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Rules of thumb for attaining 5 star energy rating for timber-floored dwellings

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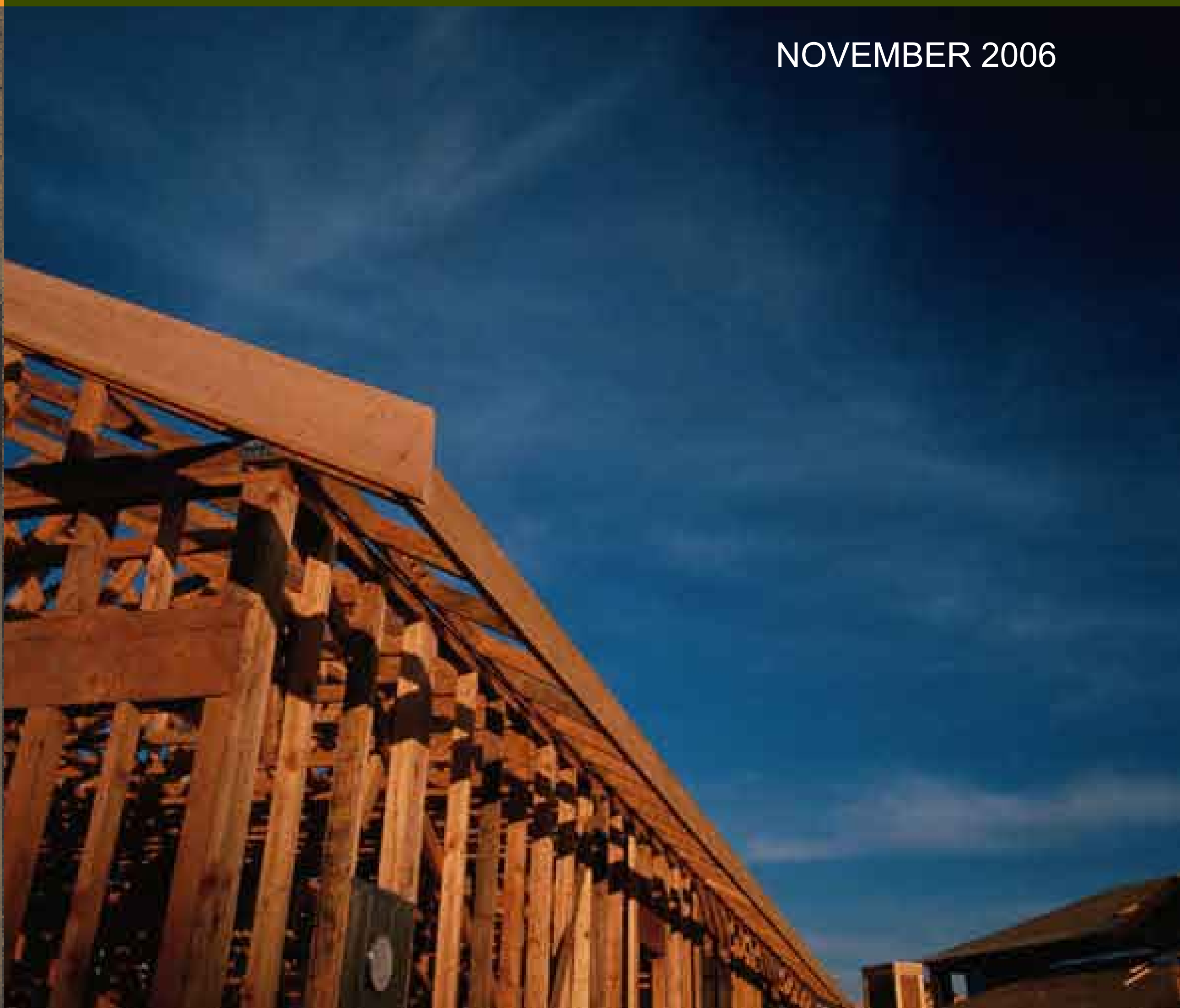

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Prepared for the

Forest & Wood Products
Research & Development Corporation

by

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1. Introduction

This project seeks to provide a selection of techniques which when applied to timber-floored dwelling designs which were compliant under the energy efficiency provisions of BCA 2003 (nominally 4 stars) will render them compliant under BCA 2006 (nominally 5 stars).

Builders, energy raters and the general consumer are under the impression that dwellings with suspended timber floors cannot simply and cost-effectively achieve a 5 star energy rating. With the recent finalisation of the AccuRate software, the timber industry requires simple and practical solutions for meeting a 5 star energy rating that can be easily disseminated to the broader marketplace.

A total of 36 dwellings with suspended timber floors (most of them enclosed) with an average 4 star rating were selected for the simulation and analysis of each proposed technique. The dwellings selected were simulated across eleven climate zones categorised into either hot climates, temperate climates or cool climates.

For each climate, ten techniques were recommended for best achieving a 5 star rating for suspended timber-floored dwellings. These techniques were analysed further to determine their cost effectiveness.

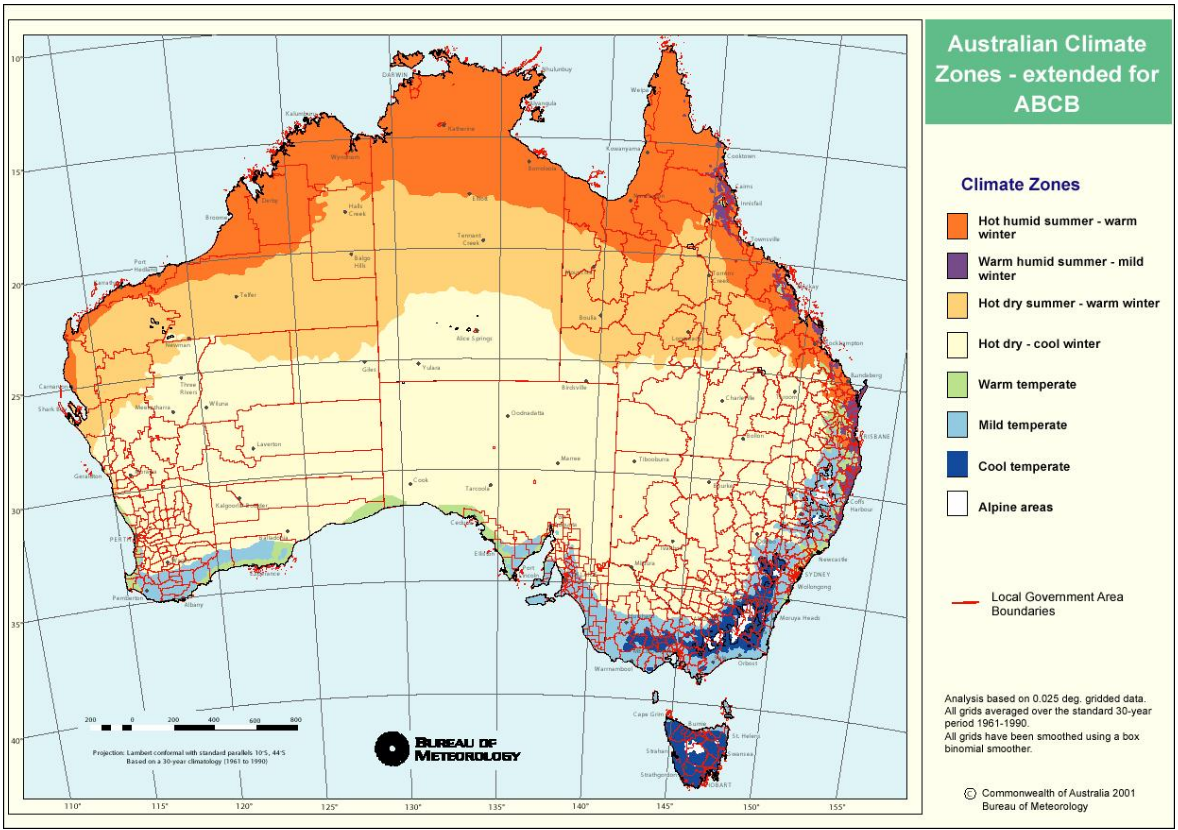

Figure 1: BCA Climate Zones.

2. Methodology

2.1. Selection of Climates for Analysis

The study utilised weather data from the new 69 climate sites in the recently updated and expanded Australian Climate Data Bank (Energy Partners, 2005). The climates in Table 1 were selected for the analysis. These climate locations include all state and territory capital cities plus three other climates so that the study covers all eight BCA climate zones as shown in Figure 1.

Climate Code[1]	AccuRate Climate #	Climate Name	Climate Category
CZ0101	1	Darwin Airport	Hot
CZ0204	10	Brisbane	Hot
CZ0306	6	Alice Springs	Hot
CZ0411	27	Mildura AMO	Temperate
CZ0504	13	Perth	Temperate
CZ0510	56	Mascot RO (East Sydney)	Temperate
CZ0512	16	Adelaide	Temperate
CZ0608	62	Melbourne (Moorabbin)	Temperate & Cool[2]
CZ0703	24	Canberra Airport	Cool
CZ0708	26	Hobart	Cool
CZ0801	25	Cabramurra	Cool

Table 1: The set of climate zones selected for the analysis.

2.2. Selection of Dwellings for Analysis

The dwellings were selected from the AccuRate Validation sample set of over 200 base designs as had been the fore-runners of this project (Energy Partners, 2006). The original floor construction was modified to timber floor where required to meet the project requirements. Twelve dwellings were selected for each of the three climate categories of hot, temperate and cool climates.

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1 Proposed new climate numbering system for AccuRate. The first two digits are the BCA climate zone, the last two digits are the Northerly ranking of that location within that BCA climate zone.

2 Climate zone 62 (Melbourne) was used to calculate the averages in both the temperate and cool climate dwelling sets.

The following criteria were used to select the dwellings:

- Timber floor, preferably with enclosed subfloor construction
- Energy rating between 3.5 and 4.5 stars in the test climate
- Single-storey dwelling
- Low to medium level bulk insulation in walls and ceilings
- Gross floor area greater than 150m^2
- Original design climate preferably similar to test climate

2.3. Key Characteristics of the Dwellings

Some of the main characteristics of the 36 selected dwellings (12 hot, 12 temperate and 12 cool dwellings) are presented in Table 2, Table 3 and Table 4. None of the base dwellings had bulk floor insulation, reflective foil in the roof or reflective foil in the walls. The window area includes the frame and glazing.

NCFA	Net Conditioned Floor Area
CB	Standard Concrete Block
WB	Weatherboard
BV	Brick Veneer
FC	Fibre-Cement Sheet (Compressed)
DB	Double Brick/Brick Cavity
MB	Mud Brick
AAC	Autoclaved Aerated Concrete

Base Dwelling Code	Main External Wall Construction	Decimal Star Rating for Darwin Climate 31 (stars)	NCFA (m^2)	External Wall Area (m^2)	Window Area (m^2)	Ceiling Insulation (R-value)	External Wall Insulation (R-value)	Sub-floor Wall Insulation (R-value)	No. Unsealed Penetrations
B5ADA000	CB 190mm (Core-filled at 1500 centres)	4.50	210.5	324.7	49.2	2.5	1.0	1.0	0
B8ADA000	CB 75mm	4.57	144.5	188.7	37.0	2.5	1.4	1.4	0
BDDS1401	CB 150mm	3.88	137.3	193.0	63.2	0.5	0.0	0.0	0
BDDS1424	WB	3.58	135.6	251.6	40.3	0.0	0.0	0.0	0
BDDS1585	CB 190mm (Core-filled at 1500 centres)	3.99	137.5	175.0	34.4	2.5	0.0	0.0	0
BHDC1627	BV	3.90	245.4	276.4	46.4	3.5	1.5	1.5	0
BLDC1587	BV	3.77	150.5	225.60	42.7	2.0	1.0	0.0	0
BMDL1005	WB	3.96	135.0	207.4	56.0	1.5	1.0	1.0	0
BPDL1606	BV	3.97	225.4	289.1	56.5	3.5	1.5	1.5	2
BTDC1631	BV	3.62	135.8	336.9	71.6	3.5	1.5	1.5	0
BTDS1617	FC 6mm	3.61	127.6	246.6	58.8	2.0	1.0	0.0	0
BWDL1502	WB	3.96	215.5	329.7	55.1	1.5	0.0	0.0	5
	AVERAGE	**3.94**	**166.7**	**253.7**	**50.9**	**2.1**	**0.8**	**0.7**	**0.6**

Table 2: Main characteristics of the 12 selected dwellings for the analysis in hot climate zones.

Base Dwelling Code	Main External Wall Construction	Decimal Star Rating for Sydney Climate 86 (stars)	NCFA (m^2)	External Wall Area (m^2)	Window Area (m^2)	Ceiling Insulation (R-value)	External Wall Insulation (R-value)	Sub-floor Wall Insulation (R-value)	No. Unsealed Penetrations
BBDC1130	BV	4.19	160.0	199.4	44.1	2.5	1.0	1.0	0
BDCD1613	BV	3.42	180.4	267.0	41.6	2.5	1.5	1.5	3
BHDC1621	BV	4.02	209.3	213.6	36.8	3.5	0.0	0.0	0
BHDC1626	BV	3.91	245.4	276.4	46.4	3.5	1.0	1.0	0
BHDC1627	BV	3.38	245.4	276.4	46.4	3.5	0.0	0.0	0
BLDC1587	MB 300mm	3.52	174.1	269.4	48.0	4.0	0.0	0.0	0
BPDL1605	BV	3.74	203.1	225.4	56.7	4.0	1.5	1.5	0
BPDL1606	BV	4.18	225.4	289.1	56.5	3.5	1.0	1.0	2
BPDL1607	BV	3.70	203.0	211.2	52.5	3.5	1.0	1.0	0
BSDC1079	BV	4.31	158.0	240.6	40.4	2.5	1.0	1.0	0
BSDS1578	MB 300mm	3.57	174.1	269.4	48.0	2.5	0.0	0.0	0
BWDB1690	DB	3.62	156.6	230.8	48.4	2.5	0.0	0.0	7
	AVERAGE	**3.80**	**194.6**	**247.4**	**47.2**	**3.2**	**0.7**	**0.7**	**1.0**

Table 3: Main characteristics of the 12 selected dwellings for the analysis in temperate climate zones.

