An Atlas for Rammed Earth Building Thermal Performance in Australia Climates

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Abstract

To understand whether the existing house energy star rating system in Australia discriminates against rammed earth houses, simulations were carried out for two sample houses each in 69 local climates at different heating and cooling thermostat temperatures with the original wall systems and with the walls replaced by rammed earth walls. Results showed that rammed earth houses may have been discriminated for climate regions with mean ambient winter temperature between 10.0 and 15.0 °C for the population group who operates heating thermostat temperature at around 15°C during winter. The findings of this study can provide useful information for building regulators on the potential impact of the existing as well as modified thermostat settings in house energy star rating software.

Introduction

In Australia, the Nationwide House Energy Rating Scheme (NatHERS) has been gradually adopted by state and territory governments and building regulators over the last two decades (Delsante, 2005). The increase in the house energy efficiency stringency has contributed to the flattening or declining of residential sector energy consumption in Australia in recent years (DOEE, 2018).

In supporting the NatHERS scheme, a dynamic building simulation tool *AccuRate* is used as the benchmark software for NatHERS star rating for houses to demonstrate compliance with Australian national construction code (NCC) energy efficiency requirements. The *AccuRate* software was developed by coupling a frequency response building thermal model and a multi-zone air flow model for heating and cooling energy requirement calculation of residential buildings (Walsh & Delsante, 1983; Delsante, 2005; Ren & Chen, 2010). Taking into account the local climate and building fabrics, *AccuRate* automatically switches the building operation between mechanical air conditioning and natural ventilation operation and calculates hourly heating and cooling energy requirement over the period of one year. Then, *AccuRate* assigns the house a NatHERS star rating from zero to ten based on the calculated total annual heating and cooling energy requirement per m² conditioned floor area. The more stars, the less likely the occupants need cooling or heating to stay comfortable. Occupants of a 10 star house are unlikely to need any artificial cooling or heating. Currently, most of the state

and territories require a minimum 6 star NatHERS rating for new houses in Australia.

For the calculation of building heating and cooling energy requirement, thermostat settings are commonly set according to standards such as ASHRAE 55-2013 (ASHRAE, 2013) for achieving required occupant thermal comfort. The heating and cooling thermostat settings used in *AccuRate* are specified in NatHERS software accreditation protocol (NatHERS, 2012). For living spaces, a heating thermostat setting of 20°C is used. For sleeping spaces, heating thermostat settings are 18°C from 7:00 to 9:00 and 16:00 to 24:00, and 15°C from 24:00 to 7:00. The cooling thermostat is set equal to the neutral temperature of January (the middle month of the summer in the southern hemisphere) for the corresponding climate zone. It is also assumed that cooling is triggered when indoor air temperature is 2.5°C above the neutral temperature which corresponds to 90% acceptability limit of the ASHRAE adaptive thermal comfort model (ASHRAE, 2013). The cooling thermostat settings, although not exactly corresponding to the ASHRAE adaptive thermal comfort model (ASHRAE, 2013), are based on the understanding that acceptable thermal conditions vary with the local climates.

Thermostat settings can significantly affect the calculation of heating and cooling energy requirement and thus impact on whether or not a house design obtains building approval. James *et al* (1996) simulated a typical house in three Florida cities and showed that cooling energy can be reduced over 20% with per °C increase in the thermostat temperature. Manning *et al* (2007) evaluated experimentally a pair of identical twin houses at the Canadian Centre for Housing Technology and showed that cooling energy reduction can be over 10% with per °C increase in the thermostat temperature. Recently, using *AccuRate* simulations, Ren & Chen (2017) demonstrated that relaxing the cooling triggering temperature from 2.5°C to 3.5°C above the neutral temperature (corresponding to 80% acceptability limit of the ASHRAE adaptive thermal comfort model) reduces 40% of the calculated space cooling energy requirement in regions with hot summer climates (e.g. Alice Springs) for a heavyweight double brick cavity construction house. For a high-set lightweight weatherboard house, such a relaxing in the cooling triggering temperature can result in 25% reduction in the cooling energy requirement and a 2 star increase in tropical regions (e.g. Darwin).

