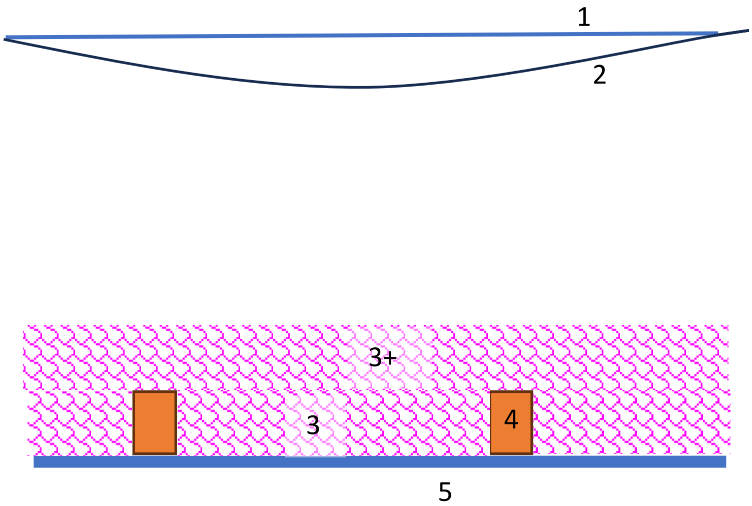



Figure 3. Ceiling insulation schematic – two layer. Key: 1. Metal roof. 2. Reflective sarking. 3. Fibreglass insulation 3+. Additional layer of fibreglass insulation. 4. Ceiling joists. 5. 12mm plasterboard

Total construction R-Values used are shown in Table 2 and Table 3. Note that these figures do not make any allowance for interruptions to insulation caused by services (e.g. recessed light fittings, ducts). R-Values have been manually calculated using standard methods with reference to Specification 36.

Table 2. R-Values used for ceiling insulation cases – Batts between joists

| Insulation Bag R-value ($m^2K/W$) | Up R-value ($m^2K/W$) | Winter: R-value ($m^2K/W$) |
|---|---|---|
| **0** | 0.88 | 1.51 |
| **2** | 2.79 | 3.43 |

| | | |
|---|---|---|
| **3** | 3.52 | 4.17 |
| **4** | 4.18 | 4.84 |
| **5** | 4.77 | 5.45 |
| **6** | 5.29 | 6 |

Table 3. R-Values used for ceiling insulation cases – two layers. Note that as no R-Values above 6 were simulated, the R-Values above 6 in this table were used to interpolate R6 values only

| Insulation Bag R-value ($m^2K/W$) | Summer: R-value ($m^2K/W$) | Winter: R-value ($m^2K/W$) |
|---|---|---|
| **0** | 0.88 | 1.51 |
| R2+R2 | 4.79 | 5.43 |
| R2+R3 | 5.52 | 6.17 |
| R2+R4 | 6.18 | 6.84 |

### 2.3.3 Capital Costs

#### Roof insulation

The capital cost figures for each roof construction were derived based on industry estimates. The costs are summarised in Table 4 and Figure 4.

Table 4. Capital cost for roof construction.

| Case Number | Summer: R-value ($m^2.K°/W$) | Winter: R-value ($m^2.K°/W$) | Cost ($/m²) |
|---|---|---|---|
| **1** | 1.14 | 1.76 | 250 |
| **2** | 1.78 | 2.4 | 307 |
| **3** | 2.74 | 3.34 | 362 |
| **4** | 3.38 | 3.99 | 377 |
| **5** | 3.99 | 4.02 | 420 |
| **6** | 5.06 | 5.08 | 440 |
| **7a** | 1.76 | 2.37 | 275 |
| **7b** | 1.96 | 2.57 | 290 |

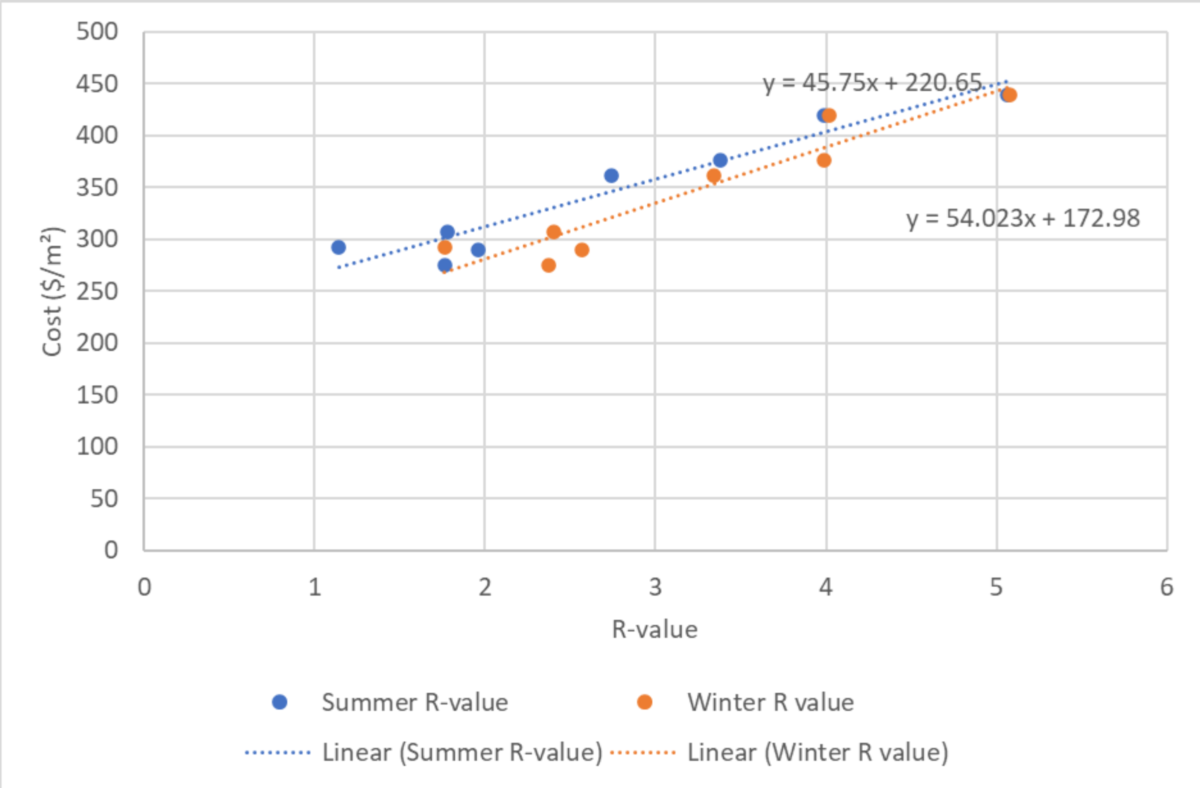



Figure 4. Roof construction costs by total R-Value.

As the simulation results were not conducted at the exact R-values of the specific constructions, an averaged cost function was used. For the sake of simplicity, this was derived as the average of summer and winter costs, i.e. Cost($/m²) = 50R+ 197

### Ceiling insulation

For ceiling insulation costs, the incremental costs were calculated[2] as:

- For batts between joists: Cost ($/m²)=15+2.87R
- For two layer: Cost ($/m²)=30+2.87R

where R is the total bag value of insulation used and the intercept only applying for the case of R≠0.

Resultant ceiling insulation costs are shown in Figure 5.

[2] This is based on an assumption of $15/m² installation costs, doubling to $30/m² for two layer, plus $2.87 per m² per R-Value based on supply costs of roof insulation batts.

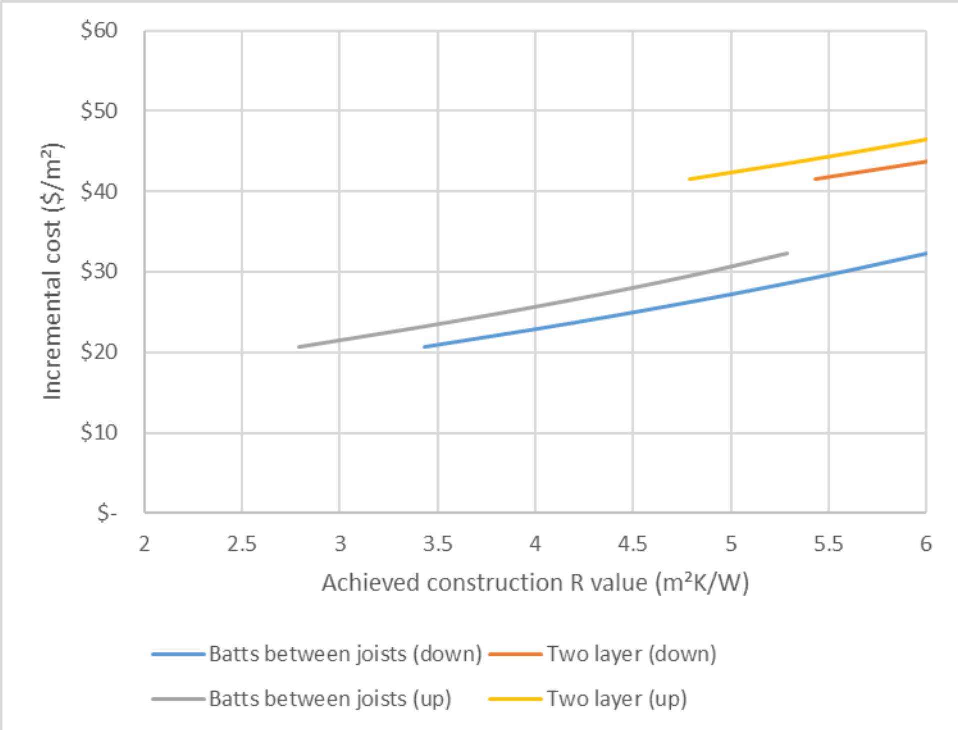



Figure 5. Ceiling insulation costs. Values above R6 were not used in the analysis.

## 2.4 Simulation Results

Simulations were conducted using the Medium Office (C5OM) and Aged Care (C9C) archetypes, both using fixed speed compressor unitary air-conditioning without economy cycle and with an EER of 2.9. A range of roof R-values was simulated covering the full range of constructions considered in Section 2.3. The roof area of the Medium Office and Aged Care archetypes were 1170m² and 2048m² respectively.

It was found that the dependence of energy use of roof R-Value for the Medium Office archetype was very limited, a surprising result that nonetheless was corroborated via multiple checks and was found to have precedent in peer-reviewed academic literature[3]. The Aged Care archetype showed a greater dependency, but still at a lower level than might have been expected. The simulation energy results are shown in Figure 6 and Figure 7.

[3] In the article Cool Roof Impact on Building Energy Need: The Role of Thermal Insulation with Varying Climate Conditions, (C. Pisellie, A. Pisello, M. Saffari, A de Gracia, F. Contana L. Cabeza *Energies* 2019, 12, 3354 doi:10.3390/en12173354). A simulation study using the EnergyPlus simulation engine identified that the minimum energy consumption roof insulation for mild climates including Sydney was high (R6.25) for a roof with low reflectivity but zero insulation for a roof with high reflectivity, and that the lowest energy use combination overall was a roof with a reflectivity of 80% and no insulation (this was also found to be the most cost effective, using a simple analysis). As the simulations for this study used a moderate reflectivity (55%) it is expected that the results show some aspect of this result. Furthermore, the HVAC energy saving associated with R6.25 insulation (vs no insulation) with a 30% reflective roof was found to be 3.5% for a single storey office building model; this is not far removed from the results found here - 4.2% for Sydney.

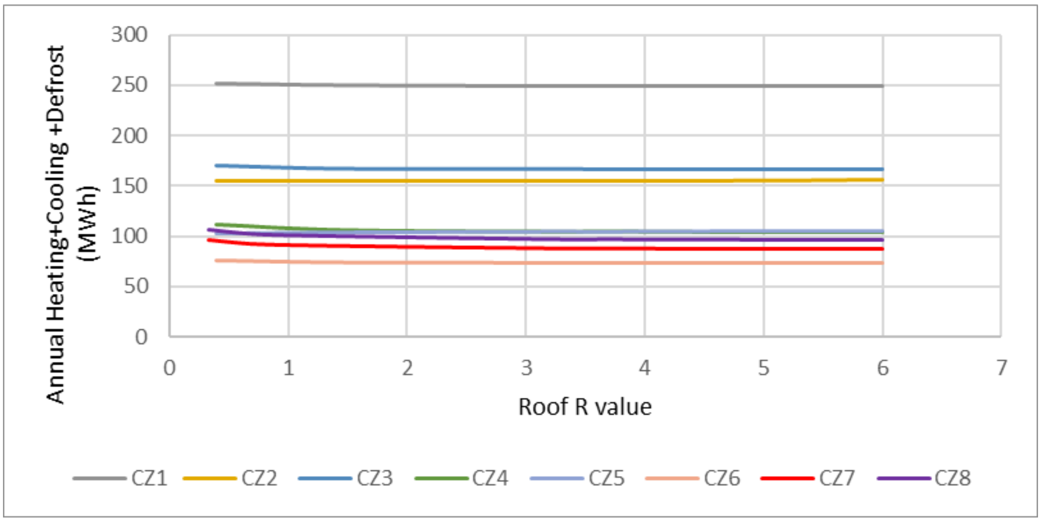



Figure 6. Impact of Roof R-value on HVAC energy use - Medium Office archetype (C5OM)

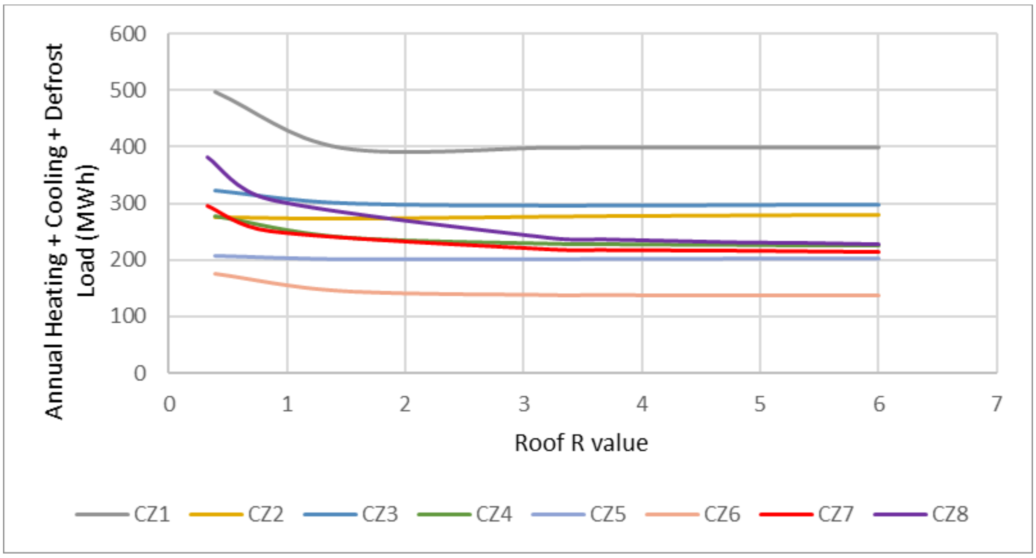



Figure 7. Impact of Roof R-value on energy use - Aged Care archetype (C9C)

The pattern of behaviour shown in the figures appears to reflect three key effects:

1. Internal loads within buildings create heat gains that cannot escape the building if it is better insulated. As a result, cooling energy use appeared largely inert to insulation level. This is projected to be particularly influential in the case of the office archetype, given its relatively high internal loads.
2. The impact of insulation on cooling is significantly reduced by the use of a light-coloured roof, as reported by Piselle et al 2019 (see footnote on previous page).
3. Heating energy is significantly impacted by roof insulation, particularly in the Aged Care archetype, where overnight operation exposes the building to lower temperatures.

The impact of roof R-value on HVAC plant sizing is somewhat more noticeable, as shown Figure 8 to Figure 11.

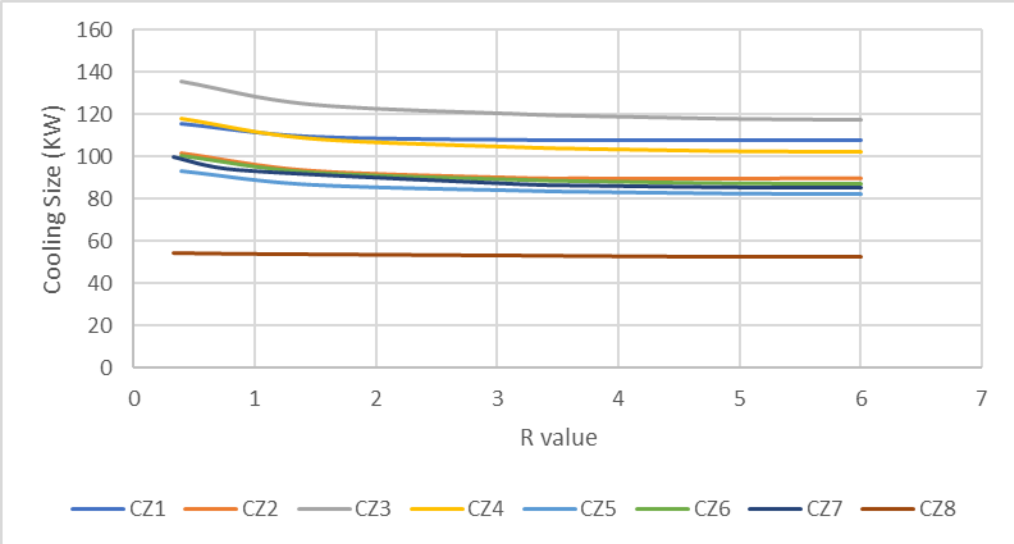



Figure 8. Effect of roof R-value on cooling capacity - Medium Office archetype (C5OM)

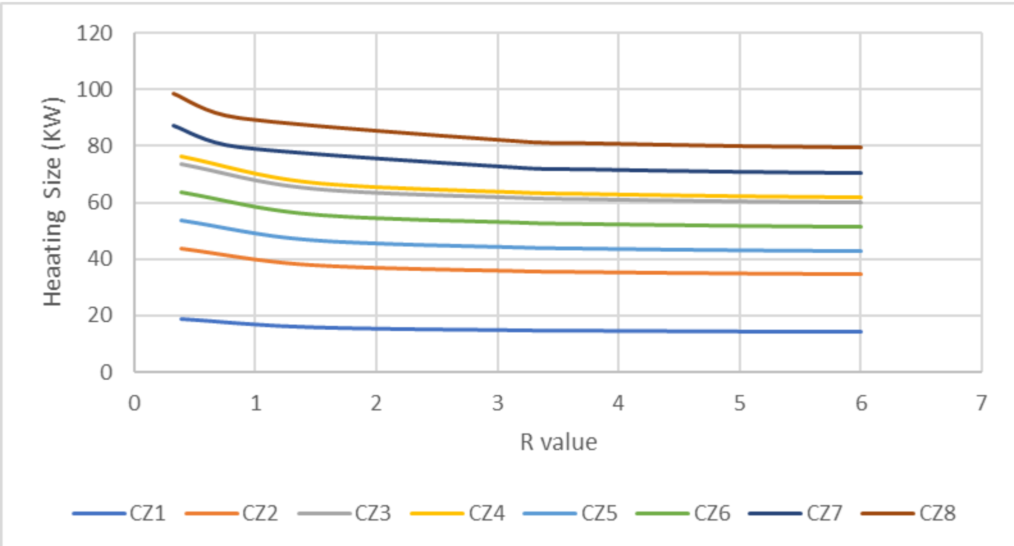



Figure 9. Effect of roof R-value on heating capacity - Medium Office archetype (C5OM)

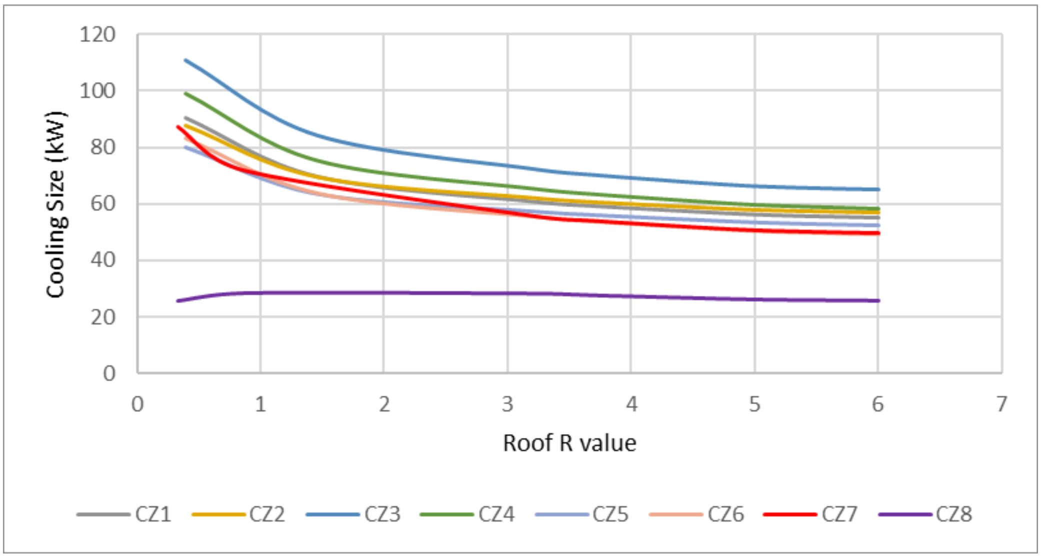



Figure 10. Effect of roof R-value on cooling capacity – Aged Care archetype (C9C)

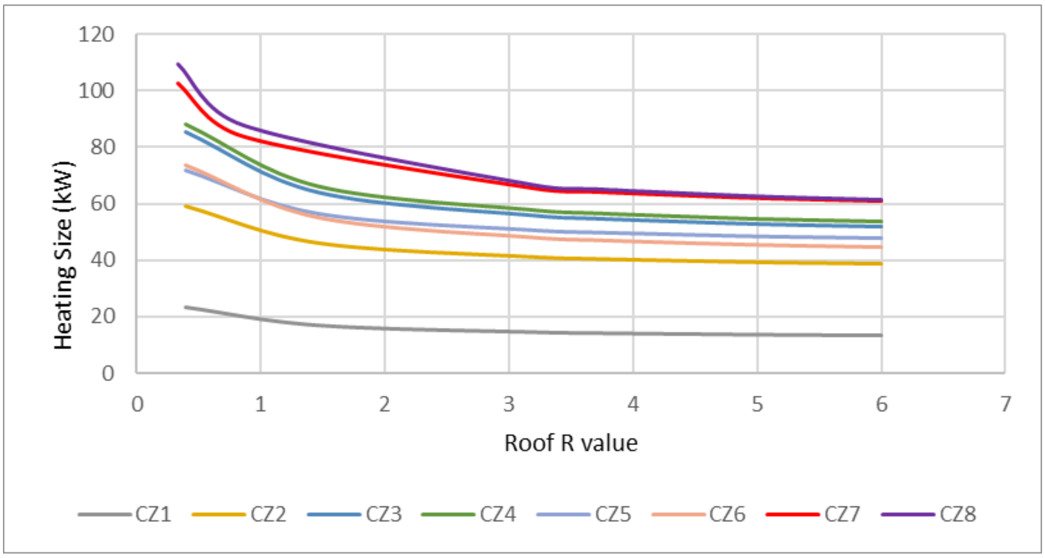



Figure 11. Effect of roof R-value on heating capacity – Aged Care archetype (C9C)

Note that the simulations modelled the roof above an uninsulated suspended ceiling in each case. Stated R-Values do not include the R-Value of the ceiling space and ceiling (typically an additional R0.24).

## 2.5 Benefit-Cost Analysis

For the purpose of the benefit-cost analysis, the ceiling insulation energy figures were taken from the roof insulation scenarios. This is a reasonable approximation within the context of interpretation for the current exercise.

### 2.5.1 Roof insulation

The base case construction for the roof construction cases was selected as the R1.46 uninsulated roof with reflective sarking.

Table 5. Benefit-cost ratios for roof insulation - Medium Office archetype (C5OM)

| CZ | R-Value 2.1 | R-Value 3.2 | R-Value 3.7 | R-Value 4.8 | R-Value 5.4 |
|---|---|---|---|---|---|
| 1 | 0.21 | 0.14 | 0.12 | 0.09 | 0.08 |
| 2 | 0.13 | 0.08 | 0.07 | 0.05 | 0.04 |
| 3 | 0.19 | 0.13 | 0.11 | 0.09 | 0.08 |
| 4 | 0.15 | 0.12 | 0.11 | 0.08 | 0.07 |
| 5 | 0.06 | 0.04 | 0.04 | 0.03 | 0.03 |
| 6 | 0.11 | 0.07 | 0.06 | 0.05 | 0.05 |
| 7 | 0.15 | 0.10 | 0.09 | 0.07 | 0.06 |
| 8 | 0.21 | 0.13 | 0.12 | 0.09 | 0.08 |

Table 6. Table 6. Benefit-cost ratios for roof insulation - Aged Care archetype (C9C)

| CZ | R-Value 2.1 | R-Value 3.2 | R-Value 3.7 | R-Value 4.8 | R-Value 5.4 |
|---|---|---|---|---|---|
| 1 | 0.62 | 0.39 | 0.34 | 0.27 | 0.24 |
| 2 | 0.25 | 0.16 | 0.15 | 0.11 | 0.10 |
| 3 | 0.52 | 0.32 | 0.28 | 0.22 | 0.20 |
| 4 | 0.49 | 0.30 | 0.27 | 0.21 | 0.19 |
| 5 | 0.21 | 0.13 | 0.11 | 0.09 | 0.08 |
| 6 | 0.32 | 0.20 | 0.18 | 0.14 | 0.13 |
| 7 | 0.43 | 0.26 | 0.23 | 0.19 | 0.17 |
| 8 | 0.63 | 0.38 | 0.34 | 0.27 | 0.25 |

### 2.5.2 Ceiling insulation

The base case for ceiling insulation cases was taken as an uninsulated ceiling below a roof with reflective sarking. R-Values reflect the entire roof and ceiling construction.

Table 7. Benefit-cost ratios for roof + ceiling insulation in the Medium Office archetype (C5OM)

| CZ | R-Value 3.11 | R-Value 3.84 | R-Value 4.51 | R-Value 5.11 | R-Value 5.64 |
|---|---|---|---|---|---|
| 1 | 0.76 | 0.78 | 0.74 | 0.68 | 0.63 |
| 2 | 0.46 | 0.46 | 0.43 | 0.40 | 0.36 |
| 3 | 0.77 | 0.83 | 0.81 | 0.75 | 0.68 |
| 4 | 0.68 | 0.75 | 0.73 | 0.68 | 0.63 |
| 5 | 0.25 | 0.27 | 0.27 | 0.26 | 0.23 |
| 6 | 0.43 | 0.45 | 0.45 | 0.42 | 0.39 |
| 7 | 0.58 | 0.63 | 0.63 | 0.59 | 0.54 |
| 8 | 0.80 | 0.83 | 0.81 | 0.77 | 0.73 |

Table 8. Benefit-cost ratios for roof + ceiling insulation in the Aged Care archetype (C9C)

| CZ | R-Value 3.11 | R-Value 3.84 | R-Value 4.51 | R-Value 5.11 | R-Value 5.64 |
|---|---|---|---|---|---|
| 1 | 2.46 | 2.56 | 2.49 | 2.36 | 2.20 |
| 2 | 0.99 | 1.05 | 1.03 | 0.97 | 0.91 |
| 3 | 2.16 | 2.29 | 2.25 | 2.11 | 1.95 |
| 4 | 1.95 | 2.06 | 2.03 | 1.92 | 1.79 |
| 5 | 0.77 | 0.81 | 0.80 | 0.77 | 0.72 |
| 6 | 1.26 | 1.34 | 1.32 | 1.25 | 1.17 |
| 7 | 1.68 | 1.78 | 1.74 | 1.65 | 1.55 |
| 8 | 2.56 | 2.71 | 2.66 | 2.51 | 2.36 |

The ceiling insulation benefit-cost results are illustrated graphically in Figure 12 and Figure 13.

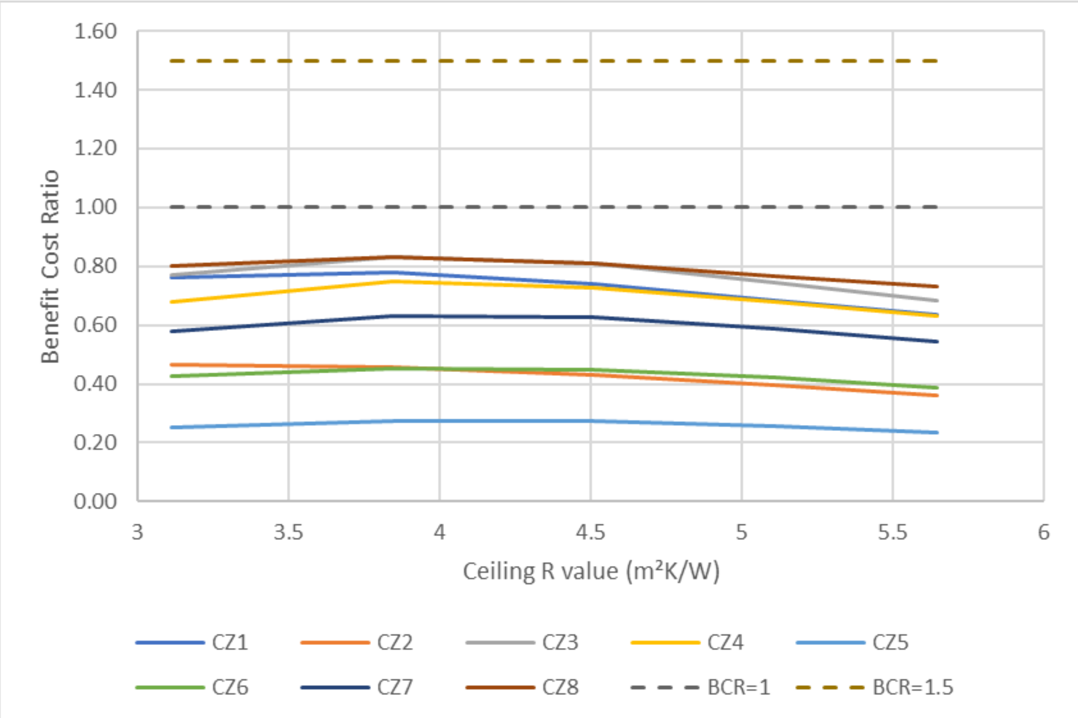



Figure 12. Benefit cost ratios for ceiling insulation in the Medium Office archetype (C5OM)

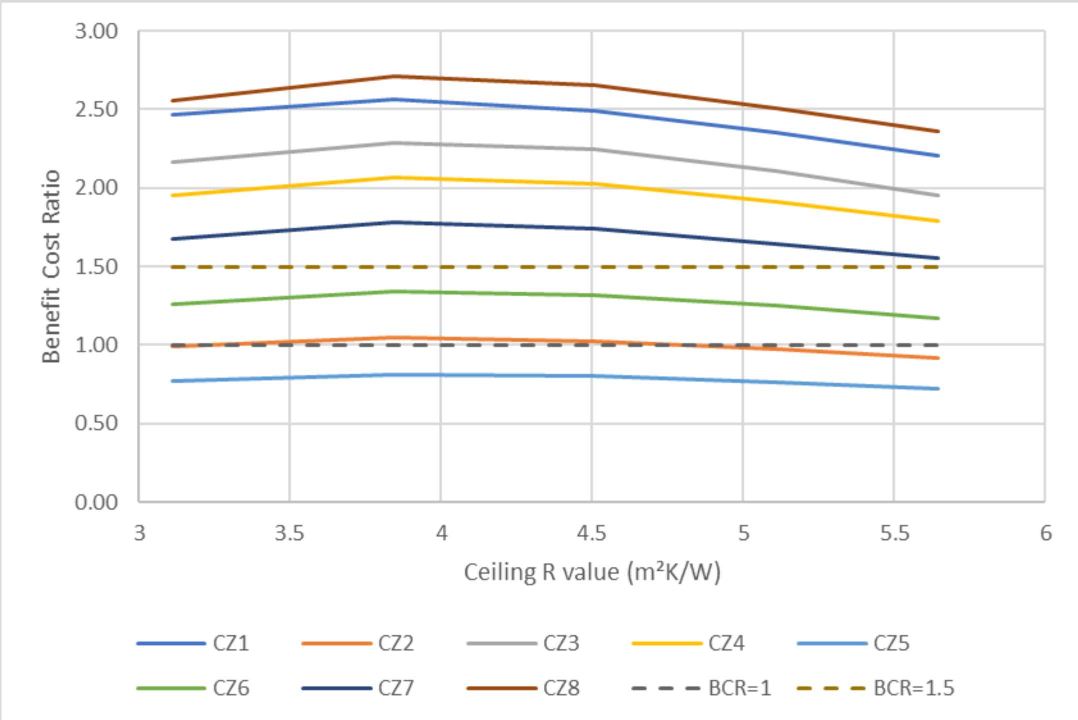



Figure 13. Benefit cost-ratios for ceiling insulation in the Aged Care archetype (C9C)

## 2.6 Discussion

### 2.6.1 Roof insulation vs ceiling insulation

The results for the roof and ceiling insulation scenarios are radically different due to the much higher costs associated with the roof insulation constructions. While certain building types may elect to not have ceilings, this is generally done as a cost saving measure so an argument can be made that additional insulation cost is a cost of that design choice. The economic analyses performed in this report does not address the potential additional cost of a building acquiring a ceiling in order to achieve insulation requirements.

In theory, a roof insulation configuration (with a ceiling) can be used as a plenum thereby avoiding the costs of return air ductwork. However, in practice many buildings will use return air ductwork in this case because of the risk of infiltration in the ceiling space, particularly below the type of lightweight metal roof considered in the roof insulation analysis.

Overall, therefore, there are many dimensions to the in-practice cost and performance of roof/ceiling insulation that go well beyond the scope of this analysis and rapidly become building and construction specific. The Code, on the other hand, needs to provide simple and straightforward measures, in which context the extensive customisation of measures to match individual construction techniques would be unhelpful. Furthermore, the mandate for the current Code update is to increase rather than relax stringency. On this basis, the ceiling insulation analysis has been used as the basis for the development of proposed NCC 2025 measures rather than the roof insulation analysis.

### 2.6.2 Stringency

The NCC 2022 minimum roof R-Values as well as the BCR=1.0 R-values determined in the current exercise are listed in **Error! Reference source not found.**. In this table, C5OM stringency is "n/a" b ecause all stringency settings examined produced BCR values below 1.0 in the C5OM archetype.

Table 9. Comparison of stringencies (R-Value, m²K/W) between NCC2022 and the current analysis using a BCR=1 criterion.

| CZ | NCC 2022 requirements | C5OM stringency at BCR=1.0 | C9C stringency at BCR=1.0 |
|---|---|---|---|
| 1 | 3.7 | n/a | >5.6 |
| 2 | 3.7 | n/a | 4.7 |
| 3 | 3.7 | n/a | >5.6 |
| 4 | 3.7 | n/a | >5.6 |
| 5 | 3.7 | n/a | n/a |
| 6 | 3.2 | n/a | >5.6 |
| 7 | 3.7 | n/a | >5.6 |
| 8 | 4.8 | n/a | >5.6 |

There is no real correspondence between the current results and the existing stringencies. In interpreting this, there are two categories of result of concern:

1. Situations where the analysis shows that the optimum R-Value is greater than the range modelled. For these it is necessary to identify a suitable maximum; in this case, this is the maximum R-Value for which there is a structure, which is approximated as R=5.0[4].
2. Situations where the analysis shows that no case is economic. This is more problematic as there is evidence, as noted earlier, that this may be a real effect of the reflectivity of the roof. However, changing the R-Value to that of an uninsulated roof would appear somewhat radical and is not recommended without significant further validation. In this context, it is worthwhile to consider the shape of the benefit-cost curves in Figure 12 and Figure 13. In both cases, the benefit-cost ratio for insulation across the range R3.2-R4.8 is close to constant, indicating that across this range there is no real difference in overall financial performance. Thus, if one makes the call that some level of insulation is desirable, then the current NCC 2022 figures of R3.2/R3.7/R4.8 are as justifiable as any lower number. Furthermore, these values carry the benefit of lowering system capacity requirements for heating and cooling, which may have downstream impacts not assessed with the current simple analysis. As a result, it is proposed that these requirements are left unchanged.

It is furthermore proposed that the results support differentiated requirements for the insulation of overnight buildings, at the higher level of R5. Finally, it is necessary to modify the analysis figures (which are the average of up and down heat flow values) to match the current regime of heat flow direction nomination (downward for CZ1-6, up for CZ7&8.) This leads to the recommended stringencies as per **Error! Reference source not found.**

[4] HigheR-Values have not been assessed but issues of practicality also intervene: the compliance of common structures with current requirements is open to question, so moving far beyond the range of R-Values in NCC2022 would appear premature.

Table 10. Recommended stringencies – roof insulation.

| CZ | NCC2022 requirements | Daytime buildings | Overnight buildings |
|---|---|---|---|
| 1 | 3.7 (down) | 3.7 (down) | 4.8 (down) |
| 2 | 3.7 (down) | 3.7 (down) | 4.4 (down) |
| 3 | 3.7 (down) | 3.7 (down) | 4.8 (down) |
| 4 | 3.7 (down) | 3.7 (down) | 4.8 (down) |
| 5 | 3.7 (down) | 3.7 (down) | 3.7 (down) |
| 6 | 3.2 (down) | 3.2 (down) | 4.8 (down) |
| 7 | 3.7 (up) | 3.7 (up) | 5.3 (up) |
| 8 | 4.8 (up) | 4.8 (up) | 5.3 (up) |

## 2.7 Proposed Measures

**J4D4 Roof and ceiling construction**

(1) A roof or ceiling must achieve a Total R-Value greater than or equal to—

(a) for a Class 2 common area, a Class 5, 6, 7, 8 or 9b building or a Class 9a building other than a ward area -

(i) in climate zones 1, 3, 4 and 5, R3.7 for a downward direction of heat flow; and

(ii) in climate zone 6, R3.2 for a downward direction of heat flow; and

(iii) in climate zone 7, R3.7 for an upward direction of heat flow; and

(iv) in climate zone 8, R4.8 for an upward direction of heat flow.

(b) for or a Class 3 or 9c building or a Class 9a ward area –

(i) in climate zones 1, 3, 4, and 6, R 4.8 for a downward direction of heat flow

(ii) in climate zones 2, R4.4 for a downward direction of heat flow

(iii) in climate zone 5, R3.7 for a downward direction of heat flow

(iv) in climate zones 7 and 8, R5.3 in an upward direction of heat flow

# 3 Wall Insulation

## 3.1 Background and context

Wall insulation is regulated in NCC2022 via three channels, being.

1. The contribution of wall insulation to the total wall/glazing U-value as identified in J4D6 (1)
2. The wall R-Value requirements for walls with less than 20% glass identified in Table J4D6a
3. The minimum wall R-Value requirements for walls with more than 20% glass identified in J4D6(4)(a)

In this component of the work, we review the stringency of the second and third items. The numerical analysis reported in Sections 3.2, 3.3 and 3.4 relates to the calculation of the second items, i.e. the minimum R-Value for largely unglazed walls. The third item is treated as a separate topic of discussion under Section 3.5.2.