Base Dwelling Code	Main External Wall Construction	Decimal Star Rating for Canberra Climate 54 (stars)	NCFA (m^2)	External Wall Area (m^2)	Window Area (m^2)	Ceiling Insulation (R-value)	External Wall Insulation (R-value)	Sub-floor Wall Insulation (R-value)	No. Unsealed Penetrations
BBDC1130	BV	4.12	160.0	199.4	44.1	2.5	1.0	0.0	0
BBDC1511	AAC 200mm & WB	4.46	215.3	291.3	70.3	3.0	1.5	1.5	7
BCDT1049	BV	3.48	183.1	219.6	47.7	2.5	1.5	0.0	2
BDCD1613	BV	3.85	180.4	267.0	41.6	2.5	1.5	1.5	3
BHDC1621	BV	4.19	209.3	213.6	36.8	3.5	0.0	0.0	0
BHDC1626	BV	3.80	179.5	219.8	35.7	3.5	0.0	0.0	1
BHDC1627	BV	3.72	245.4	276.4	46.4	3.5	0.0	0.0	0
BPDL1600	BV	4.69	176.1	224.7	41.8	4.5	1.5	1.5	0
BPDL1605	BV	4.03	203.1	225.4	56.7	4.0	1.5	1.5	0
BPDL1606	BV	4.35	225.4	289.1	56.5	3.5	1.0	1.0	2
BPDL1607	BV	4.59	203.0	211.2	52.5	3.5	1.0	1.0	0
BSDC1079	BV	4.07	158.0	240.6	40.4	2.5	1.0	1.0	0
	AVERAGE	**4.11**	**194.9**	**239.8**	**47.5**	**3.3**	**1.0**	**0.8**	**1.3**

Table 4: Main characteristics of the 12 selected dwellings for the analysis in cool climate zones.

The base dwellings above have a range of orientations. Some dwellings may have undesirable orientations but still be able achieve the 3.5 to 4.5 star rating range due to good quality construction methods and materials such as good insulation, type of construction materials used and so forth. On the other hand, badly constructed dwellings with appropriate orientations may still have made the 3.5 to 4.5 star rating range. This may explain the reason for the variations in insulation R-values, construction materials used and other construction details.

2.4. Selection of Techniques for Simulation

Various techniques will be more suited to warmer or colder climates and indeed several can improve the rating in Darwin while impairing it in Hobart (and vice versa). To explore this and ensure that a suitable range of choices are available to builders in all climates, we have analysed a set of 18 techniques and tested them in all climates. These techniques and their indicative costs are presented in Table 5 to Table 9. The impacts of orientation and shading are considered design matters and so have not been investigated within this project but are recommended for further work.

2.4.1. Roofs and Ceilings

Technique No.	Technique Description	Indicative Cost[3]
1	Add reflective foil to the underside of the roof as set by Australian Standards 2006.	$\$4/m^2$
2	Add R4.0 bulk insulation to the ceiling (in lieu of original).	$\$8/m^2$ ($\$2/m^2$ for adding to R3.0[4])
3	Add explicit ventilation of the attic space.	$\$1\text{-}2/m^2$
4	Change the roof colour to Dark (in lieu of Medium).	Nil
5	Change the roof colour to Light (in lieu of Medium).	Nil

Table 5: Roof & Ceiling Techniques.

2.4.2. Walls

Technique No.	Technique Description	Indicative Cost
6	Add R2.0 bulk insulation to the external walls (in lieu of original).	$\$6/m^2$ ($\$1/m^2$ for adding to R1.5[5])
7	Add anti-glare reflective foil to the external walls (in addition to R2.0).	$\$4/m^2$
8	Add R2.0 bulk insulation to the inter-zone walls.	$\$6/m^2$

Table 6: Wall Techniques.

2.4.3. Floors

Technique No.	Technique Description	Indicative Cost
9	Add R2.0 bulk insulation to the floor (in lieu of original).	$\$10/m^2$

3 Indicative installed costs for labour and materials per m² of GFA (Gross Floor Area) The source of costing comes mostly from industry experience and internal operations of Energy Partners.

4 Extra $\$2/m^2$ from going to R3.0 to R4.0.

5 Extra $\$1/m^2$ from going to R1.5 to R2.0.

10	Add R2.0 bulk insulation to the subfloor walls. Minimise subfloor ventilation in compliance with the BCA minimum requirements.	$2/m^2

Table 7: Floor Techniques

2.4.4. Windows

Technique No.	Technique Description	Indicative Cost
11	Change frames to Improved Aluminium (thermally similar to timber).[6]	$2/m^2 - $15/m^2
12	Change glazing to clear louvres[7] (to obtain 90% openability for ventilation).	$25/m^2
13	Change glazing to Double Glazed clear[8].	$13/m^2
14	Change glazing to Double Glazed tinted/toned external pane.	$15/m^2

Table 8: Window Techniques

2.4.5. Other Techniques

Technique No.	Technique Description	Indicative Cost
15	Weatherstrip all external doors and windows.	$2/m^2

6 Thermally enhancing aluminium windows by the thoughtful detailing of the timber reveal is generally much cheaper than the internally thermally improved aluminium window frames and hence the large variation in costs. See page 31 for sample details.

7 Cost for cyclonic areas. Lower costs apply elsewhere.

8 Incremental costs vary widely with the builder's volume and with the maturity of the double glazing market in which they trade. Our indicative costs per m² of GFA were informed by the following advice from the Australian Glass and Glazing Association (AGGA).

Additional costs for standard IGU (Insulating Glazed Unit) to major fabricators in Victoria are as low as $30 rising to $40 in NSW and $45 in Tas, SA and Qld. Costs in WA/NT are hard to pin down, but likely to be $50–60.

Fabricator to major builder can be as low as plus $50 in Victoria (available from a number of suppliers), but is more expensive in other States. Best in NSW likely to be $70-80, same for Qld, Tas, SA, WA, but numbers of suppliers is more limited than in Victoria. Fabricators in states other than Victoria are still choosing to price IGUs as 'custom' products, although there are signs that NSW is not far away from moving in the Victorian direction.

16	Seal all penetrations (exhaust fans, chimneys, vents and down-lights).	$2/m^2
17	Provide ceiling fans in all habitable rooms.	$8/m^2
18	Reduce window glazing area by 25%.	- $5/m^2

Table 9: Other Techniques

2.5. Methodology of Analysis

2.5.1. Increase In Decimal Star Rating

Each of the dwellings was modified one by one to satisfy each of the techniques. The 12 modified hot climate dwellings were simulated across each of the hot climate zones for each technique. The average increase in star rating from the base dwelling for each hot climate zone was calculated. The mean of these averages for each of the hot climate zones was taken to get a final average value in the increase in star rating for hot climates for each of the techniques. The same methodology was applied for temperate and cool climate dwellings in their respective climate zones. This final average increase in star rating for each technique was used to find the top ten techniques for each of the climate categories – hot, temperate and cool.

The top ten techniques for each climate category were applied to the respective dwellings and simulated to find out the total star rating increase that can be achieved. This was compared to the cumulative star increases of each technique separately.

2.5.2. Cost Effectiveness

Each technique in each of the climate categories was assigned a cost effectiveness. The cost effectiveness is a simple calculation that divides the indicative costs of the technique by the average increase in star rating for the particular technique in the climate category. This gives an indication of how effective the money invested in the technique increases the star rating and is in units of $/m^2 per star. The cost effectiveness will vary by +/- $0.5/m^2 per star due to rounding errors.

Where a technique cost had a range, the upper bound was used to calculate the cost effectiveness. For ceiling and wall insulation, the cost of adding to R3.0 ceiling insulation to achieve R4.0 ($2/m^2) and adding to R1.5 wall insulation to achieve R2.0 ($1/m^2) was used.

3. Results

3.1. Techniques and Indicative Costs

Table 10 shows the results of each technique. Each technique was simulated across all climates and the analysis shows the average decimal star rating difference from the base dwelling for cool, temperate and hot climates. Figure 2 is a graph of these results.

		Difference in Decimal Star Rating Average		
Technique	Indicative Cost	Hot Climates	Temperate Climates	Cool Climates
1	$\$4/m^2$	+ 0.26	+ 0.17	+ 0.08
2	$\$8/m^2$ ($\$2/m^2$ R2.5)	+ 0.34	+ 0.17	+ 0.13
3	$\$1\text{-}2/m^2$	+ 0.05	+ 0.03	- 0.01
4	Nil	- 0.40	- 0.08	+ 0.04
5	Nil	+ 0.19	+ 0.04	- 0.02
6	$\$6/m^2$ ($\$1/m^2$ R1.5)	+ 0.36	+ 0.50	+ 0.35
7	$\$4/m^2$	+ 0.06	+ 0.04	+ 0.04
8	$\$6/m^2$	+ 0.09	+ 0.15	+ 0.20
9	$\$10/m^2$	- 0.03	+ 0.03	+ 0.49
10	$\$2/m^2$	+ 0.17	+ 0.14	+ 0.13
11	$\$2/m^2$ - $15/m^2$	+ 0.12	+ 0.25	+ 0.32
12	$\$5/m^2$	+ 0.22	+ 0.10	+ 0.03
13	$\$10/m^2$	+ 0.41	+ 0.55	+ 0.58
14[9]	$\$12/m^2$	+ 0.72	+ 0.54	+ 0.40
15	$\$2/m^2$	+ 0.12	+ 0.07	+ 0.09
16	$\$2/m^2$	+ 0.02	+ 0.09	+ 0.09
17	$\$8/m^2$	+ 0.29	+ 0.09	+ 0.02
18	- $\$5/m^2$	+ 0.47	+ 0.41	+ 0.31

Table 10: Average decimal star rating difference from the base dwelling across all climates.

[9] The effects of double glazed tinted/toned windows must necessarily be compared with double glazed clear windows (Technique 13).

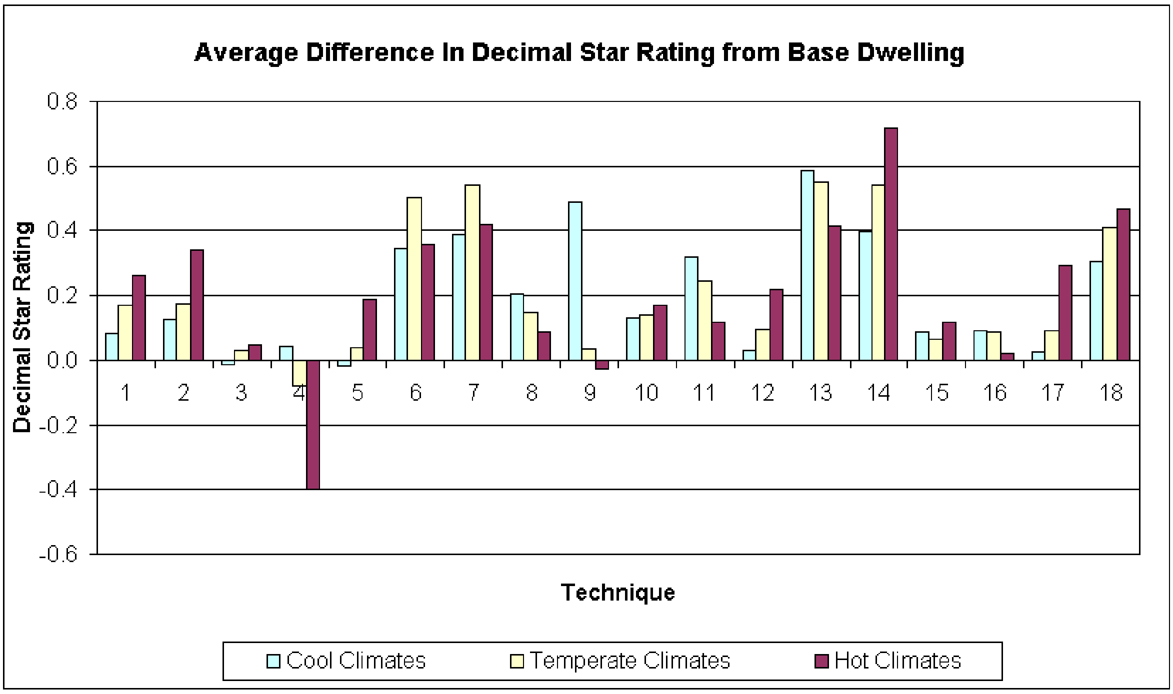


Figure 2: Average decimal star rating difference from the base dwelling across all climates.

Technique	Description
1	Reflective roof foil
2	Ceiling Insulation
3	Roof space ventilation
4	Dark roof
5	Light roof
6	Exterior wall insulation
7	Exterior wall insulation plus reflective foil
8	Inter-zone wall insulation
9	Floor insulation
10	Subfloor wall insulation and minimised ventilation
11	Improved aluminium window frames
12	Clear window louvres with 90% openability
13	Double glazed clear windows
14	Double glazed tinted/toned windows
15	Weatherstrip external doors and windows
16	Seal penetrations
17	Ceiling fans
18	Glazing area reduced by 25%

Table 11: Technique key for Figure 2.

3.2. Base Dwellings

The results for technique 2 (R4 ceiling insulation) and technique 6 (R2 exterior wall insulation) need to be viewed in conjunction with the original insulation values of the base dwelling. As can be seen from Figure 3, hot climate base dwellings that were simulated had a lower than average level of ceiling insulation. This corresponds to a higher than average increase in the decimal star rating than the cool and temperate climate dwellings. The same applies for the lower average value of exterior wall insulation for temperate climate dwellings that were simulated and the larger increase in average decimal star rating for technique 6 shown in Figure 4. None of the dwellings had under-floor bulk insulation so the increases in decimal star are relative to each other across all climates.

