DESERT KNOWLEDGE CRC

Scoping study of design and thermal performance in the desert built environment

Michael Duell
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Charmain Enthaler
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Gary James
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The Desert Knowledge Cooperative Research Centre is an unincorporated joint venture with 28 partners whose mission is to develop and disseminate an understanding of sustainable living in remote desert environments, deliver enduring regional economies and livelihoods based on Desert Knowledge, and create the networks to market this knowledge in other desert lands.

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Abbreviations/Acronyms

AAC	Aerated Autoclave Concrete
BASIX	Building Sustainability Index
BCA	Building Code of Australia
BIITE	Batchelor Institute of Indigenous Tertiary Education
CDU	Charles Darwin University
CFD	Computational Fluid Dynamics
CRM	Central Remote Model
CRRC	Central Remote Regional Council
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DKCRC	Desert Knowledge Cooperative Research Centre
DTS	Deemed to Satisfy
EHSRCNT	Environmental Health Standards for Remote Communities in the Northern Territory
ESD	Environmentally Sustainable Design
ERS	Energy Rating Scheme
FaCS	Family and Community Services
IHANT	Indigenous Housing Authority of the Northern Territory
ISA	Integrated Systems Analysis
NABERS	National Australian Built Environment Rating System
NAHS	National Aboriginal Housing Scheme
NatHERS	Nationwide House Energy Rating Scheme
NIHG	National Indigenous Housing Guide
NT	Northern Territory
NTG	Northern Territory Government
R-Value	Comparable insulation value of construction materials
WWAC	Wongatha Wonganarra Aboriginal Corporation

1. Executive summary

This report examines the internal climates of buildings in desert communities, their design and passive climate control characteristics and the energy used for active heating and cooling.

The primary outputs of this report are:

- A review of the literature on building energy efficiency
- A review of models and their applicability to the desert built environment
- A review of the applicability of the Building Code of Australia for desert communities
- An improved understanding of energy usages and costs associated with active climate control in buildings in remote desert communities
- A greater appreciation and understanding of opportunities for energy conservation through passive climate control and appropriate building design
- A platform for future improved modelling of buildings, improved data on suitable design and improved practical recommendations and guidelines, allowing for more informed decision making when designing and retrofitting
- A greater awareness of Aboriginal cultural and other user issues related to building design
- Identification of knowledge gaps that directly or indirectly influence thermal performance of the remote desert built environment.

The methodology adopted within this scoping study is to investigate each of the key areas: Desert design, the Building Code of Australia, modelling methodologies and cultural sensitivity in a direct manner to identify the scope of knowledge currently in the public domain. Based on this information, knowledge gaps have then been identified and in some instances, including the modelling methodologies section, were further pursued in the report.

1.1 Desert design

There are two broad methods for the regulation of the internal climate within a house. Active climate control refers to the conversion of electricity into energy to regulate the internal climate, while passive design relies on ambient energy sources, such as wind and solar energy to regulate the internal climate.

There is a shift towards passive climate control for a number of reasons: reduced energy consumption, potentially lower maintenance, and reduced impact on the environment. Active climate control can consume large amounts of electricity resulting in the generation of greenhouse gases. The use of electricity also places greater pressure on the community's infrastructure, which has many follow-on effects including the increase of maintenance requirements. Passive climate control relies on material properties, placement and the external environment to influence the internal climate.

The majority of buildings in most remote desert communities are houses. A number of building designs have been identified throughout these regions. House designs include standardised designs, temporary housing such as transportable buildings and shelter accommodation. There is also a variety of buildings from previous generations available for post–life cycle analysis. Two houses in particular have been analysed in detail. These appear later in the report in Section 4: Modelling methodologies.

1.2 Building Code of Australia assessment

The Building Code of Australia is a comprehensive set of requirements and standards for the design and construction of buildings and similar structures in Australia. Produced, maintained and annually updated by the Australian Building Code Board, the Building Code of Australia can be applied across Australia as a nationally uniform code that allows for variations in climatic, geological and other geographic conditions. While the Building Code of Australia sets the minimum building standard in order to eliminate poor or worst practice, the builders or consumers may choose better performing systems as part of the building design and construction process. The Building Code of Australia makes no allowance for variable social issues. However, there are a number of complementary documents to the Building Code of Australia that specifically deal with Aboriginal culture and housing.

There are two avenues to BCA compliance: Energy Rating Schemes (ERS) or Deemed to Satisfy (DTS) check lists. Energy Rating Schemes evaluate the energy consumption of a house based on the interaction of all the components as a system, taking into account characteristics such as orientation, floor materials, insulation, and glazing. Deemed to Satisfy provides a check list of requirements that ensure a minimum level of energy efficiency is achieved regardless of component interaction. The Energy Rating Schemes provide an invaluable tool for improving the thermal performance of housing as it takes into account the specific climate. However, there are questions regarding the level at which the minimum standards should be set.

Energy efficiency amendments are being proposed for the Building Code of Australia to reduce domestic energy demand. The amendments aim to bring all new houses to a level of 5 stars based on National House Energy Rating Scheme (Kennedy 2004) that essentially represents buildings of very good energy efficiency. Some states such as Victoria have already implemented these changes. In order to determine its relative merits in desert climates, two Central Remote Model standardised house designs used by the Indigenous Housing Authority of the Northern Territory were analysed for life cycles, embodied energy, the efficiency of energy saving measures and the resulting active energy consumption. The standardised houses, like others in the Northern Territory, are designed for retrofitting within 10 years. This limits the time available for savings in operational energy to exceed energy invested in installing these measures. It was found that adopting the proposed Building Code of Australia energy efficiency measures would increase the embodied energy within the houses without markedly reducing the energy requirements of evaporative air conditioners that are the primary source of active climate control. The short lifespan of these houses did not permit sufficient time to pay back the energy investment through operational energy savings. Therefore, for these desert housing designs, implementation of the Building Code of Australia's proposed energy efficiency measures was found to be out of balance.

1.3 Modelling methodologies

There are three main forms of modelling tools available: numerical simulation, theoretical calculation and experimental modelling. Numerical simulation is a popular form of modelling due to the ease of rapid evaluation of housing design. A combination of numerical simulation and full-scale experimental modelling techniques have been employed to analyse the effect of changes and to test the comfort parameters. A Central Remote Model standardised design has been numerically simulated subject to a number of variations in design, and a Wongatha Wonganarra Aboriginal Corporation house has been data logged representing a full scale model. Variations to the orientation, insulation, external wall composition, window framing and veranda depth have been examined in detail.

A standardised IHANT design, CRRC3K – a compact, concrete block 3-bedroom house with deep verandas on the north and south sides of the building – has been studied in detail by numerical simulation. There is a large variation in energy rating requirements due to the orientation of the house. The most significant improvement occurs at an orientation of 270º where a 6.7% improvement is achieved. An optimised variation is achieved through compounding the improvements based on the orientation, external wall composition and glazing variations. A clockwise rotation of 270º from the north, 200mm Autoclaved Aerated Concrete block work with 10mm of plasterboard and a change to clear double glazed windows produces a dramatically improved rated energy requirement from the base rating of over 65%.

Through project partners Murdoch University, and links with the Wongatha Wonganarra Aboriginal Corporation, a resident's house was data logged April to July 2005 in Laverton Western Australia (James 2005). The house was a novel design that incorporated a range of sustainable design concepts, including thermal performance, community development aspects and sustainable materials through the use of rammed earth (Anda 2005). The limited data logging analysis correlates well with the numerical analysis.

The CRRC3K design and the Laverton house design are performing well during the summer period but have been designed to insulate the house too much during the winter and as such require a heating load which is greater than the cooling load. This in turn leads to a greater electricity requirement during the winter, impacting on the infrastructure.

1.4 Cultural sensitivity

'To competently design appropriate residential accommodation for Aboriginal people who have traditionally orientated lifestyles, architects must understand the nature of those lifestyles' (Memmott & Go-Sam 2003). Cultural considerations must be included in Aboriginal housing design, to ensure basic needs are catered for and housing designs satisfy their main objective of providing a suitable, healthy environment in which to live. Behavioural and social sensitivity also have a significant impact on the way that a house should be designed.

Memmott (2003) states that the key premise for appropriate residential accommodation for Aboriginal people is to understand the nature of those lifestyles, particularly in the domiciliary context. As an example Fantin (2003) states that many of the Yolngu householders from north-

east Arnhem land were interested in ways of incorporating particular cultural aspects into their housing designs. The issues of avoidance laws and their associated behaviours and sorcery were investigated with relation to visual surveillance, access to houses and yards, landscaping, lighting, ablutions design and security. Keys (2003) specifically investigates the social and physical properties of a single women's camp in Yuendumu, Central Australia. In particular the ability to visually survey social and environmental conditions was highly valued by the Warlpiri women. A numerical simulation analysis of variable window height allowing for visual surveillance while sitting on the ground found that there was little impact on the overall thermal performance of the house.

There is a direct link between the temperature of the environment and the health impacts of individuals, particularly groups that are at risk such as children, the elderly and the sick. The effects of extreme temperatures are generally referred to as heat stress and can include heat stroke, exhaustion and cramps (New South Wales Government 2002) but can also induce irritation, anger and other emotions that can lead to rash actions (Leveritt 2004). It can be seen in Housing for Health data presented in Table 16 that there are a significant number of houses that exceed 30ºC. This is beyond comfort levels and is impinging on health. It can also be seen that 25% of houses did not have any form of cooling climate control.

1.5 Knowledge gaps

There have been a number of knowledge gaps identified by the project. These range from specific technical design issues to issues that are design considerations before and after the thermal performance consideration. The purpose of a house is to be functional to the resident. This means not only providing protection from the elements but also a design that is culturally sensitive. The effects of altering housing design to incorporate cultural sensitivity or shifts will have an overriding impact on the thermal performance of the housing.

Thermal performance of buildings has a large influence on the settlement's ability to provide power. The settlement energy use depends on two factors: base energy consumption and peak energy demand. The settlement's power supply must be able to handle the base load of the infra-structure, community buildings and housing. The peak loads come from fluctuations in these components. Based on simple analysis as well as anecdotal evidence it would appear that the peak loads are driven by active climate control, both heating and cooling in the settlements.

Passive design concepts can greatly reduce the energy demands of active climate control. There are two aspects to passive design: passive cooling and passive heating. It was found in the modelling analysis that the CRRC3K and Laverton designs have been over-engineered towards passive cooling for the summer period rather than passive heating for the winter period.

The Northern Territory Government has stated that one of the most urgent issues is addressing the massive shortage of housing. In addition to the issues discussed above, labour shortages for construction and maintenance in remote areas and longer term requirements, both cultural and social, also need to be considered.

2. Desert design

The hot arid regions of Australia are characterised as a harsh environment that is difficult for humans to exist in, yet 'most of the early urban civilisations of the world emerged in the arid or semi-arid zones' (Golany 1983:2). This demonstrates that desert housing design has been an evolving process for many generations. While the Australian deserts are not uncommon from other deserts around the world, the spatial distances, population distribution and cultural sensitivities of Aboriginal communities make the Australian desert region a unique place.

