A study of the user behaviours in dwellings of earth construction

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ABSTRACT: Occupant behaviours are cited as a significant factor in residential energy use, in a report prepared for the *Department of Climate Change and Energy Efficiency* in 2010. The Nationwide House Energy Rating Scheme (NatHERS), that determines the Star Rating for the Building Code of Australia (BCA) Energy Efficiency compliance, allows just a single user profile. This research explores the postulation that; *occupants of earth dwellings may have different behaviours to the generic profile prescribed by the NatHERS protocol and that these alternative behaviour profiles may affect greater household energy savings.*

If true, this indicates that the NatHERS method of Energy Efficiency compliance may be biased against occupants with ecocentric dispositions, shown to result in energy saving behaviours. This study provides empirical evidence on the occupancy behaviour profiles of a cohort of earth building users and gauges the critical effect this has on star rating output and compliance with the BCA Energy Efficiency requirements.

Questionnaire results corroborate the previously acknowledged ecocentric dispositions of occupants of dwellings incorporating earth components, whilst thermal simulation reveals the potential energy savings these behavioural trends may affect.

Conference theme: Sustainability issues
Keywords: earth building, occupant behaviour, energy efficiency regulation

1.1 INTRODUCTION

1.2 Background

Earth is the vernacular building material of the world; it can be found on almost every continent in different forms of housing. It is estimated that, even today, one third of the world's population reside in dwellings formed from un-fired earth. Often, when mainstream building materials are too expensive or unavailable, earth is used in the construction of housing and public facilities.

Earth building has origins in the Americas, Asia, Africa and Europe. Cob and pise were favoured in France and England while adobe was more widely used in arid climates such as Mexico and Africa. Despite vastly different climatic conditions, earth has been manipulated to create shelter from the most rudimentary to the palatial for hundreds of years. Throughout the years notable writers, philosophers and architects, such as Vitruvius, Francois Cointeraux, Luis Barragan, Frank Lloyd Wright, Adolf Loos, Le Corbusier and Hassan Fathy, have discovered and exalted the qualities of earth building.

Earth is commonly utilised as an alternative building material in Australian residential and commercial architecture. Various methods of earth building were introduced to Australia from Europe and the Americas as early as the late 18th century. As Australia refined earth building techniques it became widely recognised as proficient in the field. Williams-Ellis (1947), in his search for a practical wartime building material, references a New South Wales State Government publication, *The Famer's Handbook* that contained detailed instructions on building with rammed-earth.

Pise and mud brick are still the most widely used forms of earth building in Australia. Small communities of earth house owner/builders have formed throughout Australia, often representing an attitude towards the natural environment rather than employing earth purely as a tectonic building material (Rael, 2009).

In recent research (Casey, 2005) it was identified that "muddies" display different values, attitudes and behaviours to that of the general populace. Casey found that mud brick dwelling occupants could be positively linked with ecocentric attitudes towards the natural environment, which in earlier studies where associated with higher levels of energy saving behaviours and membership in environmental organisations (Thompson & Barton, 1994). Key governing protocols used in the compliance of residential construction for the Energy Efficiency requirements in Volume 2, Class 1 and 10 buildings, of the Building Code of Australia (BCA) do not acknowledge different user behaviours. This is perhaps counterintuitive in effectively achieving the objective of the BCA Energy Efficiency provisions of "*reducing greenhouse gas emissions*", as the report prepared for the *Department of Climate Change and Energy Efficiency (DCCEE)* cites "*user behaviours* [as] *critical to actual energy use*" (Pitt&Sherry, 2010). This report also acknowledges that assumptions within the Nationwide House Energy Rating Scheme (NatHERS) compliance protocols do not accurately reflect user behaviour.

The NatHERS protocol sets limits for household heating and cooling energy loads as targets for building compliance, these targets are expressed as star ratings. Intrinsic to the operation of star ratings as a measure of performance is a belief that any "human factors" involved can be standardised because "*... it would be impossible to rate the behaviour of the occupants, such as their lifestyle and appliance choice*" (DCCEE, press release Aug 2010). Once the human variable is standardised the assessment technique is essentially reduced to a problem of dealing adequately with the physics of heat flow. This indicates that if a household operates under a different basis, they are more likely to be negatively impacted by the star rating compliance method.

