TECHNICAL note

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Six-Star Concrete Housing

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CEMENT CONCRETE & AGGREGATES AUSTRALIA

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PREFACE

This Technical Note provides architects, designers and other building professionals with information on how houses* incorporating concrete walls can achieve a six-star energy rating in compliance with the requirements of the National Construction Code.2

The houses considered are single storey and double storey detached dwellings with:

- Concrete slab-on-ground floors; and
- External walls of either:
  > 'Concrete' – reinforced concrete walls with internal wall insulation and lining; or
  > 'Reverse Concrete' – reinforced concrete walls with external weatherproof wall insulation.

1 INTRODUCTION

1.1 The National Construction Code requirements

The National Construction Code (NCC), which provides the model for state building regulations, requires that buildings play their part in minimising climate change by providing building envelopes that reduce greenhouse gas emissions, the principal cause of climate change. It nominates certain requirements by reference to the BCA.

BCA Volume Two Part P 2.6.1 states:

A building must have, to the degree necessary, a level of thermal performance to facilitate the efficient use of energy for artificial heating and cooling, appropriate to –

(a) the function and use of the building; and
(b) the internal environment; and
(c) the geographic location of the building; and
(d) the effects of nearby permanent features such as topography, structures and buildings; and
(e) solar radiation being (i) utilised for heating; and (ii) controlled to minimise energy for cooling; and
(f) the sealing of the building envelope against air leakage; and
(g) the utilisation of air movement to assist cooling.

(As at 1 May 2012: Part 2.6 does not apply in New South Wales, which has alternative performance requirements incorporating BASIX; the Northern Territory and Tasmania retain the performance requirements of BCA 2009; in Victoria there are additional performance requirements covering water use.)

In the 'Deemed-to-Satisfy' section, BCA Volume Two Part P 3.12.0.1(a) states:

(a) To reduce the heating or cooling loads, a building must achieve an energy rating using house energy rating software, of not less than –

1 6 stars; or ……..[4]

It goes on to describe circumstances in Climate Zones I and 2 in which the requirement for a 6-star rating may be reduced to 5-stars when there is also a suitably roofed and insulated outdoor living area as described in the NCC.

1.2 Thermal Mass

The health and comfort of occupants are primary objectives in house design. The thermal mass of concrete internal and external walls, slab-on-ground and concrete suspended floors can be used to reduce space heating or cooling demands (and the resulting carbon dioxide emissions) while maintaining satisfactory occupancy comfort.

Thermal mass (also called thermal capacitance or heat capacity) is the capacity of a body to store heat. It is designated by C, and typically measured in units of $MJ/m^3.K$ or MJ/t.K (or the celsius equivalent $MJ/m^3.°C$ or MJ/t.°C).

Houses with a medium to high level of thermal mass are characterized by their inherent ability to store thermal energy, and then release it several hours later. In summer, heat is absorbed on hot days, preventing the internal temperature from rising excessively. Provided that the climate is such that the nights are cooler than the comfort level, the cool night air can ventilate the building and purge the accumulated heat that is emitted from the building fabric.

*In this document, the term 'house' covers a 'Class 1a detached house' as defined in the Building Code of Australia1 (BCA) Volume Two Part 1.3.2(a)(i).

