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Timber Framed Residential Housing: Thermal Bridging & The path to 7 Star NatHERS

Project number: PRA526-1920

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Forest & Wood Products Australia

Timber Framed Residential Housing:
Thermal Bridging & The path to 7 Star NatHERS

Prepared for

Forest & Wood Products Australia

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Version Control

Version Number	Comments	Date
1.0	Work to date excluding thermal bridging study	07/11/20
2.1	Revisions and updates – supersedes Version 1.0 which should be deleted.	17/02/21
2.2	Window costing updated, further Brick Veneer wall types added, expanded discussion section & addition of Further Work section.	23/02/21
2.3	Inclusion of comments from HIA and glazing costs from the Australian Glass and Window Association	20/04/21

Executive summary

With the Australian Governments in the process of considering increasing the required star ratings of houses and apartments to equivalence of 7 Star NatHERS rating in the next revision of the National Construction Code due in 2022, this work has investigated how current residential timber framed houses around Australia can meet this standard. Forest and Wood Products of Australia (FWPA) commissioned this study to investigate a variety of different floor, ceiling, wall and window types to determine what combinations will achieve better thermal performance according to NatHERS to meet future requirements. Additionally, an investigation into the implications of thermal bridging on steel and timber framed wall systems was to be assessed using both the Australian and international ISO standards.

As such the scope of this study was to (1) investigate realistic and practical measures that can be implemented to meet the new minimum of 7-stars and hence what impact that has on the nature of timber framed homes and (2) investigate the impact of thermal bridging for both steel and timber framed wall systems. Modelling has been performed in FirstRate5® house energy rating software for two house plans and four baseline homes in six capital cities around Australia with results detailing NatHERS Star rating as well as the heating and cooling loads for each home in MJ/m^2.

Solutions that achieved 7 Star NatHERS ratings in predominantly heating climates comprised either combinations of double glazing and high-performance wall insulation, single glazing and waffle pod slabs or high-performance ceiling and wall insulation with single glazing. 7 Star NatHERS rated homes were more readily achievable in more mild climates such as Sydney and warmer climates such as Brisbane with 7 Star solutions comprising more moderate upgrades to building insulation or double glazing in select rooms. These solutions were however contingent on the design of the home such that passive solar heat gain in winter was sufficient throughout living areas whilst solar heat gain in summer was minimised with either eaves or awnings. This study also found that homes constrained to a narrower lot and hence reduced passive design had difficulty in meeting the 7 Star performance band in the Melbourne climate despite significant building fabric upgrades. This highlighted the need to allow for new regulations to allow for additional compliance pathways for these homes beyond just heating and cooling energy requirements.

Thermal bridging was found to have a significant impact on both timber and steel framed wall systems reducing the apparent R value by up to 22% and 40% respectively. Light Weight Direct Fix (LWDF) systems showed the greatest susceptibility to thermal bridging and the NZS 4214 calculation method yielded higher overall R values for steel framed systems when compared to the ISO 6946 analytical method. This report recommends the use of the ISO 6946 method due to its greater accuracy and more robust calculation method. This report found that if a deemed to comply regulatory approach were adopted for steel and timber wall frame systems, such that they were to perform comparatively then the steel framing system would require increased thermal resistance (either insulation or unventilated reflective air cavities) adjacent to the thermally bridged section. Thermal breaks of approximately R = 0.5 m^2K/W would be required for a typical brick veneer steel framed wall to perform on par with a timber framed system.

Based on the analysis the following general findings have been made:

- Achieving 7 Star NatHERS ratings will require a combination of approaches which varied depending upon climate zone but typically required either double glazing in living and day use spaces or upgraded floor, R 6.0 ceiling insulation and R 2.7 wall insulation.

- The greatest influencing factor on the performance of each house was the windows, with double glazing typically adding around 0.5 stars and high-performance double glazing adding up to 1.6 Stars when compared with single glazed Low-E windows. This was true for both heating and cooling climates.
- PVC framed glazing units represented the best value in terms of cost to performance with lower cost than aluminium and superior performance with 7 Stars achievable for a typical three bedroom with approximately $2,250 of additional investment in double glazed PVC windows
- Predominantly heating climates benefited from glazing with higher Solar Heat Gain Coefficient (SHGC) windows whilst cooling climates like Brisbane benefited from lower SHGC windows.
- There was marginal benefit of double glazing in night use spaces (bedrooms) for heating climates (around 0.2 Stars) but significant benefit of double glazing in night use spaces for cooling climates (around 0.5 Stars)
- Timber frames outperformed non-thermally broken aluminium framed windows (typically adding 0.3 Stars) and performed slightly better than thermally broken aluminium framed windows (typically adding 0.1 Stars).
- Flooring systems demonstrated a large impact on building performance but without a clear trend. Frequently waffle pods were the best performing solutions however Timber Sub floor systems performed on par (when insulated with R 2.0) in Hobart but significantly worse in warmer climates such as Brisbane. Further investigation is recommended into the assumptions and validity of the Chenath engine and performance of thermal mass, earth linkage and passive design.
- Wall systems were of secondary importance when compared to windows, however when combined with high performance window solutions were able to significantly contribute to better performing homes. The high performance 140 mm lightweight cladding and reverse brick veneer were the best performing and when combined with other measures were able to obtain over 8 Stars for Sydney, Perth and Brisbane.
- Common wall systems such as brick veneer and light weight direct fix (LWDF fibre cement) performed relatively similar.
- Good passive design was also found to have a significant impact on the overall performance of the homes assessed with the HIA home outperforming the Lynvale home by an average of 1 NatHERS Stars given the same building fabric selections. Eaves, natural light in living spaces and a presence of a stairwell attached to the living space all played a major part in the home's performance.
- Higher performing buildings were more readily achievable in more mild climates such as Brisbane, Perth and Sydney. Cooler climates such as Melbourne, Canberra and Hobart all were also able to achieve 8 Stars but required more significant thermal envelope upgrades.

1.1. Introduction

The Australian and State and Territory Governments will introduce more stringent thermal performance requirements for residential homes in the next revision of the National Construction Code due in 2022. It is anticipated that a 7-star minimum (up from the current minimum of 6-stars) NatHERS Star Rating will be the requirement for new residential homes. Clearly, improvements will need to be made to the thermal envelope of residential buildings in order to meet the new standards.

As such the scope of this study is to (1) investigate realistic and practical measures that could be implemented to meet the proposed energy efficiency standards and what impact that will have on the nature of timber framed homes and (2) investigate the impact of thermal bridging on wall section R values in order to ascertain requirements for both timber and steel framed systems to perform comparably.

2. Scope of Assessment

2.1. Assessment Methods

In order to ascertain the performance of each home and subsequent parametric analysis, homes have been modelled in the FirstRate5® house energy rating software (Sustainability Victoria, 2020). This software integrates the AccuRate calculation engine (Chenath) to estimate the annual heating and cooling energy and can be used to rate an existing design or as an interactive tool to optimise the design beyond compliance. This software can be used to issue certificates of compliance for Energy Assessors, however for this project formal compliance was not required, and as such the star rating and energy consumption was recorded for each assessment.

Assessments utilised base case homes as discussed in the next section of this report. These base cases considered typical building fabric and construction methods. Modifications were then made to this base case, one at a time, in order to ascertain the impact of changing this parameter on the overall thermal performance of the home. Upon investigating individual performance changes, measures were combined in order to obtain greater NATHERS Star Ratings. The benefits of individual measures have been captured in isolation as well as when combined with other effective measures. A total of six climate zones were assessed as presented in Table 35 in the appendix.

2.2. Houses Plans

To account for variation in the layout, size and number of storeys and the impact this has on the thermal performance of different building fabric solutions, two distinct homes have been selected for analysis. Each of these homes consist of a baseline where typical minimum building practices have been selected and compared with subsequent changes in building fabric and improvements in order to meet 7-star and beyond.

2.2.1. HIA Standard Home

The HIA standard home has been used by HIA for training purposes for over a decade, and it is relatively representative of common detached housing construction in the southern states of Australia. The floor plan of the HIA home is shown in Figure 2. This home consists of three bedrooms, two bathrooms, a garage and an open plan living kitchen area. The details of which including floor area, wall area and window ratios are provided in Table 1. Full plan details are provided in the Appendix of this report.

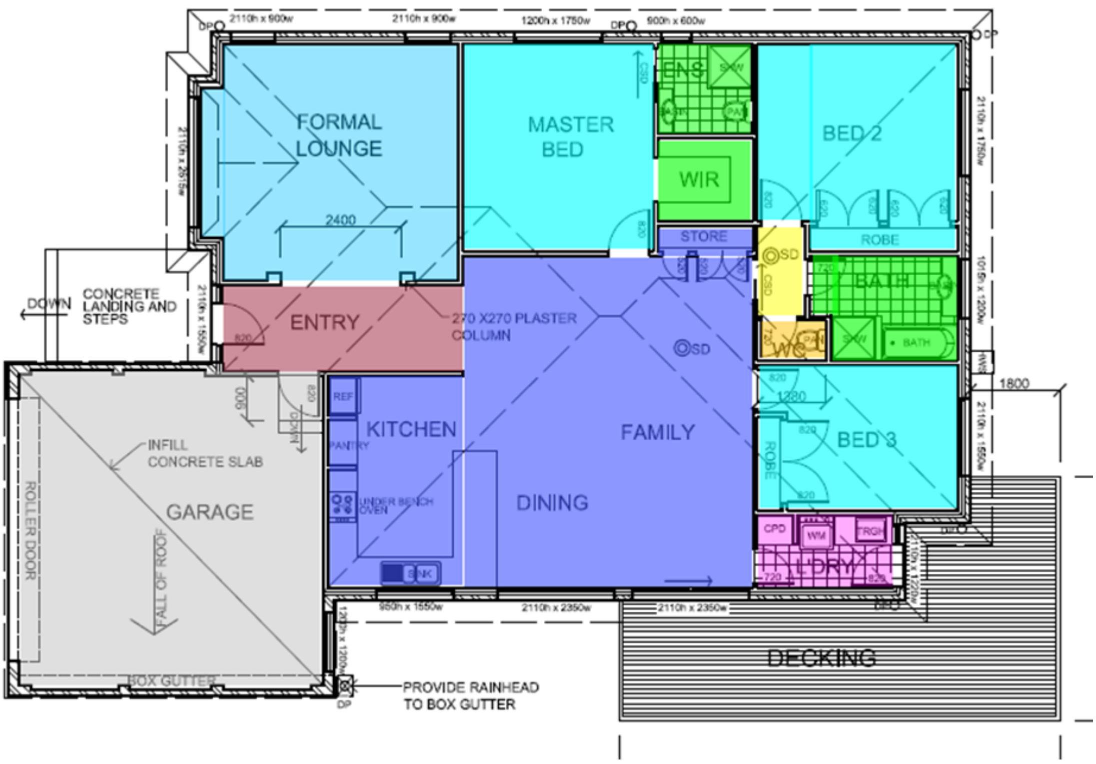


FIGURE 2. FLOOR PLAN OF THE HIA HOME

TABLE 1. DETAILS OF THE HIA HOME

Number of floors	1
Number of bedrooms	3
Total floor area	140.6 (m^2)
Total garage area	36.3 (m^2)
External wall area	148.5 (m^2)
Window area	30.8 (m^2)
Window-to-wall ratio	20.7 (%)

A total of three baseline HIA homes were assessed in this report. The first "HIA House with subfloor" was intended to represent a standard build with a sub floor rather than CSOG. The construction materials were selected to represent common building practice as well as minimum compliance to the BCA. As such this home achieved a star rating of 6.0 Stars and was calculated to require 113.7 MJ/m^2 for heating and cooling when located in Melbourne (Climate Zone 21). The baseline wall construction consisted of brick veneer with insulation and build up details provided in Table 2. As the results section will detail, this home was used to perform the most comprehensive set of parametric assessments for Melbourne to ascertain the impact of changing a variety of building attributes.

TABLE 2. HIA ECONOMICAL HOUSE WITH SUBFLOOR BASELINE BUILDING ENVELOPE DETAILS

Component	**Property**
Wall-type	Brick veneer, 90mm timber stud wall and R 2.25 insulation as detailed in Figure 45
Window-type	Aluminium Framed High Solar Gain Low-E in Living/Day spaces (U = 5.4 SHG = 0.49) and Aluminium Framed single glazed clear in bedrooms and other areas (U = 6.7 SHG = 0.57)
Floor-type	Timber Sub Floor with R 2.0 insulation
Ceiling insulation	R = 4.0 (m^{2}K/W)
Ceiling type	Discontinuous
Roof colour	Medium
Floor Coverings	Carpet in Bedroom zones, timber in living and day areas, tiles for bathrooms and laundry and concrete slab on ground (CSOG) for garage
Ceiling Height	2.4 m
Internal Walls	Standard 90mm uninsulated stud wall excluding the internal garage wall which comprised R 2.0 Insulation
Additional Fixtures	All downlights and ventilation were sealed
NatHERS Performance	★★★★★★ 6.0 113.7 79.9 33.8 [113.7 represents total heating and cooling consumption in MJ/m^2 whilst 79.9 and 33.8 represent the heating and cooling portions respectively]

The second HIA home substituted the timber sub floor with a CSOG and upgraded the windows in the night conditioned spaces to Low-E. As the results section will detail this home was used to perform the Australia wide parametric assessments to ascertain the impacts of changing more common building envelope parameters on the performance for a variety of climate zones. The baseline details and NatHERS Star rating of 6.9 in Melbourne is detailed in Table 3.

TABLE 3. HIA HOUSE WITH LOW-E WINDOWS AND CSOG - BUILDING ENVELOPE DETAILS

Component	Property
Wall-type	Brick veneer, 90mm timber stud wall and R 2.25 insulation as detailed in Figure 45
Window-type	Aluminium Framed High Solar Gain Low-E in all areas (U = 5.4 SHG = 0.49)
Floor-type	100mm CSOG
Ceiling insulation	R = 4.0 (m^2K/W)
Ceiling type	Discontinuous
Roof colour	Medium
Floor Coverings	Carpet in Bedroom zones, timber in living and day areas, tiles for bathrooms and laundry and concrete slab on ground (CSOG) for garage
Ceiling Height	2.4 m
Internal Walls	Standard 90mm uninsulated stud wall excluding the internal garage wall which comprised R 2.0 Insulation
Additional Fixtures	All downlights and ventilation were sealed
NatHERS Performance	★★★★★★☆ 6.9 85.4 63.5 21.9

The third HIA home *"HIA house with double glazing and waffle pod"* was selected to provide a high-performance solution from which to compare the impact of different building materials. As such this baseline consisted of double glazed Low-E timber framed windows and a waffle pod floor. Timber framed windows could also be substituted with PVC equivalents to reduce cost and achieve very similar performance. As detailed in the results section of this report this home was used to compare a variety of climate zones, window types, floor systems and wall types. This high-performance baseline achieved a NatHERS Star rating of 7.5 in Melbourne with the full details provided in Table 6.

TABLE 4. HIA HOUSE WITH DOUBLE GLAZING AND WAFFLE POD - BUILDING ENVELOPE DETAILS

Component	Property
Wall-type	Brick veneer, 90mm timber stud wall and R 2.25 insulation as detailed in Figure 45
Window-type	Double Glazed Low E timber framed glazing in all spaces (U = 3.1 SHG = 0.49)
Floor-type	175-85 mm Waffle pod with equivalent insulation of R 0.56 m^2K/W
Ceiling insulation	R = 4.0 (m^2K/W)
Ceiling type	Discontinuous
Roof colour	Medium
Floor Coverings	Carpet in Bedroom zones, timber in living and day areas, tiles for bathrooms and laundry
Ceiling Height	2.4 m
Internal Walls	Standard 90mm uninsulated stud wall excluding the internal garage wall which comprised R 2.0 Insulation
Additional Fixtures	All downlights and ventilation were sealed
NatHERS Performance	★★★★★★★☆ 7.5 67.2 58.5 8.7

2.2.2. The volume builder two storey home – "Lynvale"

The second home selected for assessment was selected based on publicly available plans for a typical two storey home to be referred to as the Lynvale home. This house comprises a relatively narrow frontage to allow for tighter blocks and provides four bedrooms and a cinema or multi-purpose room. This house did not include eaves nor did it have significant daylighting in the living and kitchen zones, and as such was expected to perform less favourably than the HIA standard home. The floor plan of the Lynvale home is shown in Figure 3 with the details provided in Table 6.

TABLE 5. DETAILS OF THE LYNVALE HOME

Number of floors	2
Number of bedrooms	4
Total floor area	152 (m^2)
Total garage area	30 (m^2)
External wall area	243 (m^2)
Window area	50 (m^2)
Window-to-wall ratio	20.6 (%)

Ground Floor First Floor

FIGURE 3. FLOOR PLAN OF THE LYNVALE HOME

A baseline model of Lynvale home was also developed, however given the lack of passive design for the home greater performing windows were required to achieve the minimum 6 Star NatHERS rating. Key assumptions and parameters for the Lynvale home are shown in Table 6. The same brick veneer external wall and internal walls were selected as in the HIA home.

TABLE 6. THE PROPERTIES OF THE BASELINE MODEL OF LYNVALE HOME

Component	Property
Wall-type	Brick veneer
Floor-type	Timber sub-floor with R 2.0 Insulation
Ceiling insulation	R = 4.0 (m^2K/W)
Ceiling type	Discontinuous
Roof colour	Medium
Floor Coverings	Carpet in Bedroom zones, timber in living and day areas, tiles for bathrooms and laundry and concrete slab on ground (CSOG) for garage
Ceiling Height	2.4 m
Internal walls	Standard 90mm uninsulated stud wall excluding the internal garage wall which comprised R 2.0 Insulation
Additional fixtures	Ceiling fan included in the living space whilst all downlights and ventilation were sealed
NatHERS Performance	★★★★★★ 6.0 113.1 80.9 32.2

2.3. Wall Construction Types

In order to ascertain the impact of a variety of wall build ups on the thermal performance of the two selected homes a variety of available construction types were selected for assessment. All construction types were simulated for the HIA standard home in Melbourne before. Through consultation with FWPA, the list was refined to more common and feasible construction systems that were then further assessed in the Lynvale home and for the HIA home in other major centres around Australia. Table 7 summarises the wall types assessed with the full wall build ups specified in Section 8.2. of the Appendix.

TABLE 7: SUMMARY OF WALL TYPES ASSESSED

Wall Description	Insulation thickness (mm)	Insulation R value ($m^2 \cdot K/W$)	Air Gap (mm)	Overall Wall thickness (mm)	Overall R Value (excluding any thermal bridging)[1] ($m^2 \cdot K/W$)
Brick Veneer	90	2.25	50	260	2.65
Brick Veneer High Performance	90	2.7	50	260	3.10
Brick Veneer with reflective air cavity	90	2 or 2.7	50	260	2.77-3.47
Brick Veneer 140 mm studs	140	3.5	50	310	3.97
Brick Veneer 70 mm studs	70	1.75	50	240	2.15
Cross Laminated Timber (XLAM)	66	1.5	20	205	2.78
Light Weight Direct Fix 90 mm	90	2.25	N/A	113	2.39
Light Weight Direct Fix 70 mm	70	1.75	N/A	93	1.89
High Performance 140 mm	140	3.5	20 + 45	221	3.87
Reverse Brick Veneer	90	2.25	N/A	220	2.49
High Performance Light Weight	180	4.09	N/A	199	4.18
75mm Hebel Standard	80	2.0	35	200	2.8
75mm Hebel High performance	108	2.7	35	228	3.5

2.4. Windows and Glazing

Window types that were assessed included a variety of different glazing types as well as frame systems in order to identify the benefit of each. Three different window frames were also assessed including timber, aluminium and aluminium with a thermal break. A summary of the glazing performance for each type assessed is shown in Table 8.

[1] NatHERS software currently does not take into account thermal bridging for wall, ceiling or floor framing

Table 8: Window Types in Assessment (Sustainability Victoria, 2020)

Glazing Type	Frame Type	Thermal Break	Abbreviation	U Value ($W/m^2 K$)	Solar Heat Gain Coefficient (SHGC)	Approximate Cost/m^2 ($AUD)[2]
Single glazing clear	Aluminium	No	SG-Al-CLR	6.7	0.57	124
Single glazing, Low-E	Aluminium	No	SG-Al-LE	5.4	0.49	218
Single Glazed Low-E	UPVC	No	SG-UPVC-LE	4.3	0.5	376
Double glazing clear	Aluminium	No	DG-Al-CLR	4.8	0.51	224
Double glazing clear	Timber	No	DG-Tb-CLR	3.0	0.48	451
Double Argon filled, Low-E	Aluminium	No	DGAr-Al-LE	4.1	0.52	376
Double Argon filled, Low-E	Aluminium	Yes	DGAr-Al-LE-TB	3.1	0.49	526
Double Argon filled, Low-E	Timber	No	DGAr-Tb-LE	2.0	0.31	564
Double Air filled, Low-E	UPVC	No	DG-UPVC- LE	2.3	0.26	356
Double Argon filled, Low-E	UPVC	No	DGAr-UPVC-LE	2.0	0.25	376

For the HIA standard home two key configurations were used, the first was upgraded high performance glazing only in the living and day use spaces and the second incorporated fit out of the entire home with the high-performance glazing. This was done to determine the additional benefit of installing high performance glazing in spaces that are only conditioned at night.

[2] Costing is approximate only and will vary according to location and other factors. These costs are based on supply only and exclude installation. Local data sourced using Rawlinsons Construction Guide (Rawlinsons, 2019) and the assumption that timber frames cost 50% more than standard aluminium frames whilst thermal broken aluminium frames add approximately 40% to the cost (Home Improvement Pages, 2020).

2.5. Flooring Systems

Three different base flooring systems were included in the assessment as detailed below:

2.5.1. Timber Sub Floor (Suspended)

Two variations of raised sub-floors were assessed. The first of which comprised timber with R 2.0 EPS insulation and the second increased this insulation to R 3.0. The baseline case is shown in Figure 4.

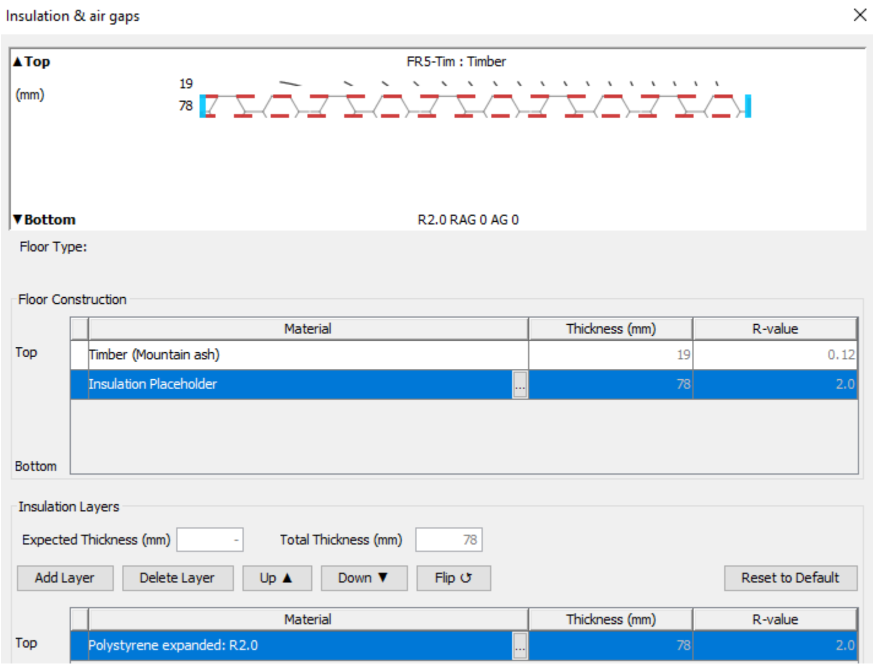


FIGURE 4: TIMBER SUB-FLOOR AND STANDARD INSULATION

2.5.2. Concrete Slab on Ground (CSOG)

For the CSOG solution a standard 100mm concrete slab with no insulation was selected. An additional parametric to investigate the additional benefit of including slab edge insulation was also investigated and discussed in the subsequent section.

2.5.3. Waffle Pod

A standard 175-85 mm waffle pod was selected for this flooring system which yielded an R value of 0.57 as shown in Figure 5 below.

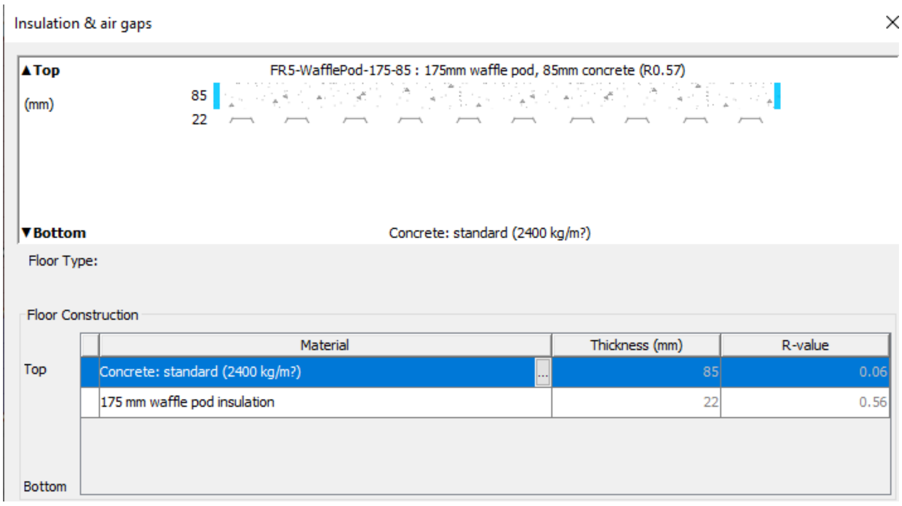


FIGURE 5: WAFFLE POD CONSTRUCTION

2.6. Other Parameters Assessed

Several additional parameters were included for the baseline HIA home in Melbourne including:

- Continuous and reflective roof/ceiling types
- Roof colour variation of Light and Dark
- Ceiling insulation increased to R 6.0.

The results of these and other parametric are presented in the subsequent results section of this report.

3. Results

3.1. Melbourne based parametric assessments.

As this study evolved, focus shifted from exploring a wide variety of wall and floor systems in Melbourne to exploring the impact of more commonly available systems and construction methods throughout Australia. Table 9 shows a summary of the parametric assessments performed for homes in Melbourne. This study's principal aim was to investigate the impact of changing window, wall, floor and other building fabric parameters on the performance of a two distinct Melbourne based homes.

TABLE 9: MELBOURNE BASED PARAMETRIC ASSESSMENTS SUMMARY

Baseline House	Windows Options	Wall Options	Floor Options	Additional Variations
"HIA Economical House with subfloor": • Window: SG-Al-LE • Walls: Brick Veneer • Ceiling: R 4.0 • Roof: Medium discontinuous • Floor: Sub floor R 2.0	• SG-Al-CLR • SG-Al-LE • DG-Al-CLR • DGAr-Al-LE • DGAr-Tb-LE	• Brick Veneer (BV) • Brick Veneer 140mm Studs (BV-140mm) • Cross laminated timber XLAM (CLT) • Light Weight Direct Fix (LWDF) • High Performance 140mm (HP-140mm) • Reverse Brick Veneer (RBV) • High Performance Light Weight (HP-180) • 75mm Hebel with R 2.0 (AAC-75 R2.0) • 75 mm Hebel with R 2.7 (AAC-75 R2.7)	• Concrete Slab on Ground (CSOG) • CSOG with R 1.0 edge insulation Subfloor Timber with R 2.0 EPS insulation • Subfloor Timber with R 3.0 EPS insulation • Waffle Pod	• Ceiling insulation R 6.0 • High performance wall insulation R 2.7 • Double glazing in day use spaces only • Roof light and dark • Continuous roof with reflective sarking
"Lynvale Standard House" • Windows: see window options • No eaves • Walls: Brick Veneer • Ceiling: R 4.0 • Roof: Medium discontinuous • Floor: Waffle Pod	Single Solution: SG-AL-LE in night conditioned spaces and DGAr-Tb-LE in day conditioned spaces	• Brick Veneer • Brick Veneer 140mm Studs • Cross laminated timber XLAM • Light Weight Direct Fix • High Performance 140mm • Reverse Brick Veneer • High Performance Light Weight • 75mm Hebel with R 2.0 • 75 mm Hebel with R 2.7	• Concrete Slab on Ground (CSOG) • CSOG with R 1.0 edge insulation • Subfloor Timber with R 2.0 EPS insulation • Subfloor Timber with R 3.0 EPS insulation • Waffle Pod	• Ceiling insulation R 6.0 • Continuous roof with reflective sarking • Roof light and dark

*SG – Single glazed; DG- Double glazed; DGAr – Double glazed Argon filled; Al – Aluminium frame; Tb – Timber frame; CLR – Clear; LE – Low-E.

3.1.1. HIA Standard House

The Baseline HIA standard home as discussed in Section 2 was designed to achieve a 6 Star Rating (minimum compliance). The subsequent parametric assessment was performed by modifying a single parameter at a time in order to ascertain the impact on energy performance and NatHERS Star Rating. The results of the parametric assessment of HIA standard home at Melbourne are shown in Table 10 on the following page. The impact of wall, window, roof and floor selections on the heating and cooling energy demand are subsequently presented.

TABLE 10. HIA HOUSE WITH SUB FLOOR SIMULATION RESULTS FOR MELBOURNE

	Parameter Variation	Energy rating	Total Energy (MJ/m^2)	Heating Energy (MJ/m2)	Cooling Energy (MJ/m2)
Wall Type	***BV (Baseline)***	***6.0***	***113.7***	***79.9***	***33.8***
	BV-140mm	6.1	109.5	76.4	33.1
	CLT	6.2	107.3	76.6	30.7
	LWDF	5.9	118.6	83.2	35.4
	HP-140	6.0	113	78.2	34.8
	RBV	6.3	104.5	75.8	28.7
	HP-180	6.0	113.4	78.8	34.6
	AAC-75 (R2.0)	5.9	114.1	80.1	34
	AAC-75 (R2.7)	6.0	113.8	79.8	34
Window	Single clear	5.7	125.5	87.6	37.9
	Single Low-E (baseline)	***6.0***	***113.7***	***79.9***	***33.8***
	Double clear	6.2	107.1	74.5	32.6
	Double argon	6.3	104	71.7	32.3
	Double argon low-e	6.6	95.9	66.2	29.7
	Double argon low-e (Timber)	7.1	81.2	61.5	19.7
Floor	***Sub floor with R 2.0 (baseline)***	***6.0***	***113.7***	***79.9***	***33.8***
	CSOG: Slab on Ground	6.2	106.1	88.4	17.7
	Waffle pod	6.6	95	73.3	21.7
	Sub floor with R 3.0	6.2	109.2	75	34.2
	CSOG edge insulation	6.4	100.6	82.8	17.8
Ceiling insulation	***R 4.0 (baseline)***	***6.0***	***113.7***	***79.9***	***33.8***
	R 6.0	6.2	106.1	73.9	32.2
Ceiling type	***Discontinuous (baseline)***	***6.0***	***113.7***	***79.9***	***33.8***
	Continuous & Reflective	5.9	114.7	80.2	34.5
Roof Colour	Light	6.0	113.4	82.3	31.1
	Medium (baseline)	***6.0***	***113.7***	***79.9***	***33.8***
	Dark	5.9	114.7	78.3	36.4
Sub Variations					
Window arrangement for double glazing	***None (baseline)***	***6.0***	***113.7***	***79.9***	***33.8***
	Day and living	6.4	99.7	69.2	30.5
	All rooms	6.6	94.9	65.4	29.5
Insulation performance in walls	***Thermal Conductivity 0.42 (Glasswool)***	***6.0***	***113.7***	***79.9***	***33.8***
	High Performance R = 2.7	6.0	112.8	79	33.8

Wall Type

The selection of wall builds up and associated insulation in the wall cavity had a minor effect on the overall star rating of the home as depicted in Figure 6. Thermal mass was shown to improve the performance of the homes with reverse brick veneer leading to the greatest reduction in heating and cooling loads followed by CLT. Higher performance wall systems including both the 140mm and 180mm (double stud) solutions did not add any tangible benefit when compared to the brick veneer wall system. This is further discussed in Section 4 of this report and is largely attributed to the poor glazing performance accounting for the vast majority of thermal gains and losses.