The NatHERS national benchmark software tool, second generation AccuRate Version 1.1.4.1, simulates the thermal performance of the building envelop and, based on predicted heating and cooling loads, produces a star rating from 0-10. A 10 star rating infers that the dwelling will require almost no additional heating and cooling. Since September 1st 2010, a 6.0 star rating is required for all new residential homes in South Australia to satisfy the BCA Energy Efficiency provisions. A Council of Australian Governments (GOAG) agreement required all States and Territories to adopt a 6 Star Rating or equivalent by May 1st 2011. Input required for simulation includes detailed information about construction, layout, shading, glazing and ventilation, while the program assumes other non-variable data, as specified by the NatHERS protocol, such as occupancy profiles, casual heat loads and appliance use. Changes made to any of the input or non-variable data represent a critical variation in the star rating realised and ultimately whether or not compliance is achieved.

The naturally low thermal resistance (R-value) of earth building elements (particularly mud brick and rammed earth walls) presents a difficulty in achieving compliance with the current Energy Efficiency requirements. This implies that houses proposing to incorporate earth components can no longer easily attain building approval, despite testimonial evidence supporting the user satisfaction of the occupants.

1.3 Literature review

The DCCEE Report, *The Pathway to 2020 for Low-Energy Low-Carbon Buildings in Australia: Indicative Stringency Study* (Pitt&Sherry, 2010), evaluates the effectiveness of the Energy Efficiency requirements, and, in particular, the NatHERS thermal simulation compliance process, in the BCA. It found that, in reference to household energy use; "*user behaviours are critical to actual energy use*" and that "*loads ascribed… are based on a number of assumptions that do not accurately reflect user behaviour*". This sentiment is shared by Harris et al (2008) in *Towards a sustainable energy balance: progressive efficiency and the return of energy conservation*; "*user behaviours… provide energy savings and lower energy consumption*". Pitt&Sherry conclude with recommendations including; "*an adjustment for the occupancy to better reflect actual user behaviour*", "*an adjustment for the thermostat operation to better reflect actual user behaviour*" and that "*the pathway must be evidence-based*". These sources demonstrate a defect within the NatHERS assessment process and a possible bias against occupants with alternative user behaviours.

The schism between the Energy Efficiency compliance process and the measured environmental and thermal performance is explored in *Comfort and energy use in five Australian award-winning houses: regulated, measured and perceived*. Williamson et al (2010), found that regulatory control as a means of;

> *"encouraging residential energy efficiency and reducing greenhouse gas emissions… will require rethinking and adjustment to include a wider range of criteria such as inhabitants' expectations and behaviours".*

This provides further support for the view that occupancy behaviours need to be compensated for within the NatHERS compliance process.

A deficit of information about the development and adoption of the occupancy profiles within NatHERS is conspicuous. The NatHERS website refers to the national benchmark software using a 'standard family' profile for thermal simulations. This 'standard family' is made up of two adults and two children (DCCEE, 2007), far from the occupancy rate in 2008 of 2.6 persons per dwelling (ABS, 2009). The use of a nuclear family scenario indicates little consideration of the diverse family typologies displayed in contemporary society. In a Regulation Impact Statement, *Proposal to Amend the Building Code of Australia to increase the Energy Efficiency Requirements for Houses* (ABCB, 2006), it appears that other occupant typologies have been considered in a cost/benefit analysis of the Energy Efficiency requirements, however there is no evidence of this impacting NatHERS regulation.

Regulating for a nonspecific population is discussed in a broader philosophical sense in *Architecture for the Poor.* Fathy (1973) condemns the irrationality of constructing parameters around the assumption of a generic user profile;

> *"By applying statistical averages to housing, these architects ignore an elementary warning to all amateur wielders of statistics. The statisticians themselves tell us that though the characteristics of a whole population are stable, the individuals in this population vary unpredictably".*

Here, Fathy highlights the importance of consideration and regulation for the individual opposed to broad generalisation.

An alternative user group to the 'generic' profile can be identified in earth building occupants. Dethier (1981), in *Down to Earth, Mud Architecture: an old idea, a new future*, recognises this in relation to the 'washing-line paradox';

> "*the millions of families who build their own homes in earth each year are similarly ignored because they do not consume according to the norms of industrial production*".

These behaviours can be described in the terms of ecocentric and anthropocentric attitudes towards the environment. Thompson and Barton (1994) explore the distinction between ecocentric, anthropocentric attitudes and their relationship to energy saving behaviours in two American samples. Ecocentrism can be defined as "*valuing nature for its own sake*" and anthropocentrism as "*valuing nature because of material or physical benefits it can provide for humans*". They found that ecocentric attitudes have a definable link to; a) relatively low levels of apathy, b) reported energy saving behaviours, c) membership in environmental organisations. Casey and Scott (2006) replicated the Thompson and Barton study with an Australian sample and found that the results were closely aligned with the pilot study. Casey (2005) also applied this methodology to a sample of mud brick house occupants and found that the residents "*have an awareness and appreciation of their oneness with nature*" translating to "*…. high levels of pro-environmental behaviour and ecocentrism, and relatively low levels of anthropocentrism and apathy*".

