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Sustainable Building Specialist

Technical Report

DTS Elemental Provisions for NCC 2022

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1 Overview: rationale and methodology

Achieving appropriate alignment with Nationwide House Energy Rating Scheme (NatHERS) 7-stars was a fundamental underpinning principle for developing the Deemed-to-Satisfy (DTS) elemental provisions for the National Construction Code (NCC) 2022. This principle helps ensure that different compliance paths offer an equivalent level of performance and therefore protects energy savings for consumers, the benefits to the energy network of restrained energy demand and the policy objective of reduced greenhouse gas emissions.

As the stringency of regulation increases, it becomes much harder to achieve alignment between performance provisions and elemental provisions within the current structure of the regulations without adding significant compliance costs. After evaluating several possible approaches, a more detailed regulatory structure was found that would allow better alignment while containing cost increases. While it is always desirable for regulation to be as simple as possible, where a more detailed option allows lower-cost compliance options, it can be a superior option.

1.1 Limitations to the alignment between DTS and NatHERS

NatHERS specifies performance in terms of a specific MJ/m^2 target. This approach is not common in other jurisdictions. For example, the USA HERS scheme uses a performance measure based on the percentage improvement over the International Energy Conservation Code (IECC) Standard Reference Design (a standard similar to elemental provisions) using an Energy Rating Index where 0 represents no improvement and 100 denotes a zero-energy dwelling. The USA rating scale does not produce dwellings that achieve an identical energy load, only a similar percentage improvement over a reference specification. This different structure reflects the historical development of energy efficiency regulations in the US and Australia. Elemental standards were developed first in the US, while NatHERS preceded the development of elemental standards in Australia.

Developing elemental standards that represent a percentage improvement over an existing elemental specification is relatively simple. However, developing elemental standards to achieve a specific energy load is more complicated. When the elemental provisions were initially developed, NatHERS was transitioning between 1st and 2nd generation methodologies and star bands were not available. This meant that the elemental provisions' structure could not be designed to reflect the nuance of 2nd generation NatHERS performance calculations.

Three further factors make it difficult to achieve alignment between elemental provisions and NatHERS:

- NatHERS adds together heating and cooling loads together to calculate the star rating. In mixed climates cooling performance can be traded off with heating performance and vice versa. NatHERS, therefore, does not embody a single measure of performance in each season. By contrast, the NCC Glazing provisions require minimum performance in summer and winter, and over-performance in one season cannot be offset against the other,
- Smaller dwellings have a larger external surface area than larger dwellings (relative to floor area) and will not perform as well when an energy load per square metre metric is used. However, smaller dwellings have a lower total energy use than larger dwellings and therefore have a lesser impact, per dwelling, on energy use and greenhouse gas emissions. An area correction is used in NatHERS to even out performance requirements across dwellings of different sizes due to surface area effects. The DTS provisions scale the requirements according to the size of the dwelling, and
- NatHERS uses 69 climate zones, while the NCC only has 8. Significant variations in the absolute energy loads and the relative impacts of various building element specifications will be reflected in NatHERS that cannot be captured by less fine-grained NCC climate allocation.

The factors described above make achieving alignment between elemental provisions and NatHERS star ratings a more difficult task. Despite these challenges, testing ratings for dwellings specified to meet the elemental provisions show that the NCC 2022 residential energy efficiency provisions produce a rating within 0.5-stars of 7 for the three Class 1 dwellings tested.

1.2 General methodology

1.2.1 Insulation requirements

Insulation requirements were derived from over 40,000 parametric NatHERS runs

The new insulation requirements were derived from NatHERS simulations. Over 5,000 variations to building element properties in each climate zone were simulated to identify the range of conditions that would allow a 7-star rating to be maintained. Deriving insulation requirements in this way helps to ensure that a level of consistent performance is maintained across the DTS NatHERS and elemental provisions. Aligning elemental and NatHERS also helps to ensure that Verification Methods (VM) are better aligned with the outcomes of DTS because the base building specification for the VM is the elemental provisions. The strength of basing the elemental provisions on simulation results is that it will give more consistent outcomes with other simulation-based compliance methods. The disadvantage is that the complexity of building performance is such that the results based on these simulations sometimes seem unintuitive. This report will explain some of these apparently initiative results, e.g. sections 2.2.5 and 3.9.

A new structure for the insulation requirements specifies a range of acceptable R-Values

The new insulation requirements have a different structure from the current regulations. Instead of specifying minimum R-Values to cover all cases, the new elemental provisions identify a broad range of building element properties and R-Values which produce acceptable performance. Beyond this range of conditions, heat flows would be too great to maintain satisfactory dwelling performance without increasing the performance of other building elements. In this case, an alternative method of demonstrating compliance will be required, such as a NatHERS or a Verification Method simulation tool. These tools provide far more flexible ways to balance performance across building elements. As many as 80% of Class 1 dwellings already use DTS NatHERS, so this should not impose an undue burden on industry.

The new structure provides greater flexibility and, in some cases, allows lower R-Values than NCC 2019

Some combinations of building element properties allow the use of lower insulation R-Values than the current NCC, even though the overall performance requirement in NCC 2022 is 7-stars instead of 6-stars. These lower R-Values are consistent with NatHERS simulations. For example, if a roof has a light colour with a reflective membrane underneath it in a hot climate, a significant portion of the heat gain has already been reduced before it reaches the ceiling. Consequently, a lower Ceiling R-Value can be maintained without losing performance. In hot and warm climates, the ceiling fan requirements also allow some elements to achieve lower specifications than in NCC 2019. Similarly, in a cold climate, lower insulation R-Values are permitted in a dark-coloured wall with little shade compared to a light-coloured or well-shaded wall. A lower R-Value applies because the dark wall surface absorbs much more solar radiation during the day and therefore has much lower heat loss.

The insulation requirements are better targeted to those cases where performance in that climate zone is poor. This approach gives the building industry greater flexibility and allows the selection of lower-cost options. It also means the regulation helps to show builders and designers which aspects of building design deliver better performance.

The new structure simplifies some parts of the regulations

The new structure eliminates the need for a broad range of qualifying clauses to allow lower insulation levels for elements like walls. This restructuring makes the new elemental provisions easier to follow. In NCC 2019, over thirty conditional clauses allow the industry to use lower R-Values or no insulation at all on a climate zone by climate zone basis. In NCC 2022, this more complex suite of conditional clauses is replaced by lookup tables.

If the industry wishes to use lower R-Values than specified in the elemental provisions, this may still be acceptable if a NatHERS rating or Performance Solution is used.

R-Values of attic spaces and subfloor spaces no longer need to be calculated

R-Values are specified for all elements which form a boundary to a discrete thermal zone. This change means that the R-Value of attic spaces and subfloors no longer need to be calculated. For example, where total R-Values are calculated in an attic roof, only the Total R-Vale of the ceiling component needs to be calculated.

Representing attics and subfloors as a single thermal resistance significantly simplifies the heat flows in these spaces and can lead to errors. Further work by the University of Wollongong showed that the effective R-Values of these spaces vary considerably over the day and from season to season. In an attic space, the effective R-Value can be negative in some circumstances. Consequently, subfloors and attic spaces cannot be accurately represented by a single R-Value. Instead, NCC 2022 specifies the R-Values of the boundary elements to these spaces, simplifies the calculation of Total R-Values and improves the correlation between elemental and NatHERS requirements.

Wall insulation requirements focus on providing solutions based on the thermal mass of the wall

In each climate zone, the wall insulation requirements are based on the dominant construction type in that climate zone:

- Brick Veneer in climate zones 2, 4, 5, 6 and 7,
- Concrete Block in climate zones 1 and 3, and
- Framed lightweight walls in climate zone 8 (Alpine).

Insulation requirements for a second wall type with a different thermal mass level are also provided. Providing R-Values for the second wall type allows coverage for Brick Cavity walls in Perth (climate zone 5) or framed lightweight walls in climate zones 1 and 3. Insulation requirements for other wall types can be derived using total R-Value calculations based on the thermal mass of the wall:

- If the wall is lightweight or has a lightweight framed component adjacent to the room it encloses, R-Values for Brick veneer are used and adjusted for the difference in the total R-Value,
- If the wall is heavyweight or has heavyweight materials adjacent to (on the same side as) the room it encloses, R-Values for Brick Cavity/Concrete Block are used and adjusted for the difference in total R-Value.
- The initial wall insulation tables had separate tables for two-storey dwellings and, if there was no lightweight wall option, lightweight walls. The additional tables were deleted and replaced with a note to the Brick veneer wall table. The note specifies the additional R-Value that must be added to a two-storey wall.
- R-Values for lightweight walls were also developed. A note to the tables specifies the additional R-Value that must be added for lightweight walls.
- The two-storey wall additional allowance is based on the R-Value for a single-storey 3-metre height wall. This is based on the greater area of the wall and the fact that upper floors are usually bedrooms that have lower heating and cooling demand.

- The allowance for lightweight walls takes into account the difference in R-Value with brick veneer walls and the slightly higher energy demand due to the absence of any thermal mass.
- These allowances may result in a required wall R-Value that will not fit within a typical 90mm stud space. A high wall R-Value would usually signify that the house is better simulated using NatHERS or a Performance Measure. However, an insulative cladding like AAC concrete panels or polystyrene board may be sufficient.

Thermal bridging mitigation measures for steel frame dwellings seek to achieve similar total R-Values for walls, floors and roof/ceilings to timber framed dwellings

The new insulation provisions also include an allowance for the thermal bridging effect of steel framing. Elements using steel framing must have a total R-Value approximating the R-Value of the same element with a timber frame. At higher insulation R-Values the extent of additional insulation that would be required to achieve the same R-Value as a timber framed element would not be cost-effective. Either due to the cost of the extra insulation or the need to change construction practices. In all cases, the required total R-Value of steel framed construction is at least 95% of the total R-Value for timber framed elements at insulation R-Values up to R3.0 and 90% over R3.0.

The calculation of total R-Value uses a modified form of NZS 4214 based on detailed research by the University of Wollongong

The technique for calculating the thermally bridged R-Value for the elemental provisions is the NZS 4214 method, as referenced in AS 4859.2. This standard was specifically developed for walls where the R-Value of internal air spaces is relatively fixed. As mentioned above, the R-Value varies depending on environmental conditions in attic spaces and subfloors. The University of Wollongong undertook detailed Computation Fluid Dynamics simulations to determine how factors like air infiltration into these spaces affect the R-Value of elements. This research developed simplified calculation techniques that achieve a much better match to actual dynamic heat flows than the current version of NZS 4214.

Not all combinations of building element properties and insulation levels can be used for elemental compliance

The 40,000 parametric NatHERS simulation runs used to set minimum R-Values were based on the ability of the combinations of building element properties and insulation levels to achieve 7-stars. Not all combinations of building element properties were able to achieve 7-stars, e.g. dark coloured unshaded walls in hot climates. In these cases, the regulation shows an X for this combination of building element properties rather than a compliant R-Value. This means that this combination of properties cannot be assessed using the DTS elemental provisions. The solution for the industry, in this case, is to either select a combination that is allowed or to use DTS NatHERS or another simulation tool using a Performance Method where the lower performance of the element can be offset by improvements to other building elements.

1.2.2 Glazing requirements

Glazing requirements are also aligned with NatHERS 7-star outcomes but use a different technique to the insulation requirements to achieve this alignment

The interaction of solar heat gain and conduction heat flows through windows within the building and their resultant impact on heating and cooling energy demand would take millions of parametric runs to enable a simple model to reflect simulation tool predictions accurately. Therefore, a different method of aligning the glazing requirements with NatHERS was taken to the parametric simulation approach used for determining insulation levels.

In each climate zone, the analysis of building fabric improvements needed to achieve 7-stars using NatHERS provided nine dwellings on a concrete slab, and nine on a timber suspended floor. The windows sizes, properties, and shading for each of these dwellings were input into the NCC 2019 glazing calculator, and the degree of compliance was observed.

The Glazing Calculations (GC) were calibrated to achieve a compliance target which represented the average seasonal performance of the 18 x 7-star dwellings simulated in each climate and a range of Glazing Calculation scores that closely reflected the range of NatHERS predicted heating and cooling loads across the 18 dwellings.

Significant changes were required to the glazing methodology to achieve alignment between the Glazing calculations and elemental provisions

Each of the dwellings used to develop the Glazing calculations achieves 7-stars which represents a level of energy efficiency at least 15% better than 6-stars across all NatHERS climates. Because the intention of NCC 2019 is to achieve 6-stars, these dwellings should, in theory, be able to comply with the NCC 2019 requirements easily, but this was not found to be the case. The range of compliance for each 7-star house with the NCC 2019 Glazing Calculator ranged from achieving a score double the Glazing Calculator required target to half the target.

Comparing the extent of non or over-compliance with the NCC 2019 Glazing calculator with dwelling window properties gave insights into the extent of change to Glazing Calculations required to develop a new algorithm that would better align with a 7-star outcome.

Achieving alignment between NatHERS and the glazing calculator required several changes and improvements to the calculation method

Improving the alignment between Glazing Calculations and NatHERS outcomes required several changes to the calculation technique.