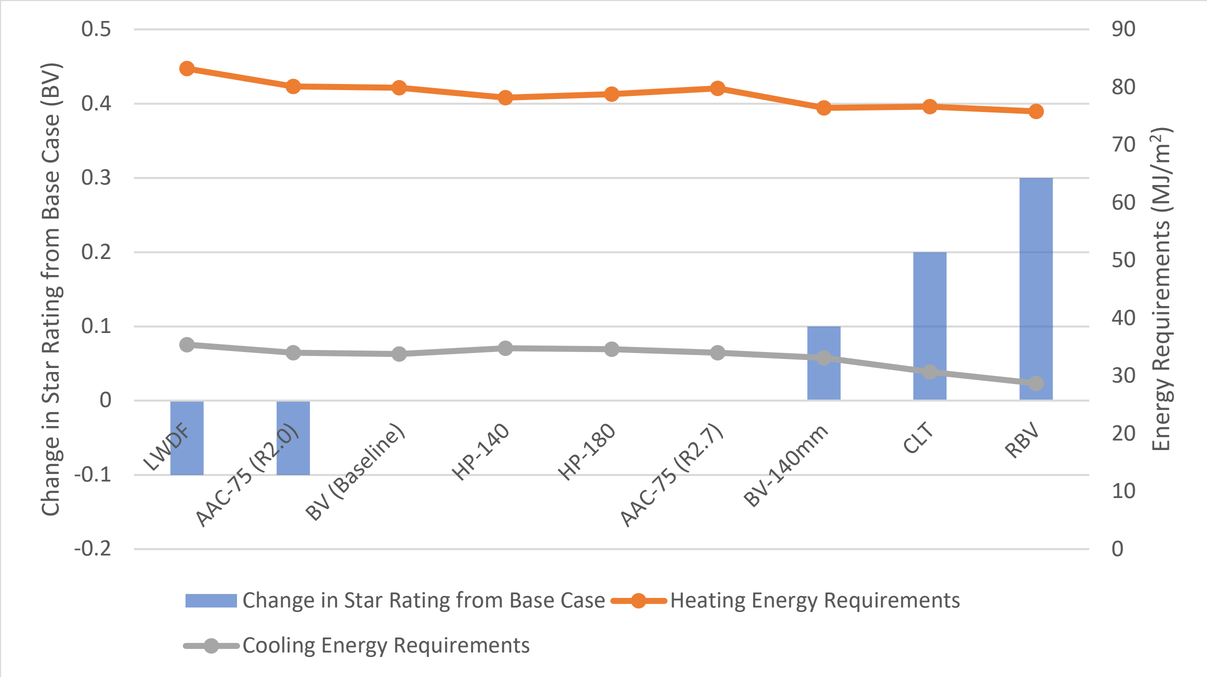


FIGURE 6: HIA HOUSE WITH SUB FLOOR - WALL TYPE ASSESSMENT RESULTS FOR MELBOURNE

Window Selection

The selection of windows had a significant impact on the overall performance of the home as detailed in Figure 7. Here it can be seen that double glazing increased the overall star value by 0.2 stars with increased benefits resulting from argon filled glazing, low-e glazing and a significant improvement in thermal performance when utilising timber framed windows. The impact of window selection on the whole of home performance is discussed in further detail in Section 4.

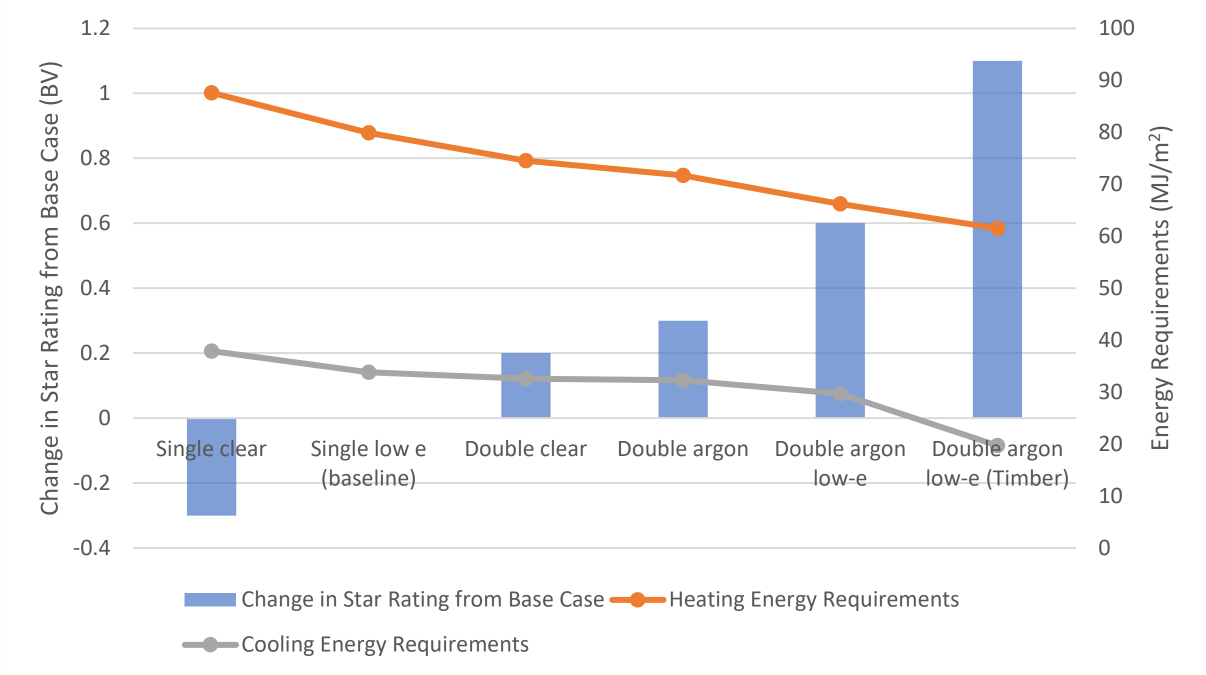


FIGURE 7: HIA HOUSE WITH SUB FLOOR - WINDOW TYPE ASSESSMENT RESULTS FOR MELBOURNE

Additional Assessments

A variety of additional parameters were also assessed to determine the impact on overall star rating, as well as annual heating and cooling requirements of the HIA home. As detailed in Figure 8 changes to the roof (either colour or material) had marginal impact on the overall star rating of the home. The use of a concrete slab on ground (CSOG) instead of the sub floor resulted in a slight improvement of 0.2 stars in the overall home rating but by reducing cooling loads and increasing heating demand. A Sub floor with R 3.0 or upgrading the ceiling insulation to R 6.0 also managed to achieve the same improvement of 0.2 Stars through a reduction in heating loads. Although uncommon in Melbourne it was also determined that CSOG with edge insulation of R 1.0 managed to improve the overall star rating by 0.4 Stars, whilst the waffle pod had the greatest impact with an improvement in the star rating of 0.6.

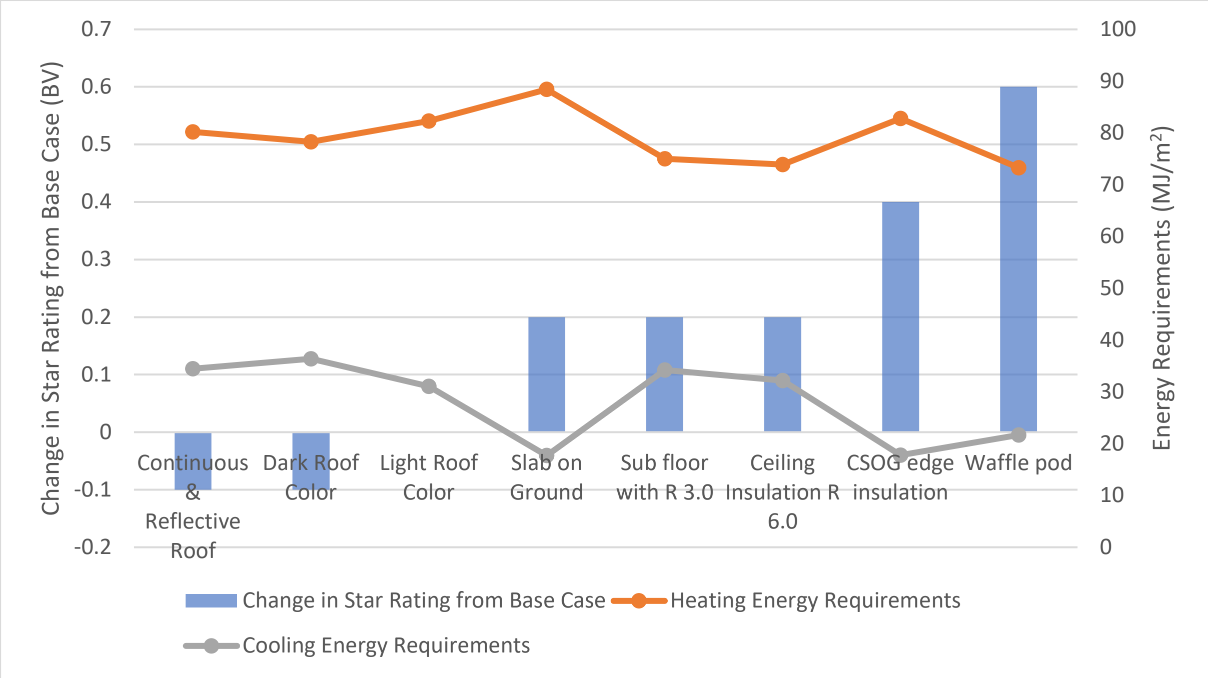


FIGURE 8: HIA HOUSE WITH SUB FLOOR - ADDITIONAL PARAMETRIC ASSESSMENT RESULTS FOR MELBOURNE

7 Star Recommendations

Based on the findings of the parametric studies a series of 7 star building envelopes have been developed based on selecting the most practical changes. For example, reverse brick veneer, 140mm studs or concrete slab edge insulation are relatively uncommon and bring about significant added costs and hence have been excluded from the assessment. The below table details the changes in building fabric from the base case in order to achieve a 7 Star Rating.

TABLE 11: PROPOSED 7 STAR SOLUTIONS FOR HIA STANDARD HOME

Star Rating	Heating Energy (Mj/m^2)	Cooling Energy (Mj/m^2)	Windows and Glazing	Wall System and Insulation	Ceiling Insulation	Floor Details
7.1	54.6	26.4	Double Glazed Argon Timber framed windows	Brick Veneer with R 2.7	R 4.0	R 3.0 Sub Floor
7.0	63.0	18.9	Double Glazed Air Filled Low-E UPVC	Brick Veneer with R 2.7 + Reflective Foil[3]	R 4.0	R 2.5 Sub Floor
7.0	53.7	28.5	Double Glazed Low-E Argon Aluminium framed windows	Brick Veneer with R 2.7 + Reflective Foil	R 5.0 with reflective roofspace	R 3.0 Sub Floor
7.0	53.5	28.2	Double Glazed Low-E Argon Aluminium framed windows	Brick Veneer with R 2.0 + Reflective Foil	R 6.0 with reflective roofspace	R 3.0 Sub Floor
7.0	66.7	16.1	Single Glazed Low-E timber framed windows	Brick Veneer with R 2.7	R 4.0	Waffle Pod Slab
7.2	61.8	15.8	Double Glazed Low-E thermally broken aluminium framed windows	Brick Veneer with R 2.25	R 4.0	Waffle Pod Slab
7.0	64.0	19.0	Double Glazed Aluminium Clear	Brick Veneer with R 2.7 + Reflective Foil	R 4.0	Waffle Pod Slab
7.1	67.3	13.3	Single Glazed Low-E UPVC windows	Brick Veneer with R 2.7	R 6.0	CSOG 100mm

As shown in Table 11 a combination of approaches is required in order to achieve 7 + NatHERS star rating without employing very high-performance glazing (which is relatively costly). Upgrading the wall insulation to higher performance batts, combined with better performing glazing and flooring allowed the standard HIA home to attain 7 stars. Reflective roof space and additional ceiling insulation also enabled the home to reach 7 Stars whilst utilising R 3.0 Sub Floor systems and high performance (but not thermally broken) aluminium windows. UPVC framed windows also enabled the HIA standard home to meet the 7 Star rating even with single glazing, when combined with high performing wall and ceiling insulation and a CSOG solution. The higher performance from the waffle pod system allowed for single glazed windows in addition to R 2.7 wall batts to also achieve 7 Stars whilst a sub floor with R 3.0 insulation required double

[3] Full details of the reflective air cavity is provided in the Appendix Section 8.2.2. and is based on CSR THERMOSEAL™ WALL WRAP XP product guidance document (CSR, 2015)

glazing and improved R 2.7 batts in the wall to achieve 7 Star rating. The most common CSOG construction method could also be combined with upgraded ceiling insulation (R 6.0) and upgraded wall insulation (R 2.7) with single glazed Low-E windows to also achieve 7 Stars. Whilst costing was beyond the scope of this report selections from Table 11 can be made based on the local construction and material costs to achieve the least cost solution that still achieves 7 Star Rating.

Best Performance Recommendations

A series of the most effective measures have been combined in order to ascertain the impact of upgrading multiple aspects of the home. These are presented in Table 12 and show that it is possible to achieve over 8 stars with either high performance or reverse brick veneer systems when combined with high performance glazing, edge insulation on the concrete slab and the inclusion of ceiling insulation of R 6.0. Timber framed windows further lifted the energy rating of these high-performance houses. It is worth noting that many of these systems are less likely to be employed due to high cost and a lack of market uptake and as such they represent what is possible rather than actual construction recommendations. Designs 5 through 7 represent a more achievable build utilising brick veneer and improved wall and ceiling insulation with all three floor types in assessment achieving 7.5 or more stars.

TABLE 12: HIGH PERFORMANCE COMBINATIONS FOR HIA STANDARD HOME IN MELBOURNE

	Wall Type	**Window**	**Floor**	**Ceiling insulation**	**Roof Colour**	**Energy rating**
Design 1	RBV	DGAr-Al-LE	CSOG + R 1.0 Edge insulation	R 6.0	Medium	**7.9**
Design 2	CLT	DGAr-Al-LE	CSOG + R 1.0 Edge insulation	R 6.0	Medium	**7.8**
Design 3	RBV	DGAr-Tb-LE	CSOG + R 1.0 Edge insulation	R 6.0	Medium	**8.2**
Design 4	CLT	DGAr-Tb-LE	CSOG + R 1.0 Edge insulation	R 6.0	Medium	**8.2**
Design 5	BV, R 2.7 + Reflective	DGAr-UPVC-LE	Sub Floor R 3.0	R 6.0 + Reflective roof	Medium	**7.5**
Design 6	BV, R 2.7 + Reflective	DGAr-UPVC-LE	Waffle Pod	R 6.0 + Reflective roof	Medium	**7.9**
Design 7	BV, R 2.7 + Reflective	DGAr-UPVC-LE	CSOG + R 1.0 Edge Insulation	R 6.0 + Reflective roof	Medium	**7.9**

***** RBV: Reverse brick veneer; CLT: Cross laminated timber.
*SG – Single glazed; DG- Double glazed; DGAr – Double glazed Argon filled; Al – Aluminium frame; Tb – Timber frame; CLR – Clear; LE – Low-E.

3.1.2. Lynvale Standard House

For the parametric assessments of the Lynvale home, the same set of windows is used for all cases, and several types of wall, floors ceiling insulation and ceiling type were investigated in Melbourne with a summary of all results presented in Table 13.

TABLE 13. RESULTS OF THE LYNVALE HOME'S PARAMETRIC ASSESSMENT AT MELBOURNE

	Model	Energy rating	Total Energy (MJ/m^2)	Heating Energy (MJ/m2)	Cooling Energy (MJ/m2)
Wall Type	**Standard BV (baseline)**	**6.3**	**103.5**	**81**	**22.5**
	BV (140mm)	6.7	92.7	72.9	19.8
	CLT	6.7	92.1	76.1	16
	LWDF	6.2	109	86	23
	HP-140LW	6.5	97	75.5	21.5
	RBV	6.8	89.2	76.8	12.4
	HP-LW	6.5	96.6	75	21.6
	FR5-AAC-75 (R2.0)	6.4	101.9	80.4	21.5
	FR5-AAC-75 (R2.7)	6.5	96.8	75.9	20.9
Ground Floor	**Waffle pod (baseline)**	**6.3**	**103.5**	**81**	**22.5**
	CSOG: Slab on Ground	5.9	114.7	95	19.7
	Sub floor with R 2.0	5.9	117.7	84.6	33.1
	Sub floor with R 3.0	5.9	115	81.5	33.5
	CSOG edge insulation	6.1	109.5	89.6	19.9
Orientations	**North (baseline)**	**6.3**	**103.5**	**81**	**22.5**
	South	6.2	108.8	89.6	19.2
	East	6.2	108.5	87.8	20.7
	West	6.2	109.1	87.1	22
Ceiling insulation	**R 4.0 (baseline)**	**6.3**	**103.5**	**81**	**22.5**
	R 6.0	6.4	98.5	76.9	21.6
Ceiling type	**Discontinuous (baseline)**	**6.3**	**103.5**	**81**	**22.5**
	Continuous Reflective	6.3	103.9	81.3	22.6
Roof Colour	Light	6.3	103.7	82.2	21.5
	Medium (baseline)	**6.3**	**103.5**	**81**	**22.5**
	Dark	6.3	103.4	79.7	23.7

Wall Type

The selection of wall build up and associated insulation in the wall cavity had a small effect on the overall star rating of the Lynvale home as depicted in Figure 9. Thermal mass improved the performance of the homes with reverse brick veneer leading to the greatest improvement of performance closely followed by CLT. Both of these walls performed well due to the thermal mass being located on the internal side of the insulation (see Figure 49 and Figure 53 for wall build up) thus reducing both peak cooling and heating loads on the home. Higher performance wall systems including both the 140mm and 180mm (double stud) solutions added small benefit when compared to the brick veneer wall system by increasing the energy rating by 0.2 Stars.

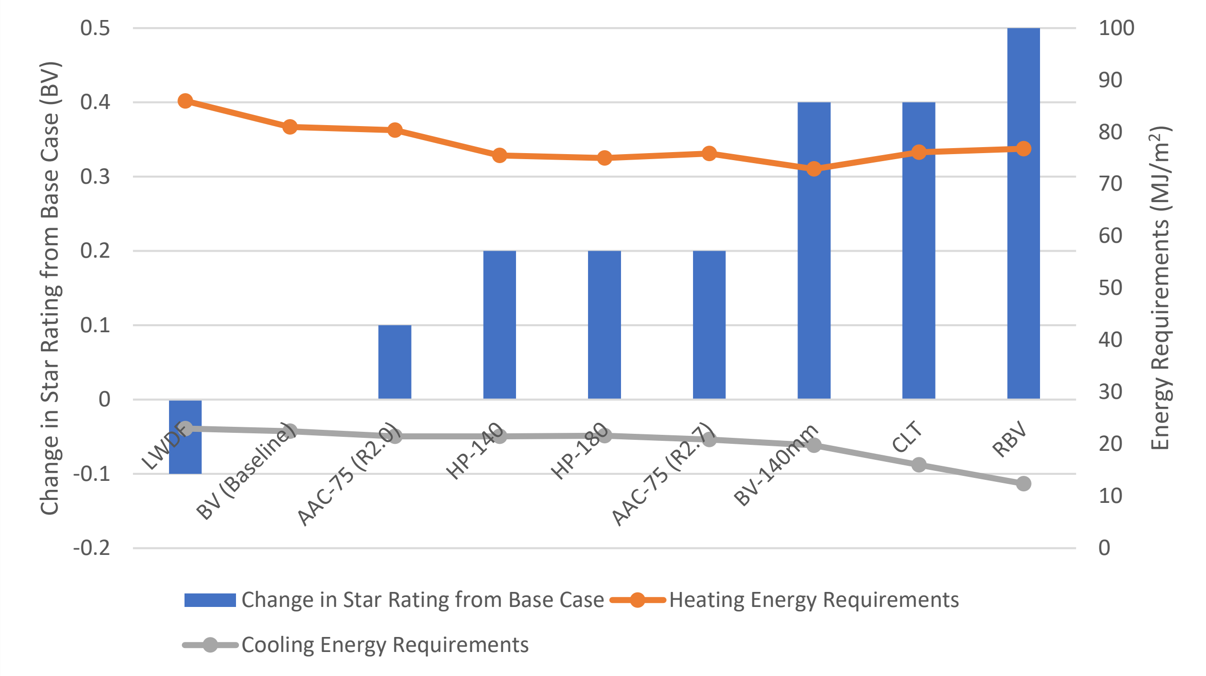


FIGURE 9: LYNVALE STANDARD HOME WALL TYPE ASSESSMENT RESULTS FOR MELBOURNE

Floor Type

A variety of floor types were also assessed to determine the impact on overall star rating, as well as annual heating and cooling requirements of the Lynvale home. As detailed in Figure 10, the use of a concrete slab on ground (CSOG) and CSOG edge insulation instead of the waffle pod resulted in a slight decrease of the cooling load but the heating demand increased. Overall, the energy rating decreased by 0.4 and 0.2 Stars for the CSOG and CSOG edge insulation, respectively demonstrating the benefits of the waffle pod slab in this assessment. A sub floor with R 2.0 and R 3.0 also performed poorer than the waffle pod slab performing on par with the CSOG.

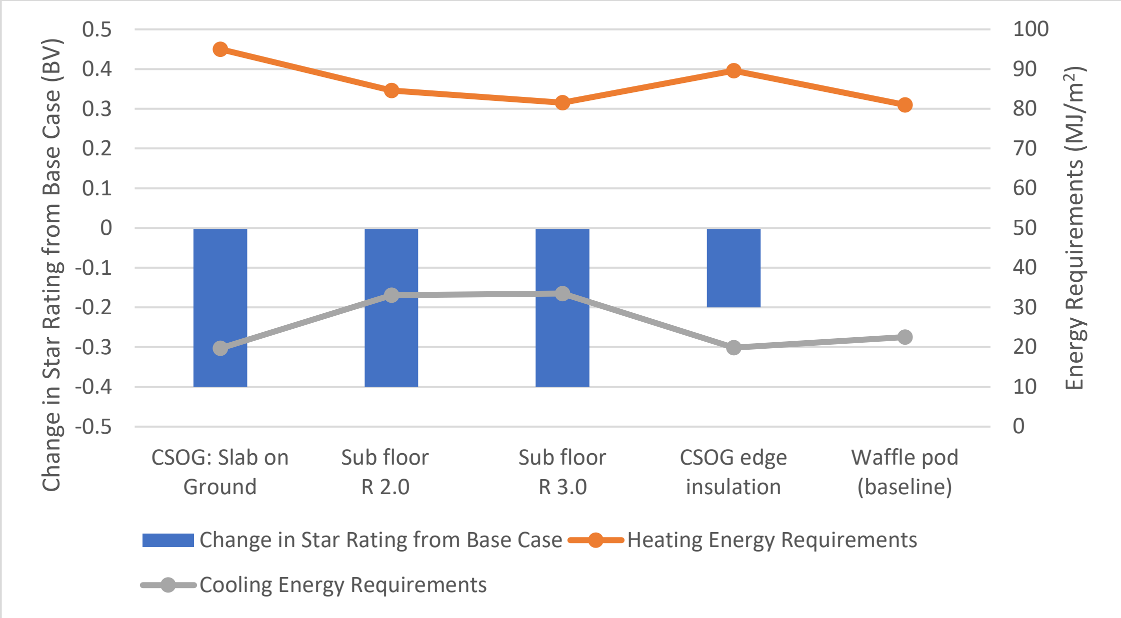


FIGURE 10: LYNVALE STANDARD HOME WALL TYPE ASSESSMENT RESULTS FOR MELBOURNE

Best Performance Recommendations

Based on the parametric assessments, the Lynvale home can achieve 6.9 stars when using RBV wall, waffle pod floor, R = 6 (m^2K/W) for ceiling insulation, and discontinuous ceiling type. The Lynvale home performed far below the HIA standard home and was unable to obtain 7 Star rating even with a variety of measures. It is surmised that this is the case due to a number of reasons. (1) The daytime living space is directly connected to the adjacent stairwell to upstairs, leading to significant heat losses in winter, (2) Due to a narrow lot the passive solar design is minimal with lesser solar heat gain in winter when compared to the HIA standard home, (3) With no eaves on the home solar heat gain in summer is more significant leading to larger cooling demand. A summary of the high-performance Lynvale homes is presented in Table 14.

TABLE 14: HIGH PERFORMANCE LYNVALE HOME COMBINATIONS

	Roof Colour	Roof Colour	Roof Insulation	Roof Colour	Star Rating
Design 1	RBV	Waffle pod	R 6.0	Medium	**6.9**
Design 2	CLT	Waffle pod	R 6.0	Medium	**6.7**
Design 3	RBV	CSOG edge insulation	R 6.0	Medium	**6.7**
Design 4	CLT	CSOG edge insulation	R 6.0	Medium	**6.7**

* RBV: Reverse brick veneer; CLT: Cross laminated timber.

3.2. Australia Wide Parametric Assessment

The second set of parametric studies comprised two new baseline houses both of which used the HIA standard floorplan. The first represented a common volume builder offering with minimum compliance and a CSOG. This home was simulated for a variety of locations and wall options as detailed in Table 15 below. The second offering utilised a higher performing HIA home with the aim of investigating the upper limits of performance for a variety of premium window offerings and common wall and flooring systems also detailed in Table 15.

TABLE 15: AUSTRALIA WIDE PARAMETRIC ASSESSMENT SUMMARY

Baseline House	Windows Options	Wall Options	Floor Options	Location(s)
"HIA house with Low-E windows and CSOG": • Window: SG-Al-LE • Walls: Brick Veneer • Ceiling: R 4.0 • Roof: Medium discontinuous • Floor: CSOG	Single Solution SG-AL-LE	• Brick Veneer • Light Weight Direct Fix • Light Weight Direct Fix 70mm (Brisbane only)	• Subfloor Timber with R 2.0 EPS insulation • Concrete Slab on Ground (CSOG) • Waffle Pod	• Melbourne • Sydney • Perth • Canberra • Hobart • Brisbane
"HIA house with double glazing and waffle pod": • Window: DGAr-Tb-LE • Walls: Brick Veneer • Ceiling: R 4.0 • Roof: Medium discontinuous • Floor: Waffle Pod	• SG-Al-CLR (Brisbane only) • SG-Al-LE • DG-Tb-CLR (Day Areas) • DG-Tb-CLR (All Areas) • DGAr-Al-LE (Day Areas) • DGAr-Al-LE-TB (Day Areas) • DGAr-Tb-LE-TB (Day Areas) • DGAr-Al-LE (All Areas) • DGAr-Tb-LE (All Areas) • DGAr-Al-LE-TB (All Areas)	• Brick Veneer • Light Weight Direct Fix • Light Weight Direct Fix 70mm (Brisbane only)	• Subfloor Timber with R 2.0 EPS insulation • Concrete Slab on Ground (CSOG) • Waffle Pod	• Melbourne • Sydney • Perth • Canberra • Hobart • Brisbane

3.2.1. HIA house with Low-E windows and CSOG

The HIA house with Low-E windows and CSOG was simulated for each major capital city in Australia, with a summary of the results presented Table 10 whilst detailed heating and cooling demand data is shown in Figure 11 through to Figure 16. The baseline model has achieved the highest energy rating at Brisbane, Sydney, and Perth. The use of the Waffle pod floor instead of the CSOG increases improvement by 0.3, 0.5, and 0.7 stars at Melbourne, Canberra, and Hobart respectively. A Subfloor with R 2.0 is comparable to CSOG in Melbourne and outperforms CSOG in Hobart, but it is less competitive in warmer climates such as Sydney, Brisbane and Perth. LWDF wall systems typically resulted in around 0.1-0.2 Star reduction in the NatHERS energy rating in all cities.

For the Melbourne HIA Standard home brick veneer slightly outperformed the LWDF wall system with a slightly increased overall R value of 0.12 from the bricks reducing the overall heating energy requirements. The Waffle pod system significantly reduced overall heating requirements leading to an improved 6.6 Star Rating. The sub floor with R 2.0 also reduced the heating energy demand but resulted in much larger cooling energy demands thus leading to a reduced star rating of 0.2 Stars compared with the CSOG as can be seen in Figure 11.

TABLE 16: HIA HOUSE WITH LOW-E WINDOWS AND CSOG IN MELBOURNE

	Model	Energy rating	Total Energy (MJ/m^2)	Heating Energy (MJ/m2)	Cooling Energy (MJ/m2)
Wall Type	***BV (baseline)***	***6.3***	***105.5***	***89.6***	***15.9***
	LWDF	6.1	109.4	92.3	17.1
Floor	Waffle pod	6.6	93.7	74.1	19.6
	CSOG: Slab on Ground	***6.3***	***105.5***	***89.6***	***15.9***
	Sub floor with R 2.0	6.1	110.1	78.7	31.4

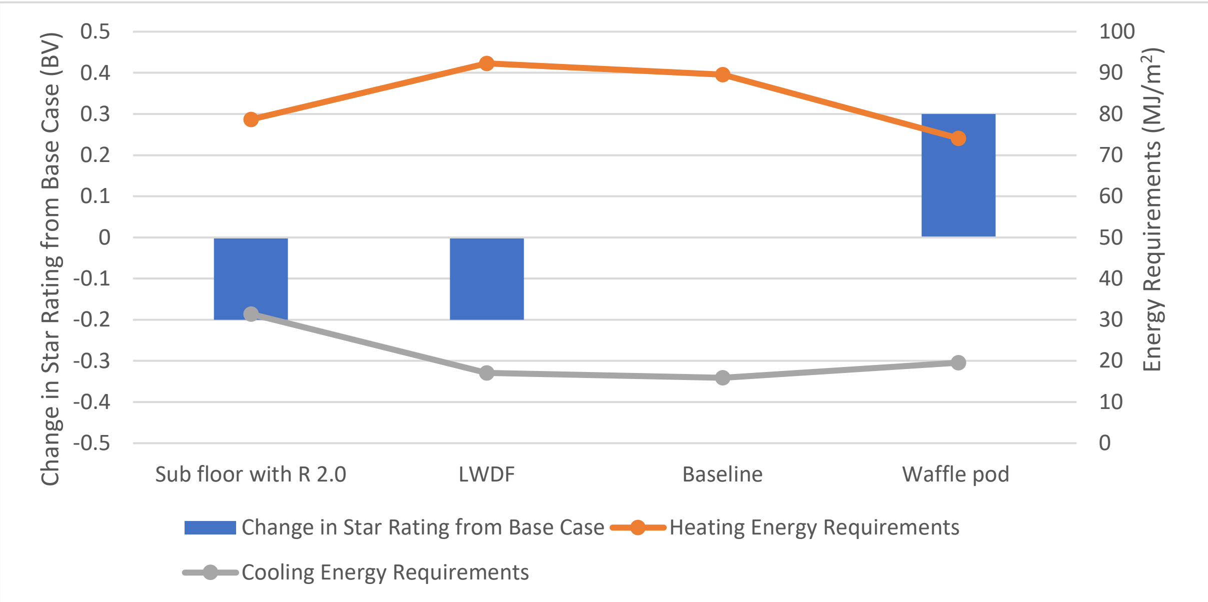


FIGURE 11: PARAMETRIC ASSESSMENT RESULTS OF THE HIA ECONOMICAL HOUSE IN MELBOURNE

The following findings were made for the HIA house with Low-E windows and CSOG in Brisbane:

- Brick veneer outperformed the LWDF wall system with the slightly increased wall R value reducing the overall cooling energy requirements (albeit slightly).
- The use of a waffle pod system resulted in a marginal decline in performance of 0.2 stars through a reduction in ground coupling and hence passive cooling.
- The sub floor with R 2.0 was one of the worst performers here reducing the Star Rating to 4.6 by effectively eliminating passive cooling through the floor, in fact removing the insulation from the sub floor actually improved the overall star rating of the home by 0.4 Stars as compared with R 2.0 insulated sub floor as seen in Figure 12.
- A narrower 70 mm LWDF system performed on par with the 90 mm LWDF light wall colour and is thus an appropriate option for warmer climates such as Brisbane.
- Single clear glazing resulted in a 0.5 Star reduction in the overall Star Rating of the home through an increase in solar heat gain with results shown in Table 16 and Figure 11.