It can be seen that earth construction attracts occupants with ecocentric dispositions therefore creating a definable alternate user group. This argument is similarly confirmed by Rael (2009) in *Earth Architecture*;

> *"the humble mud brick has long since surpassed its role as purely tectonic and pragmatic material, and today its use often symbolises a… client's or architect's desire to build responsibly and ecologically."*

The anecdotal and testimonial evidence regarding the user satisfaction of dwellings including earth components reveals a disconnect between BCA Energy Efficiency requirements, including the NatHERS compliance method, and actual occupant experience.

No known prior studies have dealt with this topic specifically, rather, focusing on the correlation (or otherwise) of NatHERS predicted heating and cooling loads with actual household heating and cooling energy use with little or no in-depth analysis of the influence of alternative occupant behaviours. One of the aims of this research is to discover if there are any consistent behaviours amongst the cohort of earth building users, and whether their behaviour may differ from the generic profiles as prescribed by NatHERS.

2. METHODOLOGY

A questionnaire was developed with a series of quantitative and qualitative questions aimed at providing information on how occupants think about and use their house. Questions include, but are not limited to, inquiries into demographic information, heating and cooling appliances and use, house construction, and occupant behaviour. The questionnaire took approximately 15 minutes to complete. The package circulated includes cover letter with rubric regarding the research project and intended outcomes, ten-page questionnaire, contact information sheet separate from the questionnaire and reply paid envelope.

The questionnaire was distributed to a range of occupants of earth houses through organisations such as *Earth Building Association Australia, Nillumbik Mudbrick Association* and *Aldinga Arts Eco Village*. It is recognised that the use of the organisations to distribute the questions inherently defines a select group of respondents.

An online version, utilising *Survey Monkey*, was made available through the websites of the above organisations. The online questionnaire almost exactly aligns with the hardcopy questionnaire except for where it was necessary to change the web page logic.

Hardcopy questionnaires were collected and manually entered into the response option on the *Survey Monkey* website. Data was then downloaded utilising the option to collate the data in a SPSS file format. The data was then analysed using SPSS statistical analysis software.

Thermal simulation, using AccuRate Version 1.1.4.1, was then used to investigate the possible impact of alternative user profiles on star rating results for one case study dwelling.

3. QUESTIONNAIRE RESULTS

3.1 Overview

Approximately 250 hardcopies of the questionnaire where distributed over 3 months. Of those circulated 86 where returned complete. The online version yielded 89 results, however 23 of those where deemed invalid because the respondents had not answered all questions. *Table 1* expresses the valid response rate disaggregated by state. Victoria produced a significantly higher proportion of responses due to the use of the industry groups in the distribution of the questionnaire.

Table 1. Response Count disaggregated by state

Response Count	State
19	NSW
92	VIC
8	QLD
20	SA
10	WA

The average occupancy rate of participants is 1.76 persons per dwelling, significantly lower than the 2008 national figure of 2.6 persons per dwelling (ABS, 2009). This figure is also much lower than the base occupancy rate used in NatHERS benchmark software of 4 persons per dwelling (DCCEE, 2007). Just over 50% of all respondents are aged 50 years and above, this indicates that the cohort surveyed is predominantly established households.

On average, the houses are approximately 25 years old, with the newest houses being from 1-3 years old and the oldest house being 200 years old! The average period of respondents living in their house is 15 years. Almost all of the houses surveyed are detached dwellings (99.3%); this figure is considerably higher than the 2008 national figure of 77% (ABS, 2008).

The dwellings surveyed are set in a wide range of contexts, from suburban with close neighbours (27%), rural, open countryside/farmland (16%), rural, bushland (32%) and *other* (23%). Responses to *'other'* are predominantly; large bushland blocks in suburban settings, and eco-villages communities.

The majority of respondents have 100% earth construction for the external walls, while less than 50% of respondents have full earth construction walls internally. *Table 2* demonstrates the main methods of earth wall construction, with mud brick or adobe being the most common technique used. Of the *'other'* responses, both are wattle and daub.