- The orientation exposure, i.e. solar gain factors, for each orientation was adjusted. The original glazing calculations consider only three summer and three winter months with the highest cooling loads, while NatHERS predicts the impact of solar gain across the year.
- Separate exposure factors have been developed for concrete slab on ground and suspended timber floors. The temperature under a slab floor is very different from that in a subfloor space. In summer, this affects heat flow by allowing heat loss to the cooler ground temperatures during the day in summer, which lowers cooling loads. In winter, the temperature of the ground below is milder and more stable on a cool day, reducing heat loss. Consequently, the impact of solar gains on dwelling performance can be quite different in dwellings with the two different floor types. The 2019 glazing calculations reflect the difference between the two floor types by using different targets for each. Simulation results show that the impact on heating and cooling loads of solar heat gain through windows for various orientations is different in dwellings with different floor types.
- In Climate Zone 5, due to the high penetration of high thermal mass cavity brick construction in Perth, a separate set of solar exposure and other factors was developed for this climate zone for use with brick cavity construction,

- The impacts of solar gains in bedrooms are reduced. While the amount of solar gain is not different in bedrooms, the impact of solar gains through windows is different in bedrooms and living areas because these rooms are occupied at different times. A factor has been developed to modify the impact of solar gain due to the occupancy of the room the window serves. For example, in summer because bedrooms are primarily occupied outside of the hours of maximum solar gain and when outside temperatures are lower overnight the impact of solar gains through windows will generally be lower.
- The impact of solar gains through windows on heating and cooling loads for upper floors is different to the impact on ground floors. Rooms on upper floors do not have the moderating effect of the lower temperatures under a slab or in a subfloor space. For example, all other factors being equal, the same amount of solar gain though an upper floor window will result in higher cooling loads than on a ground floor.
- The current 2019 glazing calculations apply only to a single level. In the 2022 version of glazing calculator, the addition of a factor to modify solar gains to the upper floor also allows the whole house to be assessed with only one set of calculations while the current Glazing Calculations must be performed separately for each dwelling level.
- Hard floor surfaces such as ceramic tiles or a polished surface on a concrete slab allow more of the solar gain through windows to be absorbed. This occurs because these floor finishes add little thermal resistance between the mass of the slab and incoming solar radiation. Using low thermal resistance floor coverings like ceramic or vinyl tiles, or having no floor covering, reduces the impact of solar gain on cooling loads and increases the amount of solar heat gain stored in the slab in winter which reduces heating.
- Window frames conduct heat from inside to outside and this is significant because their thermal resistance is low. In summer, the effect of solar radiation on a dark window frame can significantly increase cooling loads. In winter, a dark frame can help to reduce heating loads by increasing solar heat conducted through the frame. This affects window frames regardless of the frame material. While metal window frames have much lower thermal resistance than timber frames, timber frames have a greater area. Consequently, NatHERS simulations show a similar impact for each frame type. The impact of solar gains through

glazing is modified according to the frame colour with higher solar gains when window colours are darker.

- Windows with larger openable area allow the removal of excess heat gains through windows by ventilation. This ventilation also improves comfort by providing air movement. The 2022 NCC regulations allow a higher level of solar gain through windows in summer to a room depending on the openable area of windows in that room. The regulations calculate the target for solar heat gains for the whole house based on the ratio of the openable window area to the floor area of habitable rooms for the entire house. This effect is correlated against the NatHERS simulation results for the 18 dwellings in each climate zone. The benefits of additional air movement are generally much more significant in NCC 2022 than was the case in NCC 2019.
- Bedroom solar gains and conduction are weighted differently to solar gains in daytime occupied spaces due to the different times of use and thermostat temperatures in bedrooms.
- Window orientations with higher solar gain will lead to higher internal temperatures in winter. Higher internal temperatures increase conduction losses in winter. Conduction losses are adjusted depending on the orientation of the window.

More detail provides cheaper compliance options

More data inputs are required for 2022 glazing calculations than in 2019. As explained above, this new detail provides a better representation of how window properties affect heating and cooling loads. Each new data input also provides new ways for the industry to achieve compliance that unlock strategies formerly only available in simulation tools and allows additional lower cost compliance options to be utilised.

In all climate zones except zone 5, the better correlation with NatHERS across all building elements allows lower cost compliance for Glazing than NCC 2019

Most of the dwellings which achieved 7-stars did not pass the glazing calculations in NCC 2019 in all climate zones except climate zone 5. By calibrating the 2022 glazing calculations to achieve similar performance levels as the average performance of 7-star dwellings in each climate zone, significant compliance cost savings are achieved. (see Page 17 in the linked report)

Table 1 Saving in Glazing Compliance Costs NatHERS versus NCC 2019 Glazing calculator

Location	Floor Type	Change in Glazing Compliance Costs for Class 1 dwellings using elemental compliance in NCC 2022
Darwin CZ01	Slab	$1,146.31
	Timber	$1,152.11
Cairns CZ01	Slab	$841.76
	Timber	$1,607.68
Brisbane CZ02	Slab	$291.85
	Timber	No change (to cost)
Longreach CZ03	Slab	$3,229.31
	Timber	$5,018.30
Mildura CZ04	Slab	$4,693.57
	Timber	$2,469.30
Sydney CZ05	Slab	No change
	Timber	$1,136.97
Perth CZ05 with brick cavity walls	Slab	No change
	Timber	No change
Adelaide CZ05	Slab	No change
	Timber	No change
Melbourne CZ06	Slab	$5,566.34
	Timber	$2,093.88
Canberra CZ07	Slab	$4,025.45
	Timber	$2,061.45
Hobart CZ07	Slab	$3,482.33
	Timber	$2,802.06
Thredbo CZ08	Slab	$2,426.77
	Timber	$5,168.22

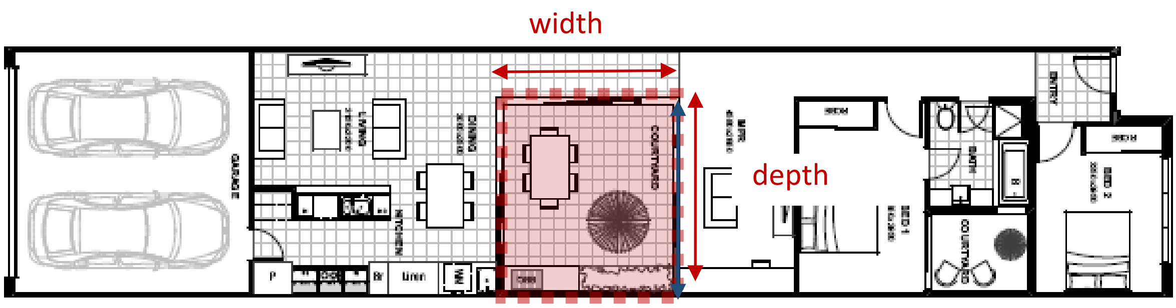
On average the 2022 glazing requirements lead to a $2,020 reduction in costs compared to 2019. Savings are small in climates 2 and 5 but can be as high as $5,000 in in cooler and inland climates. See Table 20.

Dwellings where a significant proportion of the glazing faces on to a courtyard can't be assessed using the Glazing provisions

The initial development of the new calculation method struggled to achieve a reasonable convergence with NatHERS results. One of the Class 1 dwellings assessed had virtually all its windows facing a deep courtyard. When this dwelling was excluded from the sample, a much better level of convergence was achieved. It was clear from this example that the shading by adjacent and opposite walls of the courtyard is so significant that the methodology of the glazing calculations cannot be applied.

The effective shading of the courtyard was varied in NatHERS and tested against the glazing calculations. This testing showed that where 50% or more of the total glazing to habitable rooms faces a courtyard which has a depth of at least 50% of its width, the glazing calculations cannot be used with reasonable accuracy.

Figure 1 Dwellings with deep courtyards cannot use the Glazing Calculator



Simplifying Insulation R-values for dwellings with multiple building element properties

The elemental provisions show require R-Values according to the physical properties of the element. Dwellings may contain building elements with more than one property, e.g. walls of different height or eave overhang or different types of roof. In this case compliance may be achieving by providing different insulation R-Values to each part of the building element. This may be overly complicated.

It is acceptable practice to use a single insulation R-Value across all building elements with a similar thermal mass in a dwelling by calculating the area weighted required insulation R-Value and installing this insulation level. For example Cavity Brick walls and Brick Veneer walls cannot be combined in this way, but any framed walls can. A similar approach can be used with roof/ceiling insulation, for example for roofs with different colours or where there is a mixture of attic and flat roofs.

1.2.3 Air movement requirements: ceiling fans

Ceiling fans facilitate significant reductions in the use of artificial cooling and industry is already installing them in significant numbers.

In NCC 2019 higher levels of air movement arising from a greater area of openable windows increases the amount of summer solar radiation heat gain allowed through windows. These benefits are now assessed directly in the glazing calculations and will generally allow greater solar gains than NCC 2019 for a dwelling with highly openable windows. This new methodology reflects the benefits of air movement found in NatHERS simulations.

Ceiling fans also enhance comfort in summer by providing air movement. NatHERS ratings show that using ceiling fans leads to significant cost-effective increases to star rating in hot climates (e.g. up to NatHERS 1.5 stars in climate zone 1), and smaller, but still cost-effective improvement in warm climates (up to 0.5 stars in climate zone 5). Furthermore, data on the use of ceiling fans shown in the CSIRO housing data portal based on NatHERS universal certificates demonstrate the extensive use of ceiling fans in the field, particularly in NCC climate zones 1 (average 8 per house) and 2 (average 5 per house).

Minimum requirements for ceiling fans are proposed to reflect industry practice and maximise benefits

Minimum requirements for the provision of ceiling fans are proposed for NCC 2022 in climate zones 1, 2, 3 and 5. In Climate zones 1, 2 and 3 these requirements include both day-time and night-time occupied spaces. In Climate zones 5 ceiling fans are only required in daytime occupied spaces.

Ceiling fans are not required in circulation spaces like hallways and entry foyers.

In Climate 5 lower overnight temperature and humidity mean that comfort can be achieved by opening windows to let in cooler outside air and to provide air movement. Consequently, the benefit of ceiling fans in bedroom areas is much lower in terms of the improvement to the star rating in climate zone 5, so there is no requirement for ceiling fans in bedrooms.

Minimum ceiling fan number and diameter was set according to the 7-star rating solutions developed for this project and generalised using the ceiling fan comfort algorithms embedded in Chenath (NatHERS calculation engine)

The minimum number and diameter of ceiling fans required to be installed was set by observing the installation pattern noted in the 7-star NatHERS solutions developed for this project. In each dwelling the additional comfort (in ^{o}C) provided by air movement for the installed ceiling fans was calculated using the algorithms embedded in Chenath. This additional comfort is dependent on the number and diameter of ceiling fans and the area of the space they serve. The minimum additional comfort provided in daytime and night-time spaces from the 7-star solutions was established and set as a minimum benchmark for the elemental provisions. The number and diameter of ceiling fans required to deliver this minimum comfort benchmark was calculated for rooms of various size to develop the minimum requirements.

Requiring ceiling fans in climate where they are beneficial allows lower specifications for other building elements

Increasing stringency from 6 to 7-stars in the DTS elemental provisions is challenging, particularly if those strategies which are in common use in NatHERS ratings are not given the same weighting in the elemental provisions as they are in NatHERS. By requiring that ceiling fans be used where beneficial, the stringency of other building element specifications can be moderated to levels which have reasonable costs. In Climate zone 1, in particular, where ceiling fans to all habitable rooms can increase NatHERS star ratings by much as a 1.5-stars, the 2022 requirements allow compliance costs to be contained.

1.3 Specific differences in methodology relating to Class 2

Class 2 insulation requirements have been developed to simpler than Class 1 for several reasons:

- The energy performance of windows will have a far more significant impact on the overall energy efficiency of Class 2 dwellings than Class 1.
- The exposed external surface area of Class 2 dwellings is much smaller than Class 1. It is rare for an individual apartment to have more than two external walls exposed to the outside and both an externally exposed floor and a roof. Many will only have eternally exposed walls. Further, external wall areas will generally be lower in Class 2 than Class 1 as they will have a higher overall window to wall ratios. Many developers seek to maximise window areas in apartment buildings to increase the marketability of the project.
- One of the main reasons for the development of Class 2 elemental provisions is to provide a robust reference building specification to allow non-NatHERS simulation tools to be used using a Verification Method (VM). In this case, the VM tool itself will provide the trade-off mechanisms needed to enable flexible results for the building industry. The elemental provisions themselves, therefore, do not need to provide this flexibility.
- *All current Class 2 compliance is currently assessed with NatHERS tools.* While there is some demand for elemental provisions for Class 2 as a primary compliance method, this is probably limited to smaller developments. It is anticipated that most of the demand for Class 2 elemental provisions will be to set a minimum building fabric benchmark for the use of Verification Methods.

The current minimum rating compliance level for NCC 2019 is a minimum of 5 stars and an average of 6 stars across an apartment building. The higher NatHERS stringency requires a minimum of 6-stars with an average of 7. Some apartments will need to rate as high as 8-stars for the average of all units to meet 7-stars.

This type of regulation makes it extremely difficult to develop elemental provisions which mirror the diversity of outcomes found in the field with the DTS NatHERS minimum and average performance requirement. While it would be possible to create a minimum and average approach to the elemental provisions, this would take more time and resources than is available for NCC 2022.

The Class 2 elemental provisions will, therefore, aim to provide building specifications which will deliver as close to a 7-star rating as possible for all units.

The approach to Glazing provisions for Class 2 will be similar to Class 1. A Glazing Calculator will need to be prepared for each individual unit. This is a different approach to other building classes used in Volume 1, where a façade calculator is used for the whole building.