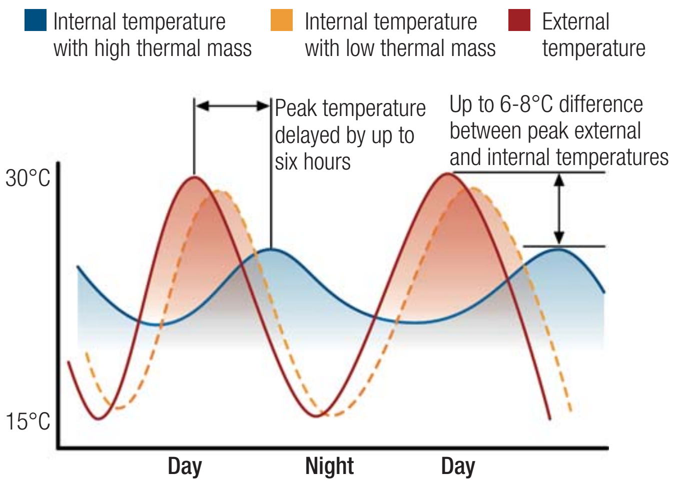

Figure 1 Stabilising effect of thermal mass on internal temperature

During winter, when heating is required, the thermal mass is used to help keep the dwelling warm and to minimise energy consumption for heating. The principle is effectively the same as for summer, except that solar gains are encouraged through appropriately specified windows on a north-facing facade. Heat is absorbed by the thermal mass during the day, and then slowly released at night. This is the same as for summer nights, the only difference being that, during winter, this is useful heat, and windows are kept shut to minimise heat loss.

Due to its high specific heat and the considerable volume in a house, concrete possesses a natural advantage in heat storage capacity (thermal mass). When used in passive solar design, concrete's thermal mass can contribute significantly to reducing energy consumption, while maintaining occupancy comfort. For further information on designing to optimize the benefits of thermal mass, see CCAA's Briefing 12[3].

To be of maximum benefit, thermal mass should be on the inside of the external walls, with an insulating layer on the outside. The AccuRATE simulations which provide the basis of this Technical Note clearly demonstrate the advantage of Reverse Concrete, in which reinforced concrete walls provide the high-thermal-mass internal layer with external weatherproof wall insulation placed on the outside.

1.3 Computer Simulations

BCA Volume Two makes provision for the use of house-energy-rating software to determine energy performance in accordance with the National House Energy Rating Scheme (NatHERS). AccuRATE is one such complying simulation tool, which may be used to assess the energy performance of houses. Over two million AccuRate simulations have been carried out and are reported herein to determine the effects of various house features, viz:

- Location and climate
- House type
- Orientation
- External wall type
- Wall reflective foil
- External wall insulation
- Reflective roof space
- Ceiling insulation
- Between-storey insulation
- Roof colour
- Eaves overhang
- Roof space ventilation
- Floor covering
- Window/glazing type

2 THE AccuRATE SIMULATIONS

2.1 House Types/locations analysed

This document provides summaries of the 2-million-plus house energy simulations prepared using AccuRATE and analysed using the Robo Rater analysis tool. It is part of a suite of documents and data available on request from Cement Concrete and Aggregates Australia to assist designers in maximising the energy efficiency and then achieve Six-Star Ratings for houses incorporating Concrete Slab-on-Ground floors and Concrete or Reverse Concrete external walls. The package comprises:

- This Technical Note
- Summary Data – Microsoft Excel Workbook, including the following:
  - General Summary, Including **Tables 2a, 2b, 2c, 3** and **4**
  - Summary Statistics for Single-storey Benchmark Detached House
  - Summary Statistics for Single-storey Optimum Detached House
  - Summary Statistics for Double-storey Optimum Detached House
  - Supporting Information

- RoboRater Analyses of AccuRATE Simulations for:
  - Single-storey Benchmark Detached House – 2 Microsoft Excel Files
  - Single-storey Optimum Detached House – 2 Microsoft Excel Files
  - Double-storey Optimum Detached House – 4 Microsoft Excel Files

- House Details for:
  - Single-storey Benchmark Detached House
  - Single-storey Optimum Detached House
  - Double-storey Optimum Detached House

The AccuRATE simulations were carried out for the locations shown in **Table 1**. Data for BCA Climate Zone 6 also provides a basis for reasonable predictions of behaviour in Climate Zones 4, 7 and 8.