Table 2. Earth wall construction methods

Construction Method	Response Per cent	Response Count
Rammed earth or stabilised earth or Pise	28.9%	46
Mud brick or Adobe	64.8%	103
Pressed Earth Bricks	5.0%	8
Cob	0.0%	0
Other	1.3%	2

The predominant reasons respondents reported for choosing earth wall construction were appearance, low energy impact and that it is a natural and renewable material. Other reasons include statements regarding the perceived thermal benefit of earth walls, the 'feel' or tactile qualities of earth walls and 'philosophy'.

3.2 Insulation in the home

Only 5% (9 responses) of respondents had a separate layer of thermal insulation in the external walls, this is significantly lower than the 2008 national figure of 30.7% homes (ABS, 2008). Of the 5% of insulated external walls, 56% of the walls had the insulation located within the wall. This indicates that a separate layer of thermal insulation is not inherent to earth wall construction methods.

Most houses (93.7%) surveyed have roof insulation with the majority having some sort of bulk insulation and reflective foil, more closely aligned with the national figure of 98% in 2008 (ABS, 2008).

3.3 Perceived Comfort Levels

Several questions sort the householder's attitude towards the climate and the conditions within their house. To the question regarding satisfaction with the immediate climate by far the majority, 91%, gave a positive response about the climate with many respondents citing seasonal variation;

> *"I like the distinct seasonal changes"* and, *"We live in a temperate climate, with warm days and cool nights, the rammed earth walls act as a thermal flywheel, heating up through the day and slowly releasing the heat into the house at night, keeping a very even temperature range"* (Anonymous, 2011).

Table 3 articulates the respondents' perceived level of comfort inside their home for different times of the year. Again, the majority of respondents answered in the positive range, the average ratings for all times of the day are above 5, demonstrating that on the whole, people living in earth houses are comfortable.

Table 3. Perceived comfort levels inside the home

Time Period	Very uncomfortable			Neutral			Very comfortable
Winter during the night time	2.1%	9.6%	6.2%	8.2%	15.1%	29.5%	29.5%
Winter during the day time	4.8%	3.4%	6.2%	4.1%	8.2%	30.1%	43.2%
Summer during the night time	5.5%	2.1%	2.1%	8.2%	11.6%	33.6%	37.0%
Summer during the day time	3.4%	3.4%	0.7%	6.8%	16.4%	32.9%	36.3%

3.4 Heating Plant and Use

All of the households surveyed have some kind of space heating, with the exception of one. This percentage is higher than the national average, however, this may be due to a high proportion of responses originating from the southern states with cool, temperate climates. The main space heaters used are open fires, and slow combustion stoves or pot-belly stoves. This is distinctly different to the most common heaters used over the broader population; gas space heater (26%), reverse cycle air-conditioners (18%) and ducted gas heaters (16%) (ABS, 2008).

Of the '*other'* space heating systems used, hydronic in-slab heating is most predominant.

Table 4. Heater Types

Heater type	Response Per cent	Response Count
Gas space heater	24.7%	36
Built-in electric heater	7.5%	11
Portable electric heater(s)	26.0%	38
Reverse cycle air-conditioning	19.2%	28
Open fire	34.9%	51
Slow combustion stove or pot-belly stove	51.4%	75
Kerosene heater	0.0%	0
None	0.7%	1
Other	24.0%	35

The majority of respondents only heat half the house or the living areas, only a small proportion heat bedrooms or studies;

> "*[the] bathroom only when in use, lounge and bedrooms only when in use, only when people are in them*" and, "*I only use an electric heater in the bathroom or my bedroom if it is really cold e.g. under 10 degrees outside"* (Anonymous, 2011).

This is decidedly different to the NatHERS occupancy patterns that assume *all* daytime living areas and bedrooms will be conditioned to maintain the prescribed comfort range. The times that heaters are reportedly used also differs to the NatHERS protocols. Most respondents only run their heaters during the afternoon and in the evening until bedtime. The respondents who heat their houses all day and night are generally those with hydronic in-slab systems that are used constantly throughout the cooler months. This is distinctly dissimilar to the NatHERS occupancy profile that assumes heating potential from 8am to 11pm (DCCEE, 2007).

In this section, some respondents also reported the thermostat settings of their heaters; the range was between 13-22 degrees, with common settings being 17, 18 and 19 degrees. This clearly demonstrates the varying comfort levels of different households and occupants, indicating that heating set point of 20 degrees in the benchmark thermal simulation software inadequately responds to the comfort perceptions of many households.

