Fitness for purpose?

Thermal performance modelling of recent Top End remote Indigenous housing in the Northern Territory

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Abstract

The principles for good thermal design of houses in hot and humid climates are well known. Heating is largely un-necessary and evaporative cooling methods often ineffective, but strategies such as ensuring good ventilation, adequate shading to walls and windows, and providing ventilated roof spaces with insulated ceilings are commonly employed as passive design elements. Passive design considerations are important when designing housing for remote Indigenous communities in tropical regions, but there are other design priorities that must be accommodated. These priorities include cultural practices and preferences regarding dwelling form, privacy and security, climate suitability, durability, and the logistics of building in remote areas. Common delivery solutions combining pre-fabricated and in-situ building processes are adopted in response to time constraints, labour skill-set availability, and cost factors.

This paper examines a case-study of recently constructed house-types in Nguiu (Wurrumiyanga) and Wadeye, in the Northern Territory. Modelled energy performance is assessed, and the effect on overall energy efficiency of design decisions reflecting cultural, material and procurement priorities identified.

Keywords: thermal performance, housing design, remote communities

1. Introduction

The form and performance of housing in remote Indigenous communities has long been recognised as a critical element in Indigenous disadvantage across a range of indicators including poverty levels, health, education, social cohesion, and employment (Memmott 1988, Pholeros 2003). To be effective and sustainable, housing design must complement social and cultural living patterns of occupants as well as the prevailing environmental and economic conditions (Fien 2008, Ross 1987). While clearly economic considerations will impinge on design decisions made in regard to social, cultural, and environmental factors, these factors themselves will also influence one another. This paper examines how design decisions related to procurement methods, long term maintenance considerations, and certain cultural preferences intersect with issues of sustainable passive cooling and occupant comfort.

The paper investigates the thermal performance of 10 houses recently built in the remote Indigenous communities of Nguiu (Wurrumiyanga), and Wadeye. Eight of the 10 dwellings were built as part of the current National Partnership Agreement on Remote Indigenous Housing, the other two as part of Indigenous Business Australia’s Home Ownership on Indigenous Land Kick-start program (see below). The purpose of the paper is two-fold, firstly to evaluate the energy efficiency of contemporary remote Indigenous housing designs in the Northern Territory, and more broadly, to investigate if modelling programs can be used to provide an insight
into the way that different design priorities interact within a dwelling and affect its performance.

The National Partnership Agreement on Remote Indigenous Housing (NPARIH) was signed between the Commonwealth and State and Territory Governments in 2009. The Agreement sets out a ten year program to build around 4,200 new dwellings and rebuild or refurbish a further 4,800 dwellings Australia-wide in remote Indigenous communities, and has a budget of $5.5 billion (FaHCSIA, 2009). In the Northern Territory, the NPARIH is worth $1.7 billion over the life of the Agreement, and sets targets of 1,456 new dwellings and 2,915 rebuilt or refurbished dwellings (ANON, 2011). The Agreement subsumed the 2008 Strategic Indigenous Housing and Infrastructure Program (SIHIP), a five year $672 million joint Commonwealth-NT program to build 750 new dwellings and refurbish 2,500 existing dwellings in 73 remote communities (NT Government, 2009). By the beginning of 2011, 179 new houses had been built and 1036 dwellings refurbished, with a further 142 new dwellings and 74 refurbishments under construction (FaHCSIA, 2011). SIHIP underwent a review in 2009, and as a result standard house designs were modified (FaHCSIA, 2009b). Designs from both before and after the 2009 review are included in the case studies for this paper and are referred to as SIHIP Stage 1 and Stage 2 designs.

Indigenous Business Australia’s Home Ownership on Indigenous Land (HOIL) Kick-start program was a $1 million project designed to complement the Commonwealth Government backed HOIL home loans scheme available to residents of remote Indigenous communities. It was intended to stimulate interest in purchasing a house in remote communities that had a long history of residents renting community or public housing stock. As part of the scheme, 4 houses were constructed on Nguiu (Wurrumiyanga) in 2009 after extensive community consultation. The houses were then sold to local residents (IBA, 2010).

2. Factors that influence thermal performance

Isaacs (2006) proposes four main factors that impact the energy requirements to maintain comfort levels in tropical climates:

**Amount of solar radiation entering through windows**

The glasshouse (or greenhouse) effect occurs when sunlight enters a room through a window causing the internal surfaces of the room (walls, floor, and furniture) to partially absorb heat. These surfaces warm up and radiate heat back into the room.
When this re-radiated heat comes into contact with a glass window pane, it is mostly reflected back into the room, effectively trapping the heat in the room. The heat can be removed by replacing the warmed air within the room with cooler air from outside. The angle of the sun’s rays hitting a window, the type of window pane (clear glass, tinted glass or opaque), and the amount of shading will affect the amount of sunlight that is able to enter a room, typically referred to as ‘solar gain’ (Szokolay, 1987:22).