Consequently, the triggering temperature and thermostat set point temperature in *AccuRate* can impact on the construction types of the residential building sector in Australia. Considering that the average service life of a house in Australia is around 60 years, the impact of the thermostat settings used in NatHERS star rating software can be significant over many years to come on the Australian residential sector energy efficiency and greenhouse gas emissions.

Although monitored heating and cooling energy generally confirms the reduction trend for houses built to higher energy efficiency star ratings (O'Leary *et al*, 2016), there are criticisms on NatHERS software tools. One long-standing criticism is that by using the above mentioned fixed heating and cooling thermostat settings, NatHERS energy rating discriminates against the application of climate responsive house construction types such as traditional heavyweight rammed earth buildings and lightweight tropical houses (Soebarto, 2000; Kordjamshidi and King, 2009; Williamson *et al*, 2010; Daniel *et al*, 2015a; Daniel, 2017).

Rammed earth is a sustainable construction material and has been widely used in numerous historical structures. In Australia, small communities of rammed earth house owners/builders are still very active. In several previous studies in Australia (Soebarto, 2000; Williamson *et al*, 2010), measured energy consumption showed that rammed earth houses are more energy efficient in comparison with average modern houses. However, the relatively low thermal resistance, R-value at 0.24 ($\text{m}^2 \cdot ^\circ\text{C}/\text{W}$) for a 300mm thick wall, has made rammed earth house designs very difficult to comply with NCC using NatHERS star rating. This noted difference between measured energy consumptions and NatHERS star rating for rammed earth houses has been attributed to the fact that occupants of rammed earth houses are generally more ecocentric (Daniel *et al*, 2015b). They considered conditions comfortable often outside of the accepted adaptive thermal comfort limits (Daniel *et al*, 2015b) with which the thermostat settings of NatHERS star rating are based on. In other words, occupants of rammed earth houses generally operate their houses at different thermostat settings to those used in NatHERS star rating. It has been suggested that the mandatory NatHERS star rating should consider the atypical preference of such group of population (Daniel *et al*, 2015b) who genuinely live more energy efficiently in traditional houses such as rammed earth houses.

So far, there is no systematic study on the impact of thermostat settings on the energy performance of rammed earth houses when compared with normal modern house designs in different Australian climates. In this study, simulated house heating and cooling energy requirements were compared in all 69 NatHERS climate zones (which cover the entire Australia) between normal modern houses and rammed earth houses using *AccuRate* with the same floor plans and realistic thermostat setting ranges based on recent monitoring studies. This study tries to answer the question whether the existing thermostat settings in NatHERS software discriminates against

rammed earth houses. It also provides information for building regulators on the potential impact of modifying existing thermostat settings in NatHERS software tools.

Methodology

Climate zones

Australia has a wide range of climates from relatively cold alpine climate to hot humid tropical climate. Eight National Construction Code (NCC) climate zones (CZ) are defined by the Australian Building Codes Board (ABCB) as listed in Table 1. Table 1 also includes the corresponding Köppen climate group for these eight NCC climate zones. For NatHERS star rating using building simulation software, a more detailed 69 local NatHERS climate zones (CZs) are used. *AccuRate* contains the Typical Meteorological Year (TMY) weather files for the 69 NatHERS CZs.

Table 2 shows the NatHERS CZs with its corresponding NCC CZ and the existing cooling thermostat temperatures.