There are two broad methods for the regulation of the internal climate within a house. Active climate control refers to the conversion of electricity into energy to regulate the internal climate, while passive design relies on ambient energy sources, such as wind and solar energy to regulate the internal climate. Examples of active and passive climate control devices are listed in Table 1.

Table 1: Forms of climate control – active and passive

Active climate control	Passive climate control
Refrigerative air conditioning	Thermal mass
Evaporative air conditioning	Shading
Ceiling fans	Natural ventilation
Pedestal fans	Insulation
Central heating	Glazing
Radiant heating (bar heaters)	Radiation
Gas heating	

There is a shift towards passive climate control for a number of reasons: reduced energy consumption, potentially lower maintenance, and reduced impact on the environment. Active climate control can consume large amounts of electricity resulting in the generation of greenhouse gases. The use of electricity also places greater pressure on the community's infrastructure, which has many follow-on effects including the increase of maintenance requirements. Passive climate control relies on material properties, placement and the external environment to influence the internal climate.

The *Your Home* guide (Reardon 2001) is an Australia-specific guide to housing design throughout all the climate zones. It is a result of the collaboration between Australian Government departments, the Building Commission and industry partners. It refers to both the construction and renovation of houses. The guide suggests a number of specific design principles for hot arid climates: high thermal mass, shading and ventilation. High thermal mass refers to materials such as concrete, rock or rammed earth that are particularly dense or heavy and have the ability to store heat energy. As the thermal mass absorbs large amounts of heat energy it can reduce the fluctuations of the external climate by minimising the peak temperatures during the day. Optimally, thermal mass would absorb the excess heat during the day and release it during the cooler night period, creating a temperature stable environment. Shading reduces the incident solar radiation, assisting in decreasing the absorbance of energy into the building envelope, while ventilation allows the house to capture transient breezes, assisting convective cooling.

There has been a shift in the form of housing provided to Aboriginal communities living in the desert regions during late European settlement. Original housing provided to remote regions was of very low habitation quality; later housing was of European design that was not suited to the desert climate. Currently the standardised designs provided by Indigenous Housing Authority of the Northern Territory (IHANT) are of a very solid design, making them more robust in an attempt to increase the lifecycles of the buildings.

Thermal performance can be implemented into new housing design, such as through Building Code of Australia (BCA) requirements, or it can be retrofitted into the existing structures. Examples of retrofitting could be the installation of insulation into cavities, the shading of walls through eaves or vegetation, or painting of a roof to a lighter colour. Justine Hill, of Healthabitat, completed her Masters thesis on the topic of retrofitting homes in desert communities. The thesis is yet to be released for public dissemination but it is considered that this thesis will be a thorough analysis of all retrofitting options. Based on this, retrofitting is only reviewed in this report in a limited manner. Another factor in considering the deliberation between new house design and retrofitting is the lifespan of remote housing. Preliminary research by Kurt Seemann indicates that the average lifespan of housing is relatively short, making housing design the more beneficial method of implementing improved thermal performance techniques (Gary Boyle, pers. comm., 2005).

2.1 Active energy consumption

The energy usage and costs associated with active climate control can be considerable. The running cost of several domestic heating and cooling appliances are compared below in Table 2. The cost per hour is based on 500 hours of use per year.

Table 2: Operating cost of heating and cooling appliances

Appliance	Input Power (Watts)	Cost per hour($/ hour)	Total cost per 6 months (12 hour days)
Reverse cycle air-conditioner (refrigerated) – cooling, bedroom unit	1000	0.1394	$306.00
Reverse cycle air-conditioner (refrigerated) – heating bedroom unit	850	0.1185	$260.00
Reverse cycle air-conditioner (refrigerated) – cooling, living room unit	2000	0.2788	$611.00
Reverse cycle air-conditioner (refrigerated) – heating living room unit	1700	0.2370	$520.00
Mobile evaporative cooler (small)	54	0.0075	$17.00
Mobile evaporative cooler (large)	103	0.0144	$32.00
Bonair Series B23 ducted evaporative air conditioner (Mechair 2005)	800	0.1115	$244.25
Ceiling fan	90	0.0125	$28.00
Small electric bar heater	750	0.1046	$229.00
Large electric bar heater	1000	0.1394	$306.00

Source: Western Power 2002

A comparison of the average operational costs of each appliance per 6-month period in Table 2 indicates that evaporative coolers are much more energy- and therefore cost-efficient than refrigerative coolers. The Bonair series evaporative air-conditioners that are currently used in IHANT standardised designs cool the entire house while operating on only 800W of power. Ceiling fans are the least costly but do not achieve the same level of cooling effectiveness as air conditioners.

Despite the low cost and energy requirements of evaporative air conditioners there is an issue with maintenance that is primarily due to the low water quality in remote desert areas. The pads that are critical in the operation of evaporative air conditioners can calcify and make the evaporative air conditioners ineffective. The low water consumption and resultant lower maintenance of refrigerative air conditioners is making them a popular choice. In a recent project proposal to the Desert Knowledge Cooperative Research Centre, Glenn Marshall states:

> *Air conditioning in remote Aboriginal housing of Central Australia is now an accepted norm. Evaporative air conditioners have been exclusively used for several years, but they suffer from substantial ongoing maintenance issues due to hard water supplies. These include rapid scaling and clogging of pads, corrosion of seals leading to leaks, rusting roof sheets and gutters from leaking air conditioners, bleed water creating permanent wet areas near houses, extended down times between maintenance intervals and generally high water consumption (measured at up to 100 litres per hour at Canteen Creek houses in Jan 2005). Evaporative air conditioners also do not work optimally in humid conditions.*
>
> *In Alice Springs, similar issues have seen a sharp move towards refrigerative reverse cycle split system air conditioning (exponential sales in the last five years). These are said to have far lower maintenance requirements, use no water and provide stable cooling in all weather conditions. Their major drawback is high power consumption including high peak loads placed on power stations. New models are emerging that are claimed to be more energy efficient and have reduced peaks ('inverter' systems).*
>
> Marshall 2005

2.2 Passive design

Passive design is the use of the natural environment to moderate the internal climate of a building. The desert regions experience extremes of temperatures, both hot and cold, and so passive design can either be expressed as passive heating or cooling. 'Passive cooling maximises the efficiency of the building envelope [and occupants] by minimising heat gain from the external environment and facilitating heat loss [through] natural sources of cooling' (Reardon 2001). The method of passive heating is synonymous to passive cooling, using a number of different mechanisms. Examples of passive design mechanisms are listed in Table 3.

Table 3: Examples of passive design mechanisms for heating and cooling in desert regions

Passive cooling	Passive heating
Air movement	Solar radiation
Cooling breezes	Thermal mass
Evaporation	Conduction
Earth coupling	

Natural sources of cooling can be easily identified in most desert homes: air movement through ceiling fans, cooling breezes being captured with open living plans, evaporative air conditioners and earth coupling through concrete slabs. The cooling methods also refer to the three forms of heat transfer that are applicable to the comfort levels of inhabitants: conduction, convection and radiation. Conduction refers to the transfer of heat through a material on an atomic level. It is most efficient in solid materials and can be demonstrated through a bathroom ceramic tiling floor where the heat is conducted away from bare feet. Convection is the transfer of heat through the movement of gas or liquids. This is exemplified through a ceiling fan moving the air around and cooling the skin through evaporation. Radiation is energy that is transported through space, a warmer body radiating to a cooler body. This is best demonstrated through the sun shining down during the day heating a person's skin. These principles also apply to passive heating: solar radiation can enter a building envelope through windows and warm the concrete floor representing thermal mass. The thermal mass then transfers the heat to the internal environment through conduction and consequently convection through warming air currents.

2.2.1 Passive cooling techniques

The simplest method of reducing the internal temperature of a house is to shade the building envelope, reducing incident radiation from the sun (solar radiation). This can be effectively done through natural vegetation as it is disconnected from the envelope, but eaves or verandas perform a similar function. Deciduous trees also have the advantage of allowing the transmittance of the winter solar radiation to the building envelope when passive heating is required.

The external ambient temperature is not influenced by shading but thermal mass can damp the transmission of the heat through the building envelope. Thermal mass is the ability of a material to store heat. A high thermal mass material such as stone or concrete will store large quantities of heat, while light weight materials such as timber or metal cladding will only store small quantities of heat. High thermal mass can be used to essentially create a time lag between the external peak temperature and the effect on the internal temperature. Ideally the thermal mass would absorb the energy from the external environment during the peak of the day and emit it during the cool of the night.

Thermal mass will damp the rate of transmission of heat but will not stop it. Insulation provides an effective barrier to this transmission. Insulation is generally made of non-conductive materials that have the effect of providing a barrier between internal and external environments. Bulk insulation consists of trapped air pockets that resist the transfer of convective heat while reflective insulation or sisalation stops radiative heat. A combination of the two types is the most common form of insulation.

Ventilation can be used both as an insulator and as a form of cooling through convective heat transfer. Air motion generated by ceiling fans and the capture of natural breezes can provide essential relief throughout the internal environment. Convective heat transfer from the inhabitants to the ambient air through breezes is affected primarily by the geometry of the house. The placement of windows and louvres, internal walls and the orientation of the house to predominant breezes are all important factors.

The orientation of the house not only affects the capture of predominant winds but also where the incident solar radiation impacts on the building envelope. ‘Good orientation increases the energy efficiency of a home, making it more comfortable to live in and cheaper to run’ (Reardon 2001:1.3.1). Rooms in the home adjacent to walls that are exposed to the sun will heat up much more rapidly than others.

There are a number of innovative forms of passive climate control that have been used in houses in different cultures throughout history. In India, Earth-Air-Tunnel systems are used to transfer heat from the ambient temperature to the cooler sub-surface ground (Kumar et al 2003). Towers protruding from the house are used in the Middle East to capture prevailing breezes directing them through the house. Cooling ponds situated in the middle of the living zones are used as natural sources of evaporative cooling in many cultures.

2.2.2 Passive heating techniques

The techniques that are used for passive cooling can also be used in passive heating. Thermal mass provides passive cooling during the daytime by absorbing energy which is released at night time as passive heating. Solar radiation can also be used to provide heat energy. During the winter period the sun crosses the sky at a lower angle. This allows verandas to be dimensioned to block summer solar radiation but admit winter solar radiation. The difference between summer and winter radiation can be viewed in Figure 1.

