

Perceived and prescribed environmental performance of award winning houses

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ABSTRACT: This paper investigates the thermal performance of three RIAA award-winning houses. It compares the occupants' assessment of the thermal environment with thermal comfort defined in ANSI/ASHRAE Standard 55-1992. Actual household energy use is compared with AGO figures for standard houses in that location and the house compliance with the recently introduced energy efficiency provisions of the Building Code of Australia is also assessed.

The study found that all three houses do not conform to the above Standard and Code. It was predicted that unacceptable amounts of heating and cooling energy would be required to achieve thermal comfort. Despite this, the actual energy consumption of these houses was lower than standard houses in the same regions. The occupants were largely satisfied with the houses' thermal performance and indicated they had no plans to modify the building or install air-conditioning or other systems to achieve the prescribed thermal comfort. This paper poses some ethical questions to be discussed, and proposes a number of suggestions.

Conference theme: Architecture and the environment

Keywords: building performance, thermal comfort

INTRODUCTION

Building regulations, including the explicit and/or implicit Standards that underlie them, represent one of the most definitive forms of government control aimed at ensuring health, safety and more recently environmental standards. They have a critical role in architectural decision-making. The recent energy-efficiency provisions introduced into the Building Code of Australia (BCA) for houses (Amendments 12 & 13), which have been adopted in most States, have however been developed from a techno-economic positivist 'habit of mind' (Guy and Shove 2000). This paradigm focus on physics, engineering and economics fails to account for the predilections of the human occupants of houses (Lutzenhiser and Shove 1999).

This (mis)framing becomes an issue because building regulations are constructed to apply to general conditions, and not to specific circumstances. The BCA, for example, 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....". Within the BCA there are three ways of complying with this requirement:

1. meeting the deemed-to-satisfy provisions
2. using computer simulation method to confirm the building meets the required energy efficiency levels or has equivalence with a reference building, or
3. submitting expert evidence to show satisfaction of the performance requirements.

Focusing in particular on the second of these methods a question arises: is it justified to say that a building that does not conform to these general levels of performance is not acceptable, that it should not be built, even though it meets the salient goals of its occupants and the community?

The work presented in this paper is part of a larger research project that aims to construct an understanding from an ethical framework of the interrelationships between attitudes, perceptions, rhetorical statements about, and actual behaviours, of a small corpus of contemporary award-winning Australian houses. This paper concentrates on the thermal performance of three houses that have won RIAA awards in recent years, but were built before the energy efficiency provisions of the BCA were introduced.

The indoor thermal performance of the houses was monitored for approximately one year. Data loggers, measuring the indoor temperature and humidity every 30 minutes, were installed in the main rooms (i.e. living, dining, and bedrooms) 1.6 – 1.8 metres above the floor. Weather data were gathered either by a weather station installed on the site or from the nearby Bureau of Meteorology recording station. Monitored results of the indoor temperature and humidity were assessed against international thermal comfort specification *ANSI/ASHRAE Standard 55-1992* (henceforth referred to as 'the Standard'). The occupant(s) and architects of the three houses were interviewed using

open-ended questions. The occupants' comments were then compared with the assessment of the houses' comfort determined by the Standard. The occupants' assessment of comfort were obtained from questions such as:

- What initial (specific) ideas and aims or goals did you have for the project?
- How easy it is to make the house comfortable?
- Do you think your original ideas have been satisfied? (Any plan to make new changes? Why?)
- Overall, how do you now feel about the house?

The houses' energy consumption records were also obtained and compared with Australian Greenhouse Office figures for energy use in 'standard' houses in the same area. Using the construction drawings, the houses' compliance with the BCA energy efficiency provisions was assessed with computer simulation program *FirstRate* (Sustainable Energy Authority Victoria 2003) and NatHERS (CSIRO 2000).

The discussions of the findings are presented in this paper.

1. THERMAL COMFORT

The widely accepted definition of thermal comfort is "that condition of mind in which satisfaction is expressed with the thermal environment" (ASHRAE 1992). To be thermally comfortable, one must not feel too cold or too hot. Moore (1993) defined thermal comfort as "a subjective state of satisfaction that varies with the individual and number of circumstantial factors". The primary physical factors that affect thermal comfort are air temperature, humidity, radiant temperature, air movement, the person's metabolic rate, and clothing type. Besides these, non-physical factors such as age of the users and degree of acclimatization also influence a person's perception of whether or not she or he is thermally comfortable in a certain condition (Stein and Reynolds 1991).