2 Insulation Requirements: Roofs

2.1 Introduction

NCC DTS elemental provisions seek to limit the amount of heat flow through a roof/ceiling building element. NCC 2019 sets minimum ceiling insulation levels dependent on:

- The climate zone: this reflects the temperature difference from inside to outside for the climate zone.
- The roof material solar absorptance: darker colours absorb more solar energy and increase the sol-air temperature of the roof. The sol-air temperature is a measure of the external temperature that includes both air temperature and solar radiation effects.
- The predominant direction of heat flow: air spaces and air films have a greater thermal resistance to heat flow down (heat gain) than heat flow up (heat loss) in a roof/ceiling. This is typically only around 30% higher for heat flow down for non-reflective air spaces but can be 200-350% higher for reflective air spaces. Roof/ceilings with a reflective air space will not need as much bulk insulation, particularly in hot climates, to achieve the same heat flows as those roof/ceilings without a reflective air space.
- The extent to which external air is allowed to enter the roof space (attic): Heat flows in a highly ventilated roof will be more dependent on the difference between internal and external *air* temperatures than the difference between external sol-air and internal air temperature. This ventilation reduces heat flows in summer conditions and increases heat flows in winter.
- Gaps in the insulation: uninsulated portions of the ceiling allow much higher heat loss. Some ceiling penetrations cannot be insulated for safety because they are hot, or to ensure the correct functioning of the penetration, e.g. a ceiling fan. To ensure the performance of the roof/ceiling is maintained, the insulated areas of the ceiling use higher R-Values.

The NCC 2022 maintains allowances for the same factors as NCC 2019 but there are some differences in the way each factor is applied:

- Base ceiling R-Values are set according to the levels required for 7-star dwellings in each climate. See section 2.2.1.
- More categories of solar absorptance are added than the current light, medium and dark classification to reflect the significant impact that small changes in roof solar absorptances can have, particularly in hot climates. In climate zones 1 to 5, an upper limit of 0.64 is set for roof solar absorptance. See section 2.2.2.
- Predominant heat flow directions are maintained to allow for the difference in the R-Value of air reflective spaces, but the impact of reflective attic spaces is no longer represented by a single R-Value. Research by University of Wollongong[1] found significant differences between the attic space R-Values published in AS 4859.2:2018 and those found with Computational Fluid Dynamics computer simulations using. Different ceiling R-Value requirements are provided for roofs with and without reflective sarking under an attic roof, based on the outputs from the AccuRate NatHERS benchmark software. Total R-Value requirements are now only based on the ceiling component in an attic roof and the calculation of attic space effective resistance is no longer required. See Section 2.2.3.
- An allowance for roof ventilation is maintained, but this is based on NatHERS outputs, and the number of roof ventilators has been increased to reflect the assumed air change rate for ventilated attic spaces in NatHERS. See Section 2.2.4.
- The allowance for ceiling insulation penetration from NCC 2019 is maintained.

2.2 Roofs with a flat ceiling and sloping roof (attic roofs)

2.2.1 Parametric simulation runs

Roof properties were modified in a 7-star version of House SBH04 in the NatHERS climate zone selected to represent houses in each of the 8 ABCB climate zones (see Appendix 1). SBH04 was

[1] University of Wollongong, Sustainable Buildings research Centre, March 29 2021, *Thermal Bridging of Horizontal Ceilings under Pitched Roofs,* A report for the ABCB, Canberra. See, for example Figure 9 page 33.

selected because it had close to the average heating and cooling load for all NatHERS Class 1 dwelling ratings. The roof properties simulated are shown in Table 2.

Table 2 Parametric simulations of roof properties

Parameter	Values simulated
Reflective surface under roof	None, and Reflective sarking installed under the roof surface with an emissivity of 0.05, facing down
Roof ventilation	NatHERS roof ventilation levels: Standard and Ventilated NatHERS assumed air change rates are based on measurements of air change rates in Australian roofs
Ceiling Insulation level	2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0
Roof solar absorptance	0.23, 0.32, 0.42, 0.53, 0.64, 0.73, 0.96
Under roof R-Value	0.0, 1.0, 1.5, 2.0. These R-Values represent the typical “anti-con” roof blanket R-Values of R1.3, 1.8 and 2.3 after allowing for the thermal bridging of roof structure.

A total of 896 variations in roof properties were simulated in each climate zone. The NCC 2022 recommended R-Values were determined by selecting the lowest ceiling R-Value that maintained the 7.0-star rating for each case.

2.2.2 Roof Colour

Due to the benefits of lighter roof colours for summer performance, and in reducing global heating and heat island effects, in Climate zones 1 to 5 the darkest roof colour allowed is a solar absorptance of 0.64. In climate zones 6 to 8, darker roofs have significant advantages in the predominant winter condition, so no upper limit to roof colour is applied.

The number of categories of roof colour has been increased from the 3 broad categories used in NCC 2019 to 7 in NCC 2022. These categories are defined by their solar absorptance. The solar absorptances used are based on an analysis of products in the market.

Table 3 below shows the Colorbond® colours and solar absorptances used to set the minimum roof/ceiling element R-Values.

Table 3 Colorbond Solar Absorptance values used

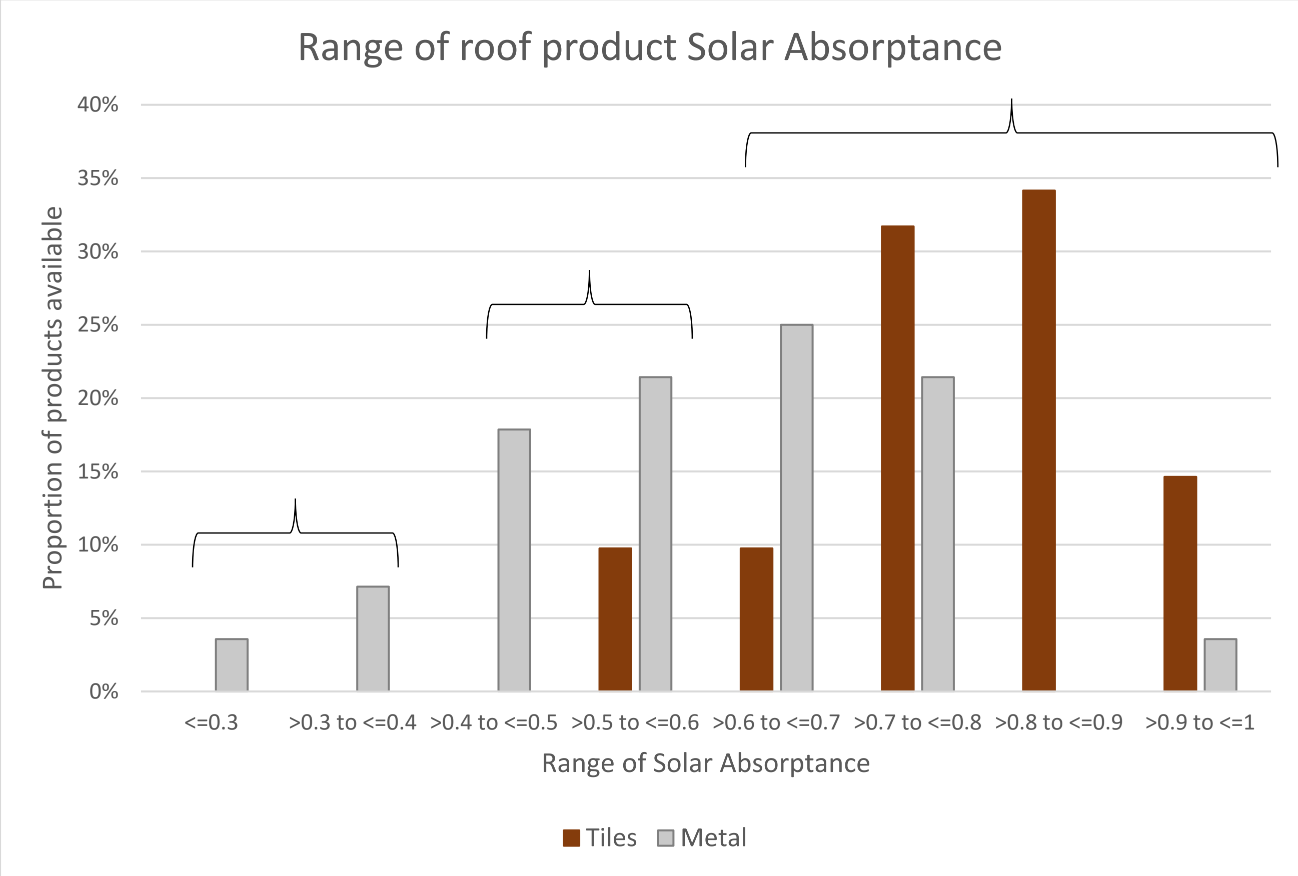
Solar Absorptance	Colorbond® colour
0.23	**Whitehaven®**
0.32	**Classic Cream™**
0.42	**Paperbark®**
0.53	**Conservatory®**
0.64	**Wallaby™**
0.73	**Monument®**
0.96	**Nightsky®**

If the roof product being used has a solar absorptance that is not exactly the same as the values in the NCC, the NCC user can either select the R-value applicable to the closest solar absorptance or use the actual solar absorptance to interpolate between the R-values.

Range of roof solar absorptances available from manufacturers

Figure 2 below shows the range of solar absorptances available in colorbond steel and Boral roof tiles (reproduced from the holistic review of elemental provisions).

Figure 2 Range of roof solar absorptance



The CSIRO Australian Housing Data portal shows that NatHERS assessors already modify roof colour to better suit the climate zone, e.g. 66% of roofs in the NT which has hot climates are light coloured[2] while only 14% of roofs are light in Tasmania which has cool climates.

2.2.3 Installation of a reflective surface under the roof

The impact of foil installed under a roof on heat flows through an attic is complex. Foil installed under a roof affects radiation heat flow between the underside of the roof and the ceiling and bulkheads exposed to the attic. The solar absorptance of the roof surface, the extent of air exchange between the attic and the outside and the R-Value of ceiling insulation will all change the relative effect of foil on total heat flows in a roof. All these critical influences on heat flow through a

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[2] In NCC 2019, solar absorptance values are grouped as: ≤0.4(light colour), >0.4 but ≤0.6 (medium colour), and >0.6 (dark colour) in Table 3.12.1.1a to 3.12.1.1g.

roof/ceiling are now reflected in the minimum required R-Values because the R-Values were determined using NatHERS simulations that model these effects dynamically for each hour over a year.

The attic space thermal resistance is no longer included in calculations of the total element R-Value for an attic roof. Total R-Value calculations for attic roofs are only required for the ceiling component of the roof/ceiling element. Research by University of Wollongong[3] found significant differences between the attic space R-Values published in AS 4859.2:2018 and those found using computer simulations using Computation Fluid Dynamics. The effective attic R-Value was found to vary considerably under different conditions and could be negative. Including a static attic R-Value could therefore lead to recommended R-Values which do not accurately reflect performance and introduce differences between the elemental and NatHERS DTS methods.

Removing the requirement to include an R-Value for a reflective attic will simplify the calculations of total element R-Value, for example, there will be no need to calculate R-Values for heat flow up and down or to select the attic R-Value from a table. Despite this advantage, the change may create some confusion. Training and industry communication materials for NCC 2022 will need to communicate this new feature effectively.

Calculation of Total R-values for ceilings in a dwelling with an attic roof uses the NZS 4214 method referenced in AS 4859.2 but modifies this for the NCC to ensure that the heat flows are accurately modelled. See section 5 on thermal bridging.

2.2.4 Roof ventilation

In NCC 2019 a ventilated roof space requires the installation of two wind-driven roof ventilators and associated ridge, gable or eave vents (3.12.1.2 b (ii) B). Calculation of the volume of air exchange using the method shown on ventrite website demonstrates that this level of air exchange is significantly less than Chenath would assume for the ventilated roof condition. It is recommended that the requirement for roof ventilation be modified in the elemental provisions to

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[3] University of Wollongong, Sustainable Buildings research Centre, March 29 2021, *Thermal Bridging of Horizontal Ceilings under Pitched Roofs,* A report for the ABCB, Canberra. See, for example Figure 9 page 33.

require one wind-driven roof vent per 50 m^2 of attic floor area. Based on trade literature, a powered roof ventilator would provide around four times the air exhaust rate of a wind-driven roof vent. This level of roof ventilation will ensure that the elemental and NatHERS roof ventilation allowance show better alignment.

Ideally, NatHERS tools would be able to enter details of roof ventilation like the number and type roof, eave ridge and gable vents and calculate the attic ventilation rate accordingly. This would allow the development of a more flexible roof ventilation requirement for the NCC elemental provisions.

2.2.5 Explaining unintuitive results

The elemental provisions have been based on NatHERS simulations. This improves the ability of the provisions to deliver consistent results with NatHERS and other simulation tools. However, because thermal performance simulations model all aspects of heat flow, the results can sometimes appear to be unintuitive. The following example is provided to help the industry better understand this[4].

As explained in section 2.1, a static R-value, like that used in previous editions of the NCC, is not an accurate measure of the thermal resistance of an attic space. University of Wollongong research showed that the effective R-Value of an attic space can even be negative in some circumstances.

NatHERS tools simulate the attic space as a thermal zone, dynamically calculating radiation heat flow between surfaces, convection heat from air exchange with the outside and conduction through the building elements bounding the attic space. Ceiling insulation requirements for NCC 2022 are based on running several hundred NatHERS simulations which accurately model all these heat flows.

Some insulation R-Values for ceiling insulation when installed in an attic roof with reflective sarking facing the attic space may seem unintuitive, particularly in cooler climates, compared to previous version of the NCC. For example, in Climate Zone 7, Table 13.2.3h shows that ceiling insulation R-

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[4] The fact that simulation tools can deliver correct, but unintuitive results, does not mean that every odd-looking requirement is merely the result of the simulation. There are thousands of values which were developed for NCC 2022. In rare cases there may be an error, so the industry should keep asking questions about requirements that don’t look quite right.

Values for a roof with standard roof ventilation are higher when reflective foil is installed in some cases and lower in others.