Studies have shown that the most effective strategy for reducing solar gain through windows in Darwin is to provide deep (1800mm) eaves, followed by using tinted glazing, and reducing the area of glazing. In Alice Springs, deep eaves are also the most effective way to reduce solar gain, while tinted glazing and reducing the size of glazing show modest reductions in solar gain. However, deep eaves increase the need to heat rooms in Alice Springs in the winter to a greater extent than using tinted glazing or smaller window areas (Isaacs, 2006).

**Air movement**

The movement of air over the human body allows people to tolerate higher temperatures and humidity, and still remain comfortable. Dwellings that promote cross-ventilation of air through open windows and doors require less mechanical cooling to maintain comfort levels. Ceiling fans can be used to artificially create air movement. The principal factors that influence the effectiveness of air movement in dwellings are:

- The direction and speed of external wind
- The location and size of openings
- The ventilation pathway through the building

Studies in Darwin and Alice Springs conclude that openings including strategically placed windows have a greater effect in Darwin as the humidity is generally higher, but that in both cities improved ventilation has a positive effect on the need to mechanically cool a dwelling over a year (Isaacs, 2006).

In remote Indigenous housing, common use of louvre window systems is made in the Top End area of the Northern Territory and coastal northern WA. Louvres allow air movement and are suitable where humidity is high, the nights and winters mild, and sand and dust inundation is not problematic.
Area, colour, shading and insulation levels of the building fabric

Shading, colour, surface area and insulation strategies are particularly important for housing in remote Indigenous communities as many are situated in exposed areas subject to extended periods of solar radiation.

There are several factors that affect heat transfer (flow) across building fabric:

- The temperature difference between the inside and the outside. This is affected by the intensity of the sun, the colour of the surface, and the wind speed. In still conditions, dark surfaces will absorb more radiation than lighter coloured surfaces. In a tropical climate such as in Darwin, roofs will have a higher gain due to the angle of the surface relative to the sun, than wall surfaces (and in addition, walls are easier to shade)
- The insulation R value. Regardless of the insulation material used, heat transfer across an element will be the same if the R value (a measure of a material’s thermal resistance properties) is the same, however doubling the R value does not double the effect of the insulation. The first R1 stops more heat flow than the next R1
- The total surface area. The greater the surface area of the building fabric, the greater the heat flow across the fabric

In a building with poor ventilation and high sun penetration, increasing the insulation will trap heat inside the dwelling and create a ‘hot box’ effect. However, where good ventilation and some shading exist, increasing insulation will have a beneficial effect by reducing heat gain through the external fabric. When a house is air-conditioned, heat flows are altered as the temperature difference across building fabric is changed. In this case, ceiling insulation can be more effective than roof ventilation and reflective foil use. Insulation also substantially reduces the effect of the colour of the fabric on heat transfer. Insulation has a bigger effect on energy use than it does on comfort. Therefore in an air-conditioned dwelling, ceiling insulation has a larger effect than ventilation and reflective foil. In either case, in warm-humid climates, controlling the heat gain from the roof space is a critical element as mean radiant temperature (MRT) is twice as important as air temperature in these conditions (Greenland, 1985).

Thermal mass of materials

In many remote Indigenous communities, the combination of harsh environmental conditions (sun, sand, salt water, flooding, cyclones, etc.) and high levels of housing use, has led to the development of houses designed for robustness and durability.
Concrete slab construction is a common response, and many new house designs include extensive use of concrete external and internal walls (FaHCSIA, 2007). This leads to a relatively high thermal mass construction, with implications for energy performance and comfort. Absorption of heat in building materials delays the effect of heat gain in a dwelling. High thermal mass buildings will tend to have a lower peak day temperature but a higher minimum night temperature. As such, they are more effective in desert than tropical conditions due to the greater diurnal temperature variation in desert regions (Szokolay, 1987). Air management strategies become more important in houses with higher thermal mass, particularly in regard to sleeping comfort.