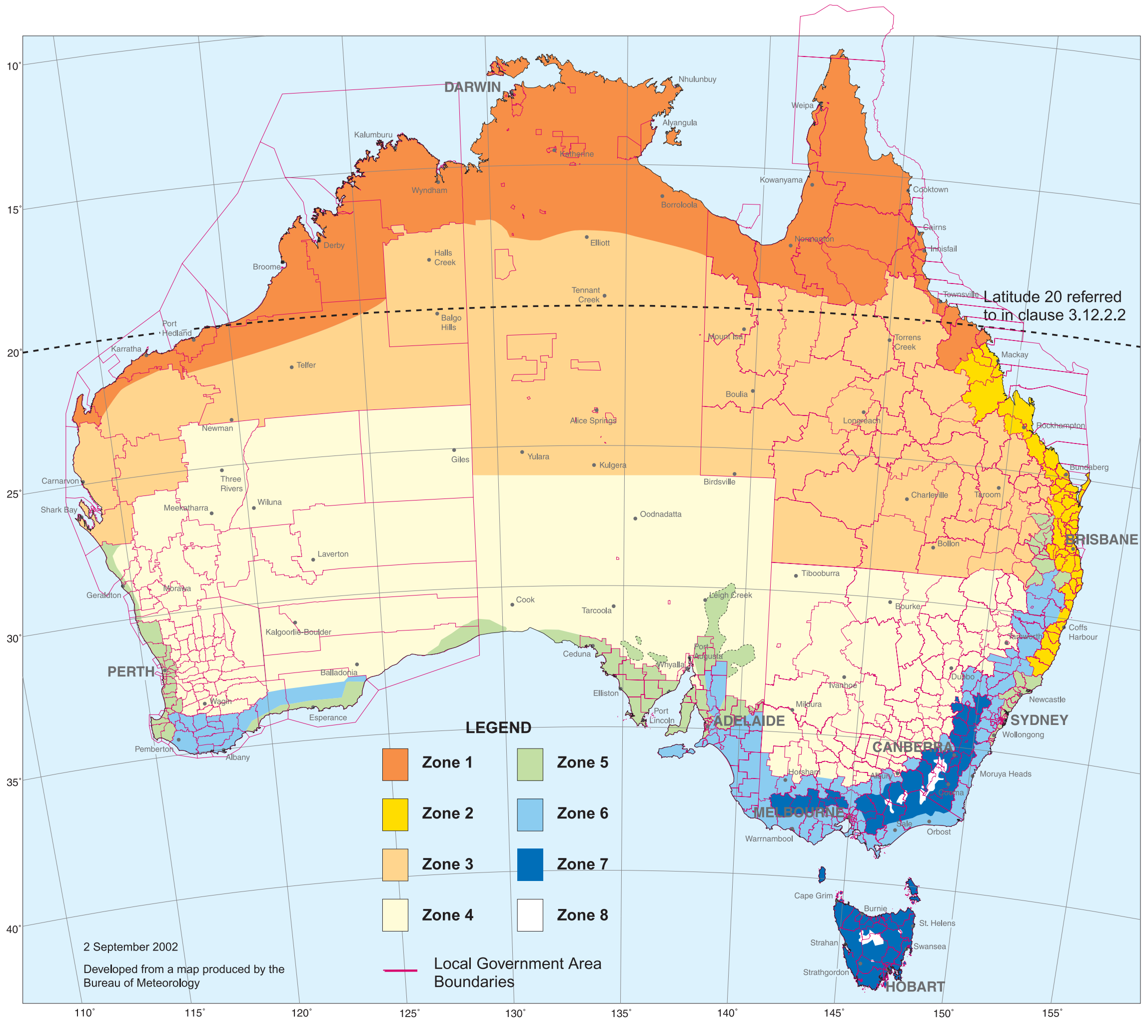

Figure 2 Climate zone map (Courtesy of Australian Building Codes Board,

Table 1 Locations of houses simulated

Climate Zone		Postcode	Location
BCA	NatHERS		
1	1	0800	Darwin
1	2	6721	Port Hedland
1	5	4810	Townsville
3	6	0870	Alice Springs
2	10	4000	Brisbane
5	17	2000	Sydney
6	21	3000	Melbourne





3 CONCLUSIONS

3.1 Principal Factors Affecting Thermal Efficiency of Houses

House Design It is well known that house design can make a significant difference to thermal efficiency, and the principles of passive design are well known. In this study, the following averages across all climate zones were observed:

- Single-storey Benchmark House (conditioned floor area 178.4m^2) consumed 201 MJ/m^2.yr.
- Single-storey Optimum House (conditioned floor area 115.9m^2) consumed 169 MJ/m^2.yr.
- Double-storey Optimum House (conditioned floor area 208.5m^2) consumed 162 MJ/m^2.yr.