## 3.2 Methodology

The outline methodology for this analysis is presented in Figure 14.

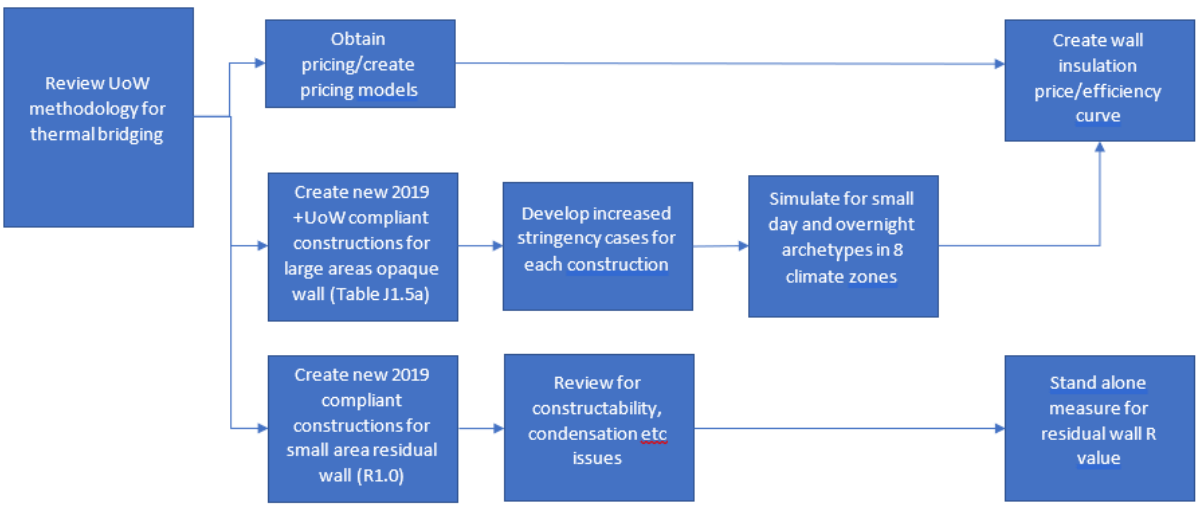



Figure 14. Outline methodology for the wall insulation analysis

### 3.2.1 Construction summary

The metal framing for all wall system typically assumes as following:

- 1.15bmt (base metal thickness) for 150mm studs
- 0.75bmt for 92mm studs
- 0.75bmt for 35mm top hats
- All metal frameworks configured at 600mm centres.

The assumption is based on typical metal framework and its arrangement that is being used as an integral part of many different façade systems. The impact of solely changing thickness does not greatly impact the thermal performance of the overall system but by its nature, having thicker metal framework is expected to result poorer thermal performance.

Wall construction R-Values were calculated using Speckel software, which provides a fast and user-friendly method for AS/NZS 4859.2 compliant calculations for built up constructions.

Table 11. NCC 2022 compliant construction for Small Area Residual Wall

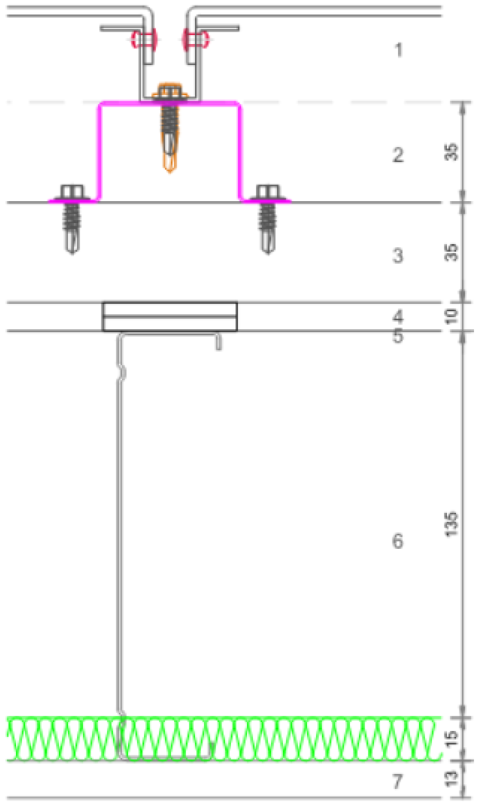
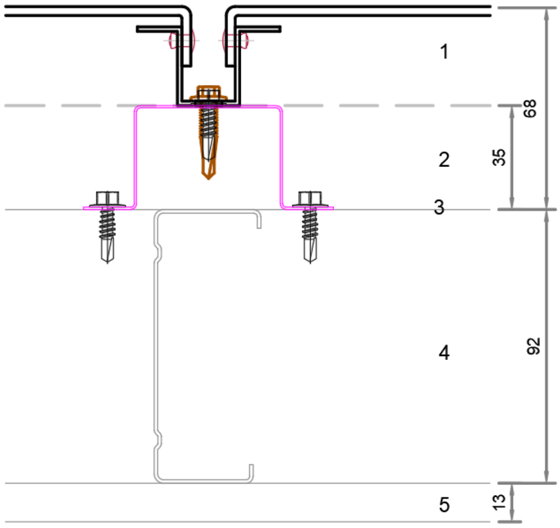
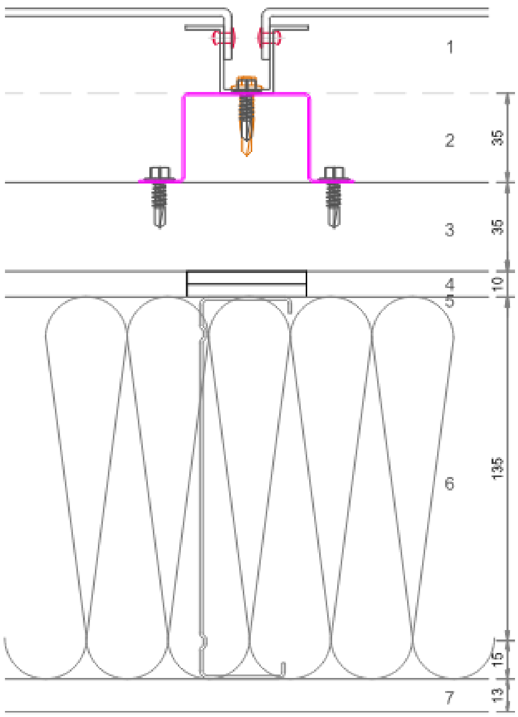
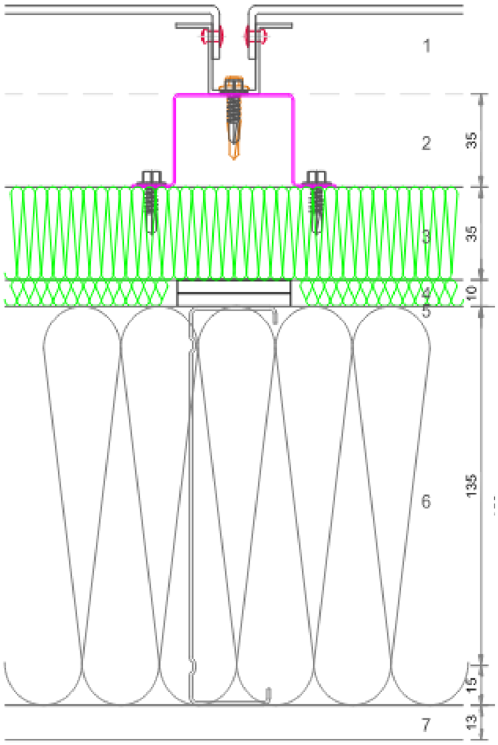
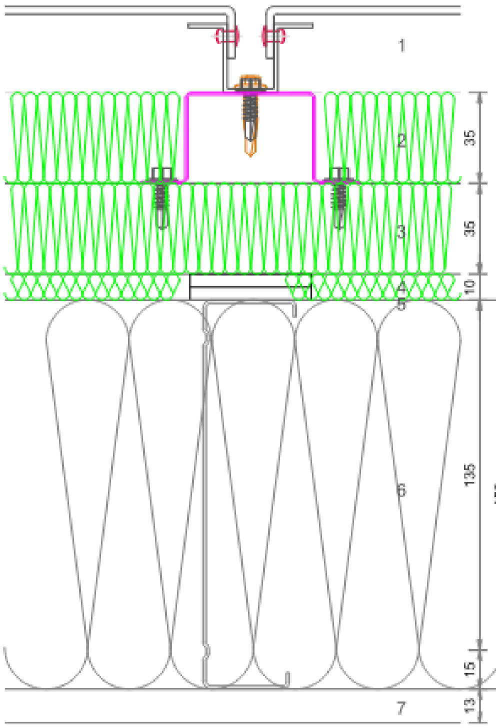
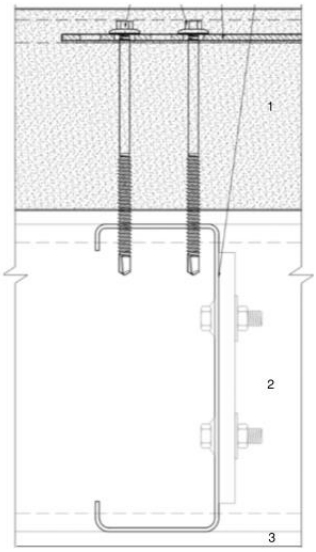
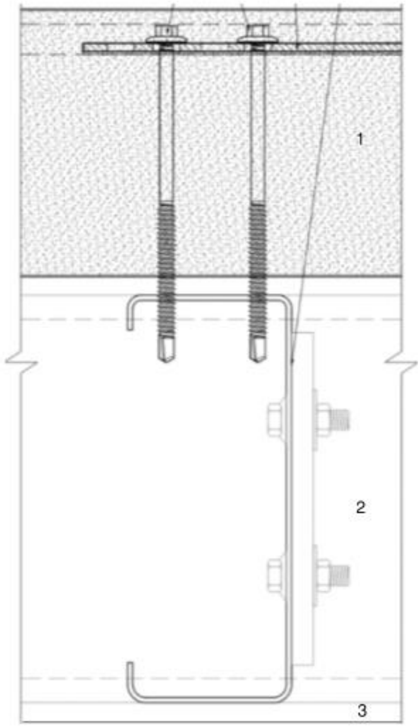
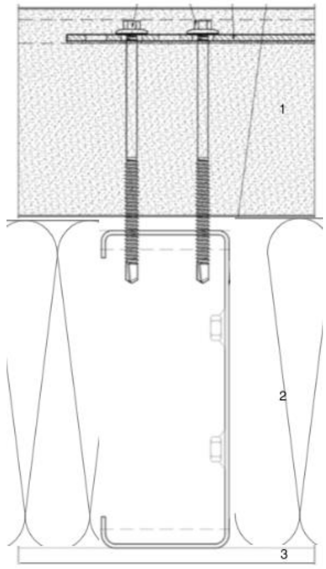
| Case Number | Description | R-value (m².K°/ W) | Configuration |
|---|---|---|---|
| **1** | 1. Metal cladding 4mm (Aluminium)<br>2. Top hat vertically framed at 600mm spacing.<br>3. Top hat horizontally framed at 600mm spacing.<br>4. Thermal break 10mm thick.<br>5.Pliable building membrane 0.6mm<br>6. Stud 150mm, 3 Noggings at 600mm horizontal spacing, 15mm Insulation (fibreglass or equivalent)<br>7. Internal lining 13mm | 1.04 |  |

Table 12. Stringency Cases

| Case Number | Description | R-value (m².K°/ W) | Configuration |
|---|---|---|---|
| **1** | 1. Metal cladding 4mm (Aluminium)<br>2. Top hat horizontally framed at 600mm spacing.<br>3.Pliable building membrane 0.6mm<br>4. Stud 150mm, 3 Noggings at 600mm horizontal spacing.<br>5. Internal lining 13mm | 0.68 |  |
| **2** | 1. Metal cladding 4mm (Aluminium)<br>2. Top hat vertically framed at 600mm spacing.<br>3. Top hat horizontally framed at 600mm spacing.<br>4. Thermal break 10mm thick.<br>5.Pliable building membrane 0.6mm<br>6. Stud 150mm, 3 Noggings at 600mm horizontal spacing. 150mm insulation (Fibreglass equivalent)<br>7. Internal lining 13mm | 2.02 |  |

| Case Number | Description | R-value (m².K°/ W) | Configuration |
|---|---|---|---|
| **3** | 1. Metal cladding 4mm (Aluminium)<br>2. Top hat vertically framed at 600mm spacing<br>3. Top hat horizontally framed at 600mm spacing + insulation rockwool 35mm<br>4. Thermal break 10mm thick + insulation rockwool 10mm<br>5. Pliable building membrane 0.6mm<br>6. Stud 150mm, 3 Noggings at 600mm horizontal spacing. 150mm insulation (Fibreglass equivalent)<br>7. Internal lining 13mm | 2.71 |  |
| **4** | 1. Metal cladding 4mm (Aluminium)<br>2. Top hat vertically framed at 600mm spacing+ insulation stone wool 40mm<br>3. Top hat horizontally framed at 600mm spacing + insulation stone wool 35mm<br>4. Thermal break 10mm thick + insulation stone wool 10mm<br>5. Pliable building membrane 0.6mm<br>6. Stud 150mm, 3 Noggings at 600mm horizontal spacing. 150mm insulation (Fibreglass equivalent)<br>7. Internal lining 13mm | 2.91 |  |

| Case Number | Description | R-value (m².K°/ W) | Configuration |
|---|---|---|---|
| **5** | 1. 175mm metal sandwich panel (e.g. Kingspan Eurobond Rockspan or equivalent)<br>2. Stud 92mm 1 Noggings at 600mm horizontal spacing.<br>3. Internal lining 13mm | 4.04 | <br> |
| **6** | 1. 200mm metal sandwich panel (e.g. Kingspan Eurobond Rockspan or equivalent)<br>2. Stud 92mm 1 Noggings at 600mm horizontal spacing.<br>3. Internal lining 13mm | 4.56 | <br> |

| Case Number | Description | R-value (m².K°/W) | Configuration |
|---|---|---|---|
| **7** | 1. 175mm metal sandwich panel (e.g. Kingspan Eurobond Rockspan or equivalent)<br>2. Stud 92mm 1 Noggings at 600mm horizontal spacing + 90mm insulation<br>3. Internal lining 13mm | 4.81 |  |

The recommended material for the external insulation is stone wool, in which it presents excellent performance in both weather-resistance and combustibility resistance. By the sub-framing configuration within the external cavity, two options of external insulation configuration have been proposed. An additional external insulation layer greatly enhances the thermal performance of the total wall configuration as seen on the table.

R-value calculation for all wall types is in accordance with NCC 2022 Specification 37 which calls up AS/NZS 4859.2 and adopts the methodology of NZS 4214 for thermal bridging effects per each layer. Thermal breaks, assumed 0.2 R-value, are also introduced at the pliable building membrane to minimise thermal bridging effects.

## 3.3 Simulation Methodology and Results

The simulation modelling was undertaken using the simplified single storey model described in Appendix B: Wall Insulation For this model, façade zones of 3.6m depth were modelled around a 35m x 35m. floorplate, with the centre zone being disregarded, giving a total floor area of 452.16m² divided equally between 4 identical cardinally facing zones without windows. The roof and floor for the zones was modelled as adiabatic, i.e., no heat transfer, so the only variable between simulations was the heat transfer through the walls.

A simplified HVAC model was used, whereby heating and cooling loads were calculated on a dynamic basis for the year but with no specific representation of HVAC plant. A COP of 2.9 was used to convert these figures into electrical demand, mimicking a minimally compliant unitary air-conditioner.

Separate models were run using daytime (office) and overnight (hospital ward) schedules.

The energy results are shown in Figure 15 and Figure 16. For the office case can be seen that combined heating and cooling energy use drops most rapidly across the range R0.5-R1, although the more extreme climate zone (CZ1, 7 and 8) shows moderate improvements in the region up to R2.5. Climate zone 5 energy use is marginally lower at lower R-Values; this is an effect relating to the ability of the building to shed heat overnight[5].

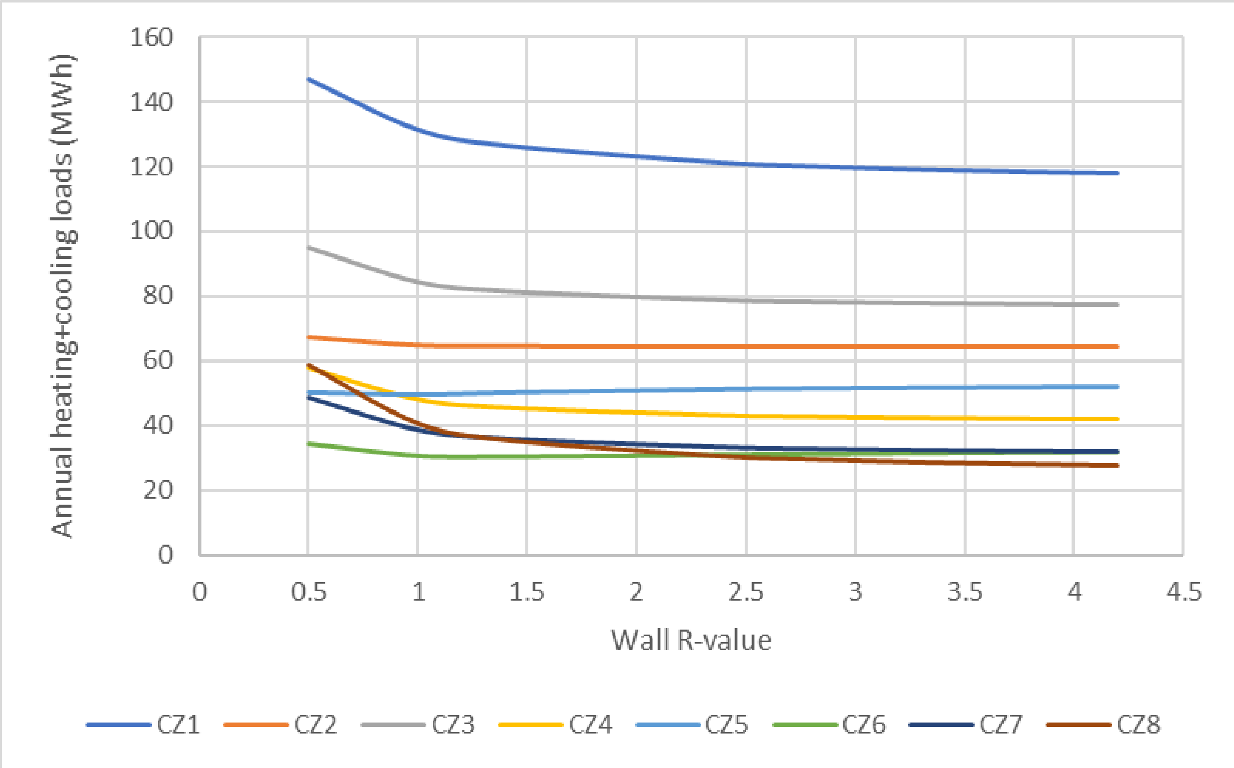



Figure 15. Simulated thermal loads (combined heating and cooling) for the wall insulation office case.

For the hospital ward case, similar behaviour displayed in the extreme climate zones but the response to wall insulation in the temperate climate zones is more nuanced, with generally a lesser overall effect and negative effects in both climate zones 5 and 6.

[5] It is possible that introduction of overnight ventilation could reduce this effect; however it has not been considered in the current analysis.

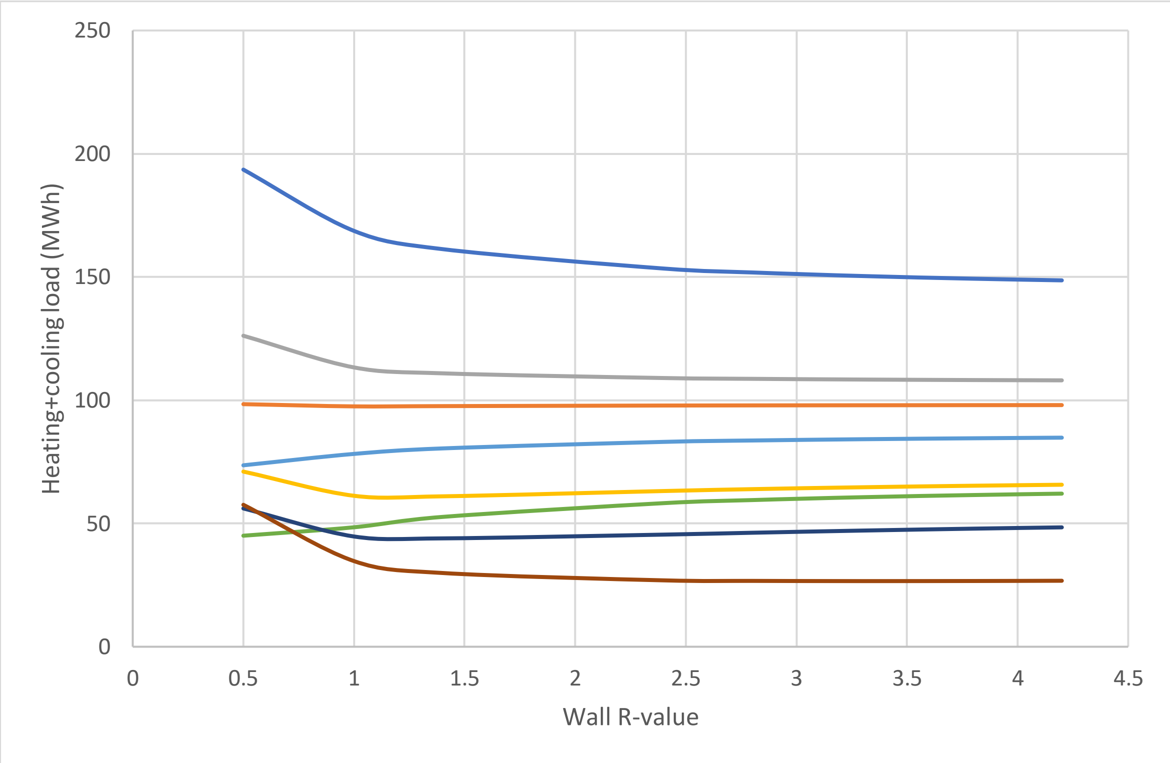



Figure 16. Simulated thermal loads (combined heating and cooling) for the wall insulation hospital ward case.

While the energy consumption is important, the wall insulation also impacts plant sizing, as shown in Figure 17 and Figure 18.

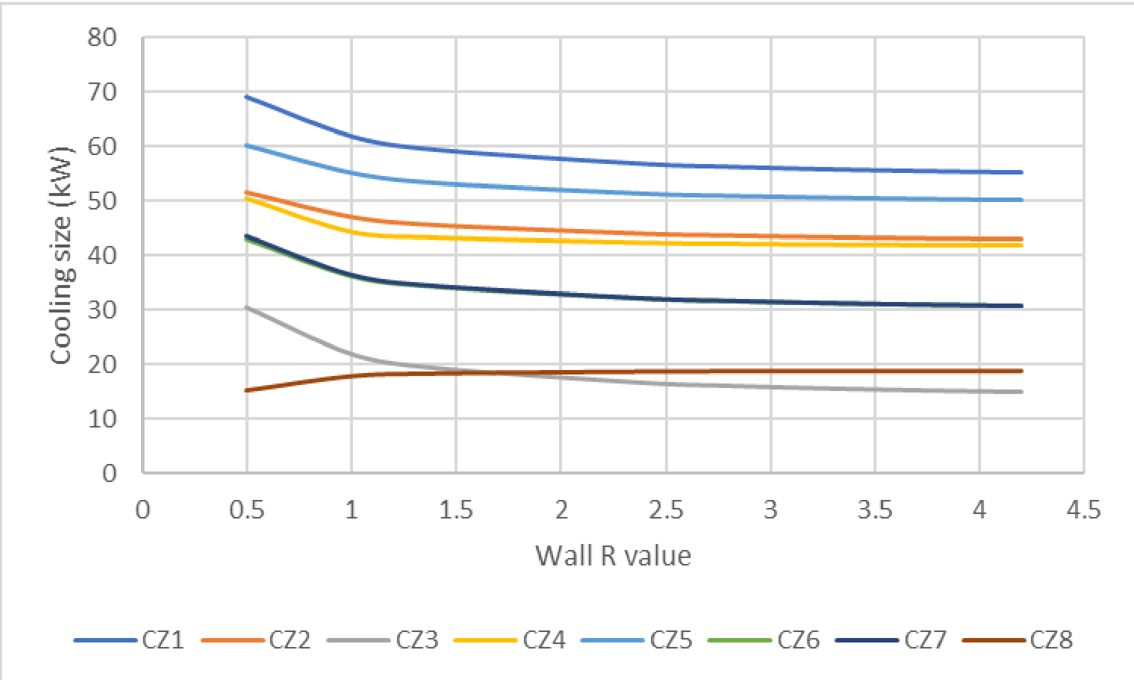



Figure 17. Impact of wall insulation on cooling plant size.

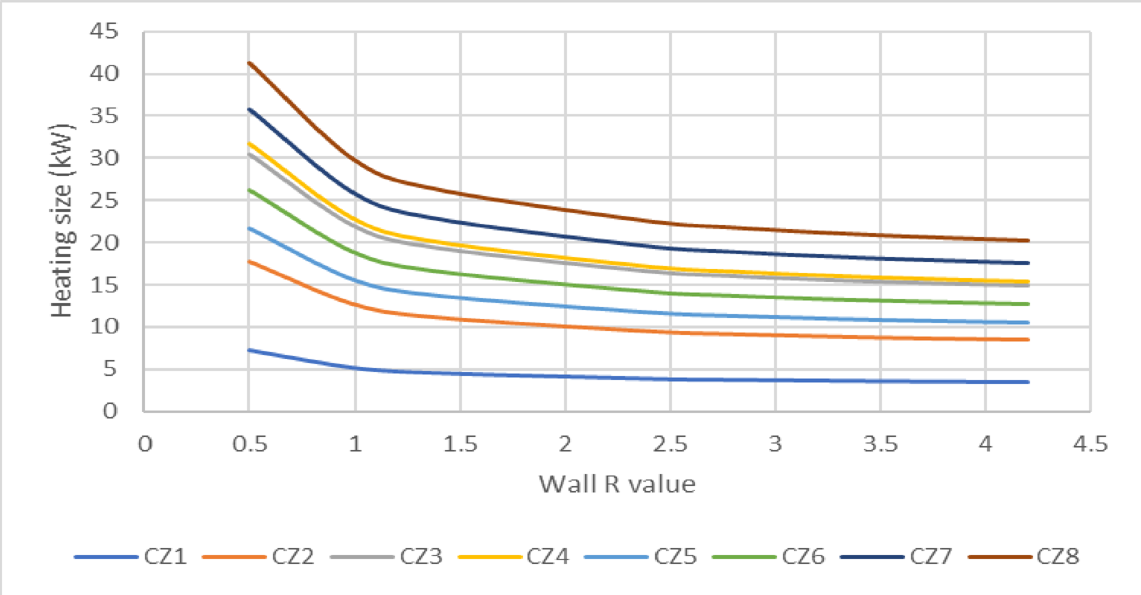



Figure 18. Impact of wall insulation on heating plant size.

The impact of insulation on heating plant size is particularly pronounced. In practice, when looking at energy use, the heating energy consumption in climate zone 1 is nil, so this plant would never be installed.

For the purposes of this analysis, the peak demand is taken to be the peak electrical demand of the plant given the sizing shown in Figure 17 and Figure 18, assuming a PAC unit operating with a COP of 2.9 in both heating and cooling.

## 3.4 Economic analysis

The economic analysis is based on the simplified zone model with wall area of 504m². A 50-year analysis frame has been used, with HVAC plant being replaced at 15-year intervals, reflecting the use of Unitary air-conditioning equipment. HVAC plant size is adjusted based on the change in the maximum of heating and cooling loads for each case relative to the R0.68 baseline at an average PAC unit cost of $474/kW$_{th}$.

The benefit cost ratios based on these figures are listed in **Error! Reference source not found.**and Table 14 and illustrated in Figure 19 and Figure 20.

Table 13. Benefit-cost ratios for wall insulation (by total R-Value) in the daytime (office) archetype.

| Climate Zone | R1 | R1.4 | R2.4 | R2.8 | R3.3 | R3.8 | R4.2 |
|---|---|---|---|---|---|---|---|
| **CZ1** | 4.73 | 2.74 | 1.32 | 1.09 | 0.90 | 0.76 | 0.68 |
| **CZ2** | 0.65 | 0.38 | 0.18 | 0.14 | 0.12 | 0.10 | 0.09 |
| **CZ3** | 2.99 | 1.76 | 0.83 | 0.68 | 0.56 | 0.47 | 0.42 |
| **CZ4** | 2.63 | 1.43 | 0.68 | 0.56 | 0.46 | 0.39 | 0.35 |
| **CZ5** | 0.32 | 0.12 | 0.02 | 0.01 | 0.00 | 0.00 | -0.01 |
| **CZ6** | 1.32 | 0.64 | 0.24 | 0.18 | 0.14 | 0.11 | 0.10 |
| **CZ7** | 3.06 | 1.68 | 0.78 | 0.64 | 0.53 | 0.44 | 0.40 |
| **CZ8** | 14.89 | 4.82 | 1.76 | 1.40 | 1.11 | 0.92 | 0.81 |

Table 14. Benefit-cost ratios for wall insulation (by Total R-value) in the overnight (hospital) archetype.

| Climate Zone | R1 | R1.4 | R2.4 | R2.8 | R3.3 | R3.8 | R4.2 |
|---|---|---|---|---|---|---|---|
| CZ1 | 5.40 | 3.53 | 1.83 | 1.53 | 1.27 | 1.09 | 0.97 |
| CZ2 | 0.46 | 0.23 | 0.09 | 0.07 | 0.06 | 0.05 | 0.04 |
| CZ3 | 6.46 | 2.65 | 1.02 | 0.81 | 0.65 | 0.54 | 0.47 |
| CZ4 | 3.63 | 1.55 | 0.49 | 0.36 | 0.26 | 0.20 | 0.17 |
| CZ5 | -0.82 | -0.60 | -0.35 | -0.30 | -0.26 | -0.22 | -0.20 |
| CZ6 | -0.61 | -0.73 | -0.53 | -0.46 | -0.40 | -0.35 | -0.32 |
| CZ7 | 6.26 | 2.17 | 0.66 | 0.49 | 0.36 | 0.27 | 0.23 |
| CZ8 | 18.56 | 5.69 | 1.90 | 1.48 | 1.15 | 0.93 | 0.81 |

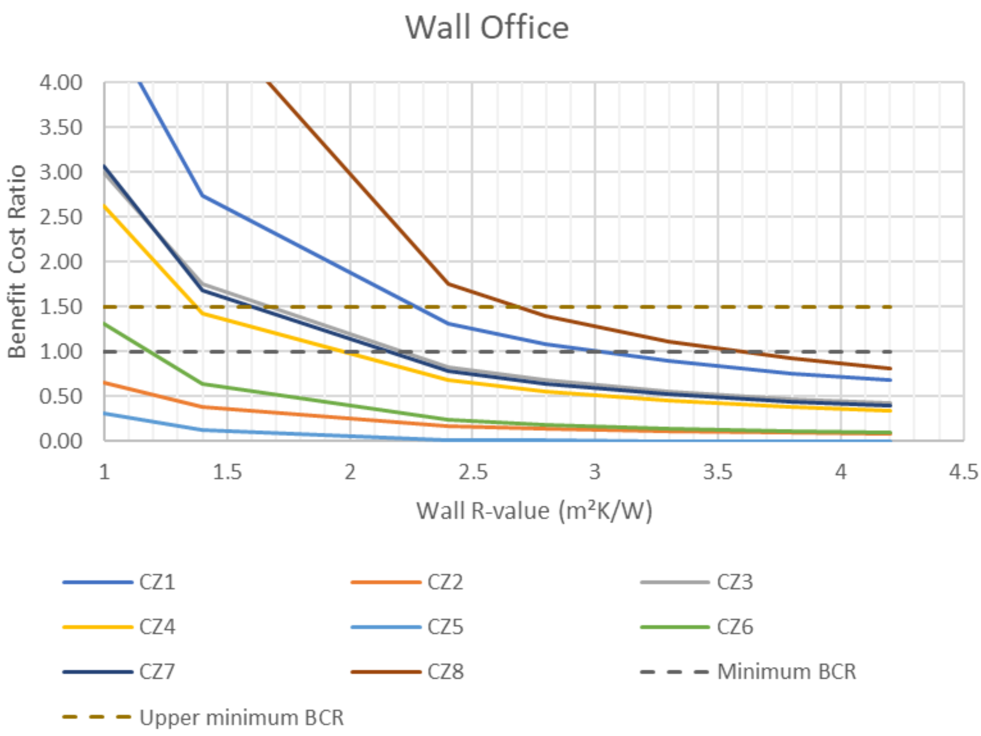



Figure 19 Benefit-cost ratios for wall insulation in the daytime (office) archetype.

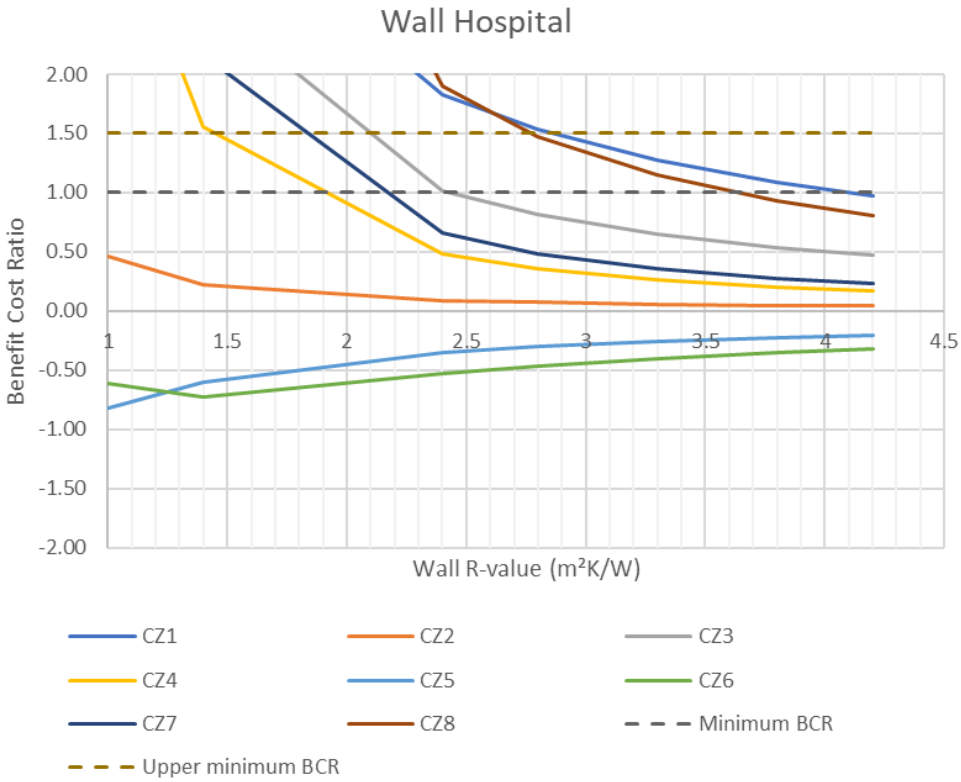



Figure 20. Benefit-cost ratios for wall insulation in the overnight (hospital) archetype.

## 3.5 Discussion

### 3.5.1 Minimum R-Value for walls with less than 20% glazing.

The recommended R-Values for walls with less than 20% glazing are listed in Table 15, along with a comparison to the values from NCC2022. The proposed insulation figures are generally higher than for NCC2022 in the more extreme climate zones but lower in milder zones; this reflects the lack of R-Value impact in these climate zones shown in the results above. For climate zone 2, 5 and 6 the recommended stringency is the minimum R-Value determined in Section 3.5.2.

Table 15. Recommended R-Values for walls with less than 20% glazing. "Min" refers to the case where the analysis does not demonstrate a cost-effective R-Value, with the result that the stringency will be set based on the minimum R-Value analysis presented in Section 3.5.2.

| Climate zone | NCC2022 Daytime | NCC2022 Overnight | NCC 2025 Daytime | NCC 2025 Overnight |
|---|---|---|---|---|
| 1 | 2.4 | 3.3 | 3.0 | 4.0 |
| 2 | 1.4 | 1.4 | Min | Min |
| 3 | 1.4 | 3.3 | 2.2 | 2.4 |
| 4 | 1.4 | 2.8 | 2.0 | 1.9 |
| 5 | 1.4 | 1.4 | Min | Min |
| 6 | 1.4 | 2.8 | 1.2 | Min |
| 7 | 1.4 | 2.8 | 2.2 | 2.2 |

| | | | | |
|---|---|---|---|---|
| 8 | 1.4 | 3.8 | 3.6 | 3.6 |

### 3.5.2 Minimum R-Value for walls with more than 20% glazing

For walls with more than 20% glazing the minimum R-Value is not a function of insulation performance but a reflection of minimum construction requirements in order to avoid condensation. When the current R1.0 minimum was set, no condensation/mould growth analysis was conducted. The purpose of the current analysis is to confirm whether the R1 figure is consistent with a construction that will not have condensation and mould issues.

The basis for assessment has been taken from NCC 2022 F8V1, which states:

"compliance with performance requirement F8P1 is verified for a roof or external wall assembly when it is determined that a mould index of greater than 3, as defined by Section 6 of AIRAH DA07, does not occur on- (a) the interior surface of the water control layer; or (b) the surfaces of building fabric components interior to the water control layer."

To achieve the compliance, Vitanen model (VTT) Mould Index Modelling is required to be conducted by using WUFI 2D software with the input assumptions in accordance with AIRAH DA07.

The following table defines mould index levels:

Table 16. Description of mould index levels

| Mould Index | Description of the growth rate |
|---|---|
| 0 | No growth |
| 1 | Small amounts of mould on surface (microscope), initial stages of local growth |
| 2 | Several local mould growth colonies on surface (microscope) |
| 3 | Visual findings of mould on surface, < 10% coverage, or, < 50% coverage of mould (microscope) |
| 4 | Visual findings of mould on surface, 10 – 50% coverage, or, > 50% coverage of mould (microscope) |
| 5 | Plenty of growth on surface, > 50% coverage (visual) |
| 6 | Heavy and tight growth, coverage about 100 % |

Please refer to Table 11 for the R1 uninsulated wall construction detail assessed.

Following assumptions were set in place:

- **External Climate Condition**: The worst case[6] from available climate data was used, which was Climate Zone 7 (Canberra) with a south orientation, rain exposure factor of 1.5 and deposition factor of 1 for the calculation.
- **Climate Condition internal**: Internal conditions were selected following the ASHRAE 160 standard methodology which is equivalent to the intermediate method for calculating indoor design humidity in Section 4.3.2 of AIRAH DA07. Assumed 2-bedroom units for moisture

[6] If the performance is satisfactory for the worst case then we can be comfortable that it is also satisfactory for less challenging situations. It is not the intent of this analysis to derive a range of minimum R-Values for a range of conditions; rather the intent is merely to validate that the existing R-Value is not in itself problematic.

generation rate approximation[7], with no active dehumidification system in place (I.e. heating and cooling system only).
- **Wall construction.** The wall has been modelled as per the construction detail Table 11, with only exception for insulation in which Rockwool has been specified due to limited data availability for the condensation model. Overall R-value change is negligible and still achieves R1.0 from this change[8].