Although these non-physical factors have been acknowledged to affect the perception of comfort, they are not included in the equation for determining thermal response and comfort in the Standards. Factors, "... such as non-uniformity of the environment, visual stimuli, age, and outdoor climate are generally considered secondary." (ASHRAE 2001:8.12) The red lines in figures 2 to 4 show the combined winter and summer ASHRAE comfort zone for typical home activity (1.2 met, sedentary activity) and clothing levels (0.9 clo in winter – heavy slacks, long-sleeved shirt and sweater; 0.5 clo in summer – light slacks and short-sleeved shirt or blouse) with fixed air motion conditions (0.15 m/s in winter and 0.25 m/s in summer). Note that the comfort zone will change if the above condition changes as well as if there is additional radiant heat.

Humphreys (1978) and Auliciems (1981) consider the effect on thermal comfort of variables such as outdoor temperature, past thermal experience and socio-cultural systems. In a free-running building, for example, Auliciems defines that the neutral temperature (that is the centre of the comfort zone) is a function of the mean monthly external temperature and can be calculated as $T_n = 17.6 + 0.31 \times T_o$, where T_n is the neutral temperature, and T_o is the mean outdoor temperature (Auliciems 1981). The width of the comfort zone is suggested to be $\pm 2^\circ\text{C}$ from the neutral temperature. A number of field studies of thermal comfort, such as Williamson et al (1989), de Dear and Fountain (1994), and Kwok (1998), also show that people's thermal comfort and preference can be region-specific.

The notion of thermal comfort is implied in the thermostat settings of the assessment tools used in building energy codes such as the tools suggested by the BCA (ie. NatHERS and FirstRate). These thermostat settings indicate when heating or cooling is 'switched on' in the computer simulations. It is interesting to note, however, that these temperature settings are not exactly the same as calculated from the comfort models above. Table 1 shows the comparison of NatHERS thermostat settings and Auliciems' neutral temperatures.

Table 1: Comparison of NatHERS thermostat settings & Auliciems' neutral temp

	Heating °C		Cooling °C	
	Auliciems	NatHERS	Auliciems	NatHERS
Adelaide	21	21	25	26
Brisbane	22	21	26	27
Darwin	24	20	27	28

While thermal comfort and preference are not fixed values and are as well affected by many non-physical factors, the thermostat settings in the BCA approved simulation tools cannot be modified by the user. The reason for this is that the provisions in the BCA are considered essentially as mechanisms to ensure a minimum level of thermal performance for the building envelope. The assumptions of fixed user profiles and the unconstrained energy use when predicted temperature falls outside the comfort zone are employed to ensure performance in a worse case scenario, where the end user is unknown. This, unfortunately, can underrate a house where different user profiles and different occupants' comfort perceptions and preferences may result in actual reduced energy use. As a result such house may not receive building approval as designed.

2. CASE STUDY HOUSES

House 1 is a two-storey detached dwelling located in a suburban sub-division in Adelaide, South Australia (34.9° south latitude and 138.5° east longitude). Adelaide has a dry-temperate climate, with average summer temperatures ranging from 16° C to 28° C and winter temperatures ranging from 8° C to 16° C. In summer, there can be a number

of hot days reaching slightly above 40°C, but winters are mild. Average relative humidity ranges from 40% in summer to 70% in winter. The external envelope of House 1 is cavity brick and insulated timber frames construction with timber cladding. Floors are suspended timber and the roof is insulated corrugated iron. On the ground floor is an open living/dining space with double height ceiling with east and north facing windows, a kitchen overlooking the street on the south side, a service area on the west, and a study room on the north-west side. On the second floor is a gallery/mezzanine overlooking the living/dining space below, a bedroom above the study room, and another service area above the one on the ground floor. The owner, who is the only occupant of this house, had particular environmental aims.

“To make the best use of the sun is probably the main one. . . And taking advantage of the view. And making it eco friendly as possible really. So collecting the water on site and things like that.”