Figure 1 expresses the average number of heating days disaggregated by state. The questionnaire results generally share a trend with the 2008 national averages, except for Queensland; this is due to a very limited survey data sample. The result below compares to the assumption within NatHERS that heating could potentially be operable 365 days per year, which, shown by the questionnaire results and ABS data, is not the case. The maximum number of heating days reported is 250 days, while the lowest, 5 days.

Figure 1. Heating days expressed by state

When asked how satisfied they are with their heaters, respondents gave an average rating of 5.7 on a 7-point scale, signifying that the majority are satisfied with their space heaters. The average rating of satisfaction closely correlates with the average rating for the questions regarding perceived comfort levels within their house during day and night in winter. This may indicate that comfort levels are closely linked to heater use.

Table 5. Correlation between comfort levels and satisfaction with space heater

	Average rating
Perceived comfort in winter during the night time	5.31
Perceived comfort in winter during the day time	5.71
How satisfied are you with your main heater(s)?	5.71

3.5 Cooling Plant and Use

66.4% of respondents do not have coolers, while the majority of those that do, have reverse cycle air-conditioning for one room. While this is the most predominant cooler, it is apparent that generally, they are only used for cooling and not heating. Of those that do not have coolers, few thought there would ever be a need to install a cooler. Many respondents cited environmental concerns and the (good) performance of their homes as reasons not to install a cooler;

> *"philosophically opposed to mechanical coolers"* and, *"At night there is good ventilation which allows heat build up from the day to escape. Sufficient lag in heat gain to not need cooling during the day"* and, *"I'm opposed to aircon on environmental ground, ceiling fans in living area and main bedroom suffice"* and, *"I don't like artificial cooling. Prefer air flow by cross ventilation or fans"* and, *"ceiling fans will be adequate - lovely cool house and generally okay in summer; also morally opposed to coolers (!) on sustainability grounds"* (Anonymous, 2011).

In 2008, 67% of Australians had a cooler (ABS, 2008); this figure is significantly higher than that of the cohort studied (35.6%). In the '*other'* section many respondents acknowledge the cooling potential of cross ventilation, fans and thermal mass.

Table 6. Cooler Types

Cooler type	Response Per cent	Response Count
Portable evaporative cooler	3.5%	5
Fixed evaporative cooler for one room	1.4%	2
Ducted evaporative cooling	0.7%	1
Reverse cycle air-conditioning for one room e.g. slipt system	23.1%	33
Ducted reverse cycle air-conditioning	3.5%	5
None	66.4%	95
Other	3.5%	5

The majority of respondents only cooled the living space or (and) one bedroom and generally only used the cooler in the afternoons and evenings with few respondents using them overnight or in the mornings. Some respondents mentioned that the cooler is only used for a few hours on days of extreme heat. *Figure 2* expresses cooling days arranged by state. None of the NSW respondents had a cooler, while the Queensland data set only represents one household. In Vic, SA and WA, where the data sets are more representative, it is possible to distinguish a lower trend in cooler use.

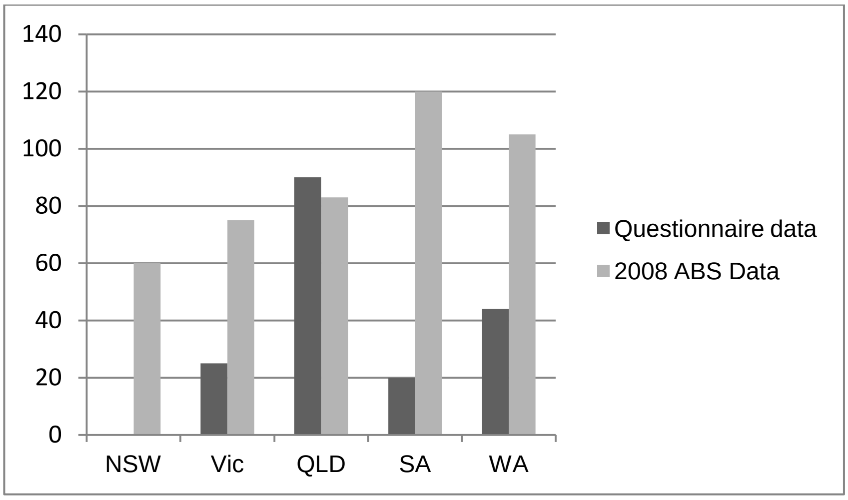

Figure 2. Cooling days expressed by state

When asked how satisfied they are with their coolers, respondents gave an average rating is 5.5 on a 7 point scale. This correlates with the perceived summer time comfort levels but as only a small proportion of respondents have cooler(s), this comfort cannot be attributed to the use of coolers.