Table 4 From NCC 2022 housing standard: Table 13.2.3h: Pitched roof with horizontal ceiling – minimum R-Value for ceiling insulation: climate zone 7

Roof ventilation	Reflective insulation under-roof	Under-roof insulation R-Value	SA ≤ 0.23	0.23 < SA ≤ 0.32	0.32 < SA ≤ 0.42	0.42 < SA ≤ 0.53	0.53 < SA ≤ 0.64	0.64 < SA ≤ 0.73	0.73 < SA ≤ 0.85	0.85 < SA ≤ 0.96
Vented	Yes	< 1.0	4.5	4.5	4.5	4.5	4.5	4.0	4.0	4.0
		≥ 1.0	4.5	4.5	4.5	4.5	4.0	4.0	4.0	4.0
	No	< 1.0	5.0	4.5	4.5	4.5	4.0	4.0	3.5	3.5
		≥ 1.0 to < 1.5	4.5	4.5	4.5	4.5	4.0	4.0	4.0	4.0
		≥ 1.5	4.5	4.5	4.5	4.5	4.5	4.0	4.0	4.0
Standard	Yes	< 1.0	4.5	4.5	4.5	4.0	4.0	4.0	4.0	4.0
		≥ 1.0	4.0							
	No	< 1.0	4.5	4.5	4.5	4.0	4.0	3.5	3.5	3.5
		≥ 1.0 to < 1.5	4.5	4.5	4.0	4.0	4.0	4.0	3.5	3.5
		≥ 1.5 to < 2.0	4.0							
		≥ 2.0	4.5	4.0	4.0	4.0	4.0	4.0	4.0	3.5

When the roof surface is a darker colour, placing reflective insulation under the roof stops the attic space from heating up as much in winter. As a result, the temperature difference between the attic and rooms below is greater when reflective insulation is installed. Consequently, and a higher R-Value is required. In NCC 2019, using a static R-Value to represent the performance of an attic space would have always seen a lower ceiling R-Value required if reflective foil was installed.

2.3 Flat, skillion and cathedral roofs

The majority of work was undertaken using roof/ceiling structures which contained an attic space. A selection of the parametric runs were converted to flat or sloping roofs and the compliant R-Value was determined. In virtually all cases, the compliant R-Value for flat or sloping roofs was very close to the R-Value for an attic roof where the attic was unventilated and contained no insulation or reflective surface under the roof. Because the differences were small, and the 2022 regulations were already more detailed than 2019, it was decided that the R-values required for each roof type should be made the same.

While the base R-Values required for attic and flat roofs have been unified, there are some significant differences between the two roof types (attic without ventilation or under-roof insulation and flat, skillion or cathedral roofs). In Flat, skillion or cathedral roofs:

- The added R-Value of a reflective air space can be assessed by simply calculating the R-Value of the air space for the predominant direction of heat flow. This is because the air change rate in the air space is much lower than in an attic space.
- The under-roof insulation level can be added to the ceiling insulation level.
- Unlike roofs containing an attic, the Total R-Value of flat, skillion and cathedral roof includes the whole building element, and not just the ceiling component.

3 Insulation Requirements: Walls

3.1 Introduction

NCC 2022 DTS elemental provisions seek to limit the amount of heat flow through a wall building element. NCC 2019 sets minimum ceiling insulation levels dependent on:

- The climate zone: this reflects the temperature difference from inside to outside for the climate zone.
- The wall material solar absorptance: darker colours absorb more solar energy and increase the sol-air temperature of the roof. The sol-air temperature is a measure of the external temperature that includes both air temperature and solar radiation effects, and
- There are a range of clauses which allow lower insulation levels:
- Walls with eave shading in hot climates, typically a 600 eave for common 2.4 m wall heights,
- Walls with higher thermal mass,
- Walls with higher thermal mass in conjunction with a slab floor, and
- Where the Glazing calculations exceed the minimum requirements by a significant amount.

This is a simplification of the requirements, there are over 30 sub clauses defining the requirements.

While stringency must be lifted to an equivalent of 7-stars there are still significant pressures in the building industry to allow no or minimal insulation requirements for high thermal mass walls in those locations where high thermal mass walls are in common use, e.g. brick cavity walls in Perth or concrete block walls used in northern Australia. This is not an unreasonable proposition, because higher thermal mass walls generally provide lower heat flows. However, allowing for this improved performance in a way which maintained 7-stars within the current structure of NCC 2019 was extraordinarily challenging. It was through the analysis of these options that the more detailed approach of NCC 2022 elemental provisions was developed.

In NCC 2022 the various exception clauses have been replaced with tables based on parametric simulations in a similar fashion to the roof/ceiling insulation requirements. These tables were developed separately for walls with different levels of thermal mass, and cover various solar absorptance values, wall heights and overhangs (e.g. eaves). The tables encapsulate all the variables considered by the 2019 sub clauses but do this by quantifying the effects, rather than providing broad allowance independent of other variables:

- Insulation requirements are developed for walls with various levels of thermal mass using parametric simulations, see section 3.2,
- A broader range of external wall solar absorptances are considered, particularly for wall types which are typically rendered or painted like concrete block walls or walls with lightweight cladding, and therefore have a greater opportunity to control solar absorptance, see section 3.4,
- Rather than consider the impact of a single eave overhang on the performance of the wall, insulation levels are prescribed for up to 9 levels of eave shading in each climate, see section 3.5 and
- In NCC 2022 wall height has also been considered. Wall height affects the surface area of the element. It is a fundamental principle of heat flow that the greater the area of an element, the greater the heat flow. Wall height also affects other determinants of heat flow. Taller walls with thermal mass contain more thermal mass, and the effect of eave overhang shading is less, see section 3.6.

The 2022 regulations take all these factors into account.

3.2 Parametric Simulation Runs

In each climate zone, the wall insulation requirements are based on the dominant construction type in that climate zone:

- Brick Veneer in climate zones 2, 4, 5, 6 and 7,
- Concrete Block in climate zones 1 and 3, and
- Framed lightweight walls in climate zone 8 (Alpine).

Insulation requirements for a second wall type with a different thermal mass level are also provided. Providing R-Values for the second wall type allows coverage for Brick Cavity walls in Perth (climate zone 5) or framed lightweight walls in climate zones 1 and 3. Insulation requirements for other wall types can be derived using total R-Value calculations based on the thermal mass of the wall (see section 3.3.1 for more detail):

- If the wall is lightweight or has a lightweight framed component adjacent to the room it encloses, R-Values for Brick veneer are used adjusted for the difference in the total R-Value,
- If the wall is heavyweight or has heavyweight materials adjacent to the room it encloses, R-Values for Brick Cavity/Concrete Block are used and adjusted for the difference in total R-Value.

The table below details the parametric NatHERS simulation variables used for analysis of wall heat flows. The NCC 2022 recommended R-Values were determined by selecting the lowest wall R-Value that maintained the 7.0-star rating for each case.

Table 5 Parametric simulations of wall properties for walls with internal framing, e.g. Brick Veneer or Weatherboard

Parameter	Values simulated
R-Values for walls with framing e.g. Brick Veneer and Weatherboard	R1.5, 2.0, 2.7 with and without a reflective air gap with the reflective surface havening an emissivity of a maximum of 0.08 and an air gap width of at least 20mm.
R-Values for Brick Cavity walls*	0.0, 0.25, 0.5, 0.75, 0.93, 1.09, 1.44 (insulation installed in the cavity between bricks)

Parameter	Values simulated
R-Values for Concrete Block walls	0.0, Reflective air space (minimum 200 thickness with a reflective surface having an emissivity of 0.05), R0.5, 1.0, 1.5 and 2.0. All insulation is assumed to be installed on the inner side of the concrete block.
Eave overhang (m)	0.0, 0.3, 0.45, 0.6, 0.9, 1.2, 1.5, 1.8, 2.4
Wall height (m)	2.4, 2.7, 3.0, 3.6
Wall solar absorptance for walls with brick outer layer	0.35, 0.5, 0.7, 0.85
Wall solar absorptance for painted or rendered finish	0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9

* see Table 6 for examples of the insulation that would provide this insulation R-Value

A total of 23,904 NatHERS parametric simulations were run for the 8 NCC climate zones covering the main and secondary/ wall types.

The table below provides examples of insulation systems that would provide the added insulation shown in Table 5. Note that the added R-Value subtracts the R-Value of the air space between the bricks that the insulation products replace.

Table 6 Insulation Systems providing added R-Value for Brick Cavity Walls used for parametric studies

Wall Insulation Type	Added R-value	Total R-value
No Insulation	0.00	0.63
10mm EPS against the inner leaf	0.26	0.89
20mm EPS against the inner leaf	0.51	1.14
10mm Polystyrene Reflective Backed against the inner leaf*	0.62	1.25
15mm Polystyrene Reflective Backed against the inner leaf*	0.75	1.38

Wall Insulation Type	Added R-value	Total R-value
10mm Polystyrene Reflective Backed (both sides) suspended between leaves*	0.93	1.56
15mm Polystyrene Reflective Backed (both sides) suspended between leaves*	1.05	1.68
Cellular Reflective Backed (both sides) suspended between leaves*	1.09	1.72
R1.1 PIR Reflective Backed against the inner leaf*	1.44	2.08
R1.1 PIR Reflective Backed (both sides) suspended between leaves*	1.77	2.40

3.3 Wall insulation levels set for walls of different thermal mass

As explained above, the predominant wall type, and a wall type with a different level of thermal mass was simulated in each climate zone. Table 4 shows that walls with higher thermal mass were simulated with significantly lower R-Values than framed walls. These lower levels were based on observing how the thermal mass of walls affects the R-Value required to achieve 7-stars in each climate zone. It reflects the lower heat flow through walls with higher thermal mass.

Note that the simulations of external wall type assumed that the internal walls matched the thermal mass of the external wall. For example, brick cavity walls were assumed to have internal walls constructed of brick (minimum thickness 100 mm) and Concrete Block external walls were assumed to have internal walls constructed of 90mm concrete block.

While no specific provision has been included in the NCC to cover high thermal mass external walls constructed with light weight internal walls, e.g. plasterboard stud walls, the external wall insulation would need to be increased to provide a 7-star equivalent outcome. Where high thermal mass external walls are constructed with light weight internal walls the maximum specified R-Value in the elemental provisions should be used.

3.3.1 Application to wall types not included in the NCC

In Climate Zones with a Brick Veneer wall option:

- If the inner part of the wall is constructed using a timber frame and lined with a thin low thermal mass material the R-Value for insulation Brick Veneer also applies to this wall.
- If the wall is clad with a material that has a higher thermal resistance than a brick, the insulation R-Value may be reduced by the difference between the thermal resistance of the Brick and the cladding system used. For example, a 75 mm aerated autoclaved concrete panel has a thermal resistance of 0.58, while a brick has a thermal resistance of 0.18. The wall insulation R-Value may be lowered by 0.58 – 0.18 = 0.4.

In Climate Zones with a Brick Cavity wall option:

- A Reverse Brick Veneer wall when constructed with internal walls of Brick, is required to have the same level of insulation as a Brick Cavity wall. If there are internal walls were plasterboard on stud frame walls, the wall would be required to have the same insulation R-Value as a Brick Veneer or framed wall.

- A Mud Brick wall when constructed with internal walls of mud brick, is required to be insulated with the same R-Value as a Brick Cavity Wall.

In Climate Zones with a Framed wall option:

- If the wall is clad with a material that has a higher thermal resistance than a weatherboard or FC sheet, the insulation R value may be reduced by the difference between the thermal resistance a weatherboard and the cladding system used. For example, a 50mm polystyrene cladding has a thermal resistance of 1.28, while a weatherboard has a thermal resistance of 0.12. The wall insulation R-value may be lowered by 1.28 – 0.12 = 1.16. Note that a polystyrene cladding would also reduce thermal bridging. A calculation of Total R-value including thermal bridging will allow even lower insulation R-Values between frames than this simple correction.

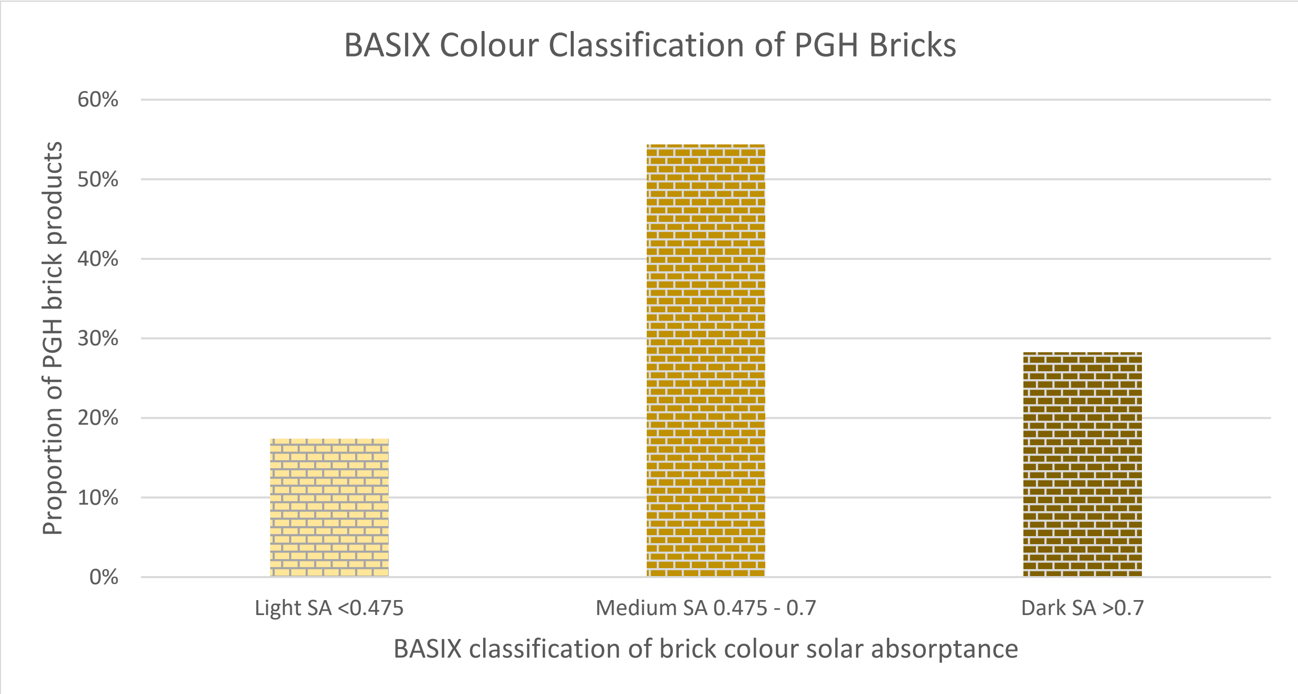
3.4 Solar absorptance

The classification of solar absorptance for walls is different for walls with a rendered or painted external surface and bricks. Walls finished with render or paint can be tinted to produce specific outcomes, so the solar absorptance ranges for these walls have a greater number of classifications than for brick walls.