3. Approach and method

Ten house types located in the Top End of the Northern Territory form the case study. The houses cover a range of sizes, bedrooms numbers and material components. All of the house types investigated have been constructed within the last 18 months. The houses in this paper were modelled using the AccuRate v1.1.4.1 software, licensed from Hearne Scientific. Thermal modelling does not indicate how much energy a particular dwelling will use in the course of a year to maintain comfortable conditions, as this varies according to many factors including; the number of occupants, the amount and type of heating and cooling appliances used, and personal preferences regarding what is too hot or too cold. Each household’s heating and cooling energy profile is unique, and building designers cannot rely solely on the performance of the building fabric alone to reduce energy bills. The composition of a building’s envelope does, however, play an important role in moderating external environmental conditions that affect internal conditions. In extreme cases, poor material and construction choices may make comfort conditions inside a dwelling more onerous (or further removed from an acceptable comfort range) than un-moderated outside conditions. By modelling different scenarios of building envelope construction against a common standard comfort definition, it is possible to rate potential envelope performance (in terms of predicted heating and cooling loads required to maintain comfort) against each other. This enables a relative scale of the effectiveness of a particular set of design decisions regarding building construction to be compared with alternative solutions. As such, it enables a valuable insight into the potential long-term behavioural patterns of occupants in regard to energy use for comfort purposes.
Location
The case study houses are located in Nguiu (Wurrumiyanga) on the Tiwi Islands and Wadeye in the Victoria Daly Shire of the Northern Territory. Both communities have a hot, humid tropical climate. In the 64 climate zones defined by the Building Code of Australia (and used by the AccuRate software), Nguiu is located in climate zone 1 (assessed at Darwin Airport) and Wadeye is located in climate zone 30 (assessed in Wyndham, WA).

Size
The houses range from 2-bedroom dwellings of between 80 and 100 m², to 4 bedroom dwellings of between 130 to 145 m². All of the dwellings have some external verandah area, ranging from 17 to 82 m². The case study includes two duplex house types (one in Nguiu, one in Wadeye), the rest are free-standing dwellings.

Material
There are three types of primary structural material used in the case study dwellings. Timber frame (including timber walls and floor), steel frame (with concrete flooring and some concrete walling in wet areas), and concrete panel (with concrete floor). All of the roofs of the case study dwellings are colourbond steel on timber or steel roof trusses. All dwellings are finished with linoleum floors. There are varying levels of insulation in the walls and ceilings of the dwellings, and all of the houses used louvre window systems with clear glass, clear polycarbonate or opaque polycarbonate louvre panels.

4. Results

Star ratings
Two star rating values are taken for each house design. These correspond to the rating at the most and least effective orientation of the dwellings (see Table 1). The issue of orientation is further discussed below. Of the ten house designs examined, the lowest rating are the two timber framed HOIL houses. The highest rating house design is the SIHIP Nguiu 2-bedroom duplex design, with an 8 star rating. The highest rating free standing house design is the Stage 1 SIHIP 6 person house. All of the SIHIP commissioned designs attained star ratings of 7.0 or above, with the exception of the SIHIP Type 1A model, and the Stage 2 SIHIP 6 person house with central breezeway, which rated fractionally below. These results are substantially in line with the SIHIP design guideline recommendation that the houses achieve a 7 star rating level (Territory Alliance 2010).
**Orientation**

The majority of dwellings in remote communities examined in this study were aligned according to a standard street layout. Typically, streets in remote communities have dwellings on either side, as is the case in almost all Australian urban and sub-urban communities. As a consequence of this street-based orientation, ideal solar and wind orientation patterns are not commonly adopted, and designs will be distributed around 360 degrees. In this section, the effect of different orientation (and differing amounts of direct solar gain), on each of the house designs is examined. The SIHIP house designs tend to perform more uniformly across differing orientations in this sample. The presence of verandahs and deep set eaves will assist in moderating the effects of orientation however, it is the lack of large, clear glazed window areas in the designs that has the largest effect on minimising problems from poor orientation. The two designs with significant areas of clear glazing (the two HOIL houses) show the most variation with orientation (see Figure 1). The effect of glazing type on the housing designs thermal performance is examined in greater detail below.