“So the paint was supposed to be kind because I didn’t want things exuding over the life time of the house. Similarly the glue that they use with kitchens and things. Some of that stuff you’ve got to be careful with as well. So he [the architect] was supposed to take into account all of those things. Natural fibres in the carpet.” (Occupant 1 2003)

The house employs a number of passive cooling strategies, including a wind tower to catch western sea breezes, openable north-facing skylights (equipped with blinds to control the solar penetration), and cavities in the ceiling of the open space to let warm air out to the vented roof space. No mechanical cooling system is used in summer. In winter the house mostly relies on solar heat gains although a gas heater in the living space is occasionally used. Gas is also used for cooking. The house generates electricity from the photovoltaic panels installed on the north-facing roof of the living space, generating energy up to 9.4 kWh per day. A solar collector is used for water heating, and rainwater is collected for washing and drinking.

House 2 is located near Lake Bonnet, about 80 km south of Darwin, Northern Territory (12.4° south latitude and 130.9° east longitude). The area is dry from May to October whereas the rest of the year it is very wet and humid (the monsoon season). On average the temperature ranges from 20° C to 32° C during the dry season and 25° C to 34° C during the wet season. During the dry season the relative humidity can be as low as 35% but during the wet season it can reach as high as 100%. Currently the house is only occupied by one person but it is designed to be occupied by a family. This house consists of three separate (steel) structures, connected with a shaded boardwalk. The middle structure is used for living, dining, and cooking. The other two structures are mirror images. Currently one is used for sleeping and the other is used for an office space although it is anticipated that this one will also be used for sleeping when the owner has children. Each of these “wings” has a bathroom. There are barely any solid walls; the only non-transparent walls are on the outside of the bathrooms. Instead, fly screens and louvers are used throughout. Timber decking is used for all the floors, with the gaps between the timber for ventilation. Also, as the occupant has said, it allows incoming rain to escape and makes cleaning the floor easier!

No mechanical cooling is used in this house, as the owner said,

I didn’t want to use air conditioning because I don’t like living in air conditioning. I find that uncomfortable and kind of claustrophobic.... So if your house isn’t going to be air-conditioned you’ve got to have lots of windows up here. And in fact you’ve got the fly screens. (Occupant 2 2003)

The house is basically self-sufficient. Electricity is generated by photovoltaic panels (the site is quite remote and there is no existing power line on the site) and a solar collector is used for water heating.

House 3 is located in a suburban area in Brisbane, Queensland (27.48° south latitude, 153.03° east longitude). The area has a mild but rainy summer and mild and dry winter. The average daily temperature is 24.5°C in summer and 15°C in winter. During summer the temperature varies from 20 to 29°C with 60-70% relative humidity, and in winter it varies from 9 to 22° C with 45-65% relative humidity. This is a family home of four people and was designed by the architect occupants who lived on the site for some time before designing the house. The occupants said that this meant that they;

“...had a really good relationship with the piece of land before we put the house on it which was a rather nice way of doing it.”

“... and we saw the construction every step of the way.”

“.... but that also made it possible to develop the design slowly. This was our hobby in a way.”
(Occupants 3 and 4 2003)

There were several large trees that had to be retained on the site and this made the buildable area relatively small. The solution was a long but narrow 2-1/2 storey building on the south side of the site with the major openings on the north walls. On the entry level is the family room, which has openings to a swimming pool. From this level, one can go down one half floor to the two bedrooms, or go up one half floor to the open living/dining/kitchen space. Sliding doors are used to separate the dining/kitchen space from the outside, but these doors are usually opened, making the outside dining deck an extension of the internal dining space. The master bedroom is above the family room, overlooking the open living space. There is also a bridge (used as a library) above the living space, connecting the master bedroom with an office space above the kitchen. The house is constructed of timber stud walls, insulated and clad. There is no mechanical heating nor cooling, except small oil column heaters and fans.

“We don't have any, I mean we've just got a little oil heater or something like that. But we find if we put that on for a little while it actually, remarkably it seems to heat that space.”

“About two winters ago we kind of kept track of how many days we [used heaters] and it was only 10 days.” (Occupants 3 and 4 2003)

3. ACTUAL PERFORMANCE

The monitoring results of the living space in each house, plotted on the Psychrometric Chart, are presented in Figures 2 to 4.