The results of the analysis are shown in Figure 23 and Figure 24. Mould growth has been assessed on the externally facing side of the gypsum plasterboard lining where it contacts the stud framing, which is the most mould-prone point in the construction.

[7] This is generally higher than most building types, so is a conservative assumption.

[8] The material used in this construction are non-organic and not mould sensitive as defined by AIRAH DA07 Table 6.1.1. As the purpose of the analysis is to show that the R1 minimum construction can be completed in normal practice without causing mould issues, this is appropriate. However, buildings choosing different constructions would have to undertake their own analyses to demonstrate F8P1 compliance.

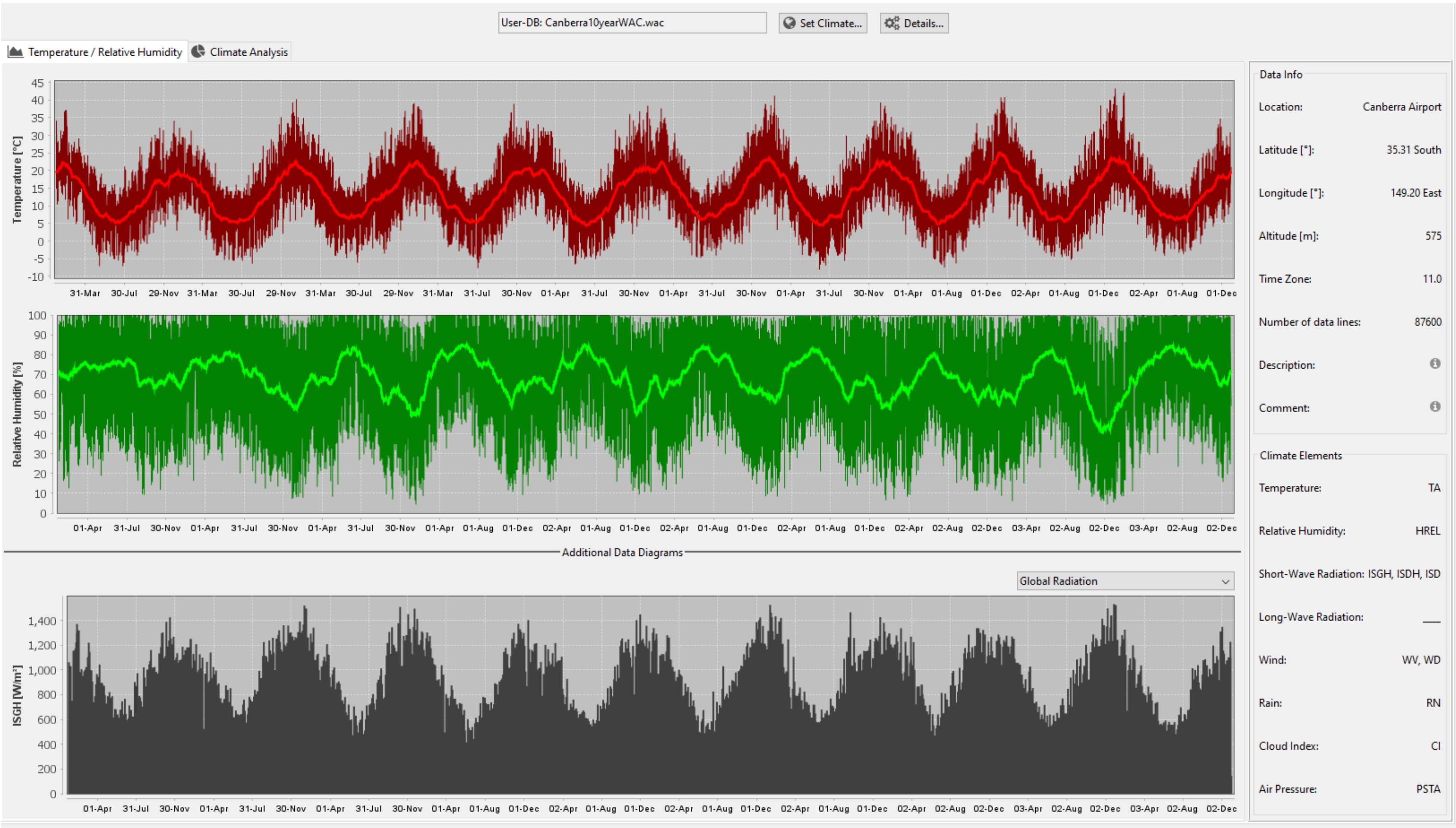



Figure 21. 10-year climate data of temperature, relative humidity and global radiation used for the condensation analysis. The data is measured from Canberra Airport, which has taken as a representative for Climate Zone 7, which is selected as a reasonable “worst case” environment for the analysis.

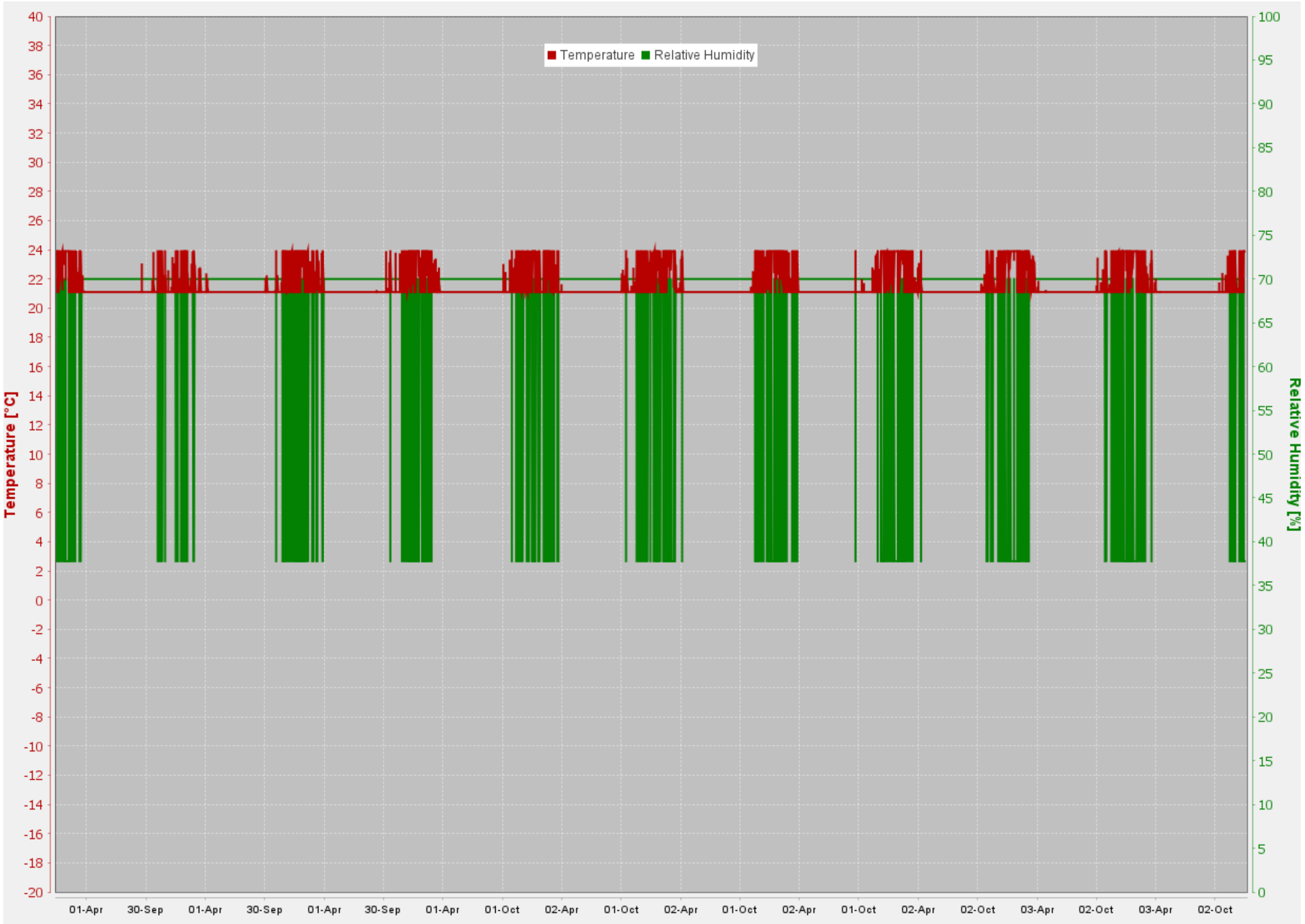



Figure 22. Internal climate condition input. The data is dependent on the external climate data where the mechanical units would be assumed to be operating when heating or cooling is required for its set points. Set point for heating is 21.1°C whilst set point for cooling is 23.9°C as per Table 4.2 in AIRAH DA07, 24/7.

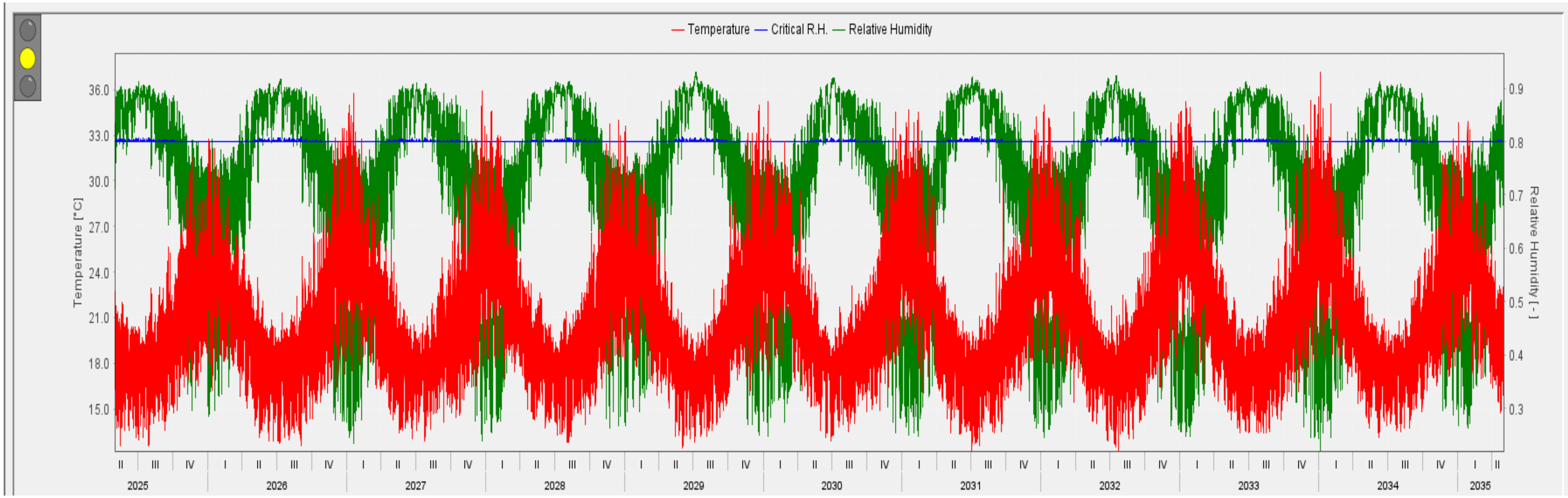



Figure 23. Relative humidity (green), temperature (red), critical relative humidity (blue) relationship graph for gypsum board internal lining interfacing with metal stud. As the relative humidity exceeds the critical relative humidity line (which is defined by mould sensitivity of the material), the mould growth index increases as seen from Figure 24.

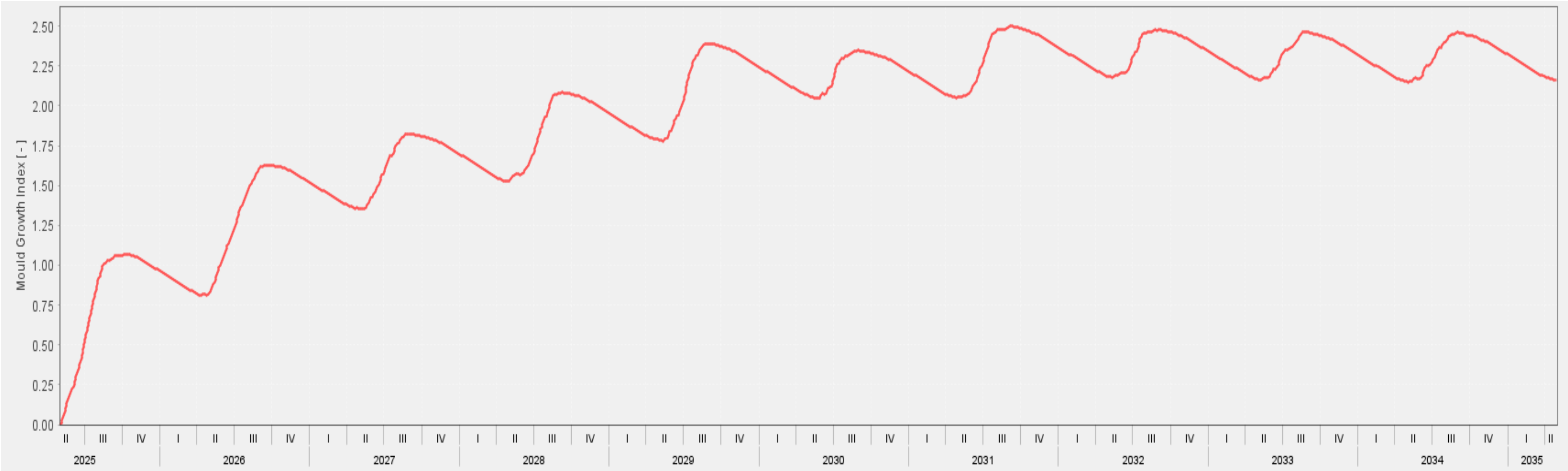



Figure 24. Mould growth index plot against time. The graph presents how the mould growth on the gypsum board internal lining in contact with the stud framing increases for the first 5 years until it reaches an approximate steady state around Mould Growth Index value of 2.5. Where surface temperature is less than or equal to 0 Cellists degree or surface relative humidity is less than or equal to critical relative humidity (AIRAH DA07 equation 6-7), mould index declines dependent on material sensitivity class. This can be observed to occur generally during summer where surface relative humidity drops lower than critical relative humidity.

The analysis above shows that the gypsum board (Internal lining) has incremental mould growth index for first 5 years before reaching approximate steady state at the value of 2.5, which is at is borderline of the criterion value of 3.0.

Thus, it is recommended that R1.0 is retained as the minimum R-Value for wall constructions in the presence of above 20% glazing.

## 3.6 Treatment of unconditioned spaces within the building envelope.

### 3.6.1 Introduction

Section J4D2 Application of Part identifies that J4 applies to elements of the building envelope, a term which has the following definition:

Envelope: For the purposes of—

(a) Section J in NCC Volume One, the parts of a building's fabric that separate a conditioned space or habitable room from—

(i) the exterior of the building; or

(ii) a non-conditioned space including—

(A) the floor of a rooftop plant room, lift-machine room or the like; and

(B) the floor above a carpark or warehouse; and

(C) the common wall with a carpark, warehouse or the like.

An identified issue with this is that there are many non-conditioned spaces with a building, such as toilets and lift shafts that are wholly or mostly enclosed (and in some cases, passively conditioned by exhaust air) and are being interpreted as requiring insulation.  This leads to unnecessary expenditure on insulation against spaces that would be expected to be close to isothermal with the conditioned areas.

A secondary issue in the phrasing of the definition is that (ii) refers to a space while (A)-(C) refer to specific surface elements.

### 3.6.2 Discussion

The issue of how to manage the interface between conditioned and unconditioned spaces is complex, as the need to insulate depends on the degree of exposure of the unconditioned space:  At one extreme an internal toilet has potentially no exposure to outdoor conditions, while an unconditioned corridor adjacent to classrooms may have high infiltration and solar heat gains.  The challenge therefore is to find a succinct way to express the concept of exposure.

The key elements that define a space being exposed are:

1. The space is not insulated as per an element of the building envelope; or
2. The space is affected by solar heat gains through windows; or
3. The space has significant untempered ventilation air or infiltration (i.e., doors in common use).

### 3.6.3 Proposed Code text

The proposed revision to Code text is as follows, applying to the definition of building envelope:

Envelope: For the purposes of—

(a) Section J in NCC Volume One, the parts of a building's fabric that separate a conditioned space or habitable room from—

(i) the exterior of the building; or

(ii) a non-conditioned space that—

(A) is not insulated and sealed to the requirements for a building envelope; or
(B) has outside air ventilation; or
(C) has windows; or
(D) has doors or other openings to the outside in regular use.

# 4 Glazing

## 4.1 Background and context

In NCC2019, the underlying basis of the assessment of glazing was relitigated, resulting in a simplification of the glazing requirements into a small table of wall/glazing U values and a small table of SHGC*WWR-Values (as opposed to many pages of requirements in NCC2016).

The basis of this simplification was to postulate that the glazing measure must start with a presumption about the function of a window. This is necessary as otherwise the fact that wall structures are generally both cheaper and more efficient than windows would mean that the economic optimum would inevitably be a building with no windows.

For NCC2019, this minimum functionality was defined as being the smallest and cheapest window that achieved a defined (and useful) level of daylighting. For this purpose, a daylight factor of 5% was used for day-only building types and 3% for overnight building types[9].

In application, this process did not necessarily yield a significant increase in stringency relative to NCC2016 but did make the process considerably more concise and arguably more robust. Major criticisms levelled at the approach appear to have been:

1. The use of daylight factor – which is based on daylighting arising from a uniform grey sky – is poorly suited to the Australian climate.
2. The differences in SHGC*WWR requirements between facades were small, which is counterintuitive to the expectation of more stringent solar mitigation requirements for North facades relative to South facades.

No changes were made to these provisions between NCC2019 and NCC2022. In the analysis for NCC 2025 we have identified two potential changes that directly and indirectly address the criticisms:

1. The daylight question has been readdressed, using sDA (specific daylight autonomy) as a metric rather than daylight factor. sDA is a measure based on hourly solar data that accounts for direct sun as well as diffuse radiation and is both climate and aspect dependent[10].
2. The possibility of adding a non-negotiable maximum solar admittance figure (in addition to the current maximum solar admittance, which can be breached via use of Section 37 Method 2). This is proposed to ensure that Code does not allow uncontrollable solar gains on sun-facing facades, while also assuring the overall efficiency outcome.

## 4.2 Methodology

The outline methodology for this analysis is shown in Figure 25.

[9] The provision of natural light is not a requirement of Code except Clause F6P1 which specifies a minimum daylight factor of 2% for class 2, 3 and 9 buildings.

[10] Daylight factor, being based on a uniform grey sky, is independent of both climate and aspect.

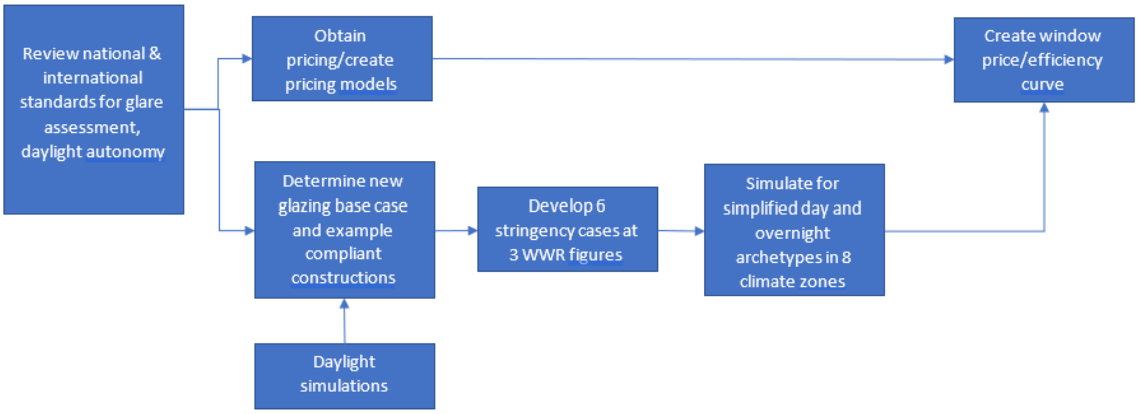



Figure 25. Outline methodology for the glazing analysis.

The process for each of the work items in the above methodology is outlined in the following sections. Where required for continuity, intermediate results have also been presented.

### 4.2.1 SDA analysis

The analysis of daylighting metrics for this project is provided in Section 7.1. In this section, it is identified that a suitable adaptation of international standards for application of SDA is that a perimeter zone should achieve an sDA equivalent 300lux being achieved 50% of the time (daylight hours when the building is occupied) across 85% of its area. This is not a direct translation of other schemes using sDA, as these specify sDA across entire floor plates, which would be incompatible with Code process (without a radical rethink).

Initial exploratory work identified that this level of sDA would not be compatible with NCC2019/22 SHGC*WWR requirements for overnight operating buildings. This arises because such buildings do not have an underlying requirement for a lighting level of 300 lux - for example the general background illumination requirements for wards from AS1680 is 160 lux rather than 320 lux (for offices). On this basis the decision was made to define the sDA requirements for these building types based on 160lux for 50% of the time for 85% of the perimeter zone area.

Analysis presented in Section 7.1 shows that the required sDA levels can be met by the following VLT*WWR[11] levels across a wide range of VLT and WWR selections.

Table 17. Minimum VLT*WWR figures required to achieve the stated sDA levels. For comparison, NCC2019 asserted 0.18 and 0.108 VLT*WWR baselines based on daylight factor.

| Aspect | VLT*WWR for 300 lux 50%/85% | VLT*WWR for 160 lux 50%/85% |
|---|---|---|
| **North** | 0.13 | 0.075 |
| **West** | 0.13 | 0.075 |
| **South** | 0.17 | 0.09 |
| **East** | 0.15 | 0.09 |

These were used in the following analyses to redefine the base case glazing.

[11] VLT is the visual light transmittance of a window.

### 4.2.2 Underlying archetypes

The glazing analysis was undertaken using a simplified archetype model consisting geometrically of one intermediate floor of the C5OL large office building, operating with loads and schedules from:

1. Large office: representing day-time operating archetypes
2. Hospital ward: representing overnight operating archetypes.

Each façade aspect was assessed separately throughout the analysis.

## 4.3 Derivation of revised solar admittance requirements

### 4.3.1 Maximum solar admittance – initial analysis

In order to convert the VLT*WWR requirements in Table 17 into solar admittance (SHGC*WWR) it is necessary to define a relationship between SHGC and WWR based on available glazing products. Based on a range of available glazing options, this relationship was identified in Figure 26. The lower line represents the lowest SHGC available for a given VLT, while the upper line is slightly more relaxed.

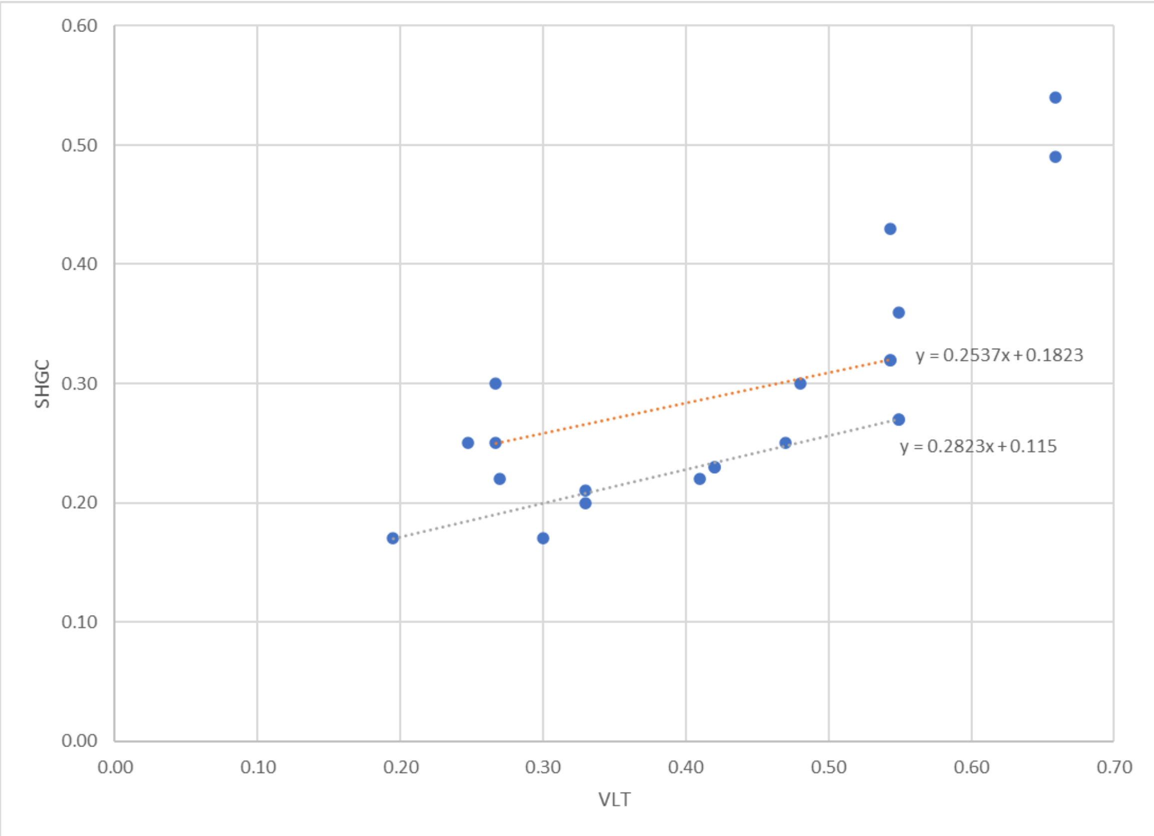



Figure 26. Identification of "best" SHGC to VLT relationship. The lower line represents the optimum SHGC to VLT relationship; the upper line represents a more relaxed standard as a comparison.

On this basis, the base case solar admittance figures were derived from the VLT*WWR figures listed in Table 17. The resultant solar admittance figures are shown in Table 18 and Table 19.

Table 18. Calculated solar admittance limits based on SDA requirements – daytime archetype.

| CZ | WWR | Lower SHGC/VLT Line - East | Lower SHGC/VLT Line - North | Lower SHGC/VLT Line - South | Lower SHGC/VLT Line - West | Upper SHGC/VLT line - East | Upper SHGC/VLT line - North | Upper SHGC/VLT line - South | Upper SHGC/VLT line - West |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 30% | 0.08 | 0.07 | 0.08 | 0.07 | 0.09 | 0.09 | 0.10 | 0.09 |
| 2 | 30% | 0.08 | 0.07 | 0.08 | 0.07 | 0.09 | 0.09 | 0.10 | 0.09 |
| 3 | 30% | 0.08 | 0.07 | 0.08 | 0.07 | 0.09 | 0.09 | 0.10 | 0.09 |
| 4 | 30% | 0.08 | 0.07 | 0.08 | 0.07 | 0.09 | 0.09 | 0.10 | 0.09 |
| 5 | 30% | 0.08 | 0.07 | 0.08 | 0.07 | 0.09 | 0.09 | 0.10 | 0.09 |
| 6 | 30% | 0.08 | 0.07 | 0.08 | 0.07 | 0.09 | 0.09 | 0.10 | 0.09 |
| 7 | 30% | 0.08 | 0.07 | 0.08 | 0.07 | 0.09 | 0.09 | 0.10 | 0.09 |
| 8 | 30% | 0.08 | 0.07 | 0.08 | 0.07 | 0.09 | 0.09 | 0.10 | 0.09 |
| 1 | 50% | 0.10 | 0.09 | 0.11 | 0.09 | 0.13 | 0.12 | 0.13 | 0.12 |
| 2 | 50% | 0.10 | 0.09 | 0.11 | 0.09 | 0.13 | 0.12 | 0.13 | 0.12 |
| 3 | 50% | 0.10 | 0.09 | 0.11 | 0.09 | 0.13 | 0.12 | 0.13 | 0.12 |
| 4 | 50% | 0.10 | 0.09 | 0.11 | 0.09 | 0.13 | 0.12 | 0.13 | 0.12 |
| 5 | 50% | 0.10 | 0.09 | 0.11 | 0.09 | 0.13 | 0.12 | 0.13 | 0.12 |
| 6 | 50% | 0.10 | 0.09 | 0.11 | 0.09 | 0.13 | 0.12 | 0.13 | 0.12 |
| 7 | 50% | 0.10 | 0.09 | 0.11 | 0.09 | 0.13 | 0.12 | 0.13 | 0.12 |
| 8 | 50% | 0.10 | 0.09 | 0.11 | 0.09 | 0.13 | 0.12 | 0.13 | 0.12 |
| 1 | 70% | 0.12 | 0.12 | 0.13 | 0.12 | 0.17 | 0.16 | 0.17 | 0.16 |
| 2 | 70% | 0.12 | 0.12 | 0.13 | 0.12 | 0.17 | 0.16 | 0.17 | 0.16 |
| 3 | 70% | 0.12 | 0.12 | 0.13 | 0.12 | 0.17 | 0.16 | 0.17 | 0.16 |
| 4 | 70% | 0.12 | 0.12 | 0.13 | 0.12 | 0.17 | 0.16 | 0.17 | 0.16 |
| 5 | 70% | 0.12 | 0.12 | 0.13 | 0.12 | 0.17 | 0.16 | 0.17 | 0.16 |
| 6 | 70% | 0.12 | 0.12 | 0.13 | 0.12 | 0.17 | 0.16 | 0.17 | 0.16 |
| 7 | 70% | 0.12 | 0.12 | 0.13 | 0.12 | 0.17 | 0.16 | 0.17 | 0.16 |
| 8 | 70% | 0.12 | 0.12 | 0.13 | 0.12 | 0.17 | 0.16 | 0.17 | 0.16 |

Table 19. Calculated solar admittance limits based on sDA requirements - overnight archetype.

| CZ | WWR | Lower SHGC/VLT Line - East | Lower SHGC/VLT Line - North | Lower SHGC/VLT Line - South | Lower SHGC/VLT Line - West | Upper SHGC/VLT line - East | Upper SHGC/VLT line - North | Upper SHGC/VLT line - South | Upper SHGC/VLT line - West |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 20% | 0.05 | 0.04 | 0.05 | 0.04 | 0.06 | 0.06 | 0.06 | 0.06 |
| 2 | 20% | 0.05 | 0.04 | 0.05 | 0.04 | 0.06 | 0.06 | 0.06 | 0.06 |
| 3 | 20% | 0.05 | 0.04 | 0.05 | 0.04 | 0.06 | 0.06 | 0.06 | 0.06 |
| 4 | 20% | 0.05 | 0.04 | 0.05 | 0.04 | 0.06 | 0.06 | 0.06 | 0.06 |
| 5 | 20% | 0.05 | 0.04 | 0.05 | 0.04 | 0.06 | 0.06 | 0.06 | 0.06 |
| 6 | 20% | 0.05 | 0.04 | 0.05 | 0.04 | 0.06 | 0.06 | 0.06 | 0.06 |
| 7 | 20% | 0.05 | 0.04 | 0.05 | 0.04 | 0.06 | 0.06 | 0.06 | 0.06 |
| 8 | 20% | 0.05 | 0.04 | 0.05 | 0.04 | 0.06 | 0.06 | 0.06 | 0.06 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 30% | 0.06 | 0.06 | 0.06 | 0.06 | 0.08 | 0.07 | 0.08 | 0.07 |
| 2 | 30% | 0.06 | 0.06 | 0.06 | 0.06 | 0.08 | 0.07 | 0.08 | 0.07 |
| 3 | 30% | 0.06 | 0.06 | 0.06 | 0.06 | 0.08 | 0.07 | 0.08 | 0.07 |
| 4 | 30% | 0.06 | 0.06 | 0.06 | 0.06 | 0.08 | 0.07 | 0.08 | 0.07 |
| 5 | 30% | 0.06 | 0.06 | 0.06 | 0.06 | 0.08 | 0.07 | 0.08 | 0.07 |
| 6 | 30% | 0.06 | 0.06 | 0.06 | 0.06 | 0.08 | 0.07 | 0.08 | 0.07 |
| 7 | 30% | 0.06 | 0.06 | 0.06 | 0.06 | 0.08 | 0.07 | 0.08 | 0.07 |
| 8 | 30% | 0.06 | 0.06 | 0.06 | 0.06 | 0.08 | 0.07 | 0.08 | 0.07 |
| 1 | 40% | 0.07 | 0.06 | 0.07 | 0.06 | 0.09 | 0.08 | 0.09 | 0.08 |
| 2 | 40% | 0.07 | 0.06 | 0.07 | 0.06 | 0.09 | 0.08 | 0.09 | 0.08 |
| 3 | 40% | 0.07 | 0.06 | 0.07 | 0.06 | 0.09 | 0.08 | 0.09 | 0.08 |
| 4 | 40% | 0.07 | 0.06 | 0.07 | 0.06 | 0.09 | 0.08 | 0.09 | 0.08 |
| 5 | 40% | 0.07 | 0.06 | 0.07 | 0.06 | 0.09 | 0.08 | 0.09 | 0.08 |
| 6 | 40% | 0.07 | 0.06 | 0.07 | 0.06 | 0.09 | 0.08 | 0.09 | 0.08 |
| 7 | 40% | 0.07 | 0.06 | 0.07 | 0.06 | 0.09 | 0.08 | 0.09 | 0.08 |
| 8 | 40% | 0.07 | 0.06 | 0.07 | 0.06 | 0.09 | 0.08 | 0.09 | 0.08 |

In the development of NCC2019, the solar admittance requirement was derived based on the minimum WWR, reflecting the philosophy of matching the minimum cost model. This approach is still valid and would favour the use of the 30% WWR for daytime archetypes and the 20% WWR for overnight archetypes. However, the approach needs to be balanced against two practical considerations:

- **Maximum WWR:** The implied maximum WWR for an unshaded window, which is the solar admittance divided by 0.17 (the lowest available VLT), which gives 35% at 0.06 and 59% at 0.1.
- **sDA at higher WWRs:** If the solar admittance standard for the smallest WWR is used to determine the maximum solar admittance, then larger WWRs will not in general achieve the intended sDA standard without the use of shading[12]. This is because the very low SHGC values are not available with suitable visual transmittance values. This issue existed in NCC2022, but was not factored into the analysis at the time.

These factors favour the use of a higher WWR in the derivation of the maximum solar admittance values. As a result, it is proposed that the solar admittance values derived for the medium WWR in each archetype is used as the basis for Stringency 1 and 2 of the overall analysis, rather than the minimum WWR. This provides somewhat of a balance between increased stringency and the desire to balance the practical considerations above. However, for Stringency 3 (net zero ready),

[12] In general, it is a limitation of the current analysis that all windows are considered without shading, which obliges all of the solar heat gain and visual transmission goals to be achieved by glass selection. Best practice in industry is to mix glazing selections with shading to achieve good solar performance while maintaining – and indeed improving – daylighting and glare performance. However, as an energy efficiency measure, shading is not cost effective. As a result, one interpretation of the solar admittance results is that if the limit is based on a given WWR, then buildings above that WWR that want to achieve the daylight result will need to use external shading to achieve this; however, buildings can still comply with the code measure without shading, just with less than ideal daylight performance.

consideration should be given to using the lower solar admittance figures arising from the use of the lower WWR.

Furthermore, in the interests of maintaining a higher overall stringency, the solar admittance values derived from the lower SHGC/VLT line are preferred. This is again consistent with the NCC2019 methodology. It can be seen in Table 18 and Table 19 however that the use of the medium WWR has the benefit of enabling sDA achievement over a reasonable range with the less constricted glazing selection.

### 4.3.2 Base case – glazing selections

Base case NCC 2022 compliant constructions were derived on the basis of a lightweight framed wall with glazing at 30%, 50% and 70% WWR for daytime archetypes and 20%, 30% and 40% for overnight operating archetypes. Compliance criteria were set as being compliance with NCC2022 Solar admittance and wall/glazing U value requirements while also meeting the VLT*WWR requirements outlined in Table 17.

The process for undertaking this was as follows (for each CZ/WWR):

1. The required solar admittance and wall/gazing U values were identified for each case (separately for each façade, each climate zone and the two base archetypes being represented)
2. Reasonable wall R-Values were selected for each case. This was mostly based on a framed structure with maximum insulation within the frame unless this produced unfeasible window U-value requirements (in which case wall R-Values were increased to achieve compliance with a realistic glazing selection). The wall R-values used are listed in Table 20. Wall R-Values used for the compliant glazing models.

Table 20. Wall R-Values used for the compliant glazing models

| Climate zone | Opaque Wall R-value ($m^2K/W$) - Simplified Office Model | Opaque Wall R-value ($m^2K/W$) - Simplified Ward Model |
|---|---|---|
| **CZ1** | 1.4 | 1.9 |
| **CZ2** | 1.4 | 1 |
| **CZ3** | 1.4 | 1.9 |
| **CZ4** | 1.4 | 1.9 |
| **CZ5** | 1.4 | 1 |
| **CZ6** | 1.4 | 1.9 |
| **CZ7** | 1.4 | 1.9 |
| **CZ8** | 1.4 | 4.07 |

3. A database of suitable glazing types was assessed for SHGC, U value and VLT properties. These were then selected to ensure compliance firstly with the VLT requirements and secondly (as far as possible) with the NCC2019 solar admittance and wall/glazing U value requirements.
4. SHGC figures for the selected glazing types were then processed to produce a revised compliance table for solar admittance.

The resultant glazing selections and properties are summarised in Table 53 and Table 58in the appendices.

### 4.3.3 Simulation Methodology

In order to complete the balance of the assessment, it was necessary to undertake simulation studies.
The simulation modelling was undertaken using the simplified single storey model consisting of a single floor from the C5OL model, with adiabatic floor and ceiling (i.e. no heat transfer). Façade zones of 3.6m depth were modelled around a 35m x 35m. floorplate, with the centre zone being disregarded, giving a total floor area of 452.16m² divided equally between 4 identical cardinally facing zones without windows.

A simplified HVAC model was used, whereby heating and cooling loads were calculated on a dynamic basis for the year but with no specific representation of HVAC plant. A COP of 2.9 was used to convert these figures into electrical demand, mimicking a minimally compliant unitary air-conditioner.

Separate models were run using daytime (office) and overnight (hospital ward) schedules.

### 4.3.4 Additional SHGC analyses

The analysis in Section 4.3.1 sets a maximum window sized based on the assertion that smaller windows inevitably means lower energy use – which is broadly true. However, it is known that in colder climates there is a balance between the reduction in cooling and the loss in passive solar heat gain, which can result in larger windows being a more efficient outcome. As a result, it is necessary to test scenarios where the solar admittance is raised above the minimum level to determine whether the energy use improves in any cases. This was achieved by varying the total solar admittance while keeping WWR constant.

Energy impacts – daytime archetype

The results for increased solar admittance for the daytime archetype are shown in Figure 27 to Figure 34.