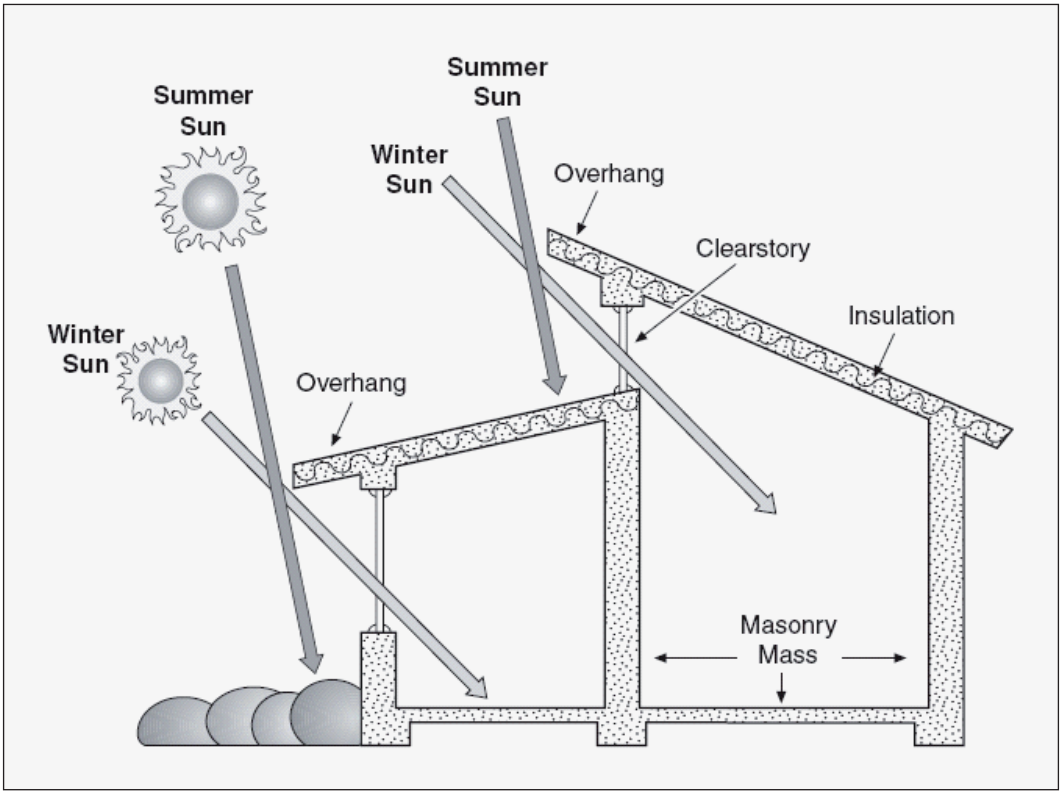

Figure 1: Winter and summer sun paths through the sky and the effects on the internal environment.
State Energy Conservation Office 2005

2.3 Case study buildings

The majority of buildings in any community are houses, particularly so in remote communities where there is limited industrial activity. A number of house designs have been identified throughout these regions including standardised designs, temporary housing such as transportable buildings and shelter accommodation. There is also a variety of buildings from previous generations available for post–life cycle analysis.

The buildings identified for brief analysis in this report are as follows:

- Central Remote Model (CRM) or IHANT standardised designs
- Transportable buildings
- Brendan Meney Big Roof
- Shelter accommodation
- Arrillhjere Demonstration House
- Dilapidated houses from previous generations
- Tangentyere Child Care centres.

2.3.1 Central Remote Model standardised designs

The CRM standardised designs are originally the result of a housing competition. Since the time of the competition, the designs have undergone a continual redesign process. Currently these designs are in the second phase of redesign in order to meet the Environmental Health Standards for Remote Communities in the Northern Territory (EHSRCNT) (NTG Environmental Health Task Group 2001). While the majority of these houses lie outside the BCA zoning regulations there is still a duty of care to 'undertake all works in accordance with the BCA and NT [Northern Territory] Building Act/regulations' (Central Remote Regional Council 2003:1) IHANT have built, upgraded or renovated approximately 2200 houses since 1995 (IHANT 2005).

A three-bedroom standardised design has been extensively modelled with respect to thermal performance in Section 4: Modelling methodologies. An innovative design in Laverton has been data logged for a number of months.

2.3.1.1 Transportable buildings

Transportable buildings are an emerging market of housing options for the remote regions. While there are a number of different designers, Murray River North is a leading developer of these building types. In a conversation with Des Rogers, a former chairperson of IHANT, transportable flat pack buildings have been trialled in the past with extremely limited success; 'A lot of mobs have gone under trying that' (D Rogers, pers. comm., 2004). Within a flat pack there are a lot of pieces to assemble and it is easily damaged en route. Despite these issues transportable buildings are still pursued as a viable option because of their cost effectiveness and limited labour requirements (Australia Unlimited 2001a).

The Goldfields-Esperance Housing Concept Design Competition was held in June 2001 with the aim of creating three unique designs for the Esperance, Kalgoorlie-Boulder and outer community regions. One of the designs was dedicated to a transportable model to be used in the hot-arid region. It is stated in the design brief that:

The transportable will need to encompass the following criteria:

- *A house that is aesthetically sympathetic and reflective of the zone*
- *A house that will incorporate energy efficient design principles wherever possible*
- *A house that will incorporate water efficient design principles*
- *Orientation of the transportable house*
- *Use of a covered outdoor living area connected in some form to the main module (allow for ease of dismantling during transportation)*
- *Provide suitable accommodation for a family – while easily adaptable to become a 3 bedroom model*
- *Provide an affordable solution that is easily transportable. Budget range of $100,000 to $150,000.*
- *Visually appealing both internally and externally*
- *Located on the site in an appropriate manner to allow for a variety of soil conditions.*

Australia Unlimited 2001b:37–38

The winner of the competition was Clem Lester Architects and the transportable house cost around $130,620. The design is centred on a modular concept that allows flexibility in the layout of the house. An illustrative diagram is presented in Figure 2.

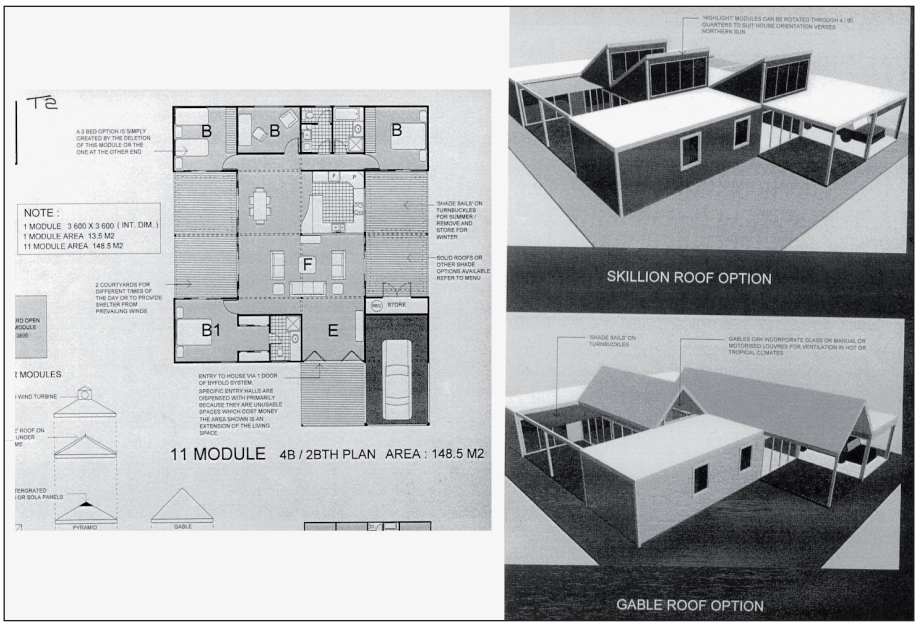

Figure 2: Transportable design winner from the Your Kinda House? Competition
Note: Designed by Christopher James Residential Design Specialists
Source: Australia Unlimited 2001c

The design features of the Christopher James transportable house are listed as follows:

- House centered on outdoor living area
- Ability to open whole house to central outdoor area
- Modular system in a repetitive format
- Concept of pre-packaged product which is easily transported and easy to erect by unskilled labour.

Source: Australia Unlimited 2001c: 2

The full exhibition catalogue of the transportable design winners can be seen in Appendix A – Transportable Design Competition Winner.

2.3.1.2 Shelter accommodation

Shelter style accommodation is a roof, concrete slab, a large lockable room and a kitchen/laundry or wet area. This style of building proved to be popular among the local transient inhabitants according to Des Rogers (pers. comm., 2004). Rogers saw particular advantages in community outstations where there were fluctuating populations. It was estimated that each shelter was worth around $50,000, about one-third the cost of a typical IHANT house.

Ted Egan, the Northern Territory Administrator, Ted stated in an interview that there needed to be a departure from Western-style housing to 'sensible shelters to shield the elements' (Darwin Independent Media 2005). Ted also said there needed to be a move towards outside living because it was a 'health matter, not a sociological matter'.

2.3.1.3 Arrillhjere demonstration house

The Arrillhjere demonstration house is a contemporary, self-sufficient living house that has been integrated into the surrounding environment (Parnell 1998). The house was envisaged by Mrs. Olive Veverbrants and was developed to become an environmental training and education centre that was in part built by the local community. The design features heavy thermal mass walls and floors, substantial insulation, shaded outdoor living areas and a passive ventilation system through ridge vents.

2.3.1.4 Intellectual property

A number of housing agencies that service the desert regions of Australia provide housing based on standardised designs. However, there are others that provide funding to consult architects and have specific designs catered to the communities' needs. There are issues with respect to the ownership of the intellectual property, because the community has provided the base knowledge critical to the design, yet the architect has provided the design experience to put it together. This generates issues when more houses need to be constructed but the designs are not reproducible because the community does not own them. This contentious issue has not yet been resolved.

3. Building Code of Australia assessment

The BCA is a comprehensive set of requirements and standards for the design and construction of buildings and similar structures in Australia. Produced and maintained by the Australian Building Code Board (Berry 2005), the BCA can be applied across Australia as a nationally uniform code allowing for variations in climatic, geological and other geographic conditions. The BCA sets the minimum building standard in order to eliminate poor or worst practice. The builders or consumers may choose better performing systems, however, as part of the building design and construction process (Williamson 2002).

3.1 Building Code of Australia documentation

The BCA has several sections in two volumes. Volume Two deals expressly with Class 1 (Houses) and Class 10a buildings (Non-habitable connected, e.g. garage). All other classes are included in Volume One. Within the volumes there are general outlining sections:

- Section 1 (General requirements): provides general information about the scope and use of the BCA
- Section 2 (Performance provisions): details the performance levels expected of buildings in terms of the structure, safety and health aspects, and energy efficiency requirements. Section 2.6 (of the BCA) deals with the energy efficiency of buildings
- Section 3 (Acceptable construction): provides minimum construction standards that if applied in a building, will achieve BCA compliance. Section 3.12 provides the acceptable construction methods for energy efficiency in buildings.

There are two avenues to BCA compliance: (1) to prove that a house satisfies the requirements through an Energy Rating Scheme (ERS), such as Nationwide House Energy Rating Scheme (NatHERS), or (2) to meet Deemed to Satisfy (DTS) criteria. ERS rate the energy consumption of a house based on the interaction of all the components as a system, taking into account characteristics such as orientation, floor materials, insulation, and glazing. DTS criteria provide a check list of requirements that ensure a minimum level of energy efficiency regardless of component interaction. There is a general movement to ERS with DTS criteria to be abolished in the near future.