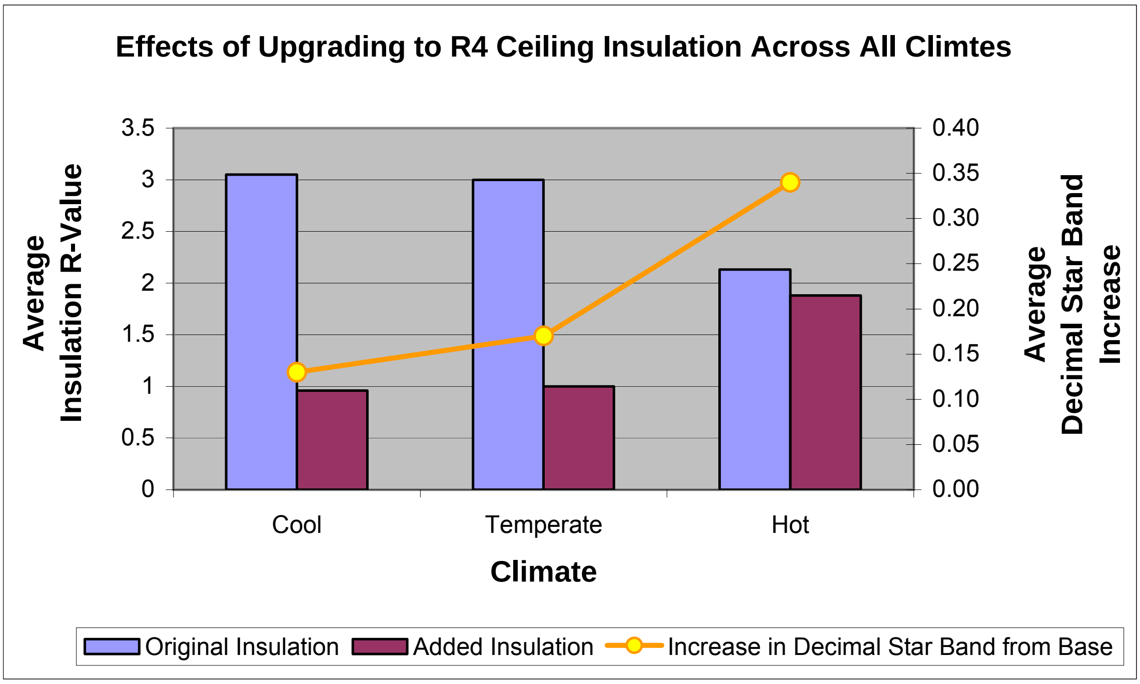


Figure 3: The average ceiling insulation R-values of the base dwellings and the average amount of insulation added to the ceiling for each climate. It also shows the average increase in the decimal star from installing R4 ceiling insulation for each climate.

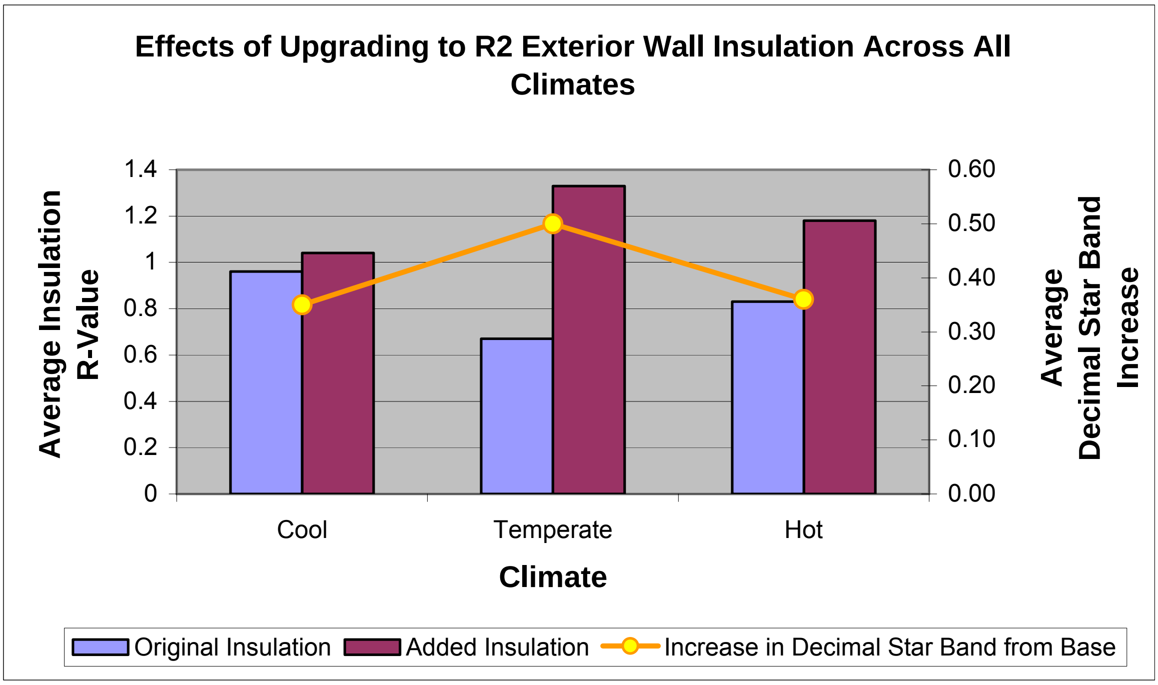


Figure 4: The average exterior wall insulation R-values of the base dwellings and the average amount of insulation added to the walls for each climate. It also shows the average increase in the decimal star from installing R2 exterior wall insulation for each climate.

None of the dwellings had reflective foil on the underside of the roof, floor or in the exterior walls. 32 out of the 36 dwellings had a 'standard ventilated' roof space consistent with unsarked tiled roofs and (with only one exception) all dwellings had an enclosed subfloor. The subfloor ventilation was not minimised in most cases. All dwellings had no floor or internal wall insulation. A high majority of dwellings had single glazed clear windows with aluminium frames with openability less than or equal to 40%. None of the dwellings had weatherstripped doors or windows and only a small number of dwellings had some unsealed penetrations, mostly exhaust fans. Most dwellings had no ceiling fans installed.

3.3. Discussion Of Results

Ceiling and wall insulation is always important in all climates for achieving a high star rating. The differences in the increases in star rating for ceiling and wall insulation, between the three climate types, are mainly due to the differences in average insulation values of the base dwellings. Floor insulation is only important for cool climates. All climates experienced considerable benefits from insulating subfloor walls and minimising ventilation, however further investigation needs to be carried out to determine whether the insulation or the ventilation has the greater impact on increasing the star rating. All climates also experienced improvements in the star rating by insulating inter-zone walls, which was increasingly more effective with cooler climates.

Dwellings in hot climates should be protected as much as possible from incoming radiation from the sun. This is the reason for the large increase in star rating for tinted/toned double glazed windows. It also mostly explains the larger increases in star rating from using reflective foil in the ceiling and walls as compared to temperate and cooler climate zones.

In cool climate zones it is beneficial to maximise the sun's radiation entering the dwelling during the winter. This explains the drop in the average increase in star rating between double glazed clear and double glazed tinted windows for cool climates. However, cooler climates still benefited from reflective foil in the ceiling and external walls. Reducing the glazing area was beneficial across all climate zones but more so in warmer climates. Reducing the glazing area for cool climate dwellings helps to reduce the winter heat loss through windows, whereas reducing the glazing area for hot climate dwellings helps to reduce the heat gain from the outside air and also the heat gain from the solar radiation. Reducing the window area also creates reductions in ventilation for cooling. Obviously there is a trade-off in cool climate zones between reducing the glazing area to minimise inside winter heat loss and increasing northerly-orientated glazing to maximise the daytime winter solar heat gain.

Improved aluminium window frames (approximately equivalent in performance to PVC or timber) were increasingly more effective in cooler climates. Double-glazing had significant positive effects across all climates, more so in cooler climates. As expected, changing windows to louvres or casements with 90% openability was increasingly more effective in hot climates.

Using a dark coloured roof in cool climates is slightly more beneficial than using a light coloured roof. The cooler the climate is, the greater the benefits dark roofs provide. On average, temperate climates benefited slightly with light coloured roofs except for climate zone 62 (Melbourne Moorabbin) which slightly benefited from a dark roof. It may be more desirable to have a medium coloured roof in temperate climates but this will need to be further investigated. A dark roof in hot climates has great negative impacts on the thermal performance of the dwelling. It is highly desirable to have a light coloured roof in such climates.

Sealing penetrations such as exhaust fans, chimneys, vents and down lights was more effective in cool and temperate climates. However, the average increase in the star rating was not great which is due to the small numbers of unsealed penetrations in most simulated dwellings. Sealing penetrations becomes very important, especially in cool and temperate climates, when there are large numbers of unsealed penetrations.

Ceiling fans only had great positive impacts in humid hot climates and some humid temperate climates. Hot dry climates did not experience a very large increase in average star rating for ceiling fans.

Draught sealing doors and windows had comparably small increases in the average star rating across all climates as well as adding explicit ventilation in the roof space.

4. Top Ten Techniques

The following lists the top ten recommended techniques for achieving a 5 star rating for cool, temperate and hot climates. These recommendations are based on the average increase in star rating from the base dwellings for each technique in each climate. Of course, each increase in the decimal star rating for the techniques is highly influenced by the original construction of the dwellings. Each technique is also accompanied by a cost-effectiveness measure showing the associated technique cost per square meter of floor area per increase in rating of one star (i.e. the indicative cost is divided by the decimal star increase in the rating).

4.1. Hot Climates

Ranking	Recommended Techniques (Technique No.)	Average Increase in Decimal Star	Indicative Cost Effectiveness ($\$/m^2$ per star)
1	Replace single glazed windows with double glazed tinted/toned (14)	+ 0.72	17
2	Reduce window glazing area by 25% (18)	+ 0.47	- 9
3	Increase external wall insulation to R2.0 from average R0.8 (6)	+ 0.36	3
4	Increase ceiling insulation to R4.0 from average R2.1 (2)	+ 0.34	6
5	Install ceiling fans in all habitable rooms (17)	+ 0.29	27
6	Install reflective foil to the underside of the roof (1)	+ 0.26	15
7	Change existing windows to clear louvres with 90% openability (12)	+ 0.22	23
8	Change roof to a light colour (5)	+ 0.19	0
9	Increase subfloor wall insulation to R2.0 from average R0.7 and minimise ventilation (10)	+ 0.17	12
10	Weatherstrip all external doors and windows (15)	+ 0.12	17
	Total of Individual Effects	**+ 3.14**	

Table 12: The top ten techniques for hot climate dwellings based on the average increase in decimal star from the base dwelling for each technique.

4.2. Temperate Climates

Ranking	Recommended Technique (Technique No.)	Average Increase in Decimal Star	Indicative Cost Effectiveness ($/m^2 per star)
1	Replace single glazed windows with double glazed clear (13)	+ 0.55	18
2	Increase external wall insulation to R2.0 from average R0.7[10] (6)	+ 0.50	2
3	Reduce window glazing area by 25% (18)	+ 0.41	- 8
4	Replace standard aluminium window frames with improved aluminium – or timber window frames (11)	+ 0.25	8
5	Increase ceiling insulation to R4.0 from average R3.0 (2)	+ 0.17	12
6	Install reflective foil to the underside of the roof (1)	+ 0.17	24
7	Install R2.0 inter-zone wall insulation (8)	+ 0.15	40
8	Increase subfloor wall insulation to R2.0 from average R0.7 and minimise ventilation (10)	+ 0.14	14
9	Change windows to clear louvres with 90% openability (12)	+ 0.10	52
10	Seal all penetrations[11] (16)	+ 0.09	11
	Total of Individual Effects	**+ 2.53**	

Table 13: The top ten techniques for temperate climate dwellings based on the average increase in decimal star from the base dwelling for each technique.

Notes:
- Bulk ceiling insulation is always important especially when there is less than R3.0.
- The sealing of penetrations such as exhaust fans, chimneys, vents and down lights becomes important when there are a large number of unsealed penetrations.
- A light roof colour is more beneficial than a dark roof colour unless the location experiences more days of cooler weather.
- Humid temperate climates will benefit from ceiling fans.

[10] The minimum wall insulation used in temperate climate zones is usually R1.5. The benefits of increasing wall insulation to R2.0 from R1.5 will be less than + 0.50 stars.

4.3. Cool Climates

Ranking	Recommended Techniques (Technique No.)	Average Increase in Decimal Star	Indicative Cost Effectiveness ($/m^2 per star)
1	Replace single glazed windows with double glazed clear (13)	+ 0.58	17
2	Install R2.0 under-floor bulk insulation from originally having none (9)	+ 0.49	20
3	Increase external wall insulation to R2.0 from average R1.0[12] (6)	+ 0.35	3
4	Replace standard aluminium window frames to improved aluminium – or timber window frames (11)	+ 0.32	6
5	Reduce window glazing area by 25% (18)	+ 0.31	- 7
6	Install R2.0 inter-zone wall insulation (8)	+ 0.20	30
7	Increase subfloor wall insulation to R2.0 from average R0.8 and minimise ventilation (10)	+ 0.13	15
8	Increase ceiling insulation to R4.0 from average R3.1 (2)	+ 0.13	16
9	Weatherstrip all external doors and windows (15)	+ 0.09	23
10	Seal all penetrations[13] (16)	+ 0.09	22
	Total of Individual Effects	**+ 2.69**	

Table 14: The top ten techniques for cool climate dwellings based on the average increase in decimal star from the base dwellings for each technique.

[12] The minimum wall insulation used in cool climate zones is usually R1.5. The benefits of increasing wall insulation to R2.0 from R1.5 will be less than + 0.35 stars.

4.4. Notes on Top Ten Techniques

The following are some additional notes on the top ten techniques of each climate category in order of cost effectiveness.

4.4.1. Hot Climates

Refer to Table 12.

1. Reducing the window to NCFA (Net Conditioned Floor Area) ratio will improve the star rating and actually reduce costs.
2. Changing the roof to a light colour (absorptance of 30%) will improve the star rating at no additional cost. A dark coloured roof in hot climates can have great negative impacts on the thermal performance of the house.
3. Adding reflective foil to the roof, R4 ceiling insulation and R2 external wall insulation are good low-cost options.
4. Ceiling fans are very beneficial in humid climates. There is a proposal to modify the software to change the star ratings to deliver a lesser advantage for ceiling fans in the humid tropics but this technique is expected to remain in the top ten even if that change proceeds.

4.4.2. Temperate Climates

Refer to Table 13.