TABLE 17: HIA HOUSE WITH LOW-E WINDOWS AND CSOG IN BRISBANE

	Model	Energy rating	Total Energy (MJ/m^2)	Heating Energy (MJ/m2)	Cooling Energy (MJ/m2)
Wall Type	**BV (baseline) (light)**	6.7	36.7	5.2	31.5
	LWDF (light)	6.4	38.2	6.0	32.2
	BV (light) 70mm	6.6	37.1	5.6	31.5
	LWDF (light) 70mm	6.4	39.0	6.6	32.4
Window	Single clear	6.2	41.4	6.4	35.0
	Single Low-E (baseline)	6.7	36.7	5.2	31.5
Floor	Waffle pod	6.5	38.0	4.2	33.8
	CSOG: Slab on Ground (Baseline)	6.7	36.7	5.2	31.5
	Sub floor with R 2.0	4.6	60	11.3	48.7
	Sub floor with R 2.0 Elevated (very open)	4.4	62.7	13.8	48.9

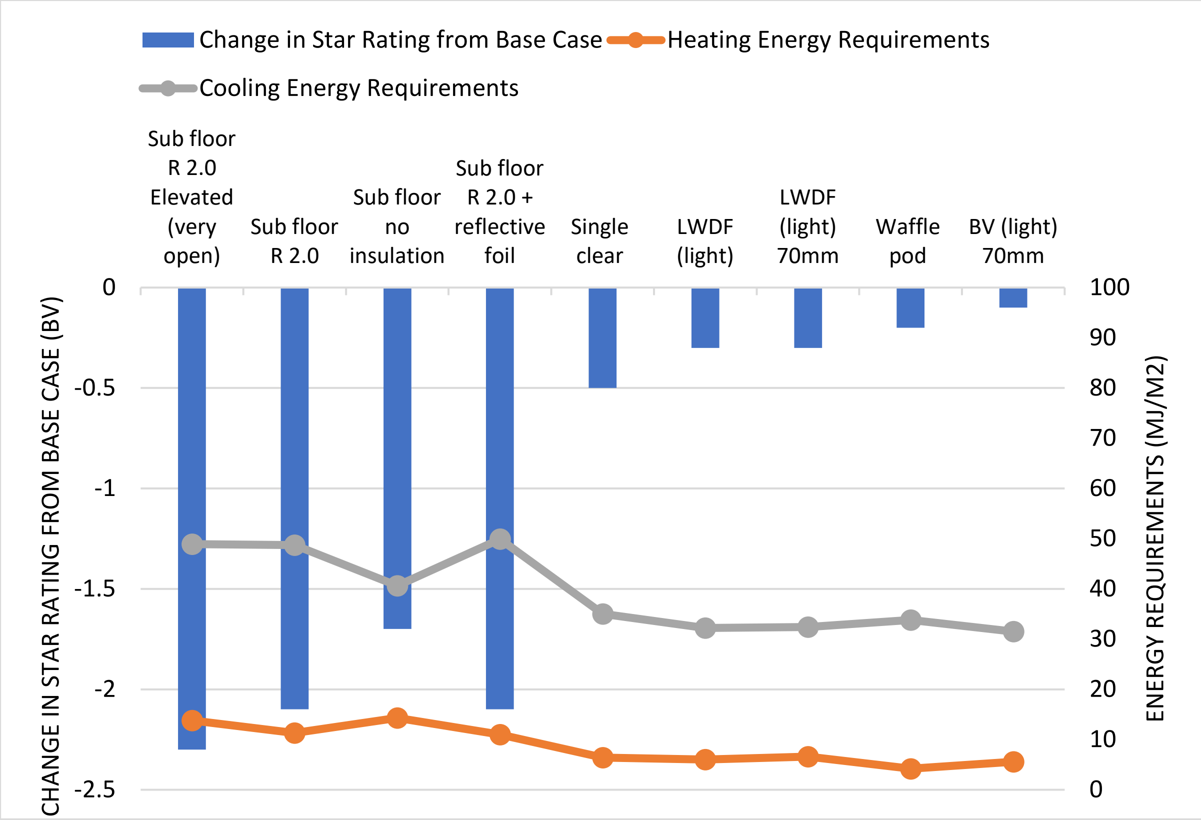


FIGURE 12: PARAMETRIC ASSESSMENT RESULTS OF THE HIA HOUSE WITH LOW-E WINDOWS AND CSOG IN BRISBANE

In order to perform well the Hobart HIA home needed to retain heat and maximise solar heat gain due to the nature of the predominantly heating climate. As such both sub-floors and waffle pod systems outperformed the CSOG flooring solution as they better decouple the house from the earth, thus reducing heat loss. There was very little difference between the LWDF and brick veneer homes here with both scoring around the 6.0 Star Rating.

TABLE 18: HIA HOUSE WITH LOW-E WINDOWS AND CSOG IN HOBART

	Model	NatHERS Energy rating	Total Energy (MJ/m²)	Heating Energy (MJ/m²)	Cooling Energy (MJ/m²)
Wall Type	***BV (baseline)***	6.0	153	150.9	2.1
	LWDF	5.9	158.1	155.6	2.5
Floor	Waffle pod	6.7	126.9	124.2	2.7
	CSOG: Slab on Ground	***6.0***	***153***	***150.9***	***2.1***
	Sub floor with R 2.0	6.7	125.6	121	4.6

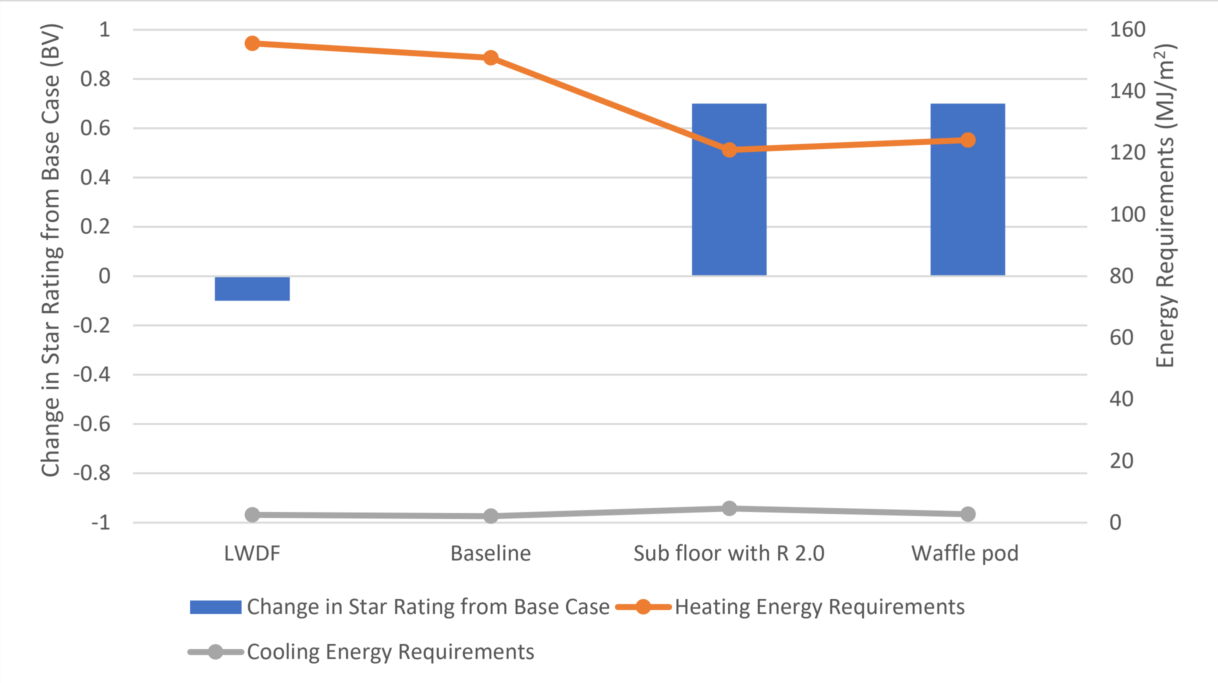


FIGURE 13: PARAMETRIC ASSESSMENT RESULTS OF THE HIA HOUSE WITH LOW-E WINDOWS AND CSOG IN HOBART

With Sydney positioned in a warm temperate (climate zone 5) the HIA home performed well across most inputs, with the baseline home scoring a 7-star rating. Notably the sub floor performed poorer than both the CSOG and Waffle Pod systems with significantly larger cooling loads required for this case.

TABLE 19: HIA HOUSE WITH LOW-E WINDOWS AND CSOG IN SYDNEY

	Model	Energy rating	Total Energy (MJ/m^2)	Heating Energy (MJ/m^2)	Cooling Energy (MJ/m^2)
Wall Type	***BV (baseline)***	***7.0***	***30***	***8.9***	***21.1***
	LWDF	6.8	32.4	10.1	22.3
Floor	Waffle pod	6.9	30.3	6.9	23.4
	CSOG: Slab on Ground	***7.0***	***30***	***8.9***	***21.1***
	Sub floor with R 2.0	5.2	48.2	13.2	35

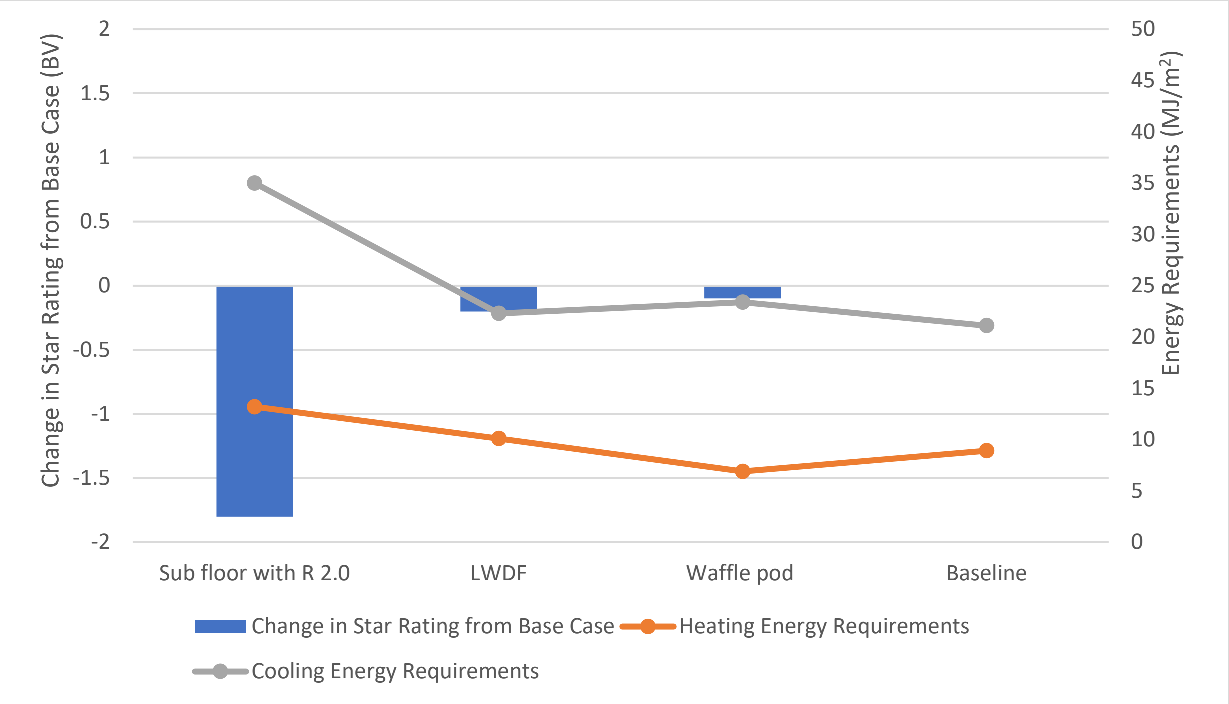


FIGURE 14: PARAMETRIC ASSESSMENT RESULTS OF THE HIA HOUSE WITH LOW-E WINDOWS AND CSOG IN SYDNEY

With Perth also positioned in a warm temperate (climate zone 5) and with a larger cooling load of approximately double that of Sydney the Star ratings were less than 7.0. Again, a similar trend was evident with the sub floor performing poorer than both the CSOG and Waffle Pod systems with significantly larger cooling loads required for this case.

TABLE 20: HIA HOUSE WITH LOW-E WINDOWS AND CSOG IN PERTH

	Model	Energy rating	Total Energy (MJ/m^2)	Heating Energy (MJ/m^2)	Cooling Energy (MJ/m^2)
Wall Type	***BV (baseline)***	***6.7***	***57.9***	***18.5***	***39.4***
	LWDF	6.4	63.3	20.7	42.6
Floor	Waffle pod	6.7	57.2	14.4	42.8
	CSOG: Slab on Ground	***6.7***	***57.9***	***18.5***	***39.4***
	Sub floor with R 2.0	4.8	93.3	25.5	67.8

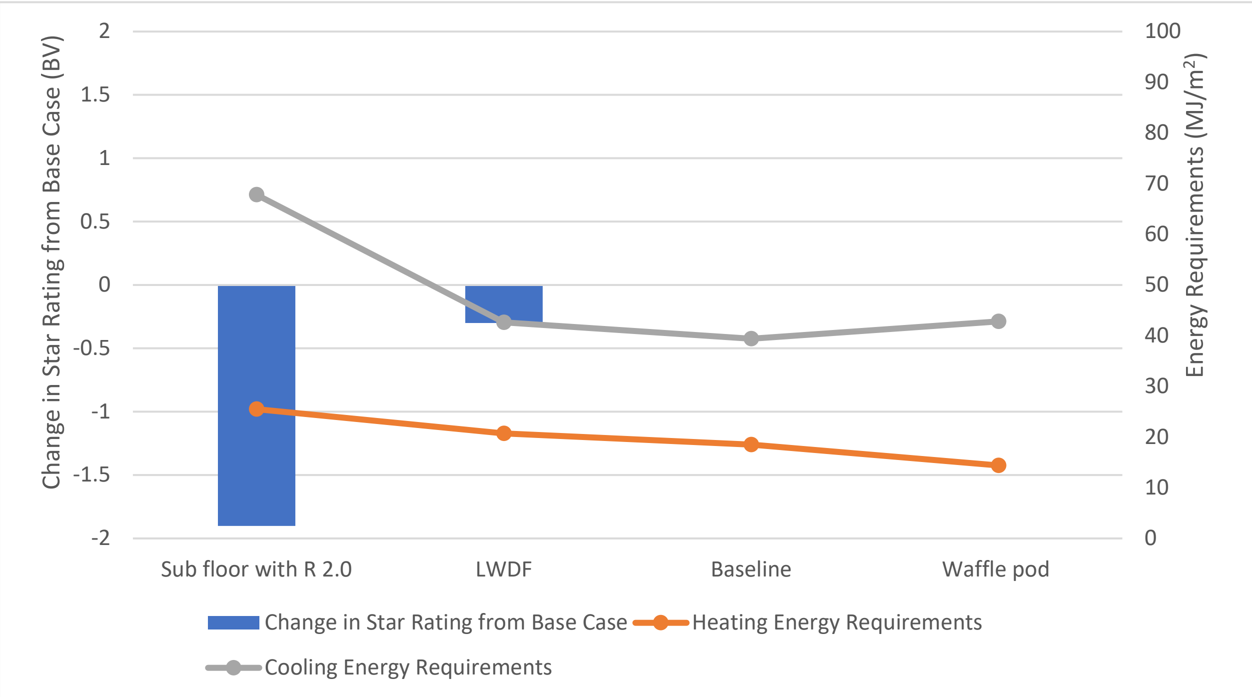


FIGURE 15: PARAMETRIC ASSESSMENT RESULTS OF THE HIA HOUSE WITH LOW-E WINDOWS AND CSOG IN PERTH

Canberra is positioned in a cool temperate climate (Climate zone 7) and as such required approximately four times the heating as cooling energy. As such both the sub floor and waffle pod performed better than the CSOG, although there was marginal benefit from the sub floor solution due to the increased cooling energy requirements.

TABLE 21: HIA HOUSE WITH LOW-E WINDOWS AND CSOG IN CANBERRA

	Model	Energy rating	Total Energy (MJ/m^2)	Heating Energy (MJ/m^2)	Cooling Energy (MJ/m^2)
Wall Type	***BV (baseline)***	***6.2***	***156.7***	***142.6***	***14.1***
	LWDF	6.0	163.9	148.4	15.5
Floor	Waffle pod	6.7	135.2	118	17.2
	CSOG: Slab on Ground	***6.2***	***156.7***	***142.6***	***14.1***
	Sub floor with R 2.0	6.3	151.3	119.4	31.9

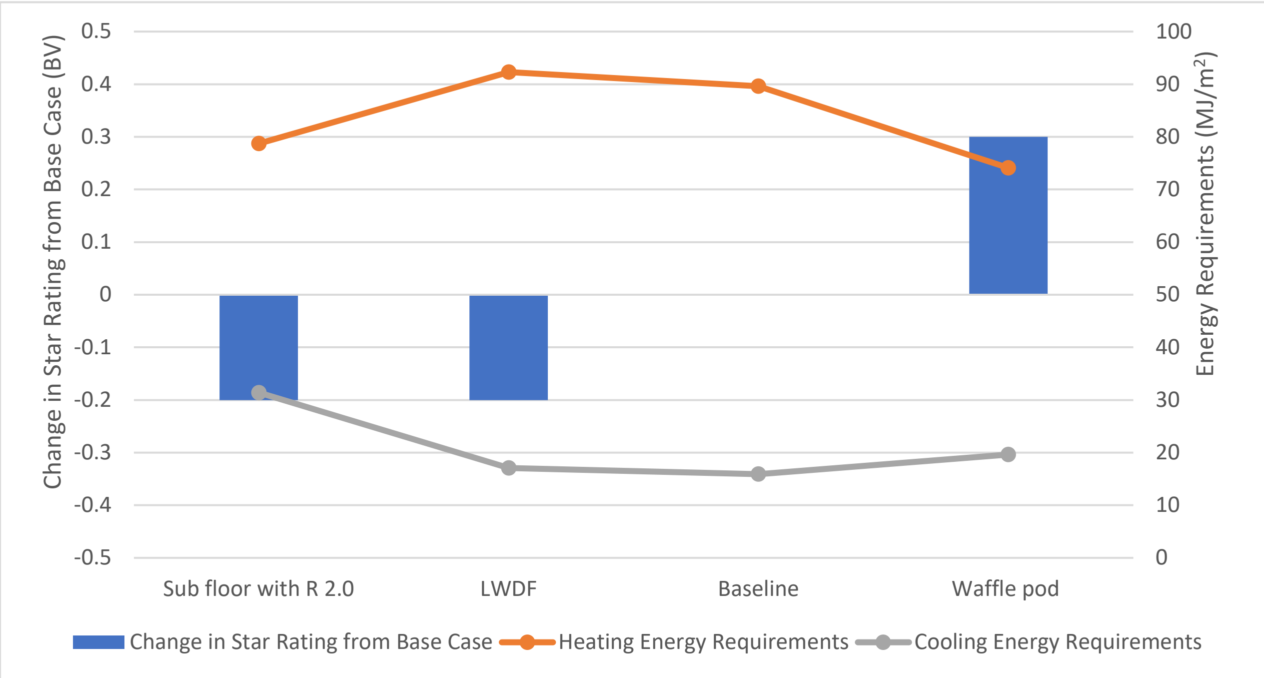


FIGURE 16: PARAMETRIC ASSESSMENT RESULTS OF THE HIA HOUSE WITH LOW-E WINDOWS AND CSOG IN CANBERRA

3.2.2. HIA house with double glazing and waffle pod

The HIA house with double glazing and waffle pod was simulated for each major city with the results summarised in Figure 17 through Figure 22. The baseline model has achieved the highest energy rating in Melbourne, Brisbane, Sydney, Perth, and Canberra. The subfloor with R 2.0 outperforms the Waffle pod flooring solution in Hobart where it has the highest energy rating but performed poorer in warmer climates such as Sydney, Brisbane and Perth. The use of double glazing improves the energy rating at least from 0.3 – 0.5 Stars compare to single Low-E glazing.

When situated in the mild temperate climate of Melbourne (Climate zone 6) the high performance HIA home was able to achieve 7 stars for all parametric assessments excluding the single glazed Low-E solution. This was largely a result of the double-glazing solutions providing significant benefits for both heat gain and loss. With the predominantly heating climate the Waffle Pod flooring system outperformed the CSOG and the Sub Floor System. It is also evident that the timber framed windows performed best when compared to aluminium framed counterparts due to their relative thermal resistance. Further implications of window selection on different zones within the home will be discussed in Section 4 of this report.

TABLE 22: HIA HOUSE WITH DOUBLE GLAZING AND WAFFLE POD IN MELBOURNE

	Model	Energy rating	Total Energy (MJ/m²)	Heating Energy (MJ/m²)	Cooling Energy (MJ/m²)
Wall Type	***BV (baseline)***	***7.5***	***67.2***	***58.5***	***8.7***
	LWDF	7.4	70.4	60.6	9.8
Window Type	Single Low-E	6.6	93.7	74.1	19.6
	Double clear timber (Day +Living)	7.1	79.2	63.3	15.9
	Double clear timber (All room)	7.3	74.1	59.4	14.7
	Double argon Low-E (Day -AL)	7.1	80.8	62.7	18.1
	Double argon Low-E (Day -AL TB)	7.2	77.9	61.2	16.7
	Double argon Low-E (Day -Timber)	7.3	75.5	62.8	12.7
	Double argon Low-E (All -AL)	7.2	76.5	58.4	18.1
	Double argon Low-E (All-AL TB)	7.4	68.2	52.2	16
	Double argon Low-E (All -Timber)	***7.5***	***67.2***	***58.5***	***8.7***
Floor	**Waffle pod (baseline)**	**7.5**	**67.2**	**58.5**	**8.7**
	CSOG: Slab on Ground	7.3	74.4	64.3	10.1
	Sub floor with R 2.0	7.1	80.2	60.9	19.3

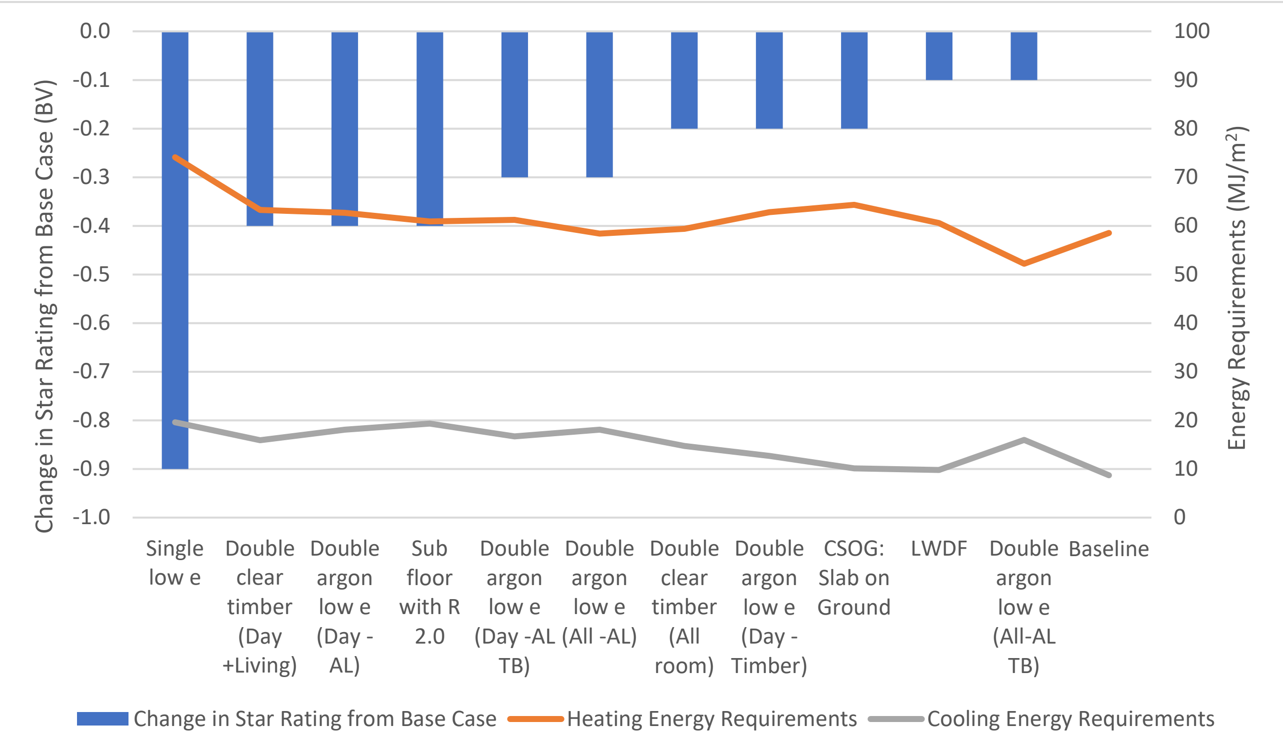


FIGURE 17: PARAMETRIC ASSESSMENT RESULTS OF THE HIA HOUSE WITH DOUBLE GLAZING AND WAFFLE POD IN MELBOURNE

Brisbane, with a warm humid summer and mild winter (Climate zone 2) performed very well, especially with timber framed glazing, exceeding the 8.4 Star Rating. Again, the trend of sub-floors performing poorer in hotter climates was evident, as was the propensity for single clear glazing to degrade performance (by over two stars compared to the base case). Thinner 70 mm wall sections did have a very minor performance hit of 0.1 Stars relative to the 90mm LWDF system again confirming their applicability to this climate zone.

TABLE 23: HIA HOUSE WITH DOUBLE GLAZING AND WAFFLE POD IN BRISBANE

	Model	Energy rating	Total Energy (MJ/m^2)	Heating Energy (MJ/m^2)	Cooling Energy (MJ/m^2)
Wall Type	***BV (baseline)***	***8.4***	***21.4***	***2.5***	***18.9***
	LWDF 90mm	8.3	22.6	3.1	19.5
	LWDF 70mm	8.2	23.6	3.6	20
Window	Single clear	6.3	39.9	5.3	34.6
	Single Low-E	6.8	35.4	4.2	31.2
	Double clear timber (Day +Living)	7.3	31.8	3.3	28.5
	Double clear timber (All room)	7.6	29.1	2.8	26.3
	Double argon Low-E (Day -AL)	7.1	33.4	3	30.4
	Double argon Low-E (Day -AL TB)	7.2	32	3	29
	Double argon Low-E (Day -Timber)	7.8	27	3	24
	Double argon Low-E (All -AL)	7.2	32.6	2.5	30.1
	Double argon Low-E (All-AL TB)	7.4	30.2	2.1	28.1
	Double argon Low-E (All -Timber) (baseline)	***8.4***	***21.4***	***2.5***	***18.9***
Floor	***Waffle pod (baseline)***	***8.4***	***21.4***	***2.5***	***18.9***
	CSOG: Slab on Ground	7.9	25.7	2	23.7
	Sub floor with R 2.0	6.7	36.1	7.3	28.8

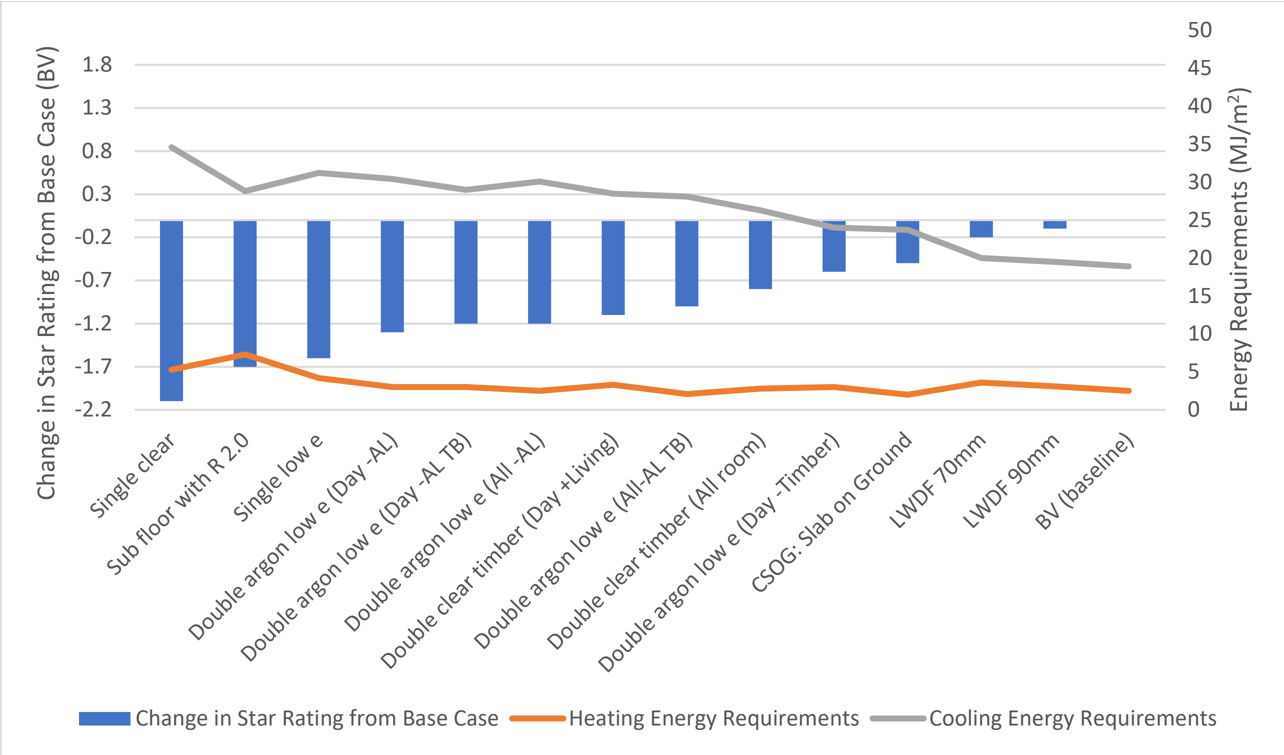


Figure 18: Parametric Assessment Results of the HIA house with double glazing and waffle pod in Brisbane

Hobart, with a cool temperate climate (Climate zone 7) performed best with the Sub Floor system due to its ability to retain heat and de-couple from the ground. The full details of the parametric results are presented in Table 24 below.