The BCA makes no allowance for variable social issues. Issues such as population distribution, services availability, maintenance, and transport limitations are not addressed by the BCA because the impact on a building is beyond the normal operation conditions. Regionally specific documents such as Basic Specification – Aboriginal Housing should be applied in conjunction with the BCA to achieve a site specific standard for housing that respects the relevant social issues.

3.2 Complementary BCA documents

There are a number of complementary documents to the BCA that specifically deal with Aboriginal culture and housing.

3.2.1 Environmental Health Standards for Remote Communities in the Northern Territory

The *Environmental Health Standards for Remote Communities in the Northern Territory* (EHSRCNT) recognise the cultural differences and subsequent requirements of the Aboriginal built environment. It has been designed for ease of use when integrating relevant sections with the BCA. The EHSRCNT was written by Aboriginal and non-Aboriginal building, health and medical professionals in conjunction with government departments. The cultural issues associated with building design are further discussed with relation to thermal performance in Section 5.2: Cultural sensitivity design modifications.

3.2.2 National Indigenous Housing Guide

The *National Indigenous Housing Guide* (NIHG) provides methods of improving the living conditions for Aboriginal people throughout the country. In particular it incorporates the nine Healthy Living Practices for Aboriginal people to improve their environmental and living conditions. In order of priority, the Healthy Living Practices (Nganampa Health Council 1987) are:

1. Washing people
2. Washing clothes and bedding
3. Removing waste safely
4. Improving nutrition: the ability to store, prepare and cook food
5. Reducing crowding
6. Reducing negative contact between people and animals, insects and vermin
7. Reducing dust
8. Controlling the temperature of the living environment
9. Reducing trauma

Number eight of the healthy living practices, controlling the temperature of the living environment, highlights the importance of maintaining comfortable internal temperatures as a method of providing healthy living conditions.

3.2.3 Basic Specification – Aboriginal Housing

The *Basic Specification – Aboriginal Housing* document specifically relates to the Anangu Pitjantjatjara people of South Australia. It is intended to specify basic workmanship standards and material selections for the construction of various types of dwellings. It was developed to provide an appropriate building solution for the social and environmental needs of Aboriginal residents.

The sections relevant to increasing energy efficiency are:

- Section 2.2b (Protection of trees): indicates that trees that are to remain on site need to be marked on plans and their preservation is the responsibility of the builder. External shading of buildings using vegetation is an important passive solar design feature, especially in hot arid regions of Australia.

- Section 4.15a (Cavity ventilation) & 4.15b (Room vents): requires insulation only where it is specifically indicated, as defined in the BCA.
- Section 10.1 (Insulation): specifically requires R3 insulation in the ceiling and a minimum of R2 in the walls unless an alternative thermal barrier is used. It is essential to install insulation properly to eliminate gaps or voids and increase its effectiveness.

3.2.4 Specification FD0009 1998/99 Information Book

This document is a Design and Supply Proposal (Tender call) for a minimum of 10 houses and a maximum of 30 houses for the Aboriginal Communities and Homelands of Anangu Pitjantjatjara. It details minimum acceptable design requirements such as ceilings requiring R3 insulation and walls needing R2 insulation if an alternative thermal barrier is not used. The requirements are specific to the needs of this particular group of Aboriginal people in South Australia.

3.2.5 Aboriginal Housing and Infrastructure Unit – Design Brief

This document provides instructions and conditions of contract for architectural services as well as submission requirements for architectural drawings of Aboriginal housing building projects commissioned by the Aboriginal Housing and Infrastructure Unit. It recognises the importance of accommodating the specific cultural and social issues of Aboriginal people.

Sections of the design brief that are relevant to energy efficient house design:

- Section 2.03 (Siting of houses): indicates that houses should be sited to gain the best advantages from prevailing winds, solar considerations, protection from the elements, and should heed the necessity for privacy and cultural requirements.
- Section 3.01 (Physical design): specifies that the house design should be done with strict community consultation, but it is recommended that it be not too far removed from standard Ministry of Housing designs. A design should reflect Aboriginal people's penchant for outdoor living.
- Section 4.12 (Ceiling insulation): stipulates the use of minimum R2.5 insulation batts in the ceiling.
- Section 4.15 (Roof insulation): demands the use of double-sided aluminium foil (if used in conjunction with ceiling batts), and Anticon placed directly under roof sheets when ceiling insulation is not specified.

3.3 Energy efficiency stringency

Energy conservation has become an issue of global significance, reflected through the growing status of Environmentally Sustainable Design (ESD) in the Australian housing industry. The objective of ESD is to achieve an efficient balance between social, environmental and economic forces (ARUP 2005). The impact of operating residential buildings has been recognised as a major environmental factor due to considerable fossil fuel use for electricity generation. Energy efficiency amendments are being proposed for the BCA to reduce domestic energy demand. Their focus is to eliminate worst practice as a first step towards better housing design (Department of Local Planning and Government 2003). The amendments aim to bring all new houses to a level of 5 stars based on NatHERS (Kennedy 2004) that essentially represents buildings of very good energy efficiency. Some states such as Victoria have already implemented these changes.

There are questions about the validity of the proposed increases in the stringency of the BCA requirements to certain elements of the community. The uncertainty is due to the relatively short lifecycles of remote housing, as the embodied energy being incorporated in building materials to improve the energy efficiency may outweigh the gains made through climate control energy reduction. An analysis of these variables for two IHANT standardised designs has been conducted by Duell et al. (2005) and is also available in Appendix F – Embodied Energy Analysis.

In summary of the paper by Duell et al. (2005), in order to determine their relative merits in desert climates, two CRM standardised house designs used by IHANT were analysed through life cycles, embodied energy, the efficiency of energy saving measures and the resulting active energy consumption. The standardised houses, like others in the NT, are designed for retrofitting within 10 years, reducing the time available for savings in operational energy to exceed energy invested in installing these measures. In addition, the spatial distances between population settlements in the NT greatly increase embodied energy values. As seen in Table 4 the embodied energy payback period well exceeds 10 years for both of the designs and both variations analysed.

Table 4: Analysis of two IHANT standardised designs incorporating cost, embodied energy and lifespan.

Design one	**With additional insulation**	**With full verandas**
Embodied energy increase (GJ)	120.65	330
Cost (AUS$) (Rawlinsons 2005)	5341. 00	14604.00
Energy savings of decreased air conditioner use (GJ)	6	6
Embodied energy payback period	20.1 years	55 years
NatHERS star rating	5	5
NatHERS cooling energy (GJ)	22	19.62
NatHERS energy savings (GJ) compared to original	1.90	4.28
NatHERS payback period	64 years	77 years
Design two		
Embodied energy increase (GJ)	123.58	366.40
Cost (AUS$) (Rawlinsons 2005)	5460. 00	18276.00
Energy savings of decreased air conditioner use (GJ)	6	6
Embodied energy payback period	21 years	61 years
NatHERS star rating	5	5
NatHERS cooling energy (GJ)	23.67	21.76
NatHERS energy savings (GJ) compared to original	0.62	2.53
NatHERS payback period	199 years	145 years

It was found that adopting the proposed measures would increase the embodied energy within the houses without markedly reducing the energy requirements of evaporative air conditioners that are the primary source of active climate control. The short lifespan of these houses did not permit sufficient time to pay back the energy investment through operational energy savings. Therefore, for these desert housing designs, implementation of the BCA's proposed energy efficiency measures was found to be out of balance.

The cost of electricity generation in these remote communities was not factored into the operational energy costs within the analysis. Remote communities in the NT typically rely on diesel generators that can cost from $0.20c to $2.00 per kWh when compared with $0.08 to $0.16 per kWh in larger towns supplied by the national electricity grid (Lloyd et al 2000). These figures will impact on the fiscal context of ESD. The social context of ESD was also only considered in a limited fashion. Broader cultural considerations, occupancy patterns and user consciousness need to be addressed to ensure the ongoing successful implementation of design changes, maximising energy savings while also building in community development such as local community members being involved with retrofitting or construction.

4. Modelling methodologies

There are three main forms of modelling tool available for analysis of residential housing: numerical simulation, theoretical calculation and experimental modelling.

Numerical simulation is a popular form of modelling due to the ease of rapid evaluation of housing design. The numerical simulations are generally based on theoretical calculations derived from empirical data. Numerical and theoretical modelling are cost-effective methods of analysing houses before construction. There is also a multitude of houses available in the community for experimental modelling to provide 'real' data.

A combination of numerical simulation and full-scale experimental modelling techniques have been employed to analyse the effect of changes and to test the comfort parameters. A CRM standardised design has been numerically simulated subject to a number of variations in design, and a Wongatha Wonganarra Aboriginal Corporation (WWAC) house has been data logged representing a full scale model.

4.1 Energy rating schemes

A software calculation engine to analyse residential housing was developed by the Australian Federal Government and Commonwealth Scientific and Industry Research Organisation (CSIRO) in the 1990s. The software calculates hourly temperatures and heating and cooling loads, based on the building design and regional weather data. The simulation engine is called Cheetah and is the basis for a range of state and territory ERSs but was primarily developed for use with NatHERS (Housing Industry Association 2003). From this base there have been variations incorporated that suit individual regions' requirements. For example, the Building Sustainability Index (BASIX) incorporates local planning requirements for the NSW region while the National Australian Built Environment Rating Scheme (NABERS) not only measures thermal performance but refrigerant use, occupant satisfaction, waste, etc.

The NatHERS software is now considered limited due to a number of modelling simplifications and graphical user interface constraints that restrict the applicability of NatHERS to the wide range of climate zones in Australia (Australian Government Productivity Commission 2004). Through funding from Commonwealth, State and Territory governments CSIRO has developed a new version of NatHERS called AccuRATE. There are a number of improvements to the software but the primary improvements have been made to comfort and ventilation models (Delsante 2003). As of July 2005 there was a national pilot program designed to both test and implement the software into the national built environment industry. The range of acceptable ERSs available within Australia is detailed in Table 5.

Table 5: Energy rating schemes available in Australia

State or Territory	Energy Rating Scheme
New South Wales	BASIX
Queensland	BERS
Australian Capital Territory	NABERS
Victoria	First Rate
National	NatHERS, AccuRATE

4.1.1 Nationwide Energy Rating Scheme

The Nationwide House Energy Rating Scheme was developed collectively by Australian Governments in the early 1990s to help create an understanding of the relative expected performance of dwellings to maintain thermal human comfort in Australia, with the goal of encouraging better home design practice and reduced energy consumption.

Berry 2005:1

NatHERS is designed to provide a relative rating of performance rather than the actual consumption of energy as performance would vary from household to household. NatHERS provides a rating which indicates how well a house performs in its climate zone based on a typical household for each of the 28 climate zones in the different regions of Australia. The star rating scheme varies from 0 stars to 5 stars, with 5 stars representing an exceptional house. The star ratings are based on theoretical energy consumption values that vary depending on the location and design characteristics of the house including size, composition and orientation.