1. Reducing the window to NCFA ratio will improve the star rating and actually reduce costs.
2. A light coloured roof (absorptance of 30%) is slightly more beneficial in warm-temperate climates zones (BCA climate zone 5) at no additional cost.
3. Adding R4 ceiling insulation, R2 external wall insulation and changing window frames to thermally improved aluminium frames (or timber window frames) are good low-cost options.
4. Sealing penetrations in temperate climates becomes more important when there are a large number of unsealed penetrations.
5. Humid temperate climates will benefit from ceiling fans.

4.4.3. Cool Climates

Refer to Table 14.

1. Reducing the window to NCFA ratio will improve the star rating and actually reduce costs.
2. A dark coloured roof (absorptance of 70%) is slightly more beneficial at no additional cost.
3. Adding R4 ceiling insulation, R2 external wall insulation and changing window frames to thermally improved aluminium frames (or timber window frames) are good low-cost options.
4. Sealing penetrations in cool climates becomes more important when there are a large number of unsealed penetrations.

4.5. Simulated Results

The top ten techniques when simulated independently were simulated as applying all together across each climate zone for each dwelling for comparison and proofing purposes. Table 15 shows the minimum, maximum and average simulated results for each climate category. The combined total of the techniques from Table 12, Table 13 and Table 14 is also presented for comparison with the simulated results. As can be seen, the simulated average increase in decimal stars is greater than the combined total for each climate category. This suggests that some techniques complement other techniques in increasing the decimal star rating. For example, insulating ceiling and walls in a cold climate with R4.0 and R2.0 bulk insulation will reduce the heat loss through the ceiling and walls to the outside. This will result in the incidental solar gains through windows and the internal heat from occupant and appliances being able to maintain comfort unaided for much longer times (in lower outside temperatures). If, in a hot climate, most of the heat gain of the dwelling during the day is caused by heat transfer through windows from the outside ambient air temperature and solar radiation, then installing double glazed tinted/toned windows will reduce this heat gain, and hence will complement the ceiling and wall insulation.

Table 15 also shows a large difference between the minimum and maximum increase in the decimal star rating especially in hot climates. It is believed that this is caused bythe fact that certain techniques did not apply to certain dwellings as they had already satisfied the technique (i.e. some dwellings already had R4.0 ceiling insulation).

Some techniques did not seem to appear additive, for example, in hot climates, replacing single glazed windows with double glazed tinted and changing existing windows to clear louvres with 90% openability. In this case, windows were changed to double glazed tinted/toned louvres with 90% openability. Conflicting techniques were satisfied by combining them into one technique.

	Simulation Results			
	Min (stars)	**Max (stars)**	**Average (stars)**	**Combined Total (stars)**
Hot Climates	+2.65	+6.54	+3.93	+3.14
Temperate Climates	+1.98	+4.19	+2.98	+2.53
Cool Climates	+2.39	+3.73	+3.04	+2.69

Table 15: The simulation results of the top ten techniques for each climate category.

5. Conclusions and Recommendations

In all climates the two most effective techniques alone were sufficient to increase the rating by more than a star. Also, in all climates there were ten techniques which increased the rating by approximately 0.1 stars or more when considered independently. Allowing for their complementarity, this effectiveness will be even higher.

Increased rating from the complementarity of techniques was highest on average in the hot climates (24%) with lesser effect in temperate climates (20%) and cool climates (13%).

Individual techniques in the top ten for the three climate types ranged in indicative cost effectiveness (cost per star per unit GFA) from -$9/m² up to $40/m².

5.1. Recommended Further Work

This project built on earlier work undertaken by Energy Partners for the Australian Greenhouse Office and for reasons of economy was restricted to a small sample of dwellings selected from the collection of 624 prepared for the project to validate the 2nd Generation NatHERS simulation software package called AccuRate. That collection comprises 208 designs each with three levels of thermal enhancement (low, BCA 2003 compliant and high). This work, however, suggests significant refinements in some cases to obtain more directly applicable results.

1. Articulate the current set of Rules of Thumb for the three archetypal climates into equivalent tables for each of the eight BCA climate zones or for each of the eleven key economic locations.

2. Investigate the impacts of insulating the subfloor walls and minimising the subfloor ventilation independently. Also analyse this impact separately for its heating and cooling season impacts to establish its effectiveness relative to insulating the floor. It appears likely that it will offer substantially superior summer performance including decreased peak cooling load with only modest loss of winter effectiveness and may substantially close the gap between the thermal efficiencies of timber floored and concrete slab on ground constructions.

3. Investigate the impacts of completely sealing the subfloor. This could be achieved in reality by using a temperature and humidity sensor in the subfloor that would be connected to a control unit. The control unit could actively open and close subfloor vents (or control its forced ventilation) in accordance with temperature benefits or detriments and humidity levels that would be tolerated for the subfloor and maintain its long service life.

4. Investigate the impact of floor insulation using foil instead of the bulk insulation assumed in this study.

5. Investigate the impacts of installing anti-glare reflective foil in the external walls without installing R2.0 bulk insulation.

6. Select or create an archetypical design for each climate and apply the most cost effective improvements cumulatively rather than independently as was necessarily done in this study.

7. Similarly, apply the technique to two archetypal tropical homes: a) single skin masonry walls; b) elevated open under-floors.

8. Refine the cost benefit analysis of the recommended techniques for each climate. Choose the top 3-5 techniques based on star rating and increase in construction costs. Simulate the dwellings with the chosen 3-5 techniques and analyse the results.

9. Determine whether a medium coloured roof in temperate climates is more beneficial than a dark or light coloured roof and to refine the rule of thumb in relation to 0.1 increments of solar absorptance.

10. Determine the effects of increasing numbers of unsealed penetrations such as exhaust fans, chimneys, vents and down lights and determine if sealing penetrations in hot dry climates has negative effects. This could best be done by creating several versions of each dwelling with a base case having large numbers of penetrations of all types. These would then be analysed by eliminating/sealing each type in turn to establish their relative significance and star rating increment.

11. For windows, rather than establish the effect of a 25% reduction of window width, establish the reduction in window areas required to achieve a particular rating improvement, say 0.3 stars. Where applicable, modify the window shape to achieve the rating improvement with a lesser reduction in window area.

12. Analyse the combined impacts that each technique has on the annual heating and cooling loads (MJ/m^2) of the dwellings. Determine the average difference in annual heating and cooling loads from the base dwelling for each technique in combination with the selected techniques already "adopted" in each climate zone. Determine if an annual cost saving can be achieved, and the magnitude of saving for the household after the completion of each technique. This could be based on the monetary cost difference of running a heating/cooling system that is common to the base dwelling and improved dwelling that meets each of their own heating and cooling loads (i.e. the cost difference between the base dwelling and improved dwelling associated with running a reverse-cycle air conditioning system to meet the load).

13. Similarly analyse the impact of the improvements on the dwellings' peak loads (kW/m^2) both in terms of the potential saving to the household in heater and/or cooler size and in terms of savings to the infrastructure costs for the electricity grid and generating capacity.

14. Investigate the impacts of orientation and shading by rotating each dwelling through 360° in 45° steps and shading windows appropriately (i.e. east and west windows).

15. For windows, relocate some of the fenestration to improve the designs' passive solar and/or cross ventilation attributes.

16. Study the rating advantages of insulation in detail. Strip all dwellings of their wall and ceiling insulation. Add insulation in steps of R0.5 first to ceilings up to R4.0. Remove

the ceiling insulation and then repeat the process for external walls up to R2.0. Determine an optimum level for the R-value of bulk insulation in the ceiling and walls based on the insulation cost and the improvement in star rating. This also could be repeated for floor insulation. This will allow builders to determine the benefits achievable by increasing the insulation say from R1.5 to R2.0.

17. Provide a ranking system for the techniques based on cost effectiveness for each climate category. This may be more appropriate after refining the cost-benefit-analysis into a system that is more detailed and thorough.

18. Provide individual recommendations for the 11 locations or eight BCA climate zones (instead of 3 broad climate categories of hot, temperate and cool). For example, provide separate detailed recommendations for mild-temperate climate zones such as Melbourne and Western Sydney (BCA climate zone 6).

19. Technique 18 reduces window area of dwellings by 25%. This resulted in an average window area to NCFA ratio for temperate and cool dwellings of less than 20%. Market factors suggest that the window area to NCFA ratio should not fall below 20%. It is recommended to modify technique 18 to analyse the effect in smaller increments (say 5%) and to limit the window area to NCFA ratio to >20% for each dwelling and investigate the new effects.

Appendix 1 Detailed Methodology and Results

Refer to Table 16 below for the detailed methodology and results.

	Difference in Decimal Star Rating Average		
Technique	Hot Climates	Temperate Climates	Cool Climates
1	+ 0.26	+ 0.17	+ 0.08
2	+ 0.34	+ 0.17	+ 0.13
3	+ 0.05	+ 0.03	- 0.01
4	- 0.40	- 0.08	+ 0.04
5	+ 0.19	+ 0.04	- 0.02
6	+ 0.36	+ 0.50	+ 0.35
7	+ 0.06	+ 0.04	+ 0.04
8	+ 0.09	+ 0.15	+ 0.20
9	- 0.03	+ 0.03	+ 0.49
10	+ 0.17	+ 0.14	+ 0.13
11	+ 0.12	+ 0.25	+ 0.32
12	+ 0.22	+ 0.10	+ 0.03
13	+ 0.41	+ 0.55	+ 0.58
14*	+ 0.72	+ 0.54	+ 0.40
15	+ 0.12	+ 0.07	+ 0.09
16	+ 0.02	+ 0.09	+ 0.09
17	+ 0.29	+ 0.09	+ 0.02
18	+ 0.47	+ 0.41	+ 0.31

Table 16: Average decimal star rating difference from the base dwelling across all climates.

* Technique 14: The effects of double glazed tinted/toned windows need to be compared with double glazed clear windows (Technique 13).

1. Reflective Roof Foil

Description:

Add reflective foil to the underside of the roof as set by Australian Standards 2006.

Methodology:

Each dwelling had reflective foil placed to the underside of the roof. The gap between the foil and roof had a width of 40mm. The side of the foil facing the underside of the roof had an emissivity value of 0.2. Australian Standards 2006 defines the emissivity of the foil side facing the underside of the roof to be 0.3. However, an emissivity of 0.2 was the closest option that could be simulated by AccuRate software. The foil side facing into the roof space was set to reflective.

Results Summary:

As expected the reflective foil placed on the underside of the roof performed best in hot climates. For the three hot climates studied, the average increase in the energy star rating was 0.26 stars. The cooler climates still had increases in the average star rating with an increase of 0.19 stars for temperate climates and an increase of 0.08 stars for cool climates.

2. Ceiling Insulation

Description:

Add R4.0 bulk insulation to the ceiling (in lieu of original).

Methodology:

All dwellings had R4.0 bulk insulation added to the ceiling in lieu of the original insulation. Dwellings that originally had a minimum of R4.0 insulation in the ceiling were not included in the simulation and analysis.

Results Summary:

12 dwellings were simulated for the hot climates, 10 dwellings for the temperate climates and 10 dwellings for the cool climates. The average value of ceiling insulation in the base dwellings was R2.1 for hot climates, R3.0 for temperate climates and R3.1 for cool climates.

The higher average increase in the star rating for hot climates compared to the increase in cooler climates is primarily due to the smaller average amount of original ceiling insulation (R2.1) in these dwellings compared to the average ceiling insulation of dwellings in temperate (R3.0) and cool climates (R3.2).

There was one hot climate dwelling that had an average increase in star rating of 1.65 stars. This was the only hot climate dwelling that had an increase in star rating above 0.68 stars and is also the only dwelling that originally had no ceiling insulation. The highest average increase in star rating over the 5 temperate climates was 0.42 stars. This temperate climate dwelling had an original ceiling insulation value of R2.5. The highest average increase in star rating over the 4 cool climates was 0.24 stars. This cool climate dwelling had an original ceiling insulation value of R2.5.

3. Roof Ventilation

Description:

Add explicit ventilation of the attic space.

Methodology:

All dwellings were modified to have a ‘very ventilated’ roof space. Dwellings that did not have a roof space (i.e. dwellings with raked ceilings) were not included in the simulation and analysis. All simulated hot climate dwellings had a ‘standard ventilated’ roof space except for one which had a ‘ventilated’ roof space. All simulated temperate and cool climate dwellings had a ‘standard ventilated’ roof space.

Results Summary:

11 dwellings were simulated for the hot climates, 10 for the temperate climates and 12 for the cool climates. The only positive substantial effect was for hot climate 1 (Darwin) which had an average increase in the star rating of 0.11 stars. The average increase in the

star rating for the other hot climates was negligible. The average increase in star rating for all three hot climates was only 0.05 stars.

The average increase in the star rating for temperate dwellings was only 0.03 stars, which is consistent for each temperate climate. The only decrease in the average star rating was in climate 62 (Melbourne Moorabbin) which had a decrease of -0.01 stars. Climate 62 can also be considered as a cool climate zone.

The average star rating across all cool climates for cool climate dwellings decreased insignificantly by –0.01 stars.

4. Dark Roof

Description:

Change roof colour to dark.

Methodology:

Each dwelling had its roof colour changed to dark (solar absorptance of 85%). Dwellings that originally had a dark roof were not included in the simulation and analysis.

Results Summary:

Out of the 11 simulated hot climate dwellings, 7 dwellings had a light coloured roof and 4 dwellings had a medium coloured roof. Out of the 12 simulated temperate climate dwellings, 1 dwelling had a light coloured roof and 11 dwellings had a medium coloured roof. Out of the 12 simulated cool climate dwellings, 3 dwellings had a light coloured roof and 9 dwellings had a medium coloured roof.

As expected this technique had negative impacts for hot climate dwellings with an average decrease in star rating of –0.40 stars. It also had a small negative impact for temperate climates where there was an average decrease in star rating of –0.08 stars. It is clear that if more temperate climate dwellings had a light coloured roof, then the average decrease in star rating would be greater. The only temperate climate that had an increase in the average star rating was climate 62 (Melbourne Moorabbin) which had an average increase of 0.05 stars. Cool climate dwellings had a very slight increase in the average star rating. Again the average star rating would increase if there were more cool climate dwellings with light coloured roofs.