Table 1: NCC climate zones and their representative cities

NCC climate zone	Represent City	Description	Köppen climate group
Zone 1	Darwin	Hot humid summer, warm winter	A(tropical)
Zone 2	Brisbane	Warm humid summer, mild winter	C(temperate)
Zone 3	Alice Springs	Hot dry summer, warm winter	B(dry)
Zone 4	Mildura	Hot dry summer, cool winter	B(dry)
Zone 5	Sydney	Warm temperate	C(temperate)
Zone 6	Melbourne	Mild temperate	C(temperate)
Zone 7	Canberra	Cool temperate	C(temperate)
Zone 8	Cabramurra	Alpine	E(polar)

Sample houses

Since October 2014, NatHERS house energy efficiency star rating using *AccuRate* has been centrally certified and stored in the HStar web portal (<https://www.hstar.com.au>) managed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) for facilitating verifying, auditing, analysing, and research. In Australia, over 70% of the dwellings are low-rise detached houses. In this study, two certified house designs were selected for each NatHERS CZ from the HStar database. Houses with brick veneer external wall construction were selected first considering that brick veneer construction is the most commonly used in many regions in Australia. If there is not enough brick veneer houses in the particular climate zone, houses with other construction types were selected. For those climate zones with less than two certified house designs in the HStar database, the house designs from neighbouring NatHERS CZs within the same NCC CZ were used with the assumption that house designs in nearby NatHERS CZs are similar. As shown in Table 2, a

total of 138 real certified house designs were thus selected in this study with a variety of external wall types including 82 with brick veneer, 17 with concrete block wall, 23 with fibre-cement wall, 11 with steel sheet wall, 4 with timber weatherboard, and 1 with double brick wall. These houses range from two bedrooms to seven bedrooms, with floor areas range from 88 m² to 621 m² as shown in Table 2. All the houses have concrete slab floors with 123 single storey houses and 15 double storey houses. So, in theory, the external and internal walls can be readily replaced with rammed earth walls. Table 3 lists the thermal resistances and the heat capacities of the wall systems used in this study. It is seen that the concrete block wall and the rammed earth wall have the lowest thermal resistances among all the wall systems investigated in this study. On the other hand, the rammed earth wall has the highest heat capacity among all the wall systems.

Table 2: House wall types, floor areas and existing cooling thermostat temperature in each NatHERS climate zone.

NatHERS CZ (NCC CZ)	City Name	Sample House External Wall Type	Sample House Floor Area (m ²)	Existing Cooling Thermostat temperature (°C)
1 (1)	Darwin	CB,CB	148,181	26.5
2 (1)	Pt Hedland	SS,BV	262,214	27
3 (3)	Longreach	BV,WB	234,307	27
4 (3)	Carnarvon	CB,CB	184,105	26
5 (1)	Townsville	CB,CB	170,281	26.5
6 (3)	Alice Springs	CB,CB	211,223	26.5
7 (2)	Rockhampton	BV,FC	198,139	26
8 (4)	Moree	BV,SS	289,180	26
9 (2)	Amberley	BV,BV	193,314	26
10 (2)	Brisbane	BV,BV	621,238	25.5
11 (2)	Coffs Harbour	BV,BV	230,261	25
12 (5)	Geraldton	BV,BV	212,243	25
13 (5)	Perth	FC,BV	189,327	25
14 (7)	Armidale	FC,BV	221,103	24
15 (5)	Williamtown	BV,BV	249,234	25
16 (5)	Adelaide	BV,BV	137,269	25
17 (5)	Sydney	BV,BV	297,168	25.5
18 (6)	Nowra	BV,BV	245,451	24.5
19 (3)	Charleville	BV,WB	234,307	27
20 (4)	Wagga	BV,BV	195,304	25
21 (6)	Melbourne	AC,BV	374,227	24
22 (6)	East Sale	BV,BV	196,141	23
23 (7)	Ti Tree Bend	BV,WB	248,91	22.5
24 (7)	Canberra	BV,BV	418,195	24
25 (8)	Cabramurra	FC,BV	216,271	23
26 (7)	Hobart	BV,BV	322,221	23
27 (4)	Mildura	BV,BV	162,317	25
28 (6)	Richmond	BV,BV	224,197	24.5
29 (1)	Weipa	FC,FC	116,155	26
30 (1)	Wyndham	SS,SS	212,154	27.5
31 (1)	Willis Island	SS,SS	154,375	26.5
32 (1)	Cairns	CB,CB	211,170	26.5
33 (1)	Broome	SS,SS	212,154	27
34 (1)	Learmonth	SS,BV	262,214	26.5
35 (2)	Mackay	BV,FC	198,139	26
36 (2)	Gladstone	BV,FC	198,139	26
37 (3)	Halls Creek	CB,CB	184,105	27
38 (3)	Tennant Creek	CB,FC	280,243	27
39 (3)	Mt Isa	CB,FC	280,243	27
40 (3)	Newman	CB,CB	184,105	28
41 (4)	Giles	BV,FC	395,211	27.5
42 (4)	Meekatharra	BV,FC	395,211	28