<table>
<thead>
<tr>
<th>Name</th>
<th>Orientation</th>
<th>Star Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>1    IBA HOIL 1 (Nguiu)</td>
<td>NE W</td>
<td>5.0 4.8</td>
</tr>
<tr>
<td>2    IBA HOIL 2 (Nguiu)</td>
<td>W SE</td>
<td>4.9 4.6</td>
</tr>
<tr>
<td>3    SIHIP Duplex 1 (Nguiu)</td>
<td>N E</td>
<td>7.4 7.1</td>
</tr>
<tr>
<td>4    SIHIP Duplex 2 (Wadeye)</td>
<td>NE S</td>
<td>8.1 7.9</td>
</tr>
<tr>
<td>5    SIHIP Stage 1 H6 (Nguiu)</td>
<td>NE S</td>
<td>7.8 7.6</td>
</tr>
<tr>
<td>6    SIHIP Type 1A (Wadeye)</td>
<td>N W</td>
<td>6.1 5.5</td>
</tr>
<tr>
<td>7    SIHIP Stage 2 H6V (Nguiu)</td>
<td>S W</td>
<td>7.2 7.0</td>
</tr>
<tr>
<td>8    SIHIP Stage 2 H6B (Nguiu)</td>
<td>S W</td>
<td>6.9 6.8</td>
</tr>
<tr>
<td>9    SIHIP SN (Nguiu)</td>
<td>N S</td>
<td>7.4 7.0</td>
</tr>
<tr>
<td>10   SIHIP H10 (Nguiu)</td>
<td>W N</td>
<td>7.8 7.7</td>
</tr>
</tbody>
</table>

Table 1: Star ratings of the case study housing types
Glazing
Design decisions regarding glazing, including the size, position, type, and material composition, have a significant effect on the thermal performance of a dwelling. Where ceilings and external walls are well insulated, solar gain through windows is the principle cause of internal temperature gain within a dwelling (followed by internally generated heat loads from people, cooking and appliances). Several factors present in remote Indigenous communities encourage windows to be relatively small and often opaque; these include a preference for visual privacy between the inside and outside of a dwelling, and a preference for good security around dwellings. These conditions act to reduce the amount of solar gain (from either direct or diffuse solar radiation). When considering the trade-off between increased ventilation versus smaller window areas, Isaacs (2006), found that in the Northern Territory, a 30% reduction in window area reduced energy consumption more than increasing open-able window area from 30 to 90%.

The house designs are rated as designed and then with the entire designated window louvre panels replaced by clear 6mm glass panels. In the case of the two HOIL designs, the clear glass panels are replaced with opaque 6mm polycarbonate panels. The two HOIL house designs show improvements in thermal performance of over 25% when their clear glass louvre panels are replaced with opaque ones. These designs were the constructed in light-weight materials (primarily manufactured
timber), and did not contain significant amounts of external wall insulation or ceiling/roof insulation. The designs relied predominantly on cross ventilation to maintain comfort conditions. Consequently, by reducing the amount of solar gain heat that the cross ventilation needed to remove from the dwelling, the performance of the houses improved (as the degree of cross ventilation remained the same). The Wadeye houses in the case study, show a greater percentage change than the Nguiu house types because the original Wadeye house types contain only opaque louvres (therefore the replacement represents a 100% change of louvre panels), whereas the Nguiu house types have mix of opaque and clear polycarbonate louvre blades (so replacement with 100% clear panels does not represent changing 100% of the original window panels).

**Room designation**
The Stage 2 SIHIP 6 person house design was rated while changing the designation of the bedrooms to either ‘living’ or ‘other daytime’ spaces. AccuRate makes presumptions regarding room occupation (activity and time-of-day), and consequently adjusts the amount and timing of mechanical comfort control (heating or cooling), depending on the room’s designation. In remote Indigenous communities, factors such as extreme weather conditions, living practice preferences, or overcrowding may result in rooms being used in ways and at times markedly different from those in the AccuRate default values. This is partially acknowledged in the common practice in Indigenous housing design of designating ‘bedrooms’ as ‘multi-purpose (or multi-function) rooms’. The primary difference between designating a room as ‘living’ and ‘other daytime’, is that default AccuRate settings assume that ‘living’ rooms are heated and cooled by AccuRate to maintain comfort, while ‘other daytime’ rooms are not. When bedrooms are defined as ‘living’ spaces in AccuRate, the energy requirements to maintain comfort increase marginally. When all three bedrooms in the Stage 2 SIHIP 6 person house were changed to living spaces the star rating of the house dropped from 7.2 to 6.9 stars. This occurs because although total ‘Conditioned Floor Area’ remains the same (both bedrooms and living spaces in AccuRate are heated and cooled automatically), the living areas are cooled to a greater degree due to the proposed hours of occupation/use (when the sun is most prominent). The larger drop off in Star Rating when bedrooms are changed to other daytime use (from 7.2 to 5.4), but are not heated or cooled, probably reflects the reduction of the area of heated and cooled space within the dwelling relative to the overall area of the buildings envelope (building fabric), implying that the conditioned areas will need to ‘work harder’ to remove heat from the dwelling.
Climate zone designation