The theoretical energy consumption is based on the heat transfer through the skin of the house that directly influences the internal temperatures. When the internal temperatures are outside the acceptable range it is assumed that the household will engage active climate control, either heating, cooling or human activity to bring the internal temperature to within range during the typical use hours: day time for living/kitchen areas and night time for bedroom regions. Human activity includes opening doors to allow for cross-ventilation and opening and closing blinds. The energy requirements are broken into heating, cooling (sensible) and cooling (latent). Heating is any warming of the air, and cooling (sensible) and cooling (latent) together represent a general cooling of the air. The different zones of the house – living/kitchen, bedroom and non-conditioned zones – have different human comfort parameters assigned to each.

ERSs do not produce actual energy consumption data as this would depend on a range of factors including the number of residents, comfort and expectation levels, when and how the house is occupied, appliances and what form of active climate control is used. Rather, ERSs rely on a ‘typical’ household that assumes a set of rules that reflect normal operation, such as cooking in the kitchen area at prescribed times, opening doors for cross ventilation when hot and pulling blinds down in the evening.

The human factors depend on pre-determined comfort levels. For example, in Alice Springs (representing climate zone 6 – typically hot arid regions) it has been defined in the NatHERS program that heating will be used in living/kitchen zones when the temperature drops below 20.0ºC, in bedroom zones when it is below 18.0ºC, and cooling when it rises above 26.5ºC in all conditioned zones (CSIRO 2005). It is possible to alter the comfort levels for each of the zones to determine the potential energy consumption. However, this will negate the star rating as the household characteristics have been varied.

4.1.1.1 Base design analysis

A CRM standardised design 'CRRC3K' (Central Remote Regional Council, design 3K) has been used to test the variation in thermal performance with design. Changes to the orientation, insulation, external wall composition, window framing and veranda depth and the resultant effect on thermal performance have been examined in detail.

There is a generally accepted approach to improving housing design for hot arid regions. The simplest and cheapest option for improvement is house colouring. A lighter colour reflects radiation, particularly solar radiation. The next option before altering the composition of the house is orientation. Through reorientation significant gains can be made without the need to change the design. However this has the potential to impact on the civil works necessary to service the house and also on aesthetics. The next stage of housing improvements incorporates changes to the composition of the house, wall construction, glazing and in particular reference to the CRRC3K design, veranda depth.

The CRRC3K design is a compact, concrete block 3-bedroom house with deep verandas on the north and south sides of the building. The floor plan is indicated in Figure 3.

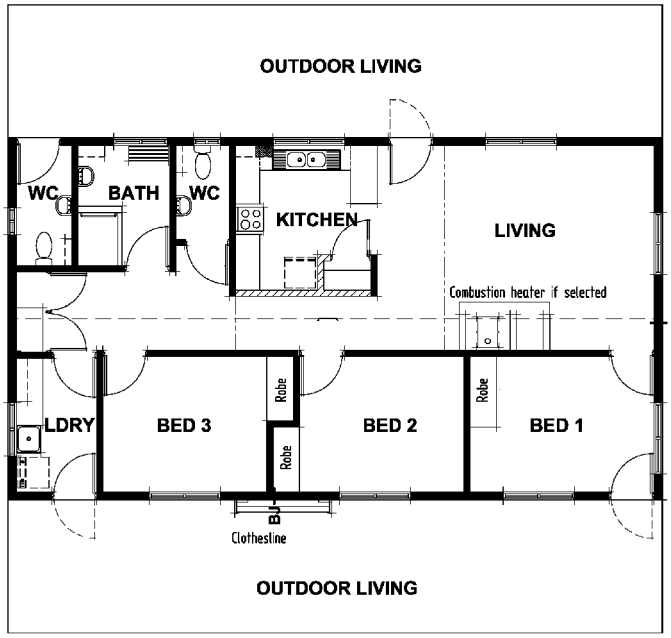

Figure 3: CRRC3K design

Note: compact concrete block work structure with north and south facing verandas. The top of the page represents north.

Source: Graszk 2004

The base design has been simulated using NatHERS and rated at 3 stars in climate zone 6. For typical household activity the breakdown in energy consumption is shown in Table 6.

Table 6: Rated energy requirements for CRRC3K as per base design

Heating	Cooling (Sensible)	Cooling (Latent)	Total Energy	
194.3	89.5	4.7	288.6	MJ/m².annum
54.0	24.9	1.3	80.2	kWh/m².annum

The breakdown of energy requirements indicates that while this house has been simulated in the hot arid region of Australia where cooling is typically seen to be the primary issue, heating is in fact the greatest issue. Heating requires twice as much energy as cooling does indicating that the house performs relatively well during the summer but then relatively poorly during the winter.

4.1.1.2 Orientation variation

The CRRC3K design satisfies normal architectural principles for the climate zone by orientating the living room to the north and providing deep complete shading to the northern side and window, and eave shading on the west and east sides. The southern shading does not protect the skin of the structure and so does not benefit the thermal performance. It does however provide additional outside living space.

To study the effect of orientation, the orientation of the design was varied by 10º increments clockwise from the base design. The variations are described in terms of base rated energy requirements (Figure 4) and percentage of improvements on the designs (Figure 5).

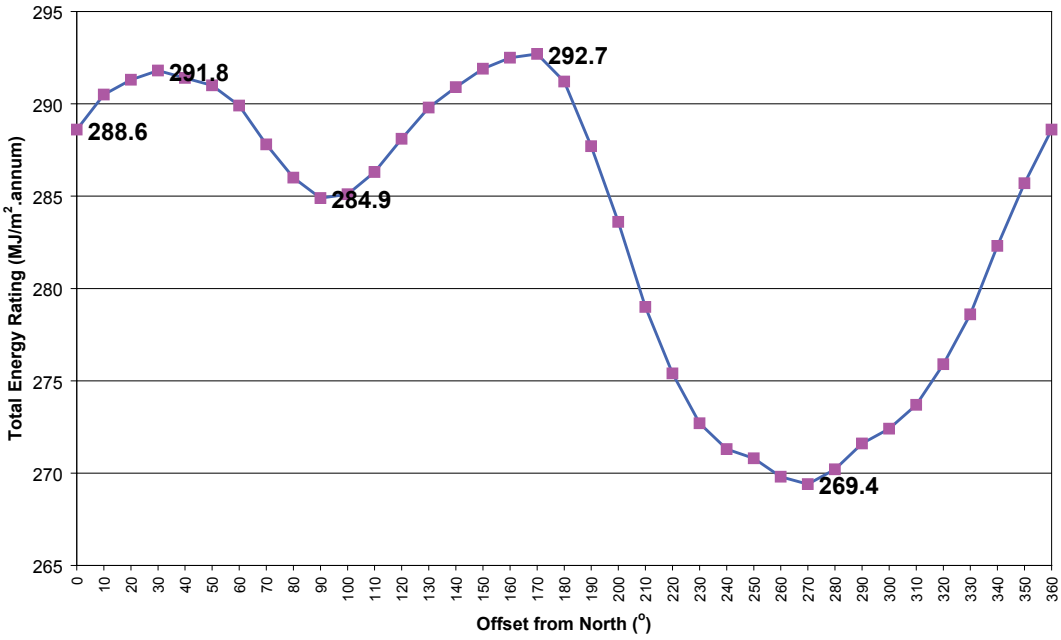

Figure 4: Variation of the CRRC3K design energy rating requirements through orientation

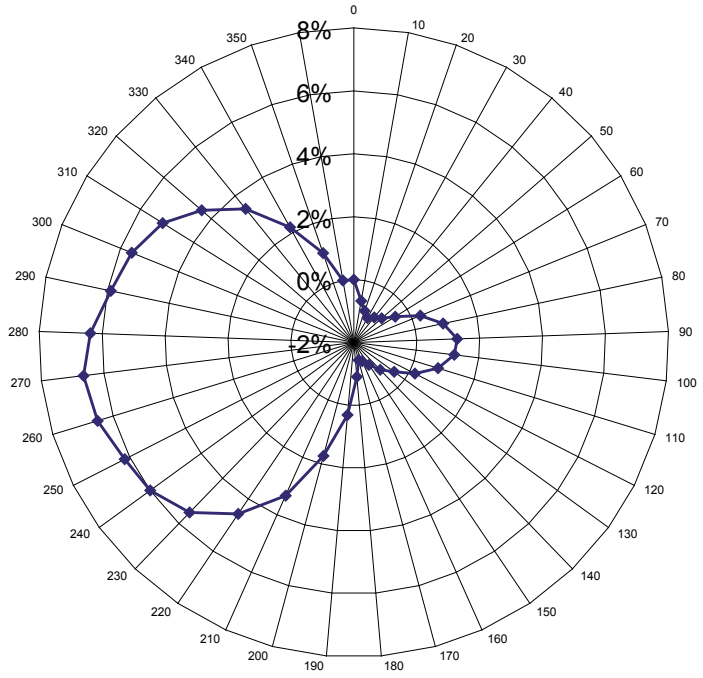

Figure 5: Orientation variation of the CRRC3K design in percentage of improvement from the base design

It is evident from the graphs that there is a large variation in energy rating requirements due to the orientation of the house design. The highest energy rating requirement occurs at 180º offset, that is, a 4.1MJ/m^2.annum increase on the base design. The most significant reduction in energy use occurs at an orientation of 270º where a 19.2MJ/m^2.annum improvement from the base design is achieved, representing a 6.7% improvement. The values of the minimum energy rating requirements due to orientation variation are specified in Table 7.

Table 7: Energy rating requirements when base design is orientated 270º offset from north

Heating	Cooling (Sensible)	Cooling (Latent)	Total Energy	
180.1	84.7	4.6	269.4	MJ/m^2.annum
50.0	23.5	1.3	74.8	kWh/m^2.annum

Note: this orientation represents a 6.7% improvement

The marked difference between the energy requirements of the 0º orientation and the 270º orientation cannot be attributed to just one feature of the house design. This is due to the complex interaction of the external and internal environments and the skin of the house. However, the fact that both the verandas are now functioning to protect the skin of the house is a positive factor to the energy rating requirements of the house.

4.1.1.3 Insulation variation

Insulation adds a layer of protection between the external and internal environments. Insulation can be applied to all regions of the external skin: roof, ceiling, external walls and floor. The CRRC3K design comes standard with R2.5 ceiling insulation and sisalation as the concrete slab floor and concrete block walls would be difficult to

insulate. This section analyses the variations in the rated energy requirements as the insulation properties of the CRRC3K design are varied. This is a comparison exercise, knowing that some options may be economically or geographically unfeasible.

Figure 6 indicates that the current insulation level provides a significant improvement on the performance of the house when compared with having no insulation in the ceiling. Increasing the level of insulation in the ceiling however, does not dramatically improve the performance of the design. The application of wall insulation generally is not as beneficial as ceiling insulation. The combination of both wall and roof insulation however, can provide dramatic improvement to the performance of the house.