5. Light Roof

Description:

Change roof colour to light.

Methodology:

Each dwelling had its roof colour changed to light (solar absorptance of 30%). Dwellings that originally had a light roof were not included in the simulation and analysis.

Results Summary:

Out of the 5 simulated hot climate dwellings, 1 dwelling had a dark coloured roof and 4 dwellings had a medium coloured roof. All 11 simulated temperate climate dwellings and all 9 simulated cool climate dwellings had a medium coloured roof.

This technique is in contrast with technique 4 and as expected, technique 5 had positive impacts for hot climates, negligible positive impacts for temperate climates and negligible negative impacts for cool climates.

Hot climate 1 (Darwin) had the greatest average star rating increase of 0.31 stars when compared to climate 6 (Alice Springs) which had an average increase of 0.13 stars and climate 10 (Brisbane) which had an average increase of 0.08 stars. This suggests that having a light coloured roof is more beneficial in hot humid climates but may need to be investigated further.

6. External Wall Insulation

Description:

Add R2.0 bulk insulation to the external walls (in lieu of original).

Methodology:

All dwellings had R2.0 bulk insulation added to the external walls. In the case of brick veneer external wall constructions, the brick-to-plasterboard cavity thickness was 140mm in the AccuRate software. For weatherboard external wall constructions, the WB-to-plasterboard cavity was 90mm. There was one dwelling with a double-brick external wall construction that had an uninsulated air cavity 40mm wide. This air gap was widened to allow R2.0 insulation to be installed. For dwellings that had no insulation and no external wall cavity such as mud brick and concrete block homes, R2.0 bulk insulation was installed to the exterior of the wall with fibro cement cladding.

Results Summary:

The average wall bulk insulation in the base dwellings was R0.83 for hot climate dwellings, R0.55 for temperate climate dwellings and R0.96 for cool climate dwellings.

Hot climate dwellings had an average increase in star rating of 0.36 stars, temperate climate dwellings had an increase of 0.50 stars and cool climate dwellings had an increase of 0.35 stars. The larger increase in the star rating for temperate climate dwellings can be explained by the lower than average value of the original exterior wall insulation of R0.55.

7. External Wall Insulation & Reflective Foil

Description:

Add anti-glare reflective foil to the external walls (in addition to R2.0).

Methodology:
All dwellings had anti-glare reflective foil installed in the air gap of the external wall construction in addition to the R2.0 bulk insulation installed from technique 6. In the case where there was no air gap in the external wall construction (mud brick and concrete block homes), a minimal 13mm air gap was created. The reflective foil bounded a still air space with emissivity values of 0.05 and 0.9.

Results Summary:
The results presented in Table 16 show the difference between the average increase in star rating by insulating external walls with R2.0 + reflective foil and the average increase in star rating by just insulating external walls with R2.0 (technique 6). The absolute increases in star rating of technique 7 for hot, temperate and cool climates are 0.42, 0.54, 0.39 stars respectfully. The effects of just installing reflective foil in the walls should be investigated further to determine if the values in Table 16 are indicative of the true effects of installing reflective foil in external walls alone.

8. Inter-zone Wall Insulation

Description:
Add R2.0 bulk insulation to the inter-zone walls.

Methodology:
Each dwelling was divided into areas of three zone types:

- day-time conditioned
- night-time conditioned
- unconditioned

R2.0 bulk insulation was added into the walls that separated these zone types. This insulation strategy put insulation in walls between the living room and bedroom, for example, but not between the living room and kitchen.

Results Summary:
This technique had positive impacts on dwellings in all climates. However this technique was increasingly more effective in cooler climates. The average increase in star rating for cool climate dwellings was 0.20 stars compared to hot climate dwellings having an average increase of 0.09 stars.

9. Floor Insulation

Description:
Add R2.0 bulk insulation to the floor (in lieu of original).

Methodology:
This technique put R2.0 bulk insulation right under the timber floorboards. None of the dwellings originally had floor insulation.

Results Summary:
This technique clearly favoured cool climate dwellings as it increased the average star rating by 0.49 stars. This technique had negligible impacts on hot and temperate climate dwellings.

10. Subfloor Wall Insulation & Ventilation

Description:
Add R2.0 bulk insulation to the subfloor walls and minimise ventilation.

Methodology:
R2.0 bulk insulation was added to the subfloor walls which were all 600 mm high. Insulation was not added to the exterior walls of habitable areas. The ventilation of the subfloor was minimised by: enclosing the subfloor; restricting airflow between the subfloor and roof space (or outdoors); and minimising the total area of subfloor ventilation openings by satisfying the requirements of the BCA 2006 with a sealed ground using an impervious membrane. The minimum area of subfloor ventilation openings with a sealed ground for each relative humidity climate zone is 1000mm^2/m for zone1, 2000mm^2/m for zone 2 and 3000mm^2/m for zone 3. Table 17 shows the relative humidity zone for each of the 11 climate zones used in the simulations.

Climate Code[14]	AccuRate Climate #	Climate Name	Relative Humidity Zone
CZ0101	1	Darwin Airport	3
CZ0204	10	Brisbane	3
CZ0306	6	Alice Springs	1
CZ0411	27	Mildura AMO	2
CZ0504	13	Perth	3
CZ0510	56	Mascot RO (East Sydney)	3
CZ0512	16	Adelaide	3
CZ0608	62	Melbourne (Moorabbin)	3
CZ0703	24	Canberra Airport	2
CZ0708	26	Hobart	3
CZ0801	25	Cabramurra	3

Table 17: The set of climate zones showing the relative humidity zone.

[14] Proposed new climate numbering system for AccuRate. The first two digits are the BCA climate zone, the last two digits are the Northerly ranking of that location within that BCA climate zone.

Results Summary:
This technique had consistent results on dwellings in all climates with an average increase of 0.15 stars. There was only one dwelling that had unrestricted open air under the house. This dwelling was a hot climate dwelling and was not included in the average results as it had an increase in star rating of 1.76 stars for climate 10 (Brisbane), 1.21 stars for climate 6 (Alice Springs) and a smaller increase of 0.16 stars for climate 1 (Darwin) which is completely inconsistent with the other results (except for climate 1 Darwin). It is also inconsistent in the base construction compared to the other dwellings.

One other noticeable effect was on a cool climate dwelling that had unrestricted airflow between the subfloor and roof space (or outside). This cool climate dwelling had an average star rating increase of 0.38 stars. This dwelling was also not included in the average results as it was not consistent in both the increase in star rating and the base construction with the other dwellings.

It is interesting to point out these two inconsistent dwellings as it shows that an enclosed subfloor can potentially be greatly beneficial for the thermal performance of the dwelling in all climates.

All other dwellings had an enclosed subfloor, obstructed airflow between the subfloor and roof space (or outside), and a total area of subfloor ventilations of 6000mm^2/m. These dwellings had star rating increases more or less close to the average value of 0.15 stars. Table 18 presents the decimal star increase from the base for each climate category and humidity zones. It can be seen that the star rating increases from cool to hot climate zones and also increases from humid to dry zones.

Note that on many sloping sites, the subfloor walls would average more than 600 mm in height. In these cases, the advantage from insulating the walls would be commensurately greater.

Humidity Zone:	**Zone 1 (dry)**	**Zone 2 ->**	**Zone 3 (humid)**	
Climate Category				**Average**
Hot	+ 0.19	n/a	+ 0.14	**+ 0.17**
Temperate	n/a	+ 0.17	+ 0.11	**+ 0.14**
Cool	n/a	+ 0.16	+ 0.09	**+ 0.13**
Average	**+ 0.19**	**+ 0.17**	**+ 0.11**	

Table 18: Average star rating increases for each climate category and humidity zone.

11. Improved Aluminium Window Frames

Description:
Change frames to Improved Aluminium (thermally similar to timber or PVC).

Methodology:
All dwellings had their window frames (including glazed doors) changed to Generic-02 windows (improved aluminium) by the AccuRate software. Base dwellings with window frames of similar energy effectiveness (e.g. wooden or PVC framed windows) were not separately included in the simulation and analysis. A wide range of costs, and hence cost effectivenesses, applies due to the wide range of approaches in manufacturing the thermally improved frames. Two examples of this range are included in Figure 5.

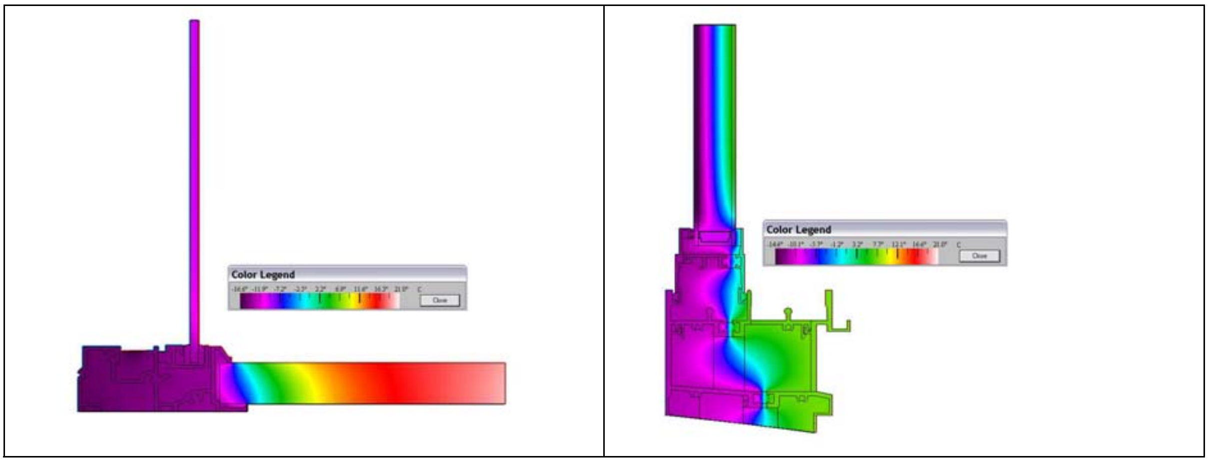


Figure 5: Examples of Thermally Improved Aluminium Window Frames. Left: low cost version using insulation value of the timber reveal. Right: high cost version using thermal breaks within the frame. Simulated temperature gradients in false colour to US NFRC conditions. Images prepared by Peter Lyons and Associates.

Results Summary:
All dwellings that were simulated had windows with standard aluminium frames. The simulation consisted of 11 hot climate dwellings, 12 temperate climate dwellings and 12 cool climate dwellings. This technique was increasingly more effective in cooler climate zones with average increases in star rating ranging from a 0.12 stars for hot climate dwellings to 0.32 stars for cool climate dwellings.

12. Window Louvres

Description:
Change glazing to clear louvres (to obtain 90% openability for ventilation).

Methodology:
All dwellings had their window glazing changed to clear louvres with an openability of 90% for ventilation. Glazing in doors was not changed. Dwellings that had similar or better window ventilation were not simulated and analysed. Note that although double glazed louvres are unusual, they are available commercially and other sash configurations (such as side hung casements) are able to provide the 90% openability which is being analysed here.

Results Summary:
This technique was increasingly more effective in hotter climate zones with an average increase in star rating ranging from a 0.03 stars for cool climate dwellings to a 0.22 stars for hot climate dwellings.

13. Double Glazed Clear Windows

Description:
Change glazing to Double Glazed clear.

Methodology:
All dwellings had their windows changed to Generic-13 windows (Double Glazed clear) by the AccuRate software including doors.

Results Summary:
All dwellings originally had single glazed windows with no tint or toning. This technique had large positive effects across all climate zones. This technique was increasingly more effective in cooler climates zones with an average increase in star rating ranging from 0.42 stars for hot climate dwellings to 0.58 stars for cool climate dwellings.

14. Double Glazed Tinted Windows

Description:
Change glazing to Double Glazed tinted/toned external pane.

Methodology:
All dwellings had their windows changed to Generic-19 windows (Double Glazed tinted/toned) by the AccuRate software including doors.

Results Summary:
All dwellings originally had single glazed windows with no tint or toning. Window tinting has been done in conjunction with double glazing and therefore the average increase in the star rating for technique 14, as shown in Table 16, is not a true reflection of the impacts of the window tinting alone. Table 19 below is the difference between the average star rating of technique 14 and the average star rating of technique 13.

Climate	Average increase in star rating (stars)
Hot	0.30
Temperate	-0.01
Cool	-0.18

Table 19: The average increase in the star rating for window tinting.

As expected window tinting has great positive impacts for dwellings in hot climates and negative impacts for dwellings in cool climates.

15. Weatherstripping

Description:
Weatherstrip all external doors and windows.

Methodology:
All dwellings were simulated by AccuRate software with all external doors and windows weatherstripped.

Results Summary:
As expected, dwellings in all climates benefited from weatherstripping external doors and windows. The greatest impact was in hot climates having an average increase in star rating by 0.12 stars.

16. Seal Penetrations

Description:
Seal all penetrations (exhaust fans, chimneys, vents and down-lights).

Methodology:
All dwellings were simulated by AccuRate software with all penetrations sealed. Only dwellings that had one or more unsealed penetrations were simulated and analysed.

Results Summary:
Only 2 hot climate, 3 temperate climate and 5 cool climate dwellings were simulated because most dwellings had no unsealed penetrations. All dwellings simulated had only unsealed exhaust fans except for one temperate climate dwelling which had unsealed ceiling vents. The results in Table 7 for this technique do not give a good indication of the effects of draught sealing penetrations due to the limited samples. Only when you investigate individual dwellings can you really see the importance of sealing penetrations.

The average number of unsealed penetrations (all exhaust fans) in the cool climate dwellings was 3. There was one cool climate dwelling that had 7 unsealed exhaust fans. This particular dwelling when simulated across the four cool climate zones, had an average increase in star rating of 0.27 stars. The other cool climate dwellings had an improvement in star rating close to the average of 0.09 stars.

The average number of unsealed penetrations in the temperate climate dwellings was 4. There was one dwelling that had 3 unsealed exhaust fans and 4 unsealed ceiling vents. Once these penetrations were sealed, this particular dwelling had an average star rating increase of 0.13 stars.

The increase in the average star rating is smaller for hot climates. There was one dwelling when simulated in climate zone 6 (Alice Springs) that had a decrease in the average star rating of –0.14 stars.