43 (4)	Oodnadatta	BV,BV	119,270	27
44 (4)	Kalgoorlie	BV,BV	385,395	26
45 (4)	Woomera	BV,BV	119,270	26
46 (4)	Cobar	BV,FC	170,267	26.5
47 (4)	Bickley	BV,BV	384,252	24.5
48 (4)	Dubbo	BV,BV	406,379	25
49 (4)	Katanning	BV,BV	252,152	24.5
50 (5)	Oakey	SS,BV	249,88	25
51 (5)	Forrest	FC,FC	188,161	25.5
52 (5)	Swanbourne	FC,FC	237,208	25
53 (5)	Ceduna	BV,FC	171,161	24.5
54 (5)	Mandurah	FC,FC	287,175	25
55 (5)	Esperance	FC,FC	188,175	24
56 (5)	Sydney Airport	BV,BV	297,168	24.5
57 (6)	Manjimup	BV,BV	338,276	23.5
58 (6)	Albany	BV,BV	338,276	23.5
59 (6)	Mt Lofty	BV,BV	165,265	23
60 (6)	Melbourne Airport	BV,BV	330,265	24
61 (6)	Mt Gambier	BV,BV	211,264	23.5
62 (6)	Moorabbin	BV,BV	307,195	24
63 (6)	Warrnambool	BV,BV	141,198	23
64 (6)	Cape Otway	BV,BV	227,264	23
65 (7)	Orange	BV,BV	156,269	23
66 (7)	Ballarat	BV,BV	253,211	23.5
67 (7)	Low Head	BV,WB	248,91	23
68 (7)	Launceston Airport	BV,DB	248,509	23.5
69 (8)	Thredbo	FC,SS	89,126	22.5

Here:

CB: Concrete block; SS: Steel sheet;
BV: Brick veneer; WB: Weather board;
FC: Fibre-cement board; DB: double brick;
AC: Aerated autoclaved concrete block

Table 3: thermal resistance and the heat capacity of the wall systems used in this study^a

Wall system	Material layers external to internal	Thermal resistance (m ² ·°C/W)	Heat capacity (kJ/m ² ·°C)
Brick veneer	Brick (110 ^b) Airgap ^c Insulation R0 – R3.1 Plasterboard (10)	0.40-3.91	169
Concrete block	Concrete block (190)	0.15	374
Fibre-cement	Fibre-cement sheet (6) Airgap ^c Insulation R0.6-R2.5 Plasterboard (10)	0.83-2.73	17
Steel sheet	Steel sheet (1) Airgap ^c Insulation R1.5-R2.5 Plasterboard (10)	1.74-2.74	13
Timber weatherboard	Timber (18) Airgap ^c Insulation R1.5-R2.5 Plasterboard (10)	1.90-2.90	28
Double brick	Brick (110) Airgap (40) Insulation (119) Plasterboard (10)	3.19	320
Rammed earth	Rammed earth (300)	0.24	582