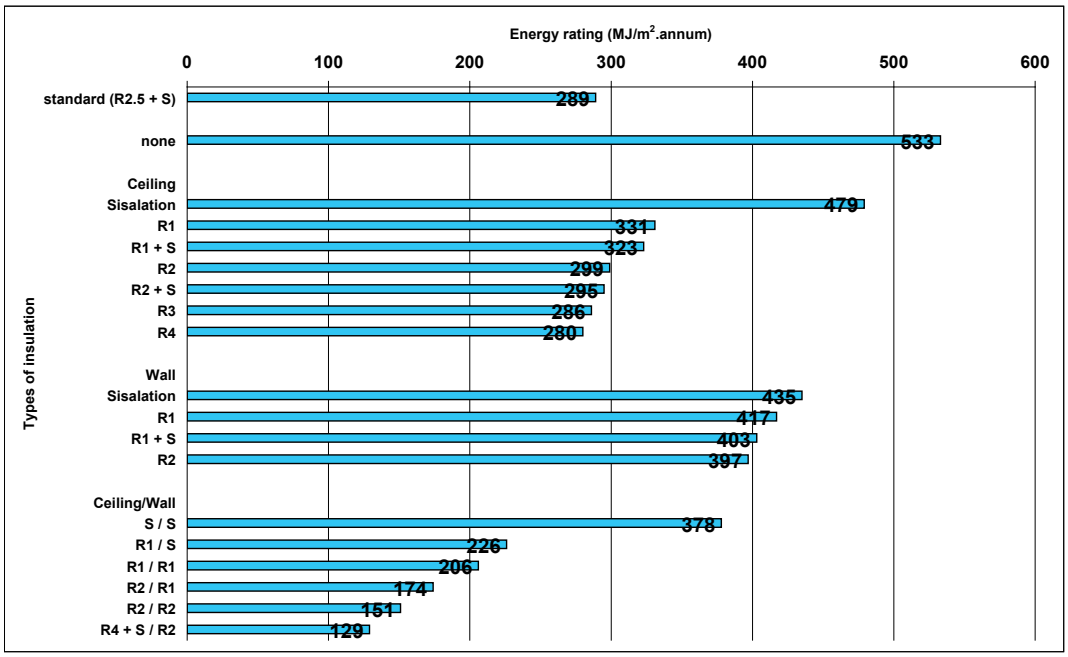

Figure 6: Variation of the energy rating requirements due to insulation in the CRRC3K design

The optimal scenario is the straight forward case of providing as much insulation as possible to the skin of the house as demonstrated in Table 8. Wall insulation in particular however, would be difficult to maintain and install without additional house infrastructure, such as studs and plasterboard. Also, the additional cost of the installation may not be as beneficial as the savings gained from the improved thermal performance.

Table 8: Energy rating requirements of the largest improvement to the CRRC3K design based on insulation variations.

Heating	Cooling (Sensible)	Cooling (Latent)	Total energy	
79.5	45.8	3.7	128.9	MJ/m².annum
22.1	12.7	1.0	35.8	kWh/m².annum

The maximum improvement is gained from R4 and sisalation in the roof space, and R2 in the walls – reflecting the notion that more insulation is better in hot arid regions.

The cost improvements for this scenario have been derived using Rawlinsons Australian Construction Handbook (Rawlinsons 2005) based on prices for Adelaide, the closest major city to Alice Springs. Given that it costs $0.039/MJ it would be possible to save $505 per year through the energy savings based on the reduced rated energy requirements. In comparison to the cost of the insulation of $1174, a potential saving of $3874 after 10 years could be gained. However, this does not account for the additional infrastructure required or the general robustness of the house.

4.1.1.4 External wall composition variation

The external walls are composed of concrete block work that is core filled approximately every third core. There are other options for the external walls such as Aerated Autoclave Concrete (AAC) block work which acts as an insulating layer as well as a structural support, and mud bricks and rammed earths that have implications for community involvement and development.

Each wall type variation was simulated in the base design configuration and is compared in Figure 7. It is evident that there are many options that can improve the thermal performance of the house with AAC block work providing significant improvement of up to 49% from the base design.

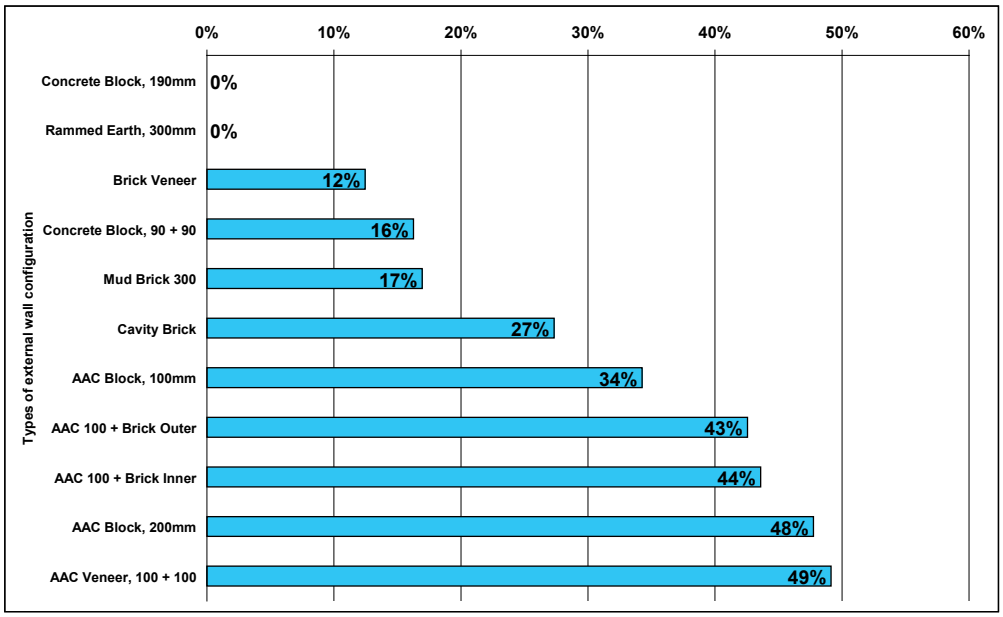

Figure 7: Percentage of improvement of external wall composition variations based on the CRRC3K base design

The reduced energy requirements of 200mm AAC block work are illustrated in Table 9. It should be noted that while the energy requirements are significantly reduced from the base design using the AAC block work, it only brings the zone dependant star rating up to 4.5 stars.

Table 9: Rated energy requirements for 200mm AAC block with a 10mm plasterboard layer on the inside of the house skin

Heating	Cooling (Sensible)	Cooling (Latent)	Total energy	
97.1	50.0	3.7	150.8	MJ/m^2.annum
27.0	13.9	1.0	41.9	kWh/m^2.annum

While there are opportunities to dramatically improve the thermal performance of the CRRC3K design there are other issues surrounding use of different types of external walls. AAC block work is not as robust as concrete block which leads to transportation issues as well as durability in the lifetime of the housing stock. Rammed earth requires heavy machinery to produce the units. Mud bricks also have durability issues but could be viewed as community development tools.

4.1.1.5 Window variations

There are two aspects of windows investigated in this section: framing and window coverings. While windows provide a direct link for solar radiation between the external and internal environments the framing also provides a link that can be highly conductive to heat transfer depending on the materials used. The window covering also is a significant component as it affects how the residents interact with the house in the modelling software.

The current standard of framing for the CRRC3K design is aluminium framing due to cost, availability and weight. However, there are a number of other framing options available: steel, aluminium with a thermal break, timber and PVC. The results of the analysis of variations from the aluminium framing base design are demonstrated in Table 10.

Table 10: Energy rating requirements of various framing types for the CRRC3K design

Types of frame	Energy rating (MJ/m^2.annum)	Improvement (MJ/m^2.annum)	Percentage of improvement
Aluminium	289	0	0%
Steel	289	0	0%
Aluminium with thermal break	279	10	3%
Timber	268	21	7%
PVC	268	21	7%

It is evident that the window framing plays a significant role in the transfer of heat. The percentage of improvement from using timber framing rather than the current aluminium framing is similar to that obtained by reorientating the house.

Incoming solar radiation provides a source of heat energy to the internal environment of the house. There are a number of components of solar radiation, including direct and scattered. Direct solar radiation is light that forms a straight line from the sun to the internal environment of the house. Typically eaves and verandas are specifically designed to stop this type of radiation. Scattered radiation is radiation reflected off

elements in the external environment, such as from the ground. Window coverings are designed to reduce the effect of this form of radiation. An analysis of the effects of window coverings is depicted in Figure 8.

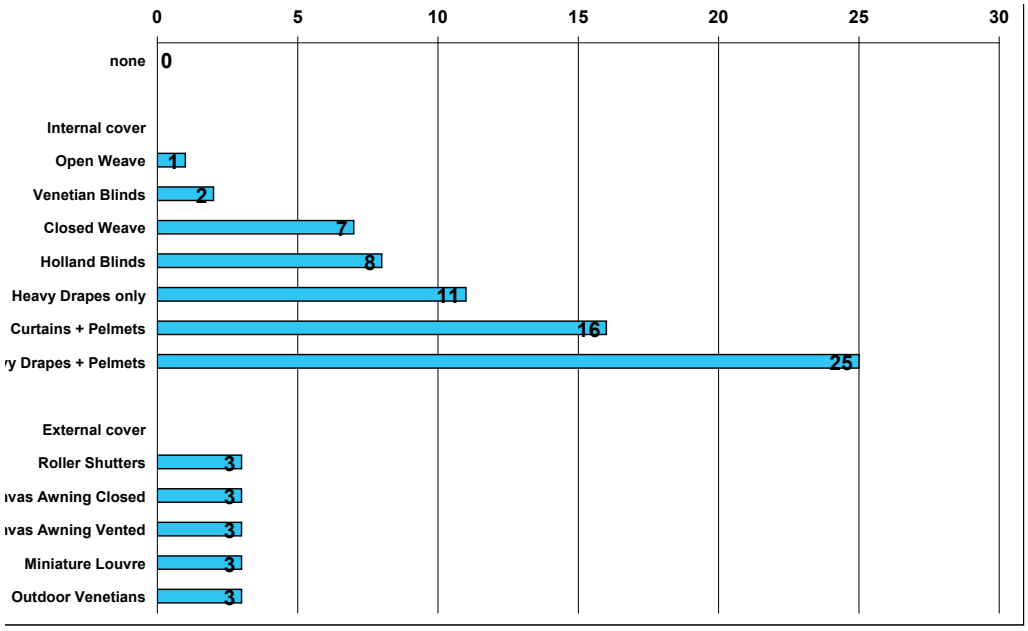

Figure 8: The effects of window coverings on the thermal performance of the CRRC3K design
Note: The effects of window coverings are quite significant, with heavy drapes and pelmets providing up to 25% improvement.

NatHERS accounts for internal covers through the simulation of the typical household, internal and external covers being used during appropriate times of the day to cool and heat the house in line with the comfort parameters. The simulations indicate that external covers provide only marginal improvements to the thermal performance of the house in comparison to internal covers. Heavy drapes provide the most protection reducing the rated energy requirements of the CRRC3K design by 25MJ/m^2.annum.