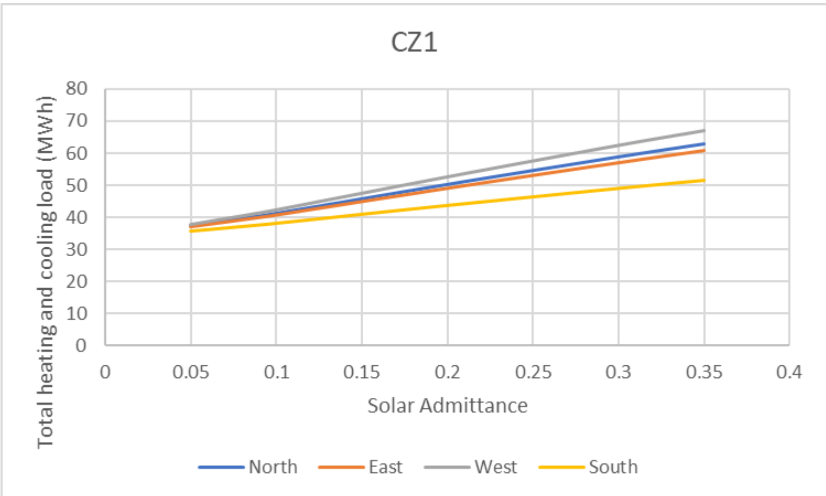



Figure 27. Total heating and cooling load versus solar admittance, daytime archetype, climate zone 1.

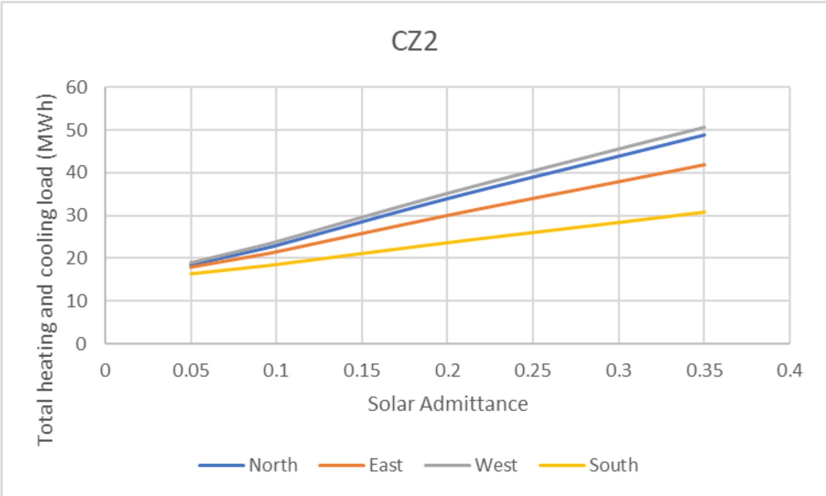



Figure 28. Total heating and cooling load versus solar admittance, daytime archetype, climate zone 2.

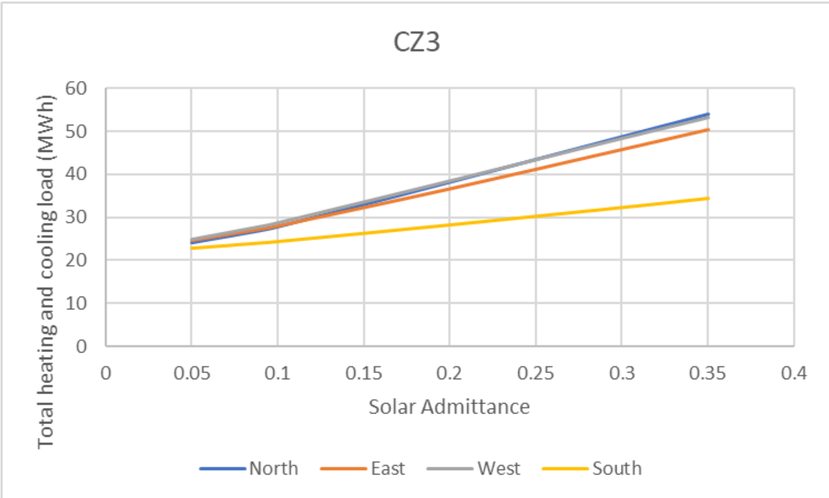



Figure 29. Total heating and cooling load versus solar admittance, daytime archetype, climate zone 3.

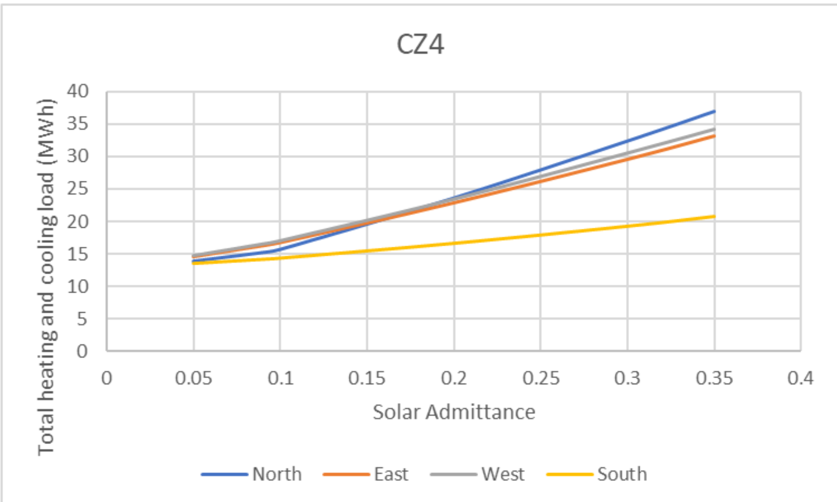



Figure 30. Total heating and cooling load versus solar admittance, daytime archetype, climate zone 4

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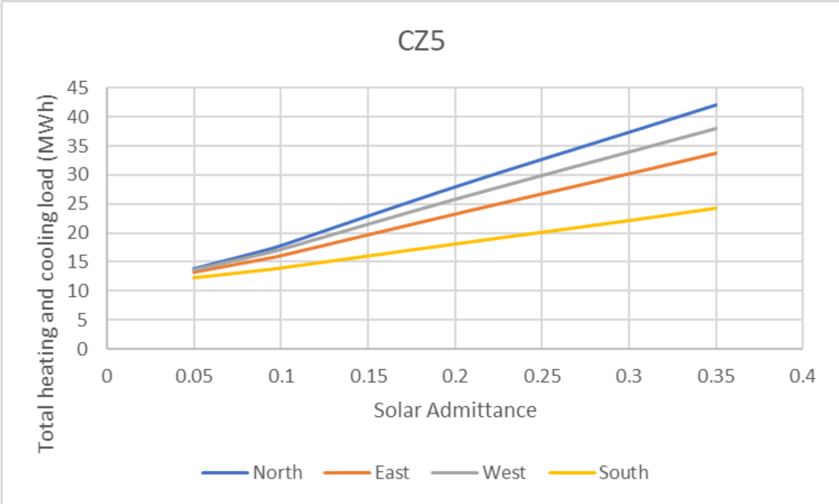


Figure 31. Total heating and cooling load versus solar admittance, daytime archetype, climate zone 5.

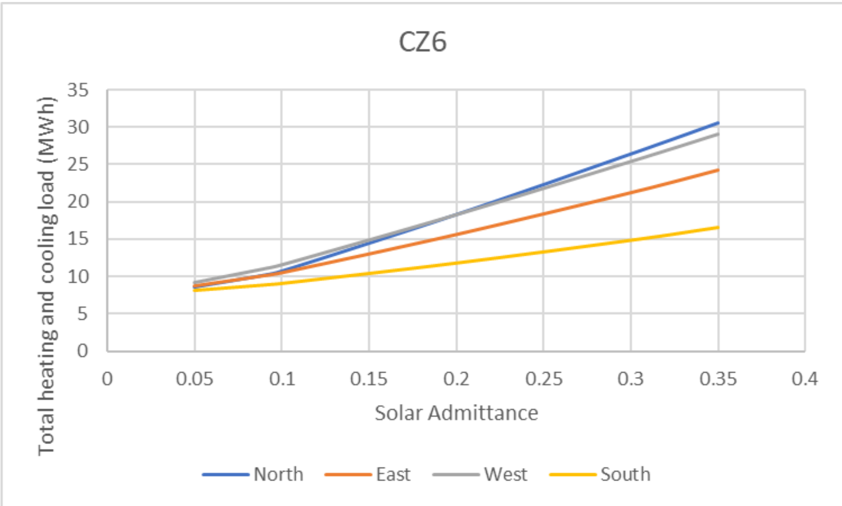


Figure 32. Total heating and cooling load versus solar admittance, daytime archetype, climate zone 6

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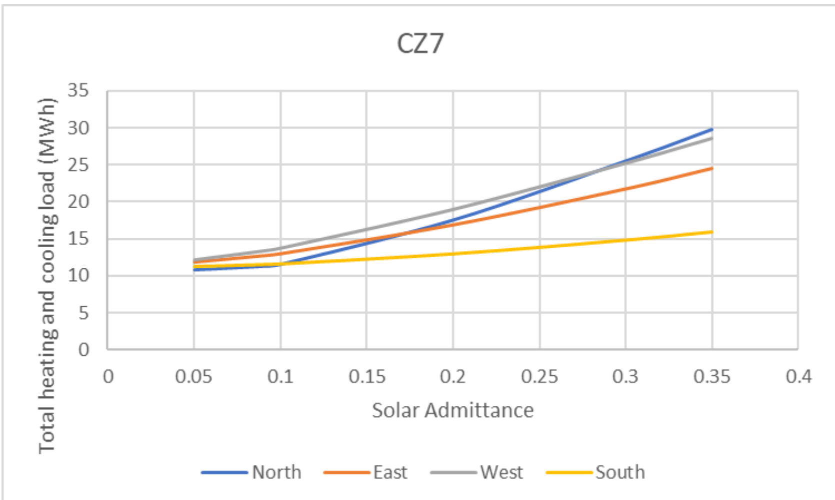



Figure 33. Total heating and cooling load versus solar admittance, daytime archetype, climate zone 7.

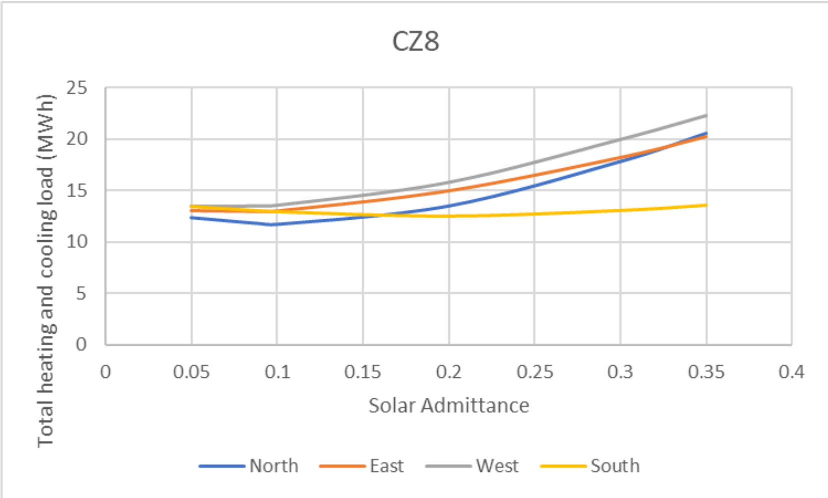



Figure 34. Total heating and cooling load versus solar admittance, daytime archetype, climate zone 8.

Only climate zone 8 shows a departure from the general model of smaller windows meaning less energy, although the relationship becomes weak for some zones in climate zone 7. The critical range of performance is in the region of a solar admittance figure of 0.1, as this reflects the stringencies favoured for 50% WWR in Table 18.

Considering each façade, for the daytime archetype under Stringencies 1 and 2:

- North: The solar admittance figure determined in Table 18 is 0.09. In all climate zones other than CZ8, retaining this figure is vindicated from an energy perspective. In CZ8 however, the figure should be adjusted to 0.1 to match the minimum energy point.
- West: The solar admittance figure determined in Table 18 is 0.09. This figure is vindicated from an energy perspective in all climate zones. However, in CZ8 the penalty for adopting a requirement of 0.1 is very small (0.5%) which should be considered to be less than the margin of error. Therefore, the higher figure of 0.1 should be used in this instance[13].
- East: The solar admittance figure determined in Table 18 is 0.10. This figure is vindicated from an energy perspective in all climate zones.
- South: The solar admittance figure determined in Table 18 is 0.11. Energy use is monotonic with solar admittance in all climate zones other than climate zone 8, which would justify the use of this figure. In CZ8, energy use is essentially flat to a solar admittance of 0.2, which indicates that this higher figure would be valid.

The resultant table of maximum solar admittance values is shown below:

Table 21. Recommended maximum solar admittance figures, daytime archetype, stringency 1&2.

| CZ | East | North | South | West |
|---|---|---|---|---|
| 1-7 | 0.10 | 0.09 | 0.11 | 0.09 |
| 8 | 0.10 | 0.10 | 0.20 | 0.10 |

[13] Thereby providing a marginal increase in design flexibility for no significant efficiency penalty.

For Stringency 3, the same analysis produces the following table:

Table 22. Recommended maximum solar admittance figures, daytime archetype, stringency 3.

| CZ | East | North | South | West |
|---|---|---|---|---|
| 1-7 | 0.08 | 0.07 | 0.08 | 0.07 |
| 8 | 0.09 | 0.10 | 0.20 | 0.07 |

The energy impacts of these revised stringencies are shown in Figure 35.

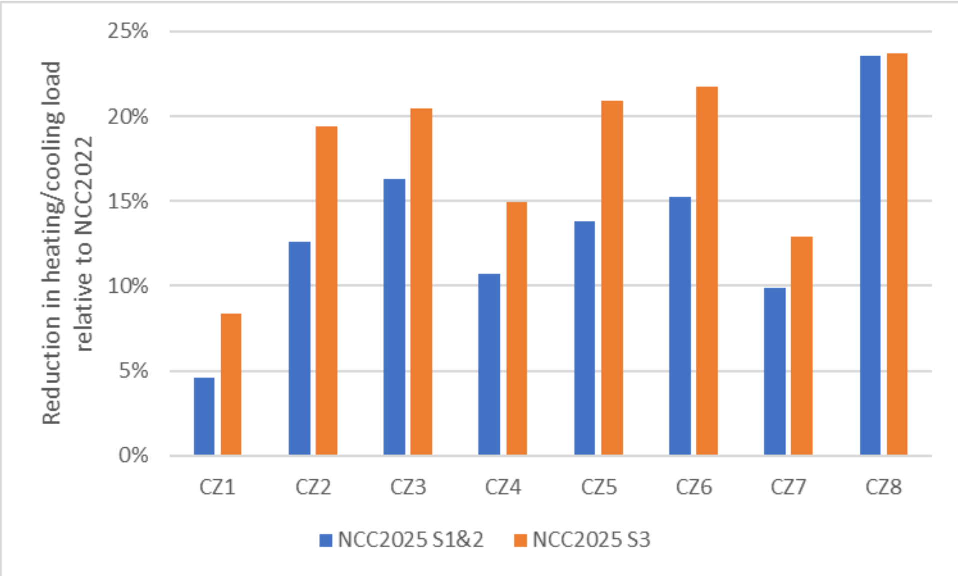



Figure 35. Energy impacts of proposed revised solar admittance stringencies, daytime archetype.

### Energy impacts – overnight archetype

A similar analysis to that reported above for the daytime archetype was conducted for the overnight archetype. However, the results were somewhat simpler, as the energy to solar admittance relationship was monotonic in all climate zones. Results for Climate zone 8 are shown in Figure 36 below as validation of this.

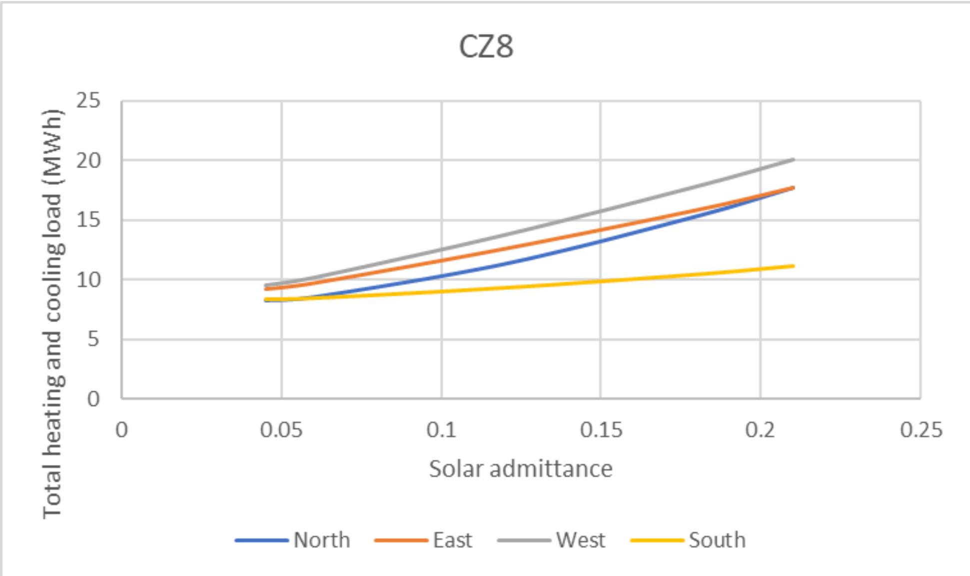



Figure 36. Total heating and cooling load versus solar admittance, overnight archetype, climate zone 8.

As a result, the analysis of solar admittance is somewhat simpler. Following the approach from the daytime archetype, the mid-WWR solar admittance values were selected as the base case, from which no further modifications need to be made.

The resultant table of maximum solar admittance values is shown below:

Table 23. Recommended maximum solar admittance figures, overnight archetype, stringency 1&2.

| CZ | East | North | South | West |
|---|---|---|---|---|
| All | 0.06 | 0.06 | 0.06 | 0.06 |

For Stringency 3, the same analysis produces the following table:

Table 24. Recommended maximum solar admittance figures, overnight archetype, stringency 3.

| CZ | East | North | South | West |
|---|---|---|---|---|
| All | 0.05 | 0.04 | 0.05 | 0.04 |

The energy impacts of the solar admittance recommendations are shown in Figure 37.

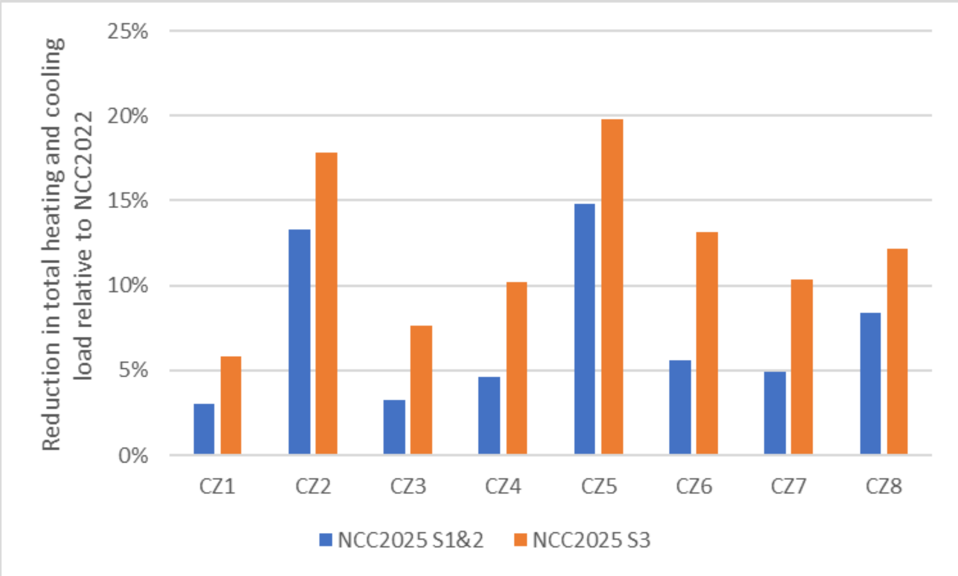



Figure 37. Energy impacts of proposed revised solar admittance stringencies, overnight archetype

### Comfort impacts

A secondary consideration for investigating increased solar admittance is to determine whether there are any situations in which higher solar admittance causes a loss of thermal comfort conditions.  This is relevant as Schedule 37 Method 2 creates the opportunity to trade glazing between facades and thereby increase the solar admittance of an individual façade significantly above the figures listed in Table 23 to Table 24.

It was found that comfort levels as measured by a PMV range of ±1 did not change across any of the scenarios (up to a solar admittance of 0.61, which is close to the maximum practical figure), so this analysis provided no additional insight into stringency.  Comfort levels to PMV±0.5 show impacts but not in a manner that assists setting a maximum solar admittance, as achievement of PMV±0.5 appears to decline with decreasing solar admittance.

It is possible that a visual comfort indicator may ultimately be the better metric for assessing a potential maximum glazing quantity from a comfort perspective.

Based on the analysis to date, however, it has been elected not to further pursue a maximum SA figure for use in Schedule 37 Method 2.

### Comparison to ASHRAE 90.1

ASHRAE 90.1 provides maximum solar admittance figures in a different format to NCC2022, in that it specifies a maximum SHGC for windows up to 40% WWR, and with no adjustment for aspect or building type.  Buildings planning to use greater than 40% WWR have to go through a performance verification method.  Translating the ASHRAE figures into solar admittance figures at 20%, 30% and 40% WWR, it can be seen in Table 25 that the resultant figures are broadly comparable to those proposed for NCC 2025 other than being somewhat less stringent in the cooler climate zones.

Table 25.  ASHRAE 90.1 window requirements translated into solar admittance values.  Figures apply irrespective of archetype or aspect.

| CZ | 20% WWR | 30% WWR | 40%WWR |
|---|---|---|---|
| 1 | 0.044 | 0.066 | 0.088 |

| | | | |
|---|---|---|---|
| 2-6 | 0.05 | 0.75 | 0.1 |
| 7 | 0.07 | 0.105 | 0.14 |
| 8 | 0.08 | 0.12 | 0.16 |

### 4.3.5 U value Stringency

#### U-value

The nature of the selection of the base case glazing options means that there is no opportunity to consider further optimisation of SHGC as further reduction of SHGC will cause failure to meet the VLT*WWR requirements stipulated for the base case. As a result, the only option for increased stringency is to decrease the window U value while maintaining the SHGC roughly constant. Options for this are, basically:

1. Thermally broken frames. The thermal resistance of window frames can be significantly improved by the use of thermal breaks in the frame structure.
2. Triple glazing. Double glazing can be replaced with triple glazing to decrease the overall window U-value

While alterations of the structure of some double-glazing types used were possible, these were generally minor in nature and often unavoidably linked to changes in SHGC, so these were not pursued.

Properties of each case are listed in

Table 26.

Table 26. Glazing properties used for U value stringency analysis.

| System | Case | Glazing SHGC | Glazing U | System SHGC | System U |
|---|---|---|---|---|---|
| 1 | Base | 0.301 | 1.706 | 0.27 | 2.771 |
| 1 | Thermally broken frames | 0.301 | 1.706 | 0.27 | 2.153 |
| 1 | Triple glazed | 0.326 | 1.087 | 0.29 | 2.31 |
| 2 | Base | 0.542 | 1.57 | 0.49 | 2.67 |
| 2 | Thermally broken frames | 0.542 | 1.57 | 0.49 | 2.051 |
| 2 | Triple glazed | 0.449 | 1.242 | 0.4 | 2.426 |
| 3 | Base | 0.186 | 1.45 | 0.17 | 2.581 |
| 3 | Thermally broken frames | 0.186 | 1.45 | 0.17 | 1.962 |
| 3 | Triple glazed | 0.17 | 1.089 | 0.15 | 2.312 |

Analysis was undertaken using a 50 year lifespan with 15 year replacement of HVAC plant (assumed to be PAC units).

Table 27. Benefit-cost ratios for improved glazing U value - daytime archetype

| Glazing selection | CZ1 | CZ2 | CZ3 | CZ4 | CZ5 | CZ6 | CZ7 | CZ8 |
|---|---|---|---|---|---|---|---|---|
| Thermally broken-East | 0.05 | 0.00 | 0.04 | 0.01 | -0.01 | -0.01 | 0.08 | 0.13 |
| Thermally broken-North | 0.05 | 0.00 | 0.04 | 0.00 | -0.01 | -0.02 | 0.07 | 0.12 |
| Thermally broken-South | 0.05 | 0.00 | 0.04 | 0.03 | -0.01 | -0.01 | 0.09 | 0.14 |
| Thermally broken-West | 0.06 | 0.00 | 0.04 | 0.01 | -0.01 | -0.01 | 0.08 | 0.13 |
| triple glazed-East | 0.13 | 0.26 | 0.38 | 0.22 | 0.19 | 0.17 | 0.02 | 0.07 |
| triple glazed-North | 0.14 | 0.24 | 0.29 | 0.22 | 0.23 | 0.21 | -0.02 | 0.06 |
| triple glazed-South | 0.03 | 0.08 | 0.13 | -0.01 | 0.07 | 0.07 | -0.02 | 0.01 |
| triple glazed-West | 0.16 | 0.29 | 0.38 | 0.23 | 0.21 | 0.22 | 0.02 | 0.08 |

Table 28. Benefit-cost ratios for improved glazing U-value - overnight archetype

| Glazing selection | CZ1 | CZ2 | CZ3 | CZ4 | CZ5 | CZ6 | CZ7 | CZ8 |
|---|---|---|---|---|---|---|---|---|
| Thermally broken-East | 0.07 | 0.00 | 0.03 | -0.01 | -0.02 | -0.04 | 0.00 | 0.01 |
| Thermally broken-North | 0.07 | 0.00 | 0.03 | -0.02 | -0.02 | -0.04 | -0.02 | 0.27 |
| Thermally broken-South | 0.06 | 0.00 | 0.02 | 0.00 | -0.02 | -0.03 | 0.01 | 0.02 |
| Thermally broken-West | 0.08 | 0.01 | 0.03 | 0.00 | -0.01 | -0.03 | 0.00 | 0.01 |
| triple glazed-East | 0.07 | 0.26 | 0.04 | 0.02 | 0.23 | 0.00 | 0.02 | 0.08 |
| triple glazed-North | 0.07 | 0.31 | 0.04 | 0.02 | 0.28 | 0.00 | 0.01 | 0.08 |
| triple glazed-South | 0.15 | 0.13 | 0.02 | 0.01 | 0.11 | -0.01 | 0.01 | 0.03 |
| triple glazed-West | 0.07 | 0.36 | 0.05 | 0.02 | 0.29 | 0.01 | 0.02 | 0.09 |

It can be seen clearly from Table 27 and Table 28 that none of the improved R-Value cases was cost-beneficial. As a result, no increase in stringency is recommended for glazing.

## 4.4 Discussion

### 4.4.1 Window-wall total system U value

As the Code does not separately regulate glazing U value, it is necessary to integrate results from the glazing and wall insulation analyses to obtain revised figures for the window-wall total system U value.

There are a number of inputs to this analysis:

1. A glazing system U value must be identified. As identified in Table 53 to Table 58, the U-value of glazing used in the NCC2022 compliant cases was close to 2.6 W/m²K in all cases. Furthermore, as identified in Section 4.3.5, no cost-effective improvement of this could be determined. As a result, for the purposes of the current exercise, a glazing system U value of 2.6 has been assumed.
2. Window-wall ratio. It is not intended that the window-wall U-value should provide a secondary constraint on window wall ratio. As a result, the maximum window wall ratio associated with the average maximum solar admittance, using an assumed minimum SHGC of 0.17, has been calculated for each case. This equates to:
    a. For Stringency 1&2
        i. Daytime archetype: Average WWR of 57% for CZ1-7, 73.5% for CZ8
        ii. Overnight archetype: 35% for all climate zones
    b. For stringency 3
        i. Daytime archetype: Average WWR of 44% for CZ1-7, 68% for CZ8
        ii. Overnight archetype: 26.5% for all climate zones
3. Wall R-values. Wall R-Values have been set at the figures derived in Section 3.5.1 as these have been cost benefit optimised.

The results are shown in Table 29 and

Table 30 below.

Table 29. Proposed window-wall total U values, daytime archetypes.

| CZ | NCC2022 | NCC 2025 Stringency 1&2 | NCC 2025 Stringency 3 |
|---|---|---|---|
| 1 | 2 | 1.6 | 1.3 |
| 2 | 2 | 1.9 | 1.7 |
| 3 | 2 | 1.7 | 1.4 |
| 4 | 2 | 1.7 | 1.4 |
| 5 | 2 | 1.9 | 1.7 |
| 6 | 2 | 1.8 | 1.6 |
| 7 | 2 | 1.7 | 1.4 |
| 8 | 2 | 2.0 | 1.9 |

Table 30. Proposed window-wall total U values, overnight archetypes.

| CZ | NCC2022 | NCC 2025 Stringency 1&2 | NCC 2025 Stringency 3 |
|---|---|---|---|
| 1 | 1.1 | 1.1 | 0.9 |

| CZ | NCC2022 | NCC 2025 Stringency 1&2 | NCC 2025 Stringency 3 |
|---|---|---|---|
| 2 | 2 | 1.6 | 1.4 |
| 3 | 1.1 | 1.2 | 1.0 |
| 4 | 1.1 | 1.3 | 1.1 |
| 5 | 2 | 1.6 | 1.4 |
| 6 | 1.1 | 1.6 | 1.4 |
| 7 | 1.1 | 1.2 | 1.0 |
| 8 | 0.9 | 1.1 | 0.9 |

The figures represent an increase in stringency relative to NCC 2025 in most cases. Exceptions arise where the cost-beneficial wall insulation has decreased in the current analysis.

## 4.5 Proposed Measures

### 4.5.1 Stringency 1&2

**J4D6 Walls and glazing**

(1) The Total System U-Value of wall-glazing construction, including wall-glazing construction which wholly or partly forms the envelope internally, must not be greater than the values in Table J4Dx.

**Table J4dx. Maximum Total system U-values (W/m²K) of wall-glazing constructions**

| Climate zone | Class 2 common area, class 5,6,7,8 9b, 9a other than a ward area | Class 3, 9c or 9a ward area |
|---|---|---|
| 1 | 1.6 | 1.1 |
| 2 | 1.9 | 1.6 |
| 3 | 1.7 | 1.2 |
| 4 | 1.7 | 1.3 |
| 5 | 1.9 | 1.6 |
| 6 | 1.8 | 1.6 |
| 7 | 1.7 | 1.2 |
| 8 | 2.0 | 1.1 |

(2) The Total System U-Value of display glazing must not be greater than 5.8 W/m²K.

(3) The Total System U-Value of wall-glazing construction must be calculated in accordance with Specification 37.

(4) {see Section 3.5.1}

(5) The solar admittance of externally facing wall-glazing construction, excluding wall-glazing construction which is wholly internal, must not be greater than—

(a) for a Class 2 common area, a Class 5, 6, 7, 8 or 9b building or a Class 9a building other than a ward area, the values specified in Table J4D6y; and

(b) for a Class 3 or 9c building or a Class 9a ward area, the values specified in Table J4D6z.

(6) The solar admittance of a wall-glazing construction must be calculated in accordance with Specification 37.

(7) The Total system SHGC of display glazing must not be greater than 0.81 divided by the applicable shading factor specified in S37C7.

**Table J4D6y: Maximum wall-glazing construction solar admittance - Class 2 common area, Class 5, 6, 7, 8 or 9b building or Class 9a building other than a ward area.**

| Climate zone | Eastern aspect solar admittance | Northern aspect solar admittance | Southern aspect solar admittance | Western aspect solar admittance |
|---|---|---|---|---|
| 1-7 | 0.10 | 0.09 | 0.11 | 0.09 |
| 8 | 0.10 | 0.10 | 0.20 | 0.10 |

**Table J4D6z: Maximum wall-glazing construction solar admittance - Class 2 common area, Class 5, 6, 7, 8 or 9b building or Class 9a building other than a ward area.**

| Climate zone | Eastern aspect solar admittance | Northern aspect solar admittance | Southern aspect solar admittance | Western aspect solar admittance |
|---|---|---|---|---|
| 1-8 | 0.06 | 0.06 | 0.06 | 0.06 |

### 4.5.2 Stringency 3

**J4D6 Walls and glazing**

(1) The Total System U-Value of wall-glazing construction, including wall-glazing construction which wholly or partly forms the envelope internally, must not be greater than the values in Table J4Dx.

**Table J4dx. Maximum Total system U-values (W/m²K) of wall-glazing constructions**

| Climate zone | Class 2 common area, class 5,6,7,8 9b, 9a other than a ward area | Class 3, 9c or 9a ward area |
|---|---|---|
| 1 | 1.3 | 0.9 |
| 2 | 1.7 | 1.4 |
| 3 | 1.4 | 1.0 |
| 4 | 1.4 | 1.1 |
| 5 | 1.7 | 1.4 |
| 6 | 1.6 | 1.4 |
| 7 | 1.4 | 1.0 |
| 8 | 1.9 | 0.9 |

(2) The Total System U-Value of display glazing must not be greater than 5.8 W/m²K.

(3) The Total System U-Value of wall-glazing construction must be calculated in accordance with Specification 37.

(4) {see Section 3.5.1}

(5) The solar admittance of externally facing wall-glazing construction, excluding wall-glazing construction which is wholly internal, must not be greater than—

(a) for a Class 2 common area, a Class 5, 6, 7, 8 or 9b building or a Class 9a building other than a ward area, the values specified in Table J4D6y; and

(b) for a Class 3 or 9c building or a Class 9a ward area, the values specified in Table J4D6z.

(6) The solar admittance of a wall-glazing construction must be calculated in accordance with Specification 37.

(7) The Total system SHGC of display glazing must not be greater than 0.81 divided by the applicable shading factor specified in S37C7.

**Table J4D6y: Maximum wall-glazing construction solar admittance - Class 2 common area, Class 5, 6, 7, 8 or 9b building or Class 9a building other than a ward area.**

| Climate zone | Eastern aspect solar admittance | Northern aspect solar admittance | Southern aspect solar admittance | Western aspect solar admittance |
|---|---|---|---|---|
| 1-7 | 0.08 | 0.07 | 0.08 | 0.07 |
| 8 | 0.09 | 0.10 | 0.20 | 0.07 |

**Table J4D6z: Maximum wall-glazing construction solar admittance - Class 2 common area, Class 5, 6, 7, 8 or 9b building or Class 9a building other than a ward area.**

| Climate zone | Eastern aspect solar admittance | Northern aspect solar admittance | Southern aspect solar admittance | Western aspect solar admittance |
|---|---|---|---|---|
| 1-8 | 0.05 | 0.04 | 0.05 | 0.04 |

# 5 Vertical Shading

### 5.1.1 Background and context

NCC 2022 Tables S37C7a and b provide multiplication factors for the calculation of solar admittance in the presence of horizontal shading. The purpose of the current assessment is to generate comparable factors for vertical shading.

### 5.1.2 Methodology

Simulations were conducted using the simplified archetype used in the main body of the glazing analysis.

Vertical shading was characterised in terms of the following variables:

- H, the height of the shade
- D, the depth of the shade and
- x, the length of window

These are shown in Figure 38 below.

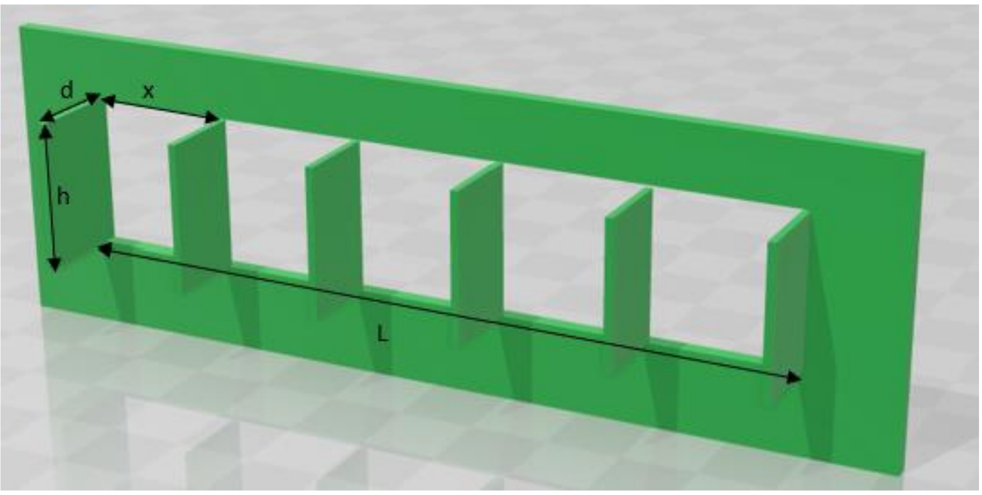



Figure 38. Vertical shading geometry.

Simulations were conducted for the following cases:

- x=L/5 d=0.1x, 0.3x, 0.5x, 0.7x
- X=L/3 d=0.1x, 0.3x, 0.5x, 0.7x
- X=L/7 d=0.1x, 0.3x, 0.5x, 0.7x
- X=L/10 d=0.1x, 0.3x, 0.5x, 0.7x

As a reference case, unshaded simulations were conducted for SHGC=0.87, 0.75, 0.5, and 0.05. A quadratic curve was fitted to the energy to SHGC relationship derived from these simulations. This was then solved using the energy simulation results from the shaded simulations to calculate an SHGC equivalent of the vertical shade. These SHGC results were then divided by 0.87 to express the answers as a multiplier for use in the solar admittance calculation.

Separate tables of multipliers were derived for North, West and East aspects in each climate zone. However, it was found that a number of climate zones were fairly similar, so the results from climate zones 1,2,3,5 and 6 were averaged into a single set of tables. The maximum deviation between the average and the original climate zone figures was 3%, which was deemed acceptable for the intended application.

The resultant tables are shown below.