Comparison of the Single-storey Optimum House with the Single-storey Benchmark House indicates the degree to which overall house efficiency can be improved by an intelligent and informed approach to design.

Comparison of the Double-storey Optimum House with the Single-storey Optimum House indicates that a small increase in efficiency can be achieved by the overlapping of conditioned spaces in the former.

Climate Zone For any particular house type, the average energy consumption is higher in the hot climates (BCA Climate Zones 1 and 3) and cold climate (BCA Climate Zone 6) than in the temperate climates (BCA Climate Zones 2 and 5). For single-storey houses in hot climates, the difference is more pronounced. Energy-efficient house design will therefore have more impact in extreme climates than in benign climates.

External Wall Type By comparing **Tables 2a, 2b** and **2c**, the relative thermal efficiency of various external wall types can be determined. (Increasing thermal efficiency is indicated by lower average energy use, higher average star rating and higher percentage of simulations achieving 6 stars and over.)

For any house type in any climate, Reverse Concrete Walls (with insulation on the outside) leads to greater efficiency than do Concrete Walls or Brick Veneer Walls (with insulation on the inside). This improved performance of Reverse Concrete results from the presence of higher thermal mass inside the house. The phenomenon occurs in all house types and in all climate zones.

3.2 Summary of results

The data obtained from the AccuRATE simulations is summarised in **Tables 2a, 2b** and **2c**.

TABLE 2a Results for Single-storey Benchmark House Gross floor area 256 m^2–including garage, excluding patio)

Climate zone BCA	Climate zone AccuRate	Location	External wall type	Energy demand: Average (MJ/m^2.yr)	Energy demand: Change from brick veneer	Average stars	Simulations achieving 6 stars or over
1	1	Darwin	Brick veneer	474		4.4	18%
			Concrete	475	+0.3%	4.4	18%
			Reverse concrete	459	–3.1%	4.6	24%
	2	Port Hedland	Brick veneer	332		4.2	19%
			Concrete	333	+0.3%	4.2	18%
			Reverse concrete	308	–7.1%	4.6	29%
	5	Townsville	Brick veneer	165		5.0	33%
			Concrete	166	+0.3%	5.0	33%
			Reverse concrete	160	–3.2%	5.1	37%
3	6	Alice Springs	Brick veneer	252		4.1	20%
			Concrete	254	+0.4%	4.1	19%
			Reverse concrete	213	–15.4%	4.8	37%
2	10	Brisbane	Brick veneer	42		4.2	19%
			Concrete	42	+0.6%	4.2	18%
			Reverse concrete	36	–14.2%	4.6	29%
5	17	Sydney	Brick veneer	37		6.3	57%
			Concrete	38	+1.4%	6.2	55%
			Reverse concrete	32	–13.0%	6.8	77%
6	21	Melbourne	Brick veneer	136		5.4	20%
			Concrete	138	+1.8%	5.3	19%
			Reverse concrete	135	–0.5%	5.4	24%
Average across all 547 775 simulations				169			

TABLE 2b Results for Single-storey Optimum House Gross floor area 166 m²–including garage, excluding patio)

Climate zone BCA	Climate zone AccuRate	Location	External wall type	Energy demand Average (MJ/m².yr)	Energy demand Change from brick veneer	Average stars	Simulations achieving 6 stars or over
1	1	Darwin	Brick veneer	391		5.5	57%
			Concrete	392	+0.4%	5.5	56%
			Reverse concrete	376	–3.9%	5.8	62%
	2	Port Hedland	Brick veneer	271		5.2	48%
			Concrete	272	+0.3%	5.2	47%
			Reverse concrete	248	–8.7%	5.7	61%
	5	Townsville	Brick veneer	138		5.9	63%
			Concrete	138	+0.4%	5.9	63%
			Reverse concrete	132	–4.4%	6.1	67%
3	6	Alice Springs	Brick veneer	219		4.6	31%
			Concrete	220	+0.3%	4.6	31%
			Reverse concrete	181	–17.5%	5.4	55%
2	10	Brisbane	Brick veneer	34		7.0	83%
			Concrete	34	+0.7%	7.0	82%
			Reverse concrete	28	–16.9%	7.6	97%
5	17	Sydney	Brick veneer	35		6.5	66%
			Concrete	36	+1.4%	6.4	64%
			Reverse concrete	30	–15.3%	7.1	85%
6	21	Melbourne	Brick veneer	126		5.7	29%
			Concrete	128	+1.8%	5.6	28%
			Reverse concrete	125	–1.0%	5.7	39%
Average across all 548 319 simulations				201			