It is reasonable to say that sealing penetrations is more important in cooler climate zones, especially if the dwellings have many penetrations such as down lights, vents, exhaust fans and chimneys. This contradicts technique 15 where the results indicate that weatherstripping is more effective in hot climates (both are forms of air sealing). The reason for this may be due to the fact that unsealed penetrations such as exhaust fans, down-lights and vents, are usually located at the ceiling level where the air is warmer compared to ground level. Unsealed penetrations in hot climate zones may then beneficially act as a solar chimney at night by letting the warm air exhaust into the roof space, hence sealing penetrations in hot climates may have a negative effect. In cool climates, retaining winter heat by sealing penetrations is more important than to leave them unsealed for summer nigh time ventilation. The effects of unsealed penetrations should be investigated further.

17. Ceiling Fans

Description:
Provide ceiling fans in all habitable rooms.

Methodology:
Ceiling fans were added to all habitable rooms where none currently existed such as living/kitchen areas, lounge rooms, bedrooms, studies, etc. Dwellings with an adequate number of ceiling fans were not simulated and analysed.

Results Summary:
As expected this technique greatly benefited hot climate dwellings, and in particular humid climates such as climate 1 (Darwin) and climate 10 (Brisbane). These two climates had an average increase of 0.42 stars under this technique. Hot climate 6 (Alice Springs) only had an average increase of 0.04 stars due to the lack of humidity. Even temperate climate 56 (East Sydney) had an average increase of 0.28 stars.

18. Window Area

Description:
Reduce the area of all windows by 25%.

Methodology:
The width of each window for each dwelling was reduced by 25% resulting in an area reduction of 25%. Reducing the window width was chosen to avoid changing the effects of eaves.

Results Summary:
This technique had great positive effects on the decimal star rating across all climates. Cold climates benefit as the winter heat loss through windows is reduced, and hot climates benefit as it reduces the heat gain from the outside air and also the heat gain from solar radiation. The increase in the decimal star rating for this technique was 0.31 stars for cool climates, 0.41 stars for temperate climates and 0.47 stars for hot climates.

Note that even better results are obtainable through the redistribution of the fenestration toward the northern façade; but modifying the design is outside the scope of this project.

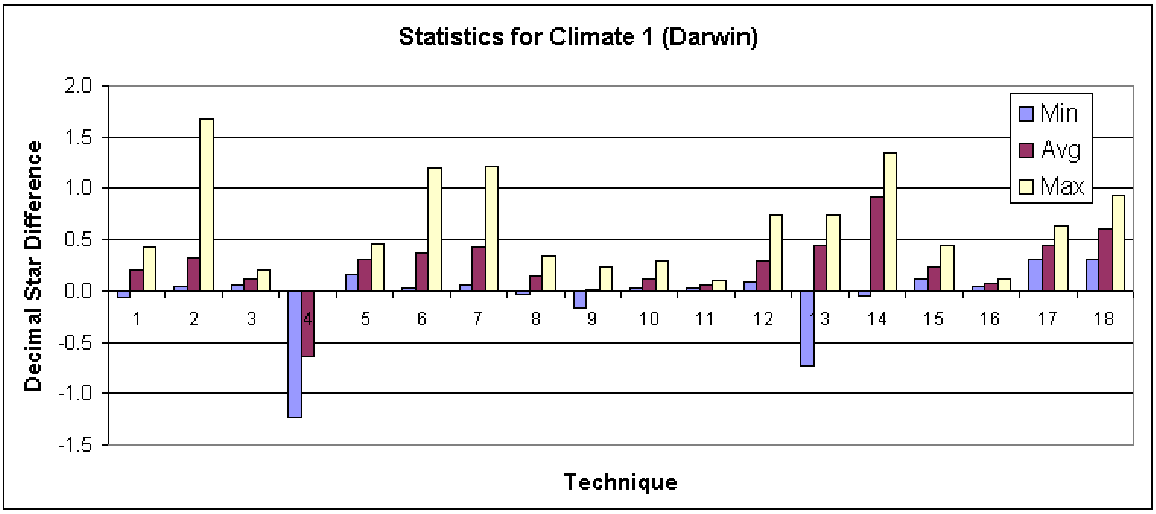
Appendix 2 Technique Statistics

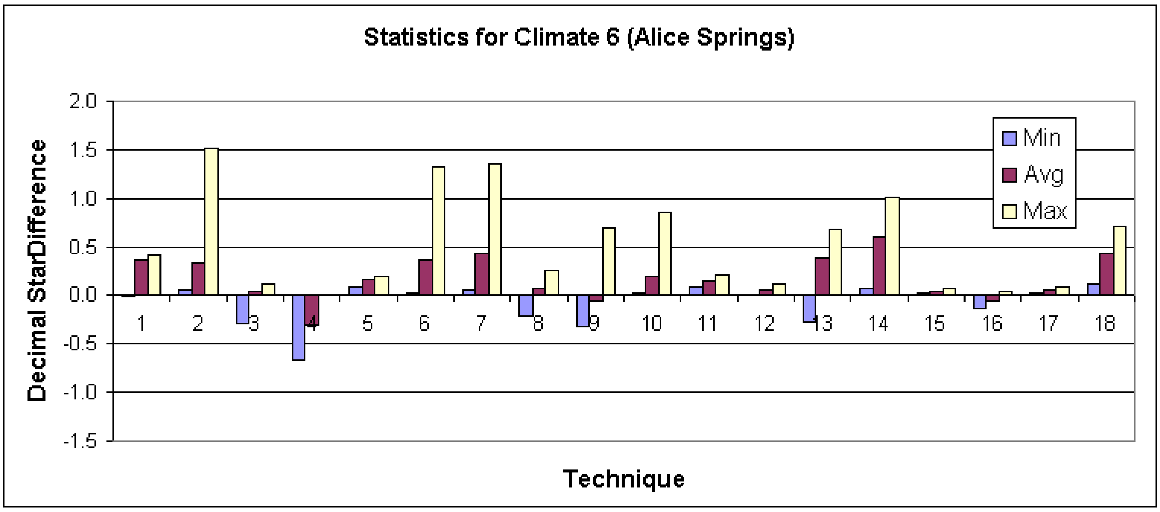
The following are statistical graphs for each climate zone showing the technique results. The decimal star difference is the star rating difference between the base dwelling and the modified dwelling with the associated technique. Each graph shows the minimum, maximum and average decimal star rating difference from the base dwelling.

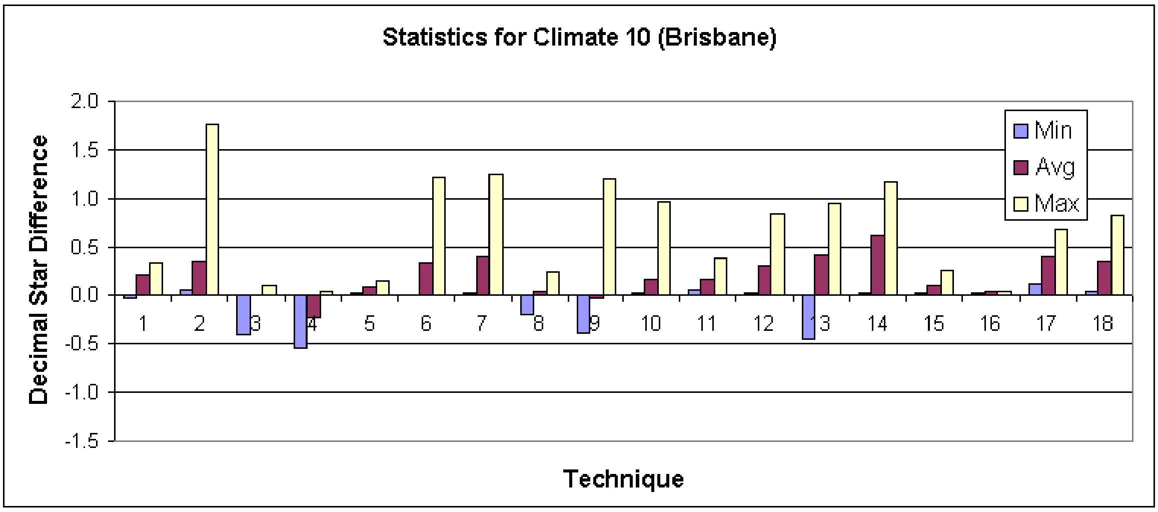
Technique	Description
1	Reflective roof foil
2	Ceiling Insulation
3	Roof space ventilation
4	Dark roof
5	Light roof
6	Exterior wall insulation
7	Exterior wall insulation plus reflective foil
8	Inter-zone wall insulation
9	Floor insulation
10	Subfloor wall insulation and minimised ventilation
11	Improved aluminium window frames
12	Clear window louvres with 90% openability
13	Double glazed clear windows
14	Double glazed tinted/toned windows
15	Weatherstrip external doors and windows
16	Seal penetrations
17	Ceiling fans
18	Glazing area reduced by 25%

Table 20: Technique key.