Table 31. Solar admittance multipliers for vertical shading on north facing windows.

| | | | | |
|---|---|---|---|---|
| **CZ1,2,3,5,6** | X=1.7h | X=h | X=0.7h | X=0.5h |
| d=0.1x | 0.91 | 0.90 | 0.90 | 0.90 |
| d=0.3x | 0.85 | 0.83 | 0.82 | 0.81 |
| d=0.5x | 0.82 | 0.78 | 0.76 | 0.74 |
| d=0.7x | 0.81 | 0.76 | 0.73 | 0.70 |
| **CZ4** | X=1.7h | X=h | X=0.7h | X=0.5h |
| d=0.1x | 0.91 | 0.91 | 0.90 | 0.90 |
| d=0.3x | 0.87 | 0.84 | 0.83 | 0.82 |
| d=0.5x | 0.84 | 0.80 | 0.78 | 0.76 |
| d=0.7x | 0.83 | 0.78 | 0.75 | 0.73 |
| **CZ7** | X=1.7h | X=h | X=0.7h | X=0.5h |
| d=0.1x | 0.92 | 0.91 | 0.91 | 0.90 |
| d=0.3x | 0.87 | 0.85 | 0.83 | 0.82 |
| d=0.5x | 0.86 | 0.82 | 0.79 | 0.78 |
| d=0.7x | 0.85 | 0.80 | 0.78 | 0.75 |
| **CZ8** | X=1.7h | X=h | X=0.7h | X=0.5h |
| d=0.1x | 0.92 | 0.92 | 0.91 | 0.91 |
| d=0.3x | 0.90 | 0.88 | 0.86 | 0.85 |
| d=0.5x | 0.91 | 0.87 | 0.85 | 0.83 |
| d=0.7x | 0.91 | 0.88 | 0.86 | 0.84 |

Table 32. Solar admittance multipliers for vertical shading on west facing windows.

| **CZ1,2,3,5,6** | X=1.7h | X=h | X=0.7h | X=0.5h |
|---|---|---|---|---|
| d=0.1x | 0.93 | 0.91 | 0.90 | 0.90 |
| d=0.3x | 0.87 | 0.85 | 0.84 | 0.84 |
| d=0.5x | 0.85 | 0.82 | 0.80 | 0.79 |
| d=0.7x | 0.83 | 0.79 | 0.77 | 0.75 |
| **CZ4** | X=1.7h | X=h | X=0.7h | X=0.5h |
| d=0.1x | 0.93 | 0.90 | 0.90 | 0.89 |
| d=0.3x | 0.88 | 0.86 | 0.85 | 0.84 |
| d=0.5x | 0.87 | 0.84 | 0.82 | 0.81 |
| d=0.7x | 0.86 | 0.83 | 0.81 | 0.79 |
| **CZ7** | X=1.7h | X=h | X=0.7h | X=0.5h |
| d=0.1x | 0.96 | 0.95 | 0.95 | 0.95 |
| d=0.3x | 0.94 | 0.94 | 0.94 | 0.93 |
| d=0.5x | 0.94 | 0.93 | 0.93 | 0.93 |
| d=0.7x | 0.94 | 0.93 | 0.93 | 0.92 |

| **CZ8** | X=1.7h | X=h | X=0.7h | X=0.5h |
|---|---|---|---|---|
| d=0.1x | 0.93 | 0.90 | 0.89 | 0.89 |
| d=0.3x | 0.90 | 0.88 | 0.87 | 0.87 |
| d=0.5x | 0.90 | 0.88 | 0.87 | 0.86 |
| d=0.7x | 0.90 | 0.89 | 0.87 | 0.86 |

Table 33. Solar admittance multipliers for vertical shading on east facing windows.

| **CZ1,2,3,5,6** | X=1.7h | X=h | X=0.7h | X=0.5h |
|---|---|---|---|---|
| d=0.1x | 0.94 | 0.94 | 0.93 | 0.93 |
| d=0.3x | 0.90 | 0.89 | 0.88 | 0.87 |
| d=0.5x | 0.88 | 0.85 | 0.84 | 0.83 |
| d=0.7x | 0.87 | 0.83 | 0.81 | 0.79 |
| **CZ4** | X=1.7h | X=h | X=0.7h | X=0.5h |
| d=0.1x | 0.94 | 0.93 | 0.92 | 0.92 |
| d=0.3x | 0.91 | 0.89 | 0.89 | 0.88 |
| d=0.5x | 0.90 | 0.88 | 0.86 | 0.85 |
| d=0.7x | 0.89 | 0.87 | 0.85 | 0.83 |
| **CZ7** | X=1.7h | X=h | X=0.7h | X=0.5h |
| d=0.1x | 0.95 | 0.94 | 0.94 | 0.93 |
| d=0.3x | 0.91 | 0.92 | 0.91 | 0.91 |
| d=0.5x | 0.93 | 0.91 | 0.90 | 0.89 |
| d=0.7x | 0.93 | 0.91 | 0.90 | 0.88 |
| **CZ8** | X=1.7h | X=h | X=0.7h | X=0.5h |
| d=0.1x | 0.94 | 0.93 | 0.93 | 0.92 |
| d=0.3x | 0.94 | 0.93 | 0.93 | 0.92 |
| d=0.5x | 0.95 | 0.94 | 0.93 | 0.92 |
| d=0.7x | 0.95 | 0.95 | 0.94 | 0.93 |

## 5.2 Proposed Measures

**S37C7 Shading**

For the purpose of calculating solar admittance, the shading multiplier is—

a) for shading provided by an external permanent projection that extends horizontally on both sides of the glazing for the same projection distance P, as shown in Figure S37C7—
   I. the value in Table S37C7a for horizontal shading on the northern, eastern or western aspects; or
   II. the value in Table S37C7b for horizontal shading on the southern aspect; or
b) for vertical shading provided by an external permanent projection that extends vertically for the height of the glazing by the same projection distance d as shown in Figure S37C8
   I. The value in Table S37C7c for vertical shading on the northern aspect; or
   II. The value in Table S37C7d for vertical shading on the western aspect; or
   III. The value in Table S37C7e for vertical shading on the eastern aspects; or
   IV. 1.0 for vertical shading on the southern aspect; or

c) 0.35 for shading that is provided by an external shading device such as a shutter, blind, vertical or horizontal building screen with blades, battens or slats, which—
   I. is capable of restricting at least 80% of summer solar radiation; and
   II. if adjustable, will operate automatically in response to the level of solar radiation.

**Table S37C7a: Horizontal shading multipliers — Northern, eastern and western aspects**

[No change to existing NCC2022 requirements in Table S37C7a]

**Table S37C7b: Horizontal shading multipliers — Southern aspect**

[No change to existing NCC2022 requirements in Table S37C7b]

**Table S37C7c: Vertical shading multipliers — Northern aspect**

| **CZ1,2,3,5,6** | X=1.7h | X=h | X=0.7h | X=0.5h |
|---|---|---|---|---|
| d=0.1x | 0.91 | 0.90 | 0.90 | 0.90 |
| d=0.3x | 0.85 | 0.83 | 0.82 | 0.81 |
| d=0.5x | 0.82 | 0.78 | 0.76 | 0.74 |
| d=0.7x | 0.81 | 0.76 | 0.73 | 0.70 |
| **CZ4** | X=1.7h | X=h | X=0.7h | X=0.5h |
| d=0.1x | 0.91 | 0.91 | 0.90 | 0.90 |
| d=0.3x | 0.87 | 0.84 | 0.83 | 0.82 |
| d=0.5x | 0.84 | 0.80 | 0.78 | 0.76 |
| d=0.7x | 0.83 | 0.78 | 0.75 | 0.73 |
| **CZ7** | X=1.7h | X=h | X=0.7h | X=0.5h |
| d=0.1x | 0.92 | 0.91 | 0.91 | 0.90 |
| d=0.3x | 0.87 | 0.85 | 0.83 | 0.82 |
| d=0.5x | 0.86 | 0.82 | 0.79 | 0.78 |
| d=0.7x | 0.85 | 0.80 | 0.78 | 0.75 |
| **CZ8** | X=1.7h | X=h | X=0.7h | X=0.5h |
| d=0.1x | 0.92 | 0.92 | 0.91 | 0.91 |
| d=0.3x | 0.90 | 0.88 | 0.86 | 0.85 |
| d=0.5x | 0.91 | 0.87 | 0.85 | 0.83 |
| d=0.7x | 0.91 | 0.88 | 0.86 | 0.84 |

**Table S37C7d: Vertical shading multipliers — Western aspect**

| **CZ1,2,3,5,6** | X=1.7h | X=h | X=0.7h | X=0.5h |
|---|---|---|---|---|
| d=0.1x | 0.93 | 0.91 | 0.90 | 0.90 |
| d=0.3x | 0.87 | 0.85 | 0.84 | 0.84 |
| d=0.5x | 0.85 | 0.82 | 0.80 | 0.79 |
| d=0.7x | 0.83 | 0.79 | 0.77 | 0.75 |
| **CZ4** | X=1.7h | X=h | X=0.7h | X=0.5h |
| d=0.1x | 0.93 | 0.90 | 0.90 | 0.89 |
| d=0.3x | 0.88 | 0.86 | 0.85 | 0.84 |
| d=0.5x | 0.87 | 0.84 | 0.82 | 0.81 |
| d=0.7x | 0.86 | 0.83 | 0.81 | 0.79 |
| **CZ7** | X=1.7h | X=h | X=0.7h | X=0.5h |
| d=0.1x | 0.96 | 0.95 | 0.95 | 0.95 |
| d=0.3x | 0.94 | 0.94 | 0.94 | 0.93 |
| d=0.5x | 0.94 | 0.93 | 0.93 | 0.93 |
| d=0.7x | 0.94 | 0.93 | 0.93 | 0.92 |
| **CZ8** | X=1.7h | X=h | X=0.7h | X=0.5h |
| d=0.1x | 0.93 | 0.90 | 0.89 | 0.89 |
| d=0.3x | 0.90 | 0.88 | 0.87 | 0.87 |
| d=0.5x | 0.90 | 0.88 | 0.87 | 0.86 |
| d=0.7x | 0.90 | 0.89 | 0.87 | 0.86 |

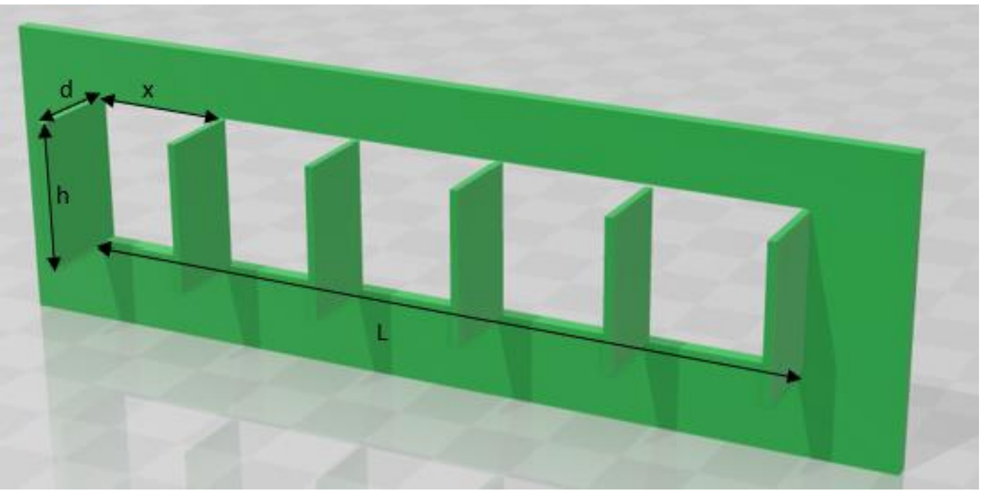
**Table S37C7e: Horizontal shading multipliers — Eastern aspect**

| **CZ1,2,3,5,6** | X=1.7h | X=h | X=0.7h | X=0.5h |
|---|---|---|---|---|
| d=0.1x | 0.94 | 0.94 | 0.93 | 0.93 |
| d=0.3x | 0.90 | 0.89 | 0.88 | 0.87 |
| d=0.5x | 0.88 | 0.85 | 0.84 | 0.83 |
| d=0.7x | 0.87 | 0.83 | 0.81 | 0.79 |
| **CZ4** | X=1.7h | X=h | X=0.7h | X=0.5h |
| d=0.1x | 0.94 | 0.93 | 0.92 | 0.92 |
| d=0.3x | 0.91 | 0.89 | 0.89 | 0.88 |
| d=0.5x | 0.90 | 0.88 | 0.86 | 0.85 |
| d=0.7x | 0.89 | 0.87 | 0.85 | 0.83 |
| **CZ7** | X=1.7h | X=h | X=0.7h | X=0.5h |
| d=0.1x | 0.95 | 0.94 | 0.94 | 0.93 |
| d=0.3x | 0.91 | 0.92 | 0.91 | 0.91 |
| d=0.5x | 0.93 | 0.91 | 0.90 | 0.89 |
| d=0.7x | 0.93 | 0.91 | 0.90 | 0.88 |
| **CZ8** | X=1.7h | X=h | X=0.7h | X=0.5h |
| d=0.1x | 0.94 | 0.93 | 0.93 | 0.92 |
| d=0.3x | 0.94 | 0.93 | 0.93 | 0.92 |
| d=0.5x | 0.95 | 0.94 | 0.93 | 0.92 |
| d=0.7x | 0.95 | 0.95 | 0.94 | 0.93 |

**Figure S37C7: Permanent external horizontal shading – measurement of P, G and H**

[No change to existing NCC2022 requirements in Figure S37C7]

**Figure S37C7: Permanent external vertical shading – measurement of d, x and h**



# 6 Cool Roofs

## 6.1 Background and context

### 6.1.1 How cool roofs work

NCC2019 includes a requirement for light coloured roofs (solar absorptance<0.45) to Class 2-9 building in Climate zones 1-7. This was based on simulation results showing a net benefit to the use of a light-coloured roof at no cost.

While light coloured roofs do provide benefits relative to dark roofs, they do not represent the peak of what can be achieved. Spectrally selective roof finishes (paints/coatings), aka cool roofs, achieve superior performance, mainly by maintaining a high level of reflectivity in the near infra-red, in contrast to conventional finishes that are essentially black in this region of the spectrum. As a significant amount of the energy in sunlight is in the near infra-red region, these spectrally selective finishes manage to achieve a higher level of overall reflectance of solar energy. As a result, while a conventional white roof will heat up significantly – often over 50°C – in direct sunlight, cool roofs maintain surface temperatures close to ambient. This lower surface temperature reduces the heat transfer through the roof structure and thus reduces building loads.

While this heat transfer effect is significant, Carter[14] identified that the larger driver of energy savings is the impact of the reduced temperature in the rooftop microclimate. This is because:

- A microclimate of higher ambient temperature in the vicinity of the roof will increase heat transfer through the roof relative to a simulation based on normal ambient temperatures.
- Roof-mounted plant will be subject to the roof-top microclimate with consequent impacts on cooling COPs and outside air-cooling loads.

These combined effects, where present, are estimated to produce energy savings several times larger than those associated with the direct heat transfer benefit. To put this in context, Carter quotes a 7% benefit simple heat transfer but a 46% measured benefit for a case study building. Other case studies reviewed (note: case studies were provided by cool roof manufacturers but included results by third parties that are plausibly independent) showed energy savings in the region of 25-55%. However, it must be recognised that these case studies often involved retrofit applications from base case conditions that are well below NCC2019 standards.

UNSW[15] identified primary savings (ignoring microclimate issues) of 0-5% for relevant new building archetypes. These lower savings may reflect higher performance base case conditions (higher roof reflectivity and better insulation) than in the Carter study. The UNSW study identified significant potential benefits in relation to mass application of cool roof finishes leading to reduced Urban Heat Island issues in built up areas. These are not explored in the current analysis.

Given the importance of the roof microclimate to the potential results, it is useful that some theoretical work has been undertaken as to the potential microclimate temperature increase, using

[14] "Issues and Solutions to More Realistically simulate Conventional and Cool Roofs" T.G. Carter, Proceedings of Building Simulation 2011: 12th Conference of International Building Performance Simulation Association, Sydney, 14-16 November.

[15] *Executive Final Report: Cool Roofs Cost Benefits Analysis*, UNSW (M Santamouris, A M Papadopoulos, R Paolini, A Khan, C B Koc, S Haddad, S Garshasbi, S Arasteh, J Feng) April 2022.

CFD. Carter and Kosasih[16] compared Zincalume to two Colorbond finishes at aged solar reflectance of 0.5, 0.63 and respectively[17] and calculated an average microclimate temperature bias of 0.3-0.7°C using CFD, with a maximum bias of 1.6-3.4°C (relevant to plant sizing and peak loads). Strong dependencies on local conditions and windspeed were noted. Total savings were found to be in the range 10-15%, and generally dominated by the primary heat transfer savings[18].

## 6.2 Methodology

The outline methodology for the cool roof analysis is shown in Figure 39.

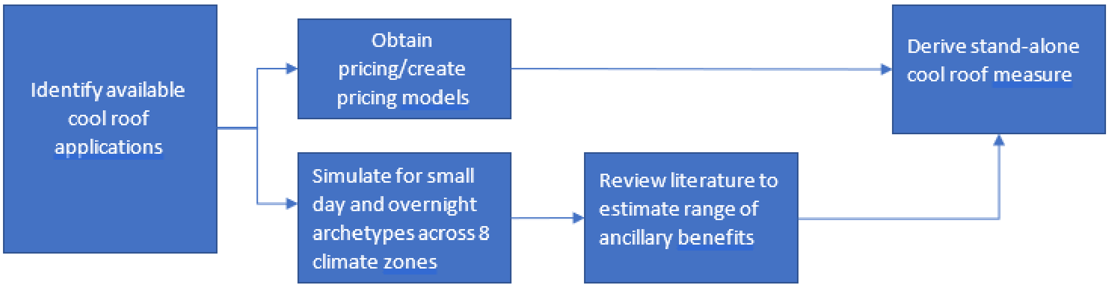



Figure 39. Outline methodology for the cool roof analysis.

### 6.2.1 Data collection and review

Data was collected by directly approaching the key product suppliers, being a number of suppliers of post-construction applied cool roof paints, and Lysaght as agents for Bluescope steel for the supply of pre-finished Colorbond[19].

### 6.2.2 Cool Roof Products

A number of manufacturers were approached for information on cool paint products. The high-level summary of information is listed in Table 34 below.

Table 34. Summary of identified cool roof products

| Manufacturer | Total solar reflectivity (TSR) | Emissivity |
|---|---|---|
| **Skycool** | 0.9 | 0.96 |
| **Astec** | 0.90-0.25 | 0.9 |
| **Solacoat** | 0.849 | 0.886 |
| **Thermaguard** | 0.95 | 0.92 |
| **Coolmax** | 0.77 | 0.87 |

.

[16] “Not so cool roofs” G Carter B Kosasih, *Ecolibrium* (Publisher: AIRAH) April 2018
[17] Emissivities were 0.2, 0.85 and 87 respectively.
[18] This was also affected by the plant assumptions which used higher efficiency chillers with cooling towers. Percentage savings appeared to be higher where the roof was insulated, as this led to higher temperatures in the rooftop microclimate.
[19] Colorbond dominates the pre-finished steel roof product market.

All the products bar the Coolmax are paints or coatings. Coolmax is an integrated precoated steel product.

Where measurement standards were cited, they were:

1. For Total Solar Reflectivity:
    a. ASTM 1549 "Test Method for Determination of Solar Reflectance Near Ambient Temperature Using a Portable Solar Reflectometer."
    b. ASTM E903-96 Standard Test Method for Absorption, Reflectance, and Transmittance of materials using integrated spheres".
1. For Emissivity:
    a. ASTM C 1371 "Test Method for Determination of Emittance of Materials near Room Temperature Using Portable Emissometers".
    b. ASTM E 408-71 "Total Normal Emittance of Surfaces Method A"

All products provided data on as-new performance, but limited information was available on time-degraded performance. This contrasts with US data (captured in the US Cool Roofs Database) which provides comprehensive data on 3-year degraded performance. The UNSW studies identified this lack of data on degraded performance as a significant issue, as it is the degraded performance that is more relevant to long terms savings. Our investigations into this area supported the UNSW conclusions in terms of data availability for local product, although all suppliers claimed that their products suffered little degradation. An insight into the range of degradation impact can be derived from the US Cool Roofs Data base, which shows an increase in average impact as roofs become lighter coloured but with a very wide range of variance, as shown in Figure 40.

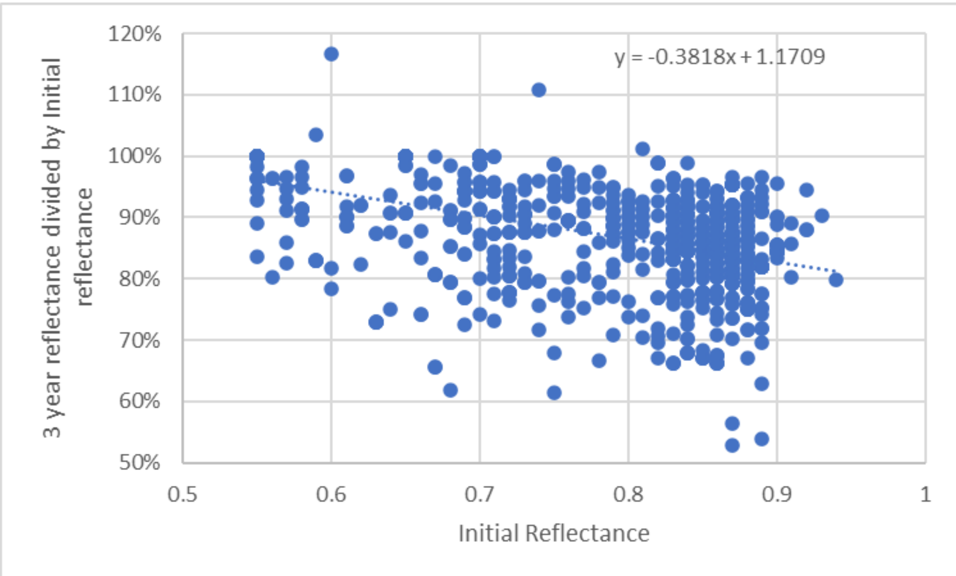



Figure 40. Comparison of 3-year degraded reflectance with initial reflectance from the US Cool Roofs database.

### 6.2.3 Simulation Methodology

Two archetypes were selected for this assessment being the Medium Office and the Aged Care archetypes. Both models have low angle (10°) roofs and in practice would be expected to include rooftop plant. An additional sensitivity analysis has been added using these same archetypes but with a 35° roof, as overseas standards for cool roof applications differentiate strongly between flat and angled roofs.

Baseline compliance was considered to be a standard light colour roof with 55% reflectivity and an emissivity of 0.85. Stringency cases were for an improved standard roof finishes at 75% reflectivity/ 87.5% emissivity and a spectrally selective cool roof at 90% reflectivity/90% emissivity. Aging effects were not considered as data on these varied widely.

The heat transfer-only savings were calculated by simulating each case with no change to plant efficiency or outside air intake temperature. For the air intake affected case, a heating element was added to the outside air intake in order to add a fixed 2°C temperature rise to the outside air entering the building. For the plant efficiency scenario, hourly simulation results were exported, and plant COP modified on the basis of a 4% drop/rise in cooling/heating COP (representing a 2°C average temperature change)[20].

### 6.2.4 Cost information

Suppliers were approached to provide pricing for the building scenarios. Responses are summarised in Table 35 below[21]:

Table 35. Spectrally selective cool roof paints – Cost estimates from suppliers (supply& install to a finished roof)

| Supplier 1 | Supplier 2 | Supplier 3 | Supplier 4 |
|---|---|---|---|
| $18-20/m$^2$ | $32-34/m$^2$ | $28-38/m$^2$ | $50-54/m$^2$ |

It is noted that the range of costs between suppliers was far greater than the range of costs for a given supplier between different archetypes. As a result, a single mid-range cost figure of $34/m$^2$ has been used in the economic analysis.

In addition, pricing was obtained from a Colorbond supplier for pre-finished roofing metal, as listed in Table 36 below:

Table 36. Colorbond prices (supply only)

| Roof Finish | Office | Aged Care |
|---|---|---|
| **Standard range** | $26.86-$28.20 | $22.80-$23.85 |
| **Coolmax** | $32.53-$34.15 | $27.46-$28.84 |

Both the 0.55 and 0.75 solar reflectivity products are available in the standard range, so for the economic analysis the incremental cost for these two products is taken as zero while for the Coolmax product an incremental cost of $5.40 has been used.

[20] Carter calibrated his data to a 5°C microclimate temperature rise and provided data indicating a 3°C temperature rise, while also providing evidence of theoretical calculations indicating a 2-3°C temperature rise. Sensitivity to this figure is tested in the results section.

[21] As these are post-applied paint finishes, these are all additional costs over and above normal construction costs for a roof.

### 6.2.5 Simulation Results

The results for the Medium Office, 10° roof case are shown in Figure 41.

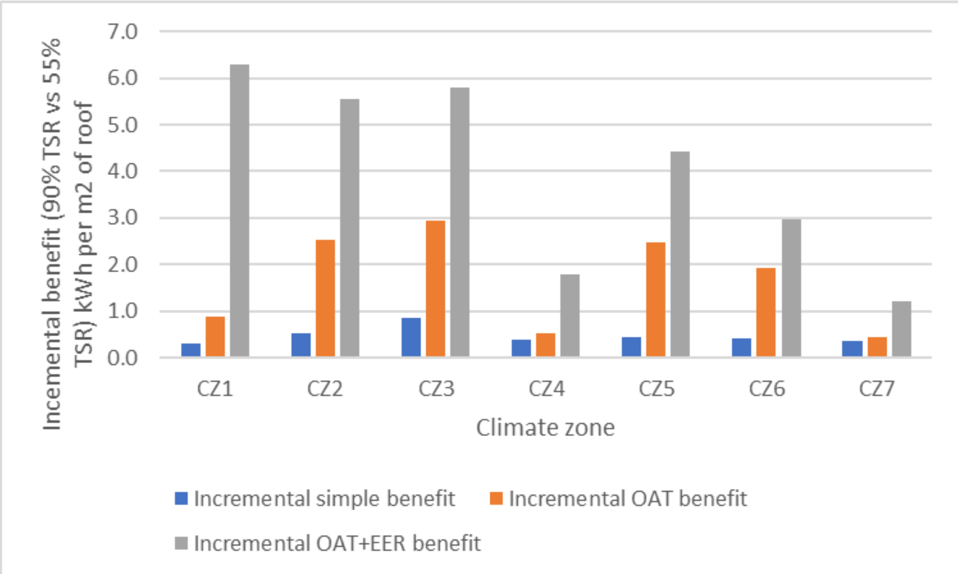



Figure 41. Cool roof impact (TSR 90% case compared to TSR 55% base case) for the Medium Office (C5OM) assuming a 2°C microclimate effect for OAT and EER impacts. All figures based on combined heating and cooling effects.

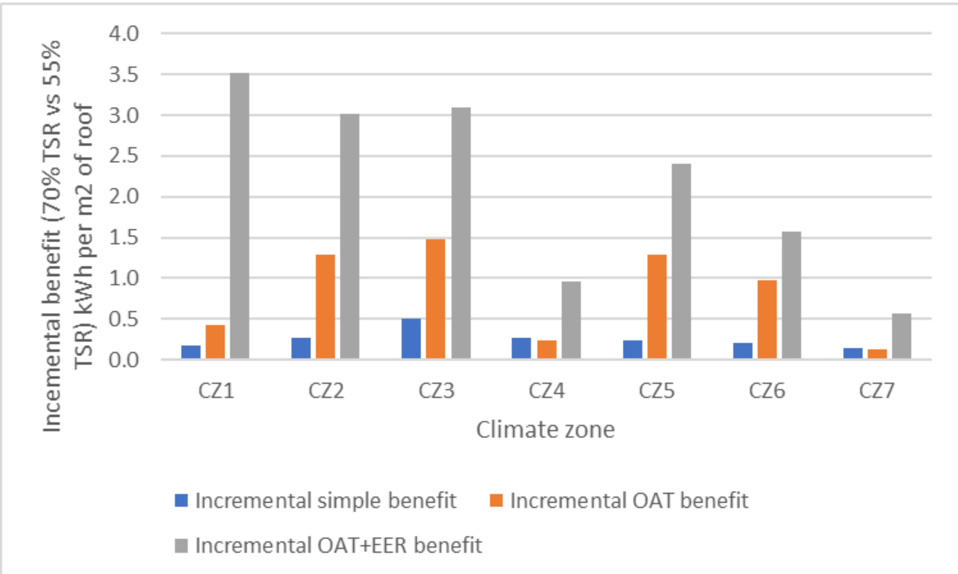



Figure 42. Cool roof impact (TSR 75% case compared to TSR 55% base case assuming a 1.14°C microclimate effect[22] for OAT and EER impacts. All figures based on combined heating and cooling effects.

It can be seen that the simple benefit – being the benefit only in relation to simple heat transfer analysis – is very small, whereas the impact when a 2°C microclimate effect is added is more appreciable.

[22] A lower microclimate effect has been imposed in proportion to TSR movement between 55% and 90%. Simulation results were manually adjusted to this figure, as actual simulation results were run assuming a 2°C microclimate effect for both 75% and 90% TSR.

It was also found that the simple benefit for the 35° roof was not simply related to the 10° roof, other than also being a very small effect. No micro-climate benefits were assessed for the 35° roof as the increased upwards convection and general exposure would be expected to make benefits highly localised.

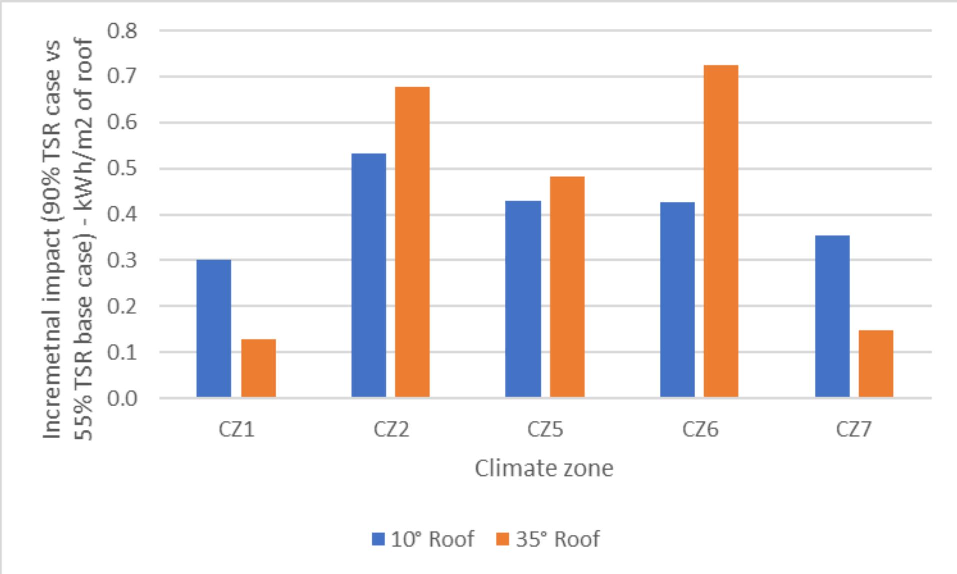



Figure 43. Simple benefit (no plant effects) for 10° and 35° roofs – Medium Office (C5OM). No simulations were run for the 35° roof in CZ3 or CZ4.

The benefit of the intermediate TSR was, as expected, somewhat proportional to the TSR difference relative to the 55% base case.

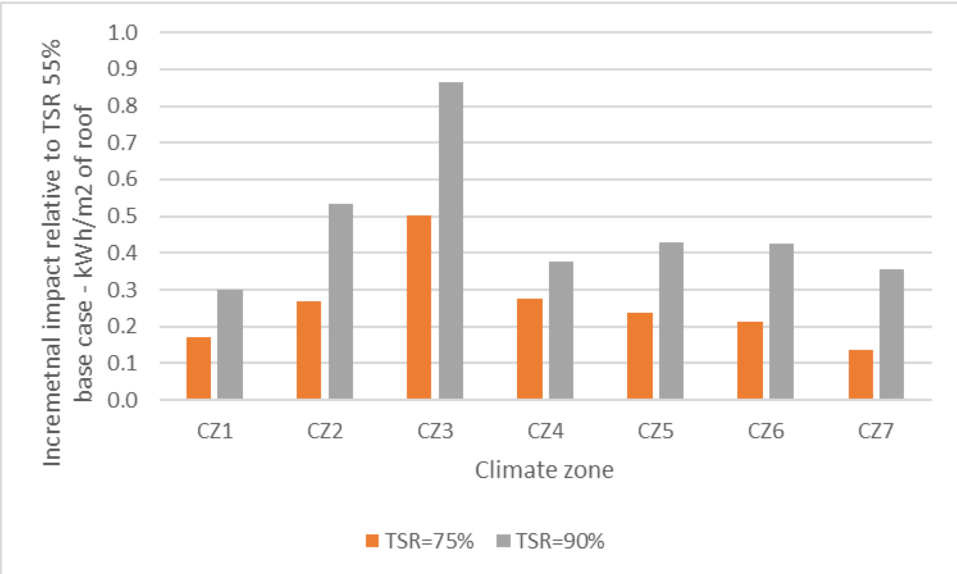



Figure 44. Simple benefits (no plant effects) for TSR 70% and 90% relative to the TSR 55% base case – Medium Office (C5OM)

Peak demand impacts were reviewed but found to be too small to be worth consideration.

### 6.2.6 Economic analysis

The economic analysis is based on the 10° roof model, using a 40-year product lifetime[23]. The inputs for the simple benefit model are listed in Table 37.

Table 37. Inputs for the cool roofs simple benefits assessment, showing incremental energy savings for each climate zone

| | Incremental cost ($/m² of roof) | Incremental cost ($/m² of roof) | kWh saved / m² roof | kWh saved / m² roof | kWh saved / m² roof | kWh saved / m² roof | kWh saved / m² roof | kWh saved / m² roof | kWh saved / m² roof |
|---|---|---|---|---|---|---|---|---|---|
| **TSR** | Post-applied paint | Pre-finished roofing | CZ1 | CZ2 | CZ3 | CZ4 | CZ5 | CZ6 | CZ7 |
| **0.75** | n/a | $0 | 0.17 | 0.27 | 0.50 | 0.27 | 0.24 | 0.21 | 0.14 |
| **0.9** | $34 | $5.60 | 0.30 | 0.53 | 0.87 | 0.38 | 0.43 | 0.43 | 0.35 |

The inputs for the HVAC effects assessment are listed in Table 38 and Table 39.

Table 38. Inputs for the cool roofs OA affected case (2°C assumed temperature rise).

| | Incremental cost ($/m² of roof) | Incremental cost ($/m² of roof) | kWh saved / m² roof | kWh saved / m² roof | kWh saved / m² roof | kWh saved / m² roof | kWh saved / m² roof | kWh saved / m² roof | kWh saved / m² roof |
|---|---|---|---|---|---|---|---|---|---|
| **TSR** | Post-applied paint | Pre-finished roofing | CZ1 | CZ2 | CZ3 | CZ4 | CZ5 | CZ6 | CZ7 |
| **0.75** | n/a | $0 | 0.8 | 2.3 | 2.6 | 0.4 | 2.3 | 1.7 | 0.2 |
| **0.9** | $34 | $5.60 | 0.9 | 2.5 | 2.9 | 0.5 | 2.5 | 1.9 | 0.4 |

Table 39. Inputs for the cool roofs OA and EER affected case (2°C assumed temperature rise).

| | Incremental cost ($/m² of roof) | Incremental cost ($/m² of roof) | kWh saved / m² roof | kWh saved / m² roof | kWh saved / m² roof | kWh saved / m² roof | kWh saved / m² roof | kWh saved / m² roof | kWh saved / m² roof |
|---|---|---|---|---|---|---|---|---|---|
| **TSR** | Post-applied paint | Pre-finished roofing | CZ1 | CZ2 | CZ3 | CZ4 | CZ5 | CZ6 | CZ7 |
| **0.75** | n/a | $0 | 6.2 | 5.3 | 5.4 | 1.7 | 4.2 | 2.7 | 1.0 |
| **0.9** | $34 | $5.60 | 6.3 | 5.5 | 5.8 | 1.8 | 4.4 | 3.0 | 1.2 |

The benefit cost ratios based on these figures are listed in Table 40 to Table 42.

Table 40. Benefit cost ratios for the cool roofs simple benefit case

| TSR | Finish | CZ1 | CZ2 | CZ3 | CZ4 | CZ5 | CZ6 | CZ7 |
|---|---|---|---|---|---|---|---|---|
| **0.75** | Paint | >1.5 | >1.5 | >1.5 | >1.5 | >1.5 | >1.5 | >1.5 |
| **0.75** | Prefinished | >1.5 | >1.5 | >1.5 | >1.5 | >1.5 | >1.5 | >1.5 |
| **0.9** | Paint | 0.15 | 0.15 | 0.13 | 0.07 | 0.10 | 0.07 | 0.06 |
| **0.9** | Prefinished | 0.89 | 0.90 | 0.82 | 0.44 | 0.63 | 0.40 | 0.35 |

[23] Which is realistic for the prefinished roofing but likely to be overly optimistic for the post-applied paint.

Table 41. Benefit-cost ratios for the cool roofs OA affected case (2°C assumed temperature rise)

| TSR | Finish | CZ1 | CZ2 | CZ3 | CZ4 | CZ5 | CZ6 | CZ7 |
|---|---|---|---|---|---|---|---|---|
| **0.75** | Paint | >1.5 | >1.5 | >1.5 | >1.5 | >1.5 | >1.5 | >1.5 |
| **0.75** | Prefinished | >1.5 | >1.5 | >1.5 | >1.5 | >1.5 | >1.5 | >1.5 |
| **0.9** | Paint | 0.20 | 0.30 | 0.31 | 0.08 | 0.26 | 0.16 | 0.07 |
| **0.9** | Prefinished | 1.23 | 1.80 | 1.86 | 0.52 | 1.56 | 0.97 | 0.40 |

Table 42. Benefit-cost ratios for the cool roofs OA and EER affected case (2°C assumed temperature rise)

| TSR | Finish | CZ1 | CZ2 | CZ3 | CZ4 | CZ5 | CZ6 | CZ7 |
|---|---|---|---|---|---|---|---|---|
| **0.75** | Paint | >1.5 | >1.5 | >1.5 | >1.5 | >1.5 | >1.5 | >1.5 |
| **0.75** | Prefinished | >1.5 | >1.5 | >1.5 | >1.5 | >1.5 | >1.5 | >1.5 |
| **0.9** | Paint | 0.50 | 0.59 | 0.59 | 0.15 | 0.40 | 0.22 | 0.12 |
| **0.9** | Prefinished | 3.06 | 3.57 | 3.61 | 0.93 | 2.45 | 1.36 | 0.73 |

As an additional sensitivity, the benefit cost ratios for the cool roofs OA and EER affected case was also run using TSR=0.75 as a base case. Results are listed below:

Table 43. Benefit cost ratios for the cool roofs OA and EER affected case using the TSR=0.75 scenario as the base case.

| TSR | Finish | CZ1 | CZ2 | CZ3 | CZ4 | CZ5 | CZ6 | CZ7 |
|---|---|---|---|---|---|---|---|---|
| **0.9** | Paint | 0.07 | 0.06 | 0.06 | 0.03 | 0.05 | 0.03 | 0.03 |
| **0.9** | Prefinished | 0.40 | 0.38 | 0.35 | 0.18 | 0.28 | 0.16 | 0.15 |

## 6.3 Discussion

### 6.3.1 Microclimate impact

The scale microclimate impact is heavily dependent on the assumed average microclimate temperature rise, a factor that carries considerable uncertainty. The simulated 2°C rise was just for convenience and not intended to represent a realistic temperature rise: as mentioned earlier, Carter and Kosasih[24] identified a 0.3-0.7°C average microclimate temperature decrease for a 0.13 increase in solar reflectance, which would imply that the 0.2-0.35 increases in solar reflectance would generate temperature decreases in the region of 0.5-1.1°C and 0.9-2.1°C respectively.

For the TSR=0.9 case, an average microclimate temperature increase midpoint would be 1.5°C which would reduce BCRs to 75% of their current value, indicating positive economic benefits for prefinished roofs in climate zones 1,2,3,5 and 6 for the OA and EER affected roofs, and in climate zones 1,2,3 and 5 for OA affected roofs

[24] "Not so cool roofs" G Carter B Kosasih, *Ecolibrium* (Publisher: AIRAH) April 2018

### 6.3.2 As supplied versus post-applied

It is clear from the results that post-construction applied finished are not economic in any of the scenarios tested. This is driven significantly by the relatively high reflectivity of the base case.