3.4.1 Brick clad walls solar absorptance

Brick wall cladding has been subject to the NCC 2019 Dark/Medium/Light classifications as well as the BASIX classification for over a decade. BASIX classifications are different to the NCC with slightly higher solar absorptances allowed for light (0.475 compared to NCC 0.4) and medium (0.7 compared to NCC 0.6) colours. Trade literature has been developed for many brick manufacturers showing the solar absorptance classification for either NCC, BASIX or both. While this is currently only in terms of Dark/Medium/Light it is assumed that the trade literature can be modified to the new classification. The graph below shows the proportion of Brick Solar Absorptances under each of the three current BASIX classifications.

Figure 3 Range of brick solar absorptances for PGH bricks



Source: PGH Bricks and Pavers, NSW Brochure

The colour classification for bricks in NCC 2022 has four grades instead of 3. This is based on the significantly different simulated energy demand for dwellings with darker solar absorptances observed in the parametric simulations.

Table 7 Change in classification of solar absorptances NCC 2019 to 2022, brick clad walls

NCC 2019 Description	NCC 2019	NCC 2022 classifications
Light	<=0.4	<=0.35
Medium	>0.4 to <=0.6	>0.35 to <=0.5
Dark	>0.6	>=0.5 to <=0.7
		>0.7 (only allowed in climates 6 to 8)

3.4.2 Walls with rendered or painted surfaces

Painted (e.g. weatherboard) and rendered e.g. concrete block) surfaces can be tinted to achieve any desired colour and therefore solar absorptance. NCC 2022 has therefore increased the number of classifications for wall with these types of external finish in climate zones 1 and 3 based on the significantly lower cooling loads with lighter colours observed in the parametric simulations.

Table 8 Change in classification of solar absorptances NCC 2019 to 2022, walls with painted or rendered finish

NCC 2019 Description	NCC 2019	NCC 2022 classifications
Light	<=0.4	<=0.3
		>0.3 to <=0.4
Medium	>0.4 to <=0.6	>0.4 to <=0.5
		>0.5 to <=0.6
Dark	>0.6	>=0.6 to <=0.7 (in climates 1 to 5, higher in other climates)

Trade literature for painted and rendered finishes does not commonly include solar absorptance unless the product has specific low absorptance properties. Typically, paint suppliers provide RGB to show the colour and LRV (light reflectance value in the visible spectrum). ***Visible spectrum reflectance is different to solar reflectance because the solar radiation spectrum contains ultraviolet and infrared radiation in addition to visible spectrum light. LRV values cannot be used for solar absorptance.***

Additional research to establish solar absorptances for rendered and painted finishes would facilitate better outcomes in the NCC. Until then, more general guidelines will need to be used.

The Chenath engine contains the following colours to provide guidance for the selection of wall solar absorptance:

Table 9 NatHERS suggested solar Absorptances

Colour	Solar Absorptance
Brick (red pressed clay)	0.79

Colour	Solar Absorptance
Concrete (dry)	0.62
Copper (aged)	0.57
Fibrocement (weathered)	0.65
Galvanised iron (new)	0.32
Galvanised iron (weathered)	0.75
Paint: Black	0.96
Paint: Light Cream	0.30
Paint: Light Green	0.50
Paint: Light Grey	0.75
Paint: Pink	0.49
Paint: White	0.23

There is not a large research base that can easily be discovered on non-academic sources. One paper, presented to the 24th Conference on Passive and Low Energy Architecture, Singapore, 22-24 November 2007, gave some examples:

Figure 4 Colour and solar absorptance

Colour	Solar Absorptance
	56
	65
	52
	67
	74
	28
	46
	62
	79
	53
	60
	43
	46
	42
	51
	79
	65

Source: Dornelles et al, Conference Paper: *Determination of the solar absorptance of opaque surfaces,* Presented at the 24th Conference on Passive and Low Energy Architecture, Singapore, 22-24 November 2007.

The paper explained that the solar absorptance also depended not only on the colour, but also on the gloss level of the paint, surface roughness and the type of surface e.g. a corrugated steel roof both shades some part and reflects solar radiation to other parts of the surface.

3.5 Eave/overhang shading

Insulation R-Values are shown for various horizontal eave overhang depths from 0 to 2.4 metres. In some climate zones there were no 7-star solutions available for eave depths over a certain value. Consequently, eave depths up to 2.4 metres are not shown for all climate zones, for example climate zones 6 to 8 only show eave depths up to 1.2 metres.

3.6 Wall height

Wall height has been introduced because it is a fundamental principle of heat flow that more heat is lost though a larger surface area. Inclusion of the wall height allowed significantly better correlation with NatHERS outcomes.

Wall heights do not only affect surface area. They also affect the proportion of the wall shaded by a given overhang depth. In addition, a greater wall height for a wall with significant thermal mass increases the thermal mass of the wall. Because the determination of minimum insulation requirements was conducted using NatHERS tools, these factors are allowed for in the regulation.

3.7 Simplification to wall insulation requirements

The initial development of wall R-Values included both single storey and two storey walls. Two storey houses have a greater wall surface area, so heat flows through walls are greater in dwellings with two (or more) stories. These additional tables have been replaced by a note to the wall insulation tables which require higher wall insulation R-Values in dwellings with two or more stories. Note that these R-Values apply to all external walls in the house, not only those walls on upper floors.

3.8 Dwellings with multiple wall properties

The elemental provisions show require R-Values according to the physical properties of the element. Dwellings may contain building elements with more than one property, e.g. walls of different height or eave overhang. In this case compliance may be achieving by providing different insulation R-Values to each part of the building element. This may be overly complicated.

It is acceptable practice to use a single insulation R-Value across by calculating the area weighted required insulation R-Value and installing this insulation level. This only applies to walls of the same thermal mass levels. For example Cavity Brick walls and Brick Veneer walls cannot be combined in this way, but any framed walls can.

3.9 Explaining unintuitive results

The elemental provisions have been based on NatHERS simulations. This improves the ability of the provisions to deliver consistent results with NatHERS and other simulation tools. However, because thermal performance simulations model all aspects of heat flow, the results can sometimes appear to be unintuitive. The following examples are provided to help the industry better understand this.

In Table 13.2.5c, (Masonry Veneer walls in climate zone 2) the R-Value required for a wall with a height of between 2.4 and 2.7 metres and an overhang of between 450 and 600 mmm is higher for a solar absorptance of 0.35 to 0.5 than it is for a solar absorptance of between 0.5 and 0.7.

Dwellings in Climate Zone 2 have more cooling required than heating, so it would seem unintuitive that a wall with lighter colour should need more insulation than a wall with a darker colour. This is what simulation results showed. In this case, the decrease in heating due to the darker colour was less than the increase in cooling due to the darker colour.

Table 10 From NCC 2022 housing standard: Table 13.2.5c: Masonry veneer wall – minimum insulation R-Value: climate zone 2

SA	Overhang (mm)	Wall height (m)			
		≤ 2.4	> 2.4 to ≤ 2.7	> 2.7 to ≤ 3.0	> 3.0 to ≤ 3.6
≤ 0.35	0	X	X	X	X
	> 0 to ≤ 300	2.0	X	X	X
	> 300 to ≤ 450	1.5	X	X	X
	> 450 to ≤ 600	1.5	2.0	X	X
	> 600 to ≤ 900	1.5	1.5	2.5	X
	> 900 to ≤ 1200	1.5	1.5	1.5	X
	> 1200 to ≤ 1500	1.5	1.5	1.5	2.5
	> 1500 to ≤ 1800	1.5	1.5	1.5	2.0
> 0.35 to ≤ 0.5	0	X	X	X	X
	> 0 to ≤ 300	2	X	X	X
	> 300 to ≤ 450	1.5	X	X	X
	> 450 to ≤ 600	1.5	2.5	X	X
	> 600 to ≤ 900	1.5	1.5	2.5	X
	> 900 to ≤ 1200	1.5	1.5	1.5	X
	> 1200 to ≤ 1500	1.5	1.5	1.5	2.5
	> 1500 to ≤ 1800	1.5	1.5	1.5	2.0
> 0.5 to ≤ 0.7	0	X	X	X	X
	> 0 to ≤ 300	2.0	X	X	X
	> 300 to ≤ 450	1.5	X	X	X
	> 450 to ≤ 600	1.5	2.0	X	X
	> 600 to ≤ 900	1.5	1.5	2.5	X
	> 900 to ≤ 1200	1.5	1.5	1.5	X
	> 1200 to ≤ 1500	1.5	1.5	1.5	X
	> 1500 to ≤ 1800	1.5	1.5	1.5	2.0

In Table 13.2.5h (masonry cavity walls in climate zone 4) the required insulation R-Values for walls with a height of between 3 and 3.6 metres are lower than for walls with a height of from 2.7 to 3 metres with deeper overhangs. Taller walls have a greater surface area, so intuition would suggest that the lower wall height should have a lower required R-Value. The simulation results showed a more nuanced picture. When cavity brick walls are taller, they also contain more thermal mass, and this can reduce heat flows, particularly for cooling. Further, because the wall is taller, the overhang shades a lower proportion of the wall for a given overhang depth which will help to reduce heat loss in winter.

Table 11 From NCC 2022 housing standard: Table 13.2.5h: Masonry cavity wall – minimum insulation R-Value: climate zone 4

Solar Absorptance	Overhang (mm)	Wall height (m)			
		≤ 2.4	> 2.4 to ≤ 2.7	> 2.7 to ≤ 3.0	> 3.0 to ≤ 3.6
≤ 0.35	0	0.25	0.25	0.51	0.75
	> 0 to ≤ 300	0.51	0.51	0.51	0.75
	> 300 to ≤ 450	0.51	0.51	0,51	0.75
	> 450 to ≤ 600	0.51	0.51	0.51	0.75
	> 600 to ≤ 900	1.08	0.75	0.75	1.08
	> 900 to ≤ 1200	1.44	1.08	1.08	1.08
	> 1200 to ≤ 1500	X	1.44	1.44	1.08
	> 1500 to ≤ 1800	X	X	X	1.44
> 0.35 to ≤ 0.5	0	0.25	0.25	0.51	0.62
	> 0 to ≤ 300	0.25	0.25	0.51	0.62
	> 300 to ≤ 450	0.51	0.51	0.51	0.62
	> 450 to ≤ 600	0.51	0.51	0.51	0.75
	> 600 to ≤ 900	0.75	0.62	0.62	0.75
	> 900 to ≤ 1200	1.08	1.08	0.75	1.08
	> 1200 to ≤ 1500	X	1.44	1.08	1.08
	> 1500 to ≤ 1800	X	X	1.44	1.44
> 0.5 to ≤ 0.7	0	0.00	0.25	0.25	0.51
	> 0 to ≤ 300	0.25	0.25	0.25	0.51
	> 300 to ≤ 450	0.25	0.25	0.51	0.51
	> 450 to ≤ 600	0.25	0.25	0.51	0.51
	> 600 to ≤ 900	0.25	0.51	0.51	0.62
	> 900 to ≤ 1200	0.51	0.62	0.62	0.75
	> 1200 to ≤ 1500	1.08	1.08	1.08	1.08
	> 1500 to ≤ 1800	1.44	1.44	1.08	1.08

4 Floors

4.1 Introduction

In NCC 2019 the required floor insulation depends on:

- Whether the floor is in contact with the ground,
- If the floor is in contact with the ground. no insulation is required for concrete slabs on ground unless:
    - the slab is heated or cooled (either in the slab or in a screed above the slab). If so, edge insulation is required to minimise heat losses from the slab,
    - the slab is in Climate Zone 8, edge and under slab insulation is required to minimise heat losses in the cold conditions this Climate Zone covers.
- if the floor is suspended over a subfloor space, the insulation level required depends on:
    - the Climate Zone,
    - the height of the subfloor, which affects the heat flow through the subfloor walls and the radiant heat exchange between the underside of the floor and the ground,
    - the material of subfloor walls,
    - the direction of heat flow. In floors there is a greater thermal resistance for air spaces to heat flow down than heat flow up.

In NCC 2022 all the impacts on heat flow through floors from 2019 are accounted for, but there are some differences in the way this is handled:

- In NCC 2019 the subfloor space was allocated a static thermal resistance depending on the subfloor wall height, wall material and direction of heat flow. Research by the University of Wollongong found that a static thermal resistance does not adequately model the performance of the space and using a static resistance could lead to erroneous results.
- A similar solution for floors over subfloors was developed to ceiling under attic spaces. The Total R-Value for floors only needs to be calculated for the floor component excluding the subfloor space and subfloor walls. The impacts of other factors are determined through

parametric AccuRate simulations and the effects are reflected in the floor and/or subfloor wall R-Value requirements.