3.1. Indoor performance

In House 1, the minimum indoor temperature in the living room was 11°C in the winter. Maximum summer temperature was 31°C (36°C in the bedroom) when it was 43°C outside. Relative humidity ranged from 22% to 80%. Overall the daytime indoor space was always cooler than the outside. At night, the indoor was always warmer than the outside, about 8°C higher. During other seasons, daytime indoor temperature was close to the outside, but was higher at night.

In House 2, the indoor temperature ranged from 17°C (the minimum in the dry season) to 43°C (the maximum in the wet season) with relative humidity ranged from 22% to 100%. These indoor temperature and humidity always followed the pattern of the outdoor condition with very little difference. This should not come as a surprise; the house barely has any solid enclosure and almost no mass.

In House 3, indoor temperature ranged from 13°C in winter to 31°C in summer with relative humidity ranged from 23% to 100%. The performance of this house was similar to House 2 in that the indoor condition was very close to the outside temperature, except at night the indoor temperature was about 5°C warmer than the outside. Like House 2, this house was almost always open to the outside during the day (but closed off at night).

3.2. Energy use

Since it was occupied in 2000, the average annual electricity use of House 1 is about 1900 kWh or 6.8 GJ. On average, the house currently generates 6 kWh/day of electricity, or 2190 kWh (or 7.9 GJ) per year, making it able to feed into the grid surplus electricity. The average gas use is 14.6 GJ per year, thus the net total energy use of this house is 13.5 GJ. The predicted total energy use by a standard house in South Australia according to AGO (1999) is 41.2 GJ; thus House 1's energy use is less than one third of this amount.

The energy use in House 2 was recorded and predicted by the owner, as this house did not have any utility records from utility companies. On average the house used 3.5 kWh per day or 1278 kWh per year (4.6 GJ) of electricity generated by the photovoltaic panels. The largest use of electricity was the refrigerator (Owner 2 2003), which uses about one-fourth of the power generated by the solar panels. Gas was used for cooking and it was estimated that 27 kg of LPG (or 1.3 GJ) was used per year. In total, this house uses about 6 GJ of energy per year, which is only 21% of the 28.3 GJ (AGO 1999) average total energy use in a standard house in that region.

At the time this paper was written, no energy use data for House 3 were available, and therefore we are unable to report it in the paper. The predicted total energy use for a standard house in Queensland according to AGO (1999) is 26.36 GJ.



Figure 1: South façade of House 1 (left), southwest façade of House 2 (centre), north façade of House 3 (right)

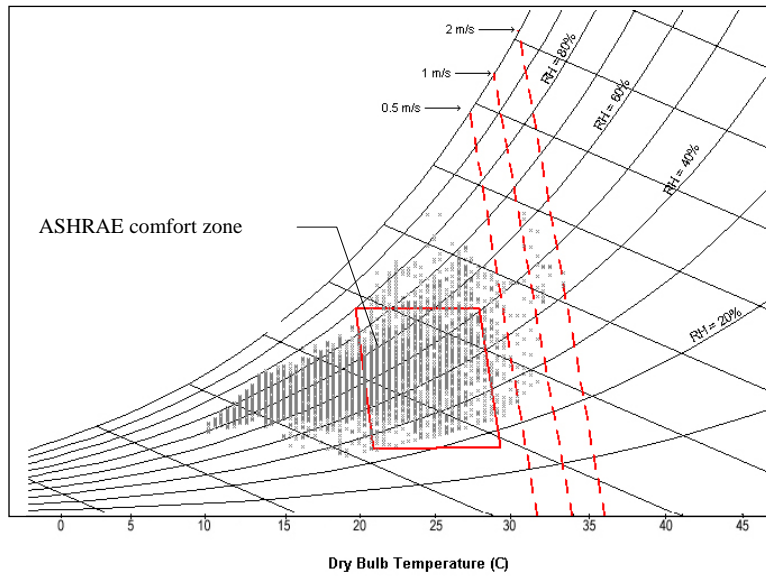


Figure 2: Monitoring of House 1 in Adelaide on the Psychrometric Chart with extended comfort zone by increased air velocity