- calculation based on AccuRate material database
- layer thickness in mm
- air gap thickness ranges from 20mm to 90mm

Heating and cooling thermostat settings

In recent years, several survey and monitoring studies on heating and cooling operation in houses have been carried out in Australia. In 2012, CSIRO did a survey and monitoring study in Brisbane, Adelaide and Melbourne (Ambroise *et al.*, 2014). Brisbane has a subtropical climate with warm humid summer, mild winter, while both Adelaide and Melbourne have mild temperate climates. Half-hourly electricity consumption data were collected by direct monitoring electricity at the switchboard for 9 months from the beginning of June 2012 to the end of February 2013. Temperature measurements at the living areas were also taken at 30-minute intervals. Monitored data from 129 houses with reverse cycle air conditioners (A/C) were analysed (Chen *et al.*, 2018). Figure 1 shows the relationship between the average heating and cooling switch on indoor temperature ($T_{switchon}$) and the average indoor air temperature for each house when A/C was in operation in winter and summer. It is clear that different householders operate their houses in significantly different heating and cooling temperatures.

Figure 1: Relationship between average A/C switch on indoor temperature and average A/C operation indoor air temperature for each house in winter and summer (Chen *et al.*, 2018).

Daniel *et al.* (2015b) surveyed and monitored 20 mud brick/rammed earth houses in Melbourne and 20 partially/fully naturally ventilated houses in tropical Darwin in 2012 and 2013. Figure 2 shows the comparison between the ASHRAE55-2013 adaptive thermal comfort ranges and the comfort votes recorded. In Figure 2, there were substantial comfort votes outside the 80% acceptability limits of the adaptive thermal comfort model, especially at the cold side. This is consistent with the findings by Kim *et al.* (2016) who monitored 27 houses in Sydney and 15 houses in Wollongong from March 2012 to March 2014. Figure 3 plotted the prevailing mean outdoor air temperature with the indoor air temperature when A/C just switched off which Kim *et al.* (2016) argued to be the thermally comfort temperature.

These recent studies in Australian houses showed that there are groups of populations considering indoor temperatures acceptable at around 12-15°C in winter and

around 30-32°C in summer. In this study, in order to provide a systematic understanding of the impact of thermostat temperatures, simulations were carried out for the 138 houses with thermostat settings extended to these relatively extreme temperature ranges.

Figure 2: Indoor temperature with comfort votes plotted against the 80% and 90% acceptability ranges defined by the ASHRAE55-2013 adaptive thermal comfort model (Daniel *et al.*, 2015b).

Figure 3: Indoor A/C switch off temperature plotted against the 80% acceptability range defined by the ASHRAE55-2013 adaptive thermal comfort model (Kim *et al.*, 2016).

Results and discussions

Simulations were carried out using *AccuRate* for all the houses with heating thermostat at existing settings as mentioned in Introduction, and at 18°C, 17°C, 16°C, 15°C, 14°C, 13°C, 12°C if the existing heating thermostat setting is higher. Simulations were also carried out for all the houses with cooling thermostat at existing settings as shown in Table 2, and at 26°C, 27°C, 28°C, 29°C, 30°C, 31°C, 32°C if the existing cooling thermostat setting is lower. For each house, simulations were carried out in its corresponding NatHERS CZ for the design with the original wall construction and for the design with the external and internal walls replaced by 300mm rammed earth walls, respectively. Thus, a total of 4416 *AccuRate*

simulations were executed in this study. The annual heating energy requirement, cooling energy requirement and the total annual heating and cooling energy requirement results presented in this section are the average values of the two houses in each NatHERS CZs.

Results for existing thermostat settings

Figure 4 compares the heating, cooling and the relative total energy requirements for the houses with original wall systems and rammed earth walls using the existing NatHERS heating and cooling thermostat settings. Here, the relative total energy requirement is the total heating and cooling energy requirement of the house with rammed earth walls divided by the total heating and cooling energy requirement of the houses with the original wall systems in each NatHERS CZ. When investigating the effect of wall construction types on house heating and cooling energy requirements, the mean ambient winter and summer temperatures are important factors. Figure 4 also plotted the mean winter and summer temperatures for each NatHERS CZ.