The Stage 1 SIHIP 6 person house on Nguiu and the SIHIP 6 person concrete panel house in Wadeye represent the highest and lowest star rated buildings of the SIHIP program’s free standing houses, the Stage 2 SIHIP 6 person dwelling on Nguiu sits somewhere in between them. There are several differences (and similarities) in the construction of the dwelling types:

- The Stage 1 Nguiu house is elevated and its wall configuration is a mix of insulated steel frame and Ritek concrete panel construction (with the concrete walls used in the wet areas of the dwelling)

- The Wadeye house is constructed on a concrete base (not elevated), with concrete panel walls from the factory at Wadeye (solid reinforced concrete panels, 100 mm thick)

- The Stage 2 Nguiu house is also on a concrete base, however the walls are concrete panels made of the Ritek wall system (which consists of 80 mm thick concrete poured in-situ sandwiched between two 9 mm thick braced fibre cement sheets

- Nguiu is in Climate Zone 1, which is modelled on temperatures measured at Darwin Airport

- Wadeye is in Climate Zone 30, which is measured on temperatures from Wyndham, WA

The different temperature profiles for Nguiu and Wadeye, simulated by the AccuRate program, have an effect on the predicted performance of the different dwelling types. Both the Nguiu buildings show a lower star rating when assessed in Climate Zone 30 (from 7.8 to 6.7 and from 7.2 to 5.9 respectively for the Stage 1 and Stage 2 designs), whereas the Wadeye building’s performance increases from a star rating of 6.1 to 7.6 when assessed in Climate Zone 1. This suggests that the greater temperature fluctuations of Climate Zone 30 (compared to Climate Zone 1), cause the simulation model to predict increased cooling loads to maintain temperatures within assumed comfort levels. This may not reflect actual temperatures within the dwellings but the difference between inside and outside temperatures and the rate of change of external temperatures (which is greater in Climate Zone 30 than Climate Zone 1).
5. Discussion

Two key issues for discussion are proposed from the examination of the thermal performance of a sample of recently built house designs in remote Indigenous communities in the Northern Territory.

Firstly, in general, the houses examined can be expected to perform well from a thermal performance perspective, with most achieving a 7 star or more rating, well above the currently mandated 5 or 6 star requirements in New South Wales and Victoria. For those that exhibit less impressive modelling performance, the most prominent factor involved is the extent of clear glazing present in the design. If we accept the modelling assumptions, clear glazing is more influential on performance than increased shading or higher levels of insulation. Coincidentally, the primary reason for a restricted use of clear glazing in many of the designs is related to cultural and social preferences of the community residents for privacy and security over increased natural light penetration and views from inside. This is reinforced by a preference for sheltered, external dwelling areas (verandahs) to be provided for socialising, occasional sleeping, work and some food preparation, as part of the everyday activity of the household. There is also a coincidental reinforcing affect between the desire for a highly robust housing design leading to concrete flooring and walling, resulting in dwellings with a high thermal mass, likewise benefiting their thermal performance.

Modelling of different house designs across different climate zones indicates that the SIHIP house designs for both Nguiu and Wadeye perform better in the Nguiu climate zone than in the Wadeye climate zone. Both are hot and humid tropical climates, and this finding allows for a more nuanced balance to be achieved between harnessing an economy of scale through standardised designs and local conditions, and modifying these by utilising the full 64 climate zones designated by the Building Code of Australia, rather than the more simplified hot/humid versus hot/dry designations.

The second issue relates to the use of thermal modelling programs such as AccuRate as research and development tools. The investigation of cultural preferences, construction materials, design and other considerations in the context of modelled thermal performance provides potential avenues for further research. Modelling may be used by designers to assess whether specific design decisions made in response to cultural and social preferences in communities would have a negative impact on thermal performance, and subsequently moderate those effects.
This approach can extend to consideration of the effect of room designation, and how different modes of occupation might affect comfort levels within a dwelling. This highlights the fact that although a particular house design may be assessed with a high star rating (using the nationally recognised standard), this in itself is not a guarantee of good internal comfort levels of the constructed dwelling, as the AccuRate software model builds in to its calculations a set of assumptions regarding the number of occupants, room occupation times and durations, door and window openings, and the amount of internal heat generated by cooking, that may not correspond to the distinct living patterns of remote Indigenous community members. As such, these ‘normalized’ patterns of occupation provide a starting point for designers to continue to incorporate consultation feedback about preferred occupation practices into the material form and composition of building envelopes as well as the spatial composition of dwelling layout. This should allow designers another option to explore housing performance ‘up-front’ while balancing the many competing factors that influence design decisions.
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