TABLE 24: HIA HOUSE WITH DOUBLE GLAZING AND WAFFLE POD IN HOBART

	Model	Energy rating	Total Energy (MJ/m²)	Heating Energy (MJ/m²)	Cooling Energy (MJ/m²)
Wall Type	***BV (baseline)***	***7.3***	***98.5***	***97.5***	***1.0***
	LWDF	7.3	102.4	101.3	1.1
Window Type	Single Low-E	6.7	125.3	122.6	2.7
	Double clear timber (Day +Living)	7.1	109.3	107.1	2.2
	Double clear timber (All room)	7.3	102.4	100.7	1.7
	Double argon Low-E (Day -AL)	7.1	108.3	105.9	2.4
	Double argon Low-E (Day -AL TB)	7.2	106.5	104.3	2.2
	Double argon Low-E (Day -Timber)	7.1	106.9	105.2	1.7
	Double argon Low-E (All -AL)	7.3	101.3	98.9	2.4
	Double argon Low-E (All-AL TB)	7.4	92.4	90.4	2
	Double argon Low-E (All -Timber)	***7.3***	***98.5***	***97.5***	***1.0***
Floor	**Waffle pod (baseline)**	***7.3***	***98.5***	***97.5***	***1.0***
	CSOG: Slab on Ground	7.0	113	111.9	1.1
	Sub floor with R 2.0	7.4	96.1	93.7	2.4

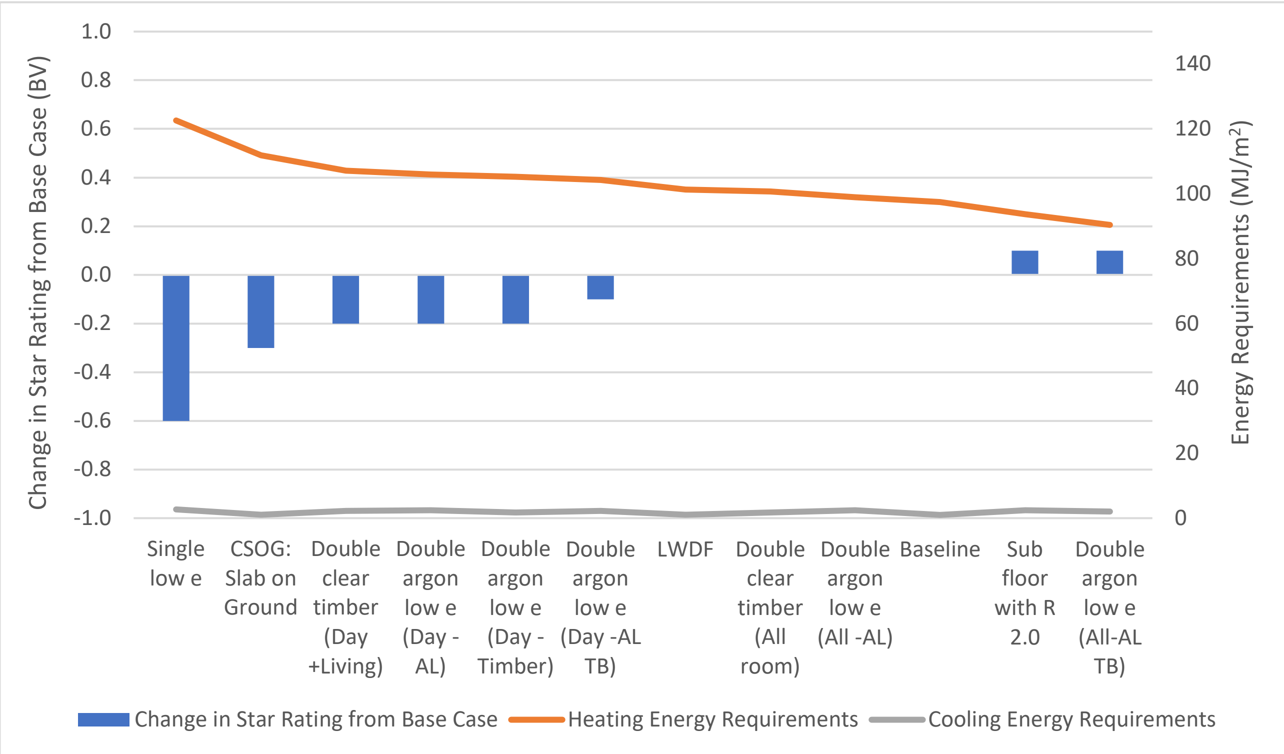


FIGURE 19: PARAMETRIC ASSESSMENT RESULTS OF THE HIA HOUSE WITH DOUBLE GLAZING AND WAFFLE POD IN HOBART

The Sydney HIA house with double glazing and waffle pod home exceeded eight stars for the base case and followed a similar trend to other homes with a mix of heating and cooling requirements, that is waffle pods performing the strongest out of the three flowing systems. High performing windows added approximately 1.5 stars to the home with single glazed Low-E glazing achieving 6.9 Stars.

TABLE 25: HIA HOUSE WITH DOUBLE GLAZING AND WAFFLE POD IN SYDNEY

Model		Energy rating	Total Energy (MJ/m²)	Heating Energy (MJ/m²)	Cooling Energy (MJ/m²)
Wall Type	***BV (baseline)***	***8.4***	***17.3***	***4.3***	***13.0***
	LWDF	8.2	20.3	4.7	15.6
Window Type	Single Low-E	6.9	30.1	7.2	22.9
	Double clear timber (Day +Living)	7.6	25.6	5.5	20.1
	Double clear timber (All room)	7.8	23.4	4.8	18.6
	Double argon Low-E (Day -AL)	7.4	26.6	5.2	21.4
	Double argon Low-E (Day -AL TB)	7.5	25.7	5.1	20.6
	Double argon Low-E (Day -Timber)	7.9	22.5	5.1	17.4
	Double argon Low-E (All -AL)	7.5	25.8	4.4	21.4
	Double argon Low-E (All-AL TB)	7.8	23.6	3.6	20
	Double argon Low-E (All -Timber)	***8.4***	***17.3***	***4.3***	***13.0***
Floor	**Waffle pod (baseline)**	***8.4***	***17.3***	***4.3***	***13.0***
	CSOG: Slab on Ground	8.2	20.2	4.1	16.1
	Sub floor with R 2.0	6.9	30.3	9.5	20.8

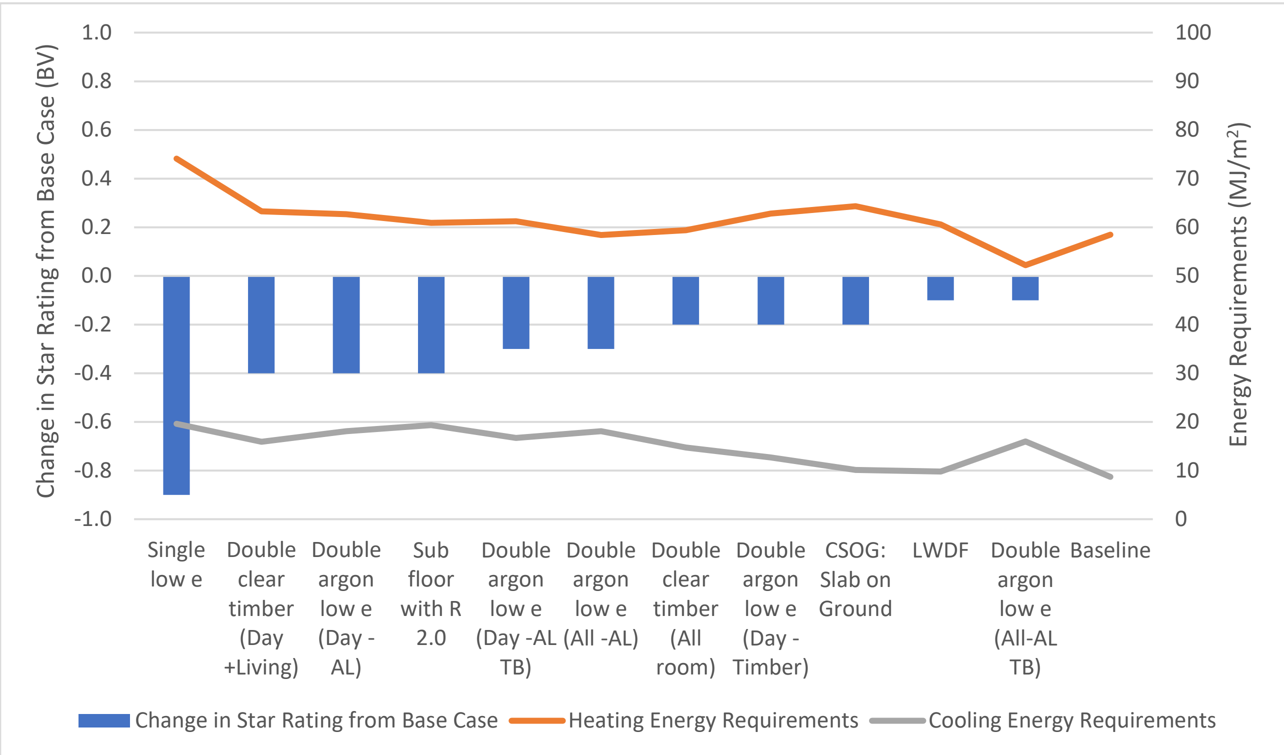


FIGURE 20: PARAMETRIC ASSESSMENT RESULTS OF THE HIA HOUSE WITH DOUBLE GLAZING AND WAFFLE POD IN SYDNEY

The Perth home exhibited similar trends to the Sydney home however exhibited a much higher cooling load. Again, the HIA home exceeded eight stars for the base case and followed a similar trend to other homes with a mix of heating and cooling requirements, that is waffle pods performing the strongest out of the three flowing systems. High performing windows added approximately 1.5 stars to the home with single glazed Low-E glazing achieving 6.7 Stars.

TABLE 26: HIA HOUSE WITH DOUBLE GLAZING AND WAFFLE POD IN PERTH

	Model	Energy rating	Total Energy (MJ/m^2)	Heating Energy (MJ/m2)	Cooling Energy (MJ/m2)
Wall Type	***BV (baseline)***	***8.2***	***30.9***	***9.8***	***21.1***
	LWDF	7.9	34.9	11.3	23.6
Window Type	Single Low-E	6.7	57	14.9	42.1
	Double clear timber (Day +Living)	7.3	46.5	11.8	34.7
	Double clear timber (All room)	7.6	42.9	10.7	32.2
	Double argon Low-E (Day -AL)	7.1	50	11.3	38.7
	Double argon Low-E (Day -AL TB)	7.3	46.8	11.1	35.7
	Double argon Low-E (Day -Timber)	7.7	39.1	11.1	28
	Double argon Low-E (All -AL)	7.2	48.8	10	38.8
	Double argon Low-E (All-AL TB)	7.5	43.4	8.5	34.9
	Double argon Low-E (All -Timber)	***8.2***	***30.9***	***9.8***	***21.1***
Floor	**Waffle pod (baseline)**	***8.2***	***30.9***	***9.8***	***21.1***
	CSOG: Slab on Ground	7.9	36.8	9.9	26.9
	Sub floor with R 2.0	6.4	61.2	18.8	42.4

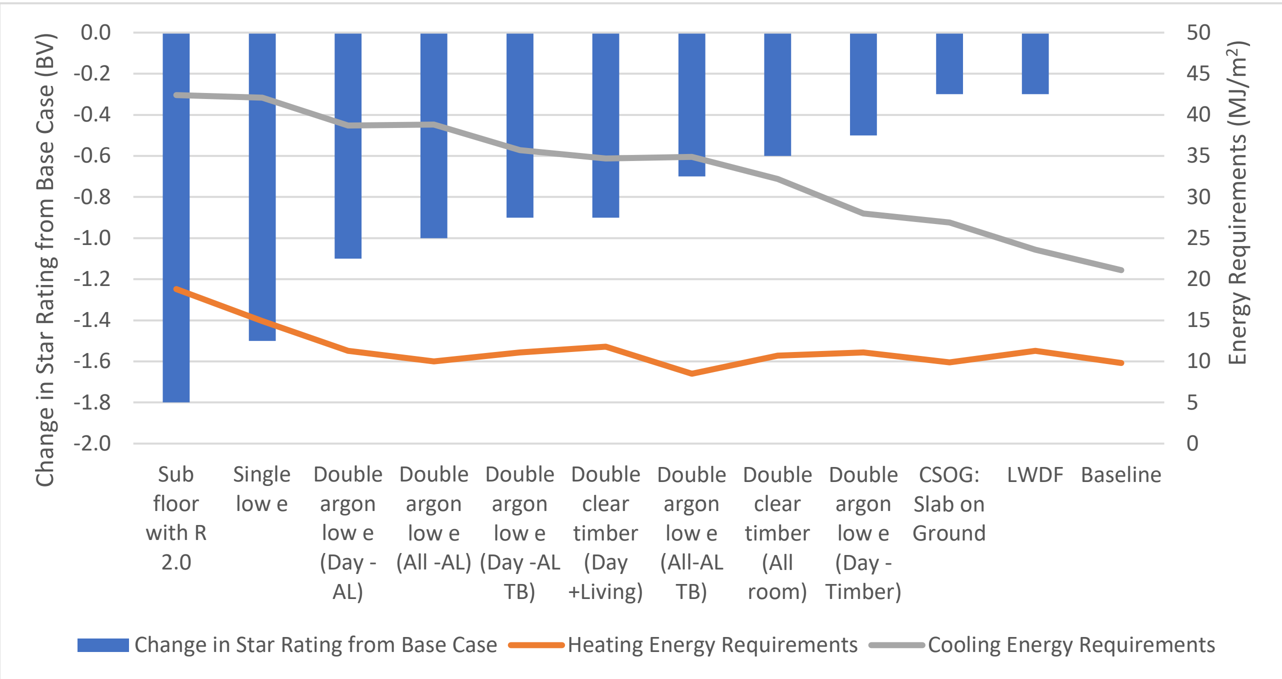


FIGURE 21: PARAMETRIC PARAMETRIC ASSESSMENT RESULTS OF THE HIA HOUSE WITH DOUBLE GLAZING AND WAFFLE POD IN PERTH

The Canberra home exhibited similar trends to both the Sydney and Perth home however exhibited a much higher heating load. Due to this HIA home only managed to achieve 7.4 Stars High performing windows added approximately 0.8 stars to the home with single glazed Low-E glazing achieving 6.6 Stars. The sub floor system performed on par with the CSOG floor but fell short of the Waffle pod by 0.3 Stars.

TABLE 27: HIA HOUSE WITH DOUBLE GLAZING AND WAFFLE POD IN CANBERRA

	Model	Energy rating	Total Energy (MJ/m²)	Heating Energy (MJ/m2)	Cooling Energy (MJ/m2)
Wall Type	***BV (baseline)***	***7.4***	***104.5***	***97.5***	***7.0***
	LWDF	7.3	109.1	101.1	8
Window Type	Single Low-E	6.6	136.7	119.9	16.8
	Double clear timber (Day +Living)	7.0	119.3	105.6	13.7
	Double clear timber (All room)	7.2	111	99	12
	Double argon Low-E (Day -AL)	7.0	119.6	104.4	15.2
	Double argon Low-E (Day -AL TB)	7.1	117	103	14
	Double argon Low-E (Day -Timber)	7.1	116.8	105.4	11.4
	Double argon Low-E (All -AL)	7.2	112	96.7	15.3
	Double argon Low-E (All-AL TB)	7.4	102.3	89	13.3
	Double argon Low-E (All -Timber)	***7.4***	***104.5***	***97.5***	***7.0***
Floor	**Waffle pod (baseline)**	***7.4***	***104.5***	***97.5***	***7.0***
	CSOG: Slab on Ground	7.1	117.6	109.6	8
	Sub floor with R 2.0	7.1	113.8	96.1	17.7

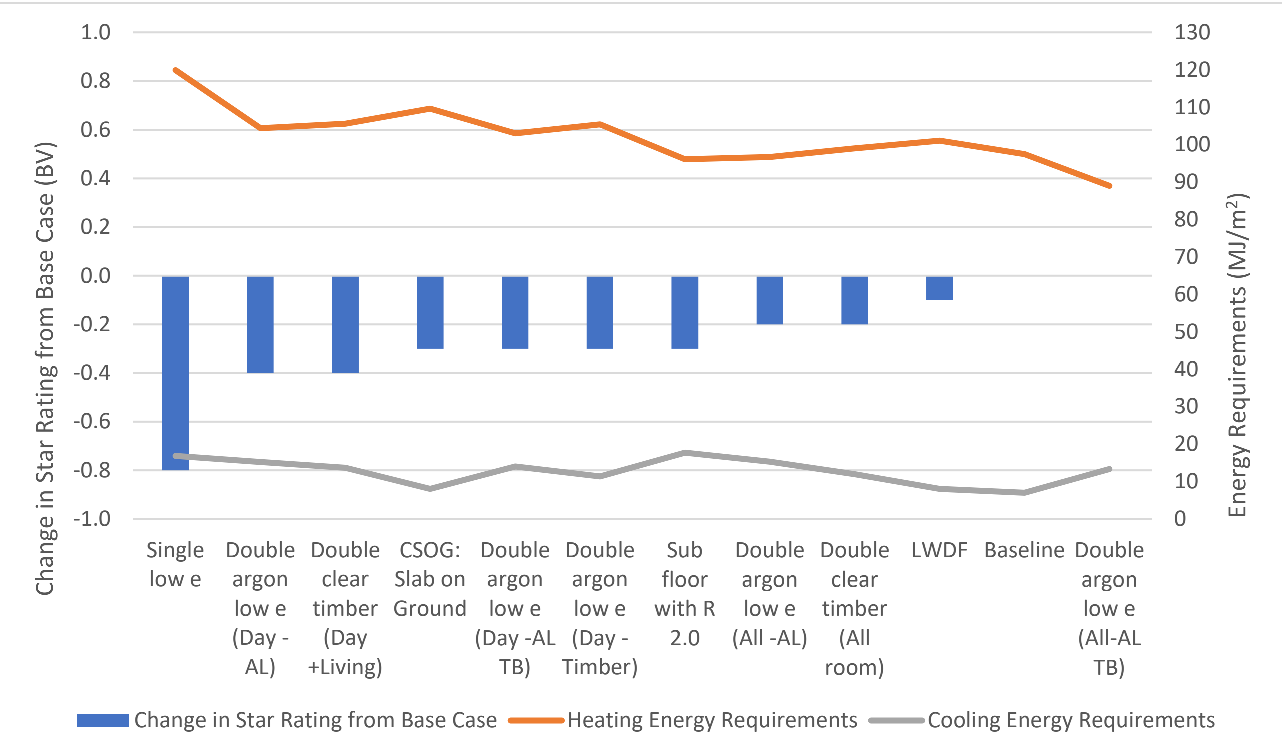


FIGURE 22: PARAMETRIC ASSESSMENT RESULTS OF THE HIA HOUSE WITH DOUBLE GLAZING AND WAFFLE POD IN CANBERRA

4. Discussion

4.1. House plan and passive design

Two different home plans were assessed, the HIA standard home and the 'Lynvale' home. The HIA home consistently performed better than the Lynvale home regardless of the selected building envelope and materials. This is particularly apparent with higher performing variants of each home where the HIA home achieved 7 Stars when utilising a variety of building envelope upgrades as detailed in Table 11 whereas the Lynvale home required more significant building envelope upgrades to achieve the 6.9 Star Rating. The key driving factors behind this discrepancy are believed to include:

- Better passive design in the HIA standard home, specifically greater solar aspect and solar heat gain to the living and day use spaces with the use of larger windows
- The upstairs section of the Lynbrook home is directly connected to the day use spaces leading to large heat losses up the stairs.

The inclusion of eaves on the home were also anticipated to have a positive influence on the energy performance in Melbourne with this flagged as a possible reason the Lynvale home did not perform as well as the HIA standard home. This however was found not to be the case as can be seen in below where removal of the eaves from the HIA standard home had no impact on the overall star rating in Melbourne. This assessment was performed for all other major cities (excluding Hobart) to ascertain the impact eaves had on the performance of the HIA home. The change in star rating in Figure 23 represents the difference the removal of eaves had on the overall performance of the home. As can be seen Figure 23 regions with greater cooling requirements such as Brisbane and Sydney benefited the most from the inclusion of eaves whilst Melbourne and Canberra had no clear benefit. The provision of either a CSOG or timber sub floor did not have a clear impact on the relative performance of eaves, with eaves delivering a greater benefit for the CSOG in Brisbane but a greater benefit for the timber sub floor in Sydney.

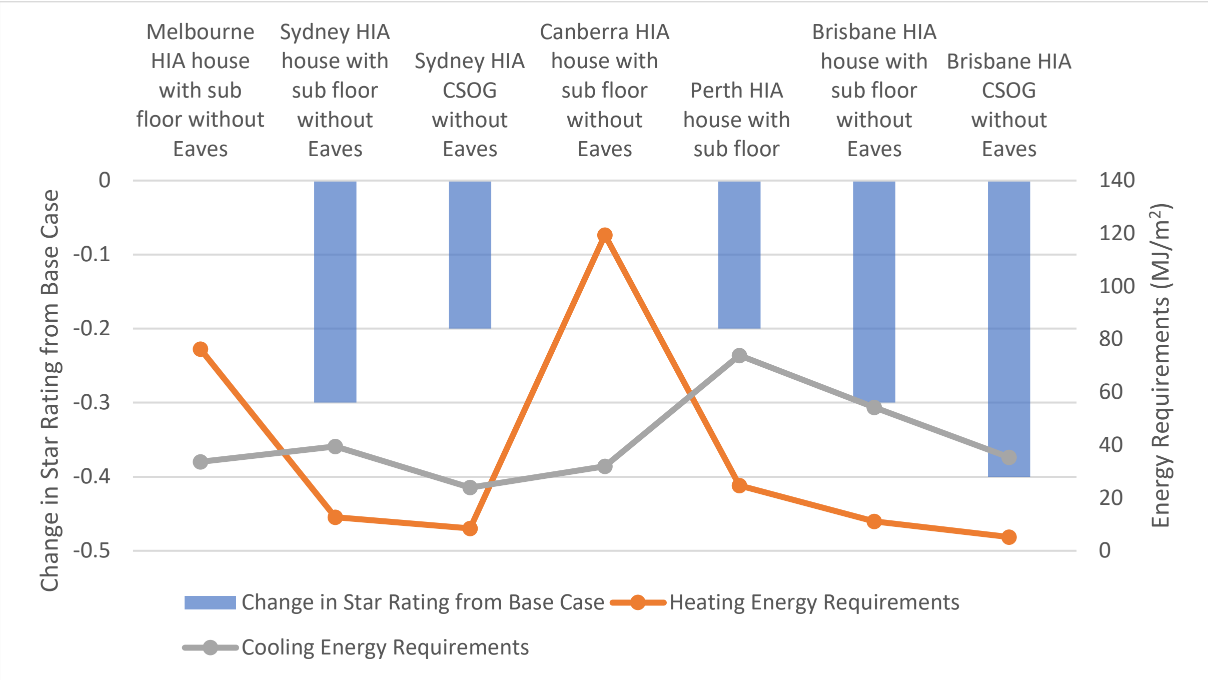


FIGURE 23: IMPACT OF EAVES ON HOME PERFORMANCE FOR THE HIA HOUSE WITH SUB FLOOR

4.2. The Importance of Window Selection

It is evident that the most influential aspect of performance on each home was the selection of windows. This held true for both heating and cooling climates and both high and low performance baseline homes. Figure 24 shows the impact of improved glazing performance, with clear double-glazing increasing performance by 0.5 Stars when just installed in the day and living spaces (when compared to low-E). There was only marginal benefit from fitting all rooms with double glazing with the Star rating increasing from 7.1 to 7.3. Timber framed windows also show around 0.2 Stars of benefit when compared to Aluminium framed windows. From a performance perspective both UPVC and timber framed windows have very similar performance with both timber and UPVC having relatively low conductivity. Therefore the performance of timber framed glazing in this report are interchangeable with UPVC framed glazing. To facilitate a basic cost benefit assessment for glazing, The Australian Glass and Window Association has provided representative average costs for a variety of glazing systems as detailed in Table 28 below.

TABLE 28: COSTING FOR WINDOWS AND GLAZING[iv,]

Window Description	Approximate Cost ($/m^2)
Single clear	$250
Single Low-E Aluminium	$280
Single Low-E PVC	$360
Double Clear Timber	$1,000
Double Clear Aluminium	$450
Double Clear PVC	$380
Double Argon Low-E Aluminium	$450
Double Argon Low-E PVC	$400
Double Argon Low-E (Aluminium with Thermal Break)	$600
Double Argon Low-E timber	$1,150

[iv] These costs are to be used as a guide only and will vary based on location and specific window designs as provided by the Australian Glass and Window Association 2021.

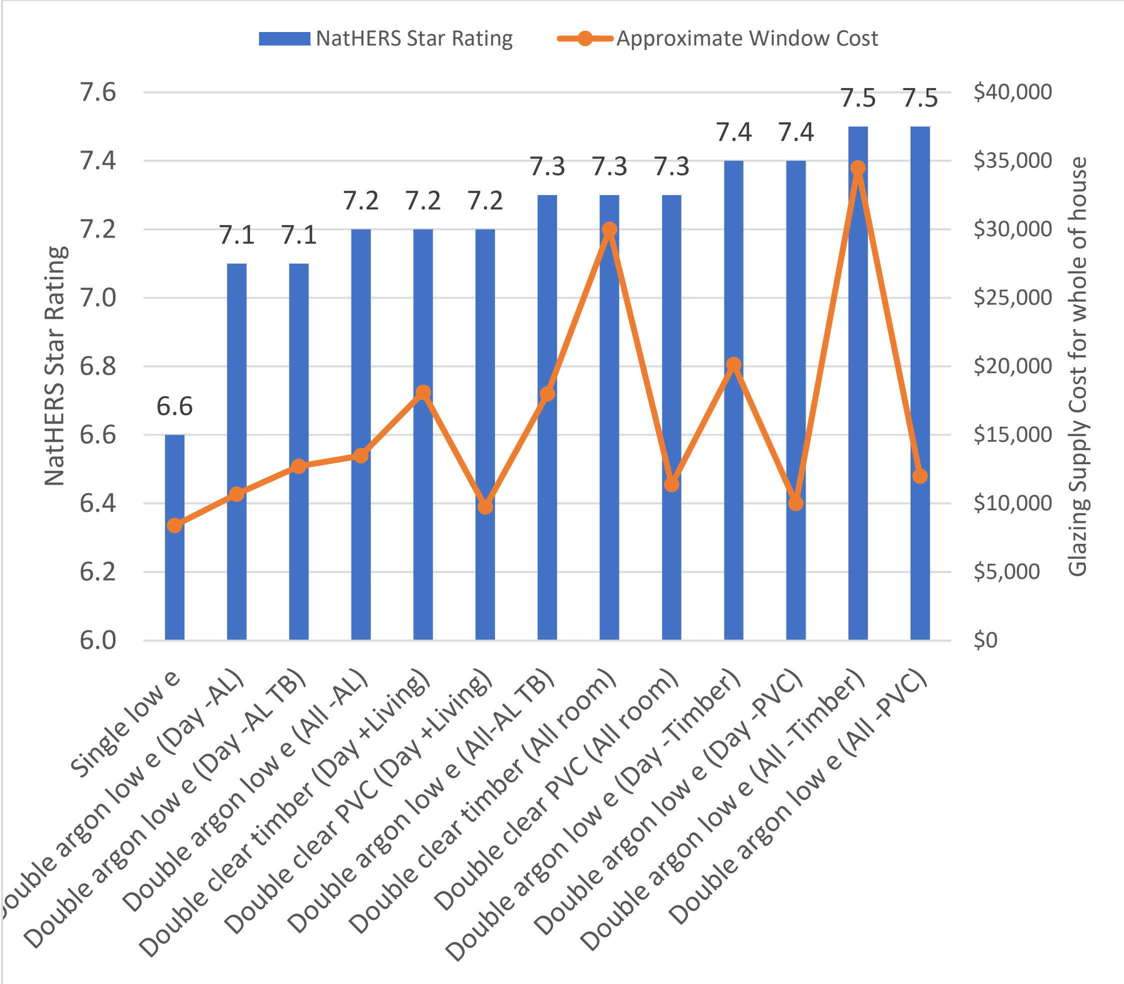


FIGURE 24. IMPACT OF GLAZING TYPE ON HIA HIGH PERFORMANCE HOME - STAR RATING AND APPROXIMATE COSTING FOR MELBOURNE[v,vi]

When overlaying approximate costing it becomes readily apparent why builders are reluctant to upgrade to double glazing unless there are regulatory drivers to do so. Single glazing was the cheapest solution, with the glazing elements for the HIA home costing approximately $8,400, closely followed by the solutions comprising low-E PVC at around the $10,000 range. Aluminium framed solutions that included double glazing increased the cost of the home to $13,500 for non-thermally broken frames up to $18,000 for all thermally broken frames throughout the house. Finally timber framed solutions were by far the most costly with glazing elements costing between $30,000 and $35,000 for the HIA home. Performance favoured both timber and PVC framed glazing with higher performing units achieving 7.4 to 7.5 Stars although it was clearly apparent that the PVC framed windows offered the best benefit cost ratio outperforming both aluminium and timber framed systems. The most cost effective solution for a 7 Star home was found to include double glazed clear PVC framed windows with the cost of glazing coming in around $9,750 for the entire home, however if a total of $10,200 was spent on high performing PVC framed windows for the day

[v] *TB (Thermally Broken), AL (Aluminium)

[vi] The HIA home consisted of 13.5 m^2 of windows in day and living spaces and 16.7 m^2 of windows in other zones.

use spaces only the HIA home could achieve 7.4 Stars. Glazing the entire home in high performance Low-E double glazing did not yield as much of a performance gain, resulting in an additional 0.1 stars to a rating of 7.5 Stars.

Window and glazing performance also had a significant impact on the Star Rating in Brisbane as shown in Figure 25. Here the high performance HIA home was selected for comparison where it can be seen that timber and PVC framed solutions generally excelled bringing about the higest star rating of any of the assessed homes at 8.4 Stars when utilised in all rooms. Two key factors influenced this difference, first the aluminium frames conduct a sizeable amount of heat into the homes when compared to the timber or PVC frames and secondly the SHGC of the aluminium window selected for this analysis was 0.49 as compared with the Timber's 0.31. As such, in hotter climates, this reduced SHGC was found to benefit the overall thermal performance of the home. From a budget perspective the single clear glazing still achieved current minimum compliance of 6.3 Stars at a cost of around $7,500, however with a cost of $9,750 a performance rating of 7.3 Stars could be obtained. In contrast to Melbourne installing high performance glazing in the night use spaces such as bedrooms added significant benefit to the overall star rating with the HIA home achieving 8.4 Stars when fully glazed in PVC or timber framed double glazed low e.