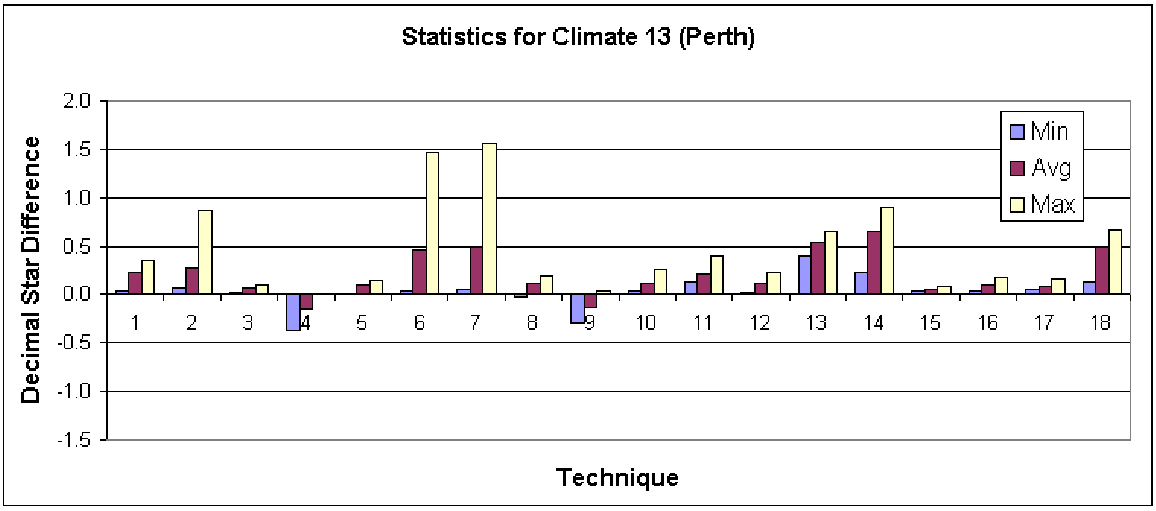
Hot Climates

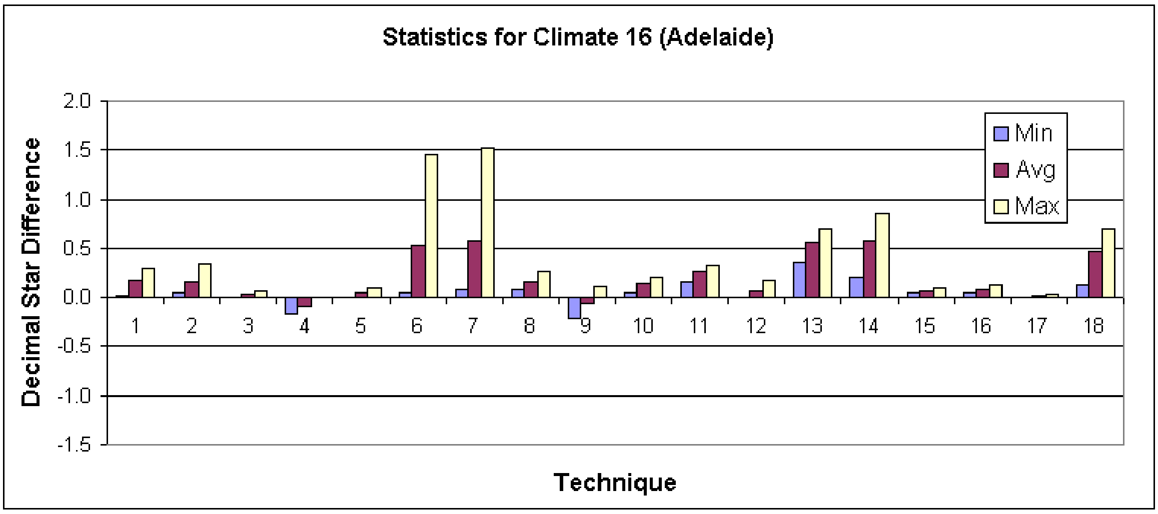


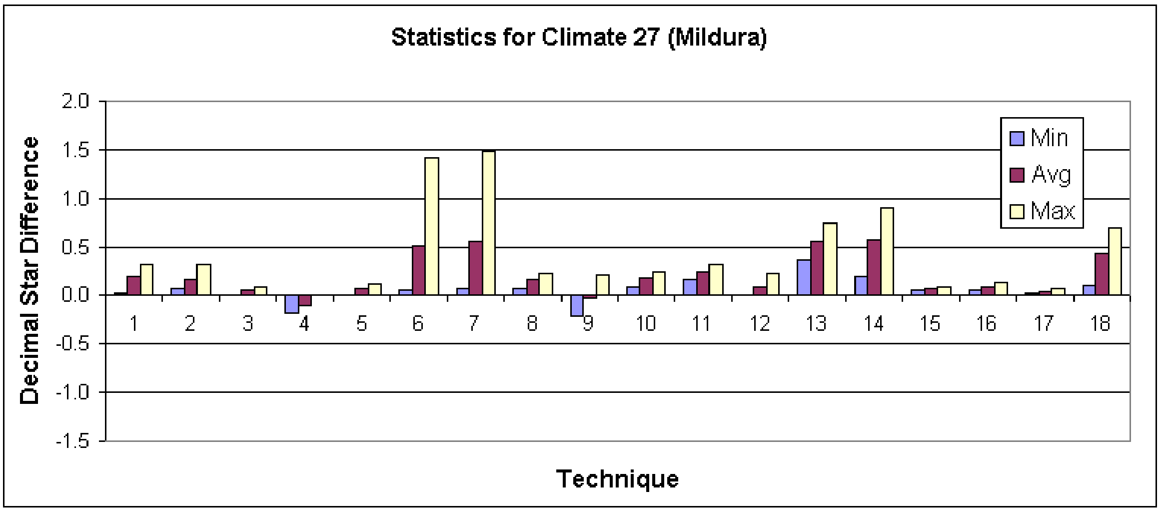


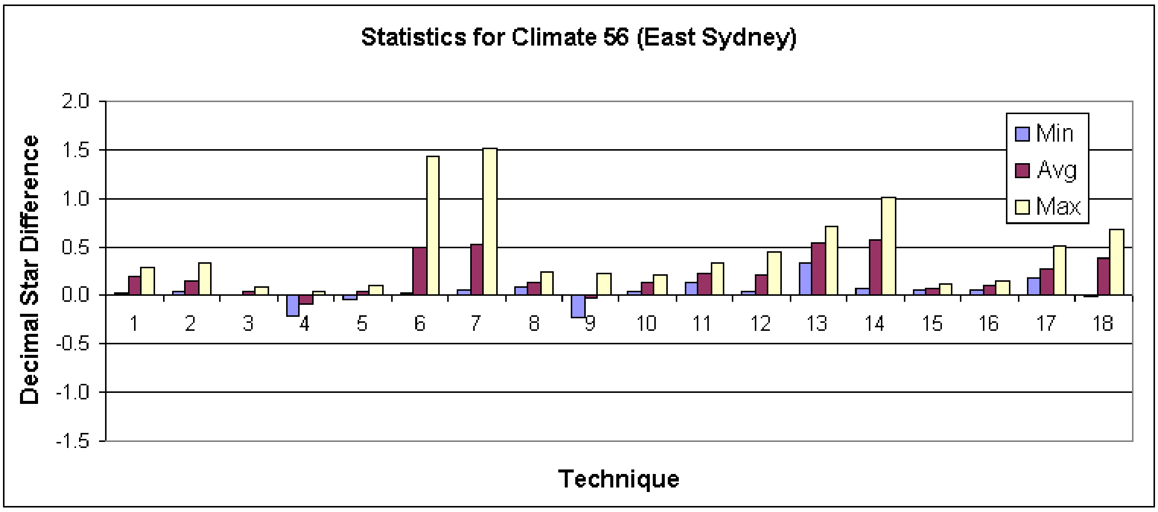


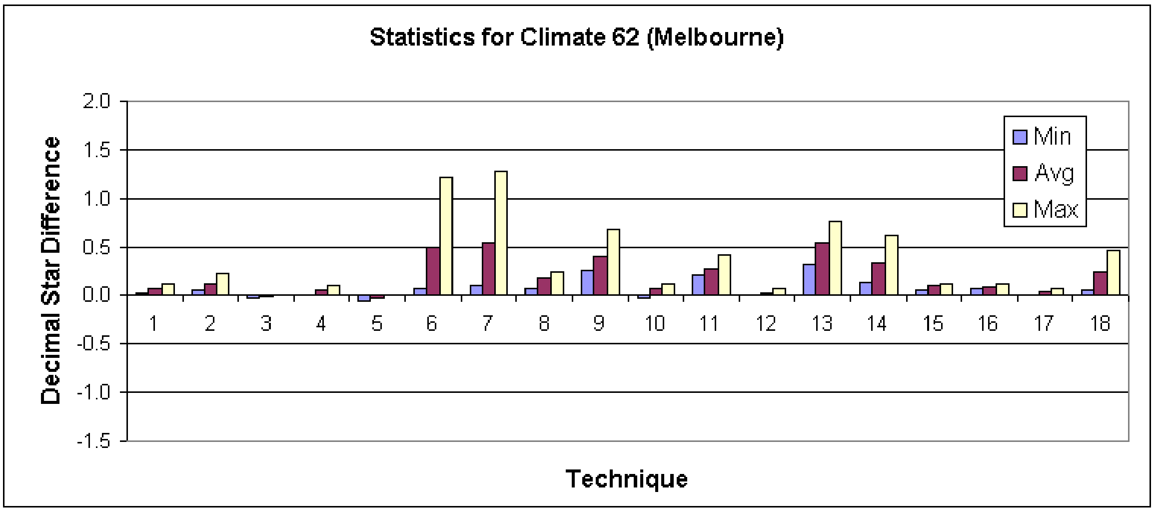
Temperate Climates



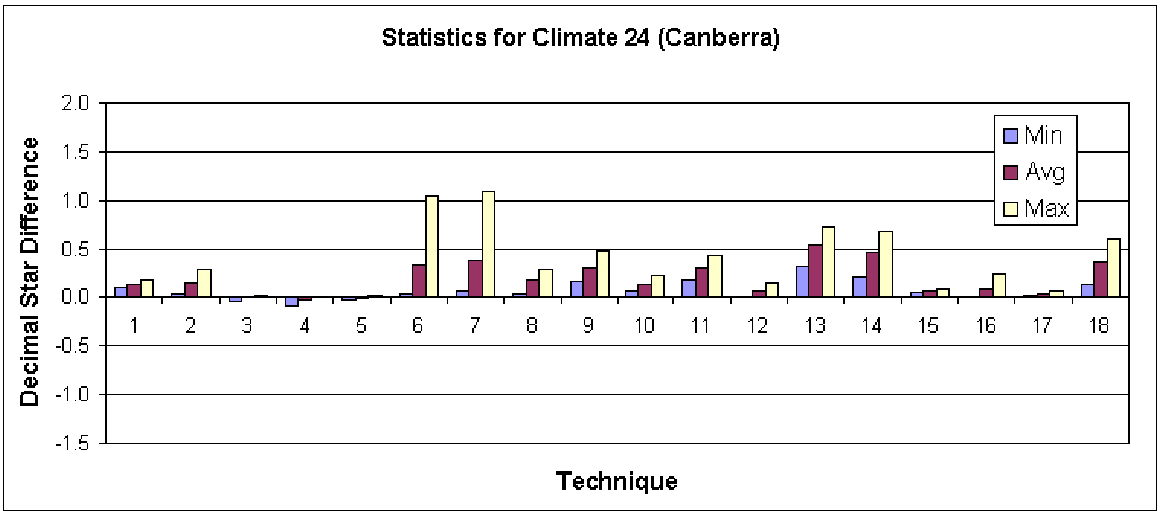

Statistics for Climate 16 (Adelaide)
Decimal Star Difference
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
Min
Avg
Max
Technique

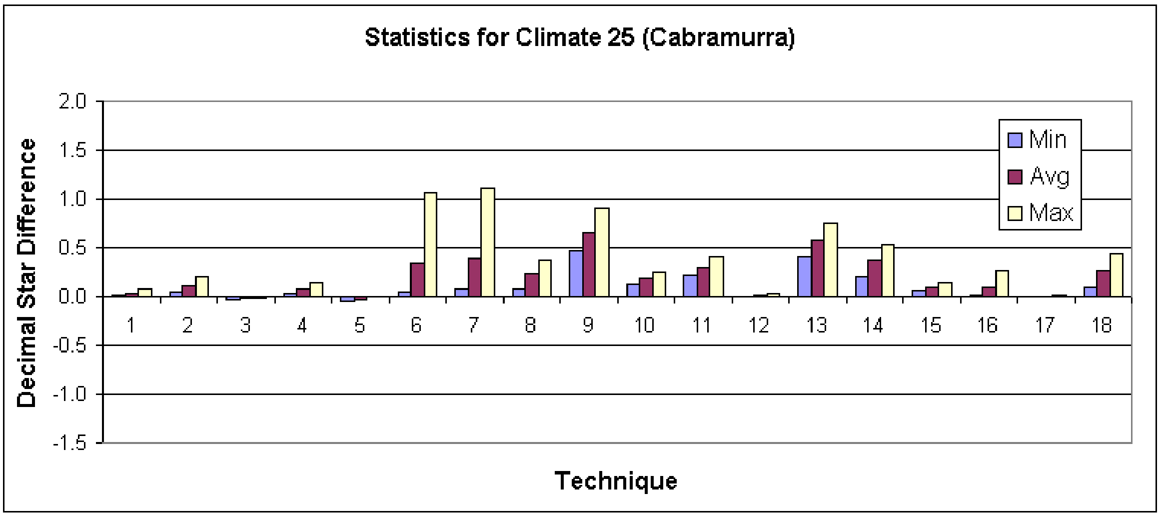

Statistics for Climate 27 (Mildura)
Decimal Star Difference
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
Min
Avg
Max
Technique

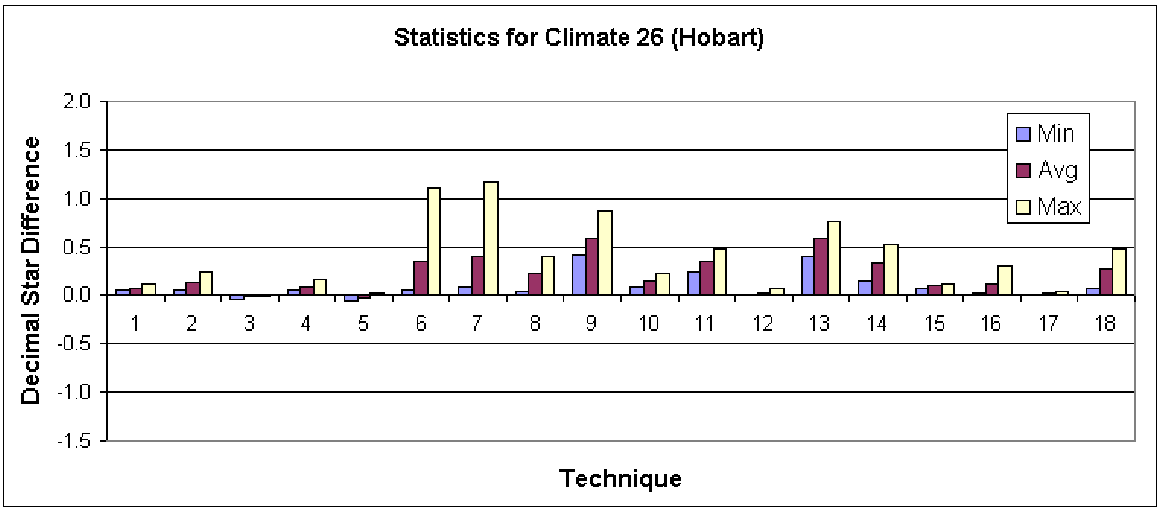

Statistics for Climate 56 (East Sydney)
Decimal Star Difference
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
Min
Avg
Max
Technique



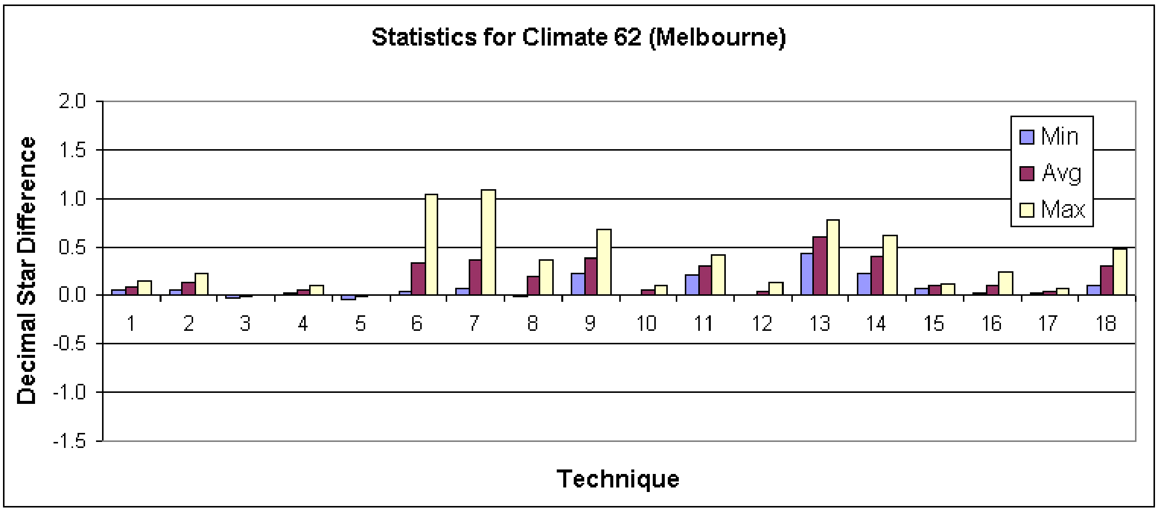
Cool Climates







Statistics for Climate 26 (Hobart)
Decimal Star Difference
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
Min
Avg
Max
Technique