- In Climate Zones 6 and 7, slabs are now required to be insulated. This insulation can be provided by a Waffle Pod slab construction style, or by insulation a traditional concrete slab on ground to an equivalent level. This reflects industry trends. In cooler climates Waffle Pod slab construction is the dominant floor type, e.g. 70% of slab floors are waffle pod in Victoria. Requiring waffle pod floors in these climate zones is simply reflecting what industry is doing to achieve compliance with NCC 2019.
- Subfloor wall insulation is not as effective at reducing heat loss in winter as underfloor insulation, but it also reduces cooling energy demand by keeping the subfloor temperatures lower in summer. Underfloor insulation increases cooling energy demand by reducing heat loss during the day to the cooler subfloor. The impact of subfloor insulation is now allowed for in NCC 2022. Because subfloor wall insulation has a much higher R-Value than the subfloor wall material, there is no longer any differential in the R-Value required for floors with different subfloor wall materials.
- Subfloor wall heights from 300 to 1800 mm were simulated, and different floor and subfloor R-Values are specified depending on the height of the subfloor walls. Wall heights over 1800 mm must use other compliance methods such as NatHERS or a Verification Method. Floor height not only affects the heat flow through subfloor walls and radiant heat exchange with the ground, it also potentially affects the height of the building and therefore its exposure to wind. At heights above 1800 mm, the air leakage to the dwelling itself may also be higher. These complex impacts mean that it is beyond the ability of elemental provisions to adequately deal with subfloor wall heights above 1800 mm.
- Higher levels of floor insulation for floors over unenclosed spaces are generally required in NCC 2022 to reflect the higher stringency. NatHERS simulation results showed that in Climate Zones 4 and 5, there were no practical levels of floor insulation that could be installed to achieve 7-stars without also improving the performance other building elements. Consequently, in Climate Zones 4 and 5, there is no R-Value of floor insulation which can be installed which will provide a compliant solution. Any dwelling constructed

with a floor over an unenclosed space will need to use NatHERS or a Verification Method to demonstrate compliance.

4.2 Parametric simulation runs

Floor properties were modified in a 7-star version of House SBH04 in the NatHERS climate zone selected to represent houses in each of the 8 ABCB climate zones (see Appendix 1). SBH04 was selected because it had close to the average heating and cooling load for all NatHERS Class 1 dwelling ratings. The floor properties simulated are shown in Table 10 below:

Table 12 Parametric simulations of floor properties

Parameter	Values simulated
Floor insulation levels	R0.0, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0
Subfloor wall heights	600, 900, 1200, 1500, 1800
Subfloor wall insulation levels	R0.0, 1.0, 1.5, 2.0
Reflective subfloor	Reflective or non-reflective

A total of 400 simulations of floors with different thermal properties were simulated to assess minimum insulation requirements for floors in NCC 2022. The NCC 2022 recommended R-Values were determined by selecting the lowest floor/subfloor wall R-Values that maintained the 7.0-star rating for each case.

4.3 Reflective insulation

4.3.1 Reflective insulation facing the subfloor

Because the heat flows through a subfloor are dynamic and can't be represented by a single R-value, like attic spaces, the thermal resistance of subfloors no longer needs to be calculated. Total R-Values are only calculated for the floor component, excluding the subfloor and subfloor walls. Different required floor R-Values are provided for subfloors with and without a reflective surface facing down. In a subfloor, reflective surfaces facing down are required to have an emissivity 0.05 or less.

Like any floor insulation product, reflective insulation to a subfloor will improve heating performance and make cooling performance worse because it reduces heat loss to the subfloor. Reflective insulation provides a greater thermal resistance to heat flow down than up. Reflective insulation in theory therefore maximises benefits and minimises disadvantages of floor insulation compared to bulk insulation. However, the difference between floor R values with and without a reflective subfloor may not demonstrate as big an advantage as it seems in theory. The impact varies from climate zone to climate zone and depends on factors like subfloor wall height and insulation.

4.3.2 Reflective insulation not facing the subfloor

Fully self-contained reflective air spaces within the floor assembly itself, and which have no air leakage to the outside or subfloor, for example created by draping reflective foil between floor joists, are included in the Total R-Value calculation of the floor component. The additional thermal resistance added by a reflective air space, therefore, contributes to the insulation R-Value for floor insulation.

4.4 Subfloor wall height and insulation

Subfloor walls and their insulation are not part of the Total R-value calculation. Different floor R-Values are shown for various combinations of subfloor wall height and subfloor wall insulation.

In Climate zones 2 and 1 all subfloor walls will need to be insulated.

4.5 Floors over unenclosed spaces in Climate Zone 4 and 5

NatHERS simulation results showed that in Climate Zones 4 and 5, there were no practical levels of floor insulation that could be installed to achieve 7-stars without also improving the performance other building elements. Consequently, in Climate Zones 4 and 5, there is no R-Value of floor insulation which can be installed which will provide a compliant solution. Any dwelling constructed with a floor over an unenclosed space will need to use NatHERS or a Performance Solution to demonstrate compliance.

5 Thermal Bridging

Thermal Bridging Mitigation (TBM) measures have been introduced to NCC 2022 for steel framed dwellings. The measures aim to mitigate thermal bridging through steel framing to achieve approximate equivalence with timber framing. Significant research was undertaken by the University of Wollongong to support the development of these measures, particularly in relation to thermal bridging through the ceilings and suspended floors.

This section provides an overview of the TBM measures. For greater detail on the thermal bridging measures refer to the reports University of Wollongong:

University of Wollongong undertook additional research to help guide the calculation of thermal bridging mitigation requirements. These reports can be downloaded at:

See reports:
University of Wollongong, Sustainable Buildings Research Centre: REPEATING THERMAL BRIDGES IN CEILINGS AND FLOORS: SIMULATION AND CALCULATION: Stage 1 final report, 2022,
University of Wollongong, Sustainable Buildings Research Centre: REPEATING THERMAL BRIDGES IN CEILINGS AND FLOORS: SIMULATION AND CALCULATION: Stage 2 final report, 2022

5.1 The impact of thermal bridging

The impact of thermal bridging by framing elements on the effective R-value of insulation was initially calculated using the methods in NZ4214 because this method is referenced by AS/NZS 4859.2 2018.

The change in the total element R-value without bridging was then compared to the total element R-value with bridging. The impact on energy demand was then predicted using AccuRate by changing the R-value of insulation by the difference in total R-values with and without bridging[5].

[5] All NatHERS tools will have thermal bridging of insulation when released for use with NCC 2022. Because this feature was not available during regulatory development, thermal bridging effects had to be calculated by hand and entered into AccuRate for this report.

The effective R-Value of the insulation was modified in the AccuRate file using the NZS 4214 method.

The thermal bridging impact on the star rating of house SBH04 on the star rating for timber and steel framing is shown on the tables below. The house has a timber floor over a suspended subfloor space and thermal bridging mitigation is applied through the use of a continuous layer of polystyrene.

Table 13 Impact of thermal bridging on the star rating of a 7-star Class 1 dwelling – thermal bridges assessed using NZS 4214.

NCC Climate Zone	Location	Stars	
		Timber frame	Steel frame
CZ01	Darwin	6.9	6.3
CZ02	Brisbane	6.7	5.9
CZ03	Longreach	6.7	6.2
CZ04	Mildura	6.4	5.4
CZ05	West Sydney	6.6	5.5
CZ06	Tullamarine	6.6	5.3
CZ07	Hobart	6.6	5.3
CZ08	Thredbo	6.6	5.1

The impact of thermal bridging on star the rating for timber frame is small, but significant. The impact of steel framing is significantly greater: as much as 1.9 stars in Alpine climates and 0.7 stars in hot climates. Addressing the thermal bridging due to steel frames was therefore set as the priority for NCC 2022.

Subsequent research by the University of Wollongong led to the development of an alternative methodology that was used to formulate the TBM measures required in the Deemed-to-Satisfy Provisions for pitched roofs with flat ceilings and suspended floors. These changes stem from the fact that the NZS standard was developed primarily with walls in mind as was not ideally suited to building elements which are adjacent to air cavities with significant ventilation like attic spaces or subfloors.

5.2 Target

The extent of TBM to be required for NCC 2022 has been limited to ensure that current construction methods can be maintained.

This is because the amount of TBM required for steel frames in NCC 2022 was subject to a cost benefit analysis. This analysis compares the cost of the TBM with the value of energy savings over time. If TBM requirements are set to a high level, additional construction costs may be incurred if typical construction methods are required to change. This additional cost could be significant. For example, a Brick Veneer wall is required to maintain a cavity width of at least 25 mm (NCC 2019, 3.3.5.6). TBM measures were developed to ensure this cavity width is maintained.

Therefore, the thermal bridging requirements have been formulated so that:

- TBM for steel framed dwellings is only required to so that the performance of building elements with steel frames is close to that of timber frames.
- For insulation R-Values of R3.0 or under, achieve 95% of the total R-Value that the element would achieve with timber frames,
- For insulation R-Values of R3.0 or over, achieve 90% of the total R-Value that the element would achieve with timber frames
- Timber frames require no additional TBM.

This is a minimal standard compared to international standards and voluntary codes which also require TBM for timber frames. TBM is new to Australian residential construction. Introduction of TBM in the NCC at the level proposed allows the building industry time to adapt to the requirements and gives time for innovative products to be developed to contain costs.

5.2.1 Why steel frames only need to get close to timber framed Total R-Values

Physical Limitations to the thickness of the TBM

Brick Veneer walls are the most commonly used external walls in Australia. The CSIRO AHD dashboard shows that 53% of all external walls in Australia use Brick Veneer. Any solution for thermal bridging must accommodate this wall construction type. A Brick Veneer wall contains a cavity that, in part, provides resistance to moisture penetration. An air-gap of at least 25mm between thermal bridging insulation and the inner surface of the brick must be maintained (NCC

2019 3.3.5.6), so there is a physical limit to the thickness of insulation that can be added. While a 25mm air gap could be maintained at higher R-values if the overall cavity width is increased, this would also have significant cost implications.

Cost of TBM materials

In addition, the type of insulation that can fit within this space and provide sufficient additional R-value to remediate thermal bridging is generally more expensive than insulation products which fit between framing members. Reflective membranes can be cheaper than the insulation product installed between frames.

Diminishing returns of insulation

It is a fundamental tenet of building physics that the first R1 of insulation reduces heat flow by a greater amount than subsequent R1, and so on. Achieving the same R-Value as timber framed building elements is therefore not as cost effective as allowing a small increase in Total R-Value for steel frames.

5.3 Calculation of thermal bridging mitigation and Total R-values

NZ4214 provides a method to calculate the total R-Value of a building element including thermal bridging. The notable features of this method are:

- The idealisation of the steel framing C section as a solid rectangular section that would provide the same heat flows as the steel frame
- The thermal resistance of the steel frame depends on the steel thickness, the depth and flange width of the C section, and
- Applying the area weighted R-Value method to the layers including the frame, insulation, thermal bridging insulation and adjacent air space to derive the effective insulation R-Value. This effective R-Value is then added to the thermal resistance of other building element layers to derive the Total R-Value.

NZ4214 was primarily developed for use with walls. The University of Wollongong found that this method was not well suited to attic spaces and subfloor spaces because the conditions in these spaces are subject to ventilation and their effective thermal resistance fluctuates over time. The studies by University of Wollongong identified an alternative method that can be applied to structures containing an attic space and subfloor to improve the accuracy of calculations.

Most of the detail of the methods used are shown in the University of Wollongong reports. This section provides an overview of key features.

5.4 Frame fraction

The impact of thermal bridging depends on the area of framing within a building element. Strictly speaking, this area varies from dwelling to dwelling, which would imply that thermal bridging effects need to be calculated on a case-by-case basis. Such an approach would require detailed thermal bridging calculations, which would be time-consuming and costly and would exceed the skills of many building practitioners involved in the regulatory certification process. A standard framed area for walls, floors, roofs and ceilings was therefore identified and forms the basis of the requirements. Based on feedback from the steel industry, slightly lower framed areas were assumed for steel-framed buildings than timber-framed buildings based on standard construction practices such as truss spacings.

The framed areas used in this report are not based on the theoretical minimum derived from simple frame spacing. The framing layout may need to have closer spacing in some areas than this theoretical minimum based on the building's dimensions. For example, additional studs may be required based on the wall length, and truss spacings may be less than the theoretical maximum based on whether the building's dimensions are a multiple of the truss spacing. Further, additional framing to walls is required around windows, and the complexity of the roof design can require additional framing. The frame ratios used in this report are therefore based on a framing layout developed for dwelling SBH04.

Table 14 Frame ratios for various building elements

Building element	Timber frame ratio	Steel frame ratio
Brick Veneer Wall	15.0%	12.0%
Lightweight clad framed wall	15.0%	12.0%
Concrete block/precast concrete wall	12.0%	12.0%
Cathedral/Skillion/Flat roofs	8.4%	8.4%
Ceilings below attic spaces	8.4%	6.0%

Building element	Timber frame ratio	Steel frame ratio
Framed floors	10.8%	10.8%

Note: In Brick Cavity walls, there is no framing, so no thermal bridging is assumed, i.e. a 0% framed area.

5.5 Multiple TBM options

There are several alternative ways in which thermal bridging can be mitigated that are in the NCC 2022 DTS elementals, for example:

- Achieve a specified Total R-Value, calculated using a method that accounts for the effects of thermal bridging (AS4859.2 is the specified calculation method for walls and suspended floors above an unenclosed subfloor. No calculation method is specified for other situations. UoW has developed a method of calculating thermal bridging in ceilings and floors above an enclosed subfloor – refer UoW Report 2 above).
- Increase the R-value of installed insulation between the frames by a specified amount (only practical at lower R-values).
- Provide a continuous layer of insulation inside or outside the frame, subject to also meeting any applicable vapour permeance requirements.