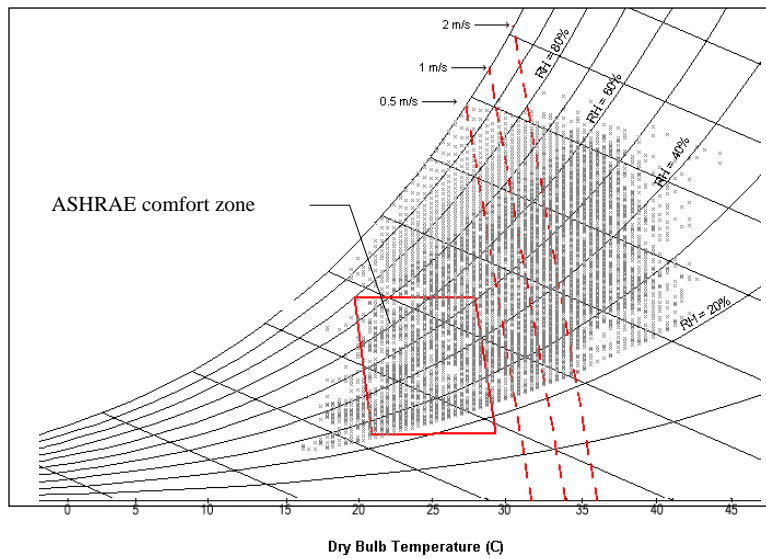


Figure 3: Monitoring of House 2 in Darwin on the Psychrometric Chart with extended comfort zone by increased air velocity

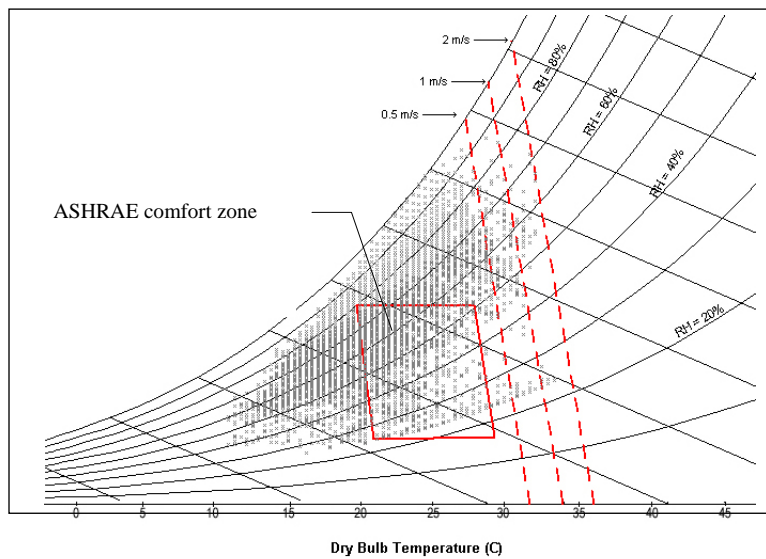


Figure 4: Monitoring of House 3 in Brisbane on the Psychrometric Chart with extended comfort zone by increased air velocity

4. ASSESSMENTS WITH STANDARD AND BCA

4.1. Thermal comfort

Looking at the monitoring results above, the indoor temperature and relative humidity of these houses often falls outside the comfort zone. In house 2, daytime temperature and relative humidity were always above the comfort zone (except during the dry season), even with an increased velocity of 2 m/s. In winter, houses 1 and 3 were much cooler than the lower boundary of the thermal comfort zone, whereas in summer house 3 was warmer than the upper boundary of the comfort zone, but could be considered comfortable with increased air velocity. This confirms that natural ventilation only is enough to make the house comfortable in summer.

4.2. "Energy" Rating

House 1 achieved a *FirstRate* rating of 1-1/2 Stars. It received total points of -94 (-45 for winter and -57 for summer). *FirstRate* indicated that the main problem was the heat loss and gain through the window glazing (44% of net conditioned floor area). *NatHERS* gave this house 1Star with predicted heating load of 223.2 MJ/m² (10.6 GJ) and cooling load of 230.7 MJ/m² (29.5 GJ). In reality, House 1 uses no cooling energy and very occasionally a little heating is used in the living and study rooms.

With *FirstRate* House 3 was predicted to perform slightly better than House 1 and scored 2.5 Stars. The total points were -81 (-3 for winter and -82 for summer). *FirstRate* indicated that the main problem was summer heat gain through the north-facing glass (36% of net conditioned floor area). In reality, this glass is shaded by the two large trees thus summer heat gain was never a problem. Unfortunately this cannot be modeled by the program (the model either puts 100% obstruction or none at all). With *NatHERS*, however, this house only received 1 Star. The heating load was predicted to be 41.6 MJ/m² (6.5 GJ) and the cooling load 372.8 MJ/m² (58.5 GJ). The actual house uses no mechanical cooling at all, but has constant air movement through all the openings to achieve comfort.