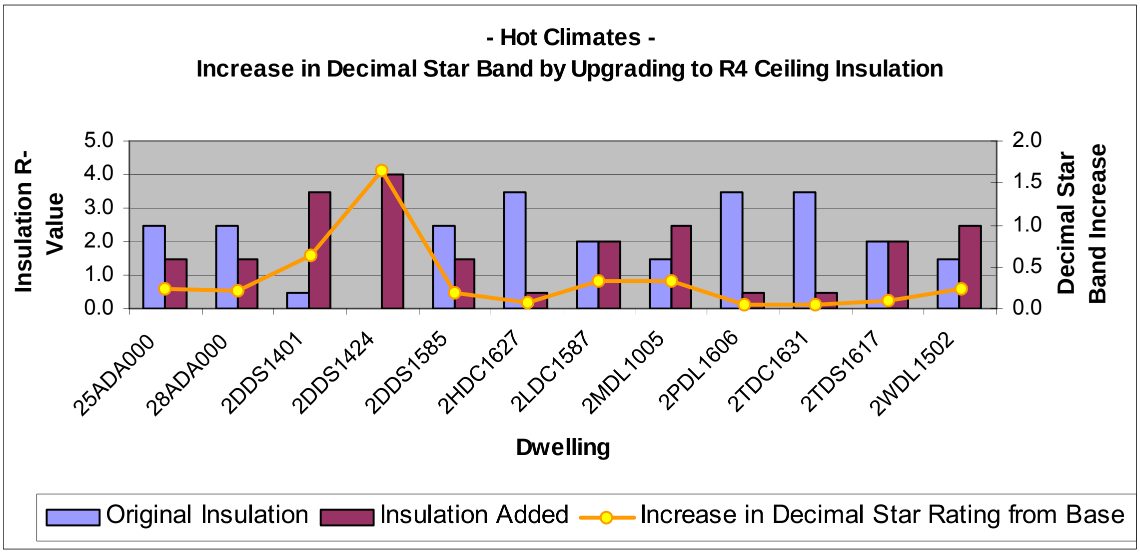


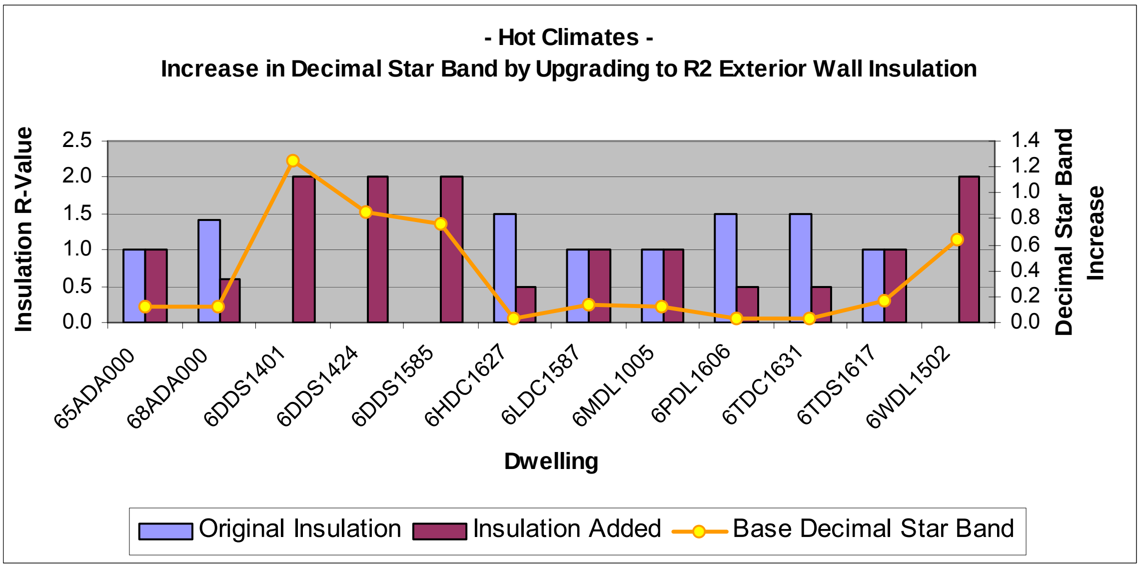
Statistics for Climate 62 (Melbourne)
Decimal Star Difference
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
Min
Avg
Max
Technique

Appendix 3 Ceiling & Wall Insulation

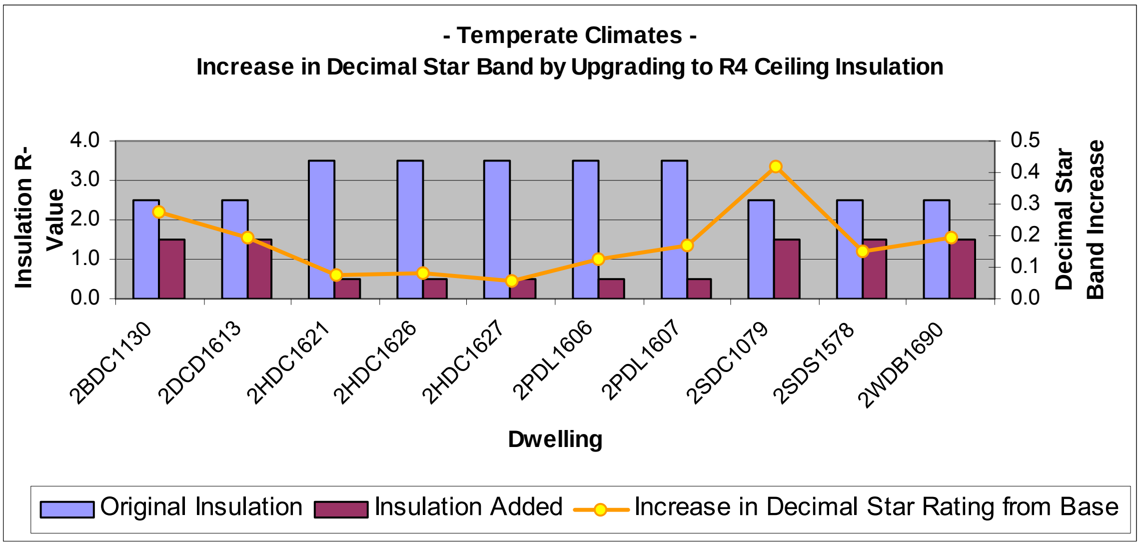
Incremental increases in insulation gave widely varying improvements due to the large range of insulation values in the base case. This variation is clearly shown in the graphs of this section. The following graphs show the original insulation of the base dwelling and the insulation added for each of the 36 dwellings selected. It also shows the increase in average decimal star rating. The codes of the base dwellings where changed by replacing the 'B' at the start of the code with the technique number – in this case '2' or '6'.

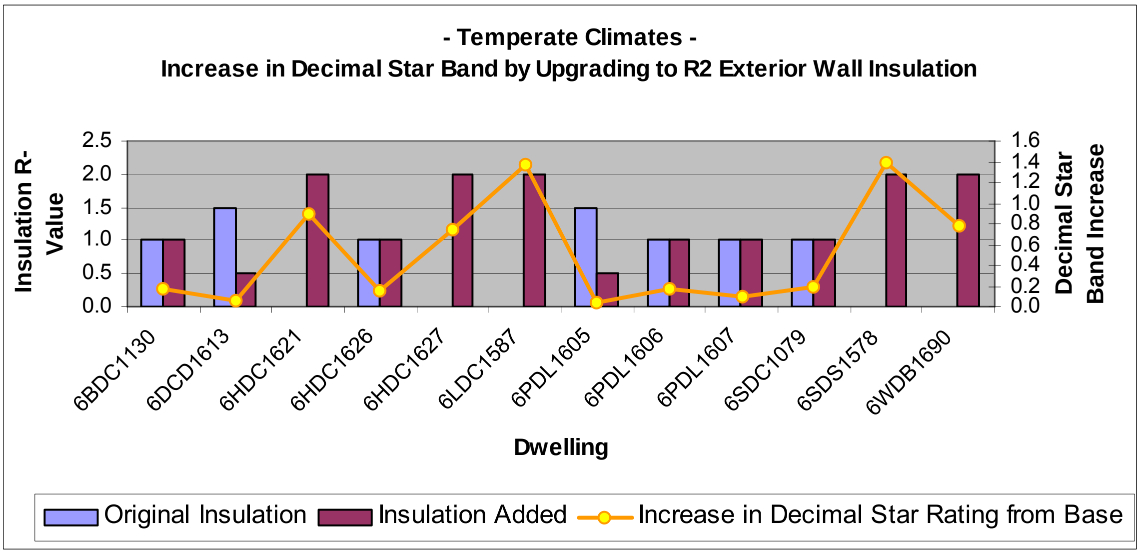
Hot Climates



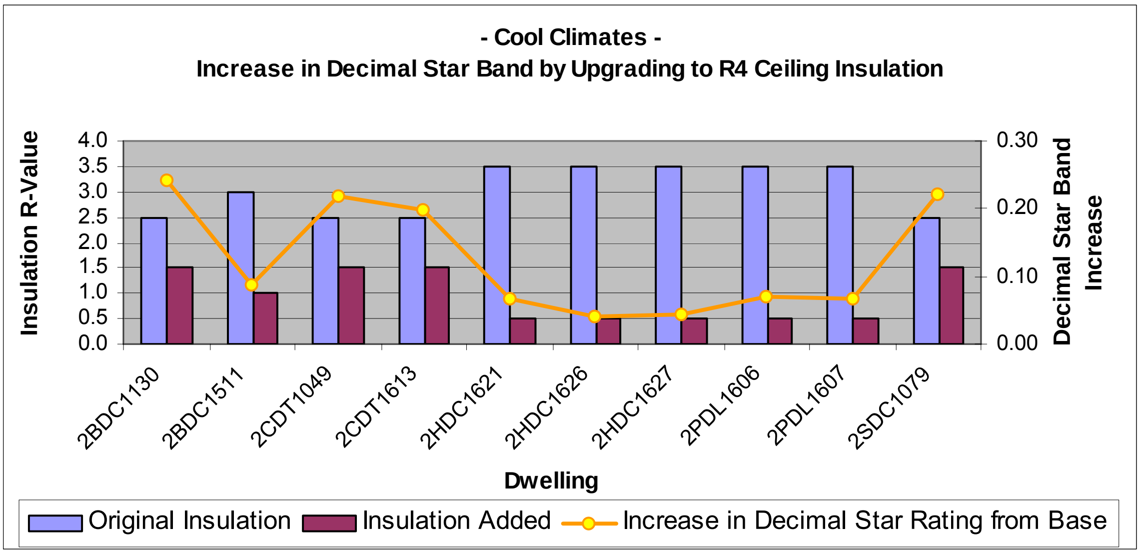


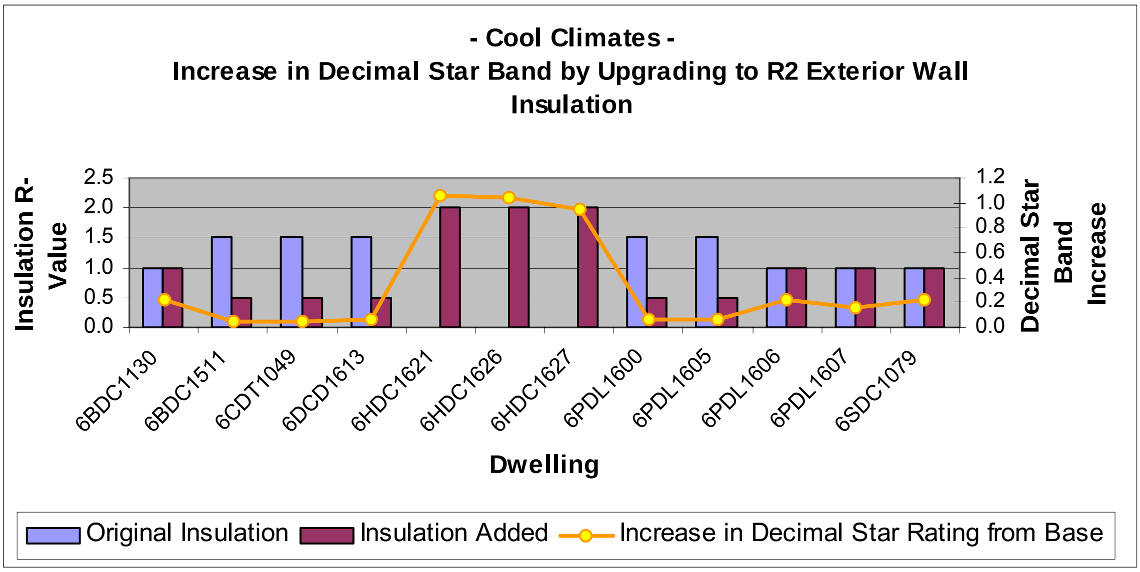
Temperate Climates





Cool Climates





Cost Effectiveness of Techniques

Table 21 shows the cost effectiveness of each technique in increasing the decimal star rating for each climate category. The cost effectiveness is a measure of how effective in monetary terms in increasing the decimal star rating. The cost effectiveness has been calculated by dividing the costs by the star increase to give the units $/m^2 per star. An error of +/- $0.5/m^2 per star in the cost effectiveness is present due to the rounding of numbers.

Climate Category >		Hot		Temperate		Cool	
Technique	Costs[15] $/m^2	Star Increase	Cost Eff. $/m^2 per star	Star Increase	Cost Eff. $/m^2 per star	Star Increase	Cost Eff. $/m^2 per star
1	4	0.26	15	0.17	24	0.08	50
2	2	0.34	6	0.17	12	0.13	16
3	2	0.05	41	0.03	62	-0.01	-152
4	0	-0.40	0	-0.08	0	0.04	0
5	0	0.19	0	0.04	0	-0.02	0
6	1	0.36	3	0.50	2	0.35	3
7	4	0.42	10	0.54	7	0.39	10
8	6	0.09	69	0.15	40	0.20	30
9	10	-0.03	-398	0.03	288	0.49	20
10	2	0.17	12	0.14	14	0.13	15
11	2	0.12	17	0.25	8	0.32	6
12	25[16]	0.22	115	0.10	262	0.03	815
13	10	0.41	24	0.55	18	0.58	17
14	12	0.72	17	0.54	22	0.40	30
15	2	0.12	17	0.07	30	0.09	23
16	2	0.02	103	0.09	23	0.09	22
17	8	0.29	27	0.09	89	0.02	320
18	-5	0.47	-9	0.41	-8	0.31	-7

Table 21: Indicative cost of each technique in $ per m^2 and the cost effectiveness of each technique in each climate category measured in $ per m^2 per star

[15] Indicative costs are given for metropolitan locations but actual costs can vary widely according to location and building culture at the time. Some costs, such as for double glazing, may be falling as volume increases in response to the more stringent building regulations which have just come into force.

[16] Cost for cyclonic areas. Lower costs apply elsewhere.

References

- Energy Partners (2005, October), 'Development of Climate Data for Building Related Energy Rating Software - Report on Climate Zones', Australian Greenhouse Office, Canberra.

- Energy Partners (2006, May), 'Thermal performance of enclosed timber floors compared with concrete slab on ground as modelled by AccuRate', Australian Greenhouse Office, Canberra.

- Standards Australia (2005, August, Draft), DR 05355, 'Amendment 1 to AS/NZS 4859.1:2002 – Materials for the thermal insulation of buildings – Part 1: General criteria and technical provisions'.