TABLE 2c Results for Double-storey Optimum House   Gross floor area 282 m²– including garage, excluding patio)

Climate zone BCA	Climate zone AccuRate	Location	External wall type	Energy demand Average (MJ/m².yr)	Energy demand Change from brick veneer	Average stars	Simulations achieving 6 stars or over
1	1	Darwin	Brick veneer	392		5.3	26%
			Concrete	395	+0.6%	5.3	26%
			Reverse concrete	389	–0.8%	5.4	29%
1	2	Port Hedland	Brick veneer	259		5.1	23%
			Concrete	260	+0.6%	5.1	23%
			Reverse concrete	243	–5.9%	5.4	35%
1	5	Townsville	Brick veneer	130		5.9	51%
			Concrete	131	+0.6%	5.9	50%
			Reverse concrete	130	–0.4%	5.9	51%
3	6	Alice Springs	Brick veneer				
			Concrete				
			Reverse concrete				
2	10	Brisbane	Brick veneer	38		6.5	69%
			Concrete	39	+0.6%	6.5	68%
			Reverse concrete	31	–18.7%	7.3	93%
5	17	Sydney	Brick veneer	36		6.4	63%
			Concrete	36	+1.5%	6.4	61%
			Reverse concrete	29	–20.4%	7.2	86%
6	21	Melbourne	Brick veneer	128		5.6	32%
			Concrete	131	+2.3%	5.6	30%
			Reverse concrete	122	–4.8%	5.8	49%
Average across all 1005 829 simulations				162			

3.3 Impact of Specific Interventions

Once the type of house, wall type and location is determined, a designer has the opportunity to maximise energy efficiency through a number of design interventions, eg adding roof and wall insulation, optimising windows, selecting appropriate roof colour.

Tables 3 and **4** set out the impacts of these various design interventions – **Table 3** analyses the maximum effects on Star Rating while **Table 4** analyses the maximum effects on energy consumed (expressed in MJ/m^2 per year).

The data in **Tables 3** and **4** is ranked from top to bottom by decreasing impact. Although the rankings are broadly similar, they are not identical. This is because, under the NatHERS rating system, the relationship between Star Ratings and energy consumption varies with location. In benign climates (eg BCA Climate Zones 2 and 5) lower energy consumption is required to achieve a particular Star Rating than in more extreme climates (eg Climate Zones 1, 4 and 6).

The impacts for particular climate zones and house types will differ from the values in these tables, but they do rank potential improvements in such a way that designers can make logical choices.

Table 3 Maximum impact of interventions on star rating

	Single-storey Benchmark House with external walls of:			**Single-storey Optimum House** with external walls of:			**Double-storey Optimum House** with external walls of:		
Intervention (in descending order of average impact)	Brick Veneer	Concrete	Reverse Concrete	Brick Veneer	Concrete	Reverse Concrete	Brick Veneer	Concrete	Reverse Concrete
Ceiling insulation	8.2	8.2	8.3	8.6	8.6	8.7	4.2	4.2	4.2
Roof colour	4.9	4.9	5.3	5.4	5.4	5.9	2.9	3.0	3.2
Reflective foil in roof space	4.7	4.7	4.7	5.4	5.6	5.4	2.5	2.5	2.5
Climate zone	3.8	3.8	3.7	4.5	4.5	4.3	2.6	2.8	3.1
Window and glazing type	2.8	2.8	2.7	2.4	2.4	2.4	2.9	2.9	2.3
External-wall insulation	1.7	1.9	2.2	1.7	1.9	2.2	1.9	2.2	2.4
Roof-space ventilation	2.1	2.0	2.2	2.4	2.4	2.4	1.2	1.2	1.2
Floor coverings	2.2	2.2	2.1	1.8	1.8	1.5	1.7	1.7	1.2
Orientation	1.5	1.6	1.8	1.3	1.3	1.5	1.0	1.0	0.9
Ceiling fans	1.4	1.4	1.6	1.0	1.0	1.3	1.2	1.2	1.4
External-wall insulation and foil	1.0	1.2	1.4	1.0	1.2	1.4	1.2	1.4	1.5
Ventilation via windows	1.0	1.0	1.0	1.4	1.4	1.4	1.0	1.1	1.1
Eaves overhang	0.6	0.6	0.6	0.6	0.6	0.6	0.3	0.3	0.3
Insulation between storeys	Not applicable			Not applicable			0.5	0.5	0.4