It was found that for NatHERS CZs with mean ambient winter temperatures below 15.0°C, the replacement with rammed earth walls generally results in much higher heating energy requirement and slightly low cooling energy requirements with the existing heating and cooling thermostat settings. The reason is that in these NatHERS CZs, heating energy requirement is generally the same magnitude or higher than cooling energy requirement. In order to comply with NCC energy efficiency requirement, external walls are normally insulated with R-values from 1.5 to 3.0. Replacing these insulated external wall systems with rammed earth walls generally results in much higher heating energy requirement due to the low thermal resistance of the latter at R0.24, while the cooling energy requirement is slightly reduced due to the high thermal mass of the rammed earth walls. Consequently, the total energy requirements with rammed earth houses are generally higher than the houses with the original walls as shown in Figure 4 (c).

On the other hand, in climates where there is no or small space heating requirements (NatHERS CZs with mean ambient winter temperatures above 15.0°C and mean ambient summer temperatures above 25.5°C), the replacement with rammed earth walls generally results in relatively lower total heating and cooling energy requirement. This is because the high thermal mass of rammed earth walls reduces cooling energy requirement, while there is smaller changes in the heating energy requirement.

In several climates, such as NatHERS CZs 1, 4-6, 32, 37 and 40 (refer to Table 2), concrete blocks were used as the original wall system. The replacement with rammed earth walls can also result in lower total heating and cooling energy requirement due to the high thermal mass of the rammed earth walls and the even lower thermal resistance of the concrete block walls at R0.15 in comparison with the rammed earth walls as listed in Table 3.

Results for different heating thermostats

Figure 5 shows the relative total energy requirements for the houses in the 69 NatHERS CZs using heating thermostat temperatures at 13.0°C, 15.0°C and 17.0°C respectively, while the cooling thermostats used the existing settings. The relative total energy requirements using the existing heating thermostat settings were also included for comparisons.

(a) Heating

(b) Cooling

(c) Relative total energy requirements

Figure 4: Energy requirements for space heating (a), space cooling (b) and the relative total energy requirements (c) for the houses with original wall systems and rammed earth walls using the existing NatHERS heating and cooling thermostat settings.

It was found that the worst thermal performance with rammed earth walls were found in NCC CZ8 (including NatHERS CZs 25 and 69) which have the coldest climates (alpine) in Australia with the mean ambient winter temperature between 1.0°C and 3.0°C. For NatHERS CZs 25 and 69, the replacement using rammed earth walls results in around 150% - 200% heating energy requirements increase. Reducing the heating thermostat from existing, 17.0°C, 15.0°C to 13.0°C does not make much improvement to the relative total energy requirements. Spacing heating is dominant in these climates with minimal summer cooling requirements. The low thermal resistance of the rammed earth wall contributes to this poor performance relative to the original wall systems which have insulation levels at R2.0 or above in these two NatHERS CZs.

Figure 5: Relative total energy requirements for the houses in the 69 NatHERS CZs using different heating thermostat temperatures at 13.0°C, 15.0°C, 17.0°C and existing settings respectively.

For NatHERS CZs with mean ambient winter temperature between 3.0 and 10.0°C, replacement with rammed earth walls generally results in poor thermal performance in the heating thermostat ranges from 15 to 20°C. Further reduction in the heating thermostat to between 12 and 15°C may make the thermal performance of a rammed earth house comparable to the house with the original wall systems in terms of the total heating and cooling energy requirement as seen in Figure 5. Although there are occupants who operate houses below 15°C, it is generally not recommended due to health considerations (Shiue and Shiue, 2014; Jevons *et al*, 2016). These regions include all the NatHERS CZs in NCC CZ7 and some NatHERS CZs in NCC CZ6 (refer to Table 2).

