# The performance of award winning houses

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ABSTRACT: This paper investigates the thermal performance of three Royal Australian Institute of Architects (RAIA) 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 energy use statistical data for standard houses in the location. Compliance with energy efficiency provisions of the Building Code of Australia is also assessed for each house.

The results will show that all houses do not conform to the comfort Standard and present Building Code requirements. The energy ratings of the houses predict 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 area. 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. The results suggest that good design rather than regulation is better able to respond to the context, the here-and-now, and the future.

Keywords: Houses, thermal performance, thermal comfort

## 1. INTRODUCTION

"Context-dependent knowledge and expertise is at the very heart of expert activity. Such knowledge and expertise also lies at the center of the case study as a research method." [1]

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 RAIA awards in recent years, but were built before energy-efficiency provisions of the Building Code of Australia (BCA) [2] were introduced in 2002. House 1 received a specific award for sustainability. Houses 2 and 3 received awards in the general Residential category. Since the RAIA award rules for the Residential category include a specific reference to "Energy Performance and Use of Energy", we could assume that the judges believed these case-study houses had some merits in this area.

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 BCA 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:

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

Focusing in particular on the second of these methods, the three case studies examined here compare the simulated assessment of thermal performance with reality.

In gathering information for the case studies the indoor condition 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* [3] (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' assessments of comfort perceptions and satisfaction 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 statistics 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 the approved computer simulation program *AccuRate* [4].

## 2. THERMAL COMFORT

The widely accepted definition of thermal comfort is "that condition of mind in which satisfaction is expressed with the thermal environment" [5]. The notion of thermal comfort is implied in the thermostat settings built into the assessment tools approved for use by the BCA. 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 but include a "political" judgement by a bureaucratic technical committee related to imagined household behaviours. Table 1 gives the *AccuRate* software control settings for locations of the case study houses.

**Table 1:** *AccuRate* software thermostat settings

| Location | Heating temperature living zones (1) | Heating temperature bedroom zones (1) | Cooling Temperature (all zones) (2) |
|---|---|---|---|
| Adelaide | 20.0°C | 18.0°C | 24.5°C |
| Darwin | 20.0°C | 18.0°C | 26.5°C |
| Brisbane | 20.0°C | 18.0°C | 25.5°C |

Notes: (1) Heating is invoked if the simulated temperature in an hour time step falls below the thermostat setting

(2) Cooling is invoked at the thermostat setting if the simulated temperature in an hour time step is above the setting plus 2.5°C plus an allowance for air speed $dT = 6*(v - 0.2) - 1.6*(v - 0.2)^2$, where v is the estimated indoor air speed (m/s).

While in reality thermal comfort and preference are not fixed values across a population of householders and are affected by many non-physical factors, the thermostat settings in the BCA approved simulation tools cannot be modified by the user. The reason given for this is that the provisions in the BCA are considered essentially 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" conditions are employed to ensure performance in a worse case scenario, where the end user is unknown (and presumably imprudent).

## 3. CASE STUDY HOUSES

House 1 is a two-storey detached dwelling located in a suburban sub-division in Adelaide, South Australia (34.9º south latitude and 138.5º 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 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 external cladding and plasterboard internal lining. 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…..the paint was supposed to be of a special kind because I didn't want things exuding over the life time of the house. Similarly the glue that they use in kitchen 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)

**Figure 1**: South Side House 1 Adelaide

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 (12.4º south latitude and 130.9º 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 gaps between the floor boards to allow for ventilation. The owner also pointed out another advantage of this feature; the gaps allow incoming rain to escape and make cleaning the floor easier!