6 Glazing

6.1 Aligning glazing calculation and NatHERS 7-star outcomes

Achieving sufficient alignment between NatHERS 7-stars and the Glazing requirements of NCC 2022 is the most challenging task in developing the new regulations:

- NatHERS is a dynamic hourly simulation for a full year. It is difficult to represent the complexity of a simulation in a simple calculation,
- the NCC provides separate summer and winter performance targets while NatHERS adds together heating and cooling to derive the star rating and therefore allows trade-offs between summer and winter performance,
- the NCC and uses a metric for winter performance of conduction losses divided by solar gain. The same ratio will lead to different heating loads in different dwellings, and it is difficult to isolate all these factors,
- NatHERS uses an area correction to even out the requirements for houses of different sizes and there is no similar weighting that can be easily developed for elemental provisions.

The impact of solar gains on heating and cooling energy use is complex. The amount of solar gain is easy to predict, but the impact on heating and cooling depends on a variety of factors:

- the temperature in the space: if a space is comfortable with minimal solar gain in winter, additional solar gain does not reduce heating energy use. With higher building fabric specifications, this will occur more frequently.
- whether the room is being conditioned at the time of the solar gain and the thermostat setting if it is,
- the amount of thermal mass affects the storage of the solar gain for future hours,
- the extent of cross ventilation available to remove excess solar gain in summer,
- one kW of solar gain can have a different impact on heating and cooling in different rooms, e.g. a one kW solar gain in winter may not impact energy use in a bedroom as if it isn't during the day but will impact heating loads in a living room, and

- many other factors.

Simulation tools take all these factors into account and trying to replicate the nuance and sophistication of a simulation in a single whole of dwelling calculation is challenging.

6.2 Process of aligning glazing calculations and NatHERS

A parametric simulation approach, used for insulation, would have taken hundreds of thousands to develop and was not possible in the time, so a different approach was taken to aligning glazing requirements to NatHERS 7-stars. The summer and winter targets are designed to represent the average heating and cooling load for slab on ground of the dwellings which were optimised to achieve exactly 7-stars in each NCC climate zone.

The windows for each of the 18 houses and 24 apartments specified to achieve 7-stars were entered into the NCC 2019 Glazing Calculator in the 8 NCC climate zones. Calculations from the GC for summer solar gain, winter solar gain and winter conduction losses and the impacts of horizontal overhangs on solar gain were extracted, entered into a spreadsheet and correlated with the heating and cooling loads predicted by AccuRate. An additional NatHERS simulation was run for each dwelling with all windows fully shaded to obtain a better picture of the impact of radiation gains on heating and cooling energy demand to allow the differences in other building fabric elements to be isolated.

The extent of compliance for the 7-star dwellings with the 2019 GC was also evaluated.

The summer and winter solar gain exposure factors for windows of various orientations were then modified to improve alignment with NatHERS. Modification of the solar exposure factors alone was not sufficient. To improve the alignment of Glazing Calculator outputs with NatHERS, additional factors were introduced. Alignment was considered to be achieved when the average score of the 7-star dwellings was 100% of the target for each season, and the range of results reflected the range of NatHERS heating and cooling loads. Factors and solar exposure values were also adjusted so that the relative ranking of dwellings using the Glazing Calculator was as close as possible to the ranking of NatHERS heating and cooling loads.

Aligning outcomes from the GC and NatHERS also involved trying to align the radiation exposure with the difference between the 7-star solution and with windows fully shaded simulations. The new factors and solar exposure values were then adjusted so that the Cshgc/Cu ranking matched the heating load ranking. It was not always possible to achieve the same relative ranking as NatHERS for the reasons explained in section 6.1.

6.3 Evaluating the impact of solar radiation gains through windows on dwelling performance

The differences between the design and specification of the 7-star dwellings mean that the NatHERS predicted cooling and heating loads by themselves do not reflect the impact of the windows on these loads.

In addition to the initial 7-star rating simulation, a second simulation was performed where each window was shaded by a shading device that would entirely block all incident radiation to windows but not walls. This second simulation helped to define the impact of radiation heat gains on the dwelling's heating and cooling loads.

This technique is not a perfect indicator of the impact of windows. Lower solar gains through windows reduce internal temperatures and therefore affects conduction heat flow through the window. Despite this limitation, this technique provides a more reliable indicator than using NatHERS simulated heating and cooling loads alone and indicates the relativities of solar exposure factors for various window orientations.

The relative ranking of window impacts using the new glazing calculation technique did not always match the NatHERS result. This outcome is only to be expected. A simplified method to set minimum performance requirements cannot hope to fully reflect the complex interactions between window solar heat gain and conduction with other elements of the building fabric as simulated by a dynamic hourly simulation perfectly. The aim of the approach is deliberately described as an alignment of outcomes, i.e. it does not seek to match outcomes, only to get them in the right ballpark.

6.4 New factors introduced to the NCC 2022 GC

6.4.1 Exposure factors

The original exposure factors were derived from tools that predicted the total radiation incident on glazing for the three months of winter and summer. By adjusting exposure factors to align with NatHERS outcomes, the exposure factors now reflect solar gains for all months that require heating and cooling. In addition, this process means that exposure factors are not simply predicting the amount of radiation incident on windows, but the impact of this radiation on heating and cooling loads. Separate sets of exposure factors and other factors were developed for dwellings with a suspended timber floor and a slab on ground.

In Climate Zone 5, where houses in Perth use high thermal mass brick cavity construction, a separate set of factors was developed for dwellings that use Brick Cavity construction and internal brick walls.

6.4.2 Level Factor

The level factor was developed to allow the GC to model all storeys in a dwelling in one calculation rather than require a separate GC for each level. This was a commonly requested feature from the building industry in previous versions. To ensure that data entry errors or gaming are avoided, the GC asks for the number of storeys to be input and checks to see whether windows have been identified as upper floor windows.

6.4.3 Bedroom factor

Bedrooms are assumed to be occupied at different times and are heated and cooled to different thermostat temperatures in NatHERS .Therefore, solar gains and conduction through glass affect these rooms differently from daytime occupied areas in the dwelling. In NatHERS ratings, it was clear that the most cost-effective method of achieving compliance is to install higher performance glazing in living areas first. This factor ensures that a similar outcome is achieved with the GC.

The bedroom factor allows some potential for gaming, e.g. labelling a study as a bedroom. The impact is not large, and it mirrors the gaming potential that already exists with NatHERS. All rooms which can be accessed only from a bedroom, like a walk-in robe or ensuite, are included in the "bedroom" definition. This definition also includes a "parent's retreat", similar to NatHERS.

6.4.4 Window Frame Solar Absorptance

NatHERS ratings showed that adjusting the window frame colour (solar absorptance) to suit the climate better was not only a no-cost improvement but also facilitated the use of larger glazing areas or reduced the need for high-performance glazing. Given the higher stringency of building fabric requirements, not allowing for frame colour would have unnecessarily limited design freedom and imposed additional cost.

Window frame colours are only required to be specified as light, medium and dark using the same definition of solar absorptance definitions as NatHERS tools[6] These broad categories allow for some colour substitution without affecting compliance.

Introducing frame colour opens up some potential for gaming and adds another factor to be checked on site. These issues also exist for compliance achieved using NatHERS. Assumptions regarding frame is therefore displayed in GC outputs. Further, providing appropriate training on the importance of window frame solar absorptance to the building and building surveying industries will be necessary. The building and design industry will also need to explain the impacts of changing colour to clients effectively.

6.4.5 Hard floor surface factor (only affect slab on ground or waffle pod slab construction)

A hard floor surface on a slab on ground significantly increases the ability of the concrete slab to store solar gains through windows. The dwellings that achieved a NatHERS 7-star rating that used ceramic tiles or a polished concrete floor finish were able to use higher windows areas and use less high-performance glazing. Including the hard floor surface factor in the elemental provisions allows similar benefits of greater design flexibility and lower cost compliance found in NatHERS.

6.4.6 Window Openability

Cross ventilation of dwellings has significant potential to reduce cooling loads. However, predicting the effects of cross ventilation is challenging to model without computer simulation because it depends on the prevailing wind direction when external temperatures are suitable to provide a cooling effect, the internal resistance to airflow in the dwelling, and the openability of windows.

Window openability is the only factor that is easy to define for the purposes of the elemental provisions. Limiting the allowance for cross ventilation to the openable window area alone will necessarily over and underestimate the effects of cross ventilation on a dwelling-by-dwelling basis. The dwellings simulated at 7-stars in each climate have a significant range of openability, in part

[6] Light: solar absorptance of 0.3, Medium 0.5 and Dark 0.85, select the value that is closest to the value for the frame. Meatal window colours often have a corresponding colorbond colours, and solar absorptances for these colours are readily available.

because well-ventilated building designs were deliberately selected for this purpose. Alignment of GC and NatHERS outcomes should at least help ensure that the effects of cross ventilation predicted are, on average, in a suitable range.

NCC 2019 provides some allowance for “highly ventilated” dwellings, allowing a higher target C_{SHGC} to be used. This alternate target typically allows only around 10% higher solar gain for highly ventilated dwellings. Designers of specialist, well-ventilated buildings in hot and warm climates have long criticised this allowance as inadequate.

The new allowance based on the total openable window area to floor area ratio provides a significantly greater allowance for more highly ventilated houses. For example, in Darwin and Sydney:

Table 15 Increase in summer window gain allowed in Darwin for various total window openability areas (CZ01)

Openable window area to net floor area ratio	CSHGC target	Change compared to 5%
5%	0.0672	100%
10%	0.0718	107%
15%	0.0770	115%
20%	0.0827	123%

Table 16 Increase in summer window gain allowed in Sydney for various total window openability areas (CZ05)

Openable window area to net floor area ratio	CSHGC target	Change compared to 5%
5%	0.0484	100%
10%	0.0538	111%
15%	0.0569	117%
20%	0.0587	121%

The openable window area allowance proposed for NCC 2022 provides designers of specialist well-ventilated buildings with considerably more design flexibility than NCC 2019.

Highly openable windows are considerably more expensive than traditional windows. Louvre windows can be a similar cost to basic double-glazed windows. Consequently, it is not likely that the take up of designs that depend on highly openable windows will be adopted in the mainstream; however, this change ensures more compliance options are available for those who want such dwellings.

It should be noted that these values were derived from AccuRate simulation results. While NatHERS tools have been criticised for not adequately allowing for cross-ventilation, it is clear that they certainly show significantly more significant benefits for ventilation than the current NCC 2019 elemental provisions.

Calculating the openable area of each window would be an onerous task. While those who wish to do so should be allowed to enter the openable percentage, it is proposed to simplify this data input to three options:

- Fixed, i.e. 0%,
- Default: the user will specify the opening style (e.g. awning, sliding, louvre etc.), and the openable percentage will be set according to research based on investigating window industry window sizing charts, and
- Highly openable: set to 90%, typical for a louvre window or bi-fold door, or
- The user may input the openable percentage in increments of 5% up to 90% (window frames will almost always obstruct some air flow).

6.4.7 Overall impacts and benefits

To help the industry better understand the impact of the new glazing calculations on construction specifications and cost, the level of compliance achieved by the 7-star dwellings with 2019 and 2022 GC is compared.

The table below shows the average compliance levels achieved for the 7-star Class 1 dwellings on a slab floor for summer and winter performance with the 2019 and 2022 GC. Compliance levels are expressed in percentages:

- 100% represents exactly meeting the GC target.
- Below 100% implies that the dwellings, on average, exceed the target, and
- Above 100% implies that the dwellings fail to meet the requirements of the target.

The 2019 Glazing Calculator is intended to achieve a level of performance consistent with 6-stars. The 7-star dwellings should have a compliance level below 100% in the 2019 GC if alignment with 6-star performance were achieved. The table below shows the average compliance with the 2019 and 2022 GC in each of the NCC climate zones.

Table 17 average compliance with the 2019 and 2022 GC in each of the NCC climate zones Class 1

Climate Zone	Average Compliance %			
	% 2019 Summer Limit Slab	% 2022 Summer limit Slab	% 2019 Winter Limit Slab	% 2022 Winter limit Slab
1	128%	101%	NA	NA
2	125%	99%	65%	100%
3	128%	100%	105%	91%
4	89%	100%	123%	100%
5	75%	101%	80%	100%
6	67%	100%	146%	100%
7	53%	77%	164%	100%
8	37%	75%	230%	100%

The table above shows that for the dwellings tested, the 2019 GC generally does not achieve ideal alignment with 6-stars. In warmer climates 1 to 3, the 7-star dwellings exceeded the 2019 summer performance limit. In the 2022 version, these same dwellings, on average, achieve 100% of the required limit. The closer alignment with NatHERS will allow significant cost savings compared to the 2019 elemental provisions in these climates, despite the higher stringency that applies to NCC 2022. Similarly, the 2019 GC evaluates the 7-star dwellings in climates 4, 6, 7 and 8 to, on average, fail to meet winter performance targets. In some cases by very significant amounts. Again, better alignment with NatHERS reduces the glazing costs for compliant dwellings in these climates.

The one outlier from the observations above is Climate Zone 5, where the GC requirements are consistent with a 6-star level, and compliance with the 2022 GC will increase compliance costs as expected.