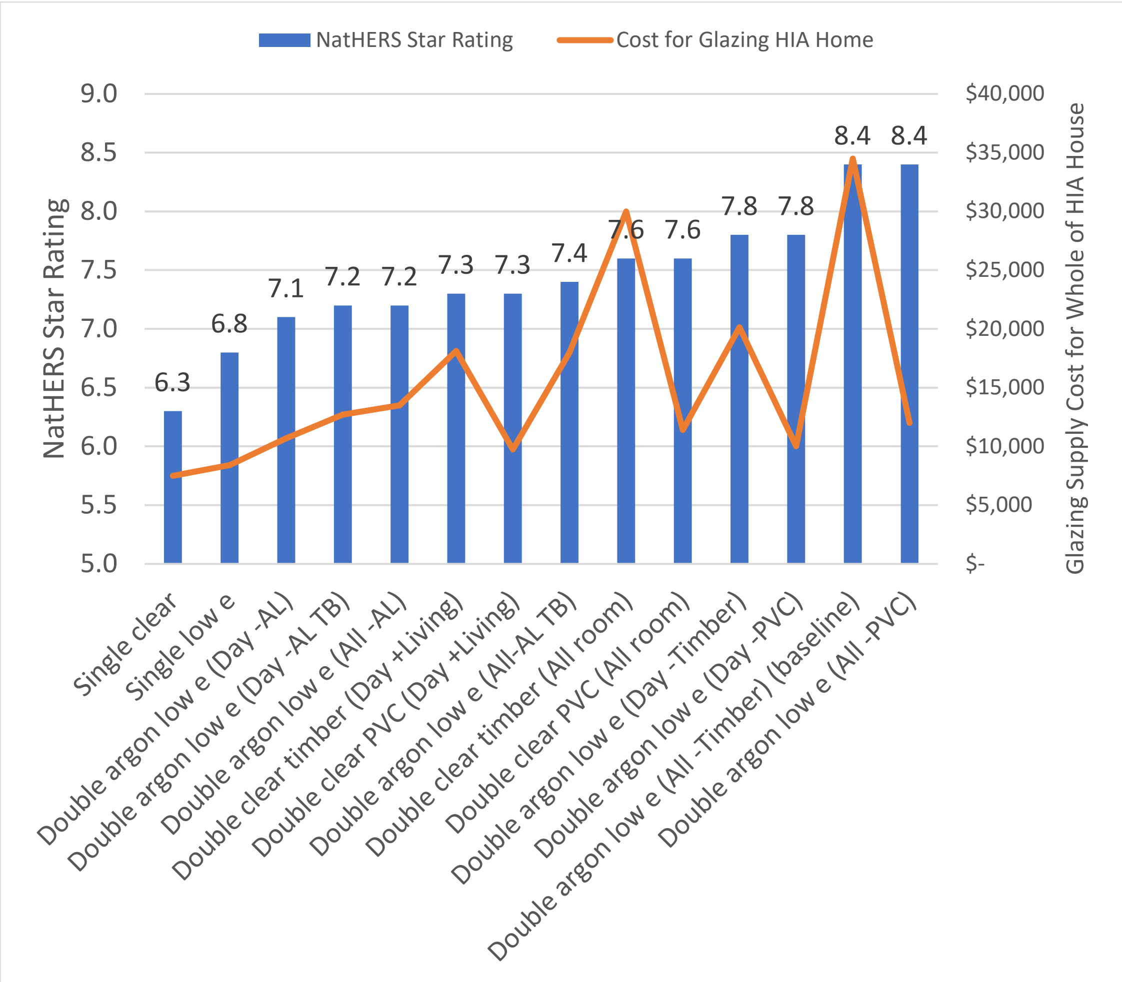


FIGURE 25: IMPACT OF GLAZING TYPE ON HIA HIGH PERFORMANCE HOME - STAR RATING AND APPROXIMATE COSTING FOR BRISBANE

Other capital cities replicated very similar trends for the other capital cities except for Hobart where the thermally broken aluminium system slightly outperformed the timber framed solution. This is almost certainly due to the higher SHGC of the aluminium window which allowed for a greater degree of passive heating.

The installation of higher performance windows in living and day use spaces only was assessed and compared with installing them in the entire house for each climate zone. Melbourne, Hobart and Canberra showed little additional benefit of installing high performance windows in the night (bedroom) use spaces with typical increases in the order of 0.2 stars. On the other-hand climates that required greater amounts of cooling such as Sydney and Brisbane showed much greater benefits of installing the double glazing in bedrooms with star rating increases of around 0.5 Stars.

4.3. The Impact of Floor Type

Flooring systems lead to significant variations in the thermal performance of each of the homes. Generally, waffle pod systems outperformed both CSOG and timber sub-floor systems, but this was not always the case. The HIA economical house showed very large differences in Melbourne with CSOG scoring a 6.3, Waffle pod scoring 6.6 and a sub floor with R 2.0 insulation scoring 6.1 NatHERS Stars. Even larger differences were evident in Brisbane where the sub floor system scored 4.6 Stars as compared to CSOG 6.7 and Waffle pod's 6.5. Defying the trend Hobart's HIA economical home scored 6.7 for both Waffle pod and timber sub floors whilst the CSOG scored only 6.0 Stars. It is not clear the reasons for this performance discrepancy, however it can be hypothesised that the timber sub floor better de-couples the home from the ground, and in cooler climates this reduces the energy requirements to heat the home and reduces the heat lost to the earth. In warmer climates this has the opposite effect, with CSOG allowing the home to lose heat into the earth hence requiring less cooling energy.

The HIA high performance home demonstrated far less variation due to flooring systems with Melbourne scoring 7.1, 7.3 and 7.5 Stars for Sub floor, CSOG and Waffle pod floors respectively. In a similar fashion to the economical HIA home, greater differences were apparent in Brisbane with Waffle pod system scoring 8.4 whereas sub floor only scored 6.7 Stars. It is quite likely that this added benefit of the Waffle pod is due to the thermal mass of the system benefiting through passive night cooling of the slab. Hobart also followed the economical home trend, but the sub-floor solution outperformed the Waffle pod, achieving a 7.4 Star rating compared to the Waffle pod 7.3. It is recommended that the key factors driving the performance of flooring systems be further investigated in future work to ensure results can be relied upon.

A higher performance of sub-floor insulation was investigated in Melbourne with the use of R 3.0 rather than R 2.0 which resulted in the improvement of 0.2 NatHERS stars. Additionally, edge insulation was also investigated for the CSOG floor with an improvement of 0.2 NatHERS stars.

4.4. The Impact of Wall Type

One of the key drivers behind this study was to investigate the impact of a variety of different wall solutions on the performance of homes in order to reach 7 Stars and beyond. However, early on it became apparent that the thermal performance of the home as a whole was more dependent upon the glazing and floor system than the wall system. Figure 26 details the variation in star rating for a variety of wall systems when utilising the HIA standard home with sub floor. It is clear that even reverse brick veneer has little overall benefit on the final star rating of the home. Figure 27 shows many of the same wall types, now assessed for the Lynvale home. Greater variations are evident in the HIA home with subfloor in Melbourne and this is likely due to the higher performance glazing selected for the Lynvale home. The high-performance light weight cladding system performed best for this home and scored 6.9 Stars, outperforming even reverse brick veneer. It is likely that the lightweight cladding system performed best due to the relatively poorer passive design of the Lynvale home.

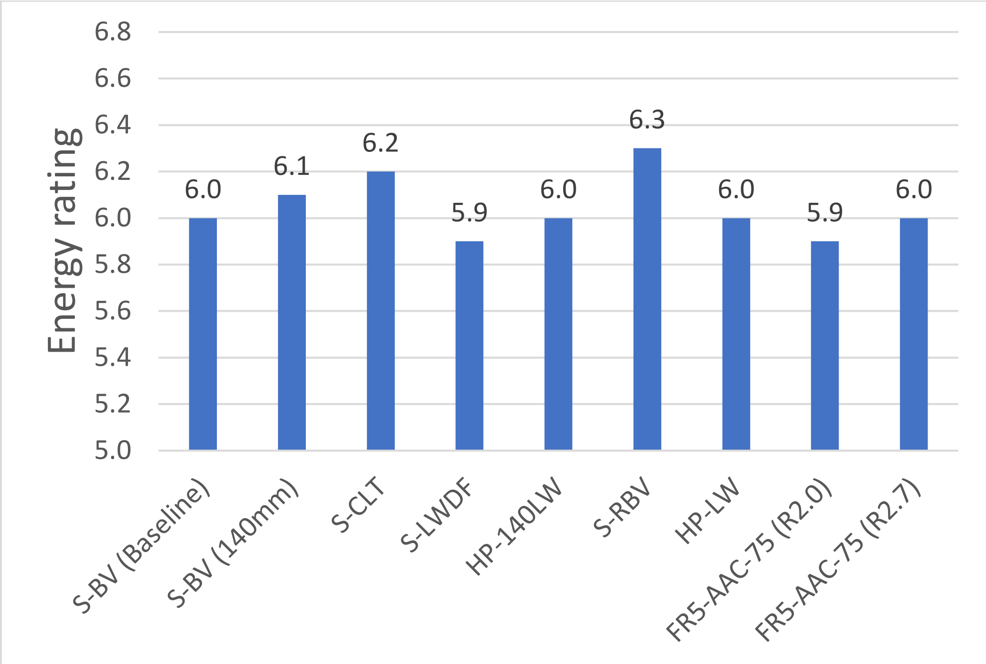


FIGURE 26. RESULTS OF THE HIA WITH SUBFLOOR HOME'S PARAMETRIC ASSESSMENT FOR WALL TYPE IN MELBOURNE

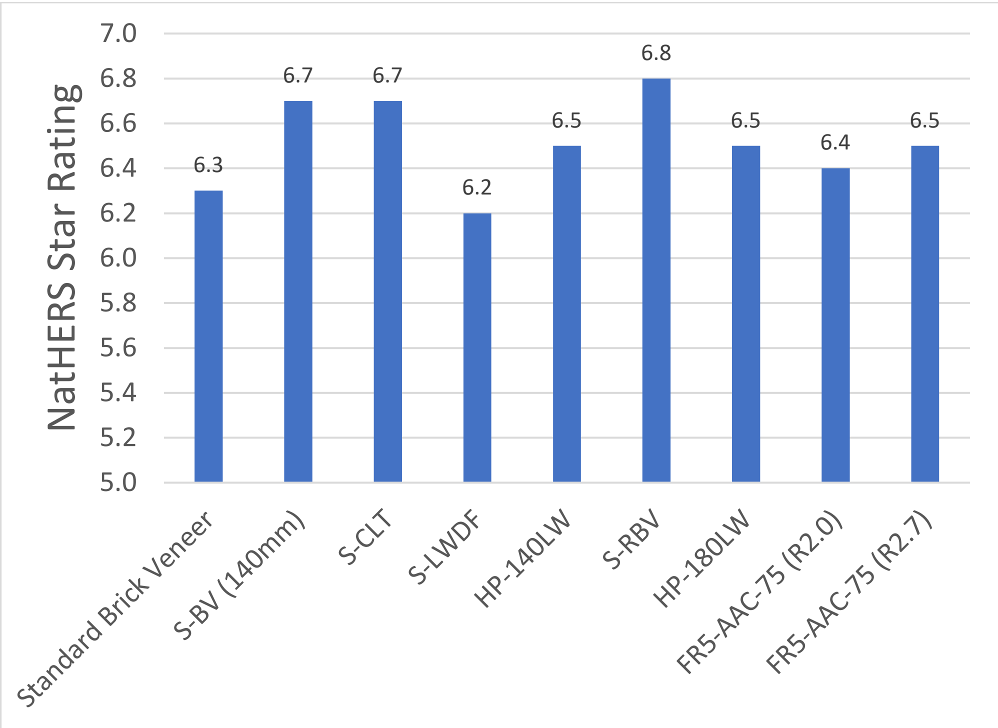


FIGURE 27. RESULTS OF THE LYNVALE HOME'S PARAMETRIC ASSESSMENT FOR WALL TYPE IN MELBOURNE

The performance of the wall becomes of greater importance when the glazing is also upgraded to a higher performance solution. To demonstrate this, the selected average 20% window to wall ratios was used to plot the impact of changing the wall R value on the overall system R value for a typical wall and window area as shown in Figure 28. In this figure the blue line represents clear single glazed windows where even significant changes in the wall R value only result in very small changes to the overall wall and window system R value. This is because all the heat is lost through the single glazed unit regardless of the performance of the opaque wall section. On the other hand, the orange line represents the high-performance timber framed double glazed argon filled, Low-E window where improvements in the wall opaque wall system have far more impact on the overall performance of the wall/window system.

FIGURE 28: IMPACT OF WALL AND WINDOW PERFORMANCE ON WALL SYSTEM R VALUE

As such some high-performance variants for the HIA home were created, combining high performance glazing as well as high performance wall systems. Upon combining these the Melbourne based HIA home could achieve over 8.2 Stars with both reverse brick veneer and the high performance lightweight 140mm wall solution when combined with the timber framed double glazed argon filled, Low-E windows.

Finally, for the Australia wide assessment two of the most common wall types were assessed, namely brick veneer and lightweight fibre cement clad stud walls. Most assessments showed the brick veneer averaging 0.1 Stars greater than the lightweight direct fix system. Brisbane also had an assessment of a 70mm wall system, which when combined with brick veneer showed no change from the 90mm studs whilst when used in just a lightweight direct fix (LWDF) system the 70mm solution scored 0.2 stars lower than the 90mm LWDF system for the high-performance home and the same as the 90 mm stud wall for the economical HIA home.

4.5. Additional Variations

Several additional variations were performed to determine the impact on the overall performance of the HIA standard home with subfloor. Additional ceiling insulation up to R 6.0 was included, which increased the star rating by 0.2 Stars demonstrating marginal benefit for this standard home type. Roof colour was also assessed with Medium and Light roofs performing on par whilst dark roof resulted in a 0.1 Star decrease (climate dependent). Discontinuous (tile) and continuous (colorbond) roofs had little difference on the overall performance of each solution with typical variations in the order of 0.1 Stars.

5. Thermal Bridging Assessment

5.1. Introduction to thermal bridging standards

Given the likely inclusion of thermal bridging in the upcoming NCC revision in 2022 this work package provides an independent assessment of the thermal bridging outcomes for the most common house wall sections. As such this study will compare the results of the two most commonly employed calculation based thermal bridging assessment methods; NZS 4214 (AS/NZS 4859.2) (Standards New Zealand, 2006)and ISO 6946 (International Organization for Standardization [ISO], 2017).

5.1.1. NZS 4214 (AS/NZS 4859.1) Method

Methods for determining the total thermal resistance of part of a building as described by NZS 4214 is founded on an isothermal planes method with the following procedure:

1) Select two planes parallel to the plane of the wall, which enclose to the portion of structure within which thermal bridging occurs.
2) Subdivide this portion into regions to have only one set of stacked "layers" within the region. Number these regions.
3) For each of these regions, calculate the area fraction (fx) and the thermal resistance, which would apply if that region existed alone.
4) Calculate the thermal resistance of the selected portion by using Eq. 1 and 2.
5) Add the resistances of any layers outside the selected portion to give the total thermal resistance.

$$\frac{1}{R_b} = \frac{f_1}{R_1} + \frac{f_2}{R_2} + \dots + \frac{f_n}{R_n} \qquad \text{(Eq.1)}$$

$$R_b = \frac{1}{\left[\frac{1}{R_b}\right]} \qquad \text{(Eq.2)}$$

Where:

f_x is the fraction of the cross-section at right angles to the direction of heat flow occupied at region x.

R_x is the thermal resistance through the region corresponding to f_x

R_b is the thermal resistance through the bridged portion of the structure.

Surface thermal resistance is the thermal resistance offered by a surface affected by the direction of heat flow, local airspeed, surface roughness, surface wetness, and radiation conditions. For compliance purposes, the following values shall be used:

- Internal surface resistance: R_{si} = 0.09 Km^2/W.
- External surface resistance: R_{se} = 0.03 Km^2/W.

The calculation of a metal frame is similar to the timber frame however, a metal frame can be replaced by a notional enclosing equivalent solid rectangle as shown in Figure 29. The calculation of the R value for this notional rectangle is detailed in subsequent equations.

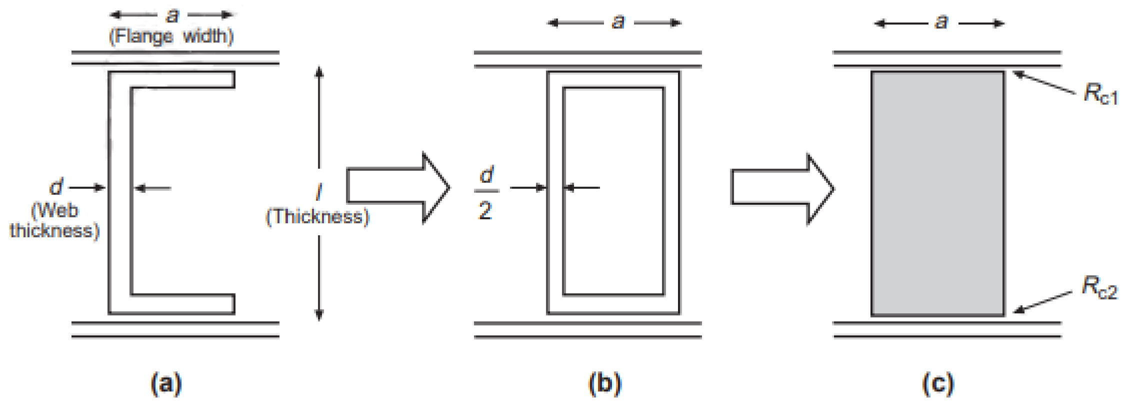


FIGURE 29: TRANSFORMATION METHOD FOR METAL FRAME SECTIONS (NZS4214-2006)

The thermal conductivity of the enclosing equivalent solid rectangle is:

$$k = \frac{d}{a} k_m \qquad \text{(Eq.3)}$$

The thermal resistance of the equivalent rectangle is

$$R = \frac{l}{k} = \frac{a \times l}{d \times k_m} \qquad \text{(Eq.4)}$$

The resistance of the whole metal frame is given in Eq. 5

$$R = \frac{l}{k} = \frac{a \times l}{d \times k_m} + R_{c1} + R_{c2} \qquad \text{(Eq.5)}$$

Where:

R is the resistance of the metal frame, including contact resistances

R_{c1} and R_{c2} are the contact resistances between the metal frame and facing (equal to 0.03 m^2K/W when the gap is 1mm, 5.7.4 NZS 4214:2006)

K_m is the conductivity of the metal.

Finally, The total thermal resistance of a plane building component is calculated using the following expression:

$$R_T = R_{si} + R_1 + R_2 + \cdots . R_n + R_{se} \qquad \text{(Eq.6)}$$

Where R_T is the total resistance, R_{si} is the internal surface resistance, R_1, R_2,…R_n are the thermal resistances of each layer including bridged layers and R_{se} is the external surface resistance.

5.1.2. ISO 6946 Method

ISO 6946:2017 provides the method of calculation of the thermal resistance and thermal transmittance of building components and building elements, excluding doors, windows and other glazed units, curtain walling, components which involve heat transfer to the ground, and components through which air is designed to permeate (ISO 6946 2017). The calculation method is based on the appropriate design thermal conductivities or design thermal resistances of the materials and products for the application concerned.

Timber frame:

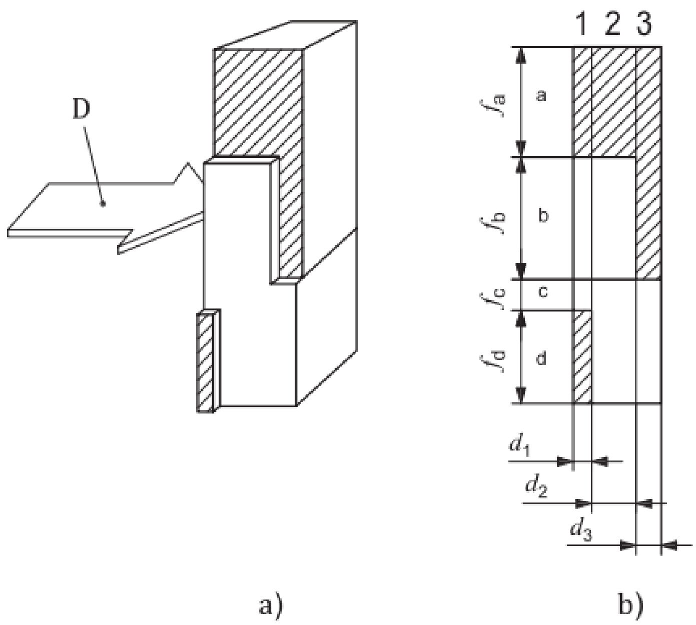
The total thermal resistance, R_t, of a component consisting of thermally homogeneous and thermally inhomogeneous layers parallel to the surface is calculated as the arithmetic mean of the upper and lower limits of the resistance:

$$R_t = \frac{R_{upper} + R_{lower}}{2} \quad \text{(Eq.7)}$$

Where

R_t is the total thermal resistance (m^2K/W)
R_{upper} is the upper limit of the total thermal resistance (m^2K/W).
R_{lower} is the lower limit of the total thermal resistance (m^2K/W).

Calculation of the upper and lower limits shall be carried out by considering the component split into sections and layers, as shown in Figure 30.



Key
D heat flow direction
a, b, c, d sections
1, 2, 3 layers

FIGURE 30. SECTIONS AND LAYERS OF A THERMALLY INHOMOGENEOUS COMPONENT

The component shown in Figure 30 is cut into sections a, b, c, d and into layers 1, 2, and 3.
The section m perpendicular to the surfaces of the component has a fractional area f_m, for m = a, b, c, d….
The layer j parallel to the surface has a thickness d_j, for j = 1, 2, 3…
The part mj has a thermal conductivity λ_{mj}, thickness d_j, fractional area f_m, and thermal resistance R_{mj}.

The upper limit of the total thermal resistance:

The upper limit of the total thermal resistance is determined by assuming one-dimensional heat flow perpendicular to the surfaces of the component. It is given by the following expression:

$$\frac{1}{R_{upper}} = \frac{f_a}{R_a} + \frac{f_b}{R_b} + \dots \frac{f_n}{R_n} \quad \text{(Eq.7)}$$

Where

R_{upper} is the upper limit of the total thermal resistance (m^2K/W).

R_n is the total thermal resistance from environment to environment for section n (m^2K/W).

f_n is the fractional area of section n.

The lower limit of the total thermal resistance:

The lower limit of the total thermal resistance is determined by assuming that all planes parallel to the surface of the component are isothermal surfaces. Calculate an equivalent thermal resistance for each thermally inhomogeneous layer using Eq. 8 as below:

$$\frac{1}{R_j} = \frac{f_a}{R_{aj}} + \frac{f_b}{R_{bj}} + \dots + \frac{f_n}{R_{nj}} \quad \text{(Eq.8)}$$

Where

R_j is an equivalent thermal resistance (m^2K/W).

R_{nj} is the thermal resistance for layer j for section n (m^2K/W).

Surface thermal resistance:

Surface resistances for the ISO 6946 method deviate slightly from the NZS 4214 method due to differing assumptions regarding wind speed, resulting in the following values being selected (Cl 6.8, ISO 6949:2017)..

- Internal surface resistance: R_{si} = 0.13 Km^2/W.
- External surface resistance: R_{se} = 0.04 Km^2/W.

Metal frame

ISO 6946 does not apply to bridging by linear metal elements. However, UK Building Research Establishment publishes a method to adapt ISO 6946 to metal framing[vii]. The basic approach to calculating R_{upper} and R_{lower} is unchanged, however, the overall R_t is weighted toward either R_{upper} or R_{lower}, depends upon the ratio of these two values and the frame geometry and spacing.

R_t is calculated as shown in Equation 9 while p is found using Equation 10 below:

$$R_t = pR_{upper} + (1-p)R_{lower} \qquad \text{(Eq.9)}$$

$$p = 0.8\frac{R_{lower}}{R_{upper}} + 0.44 - 0.1\left[\frac{Flange\_width}{40}\right] - 0.2\left[\frac{600}{stud\_spacing}\right] - 0.04\left[\frac{frame\_web\_depth}{100}\right] \qquad \text{(Eq.10)}$$

Once R_T is calculated for the metal frame the subsequent analysis follows the same procedure as for a timber framed system.

[vii] Erica Kenna, L.B., Thermal Bridging – Calculations and Impacts, in AIRAH and IBPSA's Australasian Building Simulation 2017 Conference. 2017: Melbourne, Australia. (BOLAND & KENNA, 2017)

5.2. Wall Profiles Assessed

The two most common wall systems used for construction in Melbourne have been selected for comparison, the lightweight direct fix and brick veneer frame. Each will be assessed with a typical timber and lightweight steel frame. Details of each wall build up and the associated assumptions are presented in the subsequent section.

5.2.1. Light Weight Direct Fix (LWDF) Timber frame

This wall build up utilises fibre cement external cladding, vapour membrane, 90mm studs, rockwool insulation (k = 0.04) with timber frame and internal plasterboard lining as shown in Figure 31. Using the assumptions presented, the overall frame ratio was 13%; that is 13 % of the area of the wall comprised timber framing elements.

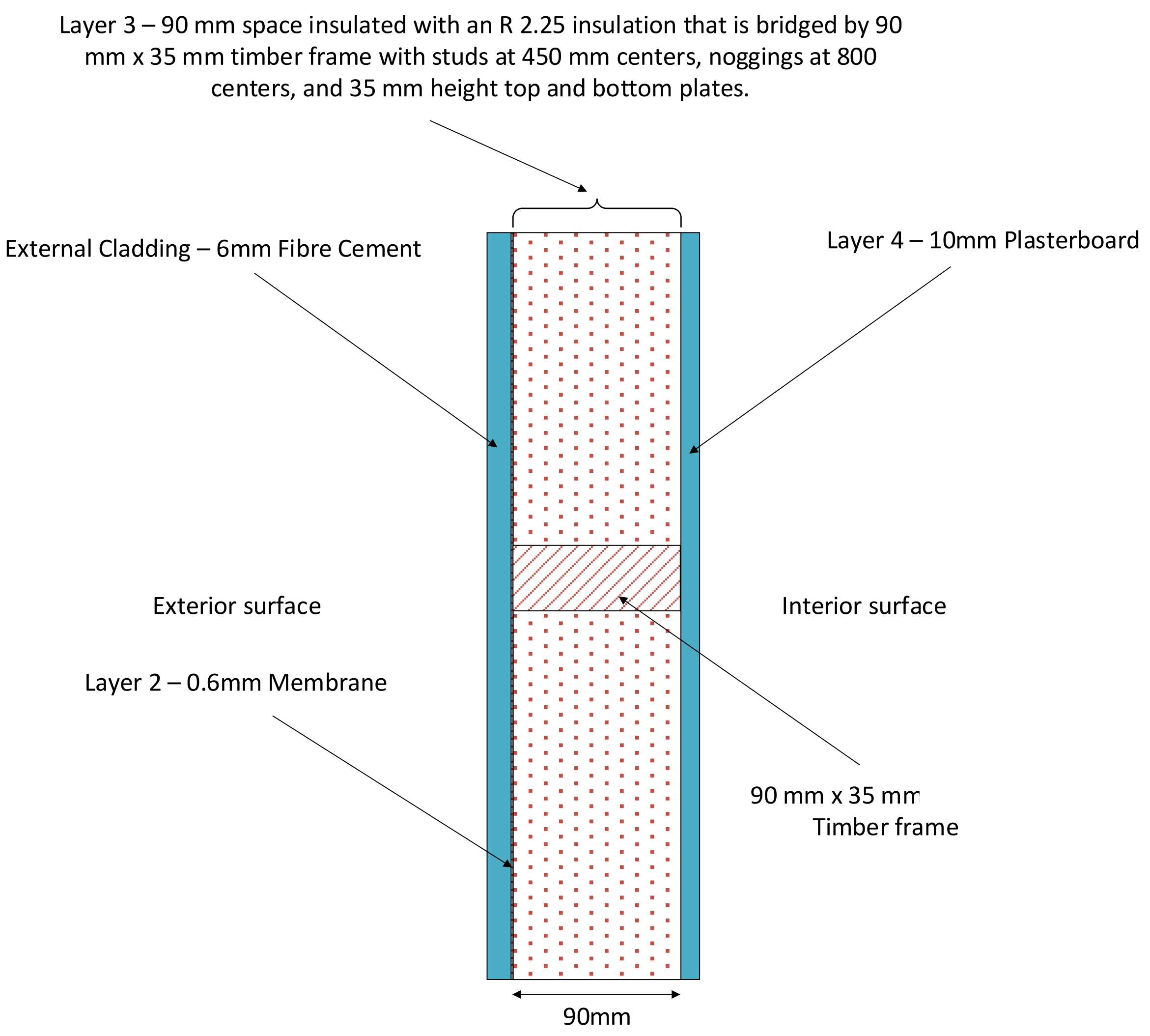


FIGURE 31: LWDF TIMBER FRAME WALL BUILD UP

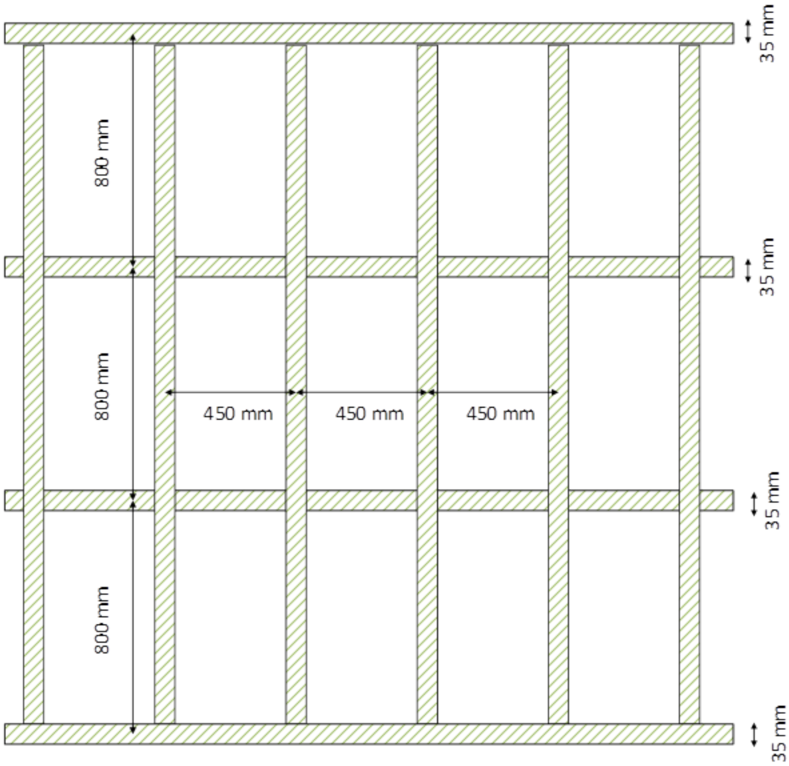


FIGURE 32: LIGHT WEIGHT DIRECT FIX EXTERNAL WALL ELEVATION PROFILE (TIMBER FRAME)

TABLE 29: MATERIAL PROPERTIES FOR LWDF TIMBER FRAME

No.	Layer	Thickness (mm)	Thermal Conductivity W/(mK)
1	Fibre Cement	6[viii]	0.2[ii]
2	Membrane	0.6	2.3
3	Timber frame	Thickness: 90 Height: 35 Noggings: 2 Horizontal spacing: 450	0.16
	Glasswool Insulation	90	0.04[ix]
4	Plasterboard	10	0.19[x]

[viii] Standard Fibre cement Sheeting (James Hardie, 2020)

[ix] FirstRate 5 Wall builder 2021 (Sustainability Victoria, 2020)

[x] Dataset on thermal properties, sound reductions, TVOC emissions, and costs of envelope components for prefabricated buildings in Australia (Naji, Aye, & Noguchi, 2020)

5.2.2. Light Weight Direct Fix Steel Frame

This wall build up utilises fibre cement external cladding, vapour membrane, 92mm studs, rockwool insulation (k = 0.04) with steel frame and internal plasterboard lining as shown in Figure 33.