A further complication to the interpretation of the results is that the best performing as-supplied finish has nil incremental cost, indicating that the requirement could be set higher at no cost.

## 6.4 Proposed Measures

### 6.4.1 Rationale

Based on the results above, there is:

1. A very marginal benefit to be obtained at no cost by the use of a 0.75 base case in the absence of any plant-related effects.
2. A marginal economic benefit to be obtained in CZ 1,2,3 and 5 for the use of a TSR=0.9 roof where the outside air intake is affected by the roof microclimate
3. A moderate economic benefit to be obtained in CZ 1,2,3,5 and 6 for the use of a TSR=0.9 roof where the outside air intake and plant EER are affected by the roof microclimate
4. Economic benefits for the TSR=0.9 case disappear when the base case is revised to the TSR=0.75 case, which is a zero-cost scenario.

Potential benefits have to be considered in the context of the impact on the market and design discretion. Given the marginality of benefits, without microclimate effects, there does not appear to be a case for requiring a TSR of 0.75 across all roofs in spite of this being a no-cost measure.

However, for situations where any plant is roof mounted, there is a case for this higher base case TSR to be required.

### 6.4.2 TSR vs SRI

The current NCC characterises roofs in terms of solar absorptivity. This approach fails to capture the influence of emissivity on the roof performance and can lead to zincalume (TSR=0.6-0.8) being used in spite of its poor solar performance (unoxidized emissivity is around 0.1).

The Solar Reflectance Index (SRI) is a more representative figure as it combines the impacts of both reflectance and emissivity. For some materials but not all, SRI is readily available; it is also open to some degree of manipulation. As a result, the preferred representation of roof properties is to specify a minimum TSR and minimum emissivity, with an equivalent SRI value. In this case, the three stringencies tested correspond to SRI figures of 61, 92 and 116.

### 6.4.3 Weathered vs new solar performance

There is considerable variability in the durability of cool roof materials, as demonstrated in Figure 45, which draws data from the US Cool Roof Rating Council database.

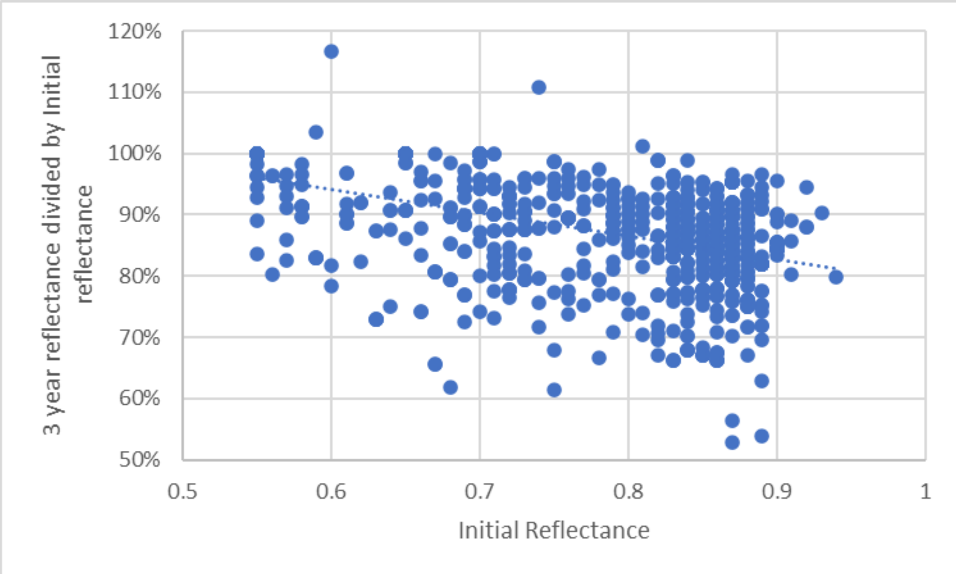



Figure 45. 3-year reflectance as a fraction of initial reflectance for products in the US Cool Roof Rating Council database.

It can be seen that for some products degradation is minimal while for others it is quite severe; there is also a general trend towards higher performance products being more likely on average to degrade significantly.

### 6.4.4 Non-metal roofs

The current code applies a blanket requirement to all roofs. The analysis presented only metal roofs. The particular result of the TSR=0.75 finish being freely available is only relevant to metal roofs, and as a result should be limited to such roofs. This is also reasonable as most other roof types compensate for lower reflectivity with higher mass, which to some extent mitigates overheating effects.

### 6.4.5 Proposed code text

**J4D4 Roof and Ceiling Construction**

(2) In climate zones 1, 2, 3, 4, 5, 6 and 7 the upper surface of any roof must have:
  a. A total solar reflectivity of higher than 0.55 and an emissivity of more than 0.85; or
  b. A Solar Reflectance Index of greater than 61.

(3) In climate zones 1, 2, 3, 5 and 6 the upper surface of a metal roof that has outside air intakes, unitary air-conditioning units or air-cooled chillers mounted on it or within 2 m above it must have:
  a. A total solar reflectivity of higher than 0.75 and an emissivity of more than 0.875; or
  b. A Solar Reflectance Index of greater than 92.

**Glossary Entries**[25]

[25] Although these have been included, we recommend that they are left out or expressed as advisory only in Code, This is because of the complexity of the Standards and associated measurement relative to the magnitude of the benefits.

Total solar reflectivity: The full-spectrum reflectivity of a material to sunlight measured to ASTM 1549 “Test Method for Determination of Solar Reflectance Near Ambient Temperature Using a Portable Solar Reflectometer” or ASTM E903-96 Standard Test Method for Absorption, Reflectance, and Transmittance of materials using integrated spheres”.

Emissivity: The full-spectrum emissivity of a material measured to ASTM C 1371 “Test Method for Determination of Emittance of Materials near Room Temperature Using Portable Emissometers”

Solar Reflectance Index: The solar reflectance index calculated to ASTM E1980-11 (2019) “Standard Practice for Calculating Solar Reflectance Index of Horizontal and Low-sloped Opaque Surfaces”

# 7 Appendix A: Glazing

## 7.1 Daylight Analysis

The development of glazing measures in a cooling dominated climate is challenging because almost inevitably two truisms hold:

1. Walls cost less to build than windows
2. Less window means lower energy use.

This would lead to the incorrect conclusion that the most economical solution is a building with no windows. To resolve this, the analysis for NCC2019 asserted that a window has a functional purpose in the form of the provision of daylight. For that analysis, this was assessed based on a Daylight Factor (DF) of 5% for daytime building archetypes and 3% for overnight archetypes.

Subsequent industry feedback noted that DF analysis is based on the assumption of a uniform grey sky, which is not representative of conditions in Australia. As a result, research for this project included a review of daylight metrics and the redefinition of suitable functional daylight levels to inform the glazing analysis. This daylighting related research is presented in this Appendix.

### 7.1.1 Daylight Metrics

The three daylight metrics in common use are:

- Daylight factor (DF)
- Daylight Autonomy (DA)
- Spatial Daylight Autonomy (sDA)

The definitions and limitations of these are presented in Table 44. It is recommended overall that sDA provides the most appropriate daylight metric for use in Code related analyses for the following reasons:

- The sDA metric provides a comprehensive evaluation of the sufficiency of ambient daylight levels in interior spaces by analysing the entire analysis area over an annual timeframe. This makes it a more reliable and robust metric compared to point-based metrics such as daylight factor or daylight autonomy, which can only evaluate specific points or locations within a space.
- The sDA metric considers the area impact, the occupancy schedule dependence, climate location and orientation which are important factors in determining the overall daylight performance of a building.

### 7.1.2 What is an appropriate level of daylight?

Daytime buildings

Having defined a metric, it is necessary to define what level of that metric qualifies as sufficient daylight. To inform this, the daylight requirements of leading Green Building tools have been collated in Table 45. It can be seen in the Table that sDA is a commonly used metric in these tools, with requirements for typically 300lux, 50% of the time across around 55-75% of the floorplate.

While 300lux/50% thresholds can be translated directly into the current analysis, the area requirement requires translation to suit context. The rating tools are setting requirements for good daylight across an entire floorplate, which involves consideration of both glazing and the ratio of perimeter to core areas in the floorplate design. However, as the NCC only has regulation of glazing, only the daylighting performance in perimeter areas can be controlled. In this context, the translation of the sDA metric in this environment is that the perimeter zone should be well daylit; we have interpreted this as being 85% of the floor area of the perimeter zone being above the 300lux threshold for 50% of the time.

### Overnight buildings

The analysis for NCC2019/22 was based on a lower threshold[26] of daylighting for overnight buildings. This is justified on the basis that these building classes have lower illuminance requirements than daytime buildings as a result of the nature of the activities undertaken. Illustrative of this, while the AS1680 lighting requirement for an office is 320lux, it is 160lux for a hospital ward. As a result, the extension of the 300lux/50%/85% metric to overnight buildings would result in significantly more daylight than required for normal tasks in such buildings. Indeed, 300lux/50%/85% is not compatible with the solar admittance requirements in NCC2022. As a result, a lower standard of 160lux/50%/85% was adopted.

[26] 3% as opposed to 5%.

Table 44. Assessment of daylight metrics.

| Metric | Definition | Orientation Dependence | Climate Dependence | Occupancy Schedule Dependence | Area Impact | Timeframe | Conclusion |
|---|---|---|---|---|---|---|---|
| **Daylight Factor (DF)** | Ratio of indoor daylight illuminance to outdoor illuminance under an unobstructed overcast sky. Expressed as a percentage (%) | No | No | No | Area Weighted | Point in Time | DF measures just a ratio of outdoor illuminance vs indoor under an overcast sky. Doesn't take into account orientation, it's not climate dependant, does not use occupancy or area for its results. |
| **Daylight Autonomy (DA)** | Percentage of the occupied time when a target illuminance at a point in a space receives more than the illuminance threshold. | Yes | Yes | Yes | Point Analysis | Annual | Daylight Autonomy is a step forward compared to DF. This takes Climate, orientation and time into account for the analysis, but it doesn't take into account an area threshold for the hours that meet the lux threshold. |
| **Spatial Daylight Autonomy (sDA)** | **Percentage(%) of analysis area that meets a minimum daylight illuminance level for a specified fraction of the operating hours per year. Expressed as a % of area.** | **Yes** | **Yes** | **Yes** | **Area analysis** | **Annual** | **Of the 3, sDA is the most thorough analysis for Daylight. It takes into account Hours of Operation, Area and lux levels as the simulation output. The modelling requirements are more thorough as well as they take climate, orientation and occupancy into account.** |

Table 45. Daylight thresholds in various Green Building rating schemes.

| Variables | NCC2019/22 | Green Star Buildings | LEED 4.1 | WELL | IES-LM-83-12/23 | Recommendations for NCC 2025 |
|---|---|---|---|---|---|---|
| **Orientation** | Not Applicable | As per Design | As per Design | As per Design | As per Design | **As per Design** |
| **Climate** | Not Applicable | Closest TMY Weather Location | Closest TMY Weather Location | Closest TMY Weather Location | Closest TMY Weather Location | **Closest TMY Weather Location** |
| **Nominated Area** | Not Applicable | Continuously occupied for more than 2 hours/ Residential: Living and Sleeping areas. Laboratories can be excluded | Regularly occupied floor area.<br>Healthcare: Perimeter Area | Regularly occupied Spaces<br>Each Dwelling | Regularly occupied Spaces | **Continuously occupied for more than 2 hours / Residential: Living and Sleeping areas.** |
| **Nominated Plane** | Not Mentioned | 0.7m above FF | 0.76m above FF | Not Mentioned | 0.8m above FF | **Between 0.7m to 0.8m Above Finished floor Level** |
| **Occupancy Schedules** | Not Applicable | Green Star Schedules as per Operational Profiles | 8:00am to 6:00pm | 8:00am to 6:00pm | 8:00am to 6:00pm | **From 9:00am to 5:00pm as per Operational Schedules NCC** |
| **Glare Control Devices / Shades** | Not Applicable | Not included as part of the Analysis | Manual or Automatic included for regularly occupied spaces. | Should be Included | Manual or Automatic included for regularly occupied spaces. | **Blinds Not Included as Minimum Requirements** |
| **Surface Reflection** | Not Mentioned | As per Design | Core and Shell: 0.2 Floor<br>0.5 Walls<br>0.8 Ceiling<br>Or as per Design | As Per Standard IES-LM-83 | As Proposed or 0.2 Floor<br>0.5 Walls<br>0.8 Ceiling | **As Per Standard IES-LM83** |
| **Time Benchmark** | Not Applicable | 80% of Nominated Hours | 50% | 50% | 50% | **50% of the Nominated hours (9:00 to 17:00)** |
| **Lux Levels** | Minimum 2% DF in limited applications | 160 Lux | 300 Lux | 300 Lux | 300 Lux | **300 Lux daytime buildings<br>160 Lux overnight buildings** |
| **Area Benchmark** | Not Applicable | 40% for non-Residential<br>60% for Class 2 and 3 of Combined Living and Bedroom | All: 55%<br>Healthcare: 75% | All except Dwellings: 55%<br>Dwellings: 55% | Nominally Accepted: 55%<br>Nominally Preferred: 75% | **85% of the Nominated Area Perimeter Zones (3.5m deep)** |

### 7.1.3 Daylight modelling

Daylight modelling was conducted on the basis of a standardised perimeter zone space of 3.5 width (to the outside), 3.5m depth and 2.7m height. Reflectance values were set at 0.2 for floors, 0.5 for walls and 0.8 for ceilings. Each orientation was tested separately.

Daylight modelling was conducted using Radiance, which is an internationally accepted model for this purpose. Local climate files were used for solar radiation input data.

#### Operational Schedules

The time period over which sDA is evaluated must be set based on realistic interpretation of hours of daylight where there is appreciable building occupancy.

Table 46 lists sunrise and sunset times for capital cities throughout Australia. It can be seen that hours of daylight commence before 8am all year round, while sunset times are in the vicinity of 5pm in winter for most major centres.

Table 46. Sunrise and sunset times for capital cities.

| City | Solstice | Sunrise Time | Sunset Time |
|---|---|---|---|
| Sydney | Winter | 6:49 am | 4:54 pm |
| | Summer | 5:42 am | 7:50 pm |
| Melbourne | Winter | 7:34 am | 5:01 pm |
| | Summer | 6:03 am | 8:47 pm |
| Brisbane | Winter | 6:37 am | 5:00 pm |
| | Summer | 4:44 am | 6:45 pm |
| Perth | Winter | 7:18 am | 5:17 pm |
| | Summer | 5:06 am | 7:21 pm |
| Adelaide | Winter | 7:18 am | 5:10 pm |
| | Summer | 5:36 am | 8:31 pm |
| Hobart | Winter | 7:39 am | 4:44 pm |
| | Summer | 5:21 am | 8:41 pm |
| Darwin | Winter | 6:36 am | 6:27 pm |
| | Summer | 6:39 am | 6:22 pm |

In order to determine the time period over which buildings are likely to be occupied, we considered NCC occupancy schedules as listed in Table 47. It can be seen from the Table that the period from 9am-5pm is a consistent period of occupancy across all classes.

As this period broadly aligns with sunlight hours, we have adopted 9am-5pm as the hours for daylight in the analysis for the sDA metric.

Details

Table 47. NCC2022 occupancy schedule

| | NCC 2019/22 Operational Profiles / Occupancy | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Class 2 | Class 3 | Class 5 | Class 6 | Class 6 | Class 7 | Class 8 | Class 9 | |
| Hours of Operation | Common Areas | Residential / Hotel | Commercial | Retail | Restaurant / Café | Warehouse | Laboratory / Production | Public Building | Recommendations for NCC 2025 |
| 12:00am to 1:00am | 0% | 90% | 0% | 0% | 0% | 0% | 0% | 0% | |
| 1:00am to 2:00am | 0% | 90% | 0% | 0% | 0% | 0% | 0% | 0% | |
| 2:00am to 3:00am | 0% | 90% | 0% | 0% | 0% | 0% | 0% | 0% | |
| 3:00am to 4:00am | 0% | 90% | 0% | 0% | 0% | 0% | 0% | 0% | |
| 4:00am to 5:00am | 0% | 90% | 0% | 0% | 0% | 0% | 0% | 0% | |
| 5:00am to 6:00am | 0% | 80% | 0% | 0% | 0% | 0% | 0% | 0% | |
| 6:00am to 7:00am | 0% | 70% | 0% | 0% | 5% | 0% | 0% | 0% | |
| 7:00am to 8:00am | 0% | 60% | 10% | 10% | 5% | 10% | 10% | 10% | |
| 8:00am to 9:00am | 0% | 60% | 20% | 20% | 5% | 20% | 20% | 20% | |
| 9:00am to 10:00am | 0% | 30% | 70% | 70% | 5% | 70% | 70% | 70% | 9:00am to 10:00am |
| 10:00am to 11:00am | 0% | 10% | 70% | 70% | 20% | 70% | 70% | 70% | 10:00am to 11:00am |
| 11:00am to 12:00pm | 0% | 10% | 70% | 70% | 50% | 70% | 70% | 70% | 11:00am to 12:00pm |
| 12:00pm to 1:00pm | 0% | 10% | 70% | 70% | 80% | 70% | 70% | 70% | 12:00pm to 1:00pm |
| 1:00pm to 2:00pm | 0% | 10% | 70% | 70% | 70% | 70% | 70% | 70% | 1:00pm to 2:00pm |
| 2:00pm to 3:00pm | 0% | 10% | 70% | 70% | 40% | 70% | 70% | 70% | 2:00pm to 3:00pm |
| 3:00pm to 4:00pm | 0% | 10% | 70% | 70% | 20% | 70% | 70% | 70% | 3:00pm to 4:00pm |
| 4:00pm to 5:00pm | 0% | 20% | 70% | 70% | 25% | 70% | 70% | 70% | 4:00pm to 5:00pm |
| 5:00pm to 6:00pm | 0% | 30% | 35% | 35% | 50% | 35% | 35% | 35% | |
| 6:00pm to 7:00pm | 0% | 40% | 10% | 10% | 80% | 10% | 10% | 10% | |
| 7:00pm to 8:00pm | 0% | 50% | 5% | 5% | 80% | 5% | 5% | 5% | |
| 8:00pm to 9:00pm | 0% | 60% | 5% | 5% | 80% | 5% | 5% | 5% | |
| 9:00pm to 10:00pm | 0% | 70% | 0% | 0% | 50% | 0% | 0% | 0% | |
| 10:00pm to 11:00pm | 0% | 70% | 0% | 0% | 35% | 0% | 0% | 0% | |
| 11:00pm to 12:00am | 0% | 90% | 0% | 0% | 20% | 0% | 0% | 0% | |

### Methodology

The daylight simulations were conducted for a matrix of window wall ratio (25%, 30%, 35% and 40%) and glazing visual light transmittance (20%, 30%, 40%, 50% and 60%). sDA figures were calculated for each case, in each climate zone and in each orientation in order to determine whether there was a value of WWR*VLT that could be selected as reliably providing the required daylight performance.

It was found that differences between climate zones were minor, so results have been processed on a national basis. The results are presented for each façade in Figure 46 to Figure 49.

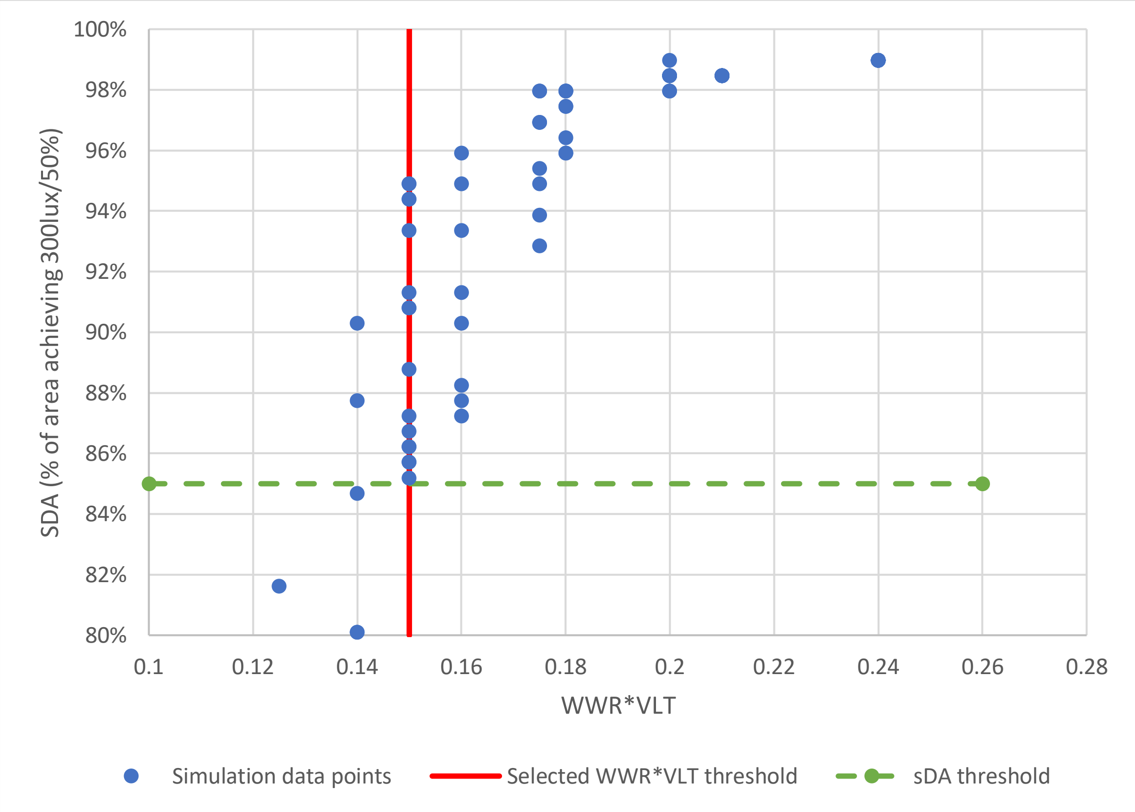



Figure 46. sDA analysis results for north zone (all climate zones).

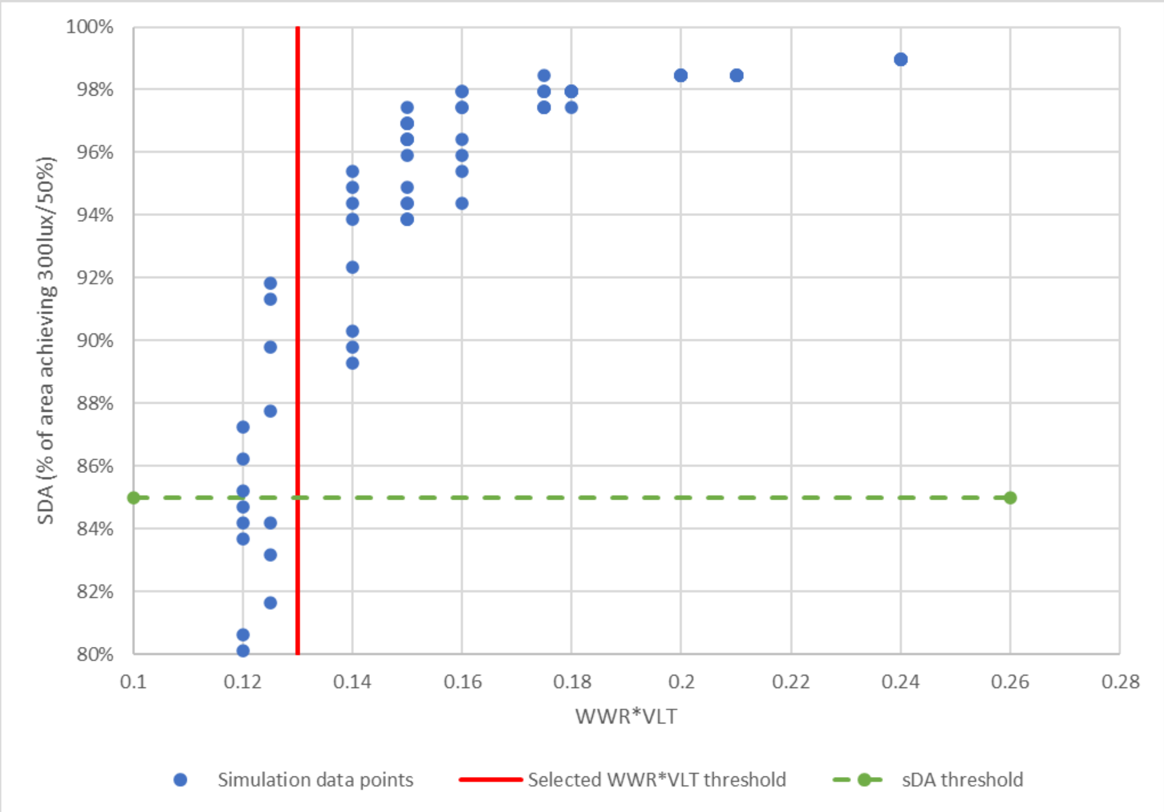



Figure 47. sDA analysis results for west zone (all climate zones).

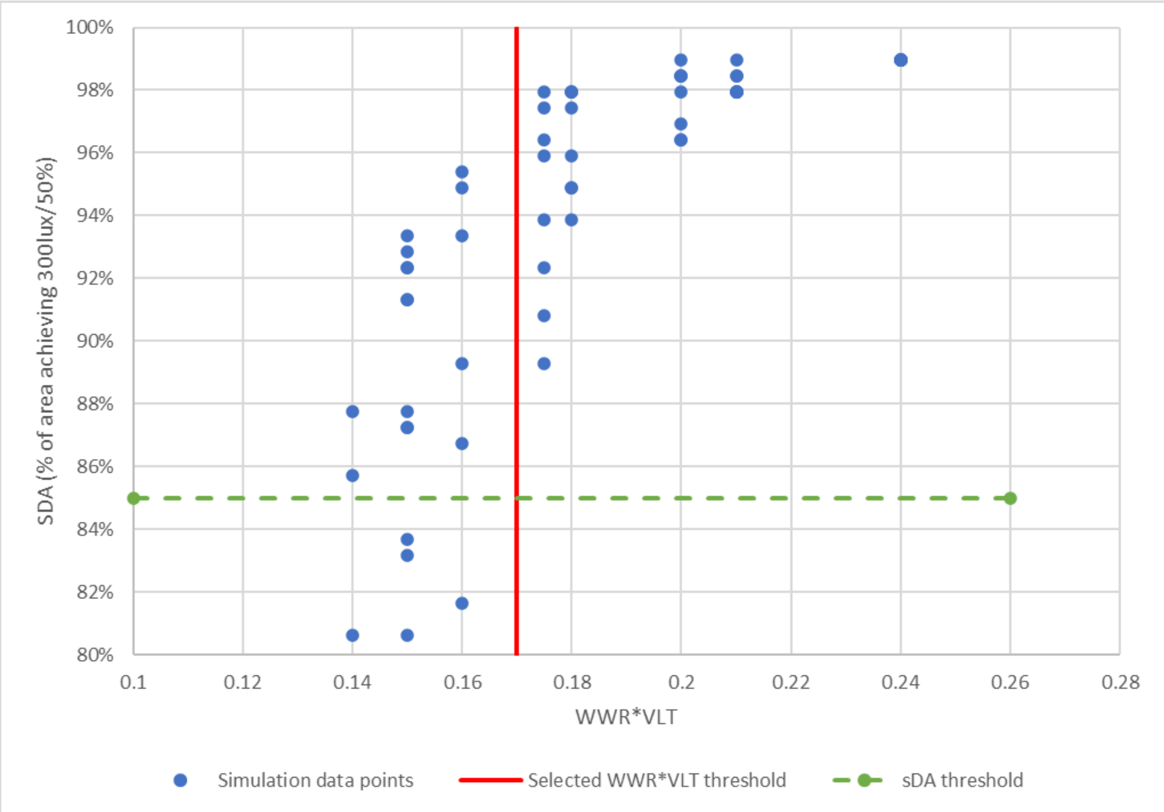



Figure 48. sDA results for south zone (all climate zones)

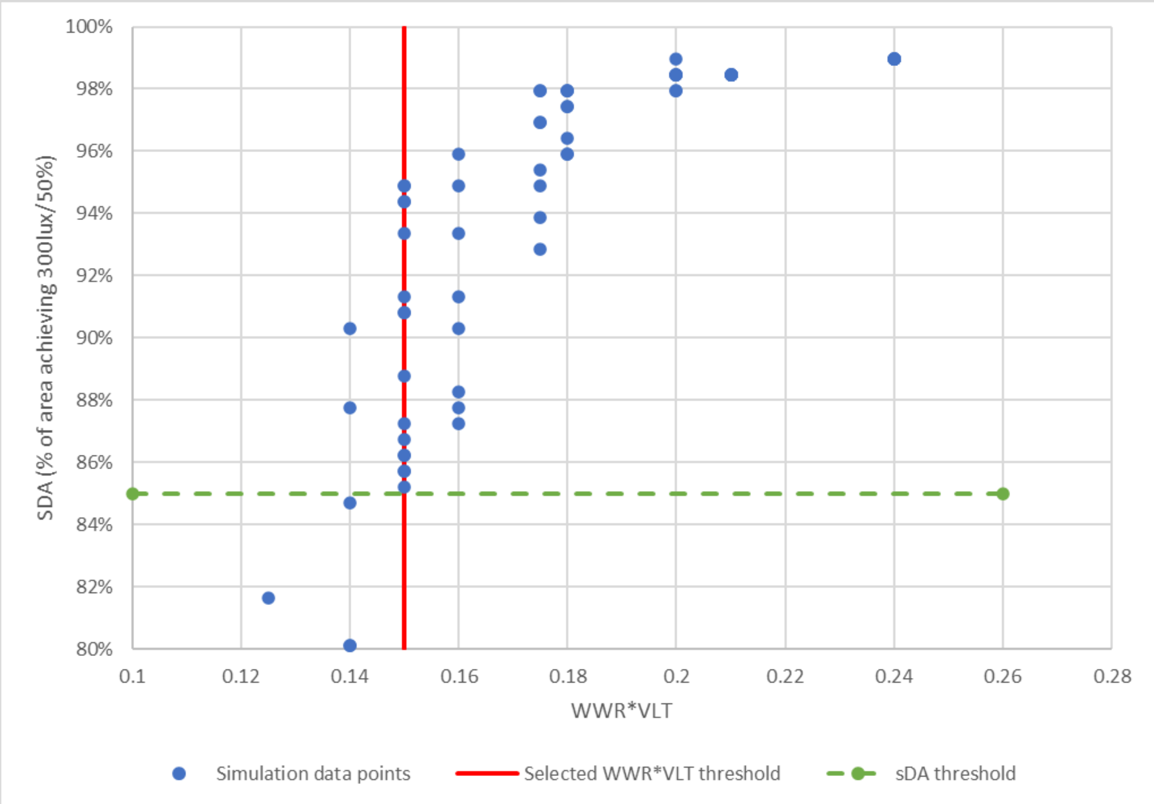



Figure 49. sDA analysis results for east zone (all climate zones)

A similar analysis was conducted for 160lux based on the results. The resultant WWR*VLT thresholds for minimum daylight performance are summarised in Table 48.

Table 48. Minimum thresholds for daylight performance.

| Aspect | VLT*WWR for 300 lux 50%/85% | VLT*WWR for 160 lux 50%/85% |
|---|---|---|
| **North** | 0.13 | 0.075 |
| **West** | 0.13 | 0.075 |
| **South** | 0.17 | 0.09 |
| **East** | 0.15 | 0.09 |

## 7.2 Glazing analysis: NCC2022 base case definition

### 7.2.1 Overall process and outcomes

The definition of a base case for glazing requires reference to the requirements of J4D6 (1), which sets out maximum U-values for window-wall constructions. As a result, the glazing base case has to be defined based on a holistic consideration of window and wall constructions to achieve these U values, with results dependent upon window-wall ratio. As noted in Section 4.3.2, wall R-Values (listed in Table 20) were selected based on wall structures with maximum insulation within the framing profile unless this was incompatible with a realistic glazing choice.

A basic set of representative glazing selections was used to define the glazing choices available, while wall constructions were considered with reference to the standard constructions listed in Table 12. An iterative process was used to select plausible standard construction meeting the NCC2022 requirements; in general, this included lower R-Value solid wall constructions as these are standard practice.

Table 49. Glazing types used for glazing analyses. Notes: a: DGU = Double Glazing Unit which compromises of two layers of glasses and either inert air or argon filled cavity in between; TGU = Triple Glazing Unit which compromises of three layers of glasses and two layers of either inert air or argon filled cavities in between. b: SHGC = Solar Heat Gain Co-efficient, c: VLT = Percentage Visual Light Transmission

| Name | Single/ DGU/ TGU[a] | Thickness (mm) | U-value (Centre) | SHGC[b] | VLT[c] |
|---|---|---|---|---|---|
| 6mm Gray | Single | 5.9 | 5.81 | 0.59 | 0.43 |
| 6mm Sunergy (AGC) | Single | 5.9 | 4.08 | 0.60 | 0.69 |
| ASG Visualite 67-1 6-12-6 air | DGU | 23.6 | 1.71 | 0.36 | 0.61 |
| ASG Visualite 70S-1 6-12-6 air | DGU | 23.6 | 1.71 | 0.30 | 0.62 |
| ASG Visualite 67-1 6-12-6 90% Argon | DGU | 23.6 | 1.44 | 0.36 | 0.61 |
| ASG Visualite 70S-1 6-12-6 90% Argon | DGU | 23.6 | 1.43 | 0.30 | 0.62 |
| 6mm Planibel | Single | 5.9 | 3.50 | 0.68 | 0.79 |
| 6mm Crystal Grey XYG | Single | 6.0 | 5.81 | 0.67 | 0.63 |
| ASG Visualite 67-1 + grey 6-12-6 90% Argon | DGU | 23.8 | 1.44 | 0.34 | 0.30 |
| ASG Visualite 70S-1 + grey 6-12-6 90% Argon | DGU | 23.8 | 1.43 | 0.28 | 0.30 |
| ASG Super S1-1 6-12-6 90% Argon | DGU | 23.6 | 1.57 | 0.54 | 0.74 |
| ASG Coolshade 42-1 crystal grey 6-12-6 90% Argon | DGU | 24.6 | 1.46 | 0.24 | 0.30 |
| ASG CoolShade 30 crustal grey 6-12-6 90% Argon | DGU | 23.9 | 1.45 | 0.19 | 0.22 |
| ASG Clear Visualite 67-1 #3 6-12-6 Argon | DGU | 23.6 | 1.45 | 0.48 | 0.61 |
| ASG Clear Visualite 70S-1 #3 6-12-6 Argon | DGU | 23.6 | 1.44 | 0.40 | 0.62 |
| ASG Super S1-1 #3 6-12-6 Argon | DGU | 23.6 | 1.57 | 0.61 | 0.74 |
| ASG Visualite 70S-1 #2 and #3 6-12-6 90% Argon | DGU | 23.7 | 1.37 | 0.27 | 0.49 |
| ASG Visualite 70S-1 6-12-6 90% Argon low e #2 and #4 Sunergy | DGU | 23.7 | 1.23 | 0.28 | 0.48 |
| TGU Visualite 67-1 6-12-3-12-6 90% Air | TGU | 38.6 | 1.28 | 0.33 | 0.55 |
| TGU Visualite 70S-1 6-12-3-12-6 90% Argon | TGU | 38.6 | 1.08 | 0.27 | 0.56 |
| TGU Visualite 70S-1 6-12-3-12-6 90% Air | TGU | 38.6 | 1.28 | 0.27 | 0.56 |
| TGU Visualite 67-1 #5 6-12-3-12-6 90% Argon | TGU | 38.6 | 1.04 | 0.45 | 0.55 |
| TGU Visualite 67-1 #5 6-12-3-12-6 90% Air | TGU | 38.6 | 1.24 | 0.45 | 0.55 |
| TGU Visualite 70S-1 #5 6-12-3-12-6 90% Argon | TGU | 38.6 | 1.04 | 0.39 | 0.56 |
| TGU Visualite 70S-1 #5 6-12-3-12-6 90% Air | TGU | 38.6 | 1.24 | 0.39 | 0.56 |
| TGU ASG Cool Shade 30 + Crystal Grey 6-12-3-12-6 90% Argon | TGU | 38.9 | 1.09 | 0.17 | 0.20 |
| TGU ASG Cool Shade 42-1+ Crystal Grey 6-12-3-12-6 90% Argon | TGU | 39.0 | 1.09 | 0.22 | 0.27 |
| TGUVisualite 70S-1 #2 and Sunergy #4 90% Argon | TGU | 41.4 | 1.07 | 0.25 | 0.43 |
| TGU Visualite 70S-1 #2 and Sunergy #6 90% Argon | TGU | 41.4 | 0.96 | 0.25 | 0.43 |
| TGU Low e Visualite 70S-1 #2 Sunergy #4 and #6 90% Argon | TGU | 41.6 | 0.82 | 0.23 | 0.34 |
| TGU Low e #2 #4 #5 17961 90% Argon | TGU | 41.6 | 0.73 | 0.22 | 0.34 |

### 7.2.2 Glazing properties calculation

Assumed panel sizes used in calculations are listed in Table 50. Assumptions are based on the WWR of each archetype, and a typical window/ door size.

Table 50. Assumed panel sizes for glazing calculations. Intermediate frames include either mullion or transom frames.

| Archetype | Glazing System | Width (m) | Height (m) | Window Intermediate Frames | Door/ Entrance Intermediate Frames |
|---|---|---|---|---|---|
| C3HS | Front View Window | 2 | 2 | None | None |
| C3HS | Rear View Window | 1.8 | 2 | None | None |
| C3HL | Main Entrance | 4 | 2.7 | Mullion and Transom | Mullion and Transom |
| C3HL | Service entrance | 8 | 3.6 | Mullion and Transom | Mullion and Transom |
| C3HL | Window 1 | 2 | 2 | Mullion and Transom | Mullion and Transom |
| C3HL | window 2 | 4 | 2 | Mullion and Transom | Mullion and Transom |
| C5OS | Main entrance | 3 | 2.7 | Mullion | Mullion |
| C5OS | Service Entrance | 8 | 3.6 | Mullion | Mullion |
| C5OS | window | 17 | 1.26 | Mullion | Mullion |
| C5OM | Main entrance | 3 | 2.7 | Mullion | Mullion |
| C5OM | Service Entrance | 8 | 3.6 | Mullion | Mullion |
| C5OM | Window long side | 48 | 1.26 | Mullion | Mullion |
| C5OM | Window short side | 24 | 1.26 | Mullion | Mullion |
| C6RS | Public entrance door | 1.2 | 2.1 | Mullion | Mullion |
| C6RS | Service Door | 2 | 3.6 | Mullion | Mullion |
| C6RS | Window long (front) side | 50 | 5.5 | Mullion | Mullion |
| C6RS | Window short side | 20 | 5.5 | Mullion | Mullion |
| C6RS | Ceiling cavity for services | n/a | 1.4 | Mullion | Mullion |
| C6RL | Entrance size | 12 | 3.5 | Mullion and Transom | Mullion |
| C9A | Main door | 4 | 3.3 | Transom | Transom |
| C9A | Service Door | 8 | 4.2 | Transom | Transom |
| C9A | Window 1 | 1 | 2 | Transom | Transom |
| C9A | Window 2 | 2 | 2 | Transom | Transom |

| Archetype | Glazing System | Width (m) | Height (m) | Window Intermediate Frames | Door/ Entrance Intermediate Frames |
|---|---|---|---|---|---|
| C9B | Main entrance | 3 | 3.3 | None | None |
| | window 1 | 48 | 1.5 | None | None |
| | Window 2 | 2 | 1.5 | None | None |
| | window 1 | 2.5 | 2 | None | None |

Two different glazing systems were considered, being a captive glazing system and a structural glazing system.