The performance targets in the 2022 GC were set at a level so that dwellings with the average heating and cooling energy loads of the 7-star sample exactly met the GC target performance. In Climate Zone 3 (e.g. Longreach), heating is such a small part of the total load that a lower level of heating performance than that of the 7-star dwellings could be permitted without significantly affecting star rating outcomes. Similarly, in climates 7 and 8, cooling loads are so low that a lower level of performance than that achieved by the 7-star sample could be allowed without affecting alignment with 7-stars. An argument could be made for deleting the summer seasonal requirement in these climates due to their very low cooling energy loads. However, because these climates represent a large geographical area with diverse conditions, e.g. Canberra is in Climate 7 and has a significant cooling load even though it is much smaller than heating, only eliminating cooling performance requirements for Alpine regions could be supported.

The development of the 2022 GC not only sought to set the stringency of the GC to represent the average compliance level of the 7-star sample, but it also sought to limit the range of compliance levels across the sample to broadly reflect the variation in heating and cooling loads found in the 7-star sample. The newly developed factors were particularly helpful in limiting the range of compliance levels. The table below shows results obtained for the 7-star sample in each climate zone expressed as a percentage of the average compliance level.

Table 18 average compliance with the 2019 and 2022 GC in each of the NCC climate zones Class 2

Climate Zone	Range of results +/- % from average			
	% 2019 Summer Limit Slab	**% 2022 Summer limit Slab**	**% 2019 Winter Limit Slab**	**% 2022 Winter limit Slab**
1	+/-27%	+/-14%	NA	NA
2	+/-43%	+/-24%	+/-24%	+/-20%
3	+/-55%	+/-27%	+/-57%	+/-23%
4	+/-35%	+/-14%	+/-43%	+/-14%
5	+/-18%	+/-21%	+/-24%	+/-11%
6	+/-21%	+/-23%	+/-65%	+/-25%
7	+/-17%	+/-15%	+/-57%	+/-20%
8	+/-8%	+/-10%	+/-89%	+/-27%

The table above shows that the range of outcomes delivered by the 2019 GC would generally be much greater than that achieved by the 2022 GC without the new factors.

During the consultation process the cost savings due to the use of the NCC 2022 calculator over the 2019 version were identified. The cost savings are shown in Table 19 below.

Table 19 Saving in Glazing Compliance Costs NatHERS versus NCC 2019 Glazing calculator

Location	Floor Type	Saving in Glazing Compliance Costs for Class 1 dwellings using elemental compliance in NCC 2022
Darwin CZ01	Slab	$1,146.31
	Timber	$1,152.11
Cairns CZ01	Slab	$841.76
	Timber	$1,607.68
Brisbane CZ02	Slab	$291.85
	Timber	No change (to cost)
Longreach CZ03	Slab	$3,229.31
	Timber	$5,018.30
Mildura CZ04	Slab	$4,693.57
	Timber	$2,469.30
Sydney CZ05	Slab	No change
	Timber	$1,136.97
Perth CZ05 with brick cavity walls	Slab	No change
	Timber	No change
Adelaide CZ05	Slab	No change
	Timber	No change
Melbourne CZ06	Slab	$5,566.34
	Timber	$2,093.88
Canberra CZ07	Slab	$4,025.45
	Timber	$2,061.45
Hobart CZ07	Slab	$3,482.33
	Timber	$2,802.06
Thredbo CZ08	Slab	$2,426.77
	Timber	$5,168.22

Source: See: Tony Isaacs Consulting, ABCB NCC 2022 – Energy Efficiency Provisions DRIS Update – Companion Technical Documentation V1.025/05/2022, ABCB, Canberra, 2022, Page 17

7 Air movement

The benefits of air movement provided by higher areas of openable windows in DTS elemental are significantly increased compared to NCC 2019 as shown in section 6.3.6. This increase is made to reflect the benefits of air movement found in NatHERS simulation. These benefits were previously covered in a separate part of NCC 2019 (3.12.4.1) but are now handled within the glazing calculator.

Ceiling fans facilitate significant reductions in the use of artificial cooling by allowing comfort to be achieved at higher air temperatures, and industry is already installing them in significant numbers. The Australian Housing Data portal shows that, in NCC Climate Zone 1, on average, around 8 ceiling fans are installed in Class 1 dwellings, and 5 ceiling Fans are installed in Climate Zone 2 and 3. On average 3 ceiling fans were installed in living areas of Class 1 dwellings in Climate Zone 5. NatHERS ratings show that using ceiling fans leads to significant cost-effective increases to star rating in hot climates, and smaller, but still cost-effective improvement in warm climates.

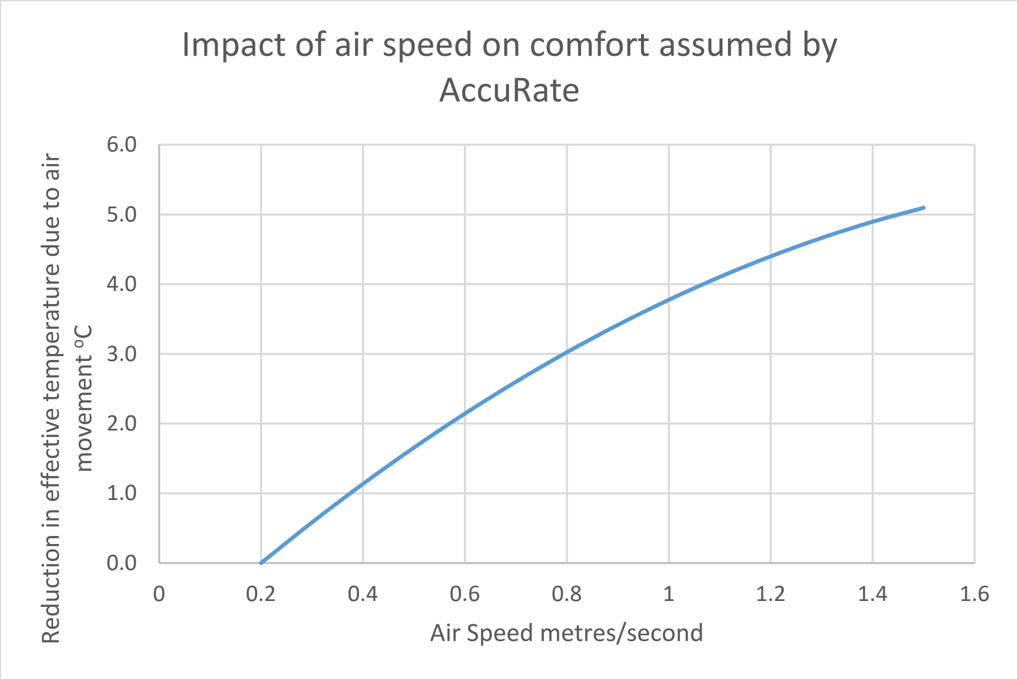
Minimum requirements for the provision of ceiling fans are proposed for NCC 2022 in climate zones 1, 2, 3 and living areas in Climate 5. In Climate zones 1 and 2 these requirements include both daytime and night-time occupied spaces. In Climate zone 5 ceiling fans are only required in daytime occupied spaces. This reflects the 7-star ratings developed for this project. In climates zone 5 ceiling fans in bedrooms did not significantly change the rating.

Ceiling fans are not required in circulation spaces like hallways and entry foyers.

In Climates 1 and 2 the higher humidity levels and lower diurnal range of temperatures (i.e., overnight temperatures are higher than in other climates) mean that significant benefit is derived through the installation of ceiling fans in bedroom areas. In Climate zone 5 lower overnight temperatures mean that comfort can be achieved by opening windows to let in cooler outside air and provide air movement. Consequently, the benefit of ceiling fans in bedroom areas is much lower in terms of the improvement to the star rating. In addition, the installation of ceiling fans found in these climate zones is significantly lower than for Climate zones 1 and 2. Not requiring ceiling fan installation in bedrooms in Climate zones 3 and 5 is therefore consistent with current industry practice.

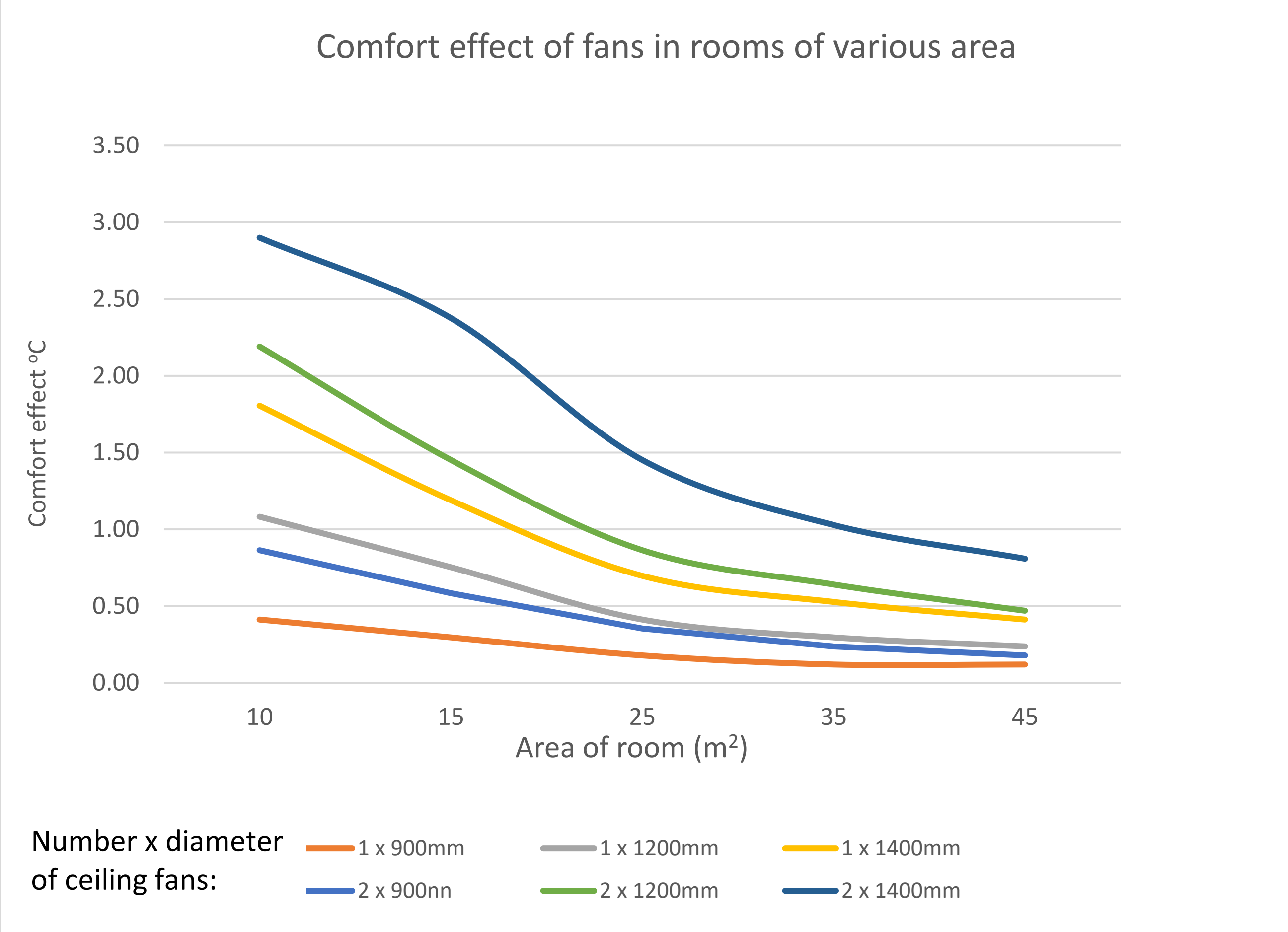
Minimum ceiling fan number and diameter for the NCC 2022 provisions was set according to the 7-star rating solutions developed for this project and generalised using the ceiling fan comfort algorithms embedded in Chenath. The graph below shows the Relationship between air speed and additional thermal comfort provided by ceiling fans in Chenath.

Figure 5 Relationship between air speed and additional thermal comfort provided by ceiling fans in Chenath



In each 7-star dwelling assessed for NCC 2022 RIS the additional comfort (in °C) provided by air movement for the installed ceiling fans was calculated using the algorithms embedded in Chenath. This additional comfort is dependent on the number and diameter of ceiling fans and the area of the space they serve. The graph below shows the extent of additional comfort provided by ceilings fans in rooms of various size by ceiling fans of various numbers and diameter.

Figure 6 Comfort provided by number and size of ceiling fan in rooms of various area



The average minimum additional comfort provided in daytime and night-time spaces by ceiling fans was established and set as a minimum benchmark. The number and diameter of ceiling fans required to deliver this minimum comfort benchmark was calculated for rooms of various size to develop the minimum requirements. Note that Bedroom sizes are typically below 20m^2, while living sizes would be over 20m^2.

8 Appendix 1: NatHERS climate zones used to represent ABCB climates

Table 20 NatHERS climate zones used to develop NCC elemental regulations

NCC Climate Zone	Population centre	NatHERS Climate Zone used	Comment
1	Darwin	01 Darwin	
2	Brisbane	10 Brisbane	
3	Longreach	03 Longreach	
4	Mildura	27 Mildura	
5	Sydney	28 West Sydney	Used for Class 1 because this has the highest construction volume in this NCC climate
5	Mascot	56 Mascot	Used for Class 2 because this has the highest construction volume in this NCC climate
5	Perth	13 Perth	Wall insulation levels for Brick cavity walls, and special subcategory for Glazing Calculations in this climate for dwellings with brick cavity external walls AND brick internal walls
6	Melbourne	21 Melbourne	Used for Class 2 because this has the highest construction volume in this NCC climate
6		60 Tullamarine	Used for Class 1 because this has the highest construction volume in this NCC climate
7	Hobart	26 Hobart	For insulation requirements
7	Canberra	24 Canberra	For glazing requirements
8	Thredbo	69 Thredbo	