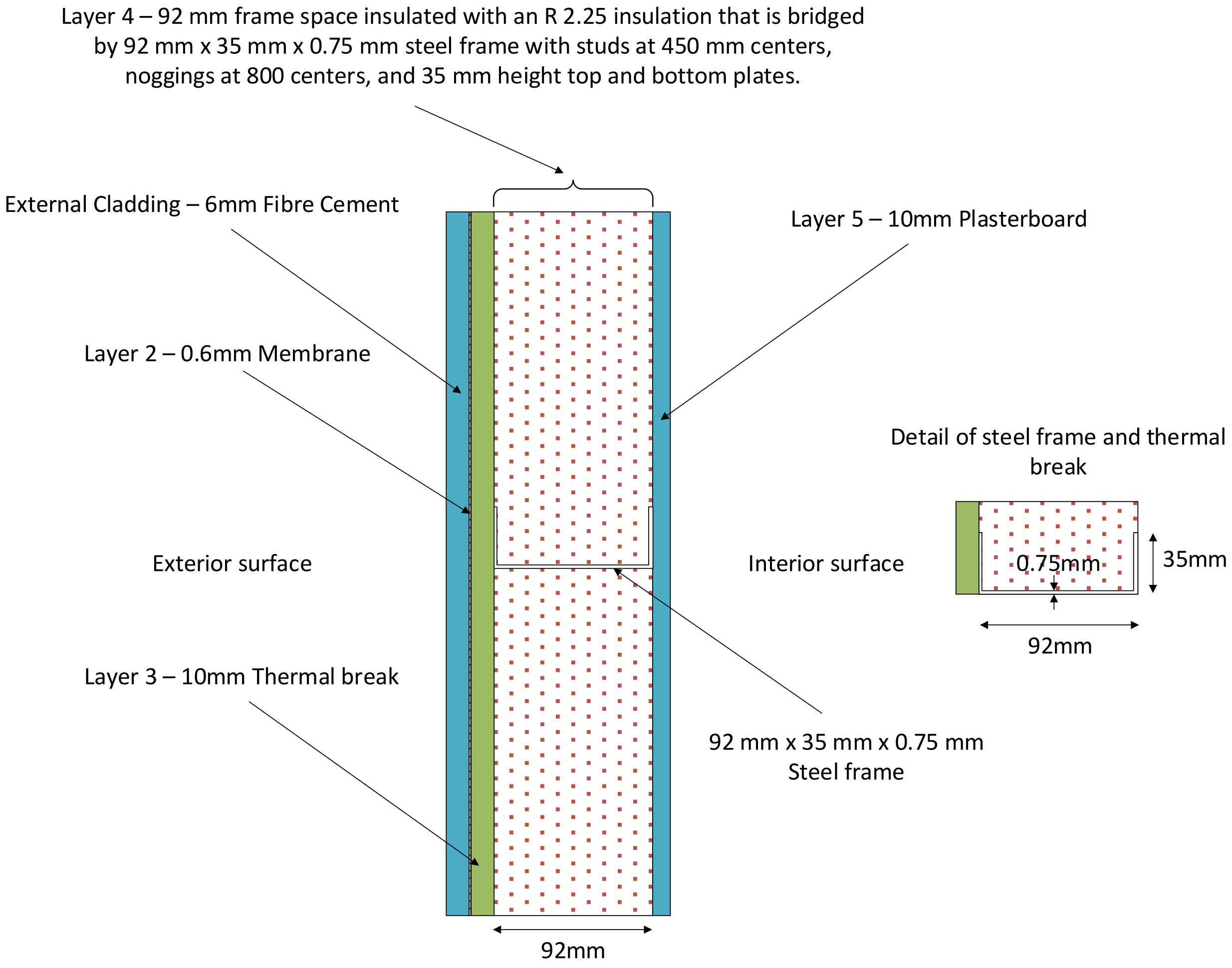


FIGURE 33: LWDF STEEL FRAME WALL BUILD UP

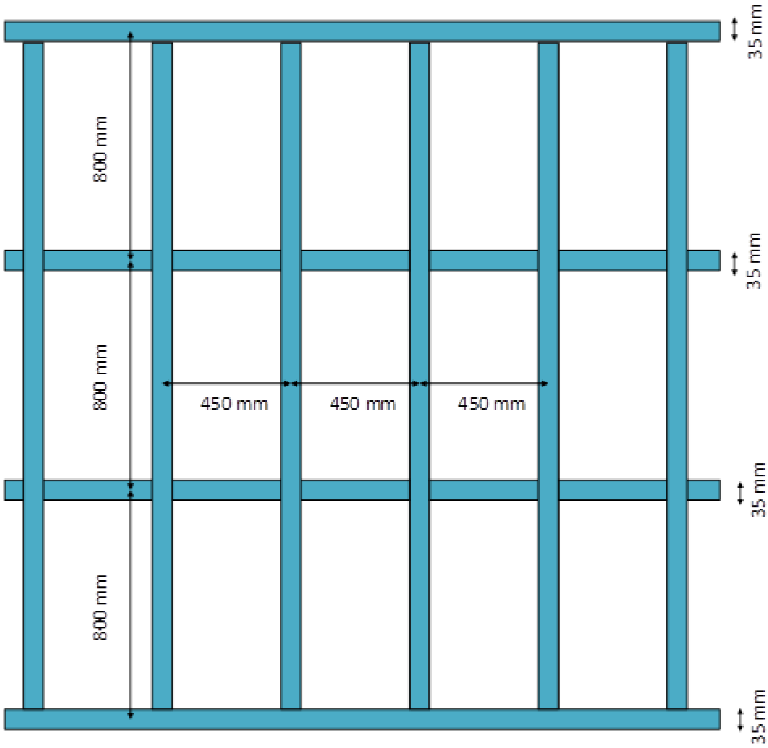


FIGURE 34: LWDF STEEL FRAME WALL ELEVATION PROFILE

TABLE 30: MATERIAL PROPERTIES FOR LWDF STEEL FRAME

No.	Layer	Thickness (mm)	Thermal Conductivity W/(mK)
1	Fibre Cement	6	0.2[iv]
2	Membrane	0.6	2.3
3	Thermal Break	10	0.05
	Steel frame	Stud Width: 92 mm Horizontal spacing: 450 mm BMT: 0.75 mm Flange width: 35 mm Noggings: 2	47.5
	Glasswool Insulation	92	0.04[xi]
4	Plasterboard	10	0.19[x]

5.2.3. Brick Veneer Timber frame

This wall builds up utilises concrete/masonry layer with 50mm air cavity, vapour membrane, and 90 mm stud wall with standard insulation (k = 0.04) with timber frame and internal plasterboard lining as shown in Figure 35.

[xi] FirstRate 5 Wall builder 2021

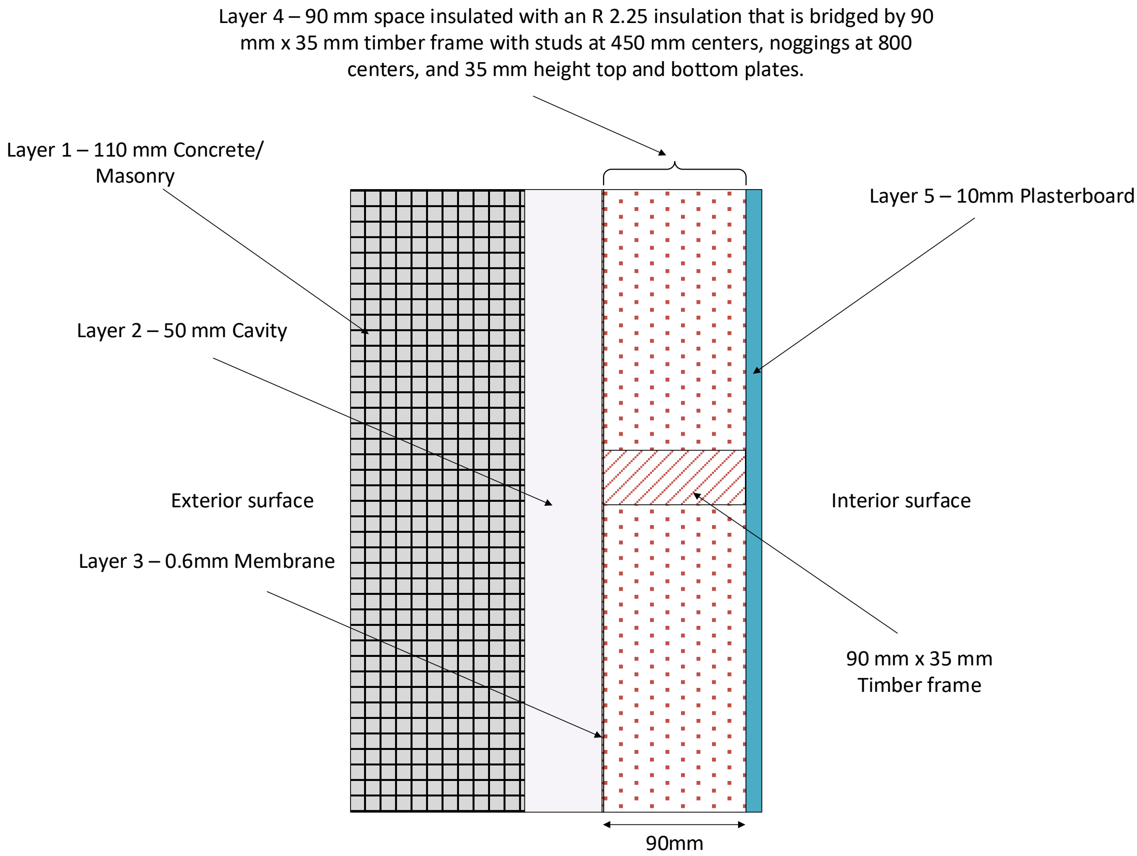


FIGURE 35: WALL BUILD UP FOR BRICK VENEER TIMBER FRAME

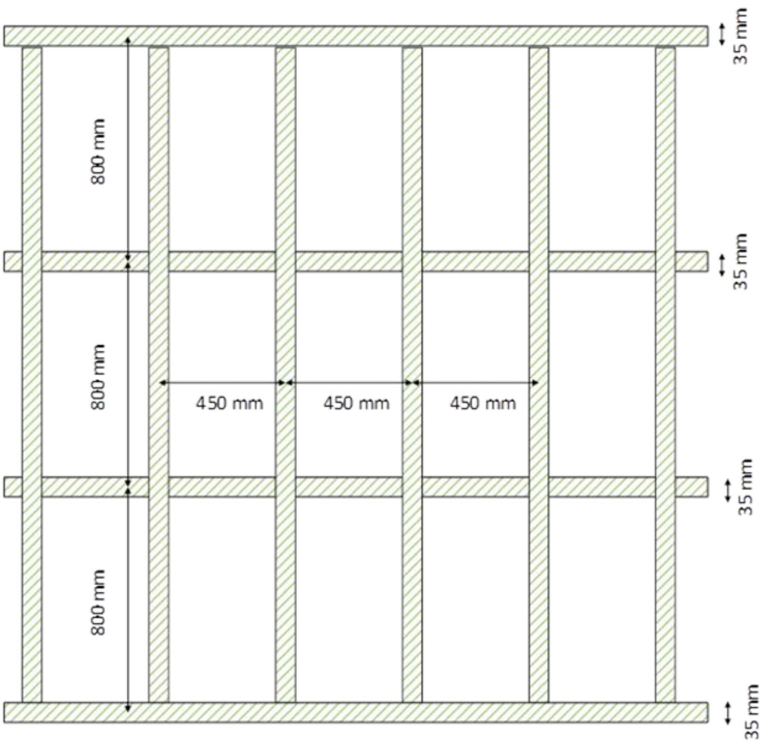


FIGURE 36: BRICK VENEER TIMBER FRAME ELEVATION PROFILE

TABLE 31: MATERIAL PROPERTIES FOR BV TIMBER FRAME

No.	Layer	Thickness (mm)	Thermal Conductivity W/(mK)
1	Concrete/Masonry	110	0.65^x
2	Cavity	50	0.31
3	Membrane	0.6	2.3
4	Timber frame	Thickness: 90 Height: 35 Noggings: 2 Horizontal spacing: 450	0.16
	Glasswool insulation	90	0.04
5	Plasterboard	10	0.19^x

5.2.4. Brick Veneer Steel frame

This wall build up utilises concrete/masonry layer with 50mm air cavity, vapour membrane, and 92 mm stud wall with standard insulation (k = 0.04) with steel frame and internal plasterboard lining as shown in Figure 37.

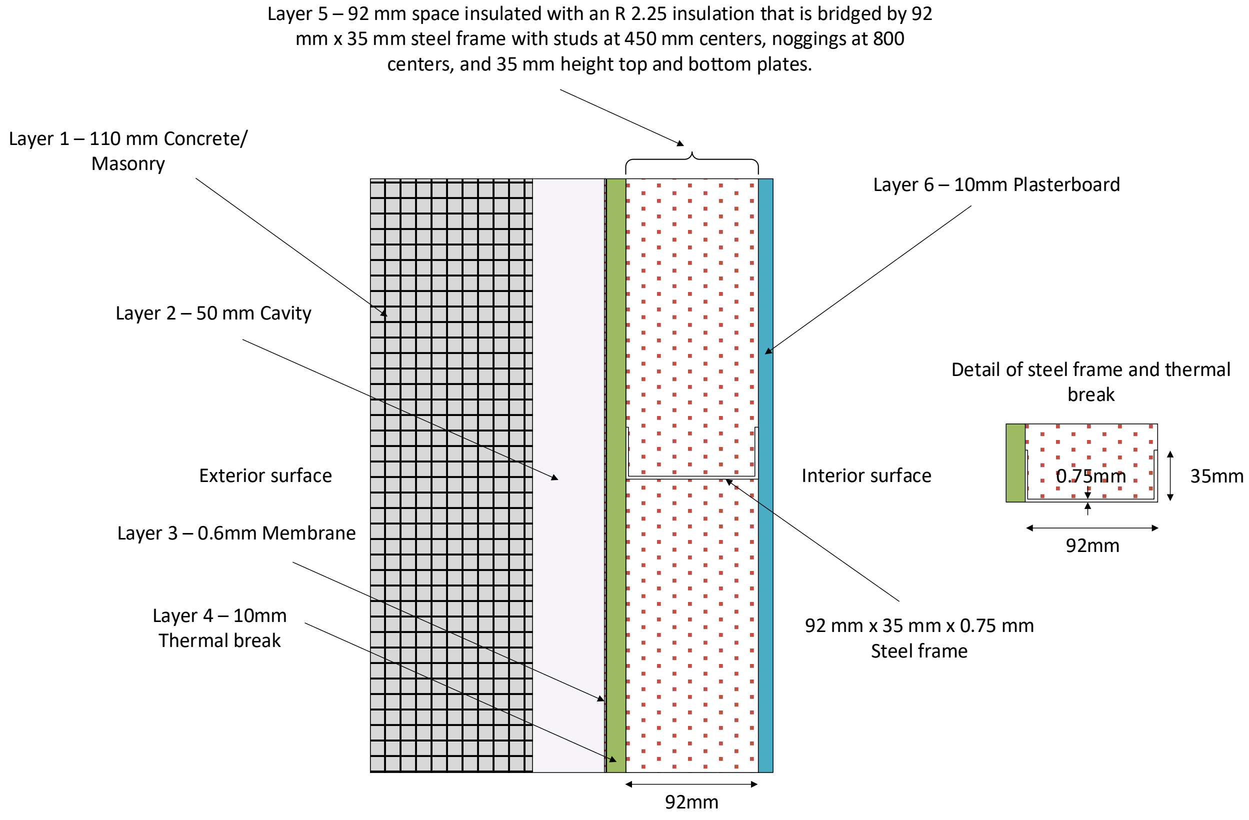


FIGURE 37: WALL BUILD UP FOR BRICK VENEER STEEL FRAME

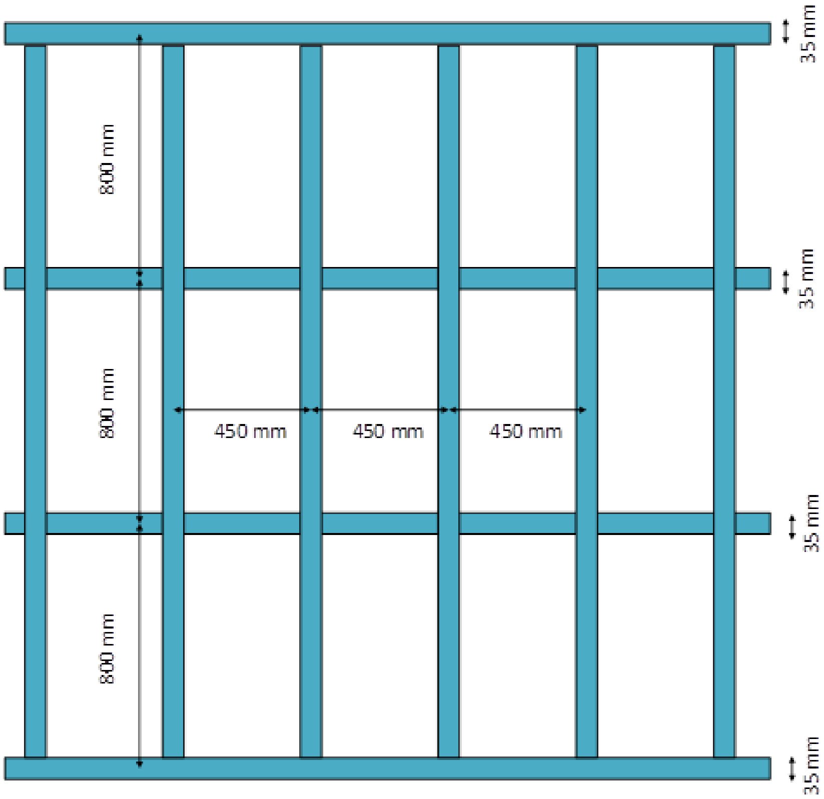


FIGURE 38: BRICK VENEER STEEL FRAME ELEVATION PROFILE

TABLE 32 MATERIAL PROPERTIES FOR BV STEEL FRAME

No.	Layer	Thickness (mm)	Thermal Conductivity W/(mK)
1	Concrete/Masonry	110	0.65[x]
2	Cavity	50	0.31
3	Membrane	0.6	2.3
4	Thermal Break	10	0.05
	Steel frame	Thickness: 92 Horizontal spacing: 450 Stud thickness: 0.75 Flange width: 35 Noggings: 2	47.5
	Insulation	92	0.04
5	Plasterboard	10	0.19[x]

5.3. Thermal Bridging Results

The wall systems as presented in Section 5.2. were assessed using both NZS 4214 and ISO 6946 methods with detailed calculations presented in the Appendix and the key results shown in Table 33 below.

TABLE 33. R-VALUE OF EACH WALL TYPE BASED ON NZS 4214 AND ISO 6846

Wall type	NZS 4214			ISO 6946		
	Without thermal bridging	Timber Frame	Steel Frame	Without thermal bridging	Timber Frame	Steel Frame
Light Weight Direct Fix	2.45	1.82	1.58	2.50	1.92	1.55
Brick Veneer	2.75	2.12	1.88	2.57	2.25	1.77

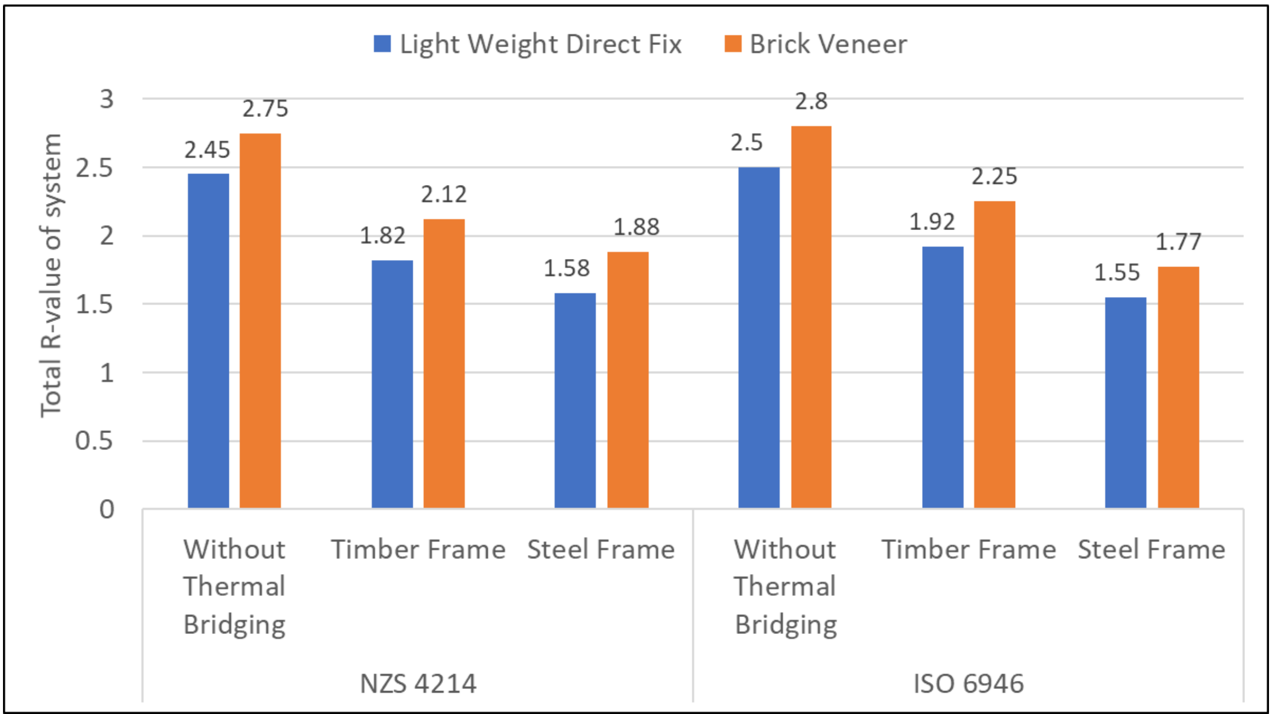


FIGURE 39: COMPARISON OF R-VALUE OF SYSTEM

Figure 39 shows that the R-values of both the timber and steel wall systems are significantly reduced when considering the thermal bridging. As anticipated the timber framed systems exhibited a higher total R-value than the steel frame by an average of R = 0.25 when using the NZS standard and 0.45 when using the ISO standard. These results have been further validated by comparing with available calculation tools, including Kompli and Speckel, as shown in Table 34.

TABLE 34. R-VALUE OF EACH WALL TYPE BASED ON NZS 4214 AND ISO 6846 (SPECKEL 2021, KOMPLI 2021)

Wall type	Timber frame				Steel frame			
	NZS 4214	ISO 6946	Kompli	Speckel	NZS 4214	ISO 6946	Kompli	Speckel
Light Weight Direct Fix	1.82	1.92	1.87	1.84	1.58	1.55	1.5	1.54
Brick Veneer	2.12	2.25	2.16	2.15	1.88	1.77	1.78	1.8

The results from Kompli and Speckel are very similar to the results from NZS 4214 for both framing systems due to the fact that they both employ the same methodology. Slight differences are likely accounted for in as Kompli and Speckel do not consider the contact resistances between the steel frame and facing while the calculations in this report did include this resistance. The ISO 6946 method also assumes that contact resistances does not contribute to the overall thermal resistance of the wall section.

5.3.1. Parametric Assessments

The effects of the contact resistances on the total R-value of the wall system are shown in Figure 40. Here it can be shown that the R-value of systems increases by 0.15 (m^2K/W) when accounting for a contact resistance of 0.3 (the equivalent of a 1 mm gap between the steel and the fixing sheet). There is some uncertainty regarding the correct value for contact resistance, with a conservative approach would be to select a value of zero.

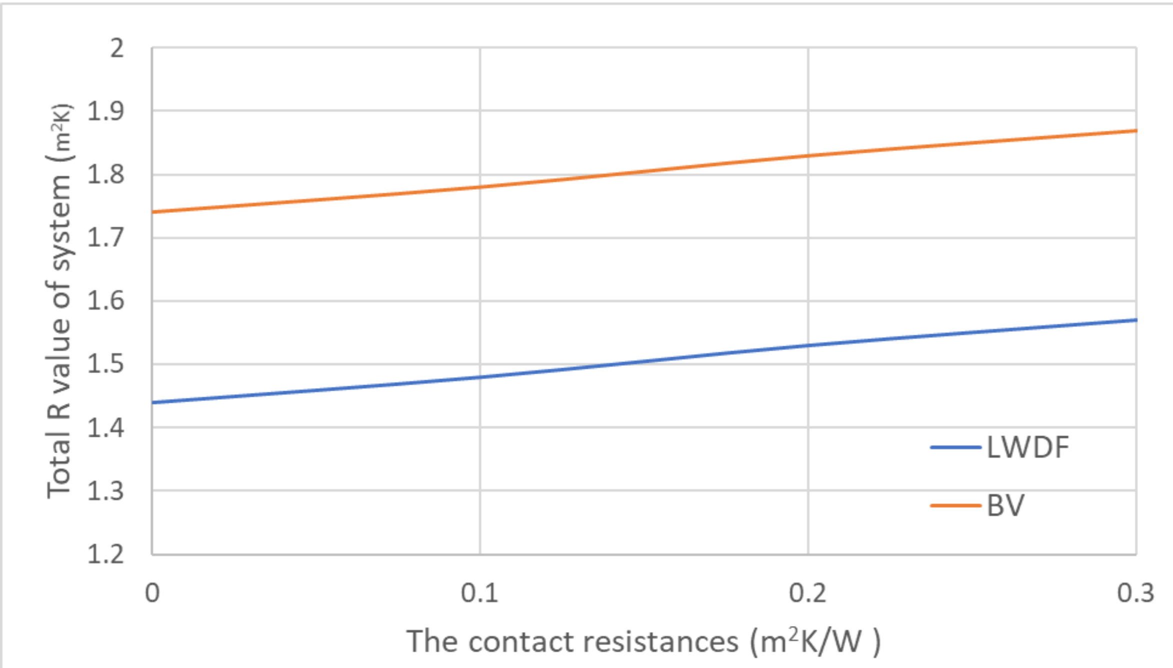
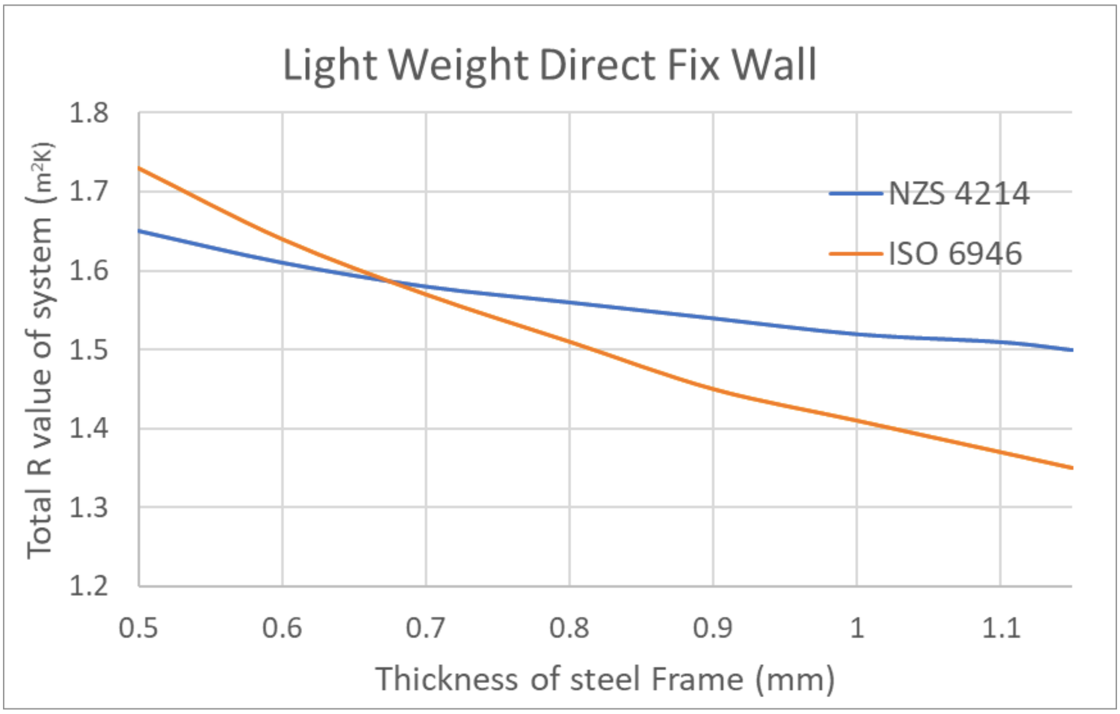
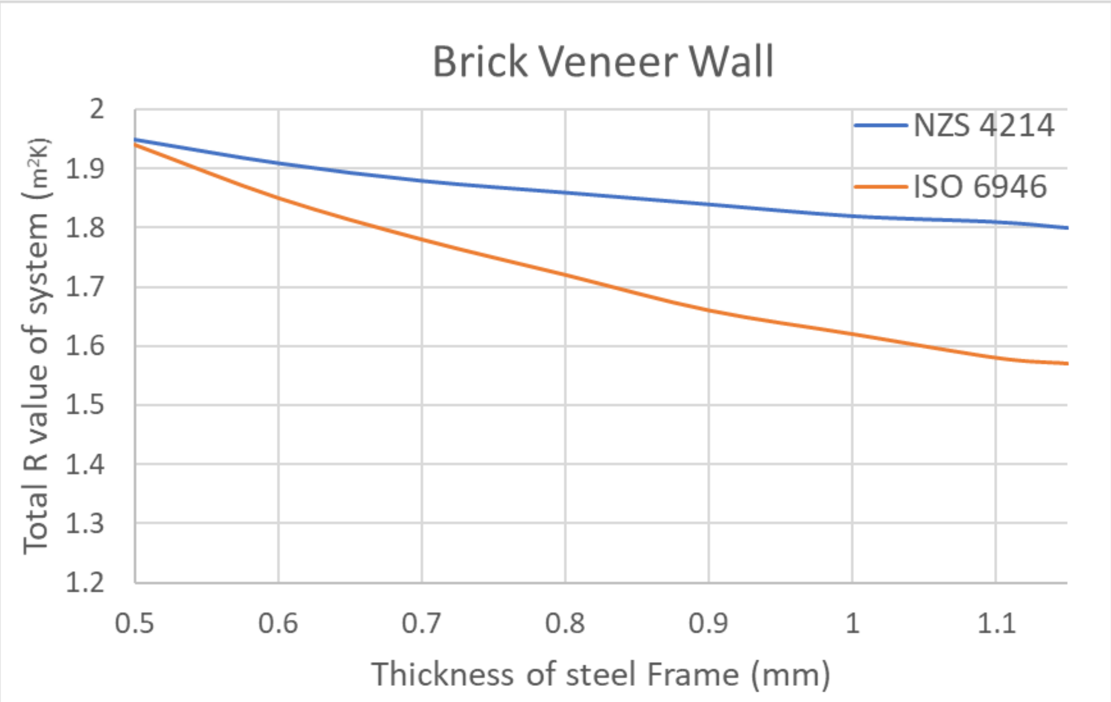


FIGURE 40: THE EFFECT OF THICKNESS OF THE CONTACT RESISTANCES ON THE TOTAL R-VALUE OF A WALL SYSTEM.

The steel frame system assumed a BMT of 0.75mm, and a parametric study was also performed in order to show how the thickness of steel affects the total R-value of the whole system with the results shown in Figure 41.