4.1.1.6 Veranda and eave variation

The CRRC3K design has particularly deep verandas on the north and south sides, being 4m deep. This protects the internal environment from the summer heat by shading not only the windows but also the walls. There is also an eave overhang from the gable roof that is relatively small, 0.6m deep, on the east and west faces of the house with 1m eaves over each of the windows.

Verandas protect against excessive heat gain through direct solar radiation that is particularly relevant in the summer period of hot arid regions. However they can be equally disadvantageous during the winter period when heat gain is required. The effects of veranda depth and eaves on the CRRC3K design are explored in Table 11.

Table 11: Veranda and eave variations impacts on rated energy requirements for the CRRC3K design

Veranda (north and south) and eave variations (east and west)	Rated energy requirements (MJ/m².annum)
4m verandas and 1m window eaves	289
3m verandas and 1m window eaves	286
2m verandas and 1m window eaves	280
1m verandas and 1m window eaves	264
Only eaves around the house	255

It is observed that the rated energy requirements are successively reduced as the veranda depth is shortened, representing an improvement in thermal performance. It turns out that the veranda design is performing well during the summer period but poorly during the winter, blocking out solar radiation and subsequent passive heating. Verandas do however provide necessary outdoor living space that goes beyond the issue of thermal performance alone.

4.1.1.7 Optimised variation

Based on the study of different orientations, external wall compositions and glazing variations an optimised design variation can be achieved. A clockwise rotation of 270º from the north, 200mm AAC block work with 10mm of plasterboard and a change to clear double-glazed windows produces a dramatically improved rated energy requirement from the base rating. The base design rates at 3 stars or 288.6MJ/m².annum and is improved to 5 stars or 100.7MJ/m².annum in the optimised variation. The details of the improvements are stated in Table 12.

Table 12: Energy rating requirements for the optimised variations of orientation, external wall composition and glazing

Heating	Cooling (Sensible)	Cooling (Latent)	Total Energy	
65	32.8	3	100.7	MJ/m².annum
18	9.1	0.8	28	kWh/m².annum

4.1.2 AccuRate

NatHERS has been revised by CSIRO through funding from Commonwealth, State and Territory governments to produce AccuRate. AccuRate has many improved features but the ventilation and comfort modelling are particularly important to hot arid regions of Australia.

As in the old version, AccuRate tries to avoid artificial cooling by using natural ventilation. However, whereas in the old version ventilation was simply used to reduce the indoor air temperature (whenever the indoor air was warmer than the outdoor air), in AccuRate the effect of ventilation-induced moving air on the sensation of thermal comfort is also taken into account.

Delsante 2003:5

The CRRC3K design has been re-evaluated using AccuRate to determine the effects of the improved modelling capabilities. The results of the base analysis are presented in Table 13.

Table 13: Rated energy requirements from the re-evaluation using AccuRate

Heating	Cooling (Sensible)	Cooling (Latent)	Total energy	
155.2	54.0	4.4	213.6	MJ/m^2.annum
43.1	15.0	1.2	59.3	kWh/m^2.annum

There has been a 26% improvement in the total energy requirements from the improvements of the modelling software. This value is not linear across the energy requirements. There has been a 20% improvement to the heating requirements of the design but a 40% improvement to the sensible cooling requirements through the improved ventilation modelling aiding convective cooling. The AccuRate modelling indicates even more strongly that winter heating is a greater energy consumer than summer cooling.

4.2 Full-scale modelling

Experimental modelling can include both scale modelling and full-scale modelling of houses. Given the multitude of houses it is feasible to pursue the concept of full-scale modelling. Full-scale modelling provides accurate 'real life' data.

Through project partners Murdoch University and links with WWAC, a resident's house was data logged between April and July 2005 in Laverton Western Australia (James 2005). The house was a novel design that incorporated a range of sustainable design concepts, including thermal performance, community development aspects and sustainable materials through the use of rammed earth (Anda 2005). The style of house is pictured in Figure 9.

Figure 9: Novel house design in Laverton, Western Australia, April 2005

The house was data logged from the 20th of April 2005 to the 14th of July 2005 at hourly intervals. Data loggers were placed in bedrooms, living areas and outside. Ambient temperatures are represented by Outside South and Outside Table data series. These loggers were placed in shaded areas that were still exposed to the natural environment. The living areas consisted of a living area and

kitchen and were quite large. Data loggers were placed in three locations in this zone, represented by Living East, Living North and Living West data series. Data loggers were also located in bedrooms on opposite sides of the house represented by South Bedroom and West Bedroom data series.

During the entire recording period the maximum external temperature recorded was 36.5ºC and the minimum was 1ºC. The maximum living room internal temperature recorded was 35.5ºC while the minimum was 10ºC. The maximum bedroom temperature 35.5ºC while the minimum was 4.5ºC. A detailed examination of the April period (warmer) is presented in Figure 10 while the July period (cooler) is presented in Figure 11.

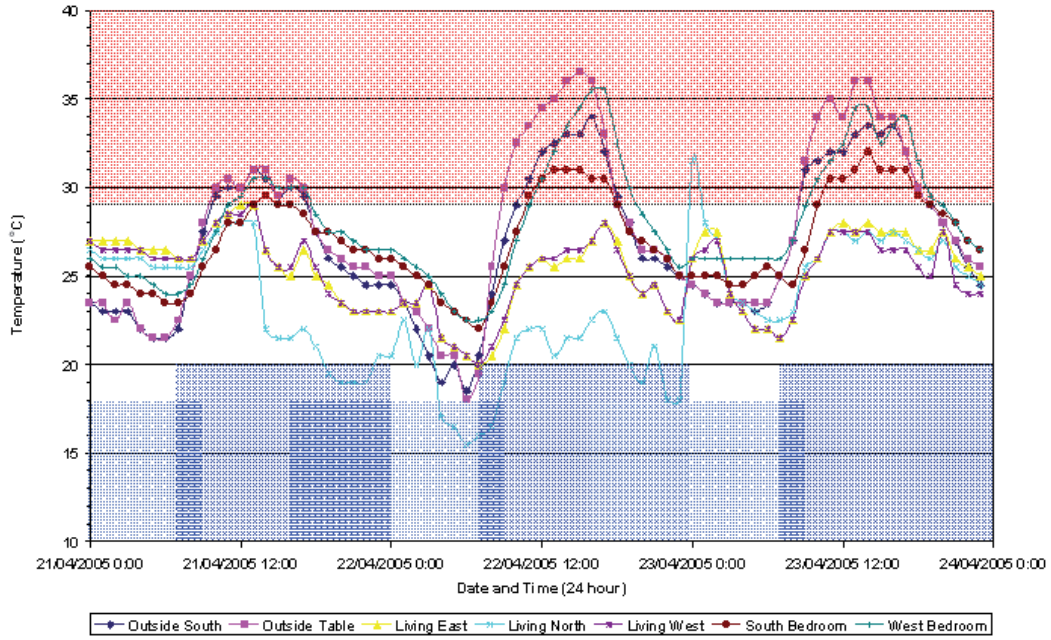

Figure 10: Graph of temperatures from the novel house design in Laverton, WA during the period 21st of April to the 24th of April

Note: The shaded areas of the graph represent comfort conditions programmed into NatHERS. The red area represents maximum comfort levels. The light blue areas represent minimum comfort levels for bedrooms and dark blue areas represent minimum comfort levels for living areas.

It can be seen that during the April analysis there are periods where the ambient temperature exceeded 35ºC. The indoor temperature also exceeded 35ºC; however, this was the western bedroom that is typically not used during the day time. The living area temperatures over the 3-day period typically remained well below the ambient temperatures and within the NatHERS comfort levels. During the data logged period of April the ambient temperature reached 36.5ºC while the maximum indoor temperatures reached were 31.5ºC in the living area and 35.5ºC in the bedrooms.

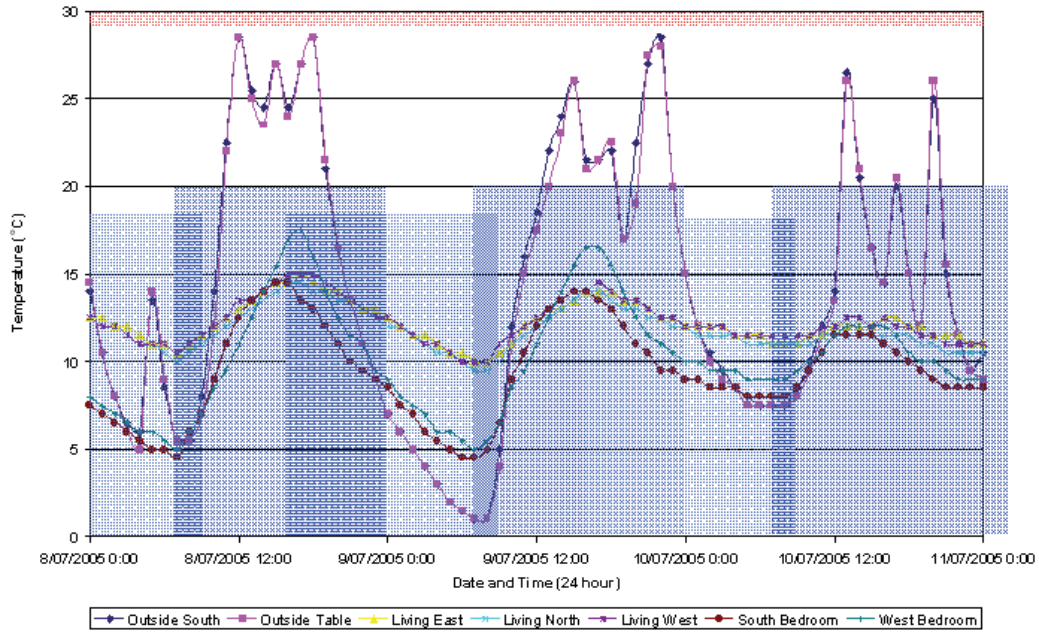

Figure 11: Graph of temperatures from the novel house design in Laverton WA, during the period 8th of July to the 10th of July

Note: The shaded areas of the graph represent comfort conditions programmed into NatHERS. The red area represents maximum comfort levels. The light blue areas represent minimum comfort levels for bedrooms and dark blue areas represent minimum comfort levels for living areas.

The July analysis reveals that the indoor temperatures remained much more stable than the fluctuating external temperatures. The indoor temperatures did not rise above 17.5ºC or drop below 4ºC. From the NatHERS comfort regions it can be observed that there were no periods where the internal temperatures exceeded the maximum comfort levels. However, the entire period exceeded the minimum comfort levels indicating that the house was insulating the internal environment too much from the external environment.

It can also be seen that the living room retains the heat energy much better than the bedrooms, reflecting the design of heavy weight living area and light weight bedrooms. The bedrooms have been constructed to be light weight and elevated to ensure adequate cooling while the living room is designed around the thermal mass of the concrete slab and rammed earth walls. The high thermal mass ensures that the extremes of the day are damped out, leading to a much higher minimum temperature than in the bedrooms, although it is still below the minimum NatHERS comfort level.