For NatHERS CZs with mean ambient winter temperature between 10.0 and 15.0°C, the thermal performance of rammed earth wall houses relative to the houses with the original wall systems can be significantly improved by lowering the heating thermostat setting temperature. Rammed earth houses can in general achieve similar or better thermal performances when the heating thermostat is around 15°C in comparison with the original house designs. These regions include all the NatHERS CZs in

NCC CZ5 and some NatHERS CZs in NCC CZs 3, 4 and 6.

This finding has several implications. First, in these regions in Australia, the population group, who considers thermally comfortable or prefers a heating thermostat setting temperature at around 15.0°C, will in theory consume similar or less space heating energy in the rammed earth houses than in the corresponding houses with the original wall constructions. It should be noted that the rammed earth houses in these regions are generally achieve lower star ratings (i.e. predicted to consume more space heating energy) than the houses with the original wall constructions according to NatHERS star rating. Second, the reduction in heating energy consumption for the rammed earth houses is higher than that for the houses with the original wall constructions if the occupants set the heating thermostat temperatures at 15°C instead the existing heating thermostat temperatures. This confirms that NatHERS rating does discriminate rammed earth constructions in these climate regions in the view of this particular population group who consider thermally comfortable or prefer a lower heating thermostat temperature at around 15.0°C.

For NatHERS CZs with mean ambient winter temperatures above 15.0°C, heating thermostat temperature changes have small effect on the relative total energy requirement of the houses with both wall constructions (rammed earth walls and the original walls). Winters in these regions are relatively mild and warm with no or minimal space heating requirement. Thus, reductions in the heating thermostat temperature have no or very small effect on the total heating and cooling energy requirement in these climates. These regions include all the NatHERS CZs in NCC CZ1, and the majority of the NatHERS CZs in NCC CZ2 and NCC CZ3.

Results for different cooling thermostats

Figure 6 shows the relative total energy requirements for the houses in the 69 NatHERS CZs using cooling thermostat temperatures at 27°C, 29°C and 31°C respectively, while the heating thermostats used the existing settings. The relative total energy requirements using the existing heating thermostat settings were also included for comparisons. For NCC CZ8 (including NatHERS CZ 25 and 69) which has the coldest climate in Australia with the mean ambient winter temperature between 1.0°C and 3.0°C, changes in the cooling thermostat temperature do not change the poor performance of the rammed earth wall construction since there is no need of cooling in these regions.

For NatHERS CZs with mean ambient winter temperature between 3 and 15.0°C, replacing with rammed earth walls generally results in high total energy requirement with all the cooling thermostat temperatures investigated in this study. This is mainly due to the poor performance of houses with rammed earth walls for space heating. It was also observed that with the increase in the cooling thermostat temperature, the relative total energy requirement of the houses becomes higher. This can be

explained with one of the example houses in Melbourne NatHERS CZ21.

Figure 6: Relative total energy requirements for the houses in the 69 NatHERS CZs using cooling thermostat temperatures at 27°C, 29°C and 31°C respectively.

Table 4 lists the total annual heating and cooling energy requirement per m² of conditioned floor area for the brick veneer house (refer to Table 2) with original wall system and rammed earth walls at the existing and at 27°C cooling thermostat temperatures respectively in Melbourne. This three-bedroom two-storey house has R2.5 insulation in its original external brick veneer wall construction. It was found that the cooling energy requirement was already reduced with the replacing of the original wall system by rammed earth walls at the existing cooling thermostat temperature which is 24°C in Melbourne (refer to Table 2). Although the cooling energy requirement is further reduced to around zero (no cooling requirement) for the house with rammed earth walls at 27°C cooling thermostat temperature, the reduction in the cooling energy requirement with the original wall system is larger when the cooling thermostat changes from existing (24°C) to 27°C. This explains the observation in Figure 6 that the relative total energy requirement of the houses increases if the cooling thermostat temperature is increased. However, it should be noted that rammed earth wall house designs do perform better during summer period and a total removal of space cooling system may be achievable as demonstrated with this sample house in Melbourne as shown in Table 4.