**Figure 2**: House 2

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 with battery storage (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,

“*[We]…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.*” (Occupant 3 2003)

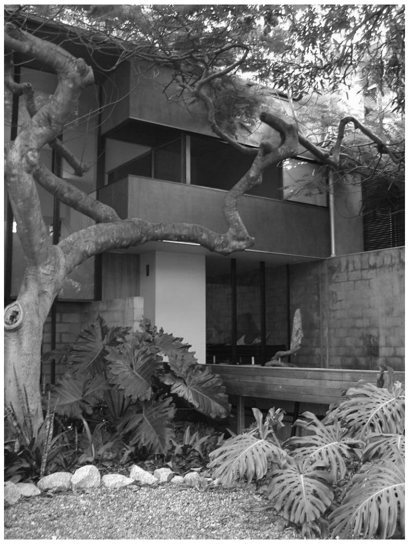

**Figure 3**: House 3

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 half a level to the two bedrooms, or go up half a level 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 with lightweight internal lining and external cladding. There is neither mechanical heating nor cooling, except small electric oil filled 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.*" (Occupant 3 2003)

## 4. ACTUAL PERFORMANCE

4.1 Indoor Performance

The monitoring results of the living space in each house, plotted on the Psychrometric Chart, are presented in Figures 4 to 6.

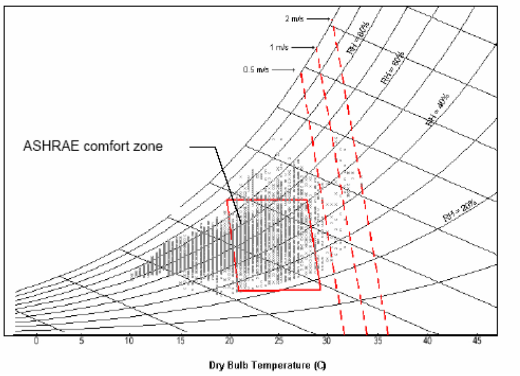


**Figure 4**: Monitoring of House 1 Adelaide, note the psychrometric chart has comfort zone extended for increased air velocity

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.

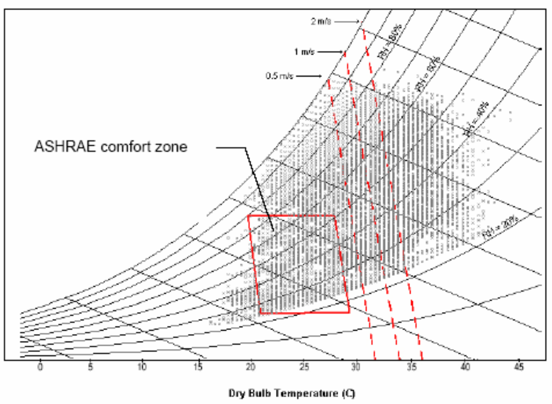


**Figure 5**: Monitoring of House 2 Darwin, note the psychrometric chart has comfort zone extended for increased air velocity

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.

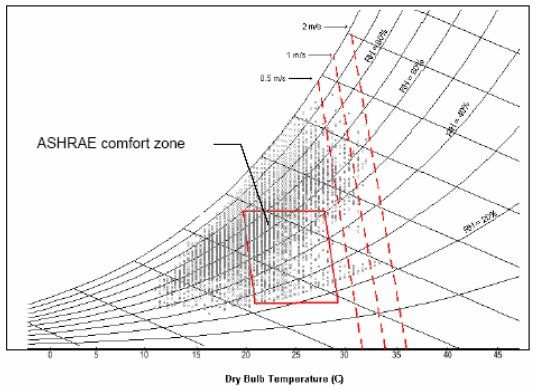


**Figure 6**: Monitoring of House 3 Brisbane, note the psychrometric chart has comfort zone extended for increased air velocity

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).

4.2 Energy Use

Since it was occupied in 2000, the average annual electricity use of House 1 is about 1900 kWh or 6.8 GJ. However, 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 Adelaide with similar occupancy is 33.4 GJ; thus House 1's energy use is less than half this amount.

The energy use in House 2 was recorded 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 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 6.0 GJ of energy per year, which is only one-fifth of the average total energy use in a standard house in that region.

The annual energy use for House 3 combining electricity and gas was 52.0GJ. The average house in Brisbane uses around 30.8GJ [6]. An energy audit revealed the cause of this anomaly. Because of a faulty timer the swimming pool pump (0.91kW) has been operating 24 hours/day over the last few years. When this is taken into account the "normal" household energy use is 23.3GJ.

## 5. ASSESSMENTS

4.1. Thermal comfort

Looking at the monitoring results above, the indoor temperature and relative humidity for each house 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 allowing for 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 perhaps supplemented by fans is enough to make the house comfortable in summer.