(A)



(B)

FIGURE 41: THE EFFECT OF THICKNESS OF STEEL ON (A) LIGHT WEIGHT DIRECT FIXED WALL, (B) BRICK VENEER WALL

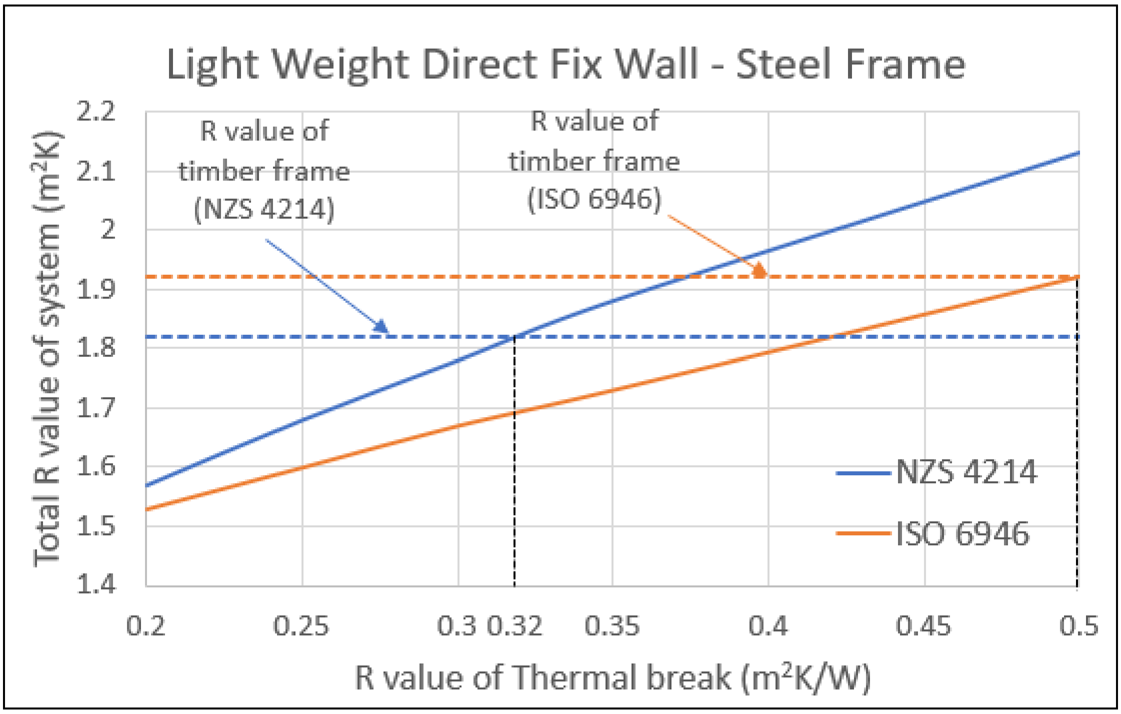
The thickness of steel has more impact when using the ISO 6946 standard rather than NZS 4214. In fact, the impact of changing the steel thickness from 0.5 mm BMT to 1.2 BMT reduced the equivalent R value of the wall by 0.4 or almost 20%.

5.3.2. Mitigating thermal bridging for steel wall frames

In order to ensure that steel wall frames perform as well as timber framed walls this report investigated thermal breaks and the inclusion of additional insulation as methods to increase the thermal performance of the steel frame to match that of the timber (when accounting for thermal bridging). The base case BV and LWDF wall section has a selected R value for the insulation 2.25 for this assessment.

Increasing the Thermal Break

Currently a minimum thermal break of 0.2 needs to be applied to steel framed exterior walls in Australia. This study investigated what additional required thermal break material would be required such that the steel frame performance was on par with a timber framed system. The results of this are shown in Figure 42 where it can be observed that for the Lightweight Direct Fix wall, the steel frame requires a thermal break of R = 0.32 (m^2K/W) to have the same thermal performance as the timber frame when calculating by NZS 4214. However, when utilizing the ISO 6946 analytical method the steel frame wall needs a thermal break with R = 0.5 (m^2K/W). Results were similar for the Brick Veneer wall with the steel frame requiring a thermal break layer of R = 0.32 m^2K/W using NZS 4214 and R = 0.59 m^2K/W when using ISO 6946.



(A)

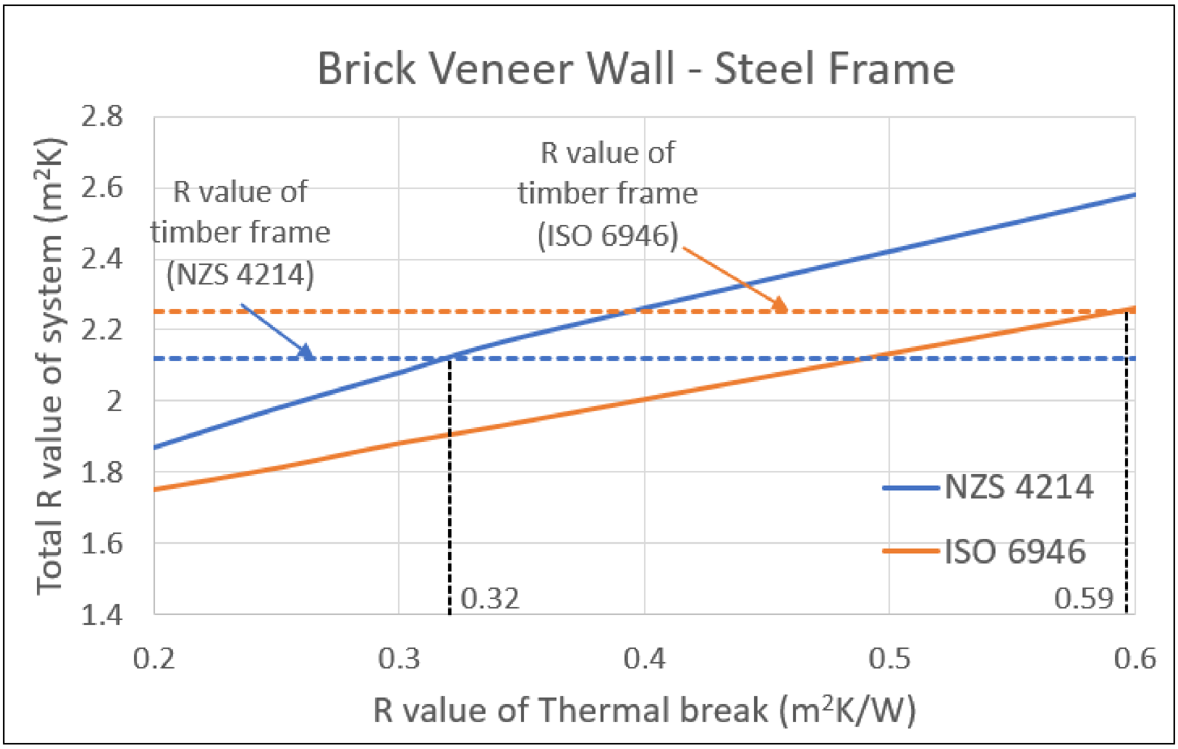
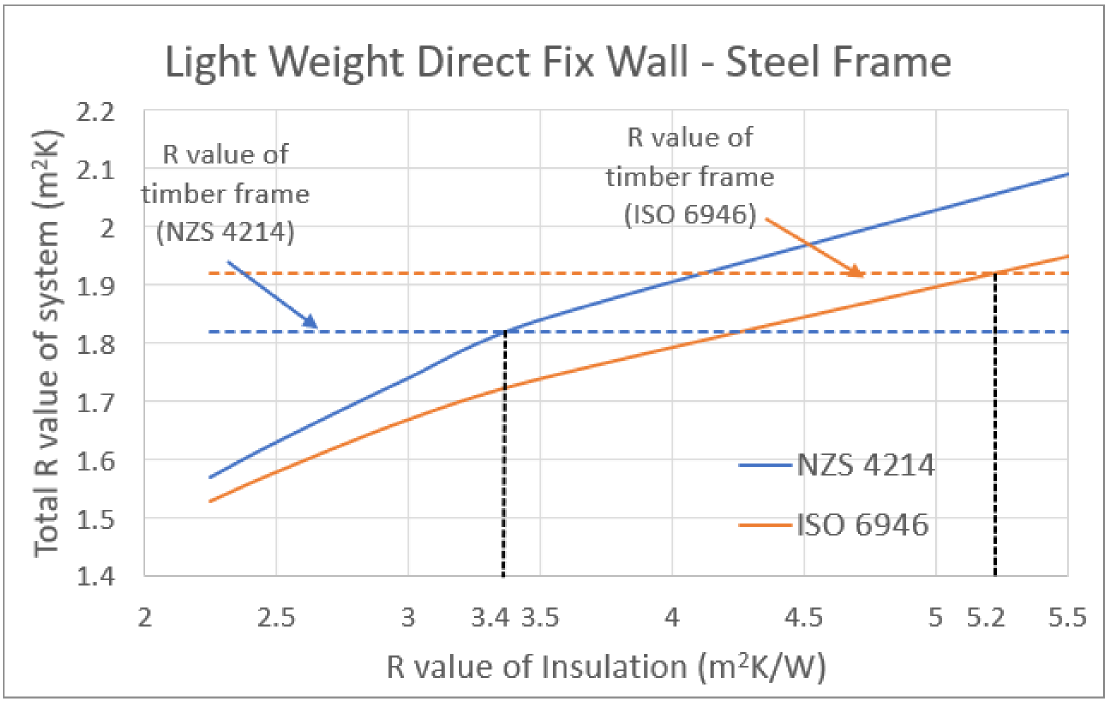


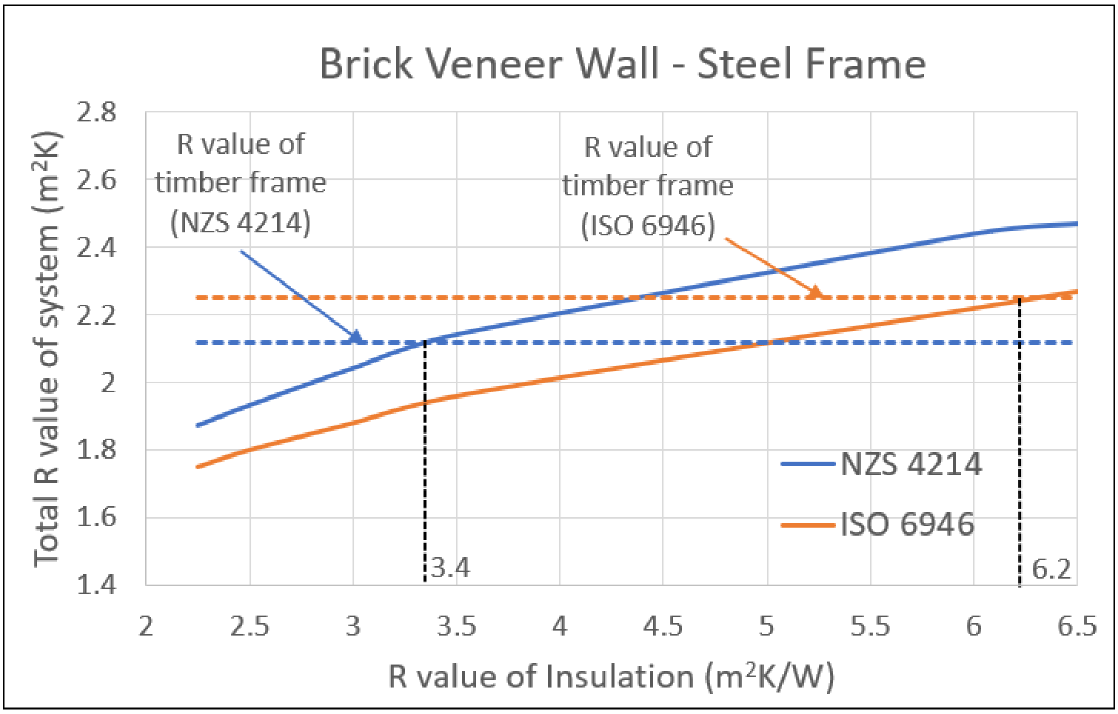
FIGURE 42 THE EFFECT OF THERMAL BREAK ON (A) LIGHT WEIGHT DIRECT FIXED WALL, (B) BRICK VENEER WALL

Increased insulation material between framing elements

Instead of increasing the thermal break for the steel framed system, another approach is to add additional insulation to ensure that steel framed system meets the same equivalent R-value as the timber framed system. Assuming a thermal break of R = 0.2 m^2K/W is already in place Figure 43 details the equivalent R value of insulation required to meet the performance of the timber frame (with R 2.25) for both NZS 4214 and ISO 6946.



(A)



(B)

FIGURE 43 THE EFFECT OF INSULATION ON (A) LIGHT WEIGHT DIRECT FIXED WALL, (B) BRICK VENEER WALL

NZS 4214 requires the steel frame system to have an insulation of R value = 3.4 m^2K/W for both Light Weight Direct Fix wall and Brick Veneer wall to perform the same with timber frame system. Utilising the ISO 6946 method this increases significantly with the steel frame system needing to increase the R-value of the insulation layer to 5.2 (m^2K/W) and 6.7 (m^2K/W) in Light Weight Direct Fix wall and Brick Veneer wall, respectively. Clearly this is not practical with a 90mm stud space unable to accommodate more than about R 2.7 insulation. As such for steel to perform on par with timber wall framing systems methods that increase the overall R value on either side of the steel frame are necessary, such as the aforementioned thermal breaks or unventilated and reflective air cavities.

5.4. Thermal Bridging Summary

Consideration of thermal bridging had a significant impact on both timber and steel framed wall systems with steel framing exhibiting the greatest reduction in overall R value. Both BV and LWDF systems showed susceptibility to thermal bridging however BV systems generally performed better due to the added air gap effectively de-coupling the thermal bridged section of the wall. The NZS 4214 method yielded higher overall R values for steel framed systems when compared to the ISO 6946 analytical method. It is recommended that the ISO 6946 method is used for thermal bridging assessments instead of the NZS 4214 due to its international recognition and better correlation to numerical and experimental simulation results. Further supporting the use of the ISO standard, Santos, Gonçalves, Martins, Soares, and Costa (2019) compared the R value results using 2D finite element simulations to those obtained using ISO 6946 and found that results varied by no more than 2.6% for lightweight steel frame walls.

If a deemed to comply regulatory approach were adopted for steel and timber wall frame systems, such that they were to perform comparatively then sizeable changes would be required for the steel framing system. This report found that the only practical approach would be to increase the walls resistive value on either side of the thermally bridged section as it became impractical to add sufficient insulation between bridging elements. In order for the Light Weight Direct Fix (LWDF) wall to meet the performance of the timber framed system a thermal break of value R = 0.5 m^2K/W would be required. This increased to a value of 0.59 m^2K/W for the Brick Veneer Wall or the equivalent of approximately 23mm thick expanded polystyrene sheet. Additional measures that could facilitate the improved R value for steel framed wall systems include unventilated and reflective air cavities incorporated into the wall system.

6. Conclusions

This report investigated a variety of methods for residential detached dwellings to achieve 7 Star NatHERS ratings. It was found that 7 Star NatHERS homes are achievable throughout Australia and can be achieved through a variety of building fabric upgrades. Solutions that achieved 7 Star NatHERS ratings in predominantly heating climates comprised either combinations of double glazing and high-performance wall insulation, single glazing and waffle pod slabs or high-performance ceiling and wall insulation with single glazing. 7 Star NatHERS rated homes were more easily achievable in more mild climates such as Sydney and warmer climates such as Brisbane with solutions comprising more moderate upgrades to building insulation or double glazing in select rooms.

Window selection both in terms of glazing and framing was found to have a large impact on performance however from a cost perspective, cooler climates benefited principally from double glazing in day and living spaces whilst warmer climates such as Brisbane benefited equally from upgrading night use spaces such as bedrooms. Timber frames and aluminium thermally broken frames also provided a significant performance improvement over the more conductive aluminium framed counterparts although they also added significant costs to homes.

Well performing 7-star solutions were however contingent on the design of the home such that passive solar heat gain in winter was sufficient throughout living areas whilst solar heat gain in summer was minimised with either eaves or awnings. Stairwells on double storey homes were also found to degrade performance significantly if directly attached to the living zone in a predominantly heating climate such as Melbourne.

Wall build up and performance, although one of the original objectives of this report was found to have a lesser overall impact on the performance of the home. Upgrading the performance of the wall, either by increasing the insulation or width had a very minor impact on the star rating of the home, unless it was done in conjunction with other building fabric upgrades, principal of which was the glazing performance. It was also found that warmer climates such as Brisbane had negligible benefit from using 90mm studs over 70mm studs (with the same insulation k value) and as such it is recommended that 70mm studs are sufficient for this climate zone.

Thermal bridging was found to have a significant impact on both timber and steel framed wall systems reducing the apparent R value by up to 22% and 40% respectively. LWDF systems showed the greatest susceptibility to thermal bridging and the NZS 4214 calculation method yielded higher overall R values for steel framed systems when compared to the ISO 6946 analytical method. This report recommended the use of the ISO 6946 method due to its greater accuracy. This report found that if a deemed to comply regulatory approach were adopted for steel and timber wall frame systems, such that they were to perform comparatively then the steel framing system would require increased thermal resistance (either insulation or unventilated reflective air cavities) on either side of the thermally bridged section. Thermal breaks of approximately R = 0.5 m^2K/W would be required for a typical brick veneer steel framed wall to perform on par with a timber framed system.

The following additional general conclusions can be made.

- The greatest influencing factor on the performance of each house was the windows, with double glazing typically adding around 0.5 stars and high-performance double glazing adding up to 1.6 Stars when compared with single glazed Low-E windows. This was true for both heating and cooling climates.
- Predominantly heating climates benefited from glazing with higher SHGC whilst cooling climates like Brisbane benefited from lower SHGC.
- There was marginal benefit of double glazing in night use spaces for heating climates (around 0.2 Stars) but significant benefit of double glazing in night use spaces for cooling climates (around 0.5 Stars).
- Timber frames outperformed non-thermally broken aluminium framed windows and performed slightly better than thermally broken aluminium framed windows.
- Flooring systems demonstrated a large impact on building performance but without a clear trend. Frequently Waffle Pod were the best performing solutions however Timber Sub floor systems performed on par (when insulated with R 2.0) in Hobart but poorer in warmer climates such as Brisbane. Further investigation is recommended into the assumptions and validity of the Chenath engine and performance of thermal mass, earth linkage and passive design.
- Wall systems were of secondary importance when compared to windows, however when combined with high performance window solutions were able to contribute to significant thermal benefits to homes. 140 mm high performance lightweight cladding and reverse brick veneer were the best performing under these circumstances and when combined with other building fabric upgrades homes obtained over 8 Stars in many climate zones.
- Common wall systems such as brick veneer and light weight direct fix (fibre cement) performed very similar with brick veneer typically scoring 0.1 Stars greater than the LWDF.
- Good passive design was also found to have a significant impact on the overall performance of the homes assessed with the HIA homes outperforming the Lynvale home by an average of 1 NatHERS star given the same building fabric selections. Eaves, natural light in living spaces and a presence of a stairwell attached to the living spaces all played a major part in the home's performance.
- Higher star ratings were more readily achievable in more mild climates such as Brisbane, Perth and Sydney with high performance home systems ratings exceeding 8 stars. Cooler climates such as Melbourne, Canberra and Hobart all were only able to achieve approximately 7.5 Stars for optimal configurations.
- To achieve 7 Star NatHERS ratings a variety of methods could be implemented usually consisting of multiple building fabric upgrades with glazing being the most significant factor whilst wall, ceiling and floor insulation all contributed to the home's performance

7. Further Work

This project investigated what building fabric upgrades would be required to meet the 7 Star NatHERS for a variety of Climate Zones throughout Australia. Further investigation is recommended into the following key areas:

1. Investigate performance of the narrower lot 'Lynvale' home in a wider variety of climate zones to determine 7 Star requirements in climates dissimilar to Melbourne.
2. Determine the validity of the thermal performance results for a variety of flooring systems, specifically slab on ground, waffle pod and timber sub floors the results of which are highly dependent upon the ground coupled heat transfer. It is recommended to validate the Chenath model using 3D numerical simulations for a variety of different geology's and flooring systems.
3. Investigate methods to improve the thermal performance of an insulated subfloor. This could include active ventilation systems that vent the subfloor in 'summer' mode and completely seal the subfloor in 'winter' mode. Completely sealing the sub floor has the potential to add to the thermal performance of homes, particularly in winter.
4. Assignment of typical costs to different building fabric and insulation products such that a cost-effective hierarchy to achieve 7 Stars could be determined.
5. Repeat the thermal bridging investigation for both ceiling, roof and steel/timber sub floor systems to determine what the insulation/thermal break requirements would be for steel systems to perform on par with timber

8. Appendix

8.1. Climate Zone Details

TABLE 35: LOCATION AND CLIMATE ZONES

Location	NatHERS Climate Zone	ABCB Climate Zone	ABCB Climate Description
Melbourne	21	6	Mild Temperate
Sydney	17	5	Warm Temperate
Brisbane	10	2	Warm Humid Summer, Mild Winter
Hobart	26	7	Cool Temperate
Canberra	24	7	Cool Temperate
Perth	13	5	Warm Temperate

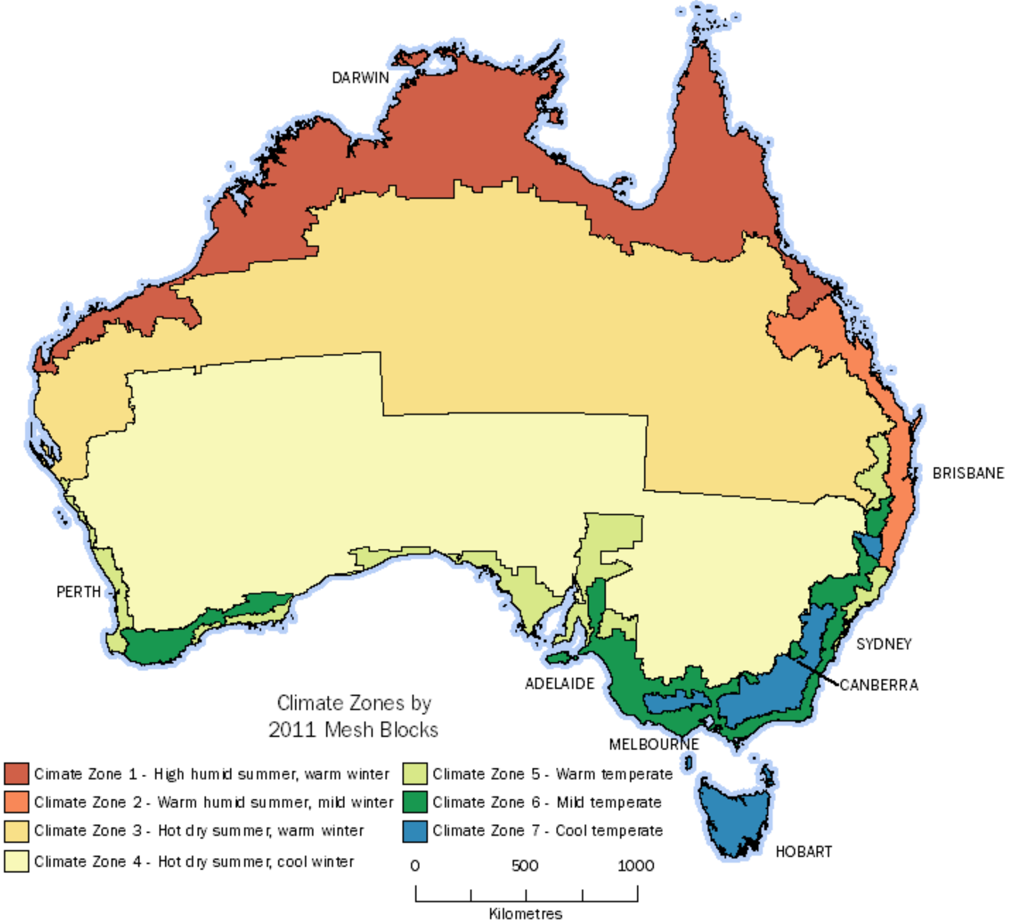


FIGURE 44: ABCB CLIMATE ZONES (AUSTRALIAN BUREAU OF STATISTICS, 2013)

8.2. Wall Construction Types

8.2.1. Standard Brick Veneer Wall 90 mm studs

The baseline home consisted of standard brick veneer wall with 50mm slightly ventilated air cavity and 90 mm stud wall with standard insulation (k = 0.04) as detailed in Figure 45. A high-performance insulation variation was also assessed for the Melbourne HIA standard home with an R value of 2.7 in the 90mm cavity.

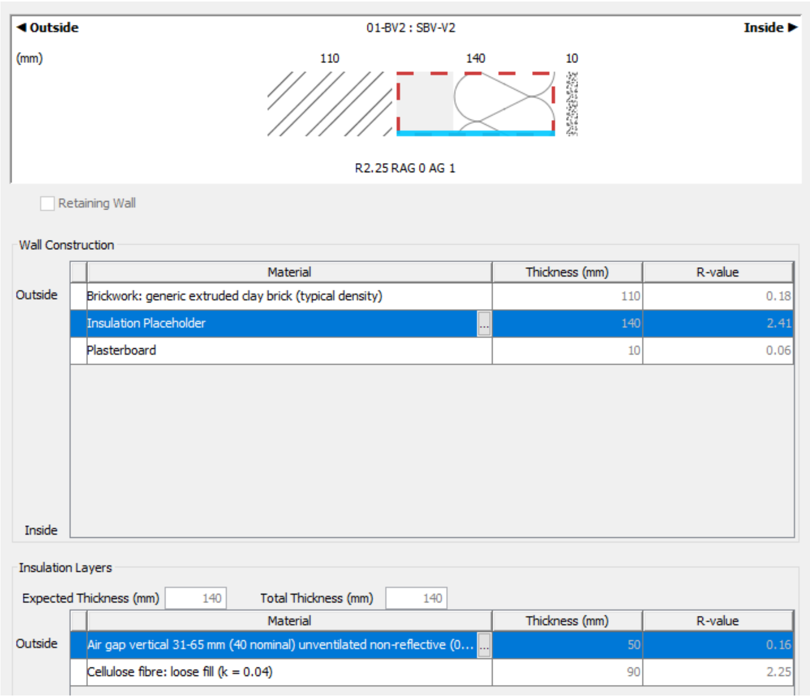


FIGURE 45: BRICK VENEER EXTERNAL WALL CONSTRUCTION AND INSULATION

8.2.2. Standard Brick Veneer Wall 90 mm studs and reflective air cavity

This wall system utilised the same build up as the standard brick veneer wall with the provision of a double sided Thermoseal Wall Wrap XP as detailed in Figure 47 (CSR, 2015). A high-performance insulation variation was also assessed for the Melbourne HIA standard home with an R value of 2.7 in the 90mm cavity. The provision of this reflective air cavity added 0.53 to the overall R value.

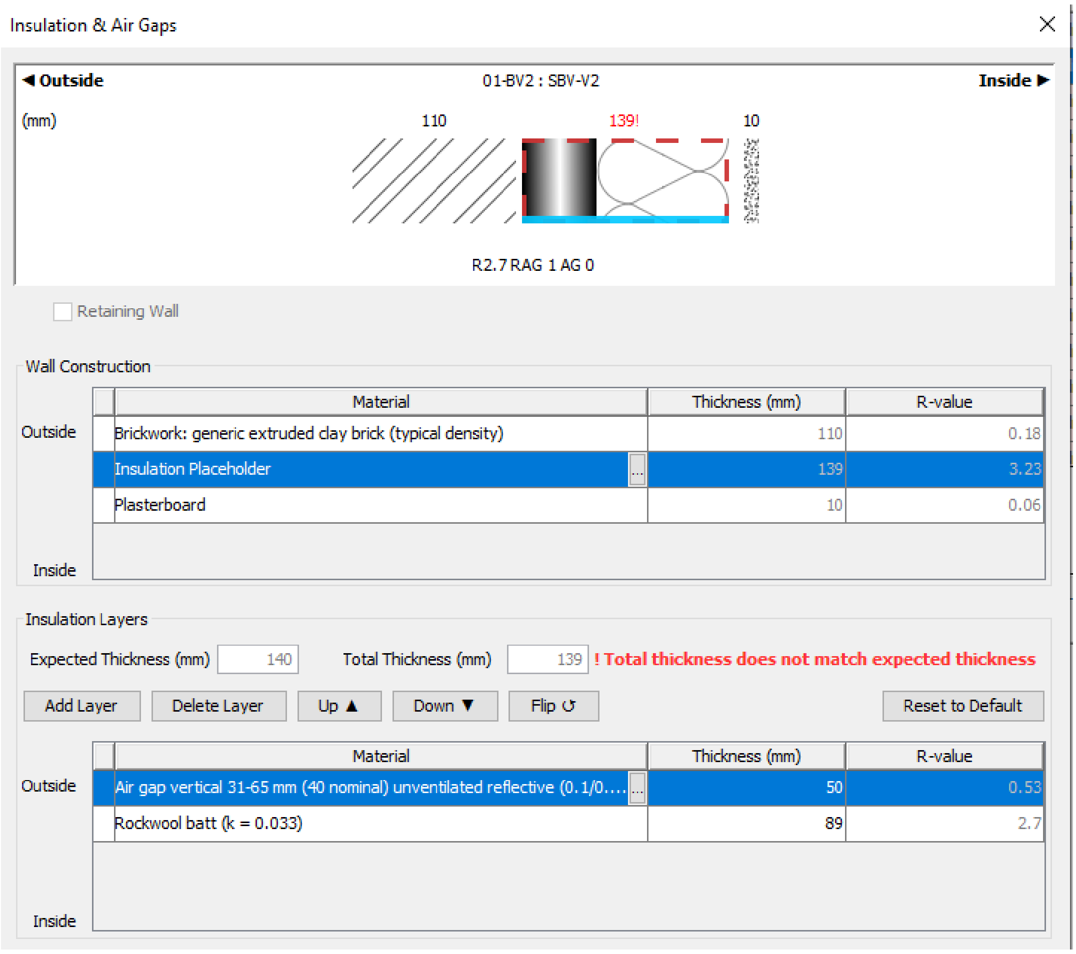


FIGURE 46: BRICK VENEER WITH REFLECTIVE AIR CAVITY SHOWN HERE WITH R 2.7 BATTS

8.2.3. Brick Veneer 140 mm studs

This wall construction type provided for a significantly larger frame with 140mm studs selected along with the corresponding insulation of R value 3.5. The selected wall build up is shown in Figure 5.

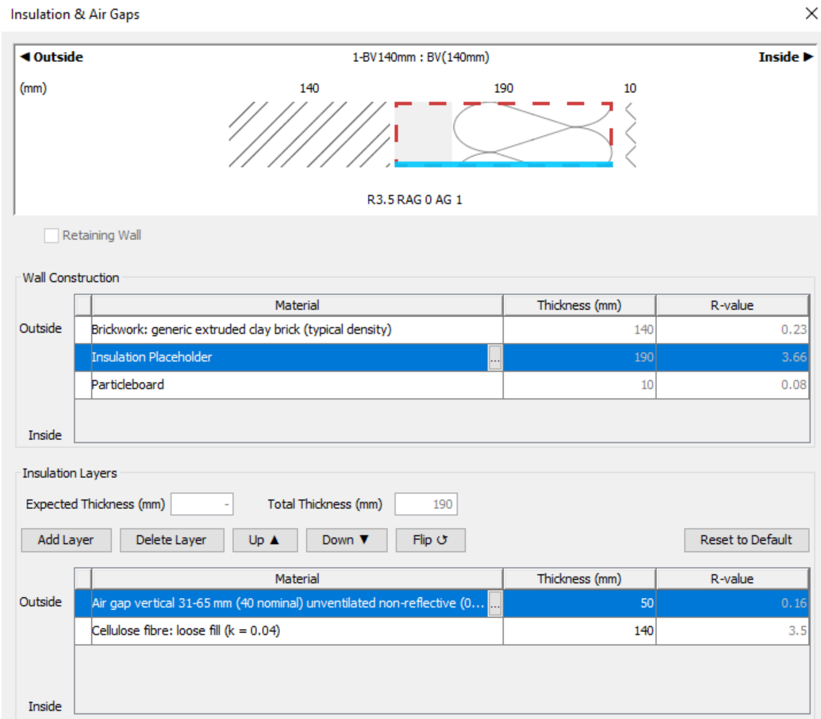


FIGURE 47: BRICK VENEER 140 MM EXTERNAL WALL CONSTRUCTION AND INSULATION

8.2.4. Brick Veneer 70 mm Studs

This wall construction type has a smaller frame with 70mm studs selected along with the corresponding of R value 1.75.