Table 4 Maximum impact of interventions on energy reduction

Intervention (in descending order of average impact)	Single-storey Benchmark House with external walls of: Brick Veneer	Concrete	Reverse Concrete	Single-storey Optimum House with external walls of: Brick Veneer	Concrete	Reverse Concrete	Double-storey Optimum House with external walls of: Brick Veneer	Concrete	Reverse Concrete
Climate zone	727	730	734	727	730	734	493	500	500
Ceiling insulation	751	751	736	751	751	736	288	286	291
Roof colour	520	520	509	520	520	509	222	221	225
Reflective foil in roof space	419	421	414	419	421	414	168	171	176
Window and glazing type	143	145	135	143	145	135	143	141	142
Roof-space ventilation	160	163	160	160	163	160	87	89	93
Orientation	114	116	104	114	116	104	96	95	93
Floor coverings	93	92	75	93	92	75	50	50	44
Ventilation via windows	55	55	49	55	55	49	84	81	79
External-wall insulation	45	53	58	45	53	58	65	73	73
Ceiling fans	47	48	57	47	48	57	33	33	43
External-wall insulation and foil	27	33	38	27	33	38	46	48	50
Insulation between storeys	Not applicable			Not applicable			23	22	23
Eaves overhang	18	20	18	18	20	18	13	14	13

Notes

- *These Tables give the maximum change in star rating (Table 3) and reduction in energy consumption (Table 4) that can be achieved by changing each intervention, while holding the others constant. High impacts are shown in the darkest colour, low impacts in the lightest colour.*
- *Analysis for 'Roof colour' is based on solar absorbtance.*
- *'Floor coverings' may be ceramic tiles or carpet, and are analysed in the living zones only.*
- *'Insulation between storeys' refers to insulation placed under the suspended floor in the Double-storey House.*

Climate zone **Table 4** indicates that the climate in which a house is located is the major determinant of the energy consumption. Extreme climates, either hot or cold, demand higher cooling or heating energy to maintain a reasonable comfort level. The lower ranking of Climate Zone in **Table 3** reflects the fact that, in the NatHERS rating system, the relationship between Star Ratings and energy consumption varies with location.

Ceiling insulation Most of the heat entering or leaving an uninsulated house is via the roof. The inclusion of ceiling insulation is therefore the most effective design intervention to improve both Star Rating and energy efficiency. This is most pronounced in single storey houses. In double storey houses, the lower ratio of roof area to floor area means that energy efficiency is affected less (although still significantly) by roof insulation.

Roof colour Roofs with a low solar absorbance (generally associated with a light colour) lead to a substantial improvement in Star Rating and energy efficiency, as indicated in **Tables 3** and **4**. Examination of the individual simulations indicates that this improvement occurs in the hot climates.

Reflective foil in roof space The use in the roof space of insulation with a reflective surface can have a significant influence on Star Rating and energy efficiency, particularly in hot climates.

Window/glazing type Many types of windows are commercially available in Australia, exhibiting a range of performance. The use of windows with low thermal transmittance and low solar heat gain coefficient can significantly improve thermal performance. The options include:

- Toned (or tinted) glass, in which metal oxides in the glass reduce the solar heat gain coefficient.
- Low 'E' glass, with a transparent metal coating on the glass surface to reduce both the solar heat gain coefficient and thermal transmittance.
- Double glazing with two (or more) glass panes separated by an insulating air space.
- Reflective glass with metal coating applied to the glass surface to produce a slight mirror effect.