### 100mm Captive glazing system

This glazing system adopts dry gasket and an aluminium cap to keep the glass within the channel.

Table 51. Calculated U-value per each detail of the captive glazing system using THERM modelling. Typical 6mm float glass of 5.82 U-value, 0.88VLT and 0.82SHGC has been used to calculate as a reference.

| Label | Description | U frame W/m².K° | U edge W/m².K° | Frame width (mm) | SHGC perimeter (mm) |
|---|---|---|---|---|---|
| H | Horizontal Vision | 15.89 | 3.78 | 56.4 | 79.7 |
| SS | Subsill Vision | 11.55 | 3.79 | 75.0 | 103.5 |
| SH | Subhead Vision | 9.24 | 3.78 | 83.0 | 101.1 |
| MS | Mullion Split Vision | 14.81 | 3.78 | 58.0 | 81.3 |
| SJ | Sub Jamb Vision | 8.91 | 3.78 | 98.0 | 119.3 |

Typical details in reference to the labels in Table 51 are shown in Figure 50 :

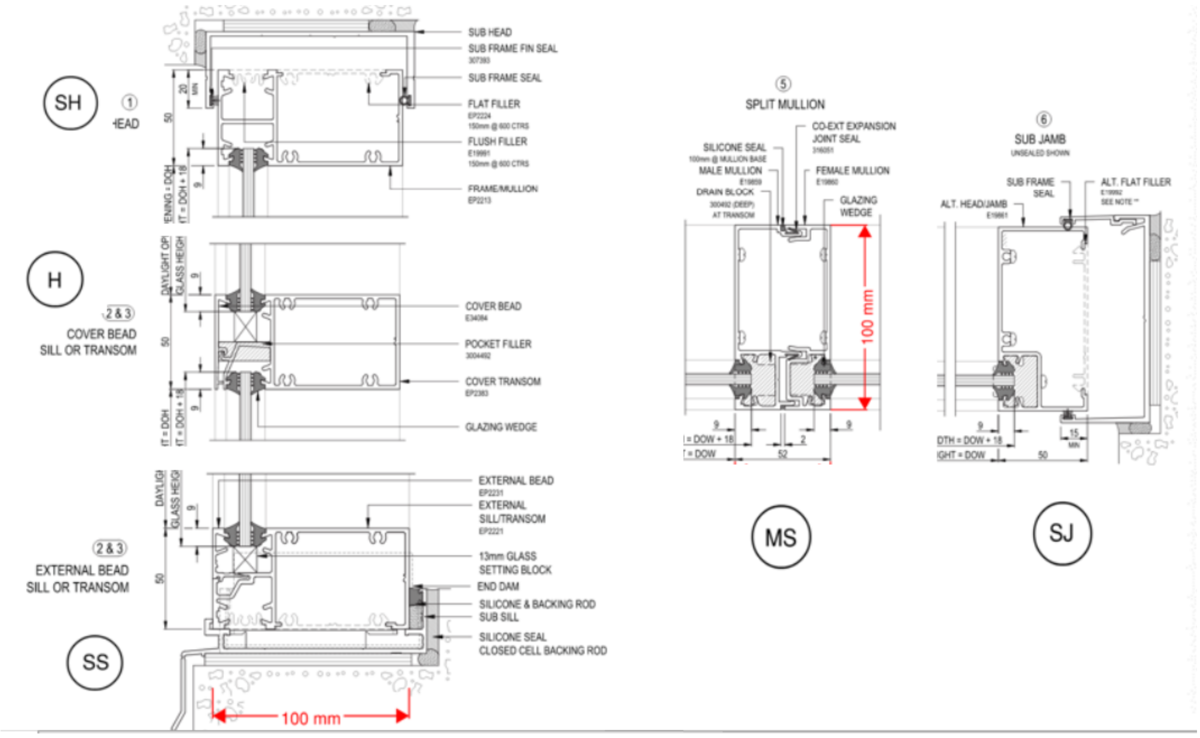



Figure 50. Typical detail of captive glazing system with referenced 100mm depth profile.

### 150mm Structural glazing system

This glazing system adopts structural silicone to adhere the glass onto the frame. A larger profile has been selected as generally used for double glazing system and structurally required to accommodate the increased thickness of the glass.

Table 52. Calculated U-value per each detail of the glazing system using THERM modelling. Typical ASG Visualite 67-1 6-12-6 air of 31.72 U-value, 0.61VLT and 0.36SHGC has been used to calculate as a reference.

| Label | Description | U frame W/m².K° | U edge W/m².K° | Frame width (mm) | SHGC perimeter (mm) |
|---|---|---|---|---|---|
| H | Horizontal Vision | 11.44 | 1.71 | 55.0 | 55.0 |
| SS | Subsill Vision | 12.66 | 2.06 | 75.7 | 214.9 |
| SH | Subhead Vision | 9.40 | 1.91 | 97.9 | 117.0 |
| MS | Mullion Split Vision | 11.98 | 1.68 | 53.5 | 53.5 |
| SJ | Sub Jamb Vision | 9.40 | 1.91 | 97.9 | 117.0 |

Typical details in reference to the labels in Table 52 are shown in Figure 50:

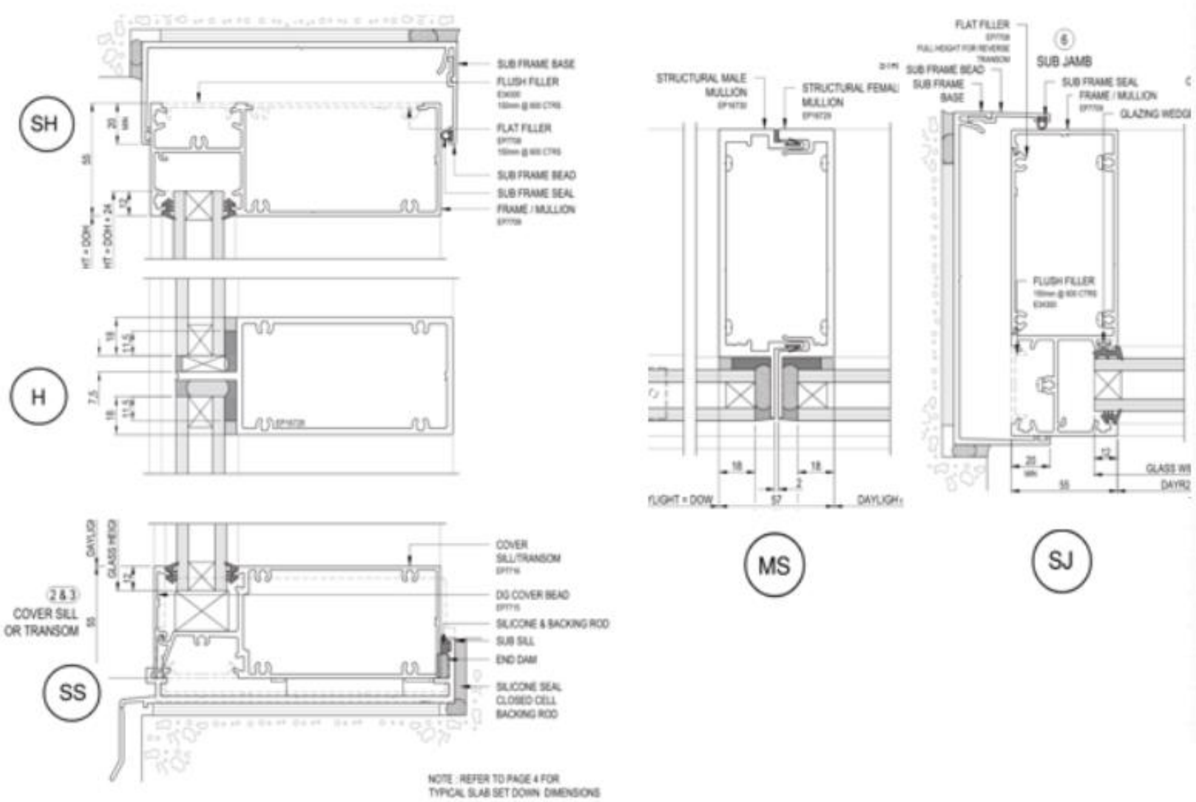



Figure 51. Typical detail of structural glazing system with referenced 150mm depth profile.

## 7.2.3 NCC2022 compliant base case glazing selections for glazing analysis

Using the glazing systems derived in Section 7.2.2, a matching process was used to obtain glazing selections that met the NCC2022 criteria for solar admittance and window-wall U value. The selected glazing systems are documented in Table 53 to Table 58.

Table 53. NCC2022 compliant glazing selections determined for Section 4.3.2 for office/daytime archetype, 30% WWR

| Archetype | CZ | WWR | Aspect | Glazing selection | Glazing SHGC | Glazing U value | System SHGC | System U |
|---|---|---|---|---|---|---|---|---|
| **C5OL** | 1 | 30% | East | ASG Clear Visualite 70S-1 #3 6-12-6 Argon | 0.402 | 1.436 | 0.36 | 2.57 |
| | | | North | ASG Clear Visualite 70S-1 #3 6-12-6 Argon | 0.402 | 1.436 | 0.36 | 2.57 |
| | | | South | ASG Super S1-1 6-12-6 90% Argon | 0.542 | 1.57 | 0.49 | 2.67 |
| | | | West | ASG Clear Visualite 70S-1 #3 6-12-6 Argon | 0.402 | 1.436 | 0.36 | 2.57 |
| **C5OL** | 2 | 30% | East | ASG Clear Visualite 67-1 #3 6-12-6 Argon | 0.479 | 1.446 | 0.43 | 2.578 |
| | | | North | ASG Clear Visualite 67-1 #3 6-12-6 Argon | 0.479 | 1.446 | 0.43 | 2.578 |
| | | | South | ASG Super S1-1 6-12-6 90% Argon | 0.542 | 1.57 | 0.49 | 2.67 |
| | | | West | ASG Clear Visualite 67-1 #3 6-12-6 Argon | 0.479 | 1.446 | 0.43 | 2.578 |
| **C5OL** | 3 | 30% | East | ASG Super S1-1 6-12-6 90% Argon | 0.542 | 1.57 | 0.49 | 2.67 |
| | | | North | ASG Super S1-1 6-12-6 90% Argon | 0.542 | 1.57 | 0.49 | 2.67 |
| | | | South | ASG Super S1-1 6-12-6 90% Argon | 0.542 | 1.57 | 0.49 | 2.67 |
| | | | West | ASG Super S1-1 6-12-6 90% Argon | 0.542 | 1.57 | 0.49 | 2.67 |
| **C5OL** | 4 | 30% | East | ASG Clear Visualite 67-1 #3 6-12-6 Argon | 0.479 | 1.446 | 0.43 | 2.578 |
| | | | North | ASG Clear Visualite 67-1 #3 6-12-6 Argon | 0.479 | 1.446 | 0.43 | 2.578 |
| | | | South | ASG Super S1-1 6-12-6 90% Argon | 0.542 | 1.57 | 0.49 | 2.67 |
| | | | West | ASG Clear Visualite 67-1 #3 6-12-6 Argon | 0.479 | 1.446 | 0.43 | 2.578 |
| **C5OL** | 5 | 30% | East | ASG Clear Visualite 67-1 #3 6-12-6 Argon | 0.479 | 1.446 | 0.43 | 2.578 |
| | | | North | ASG Clear Visualite 67-1 #3 6-12-6 Argon | 0.479 | 1.446 | 0.43 | 2.578 |
| | | | South | ASG Super S1-1 6-12-6 90% Argon | 0.542 | 1.57 | 0.49 | 2.67 |
| | | | West | ASG Clear Visualite 67-1 #3 6-12-6 Argon | 0.479 | 1.446 | 0.43 | 2.578 |
| **C5OL** | 6 | 30% | East | ASG Clear Visualite 67-1 #3 6-12-6 Argon | 0.479 | 1.446 | 0.43 | 2.578 |
| | | | North | ASG Clear Visualite 67-1 #3 6-12-6 Argon | 0.479 | 1.446 | 0.43 | 2.578 |
| | | | South | ASG Super S1-1 6-12-6 90% Argon | 0.542 | 1.57 | 0.49 | 2.67 |
| | | | West | ASG Clear Visualite 67-1 #3 6-12-6 Argon | 0.479 | 1.446 | 0.43 | 2.578 |
| **C5OL** | 7 | 30% | East | ASG Clear Visualite 67-1 #3 6-12-6 Argon | 0.479 | 1.446 | 0.43 | 2.578 |
| | | | North | ASG Clear Visualite 67-1 #3 6-12-6 Argon | 0.479 | 1.446 | 0.43 | 2.578 |
| | | | South | ASG Super S1-1 6-12-6 90% Argon | 0.542 | 1.57 | 0.49 | 2.67 |
| | | | West | ASG Clear Visualite 67-1 #3 6-12-6 Argon | 0.479 | 1.446 | 0.43 | 2.578 |
| **C5OL** | 8 | 30% | East | ASG Super S1-1 #3 6-12-6 Argon | 0.605 | 1.568 | 0.54 | 2.668 |
| | | | North | ASG Super S1-1 #3 6-12-6 Argon | 0.605 | 1.568 | 0.54 | 2.668 |
| | | | South | ASG Super S1-1 #3 6-12-6 Argon | 0.605 | 1.568 | 0.54 | 2.668 |
| | | | West | ASG Super S1-1 #3 6-12-6 Argon | 0.605 | 1.568 | 0.54 | 2.668 |

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Table 54. NCC2022 compliant glazing selections determined for Section 4.3.2 for office/daytime archetype, 50% WWR.

| Archetype | CZ | WWR | Aspect | Glazing selection | Glazing SHGC | Glazing U value | System SHGC | System U |
|---|---|---|---|---|---|---|---|---|
| **C5OL** | 1 | 50% | East | ASG Visualite 70S-1 6-12-6 air | 0.301 | 1.706 | 0.27 | 2.771 |
| | | | North | ASG Coolshade 42-1 crystal grey 6-12-6 %90 Argon | 0.239 | 1.46 | 0.22 | 2.588 |
| | | | South | ASG Visualite 70S-1 6-12-6 air | 0.301 | 1.706 | 0.27 | 2.771 |
| | | | West | ASG Coolshade 42-1 crystal grey 6-12-6 %90 Argon | 0.239 | 1.46 | 0.22 | 2.588 |
| **C5OL** | 2 | 50% | East | ASG Visualite 70S-1 6-12-6 air | 0.301 | 1.706 | 0.27 | 2.771 |
| | | | North | ASG Visualite 70S-1 + Grey 6-12-6 Argon | 0.281 | 1.44 | 0.25 | 2.573 |
| | | | South | ASG Visualite 70S-1 6-12-6 air | 0.301 | 1.706 | 0.27 | 2.771 |
| | | | West | ASG Visualite 70S-1 + Grey 6-12-6 Argon | 0.281 | 1.44 | 0.25 | 2.573 |
| **C5OL** | 3 | 50% | East | ASG Visualite 67-1 6-12-6 90% Argon | 0.356 | 1.45 | 0.32 | 2.581 |
| | | | North | ASG Visualite 67-1 6-12-6 90% Argon | 0.356 | 1.45 | 0.32 | 2.581 |
| | | | South | ASG Visualite 67-1 6-12-6 90% Argon | 0.356 | 1.45 | 0.32 | 2.581 |
| | | | West | ASG Visualite 67-1 6-12-6 90% Argon | 0.356 | 1.45 | 0.32 | 2.581 |
| **C5OL** | 4 | 50% | East | ASG Visualite 70S-1 6-12-6 air | 0.301 | 1.706 | 0.27 | 2.771 |
| | | | North | ASG Visualite 70S-1 + Grey 6-12-6 Argon | 0.281 | 1.44 | 0.25 | 2.573 |
| | | | South | ASG Visualite 70S-1 6-12-6 air | 0.301 | 1.706 | 0.27 | 2.771 |
| | | | West | ASG Visualite 70S-1 + Grey 6-12-6 Argon | 0.281 | 1.44 | 0.25 | 2.573 |
| **C5OL** | 5 | 50% | East | ASG Visualite 70S-1 6-12-6 air | 0.301 | 1.706 | 0.27 | 2.771 |
| | | | North | ASG Visualite 70S-1 + Grey 6-12-6 Argon | 0.281 | 1.44 | 0.25 | 2.573 |
| | | | South | ASG Visualite 70S-1 6-12-6 air | 0.301 | 1.706 | 0.27 | 2.771 |
| | | | West | ASG Visualite 70S-1 + Grey 6-12-6 Argon | 0.281 | 1.44 | 0.25 | 2.573 |
| **C5OL** | 6 | 50% | East | ASG Visualite 70S-1 6-12-6 air | 0.301 | 1.706 | 0.27 | 2.771 |
| | | | North | ASG Visualite 70S-1 + Grey 6-12-6 Argon | 0.281 | 1.44 | 0.25 | 2.573 |
| | | | South | ASG Visualite 70S-1 6-12-6 air | 0.301 | 1.706 | 0.27 | 2.771 |
| | | | West | ASG Visualite 70S-1 + Grey 6-12-6 Argon | 0.281 | 1.44 | 0.25 | 2.573 |
| **C5OL** | 7 | 50% | East | ASG Visualite 70S-1 6-12-6 air | 0.301 | 1.706 | 0.27 | 2.771 |
| | | | North | ASG Visualite 70S-1 + Grey 6-12-6 Argon | 0.281 | 1.44 | 0.25 | 2.573 |
| | | | South | ASG Visualite 70S-1 6-12-6 air | 0.301 | 1.706 | 0.27 | 2.771 |
| | | | West | ASG Visualite 70S-1 + Grey 6-12-6 Argon | 0.281 | 1.44 | 0.25 | 2.573 |
| **C5OL** | 8 | 50% | East | ASG Clear Visualite 70S-1 #3 6-12-6 Argon | 0.402 | 1.436 | 0.36 | 2.57 |
| | | | North | ASG Clear Visualite 70S-1 #3 6-12-6 Argon | 0.402 | 1.436 | 0.36 | 2.57 |
| | | | South | ASG Super S1-1 #3 6-12-6 Argon | 0.605 | 1.568 | 0.54 | 2.668 |
| | | | West | ASG Super S1-1 #3 6-12-6 Argon | 0.605 | 1.568 | 0.54 | 2.668 |

Table 55. NCC2022 compliant glazing selections determined for Section 4.3.2 for office/daytime archetype, 70% WWR

| Archetype | CZ | WWR | Aspect | Glazing selection | Glazing SHGC | Glazing U value | System SHGC | System U |
|---|---|---|---|---|---|---|---|---|
| **C5OL** | 1 | 70% | East | ASG Coolshade 42-1 crystal grey 6-12-6 %90 Argon | 0.239 | 1.46 | 0.22 | 2.588 |
| | | | North | ASG CoolShade 30 crystal grey 6-12-6 90% Argon | 0.186 | 1.45 | 0.17 | 2.581 |
| | | | South | ASG Coolshade 42-1 crystal grey 6-12-6 %90 Argon | 0.239 | 1.46 | 0.22 | 2.588 |
| | | | West | ASG CoolShade 30 crystal grey 6-12-6 90% Argon | 0.186 | 1.45 | 0.17 | 2.581 |
| **C5OL** | 2 | 70% | East | ASG Coolshade 42-1 crystal grey 6-12-6 %90 Argon | 0.239 | 1.46 | 0.22 | 2.588 |
| | | | North | ASG CoolShade 30 crystal grey 6-12-6 90% Argon | 0.186 | 1.45 | 0.17 | 2.581 |
| | | | South | ASG Coolshade 42-1 crystal grey 6-12-6 %90 Argon | 0.239 | 1.46 | 0.22 | 2.588 |
| | | | West | ASG CoolShade 30 crystal grey 6-12-6 90% Argon | 0.186 | 1.45 | 0.17 | 2.581 |
| **C5OL** | 3 | 70% | East | ASG Coolshade 42-1 crystal grey 6-12-6 %90 Argon | 0.239 | 1.46 | 0.22 | 2.588 |
| | | | North | ASG Coolshade 42-1 crystal grey 6-12-6 %90 Argon | 0.239 | 1.46 | 0.22 | 2.588 |
| | | | South | ASG Coolshade 42-1 crystal grey 6-12-6 %90 Argon | 0.239 | 1.46 | 0.22 | 2.588 |
| | | | West | ASG Coolshade 42-1 crystal grey 6-12-6 %90 Argon | 0.239 | 1.46 | 0.22 | 2.588 |
| **C5OL** | 4 | 70% | East | ASG Coolshade 42-1 crystal grey 6-12-6 %90 Argon | 0.239 | 1.46 | 0.22 | 2.588 |
| | | | North | ASG CoolShade 30 crystal grey 6-12-6 90% Argon | 0.186 | 1.45 | 0.17 | 2.581 |
| | | | South | ASG Coolshade 42-1 crystal grey 6-12-6 %90 Argon | 0.239 | 1.46 | 0.22 | 2.588 |
| | | | West | ASG CoolShade 30 crystal grey 6-12-6 90% Argon | 0.186 | 1.45 | 0.17 | 2.581 |
| **C5OL** | 5 | 70% | East | ASG Coolshade 42-1 crystal grey 6-12-6 %90 Argon | 0.239 | 1.46 | 0.22 | 2.588 |
| | | | North | ASG CoolShade 30 crystal grey 6-12-6 90% Argon | 0.186 | 1.45 | 0.17 | 2.581 |
| | | | South | ASG Coolshade 42-1 crystal grey 6-12-6 %90 Argon | 0.239 | 1.46 | 0.22 | 2.588 |
| | | | West | ASG CoolShade 30 crystal grey 6-12-6 90% Argon | 0.186 | 1.45 | 0.17 | 2.581 |
| **C5OL** | 6 | 70% | East | ASG Coolshade 42-1 crystal grey 6-12-6 %90 Argon | 0.239 | 1.46 | 0.22 | 2.588 |
| | | | North | ASG CoolShade 30 crystal grey 6-12-6 90% Argon | 0.186 | 1.45 | 0.17 | 2.581 |
| | | | South | ASG Coolshade 42-1 crystal grey 6-12-6 %90 Argon | 0.239 | 1.46 | 0.22 | 2.588 |
| | | | West | ASG CoolShade 30 crystal grey 6-12-6 90% Argon | 0.186 | 1.45 | 0.17 | 2.581 |
| **C5OL** | 7 | 70% | East | ASG Coolshade 42-1 crystal grey 6-12-6 %90 Argon | 0.239 | 1.46 | 0.22 | 2.588 |
| | | | North | ASG CoolShade 30 crystal grey 6-12-6 90% Argon | 0.186 | 1.45 | 0.17 | 2.581 |
| | | | South | ASG Coolshade 42-1 crystal grey 6-12-6 %90 Argon | 0.239 | 1.46 | 0.22 | 2.588 |
| | | | West | ASG CoolShade 30 crystal grey 6-12-6 90% Argon | 0.186 | 1.45 | 0.17 | 2.581 |
| **C5OL** | 8 | 70% | East | ASG Visualite 70S-1 6-12-6 air | 0.301 | 1.706 | 0.27 | 2.771 |
| | | | North | ASG Visualite 70S-1 6-12-6 air | 0.301 | 1.706 | 0.27 | 2.771 |
| | | | South | ASG Super S1-1 #3 6-12-6 Argon | 0.605 | 1.568 | 0.54 | 2.668 |
| | | | West | ASG Super S1-1 6-12-6 90% Argon | 0.542 | 1.57 | 0.49 | 2.67 |

Table 56. NCC2022 compliant glazing selections determined for Section 4.3.2 for hospital/overnight archetype, 20% WWR.

| Archetype | CZ | WWR | Aspect | Glazing selection | Glazing SHGC | Glazing U value | System SHGC | System U |
|---|---|---|---|---|---|---|---|---|
| **C9A** | 1 | 20% | East | ASG Visualite 67-1 6-12-6 air | 0.36 | 1.715 | 0.32 | 2.778 |
| | | | North | ASG Visualite 67-1 6-12-6 air | 0.36 | 1.715 | 0.32 | 2.778 |
| | | | South | ASG Super S1-1 6-12-6 90% Argon | 0.542 | 1.57 | 0.49 | 2.67 |
| | | | West | ASG Visualite 67-1 6-12-6 air | 0.36 | 1.715 | 0.32 | 2.778 |
| **C9A** | 2 | 20% | East | ASG Super S1-1 6-12-6 90% Argon | 0.542 | 1.57 | 0.49 | 2.67 |
| | | | North | ASG Super S1-1 6-12-6 90% Argon | 0.542 | 1.57 | 0.49 | 2.67 |
| | | | South | ASG Super S1-1 6-12-6 90% Argon | 0.542 | 1.57 | 0.49 | 2.67 |
| | | | West | ASG Super S1-1 6-12-6 90% Argon | 0.542 | 1.57 | 0.49 | 2.67 |
| **C9A** | 3 | 20% | East | ASG Visualite 67-1 6-12-6 air | 0.36 | 1.715 | 0.32 | 2.778 |
| | | | North | ASG Visualite 67-1 6-12-6 air | 0.36 | 1.715 | 0.32 | 2.778 |
| | | | South | ASG Visualite 67-1 6-12-6 air | 0.36 | 1.715 | 0.32 | 2.778 |
| | | | West | ASG Visualite 67-1 6-12-6 air | 0.36 | 1.715 | 0.32 | 2.778 |
| **C9A** | 4 | 20% | East | ASG Visualite 67-1 6-12-6 air | 0.36 | 1.715 | 0.32 | 2.778 |
| | | | North | ASG Visualite 67-1 6-12-6 air | 0.36 | 1.715 | 0.32 | 2.778 |
| | | | South | ASG Visualite 67-1 6-12-6 air | 0.36 | 1.715 | 0.32 | 2.778 |
| | | | West | ASG Visualite 67-1 6-12-6 air | 0.36 | 1.715 | 0.32 | 2.778 |
| **C9A** | 5 | 20% | East | ASG Super S1-1 6-12-6 90% Argon | 0.542 | 1.57 | 0.49 | 2.67 |
| | | | North | ASG Super S1-1 6-12-6 90% Argon | 0.542 | 1.57 | 0.49 | 2.67 |
| | | | South | ASG Super S1-1 6-12-6 90% Argon | 0.542 | 1.57 | 0.49 | 2.67 |
| | | | West | ASG Super S1-1 6-12-6 90% Argon | 0.542 | 1.57 | 0.49 | 2.67 |
| **C9A** | 6 | 20% | East | ASG Visualite 67-1 6-12-6 air | 0.36 | 1.715 | 0.32 | 2.778 |
| | | | North | ASG Visualite 67-1 6-12-6 air | 0.36 | 1.715 | 0.32 | 2.778 |
| | | | South | ASG Visualite 67-1 6-12-6 air | 0.36 | 1.715 | 0.32 | 2.778 |
| | | | West | ASG Visualite 67-1 6-12-6 air | 0.36 | 1.715 | 0.32 | 2.778 |
| **C9A** | 7 | 20% | East | ASG Visualite 67-1 6-12-6 air | 0.36 | 1.715 | 0.32 | 2.778 |
| | | | North | ASG Visualite 67-1 6-12-6 air | 0.36 | 1.715 | 0.32 | 2.778 |
| | | | South | ASG Clear Visualite 70S-1 #3 6-12-6 Argon | 0.402 | 1.436 | 0.36 | 2.57 |
| | | | West | ASG Visualite 67-1 6-12-6 air | 0.36 | 1.715 | 0.32 | 2.778 |
| **C9A** | 8 | 20% | East | ASG Clear Visualite 70S-1 #3 6-12-6 Argon | 0.402 | 1.436 | 0.36 | 2.57 |
| | | | North | ASG Clear Visualite 70S-1 #3 6-12-6 Argon | 0.402 | 1.436 | 0.36 | 2.57 |
| | | | South | ASG Clear Visualite 70S-1 #3 6-12-6 Argon | 0.402 | 1.436 | 0.36 | 2.57 |
| | | | West | ASG Clear Visualite 70S-1 #3 6-12-6 Argon | 0.402 | 1.436 | 0.36 | 2.57 |

Table 57. NCC2022 compliant glazing selections determined for Section 4.3.2 for hospital/overnight archetype, 30% WWR

| Archetype | CZ | WWR | Aspect | Glazing selection | Glazing SHGC | Glazing U value | System SHGC | System U |
|---|---|---|---|---|---|---|---|---|
| **C9A** | 1 | 30% | East | ASG Visualite 70S-1 6-12-6 air | 0.301 | 1.706 | 0.27 | 2.771 |
| | | | North | ASG Coolshade 42-1 crystal grey 6-12-6 %90 Argon | 0.239 | 1.46 | 0.22 | 2.588 |
| | | | South | ASG Visualite 67-1 6-12-6 air | 0.36 | 1.715 | 0.32 | 2.778 |
| | | | West | ASG Coolshade 42-1 crystal grey 6-12-6 %90 Argon | 0.239 | 1.46 | 0.22 | 2.588 |
| **C9A** | 2 | 30% | East | ASG Visualite 67-1 6-12-6 air | 0.36 | 1.715 | 0.32 | 2.778 |
| | | | North | ASG Visualite 67-1 6-12-6 air | 0.36 | 1.715 | 0.32 | 2.778 |
| | | | South | ASG Visualite 67-1 6-12-6 air | 0.36 | 1.715 | 0.32 | 2.778 |
| | | | West | ASG Visualite 67-1 6-12-6 air | 0.36 | 1.715 | 0.32 | 2.778 |
| **C9A** | 3 | 30% | East | ASG Visualite 70S-1 6-12-6 air | 0.301 | 1.706 | 0.27 | 2.771 |
| | | | North | ASG Coolshade 42-1 crystal grey 6-12-6 %90 Argon | 0.239 | 1.46 | 0.22 | 2.588 |
| | | | South | ASG Visualite 70S-1 6-12-6 air | 0.301 | 1.706 | 0.27 | 2.771 |
| | | | West | ASG Coolshade 42-1 crystal grey 6-12-6 %90 Argon | 0.239 | 1.46 | 0.22 | 2.588 |
| **C9A** | 4 | 30% | East | ASG Visualite 70S-1 6-12-6 air | 0.301 | 1.706 | 0.27 | 2.771 |
| | | | North | ASG Coolshade 42-1 crystal grey 6-12-6 %90 Argon | 0.239 | 1.46 | 0.22 | 2.588 |
| | | | South | ASG Visualite 70S-1 6-12-6 air | 0.301 | 1.706 | 0.27 | 2.771 |
| | | | West | ASG Coolshade 42-1 crystal grey 6-12-6 %90 Argon | 0.239 | 1.46 | 0.22 | 2.588 |
| **C9A** | 5 | 30% | East | ASG Visualite 67-1 6-12-6 air | 0.36 | 1.715 | 0.32 | 2.778 |
| | | | North | ASG Visualite 67-1 6-12-6 air | 0.36 | 1.715 | 0.32 | 2.778 |
| | | | South | ASG Visualite 67-1 6-12-6 air | 0.36 | 1.715 | 0.32 | 2.778 |
| | | | West | ASG Visualite 67-1 6-12-6 air | 0.36 | 1.715 | 0.32 | 2.778 |
| **C9A** | 6 | 30% | East | ASG Visualite 70S-1 6-12-6 air | 0.301 | 1.706 | 0.27 | 2.771 |
| | | | North | ASG Coolshade 42-1 crystal grey 6-12-6 %90 Argon | 0.239 | 1.46 | 0.22 | 2.588 |
| | | | South | ASG Visualite 70S-1 6-12-6 air | 0.301 | 1.706 | 0.27 | 2.771 |
| | | | West | ASG Coolshade 42-1 crystal grey 6-12-6 %90 Argon | 0.239 | 1.46 | 0.22 | 2.588 |
| **C9A** | 7 | 30% | East | ASG Visualite 70S-1 6-12-6 air | 0.301 | 1.706 | 0.27 | 2.771 |
| | | | North | ASG Coolshade 42-1 crystal grey 6-12-6 %90 Argon | 0.239 | 1.46 | 0.22 | 2.588 |
| | | | South | ASG Visualite 70S-1 6-12-6 air | 0.301 | 1.706 | 0.27 | 2.771 |
| | | | West | ASG Coolshade 42-1 crystal grey 6-12-6 %90 Argon | 0.239 | 1.46 | 0.22 | 2.588 |
| **C9A** | 8 | 30% | East | ASG Visualite 70S-1 6-12-6 air | 0.301 | 1.706 | 0.27 | 2.771 |
| | | | North | ASG Visualite 70S-1 + Grey 6-12-6 Argon | 0.281 | 1.44 | 0.25 | 2.573 |
| | | | South | ASG Visualite 70S-1 6-12-6 air | 0.301 | 1.706 | 0.27 | 2.771 |
| | | | West | ASG Visualite 70S-1 + Grey 6-12-6 Argon | 0.281 | 1.44 | 0.25 | 2.573 |

Table 58. NCC2022 compliant glazing selections determined for Section 4.3.2 for hospital/overnight archetype, 40% WWR

| Archetype | CZ | WWR | Aspect | Glazing selection | Glazing SHGC | Glazing U value | System SHGC | System U |
|---|---|---|---|---|---|---|---|---|
| **C9A** | 1 | 40% | East | ASG Coolshade 42-1 crystal grey 6-12-6 %90 Argon | 0.239 | 1.46 | 0.22 | 2.588 |
| | | | North | ASG CoolShade 30 crystal grey 6-12-6 90% Argon | 0.186 | 1.45 | 0.17 | 2.581 |
| | | | South | ASG Coolshade 42-1 crystal grey 6-12-6 %90 Argon | 0.239 | 1.46 | 0.22 | 2.588 |
| | | | West | ASG CoolShade 30 crystal grey 6-12-6 90% Argon | 0.186 | 1.45 | 0.17 | 2.581 |
| **C9A** | 2 | 40% | East | ASG Coolshade 42-1 crystal grey 6-12-6 %90 Argon | 0.239 | 1.46 | 0.22 | 2.588 |
| | | | North | ASG Coolshade 42-1 crystal grey 6-12-6 %90 Argon | 0.239 | 1.46 | 0.22 | 2.588 |
| | | | South | ASG Coolshade 42-1 crystal grey 6-12-6 %90 Argon | 0.239 | 1.46 | 0.22 | 2.588 |
| | | | West | ASG Coolshade 42-1 crystal grey 6-12-6 %90 Argon | 0.239 | 1.46 | 0.22 | 2.588 |
| **C9A** | 3 | 40% | East | ASG Coolshade 42-1 crystal grey 6-12-6 %90 Argon | 0.239 | 1.46 | 0.22 | 2.588 |
| | | | North | ASG CoolShade 30 crystal grey 6-12-6 90% Argon | 0.186 | 1.45 | 0.17 | 2.581 |
| | | | South | ASG Coolshade 42-1 crystal grey 6-12-6 %90 Argon | 0.239 | 1.46 | 0.22 | 2.588 |
| | | | West | ASG CoolShade 30 crystal grey 6-12-6 90% Argon | 0.186 | 1.45 | 0.17 | 2.581 |
| **C9A** | 4 | 40% | East | ASG Coolshade 42-1 crystal grey 6-12-6 %90 Argon | 0.239 | 1.46 | 0.22 | 2.588 |
| | | | North | ASG CoolShade 30 crystal grey 6-12-6 90% Argon | 0.186 | 1.45 | 0.17 | 2.581 |
| | | | South | ASG Coolshade 42-1 crystal grey 6-12-6 %90 Argon | 0.239 | 1.46 | 0.22 | 2.588 |
| | | | West | ASG CoolShade 30 crystal grey 6-12-6 90% Argon | 0.186 | 1.45 | 0.17 | 2.581 |
| **C9A** | 5 | 40% | East | ASG Coolshade 42-1 crystal grey 6-12-6 %90 Argon | 0.239 | 1.46 | 0.22 | 2.588 |
| | | | North | ASG Coolshade 42-1 crystal grey 6-12-6 %90 Argon | 0.239 | 1.46 | 0.22 | 2.588 |
| | | | South | ASG Coolshade 42-1 crystal grey 6-12-6 %90 Argon | 0.239 | 1.46 | 0.22 | 2.588 |
| | | | West | ASG Coolshade 42-1 crystal grey 6-12-6 %90 Argon | 0.239 | 1.46 | 0.22 | 2.588 |
| **C9A** | 6 | 40% | East | ASG Coolshade 42-1 crystal grey 6-12-6 %90 Argon | 0.239 | 1.46 | 0.22 | 2.588 |
| | | | North | ASG CoolShade 30 crystal grey 6-12-6 90% Argon | 0.186 | 1.45 | 0.17 | 2.581 |
| | | | South | ASG Coolshade 42-1 crystal grey 6-12-6 %90 Argon | 0.239 | 1.46 | 0.22 | 2.588 |
| | | | West | ASG CoolShade 30 crystal grey 6-12-6 90% Argon | 0.186 | 1.45 | 0.17 | 2.581 |
| **C9A** | 7 | 40% | East | ASG Coolshade 42-1 crystal grey 6-12-6 %90 Argon | 0.239 | 1.46 | 0.22 | 2.588 |
| | | | North | ASG CoolShade 30 crystal grey 6-12-6 90% Argon | 0.186 | 1.45 | 0.17 | 2.581 |
| | | | South | ASG Coolshade 42-1 crystal grey 6-12-6 %90 Argon | 0.239 | 1.46 | 0.22 | 2.588 |
| | | | West | ASG CoolShade 30 crystal grey 6-12-6 90% Argon | 0.186 | 1.45 | 0.17 | 2.581 |
| **C9A** | 8 | 40% | East | ASG Coolshade 42-1 crystal grey 6-12-6 %90 Argon | 0.239 | 1.46 | 0.22 | 2.588 |
| | | | North | ASG CoolShade 30 crystal grey 6-12-6 90% Argon | 0.186 | 1.45 | 0.17 | 2.581 |
| | | | South | ASG Coolshade 42-1 crystal grey 6-12-6 %90 Argon | 0.239 | 1.46 | 0.22 | 2.588 |
| | | | West | ASG CoolShade 30 crystal grey 6-12-6 90% Argon | 0.186 | 1.45 | 0.17 | 2.581 |

## 7.3 Glazing Cost Information

Glazing costs are based on the combined framing system cost and average glass costs. The glazing costs in particular are quite generalized in the market, with differentiation based on number of panes, gas filling and quantity of silver coatings. Configuration of panes in the glazing system was not a factor in pricing.