4.2. Energy Rating

House 1 achieved an *AccuRate* result of 3.5 Stars, that is, below the 5 Stars necessary to achieve building approval. The simulation predicted a heating load of 133.6 MJ/m$^2$ and cooling load of 82.0 MJ/m$^2$. If we assume a reverse-cycle air-conditioner for heating and cooling these figures would translate to an energy consumption of around 12GJ/annum. In reality, House 1 uses no cooling energy and very occasionally a little heating is used in the living and study rooms.

House 3 received a Star rating of 2.5, again not sufficient to pass the Building Code requirements. A cooling load was predicted by the software at 149.8 MJ/m$^2$ with a heating load of 54.4 MJ/m$^2$. These would covert in an energy use of approximately 11.2GJ/annum. The actual house uses no mechanical cooling at all, but has constant air movement through all the openings to achieve comfort. Heater use is minimal.

Because of its complicated geometry and unusual construction techniques House 2 presents a challenge to any simulation software (and operator). All attempts at simulation have produced 0 Stars.

## 6. OCCUPANTS VIEW

5.1. Occupants' view

Achieving "perfect" thermal comfort (meaning relatively 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. …. 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*." (Occupants 3 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.

## 7. DISCUSSION

The recent energy-efficiency provisions introduced into the BCA for houses have been developed from a techno-economic positivist 'habit of mind' [7]. This paradigm focus on physics, engineering and economics fails to account for the predilections of the human occupants of houses.

This (mis)framing becomes an issue because building regulations are constructed to apply to general conditions, and not to specific circumstances. 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 or produce excessive greenhouse gas emissions (thus, the community benefit). The problem is that in a given climate these outcomes depend on both the building *and* the user.

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. Chappells and Shove [8] have detailed three different understandings of thermal comfort as,

- a fixed and natural condition (exemplified by the ASHRAE approach)
- a process of adaptation
- socially constructed.

This study clearly shows that the occupants of the houses express general satisfaction with indoor conditions that fluctuate with external conditions, and they do not act to maintain “fixed” conditions. 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, when these houses are assessed against current BCA compliance requirements they do not achieve the necessary level of performance.

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 sub-optimal solutions that result in increase reliance on heating and cooling appliance use.

While regulation provides individuals and corporations with guidelines for acceptable practices, they do however tend to take on a life of their own, often leaving rationality, innovation, and possibly social interest behind. The presence of single issue standards/regulations in a situation of multi-dimensional decision making is more likely to lead to suboptimal outcomes that meet the standard rather than optimal behaviour that violate the standard. Individuals exhibit preference inconsistencies in single (one option evaluated at a time) versus multiple-choice (multiple options evaluated together) contexts.

This is a very important point. By disallowing future choices about house design that have in the past enabled modes of occupant behaviour that can be shown to be entirely consistent with society’s objectives of reduced energy use and greenhouse gas emissions, those objectives are hindered rather than advanced. The considered judgements of the juries making these awards, taking into account the comments of the house occupants, respond to the realities of multidimensional design and how it serves the aspirations and lifestyles of real people.

Judgments about what makes a ‘good’ house require an appreciation of the complex relationship between site, built-form and peoples’ desires and preferences. In judging these houses to be meritorious, the RAIA awards judges would have considered the environmental performance of each house in the context of a myriad of other concerns. By their very nature, Standards and Codes are unable to do this and this limits their usefulness as tools for determining whether a house is ‘good’ or not.

7.1 Postscript

While it is generally conceded that “present” occupants may be responsible, the question of a possibly less savvy and less responsible unknown and future occupant is often put as a justification for energy-efficiency building regulation. The view of the occupant as a consumer who needs to be protected from themselves is however fundamentally flawed because we cannot be sure of the needs and preferences of future occupants (the near future and especially the distant future). Properly conceived designs are most likely to create their own market appeal. Adelaide House 1, for example, has recently been sold and the new owner is equally (or perhaps more) committed to the objectives of the original project. The new owner is able to enjoy and take advantage of all the design features and without the psychological baggage of having been through the construction process.

## ACKNOWLEDGEMENT

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