FirstRate cannot be used to rate House 2 which is in a hot humid climate. With *NatHERS* the house received no Star at all and the cooling load was predicted to be 1595.7 MJ/m² (130 GJ). The main problem for this high cooling load was that *NatHERS'* comfort temperatures are set at 18 to 24°C from 7 am to 12 midnight and from 12 to 18°C for the other hours, which are unsuitable settings for houses in the tropics.

5. OCCUPANTS' VIEW AND THE ARCHITECTS' INTENTIONS

5.1. Occupants' view

Achieving "perfect" thermal comfort (meaning constant indoor climate) was not a consideration for these occupants. They valued a sense of "openness" and "connection to the outside" and indicated that they enjoyed changes in the indoor environment. They preferred to be part of what was happening outside even if that meant feeling warm when it was hot outside, and feeling cool when the outside was chilly.

As the owner of House 2 says,

"I moved here to take advantage of the climate, to take advantage of what's here. I moved to Darwin for a reason and there are houses that don't advantage of what Darwin is."

"I only usually turn the fan on when I'm feeling hot. At about 30 or 32 I start feeling hot and I will put the fan on. Louvres I will open up with I'm in the room. Except if I think I'm not going to be in there long, I will just keep them closed. And of course if it's expected to rain I will close it down. In the dry season things are just open. In the dry season you don't need the fans on either, there is so much wind up here."

"My house gets hot during mid-day during the buildup; if it's 40° C outside it's 40° C inside. However, it's more tolerable than the cement block unit I was in that was 32-33° C all the time, day and night. I think this is because the body can take high heat for a few hours, but not constantly. Come 5PM my house cools off and I feel fine. By 9 PM it's near 28° C in the building. By 6 AM it's 23-25° C. I remember feeling stressed in my cement block unit because I never felt like I escaped from the heat." (Occupant 2 2003)

The occupants of House 3 were satisfied with the house. They have added film to some windows but in this case it was for privacy. Perfect thermal comfort was not the main issue but environmental delight was important.

"We've changed a little bit actually.... Our boys aren't as comfortable in the glazed living room [being visible from the street]. So we added some [obscuring film] just at the bottom of those windows. "

[Sunlight makes] rainbows of light at terrific... angles right into the back wall of the building. We can choreograph them on the wall just by moving the windows up and down." (Occupant 3 & 4 2003)

For all three houses, issues to do with occupants' thermal comfort were inseparable from ideas about environmental concerns, budget, as well as the importance of connections between indoor and outdoor spaces.

5.2. Architects' intentions

House 3 is the architects' own house, and is therefore a direct reflection of its occupants' aims as a place to live. In the other two houses the client/future occupants were involved in the design process and clear about their aims. Whereas the codes make little recognition of the effect on thermal comfort of differing degrees of air movement, this is recognised and made a high priority in the designs: mesh screens rather than glass in House 3, the ability to open up a window wall supplemented by small desk fans in House 3, and a wind catcher in House 1. For example, at House 1,

“the operation is to catch down the breeze, drawing down.... We wanted to have a convection, so a big baffle, an 'eco fan', it's a low voltage fan. ... And the ceiling is being ventilated.” (Architect 1 2003)

These design features are intended to work together to be energy efficient. “[T]he whole idea is to get something to work, and also to express the house...” (Architect 1 2003). Although this house can be cool in winter “[Y]ou can always put more clothes if you are cold.” Another issue unrecognised in the codes but important in these designs is the notion that an occupant can move to a comfortable place rather than keeping the whole house comfortable.

“I have been counting on the ideas that the study where she will get a lot of winter sun, so you'll have the ability to go the space which is more suitable for a particular the time” (Architect 12003).

The conflict between designing for conventional ideas of thermal comfort and other priorities is most clearly manifested in House 2. Here the overriding aim was to 'enjoy the place'. The architect and client both referred to this when interviewed: this was a place carefully chosen by a client who, because of the nature of his IT business, could live anywhere, and the views and moods of the place were to be accepted and experienced. This included the variations between the 'dry' and the 'wet', the storms and the heat.