For NatHERS CZs with mean ambient winter temperature above 15.0°C and mean ambient summer temperatures above 25.5°C, replacing with rammed earth walls generally results in better thermal performance with increased cooling thermostat temperature range investigated in this study. This is expected since in these climates, cooling dominates with no or minimal heating requirement, while the high thermal mass of the rammed earth walls may achieve reduction in cooling energy requirement in comparison with the original wall systems.

It was found that when the cooling thermostat is above certain temperature, both the original and the rammed earth houses require no or minimal cooling energy and their performance difference in terms of total heating and

cooling energy requirement become small. In other words, the energy performance of the original house design and the house with rammed earth are similar in terms of energy performance.

Consequently, for cooling energy requirement, increasing the cooling thermostat temperature in general can only benefit to rammed earth wall constructions in NatHERS CZs with mean ambient winter temperature above 15.0°C and mean ambient summer temperatures above 25.5°C.

Table 4: Heating and cooling energy requirement at different cooling thermostat temperatures for one sample house in Melbourne, NatHERS CZ21.

	Heating (MJ/m ²)	Cooling (MJ/m ²)	Relative Total Energy (%)
Original Wall, existing	87.4	33.7	223%
Rammed earth wall, existing	254.9	15.3	
Original Wall, 27°C	87.3	9.1	265%
Rammed earth wall, 27°C	254.9	0.8	

Discussions

It is understood that two houses in each climate zone are relatively small sample sizes. It is also noted that rammed earth wall houses may perform better in extreme hot days when the house is in free-run operation with no cooling. On the other hand, although the cooling energy may be reduced in NatHERS CZs with mean summer temperature above 25.5°C using rammed earth walls, the high thermal mass in hot climates may result in slow cooling down during sleeping hours in comparison with lightweight wall houses. Further, comparison between rammed earth wall construction and other wall types may need specific house designs which are appropriate for the wall systems used. Therefore, the current study may provide general guidance on the performance of rammed earth wall houses in Australian climates at different heating and cooling thermostat temperatures. The findings provide useful information for building regulators on the potential impact of modifying existing thermostat settings in NatHERS software. However, further detailed research is needed in the future to cover the aspects discussed in this section.

Conclusions

To answer the question whether the existing NatHERS rating discriminates against rammed earth constructions, simulations were carried for two sample houses each in all NatHERS CZs at different heating and cooling thermostat temperatures for the design with the original wall systems and for the design with rammed earth walls respectively. Results showed that for NatHERS CZs with mean ambient winter temperature between 3.0 and 10.0°C, replacement using rammed earth walls generally results in poor thermal performance unless reducing the heating thermostat to 12-15°C (note that this is not recommended considering health issues). However, for NatHERS CZs with mean ambient winter temperature between 10.0 and 15.0°C, the population group, who

considers thermally comfortable or prefer a heating thermostat setting temperature around 15.0°C, is predicted to consume similar or less space heating energy in the rammed earth houses than that in the houses with the original wall constructions. This confirms that NatHERS rating does discriminate against rammed earth constructions in these climate regions in the view of this particular population group.

For cooling energy requirement, increasing the cooling thermostat temperature in general only benefit to rammed earth wall constructions in NatHERS CZs with mean ambient summer temperatures above 25.5°C. The findings can provide useful information for building regulators on the potential impact of modifying existing thermostat settings in NatHERS software. Although the study focused on Australia context, the general findings from this study are mainly climate related and should be applicable to locations with similar climates in other countries. Further detailed research is needed in the future by involving more sample houses and by including thermal performance in free-run house operation.

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