3.6 Energy Management

The participants were asked a series of questions aimed at discovering more about how they use their house and their response to thermal comfort (or otherwise). 61% of respondents have made some kind of change to the house to improve thermal comfort, indicating an active awareness of their personal comfort levels. When asked about the indoor air quality the majority of participants reported that air quality is *'about right'*; with many stating that if the conditions are not ideal they take action to improve the air quality;

> *"I regularly have the doors open and windows to allow movement of air through the house, in the summer this is assisted by the ceiling fans"* and, *"windows and doors + fans, actively used to optimise conditions. Actively engage with outside environment"* and, *"We are conscious of opening up and closing down the house and greenhouse according to need"* (Anonymous, 2011).

This is further supported by many of the respondents *'operating'* the home for maximised thermal comfort, expressed in *Table 7*.

Table 7. Operation of windows, doors and indoor window coverings for thermal comfort

	Response Per cent
In hot weather, do you keep some doors and windows open during the day?	
No	55.70%
Yes	44.30%
On hot nights, do you open most windows?	
No	16.40%
Yes	83.60%
During hot days, do you close your drapes/curtains/blinds?	
No	25.70%
Yes	74.30%
During cold nights in winter, do you close your drapes/curtains/blinds?	
No	19.30%
Yes	80.70%

In addition to the operation of windows, doors and indoor window coverings, approximately 31% of all respondents have window coverings that thermally perform 'better' than Holland blinds, the generic indoor window covering assumed in the NatHERS benchmark software.

4. DEMONSTRATIVE ACCURATE RUNS

In order to demonstrate how the behavioural trends shown in the surveyed cohort differ to the generic profiles assumed within NatHERS several preliminary AccuRate runs were conducted.

The dwelling used for simulation is located in NatHERS climate zone 16 (Adelaide). It has two bedrooms, study, sewing room and an open plan living, dining and kitchen area. The total floor area is 195m^2 with 30% dedicated to the northern facing living area. The base run simulates the dwelling with typical brick veneer construction and standard levels of thermal insulation to the ceiling and external walls. It achieves 6.0 stars, the minimum mandatory requirement for all new houses in South Australia. The second run demonstrates the effect of changing both the internal and external walls to 300mm uninsulated mud brick. The dwelling performs worse, achieving only 5.4 stars. The third run applies heating and cooling only to the living area and the two bedrooms, resulting in a decrease in the total energy loads, although still not achieving compliance. The forth test removes all cooling loads, reflecting the 66.4% of respondents who do not have coolers; this effects the most significant change in estimated loads, achieving a rating 6.9 star which is significantly above that needed for compliance. Finally, the effect of improved indoor window covering is tested, the standard Holland blinds were replaced with Heavy drapes & Pelmets, again, a substantial reduction in heating load is affected, achieving 7.8 stars.

These preliminary AccuRate runs show that the 'household energy use target' set by the required 6.0 star rating can be met when using earth wall construction through the consideration of alternative user behaviours.

Table 8. Summary of AccuRate runs

AccuRate Run	Total MJ/m^2	Star Rating	Compliance Achieved?
Base Case	96.0	6.0	Yes
Earth internal and external walls	112.2	5.4	No
Conditioning only the living space and two bedrooms	98.8	5.9	No
Removal of 'cooling' load	70.7	6.9	Yes
Improved indoor window covering	52.8	7.8	Yes

5. CONCLUSION

The questionnaire results support the previously identified ecocentric attitudes, values and behaviours of residential earth building occupants. The subsequent reported user preferences of the cohort studied appear to be alternative when compared to the 2008 national averages of Australian households. These preferences also show distinct contrast to many of the generic occupancy assumptions within the Nationwide House Energy Rating Scheme.

Thermal simulation, using the NatHERS benchmark software, revealed that these behavioural trends have the capacity to affect greater household energy savings, potentially satisfying the BCA Energy Efficiency Objective; "*to reduce greenhouse gas emissions*" (ABCB, 2010), with greater efficacy than current framework allows.

The research presented in this paper is part of an ongoing study into the user behaviours of occupants in dwellings of earth construction. Temperature data logging is currently taking place in five dwellings in South Australia. This collected data will then be used with extensive thermal simulation runs to further investigate the subject area, including the influence of occupant behaviours on household energy use and Energy Efficiency requirements compliance.

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