The use of frames of materials with low thermal transmittance (such as timber) will also improve the thermal transmittance of the window as a whole.

The window and glazing types used in the simulations and shown in **Table 5**.

Table 5 Windows/glazing types used in the simulations

Window/glazing type	Thermal transmittance or U-value (W/m²/K)	Solar heat gain coefficient (SHGC)
Aluminium sliding window with single glazed 4-mm green tinted glass	6.49	0.62
Aluminium sliding window with single glazed 3-mm clear glass	6.27	0.74
Timber sliding door with single glazed 3-mm clear glass	5.35	0.71
Aluminium sliding window with single glazed 6.38-mm glass with neutral Low E coating	4.34	0.46
Timber tilt and turn window with double glazed 4-mm green tinted glass, 16-mm argon gap and 4-mm clear glass with Low E coating	1.82	0.32

Notes

- Thermal transmittance or U-value (W/m²/K) is the rate of transfer of heat per unit area per unit temperature difference.
- The solar heat gain coefficient (SHGC) indicates the ability of a window to block heat from sunlight, on a scale of 0 to 1. A window with a low SHGC transmits less solar heat.

Roof-space ventilation Ventilating the roof space is one of the interventions that maximises the effectiveness of passive solar design and the influence of thermal mass. Both **Tables 3** and **4** demonstrate the moderate effectiveness of roof ventilation.

Orientation Appropriate orientation of a house on any particular site can also moderately assist the effectiveness of passive solar design. However, site constraints often dictate against optimum orientation and the contribution to thermal efficiency should not be over-stated. This is indicated by the lower middle ranking in **Tables 3** and **4**.

Floor coverings The use of ceramic tiles in preference to carpets in the living zones of houses in hot climates can provide moderate improvement. On the other hand, the use of carpets in the living zones of houses in cool climates can assist efficiency.

Ceiling fans and ventilation via windows Adequate ventilation of houses, particularly in summer in hot climates will help to reduce cooling energy. They are an essential element of passive solar design, maximising the effectiveness of thermal mass. This is demonstrated in **Tables 3** and **4** by the higher impact on Reverse Concrete houses than on Concrete and Brick Veneer houses.

External-wall insulation and foil The use of external wall insulation and external wall foil have only a moderate effect on increasing the Star Rating (up to 2 Stars under ideal conditions) and reducing energy consumption. Much more effective interventions are available to designers, eg increasing ceiling insulation, lightening roof colour and using improved windows. Compared to these interventions, the addition of wall insulation and reflective foil have significantly lower benefit.

Eaves overhang The extension of eaves from 450 mm to 600 mm provides additional shading in hot climates, thus helping to keep buildings cool. The low ranking in **Tables 3** and **4** indicates that, while there is a moderate contribution in hot climates, there is little benefit in cool climates.

Insulation between storeys This is applicable only in double-storey houses. It reduces heat movement between the conditioned and unconditioned parts of the house, but the effect is not particularly great. Notwithstanding, it is a relatively low-cost intervention, and may assist in gaining an extra half star.

4 DETAILING FOR THERMAL EFFICIENCY

Concrete can be used in houses for slab-on-ground construction with stiffening beams, wall panels and suspended concrete floors with supporting beams and columns. Sensitive detailing of each of these will maximise the thermal efficiency of houses.

Concrete Slab-on-Ground The edge of a slab-on-ground floor, especially the northern edge that acts as the prime heat store, should be insulated to reduce the heat loss to the earth. Thickening the concrete slab to the depth of 250 mm in a two-metre-wide strip along the northern edge, and insulating the outer face of the internal leaf of external walls may be considered. Refer to **Figure 3**, see also **Figures 4** and **5** in *Passive Solar Design*[4]. Consideration must also be given to suitable termite control and inspection.