Table 59. Glass costs

| Name | Number of panes | Thickness (mm) | U – Centre, Winter | SHGC | $T_{vis}$ | Average Cost ($/m²) |
|---|---|---|---|---|---|---|
| 6mm Gray | 1 | 5.9 | 5.81 | 0.59 | 0.43 | $25.00 |
| 6mm Sunergy (AGC) | 1 | 5.9 | 4.08 | 0.60 | 0.69 | $25.00 |
| ASG Visualite 67-1 6-12-6 air | 2 | 23.6 | 1.71 | 0.36 | 0.61 | $135.00 |
| ASG Visualite 70S-1 6-12-6 air | 2 | 23.6 | 1.71 | 0.30 | 0.62 | $156.00 |
| ASG Visualite 67-1 6-12-6 90% Argon | 2 | 23.6 | 1.44 | 0.36 | 0.61 | $144.50 |
| ASG Visualite 70S-1 6-12-6 Argon | 2 | 23.6 | 1.43 | 0.30 | 0.62 | $165.50 |
| 6mm Planibel | 1 | 5.9 | 3.50 | 0.68 | 0.79 | $100.00 |
| 6mm Crystal Grey XYG | 1 | 6.0 | 5.81 | 0.67 | 0.63 | $25.00 |
| ASG Visualite 67-1 + grey 6-12-6 90% Argon | 2 | 23.8 | 1.44 | 0.34 | 0.30 | $144.50 |
| ASG Visualite 70S-1 + grey 6-12-6 90% Argon | 2 | 23.8 | 1.43 | 0.28 | 0.30 | $165.50 |
| ASG Super S1-1 6-12-6 90% Argon | 2 | 23.6 | 1.57 | 0.54 | 0.74 | $144.50 |
| ASG Coolshade 42-1 crystal grey 6-12-6 %90 Argon | 2 | 24.6 | 1.46 | 0.24 | 0.30 | $144.50 |
| ASG CoolShade 30 crystal grey 6-12-6 90% Argon | 2 | 23.9 | 1.45 | 0.19 | 0.22 | $144.50 |
| ASG Clear Visualite 67-1 #3 6-12-6 90% Argon | 2 | 23.6 | 1.45 | 0.48 | 0.61 | $144.50 |
| ASG Clear Visualite 70S-1 #3 6-12-6 90% Argon | 2 | 23.6 | 1.44 | 0.40 | 0.62 | $165.50 |
| ASG Super S1-1 #3 6-12-6 90% Argon | 2 | 23.6 | 1.57 | 0.61 | 0.74 | $144.50 |
| TGU Visualite 67-1 #2 6-12-3-12-6 90% Argon | 3 | 41.6 | 1.08 | 0.31 | 0.39 | $250.50 |
| TGU Visualite 67-1 #2 6-12-3-12-6 90% Air | 3 | 38.6 | 1.28 | 0.33 | 0.55 | $237.50 |
| TGU Visualite 70S-1 #2 6-12-3-12-6 90% Argon | 3 | 38.6 | 1.08 | 0.27 | 0.56 | $275.70 |
| TGU Visualite 70S-1 #2 6-12-3-12-6 90% Air | 3 | 38.6 | 1.28 | 0.27 | 0.56 | $262.70 |
| TGU Visualite 67-1 #5 6-12-3-12-6 90% Argon | 3 | 38.6 | 1.04 | 0.45 | 0.55 | $250.50 |
| TGU Visualite 67-1 #5 6-12-3-12-6 90% Air | 3 | 38.6 | 1.24 | 0.45 | 0.55 | $237.50 |
| TGU Visualite 70S-1 #5 6-12-3-12-6 90% Argon | 3 | 38.6 | 1.04 | 0.39 | 0.56 | $275.70 |
| TGU Visualite 70S-1 #5 6-12-3-12-6 90% Air | 3 | 38.6 | 1.24 | 0.39 | 0.56 | $262.70 |
| TGU ASG Cool Shade 30 + Crystal Grey 6-12-3-12-6 90% Argon | 3 | 38.9 | 1.09 | 0.17 | 0.20 | $250.50 |

| Name | Number of panes | Thickness (mm) | U – Centre, Winter | SHGC | $T_{vis}$ | Average Cost ($/m²) |
|---|---|---|---|---|---|---|
| TGU ASG Cool Shade 42-1+ Crystal Grey 6-12-3-12-6 90% Argon | 3 | 39.0 | 1.09 | 0.22 | 0.27 | $250.50 |
| TGU Visualite 70S-1 #2 and Sunergy #4 90% Argon | 3 | 41.4 | 1.07 | 0.25 | 0.43 | $275.70 |
| TGU Visualite 70S-1 #2 and Sunergy #6 90% Argon | 3 | 41.4 | 0.96 | 0.25 | 0.43 | $275.70 |
| TGU Low e Visualite 70S-1 #2 Sunergy #4 and #6 90% Argon | 3 | 41.6 | 0.82 | 0.23 | 0.34 | $275.70 |
| TGU Low e #2 #4 #5 17961 90% Argon | 3 | 41.6 | 0.73 | 0.22 | 0.34 | $275.70 |
| ASG Visualite 70S-1 #2 and #3 6-12-6 90% Argon | 2 | 23.7 | 1.37 | 0.27 | 0.49 | $165.50 |
| ASG Visualite 70S-1 6-12-6 90% Argon low e #2 and #4 Sunergy | 2 | 23.7 | 1.23 | 0.28 | 0.48 | $165.50 |
| ASG Coolshade 42-1 + clear 6-12-6 %90 Argon | 2 | 23.7 | 1.46 | 0.25 | 0.42 | $144.50 |
| ASG CoolShade 30 + clear 6-12-6 90% Argon | 2 | 23.7 | 1.45 | 0.19 | 0.31 | $144.50 |
| ASG Clear Visualite 67-1 #2 and #3 6-12-6 90% Argon | 2 | 23.7 | 1.38 | 0.33 | 0.48 | $144.50 |

Table 60. General glass costs

| Glass type | Average Values ($/m²) |
|---|---|
| Single glazed (not used) | $ 25.00 |
| Single glazed triple silver (not used) | $ 100.00 |
| Double glazed, air, double silver | $ 135.00 |
| Double glazed, argon, double silver | $ 144.50 |
| Double glazed, air, triple silver | $ 156.00 |
| Double glazed, argon, triple silver | $ 165.50 |
| Triple glazed, air, double silver | $ 237.50 |
| Triple glazed, argon, double silver | $ 250.50 |
| Triple glazed, air, triple silver | $ 262.70 |
| Triple glazed, argon, triple silver | $ 275.70 |

Table 61. Framing costs

| Framing Systems | Frame Only ($/m²) |
|---|---|
| Single Non thermally broken | $ 600.00 |
| Double glazed non thermally broken | $ 813.83 |
| Single Thermally broken | $ 725.00 |
| Double glazed thermally broken | $ 1,005.50 |
| Triple glazed thermally broken | $ 1,009.50 |

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# 8 Appendix B: Wall Insulation

## 8.1 Cost Information

Different parties including sub-contractor and quantity surveyor were approached to provide an estimated pricing for different wall build ups in respect to the proposed stringency wall cases. As the costing is dependent on many different external variables following has been assumed:

- Minimum 500 m² quantity
- Rates assumed as per current market rate as of 2023.
- Inclusive of sub-contractor's margin

Pricing for a range of R-values was obtained for two different system types, insulation added inside metal cladding and externally installed Kingspan panels. The average incremental cost per R-value for both systems was found to be very similar and the combined average value was used to determine stringency costs.

### Stringency wall cases

Table 62. External wall system costs

| Case Number | Metal Cladding: R-value (m². K°/W) | Total system cost ($/m²) | Kingspan: R-value (m². K°/W) | Total system cost ($/m²) |
|---|---|---|---|---|
| **1** | 0.68 | 625 | 1.64 | 245 |
| **2** | 0.83 | 675 | 1.91 | 265 |
| **3** | 1.87 | 645 | 2.43 | 275 |
| **4** | 2.02 | 695 | 2.96 | 320 |
| **5** | 2.57 | 690 | 3.49 | 340 |
| **6** | 2.71 | 740 | 4.04 | 365 |
| **7** | 2.91 | 785 | 4.56 | 400 |
| **8** | | | 4.81 | 385 |
| **Average per R-value** | | 48.87 | | 47.99 |
| **Combined Average per R-value ($/m²)** | | **48.43** | | |

**Stone wool insulation** cost table varying its thickness. Pricing varies depending on standard product sizing.

Table 63. Table 63. Wall, insulation only costs

| THICKNESS (mm) | R-value (m². K°/W) | STANDARD ($/m²) |
|---|---|---|
| **25** | 0.7 | 24 |
| **50** | 1.5 | 34 |
| **75** | 2.1 | 61 |
| **90** | 2.5 | 64 |
| **100** | 2.8 | 79 |

The assumptions for the cost table above are as followings:

- High level costing
- Price sold to the public, may differ to sale price to commercial.
- Information extracted from publicly available costing.

**Sandwich panel** cost table varying its thickness. Pricing varies depending on standard product sizing.

Table 64. Sandwich panel costs

| THICKNESS (mm) | R-value ($m^2.K°/W$) | STANDARD PANELS ($/$m^2$) |
|---|---|---|
| **50** | 1.25 | $125 |
| **75** | 1.85 | $145 |
| **100** | 2.50 | $155 |
| **120** | 3.00 | $200 |
| **150** | 3.75 | $220 |
| **175** | 4.40 | $255 |

The assumptions for the cost table above are as following:

- sale price to the contractor
- in consideration of delivery of the product from the supplier's factory to the nearest big city within the state.
- high-level costing advice only, may subject project by project.
- information extracted by relevant supplier.
- Product R-value claimed by the manufacturer is measured at 23 Celsius degrees.

# 9 Appendix C: Roof Insulation

## 9.1 Cost Information

Different parties including sub-contractor and quantity surveyors, were approached to provide an estimated pricing for different roof build ups in respect to the proposed stringency wall cases. As the costing is dependent on many different external variables following has been assumed:

- Minimum 500 m² quantity
- Rates assumed as per current market rate as of 2023.
- Inclusive of sub-contractor's margin

Pricing for a range of R-values was obtained for various roof constructions and also for adding insulation to a ceiling only. Costs for insulated roofing were highly dependent on the construction complexity, while insulation only costs are simplified because of ease of install and varying thickness levels in a ceiling cavity.

### Stringency Roof Cases

Table 65. Roof system costs

| Case Number | Summer: R-value (m². K°/W) | Winter: R-value (m². K°/W) | Total system cost ($/m²) |
|---|---|---|---|
| **1** | 2.74 | 3.34 | 292 |
| **2** | 3.38 | 3.99 | 307 |
| **3** | 3.99 | 4.02 | 420 |
| **4** | 5.06 | 5.08 | 440 |

**Ceiling Insulation - Mineral Wool** cost table varying its thickness is as followings:

Table 66. Ceiling, insulation on costs

| THICKNESS (mm) | R-value (m². K°/W) | STANDARD ($/m²) |
|---|---|---|
| **140** | 2.5 | 6 |
| **165** | 3 | 8 |
| **185** | 3.5 | 12 |
| **240** | 5 | 15 |

The assumptions for the cost table above are as followings:

- High level costing
- Price sold to the public, may differ to sale price to commercial.
- Information extracted from publicly available costing.

# 10 Appendix D: Thermal bridging

## 10.1 Introduction

Insulated structures in real construction consist of a mix of structural components and insulation components that together generate the overall insulation performance of the structure. In most cases, heat transfer through the structure can partially bypass the insulation via structural elements. These bypass routes are known as thermal bridges.

The best understood set of thermal bridges are known as repeating thermal bridges. These occur at regular points in a structure, typically at joists, rafters and studs. Under NCC 2022, the treatment of thermal bridging is captured in J4D3 (1) (Figure 52).

**J4D3 Thermal construction — general**

[2019: J1.2]

(1) Where *required*, insulation must comply with AS/NZS 4859.1 and be installed so that it—

(a) abuts or overlaps adjoining insulation other than at supporting members such as studs, noggings, joists, furring channels and the like where the insulation must be against the member; and

(b) forms a continuous barrier with ceilings, walls, bulkheads, floors or the like that inherently contribute to the thermal barrier; and

(c) does not affect the safe or effective operation of a *service* or fitting.

Figure 52. Clause J4D3 relating to thermal construction.

Clause J4D3(5) and Specification 37 cross reference AS/NZS4259.2 for calculation methodologies, which in turn cross references NZS4214 for the calculation the impact of repeating thermal bridges. The two major weaknesses of calculation methodology from NZS4214 are:

1. The methodology only covers repeating thermal bridges; and
2. The methodology has no treatment of thermal mass, which can affect the accuracy of calculation for high mass thermal bridges.

Non-repeating thermal bridges occur where specific structural changes occur that do not reflect the general construction of a surface. Examples include wall joints, wall framing around windows, exposed edges of floor slabs, and balconies that are extensions of the floor slab.

The University of Wollongong was commissioned by the Australian Government to review the impact and potential treatment of non-repeating thermal bridges[27]. Key findings from their review were:

1. Thermal bridges were a potentially significant contributor to overall building performance.
2. The mass of thermal bridges can significantly alter – and mainly reduce – the impact of high mass thermal bridges relative to a naïve massless calculation.
3. The mass effect can be modelled with reasonable accuracy by use of a proposed methodology which creates a separate, massed thermal structure containing the thermal bridge elements.

[27] *Green, A, Kempton, L, Beltrame, S, Pickup, C, Kokogiannakis, G, Heffernan, E & Cooper, P, 2021, Thermal bridging energy impacts modelling, Sustainable Buildings Research Centre, University of Wollongong, Australia*

It is noted that the UoW study only considered non-repeating thermal bridges, although the calculation methodology developed could apply to repeating thermal bridges.

## 10.2 Interpretation of UoW results

Within the report, UoW provided cost and benefit calculations for a range of thermal bridge mitigations across a range of archetypes. The cost assumptions in their analysis are not dissimilar to those being used for this analysis, albeit without a cost of carbon, and have been used directly without adjustment in this discussion. The results have been collated visually in Figure 53.

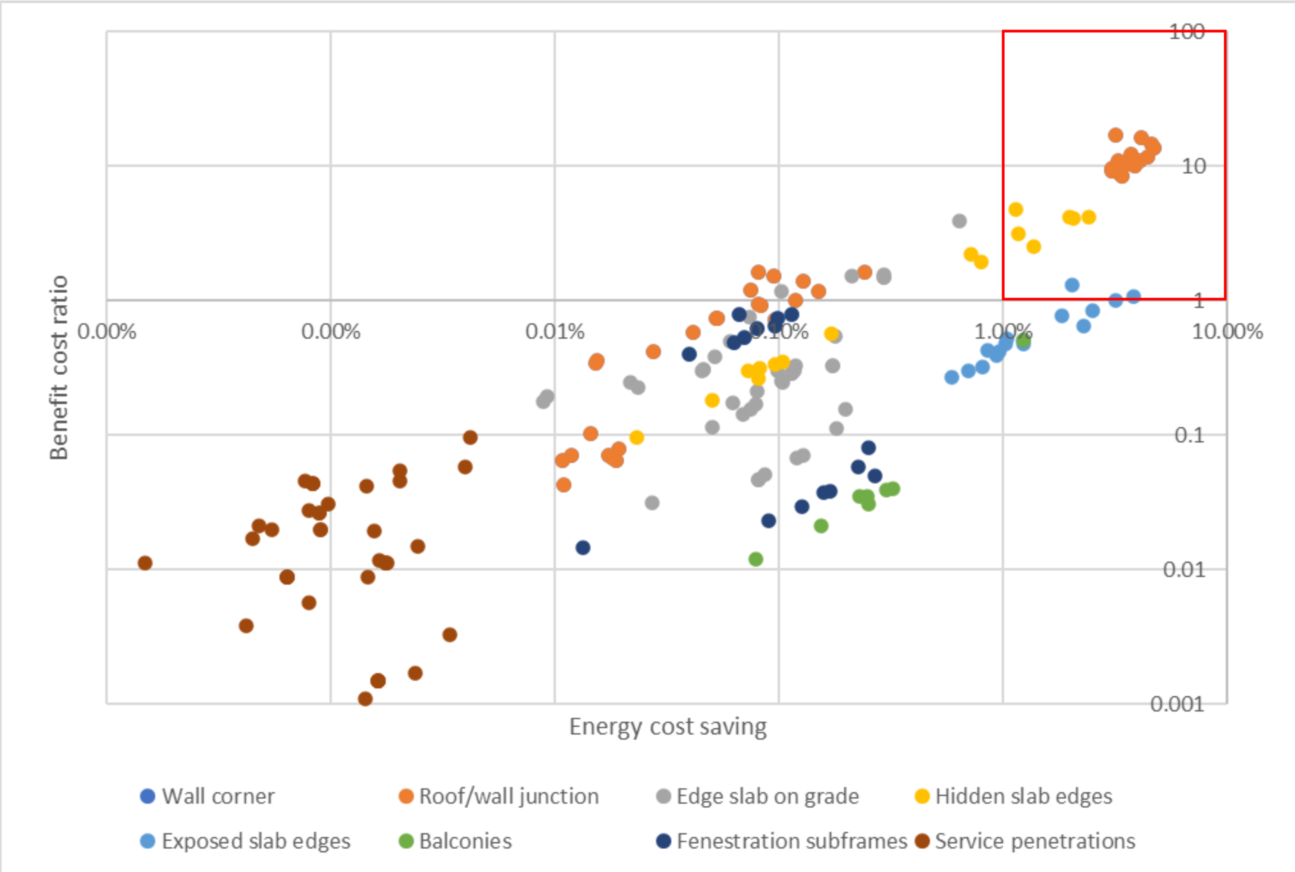


Figure 53. Collation of UoW cost/benefit analyses for various thermal bridge mitigations across a range of archetype building and climate zones. The red box indicates the measures that were both cost beneficial (BCR>1) and significant (impact>1%)

It is clear from Figure 53 that the vast majority of thermal bridging mitigations are not cost-effective, and indeed most are also of minimal impact. This may appear in contradict one of the headline findings of the UoW study, but in reality reflects that while thermal bridges are potentially significant, their mitigations are not always particularly effective.

The three classes of thermal bridge that occur within the marked significant and cost-effective range in Figure 53 are: Roof wall junctions, hidden slab edges, and exposed slab edges. These are discussed in the sections below.

### 10.2.1 Potentially significant thermal bridges

#### Roof/wall junction

The UoW thermal bridging report characterises the roof/wall junction thermal bridge in the diagram in Figure 54.

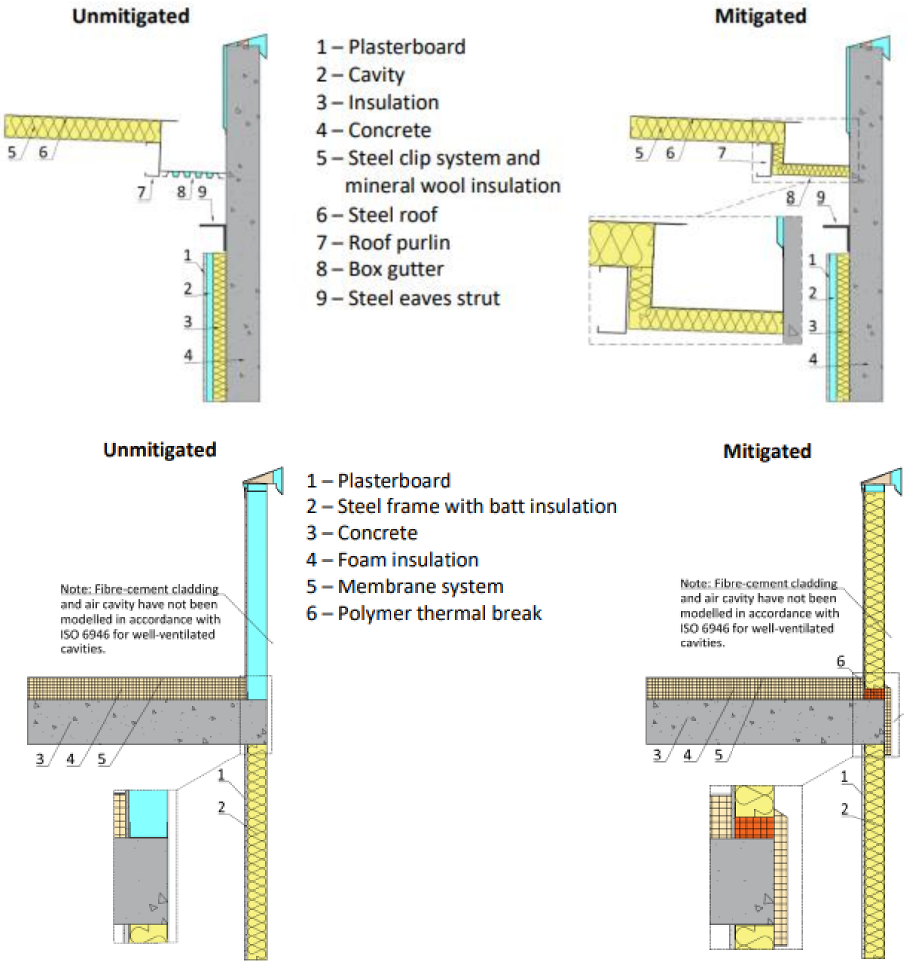


Figure 54. UoW characterisations of a roof/wall junction thermal bridge.

It can be seen that the thermal bridge in the first instance is a combination of an uninsulated box gutter and a section of uninsulated parapet wall. The mitigation only addresses the box gutter insulation. Notably, the box gutter is a low mass thermal bridge which can be readily assessed under standard heat transfer calculations; similarly, in many walls, the top-of-parapet bridge is also low mass.

The second instance is effectively an exposed slab edge, which is considered in the next section.

#### Hidden/exposed slab edges

The UoW characterisation of hidden and exposed slab edges is shown in Figure 55 and Figure 56.

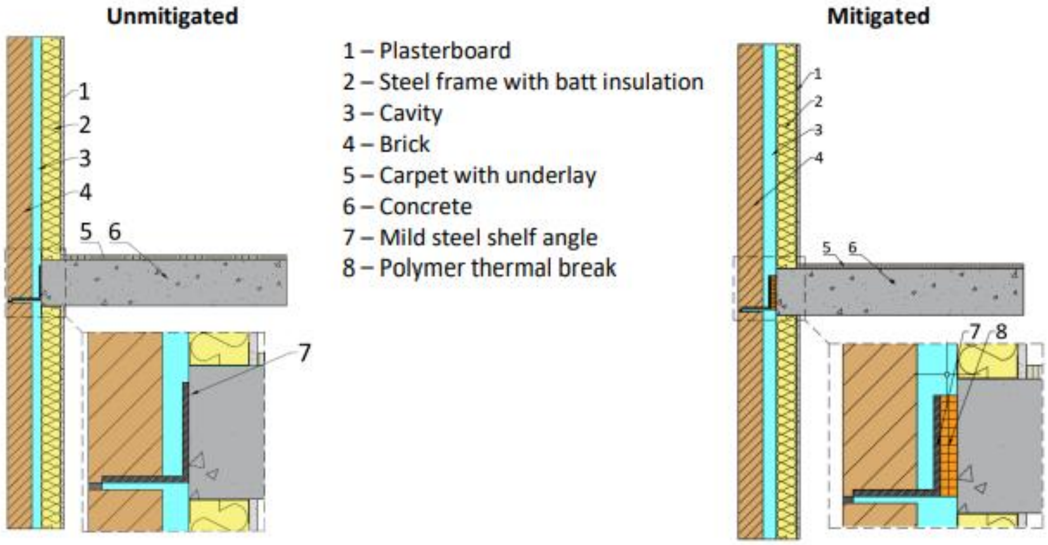


Figure 55. UoW characterisation of a hidden slab edge thermal bridge.

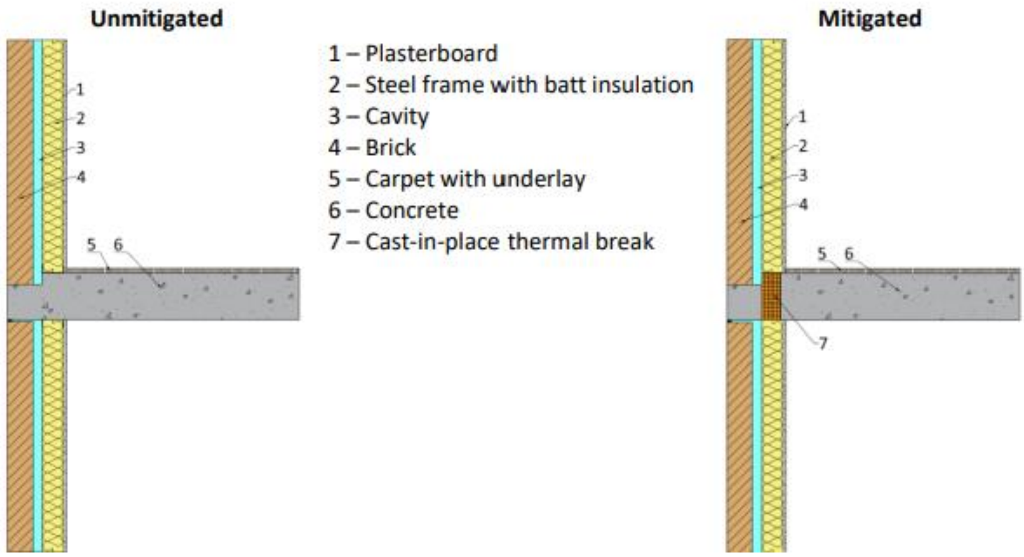


Figure 56. UoW characterisation of an exposed slab edge thermal bridge.

The slab edge thermal bridges occur at intermediate floors (i.e. not related to slab-on-grade) and consist of heat transfer into the building via the exposed floor slab. These are inherently high mass thermal bridges.

### 10.2.2 Discussion

Given the limited impact of the thermal bridges on overall building performance, a balance needs to be struck between avoiding or mitigating thermal bridges and the complexity of doing so. The UoW calculation methodology is more complex than the already highly complex methodology used in NZS4214, so it would be both difficult to implement effectively and difficult to justify as an addition to the NCC.

When reviewing the identified higher impact thermal bridges, it is notable that each of these could be treated using conventional (zero mass) calculation methods. In comparisons of calculation methods the massless approach was shown to generally over-predict the impact of high mass thermal bridges, so a calculation on this basis can be argued as conservative.

A further issue is that each of these thermal bridges is also arguably already identified in Code text, as J4D3 (1) (b) requires that insulation "forms a continuous barrier with ceiling, wall, bulkheads, floors or the like that inherently contribute to the thermal barrier". This statement fairly clearly covers the hidden and exposed slab edges and implicitly covers box gutters. As a result, there is a reasonable argument that a failure to insulate (or calculate the impact of failing to insulate) these items is actually a breach of Code.

## 10.3 Recommendations

It is recommended that the issue of thermal bridges is deal with in a strengthening of Code text in several areas, as outlined below.

### 10.3.1 Proposed Code Text: Definitions

Thermal bridging: Thermal bridging means the reduction in effective thermal resistance of a structure caused by:

a. Supporting members such as studs, noggins, joists, furring channels and the like where insulation must be against a member.
b. Breaks or reductions in insulation caused by box gutters, and the interface between a slab edge and the wall structure for a floor other than slab on grade.

Note that this provides context for the references to thermal bridging in J4D3 (5) and Specification 37.

### 10.3.2 Proposed Code Text: J4 D3.

(1) Where required, insulation must comply with AS/NZS 4859.1 and be installed so that it –
- a) Abuts or overlaps adjoining insulation other than at supporting members such as studs, noggings, joists, furring channels and the like where insulation must be a against a member
- b) Forms a continuous barrier with ceilings, walls, bulkheads, floor slab edges, box gutters or the like ~~that form part of the building envelope~~
- c) Does not affect the safe of effective operation of a service or fitting

### 10.3.3 Proposed Code Text S34C3

(1) The annual greenhouse gas emissions must be calculated for the proposed building and the reference building using the same-

….

h) fabric and glazing in accordance with (5); and

…..

(5) For the purposes of (1)(h), fabric and glazing must include—
- a. quality of insulation installation except insofar as the proposed building fails to address thermal bridging in accordance with J4D3(1); and
- b. thermal resistance of air films including any adjustment factors, moisture content of materials and the like; and

c. dimensions of external, internal and separating walls; and
d. internal shading devices, their colour and their criteria for operation

# 11 Appendix E: Simulation Models

## 11.1 Medium Office C5OM

The Medium Office archetype was used in the assessment of the following measures:

- PAC
- VRF
- Economy cycle
- Roof

### 11.1.1 General Layout

The Medium Office model represents a 2 storey, 2,304 m²office building with a rectangle footprint as shown in Figure 57. The conditioned area of the building is 2,080m².

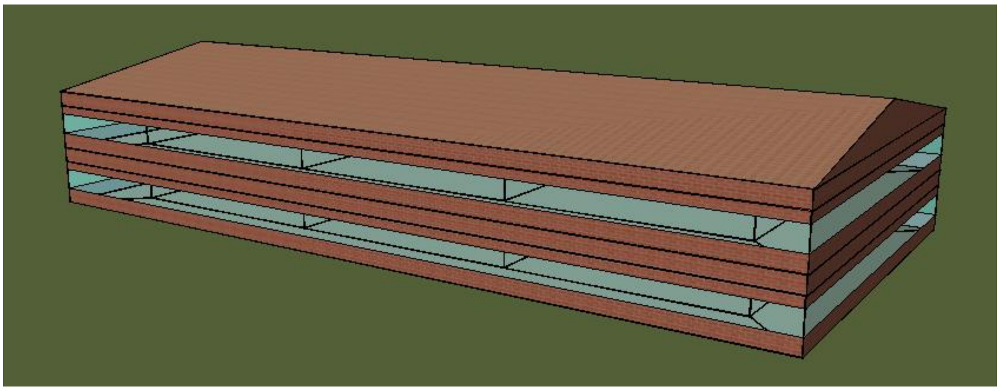

Figure 57. C5OM Modelled Geometry View.

The Floorplate is divided in façade and centre zones as shown in Figure 58.

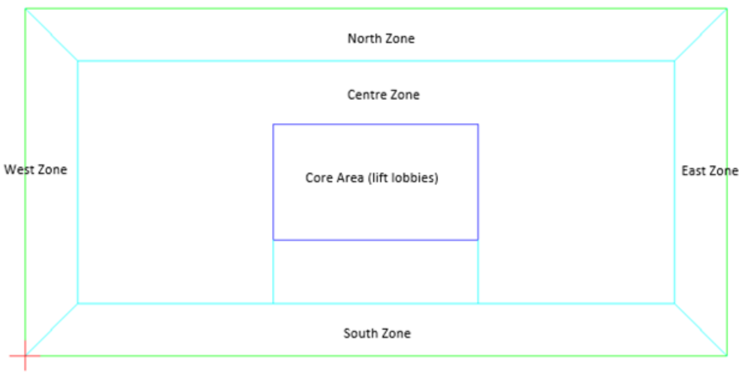


Figure 58. C5OM Modelled Zoning.

### 11.1.2 HVAC

Major plant

Air-conditioning for this archetype is provided by PAC systems. The supply airflow was modelled as constant flow system. The PAC units are sized with an oversizing factor of 1.2.

Control

The zone temperature control was modelled with a 2°C deadband from 21.5°C to 23.5°C with 0.5°C proportional band on either side.

The drybulb economy cycle and the $CO_2$ control to the minimum outside air was modelled when required as per NCC2022.

### 11.1.3 Schedules and Internal Loads

The schedules and internal loads for this archetype are modelled as per Table S35C2c, Table S35C2d, Table S35C2l and Table S35C2n in NCC2022.

## 11.2 Aged Care/Small Hospital C9C/C9AS

The Aged Care/small hospital archetype was used in the assessment of the following measures:

- PAC (C9C)
- VRF (C9C)
- Economy cycle (C9AS)
- Roof (C9AS)

### 11.2.1 General Layout

The Aged Care/small hospital model represents a single storey, 2,048m² building with a donut shape footprint as shown in Figure 59.

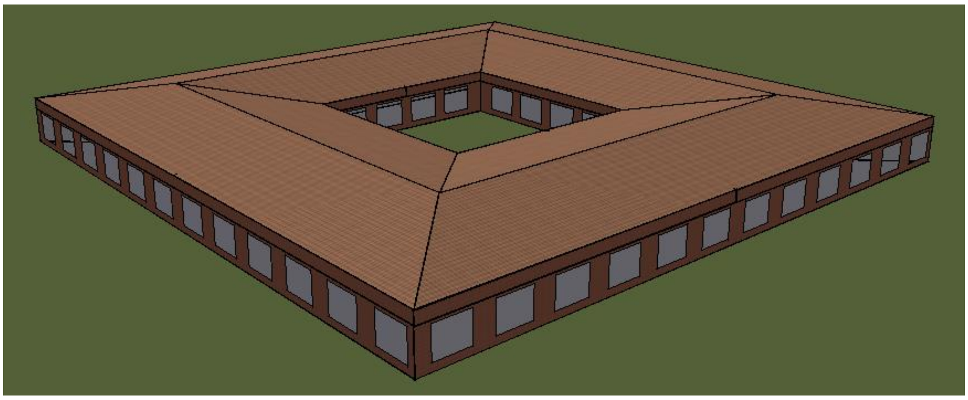

Figure 59. C9A/C9AS Modelled Geometry View.

The Floorplate is divided in bedroom/wardroom and corridor as shown in Figure 60.

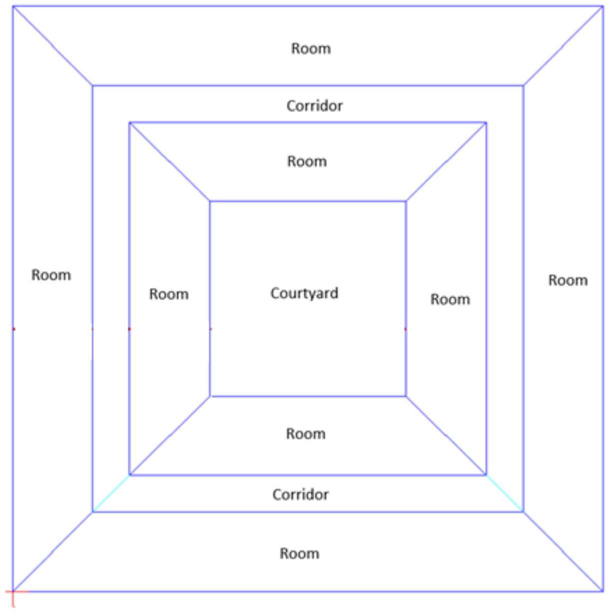


Figure 60. C9C/C9AS Modelled Zoning.

### 11.2.2 HVAC

#### Major plant

Air-conditioning for this archetype is provided by PAC systems except when testing VRF measure. The supply airflow was modelled as constant flow system. The PAC units are sized with an oversizing factor of 1.2.

When this archetype was used to test VRF, the air-conditioning system was converted to VRF systems. The supply air was delivered to the zones by constant flow FCUs. The FCU cooling coils and heating coils were served by outdoor VRF unit. The coils and VRF unit are sized with an oversizing factor of 1.1.

#### Control

The zone temperature control was modelled with a 2°C deadband from 21.5°C to 23.5°C with 0.5°C proportional band on either side.

The heat exchanger used to precondition the minimum outside air was modelled when required as per NCC2022.

### 11.2.3 Schedules and Internal Loads

The schedules and internal loads for this archetype are modelled as per Table S35C2g/ Table S35C2k, Table S35C2l and Table S35C2n in NCC2022. Note that the only differences between the C9C and C9AS versions of this archetype are in the schedules and internal loads. The change to C9AS (which has continuous HVAC operation) from C9C (which has no HVAC operation from 10am-4pm) arose as it was found that the lack of daytime HVAC operation was both unrealistic for the archetype and distortionary. Time and resources did not permit the rerunning of earlier analyses using the C9AS model; however, the whole building analysis will be conducted using this model and will therefore draw out any effects.

## 11.3 Simplified Single Storey

The simplified single storey model was used in the assessment of the following measures:

- Glazing
- Vertical shading
- Wall

### 11.3.1 General Layout

The simplified single storey building has 1,104 m² of conditioned area with a square footprint as shown in Figure 61. The ground floor, roof and internal partition was set to be adiabatic. This is to make sure the heat transfer is only through the external wall or glazing and eliminate the interference between the zones. When wall insulation was tested in this model, all the glazing was removed.

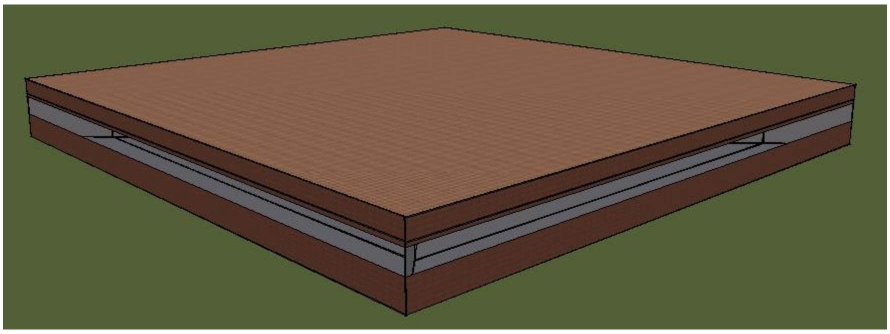

Figure 61. Modelled Geometry View for the Simplified Singel Storey Building.

The zoning is shown in Figure 62.

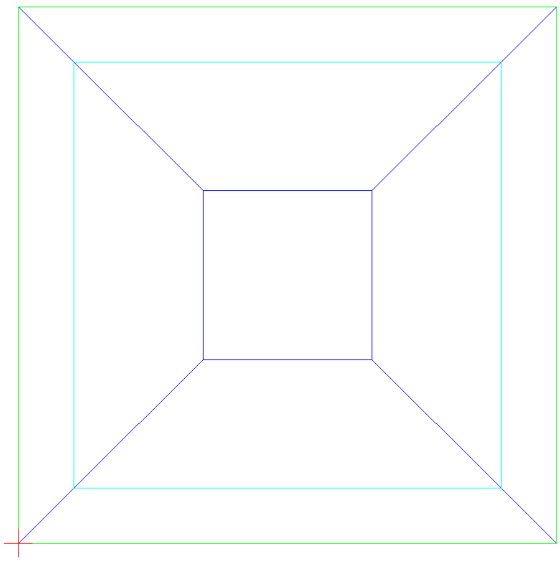

Figure 62. C5OM Modelled Zoning.

### 11.3.2 HVAC

This model is only to test the impact of glazing, vertical shading and wall insulation on the thermal load. Hence, the detailed HVAC was not modelled. In the thermal load simulation, the zone temperature setpoints were set to 21°C for heating and 24°C for cooling.

### 11.3.3 Schedules and Internal Loads

To test the glazing, vertical shading and wall insulation for daytime operation building and 24/7 operation building, the internal loads and schedules for office and hospital ward were used for this model respectively.

The internal loads and schedules for office are modelled as per Table S35C2c, Table S35C2d, Table S35C2l and Table S35C2n in NCC2022.

The internal loads and schedules for hospital ward are modelled as per Table S35C2g, Table S35C2l and Table S35C2n in NCC2022.