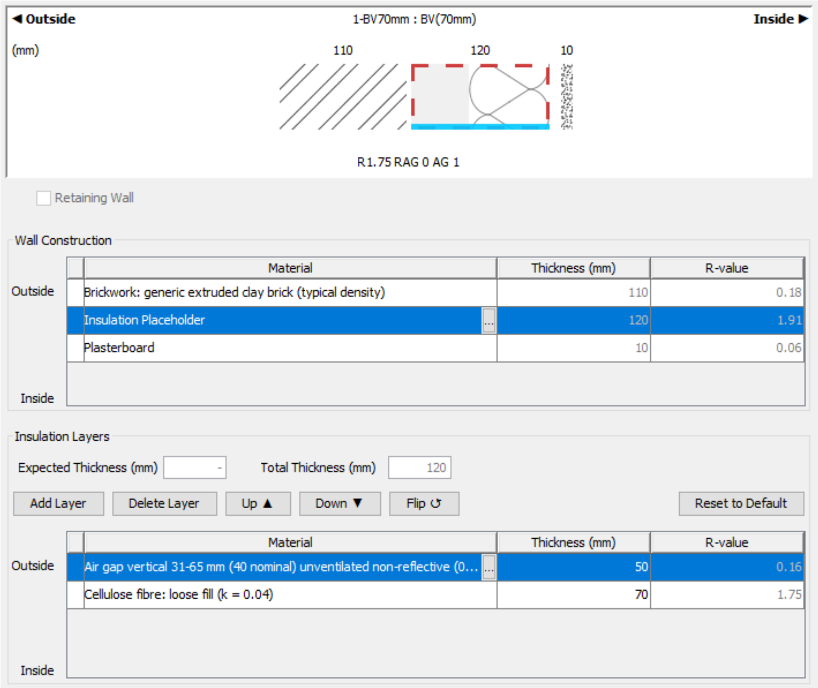


FIGURE 48: BRICK VENEER 70 MM EXTERNAL WALL CONSTRUCTION AND INSULATION

8.2.5. Cross laminated timber (CLT) XLAM

This wall construction type has 20mm slightly ventilated air cavity, an insulation layer (R 1.5) and a cross laminated timber XLAM layer with the corresponding insulation of R value 1.13 as detailed in Figure 7.

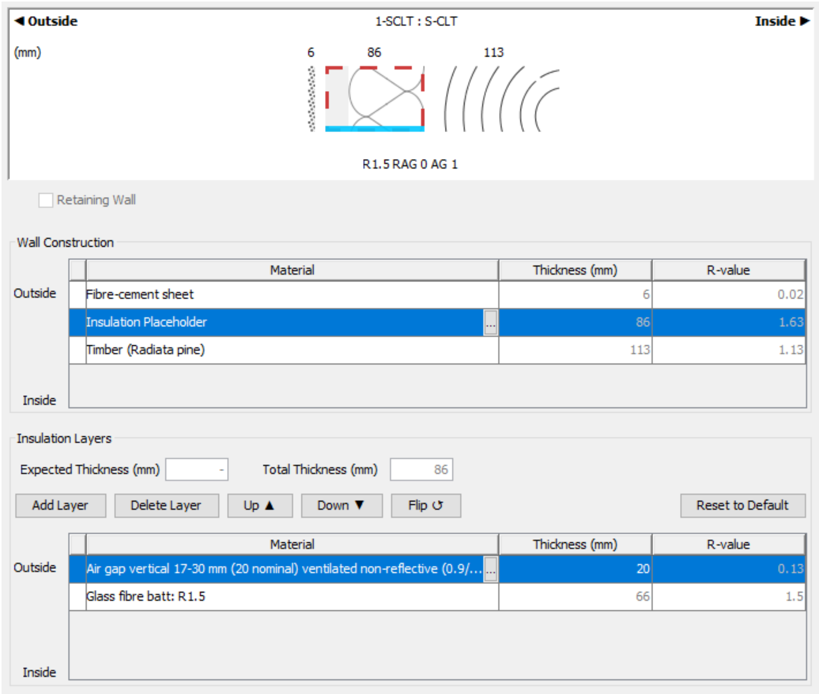


FIGURE 49: CROSS LAMINATED TIMBER XLAM EXTERNAL WALL CONSTRUCTION AND INSULATION

8.2.6. Light Weight Direct Fix

The Light Weight Direct Fix wall has 90 mm insulation (k = 0.04) as shown in Figure 8.

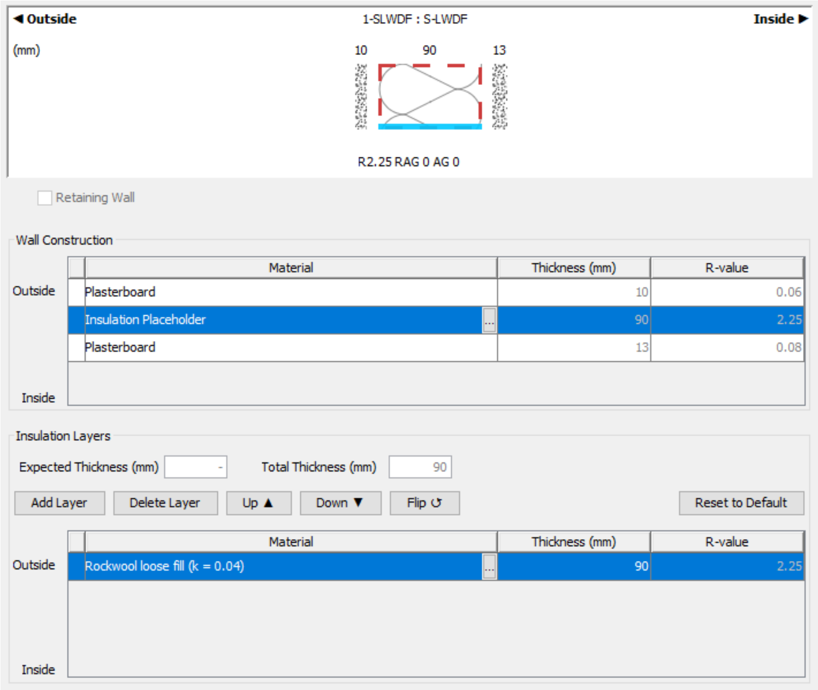


FIGURE 50: LIGHT WEIGHT DIRECT FIX EXTERNAL WALL CONSTRUCTION AND INSULATION

8.2.7. Light Weight Direct Fix 70mm

This wall construction type has the same properties with the above wall type, but it comes with an 70 mm insulation (k = 0.04).

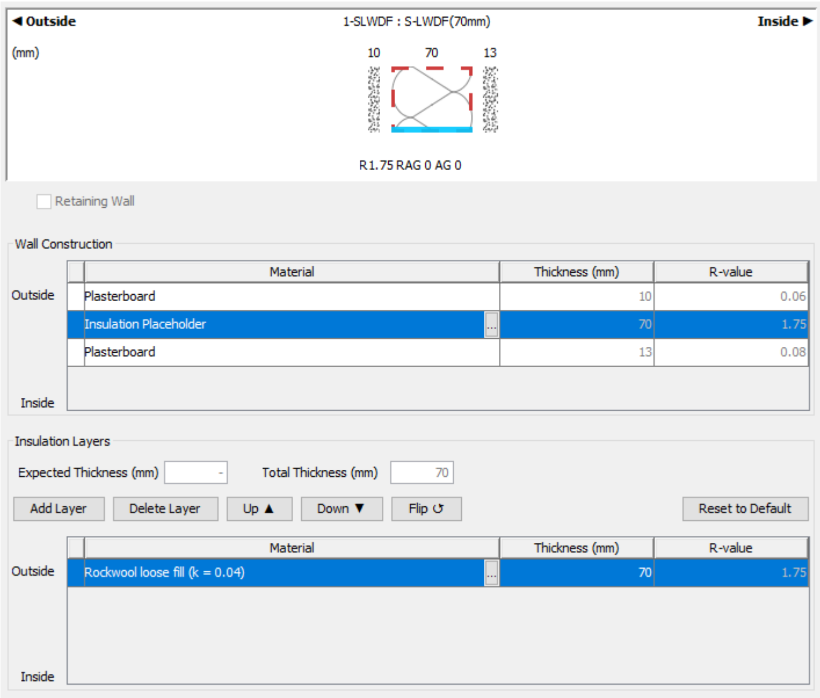


FIGURE 51: LIGHT WEIGHT DIRECT FIX 70 MM EXTERNAL WALL CONSTRUCTION AND INSULATION

8.2.8. High Performance 140mm

This wall construction type has 140 mm standard insulation (k = 0.04) placed in the middle of two air cavity layers.

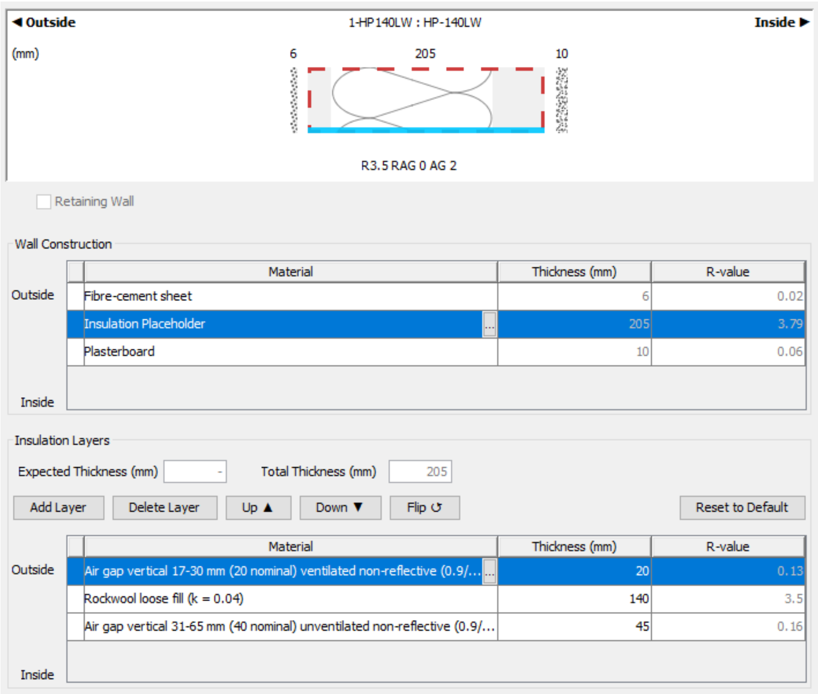


FIGURE 52: HIGH PERFORMANCE 140MM EXTERNAL WALL CONSTRUCTION AND INSULATION

8.2.9. Reverse Brick Veneer

This wall construction type reverses the position of brick veneer layer and the insulation layer compared to the standard brick veneer wall.

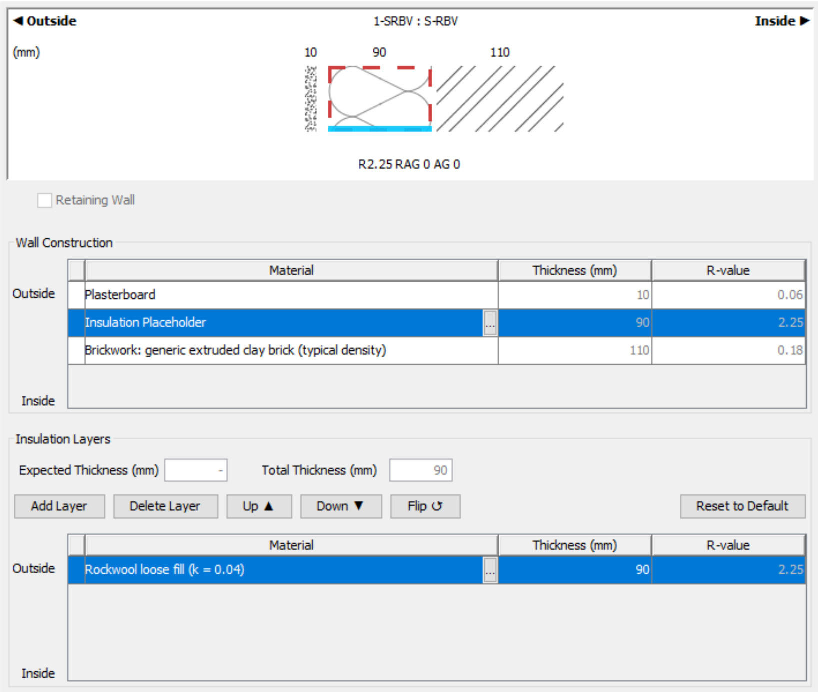


FIGURE 53: REVERSE BRICK VENEER EXTERNAL WALL CONSTRUCTION AND INSULATION

8.2.10. High Performance Light Weight

This wall construction type double 90 mm studs allowing for 180 mm of glass fibre batts (k = 0.044) as shown in Figure 12.

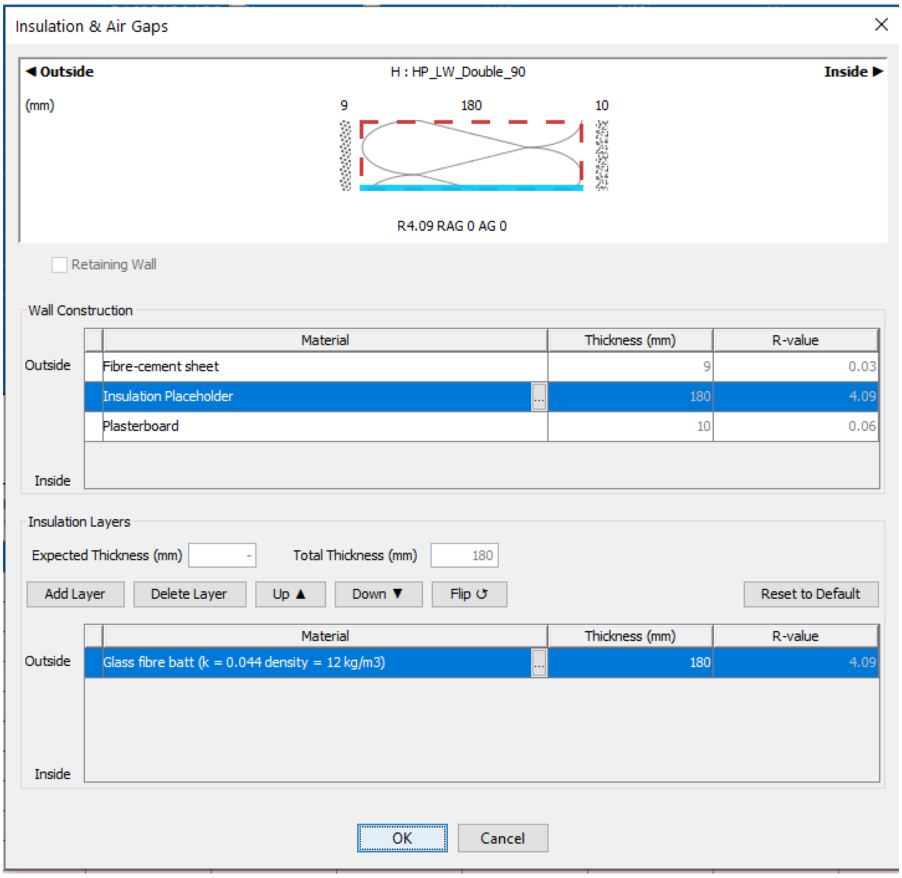


FIGURE 54: HIGH PERFORMANCE LIGHT WEIGHT EXTERNAL WALL CONSTRUCTION AND INSULATION

8.2.11. 75mm Hebel with R 2.0

This wall construction type includes an 75mm Hebel panel and a standard insulation with the corresponding insulation of R value 2.0.

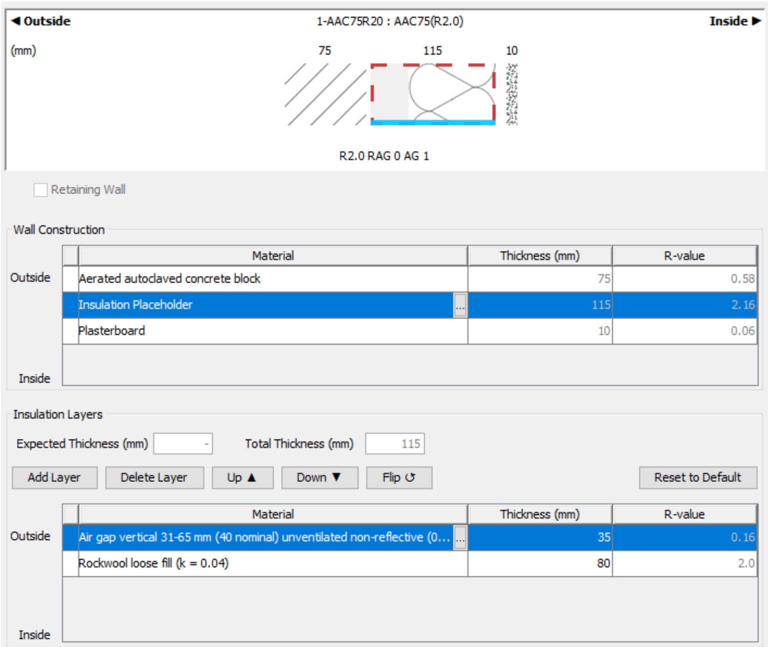


FIGURE 55: 75MM HEBEL WITH R 2.0 EXTERNAL WALL CONSTRUCTION AND INSULATION

8.2.12. 75 mm Hebel with R 2.7

This wall construction type has the same properties with the above wall type, but the R value of insulation layer is increased to 2.7.

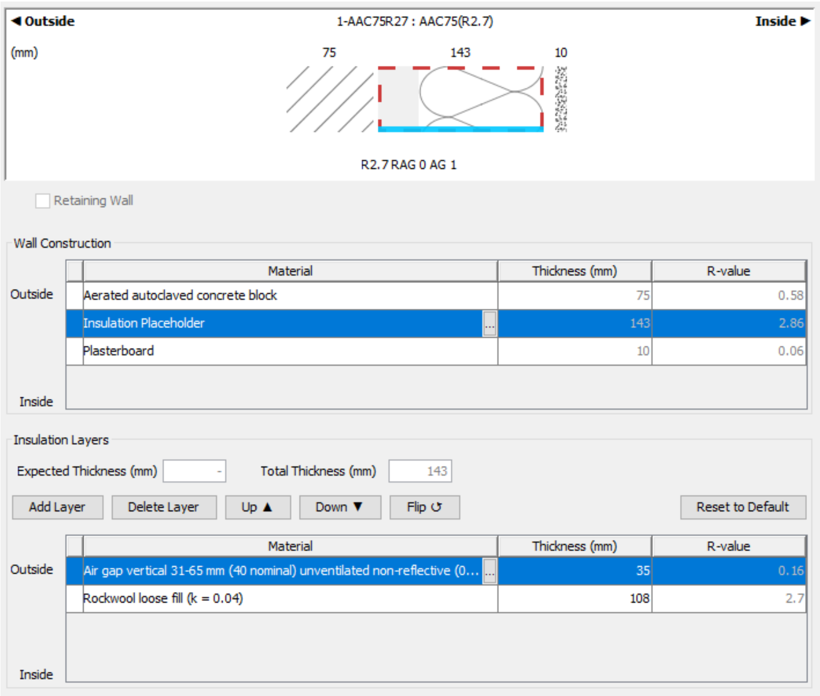


FIGURE 56: 75MM HEBEL WITH R 2.7 EXTERNAL WALL CONSTRUCTION AND INSULATION

8.3. HIA Standard Home Plans

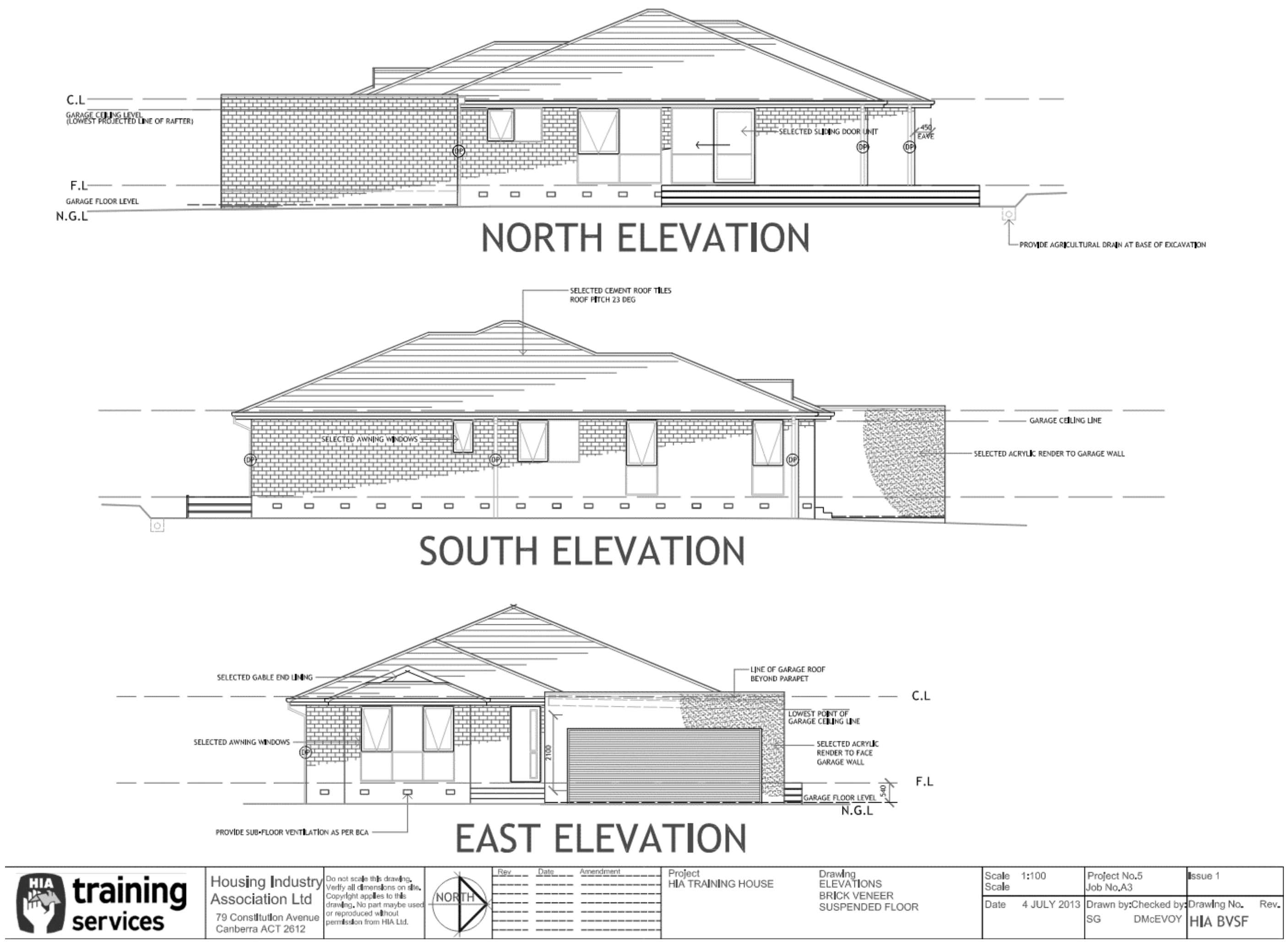


FIGURE 57: HIA STANDARD HOME (HIA 2013)

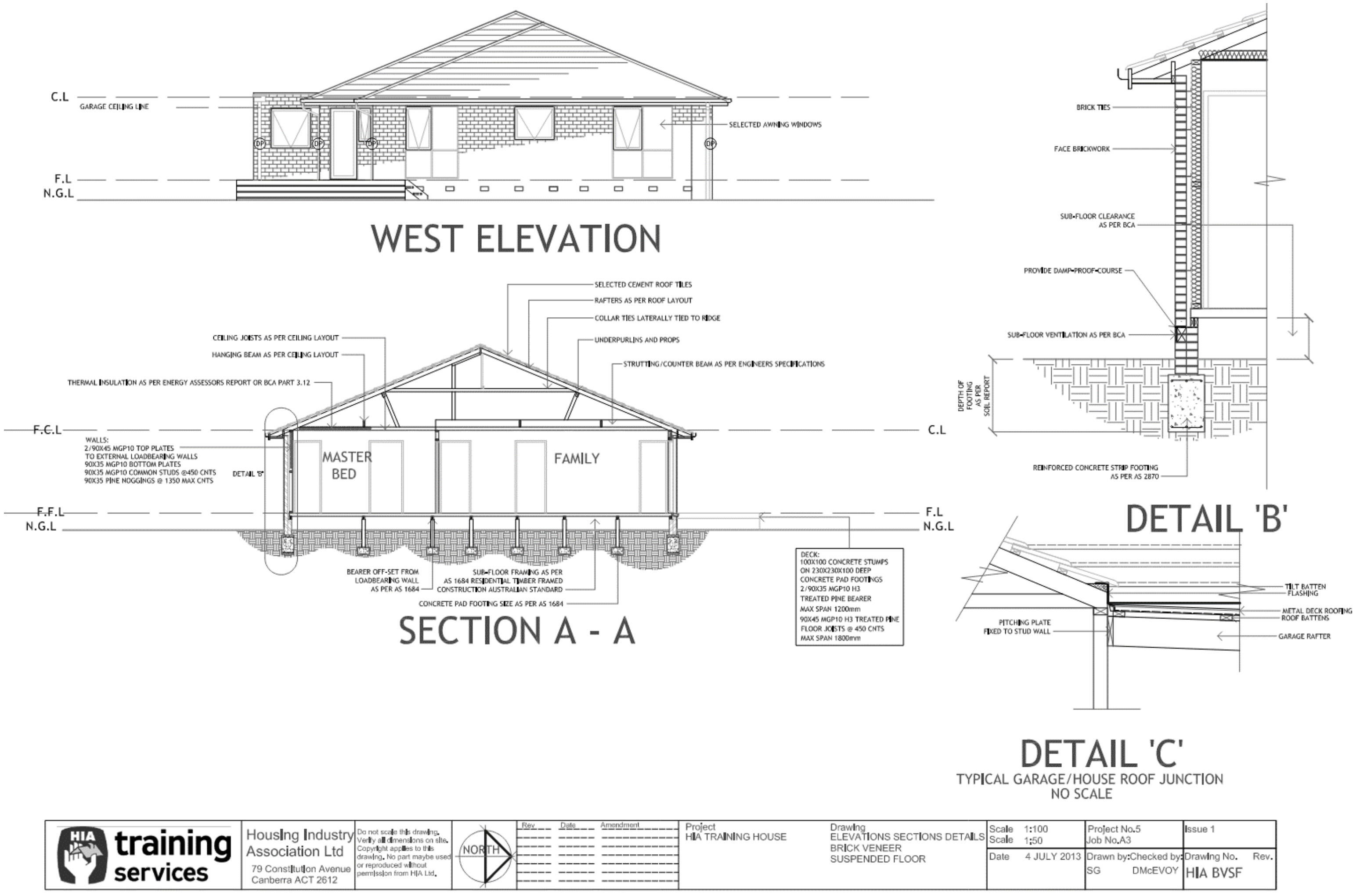


FIGURE 58: HIA STANDARD HOME SECTIONS (HIA 2013)

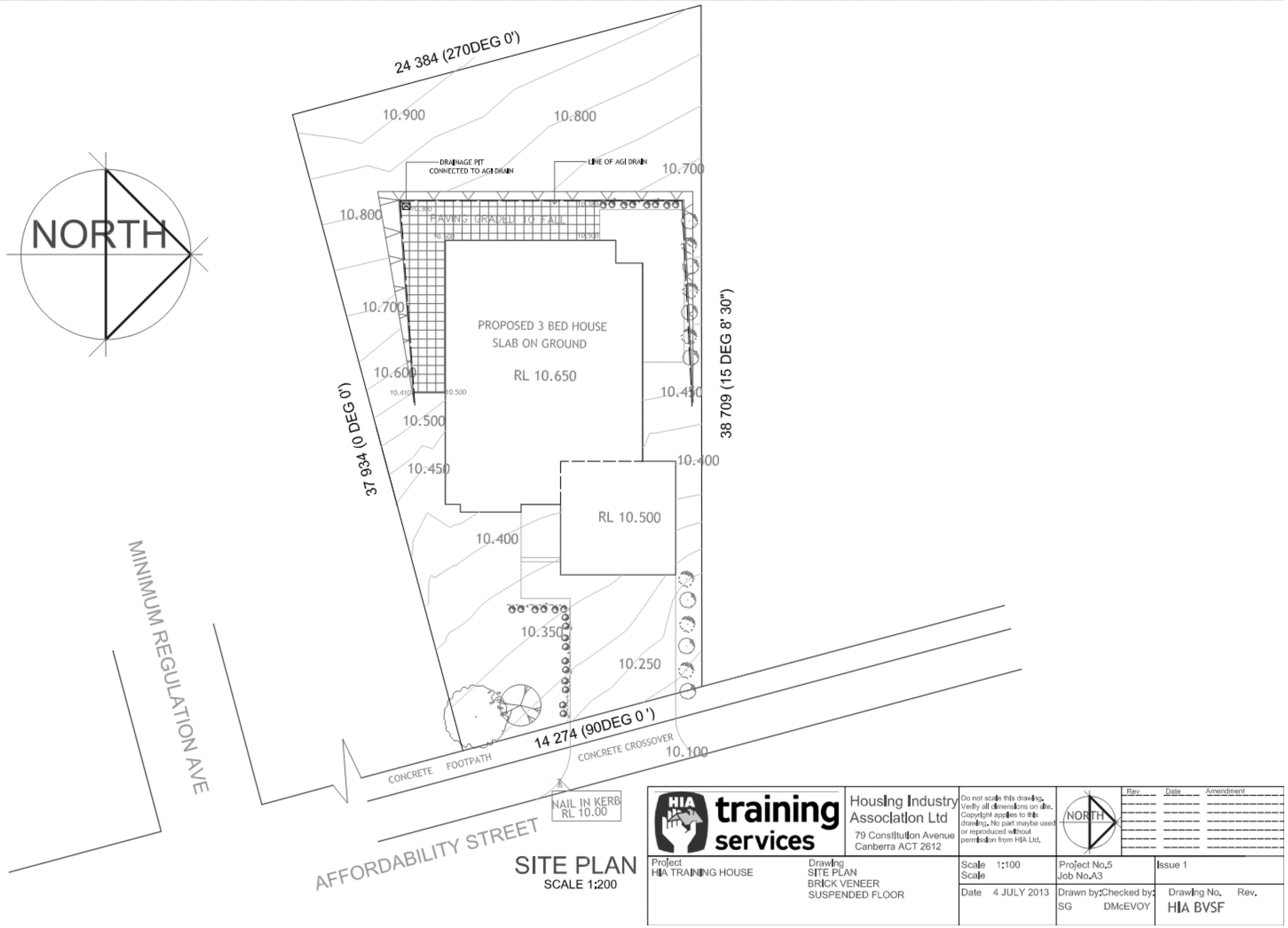


FIGURE 59: HIA STANDARD HOME SITE MAP (HIA 2013)

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