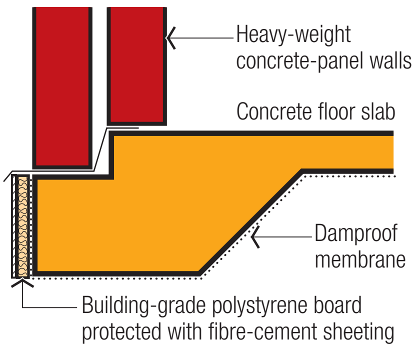

Figure 3 Slab-edge insulation

Walls It is recommended that the external walls of houses be constructed of high-thermal-mass concrete together with added insulation.

One form of construction, with internal insulation and lining is very similar to traditional brick veneer, except that the outer leaf is precast concrete, site-cast concrete or a combination of both. The use of precast concrete opens up many opportunities for incorporating windows, doors and other features into the walls during the precasting process. The energy efficiency of this system is very similar to that of traditional brick veneer.

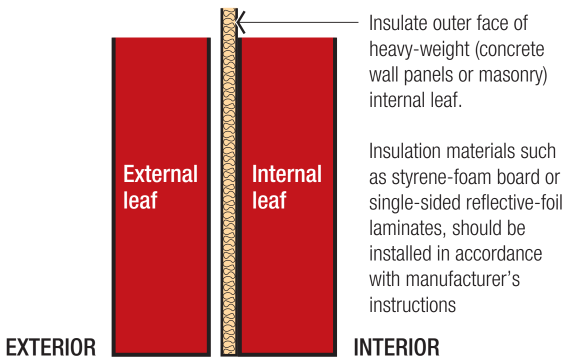

Figure 4 Internal wall insulation

Alternatively, a Reverse Concrete system gives significant energy savings and lower greenhouse emissions. Precast or site-cast reinforced concrete walls prove a high-thermal-mass inner leaf, while coated weatherproof wall insulation provides a high thermal resistance to the outer leaf.

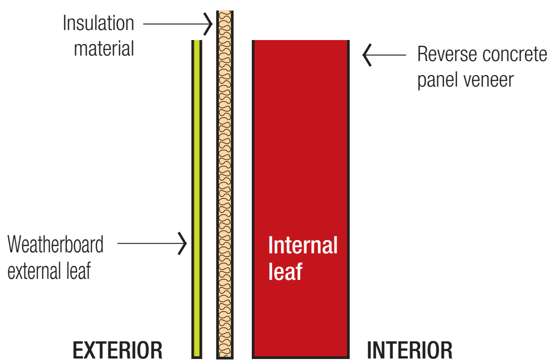

Figure 5 Reverse Concrete insulation

5 CONCRETE – THE ENERGY-EFFICIENT CHOICE

In Australia, there has been growing awareness of the need to build energy-efficient houses, with optimised thermal performance and occupancy comfort. This is reflected in the performance requirements of the National Construction Code and the corresponding deemed-to-satisfy provision for 6-star ratings to NatHERS.

This Technical Note provides the analysis of over two million AccuRATE simulations, and demonstrates the combinations of various design interventions that can achieve 6 stars and more.

The significant benefit of Reverse Concrete walls (ie walls that have insulation on the outside and high thermal mass concrete on the inside) has been well demonstrated. With the additional thermal mass provided by concrete slab-on-ground construction, houses can be readily designed to achieve the requisite 6 stars and associated savings in energy demand and greenhouse gas emissions.

6 REFERENCES

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SYDNEY OFFICE
Level 6, 504 Pacific Highway
St Leonards NSW Australia 2065
POSTAL ADDRESS
Locked Bag 2010
St Leonards NSW 1590
TELEPHONE (61 2) 9437 9711
FACSIMILE (61 2) 9437 9470

BRISBANE OFFICE
Suite 2, Level 2
485 Ipswich Road
Annerley QLD 4103
TELEPHONE (61 7) 3227 5200
FACSIMILE (61 7) 3892 5655

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South Yarra VIC 3141
TELEPHONE (61 3) 9825 0200
FACSIMILE (61 3) 9825 0222

PERTH OFFICE
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West Perth WA 6005
TELEPHONE (61 8) 9389 4452
FACSIMILE (61 8) 9389 4451

ADELAIDE OFFICE
Greenhill Executive Suites
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Eastwood SA 5063
TELEPHONE (61 8) 8274 3758

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