“All of the functions that you use to keep the building cool, to keep air movement and shade and reduce radiant heat are integral to the design of the building and require no further action other than perhaps to shut it down when you get the cold in the dry season. But you shut it down for the whole of the dry season until you need to open it up again. And that's really the only interaction. So that notion that we are doing it to save energy but we need to save energy because we will be generating our own. But the whole thing driving all of that is that's the way you want to live anyway. That's camping. That's what you enjoy. That's why you are out there.” (Architect 3 2003).

6. DISCUSSION AND CONCLUSIONS

The implied intentions of the energy efficiency provisions of the BCA are to ensure that the building is comfortable for its occupants (thus, the individual benefit) and to ensure that the process of occupying the building does not entail the excessive use of energy (thus, the community benefit). The problem is that in a given climate these outcomes depend on both the building *and* the user, whereas the BCA provisions only address the building. Moreover, in order to decide how to control the building, the actions of the user are assumed. He or she is assumed to act to maintain thermal comfort conditions inside the building at all times, by 'topping up' the indoor conditions that would result from certain design strategies, such as building form, orientation, insulation, and so on, with the 'necessary' amount of heating or cooling. This follows from an assumption that the 'individual benefit' of a constant level of thermal comfort is a universally accepted necessary condition for dwelling, and that everyone will act to achieve that condition.

This study clearly shows that the occupants of these houses do not follow the “accepted” behavior paradigm. Instead, they express general satisfaction with indoor conditions that fluctuate with external conditions, and they do not act to maintain constant 'thermal comfort'. They are satisfied with the environmental performance of their houses, and where they were not they have made appropriate modifications. All the occupants displayed an understanding of, and commitment to, using passive techniques to achieve thermal comfort. There is no evidence that their health suffers because of their choices, and they assert that other benefits of 'openness' and 'connection with the outside' outweigh any minor thermal discomfort. In terms of the 'community benefit', they are using less energy than is considered 'normal' for houses in their respective locations. Yet, if these houses were assessed after the BCA was introduced, they would not have been allowed to be built.

The problem with building regulations such as the BCA arises because occupants are assumed to act in a way that they do not act, thereby restraining 'individual benefits' and prohibiting them from building houses according to their preferences, such as enjoying the openness and connections to the outside. In this case, their thermal comfort may be impaired because conforming to the regulations may result in houses with lesser airflow.

The authors believe that a house or house design that does not conform to the Standards and Regulations cannot necessarily be judged as no good and therefore should not be built. The judgment must include considering the goals of the occupants and the intentions of the architect, and whether or not the way to achieve these goals has a negative impact on the environment and/or community. The houses in this study, for example, are predicted to be uncomfortable for many days in a year and therefore assumed to require significant amounts of energy for heating or cooling. Yet, in reality, being constantly comfortable is not the main goal of these owners or occupants. They have no plans to modify the building or install air conditioning or other systems to make their houses “comfortable” according to the prescribed standards, and which in reality would probably ensure the houses consume more energy.

This “micro–analysis” of individual cases does not actually “mask the understanding that the proposed measures form a complete package that is designed to improve the use of energy in domestic construction as a whole” (ABCB 2002: vi), but rather throws into doubt the fundamental assumptions that informed the framing of the provisions in such a way that the energy-efficiency objectives in the BCA are seriously diluted. This paper therefore makes three main suggestions. First, if the compliance with the BCA is to be demonstrated by computer simulation, then the assumptions in the software should not be fixed; variables such as thermostat settings should be adjustable to match the comfort preference of the occupants. Second, houses that are intended to be open to the outside and to have no mechanical heating or cooling should not be assessed on the same basis as houses that are intended to be mechanically heated and cooled. The goals of the occupants must be recognized and rewarded because they can benefit the environment and the community. Third, on a broader level, we suggest that as current regulatory processes do not allow this, if we are serious about reducing residential energy use, we must investigate the possibilities of assessing buildings in ways that acknowledge the interaction of individual preferences, technical concerns, bio-climatic matters and the socio-political context.

ACKNOWLEDGMENT

The authors wish to acknowledge the Australian Research Council for the Discovery Research Grant provided to conduct the research. We are also grateful to the owners and architect of these houses for providing information about the houses. To respect their privacy the occupants and architects are not identified in this paper.

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