The limited data logging analysis correlates well with the NatHERS analysis. The CRRC3K design and the Laverton house design are performing well during the summer period but have been designed to insulate the house too much during the winter and as such require a heating load which is greater than the cooling load.

4.3 Computational fluid dynamics

Computational Fluid Dynamics (CFD) is a method of accurately determining the heat and mass transfer within complex systems. This is particularly relevant to house design as the heat transfer from the external to the internal environment through the house skin is a multifaceted problem. NatHERS and AccuRate are based on theoretical and empirical formulations that produce approximations to the system. CFD analyses the system from first principles to determine the fundamental properties of the heat transfer through the walls and the resulting fluid flow.

CFD is able to model the following systems and more:

- Solar radiation patterns (see Figure 12)
- Ventilation characteristics
- Heat transfer through walls (see Figure 13)
- Heat storage in thermal mass
- Conduction to the ground (see Figure 14).

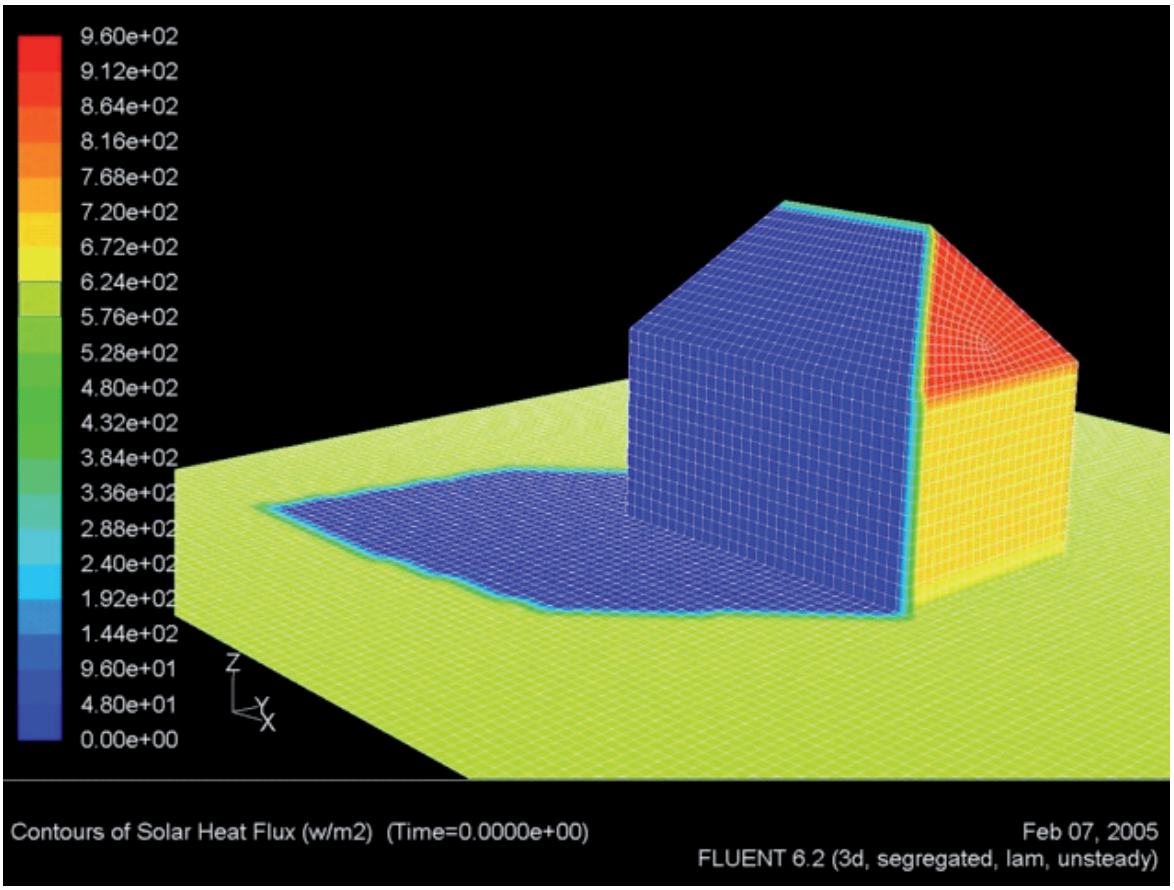

Figure 12: Snapshot of a simulation of solar flux over a house during a hot day in summer
Note: The blue areas effectively represent shading as there is zero heat flux.

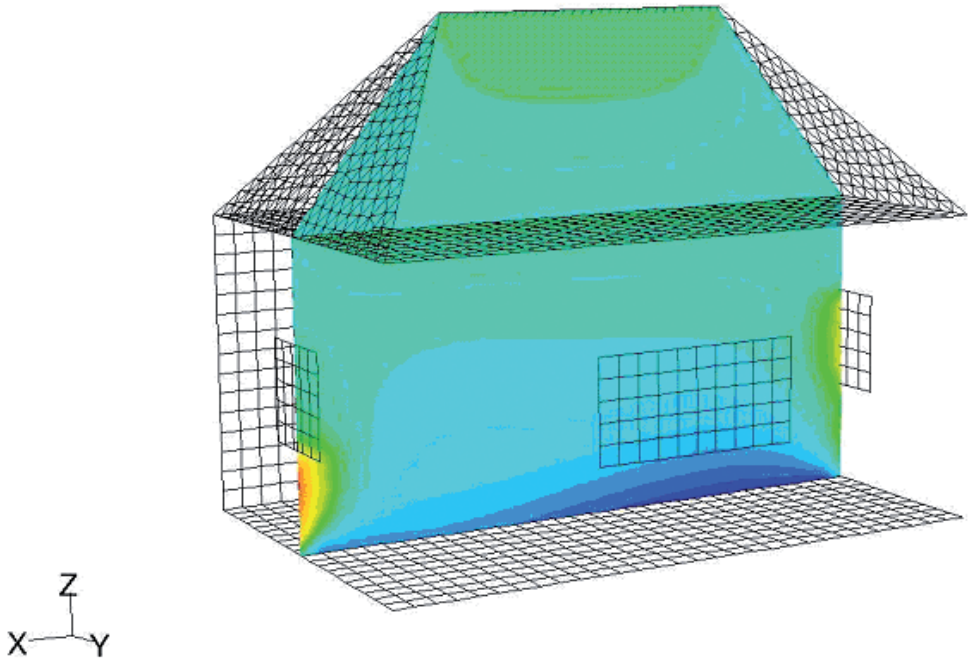

Figure 13: Temperature distribution throughout the structure

Note: Temperature variations are illustrated by hot areas in red shades and cooler areas in blue. It is evident that the concrete slab provides a heat sink. Solar radiation is observed to enter through the right hand window and shine on the left hand wall, generating heat. The differential heating pattern is also causing convection demonstrated by the unsymmetrical temperature contours.

The figures shown above are by no means an exhaustive representation of the capabilities of CFD analysis. The modelling capabilities make it possible to: determine the precise temperatures at any point within the house structure; study the effects of natural shading including thermo transpiration from vegetation; and analyse storage capabilities of thermal mass and ventilation patterns through the house. CFD is also particularly suited to determining how the novel passive cooling techniques illustrated earlier in the report (Section 2.2.1: Passive Cooling Techniques) interact with the house design.

There has been limited application of CFD in this thermal performance project. However, future work has been planned to investigate the passive cooling technique of night purging. Appendix B – CFD Research Proposal, details a transcript of the project proposal to Integrated Systems Analysis (ISA) technologies, who have confirmed a $25,000 in kind contribution to the project through super computer time (Martini 2005).

5. Cultural sensitivities

> *To competently design appropriate residential accommodation for Aboriginal people who have traditionally orientated lifestyles, architects must understand the nature of those lifestyles.*
>
> Memmott & Go-Sam 2003

Cultural considerations must be included in Aboriginal housing design, to ensure basic needs are catered for and housing designs satisfy their main objective of providing a suitable, healthy environment in which to live. However, behavioural and social sensitivity also have a significant impact on the way that a house should be designed. This section incorporates all three levels of sensitivity into the analysis.

5.1 Aboriginal housing

It is stated by Hughes (2005:1) that traditional Aboriginal housing was primarily used for the protection of residents from the weather, namely wind and rain. In response to a push for better Aboriginal housing, the Commonwealth, State and Territory Housing Ministers in 2001 developed the policy *Building a Better Future: Aboriginal Housing to 2010*. One of the principal outcomes of this policy was the development of better housing: 'Housing that meets agreed standards, is appropriate to the needs of Aboriginal and Torres Strait Islander people, and contributes to their health and well being' (Family and Community Services 2001:2). In response to the increasing costs of delivering houses on an individual basis the governing Aboriginal bodies in the NT developed standardised housing (Jardine-Orr 2004) known as the Central Remote Model (CRM).

> *The CRM was developed by the CRRC, in association with ATSIC and IHANT, in response to the increasing costs associated with the prevailing community-by-community approach to the provision of housing under IHANT's Construction Program and the lack of opportunities for Aboriginal youth in remote communities.*
>
> Jardine-Orr 2004:25

There are three main advantages of the CRM: a single project manager, standardised designs and the training employment program, all designed to improve the delivery of housing to remote communities. The CRM was first developed around the Papunya, Laramba, Urapuntja, Santa Teresa, Ntaria, Pipalyatjara and Willara settlements. The training program centred on a three-year program that would eventually develop building teams in each of the communities. The aim of the standardised designs was the 'development of a range of standard, high quality designs with standard, robust and interchangeable fixtures and fittings to make maintenance easier in future' (Jardine-Orr et al 2004:25). However, the designs are claimed to have lost cultural sensitivity during the design process (Z Hughes, pers. comm., 2004).

Lee and Morris (2005) investigated the best practice model for effective consultation focusing on the built environment, with their research seeking 'to identify where endurable best practice methods for cross-cultural and cross-disciplinary consultation have been employed'. While the BCA does not take into account the cultural sensitivities of the Aboriginal population, the EHSRCNT states that as part of the performance requirements 'designs must address cultural requirements including high and fluctuating occupancy levels' (NTG Environmental Health Task Group 2001:B40). Other requirements stated as necessary are indicated in Table 14.

Table 14: Requirements as stated by the EHSRCNT as necessary to allow for cultural sensitivity

Bedrooms	• Reasonable degree of privacy without necessarily requiring curtains (e.g. opaque or obscured glass).
Location of wet areas	• Discrete entry • Outside access for visitors
Avoidance Relationships	• Good views from the main areas of the house towards visitors' arrival path • Consideration of more than one entry/exit from the main living area
Occupancy levels	• Provision of overflow sleeping areas • Verandas as overflow sleeping areas must have a minimum width of 3m • Provision of adequate food preparation, bathroom, laundry and toilet facilities, sewage disposal capacity and hot water capacity

Source: (NTG Environmental Health Task Group 2001:B40–41)

5.2 Cultural sensitivity design modifications

Memmott (2003) states that the key premise for appropriate residential accommodation for Aboriginal people is to understand the nature of those lifestyles, and in particular the domiciliary context. As an example, Fantin (2003) states that many of the Yolngu householders from north-east Arnhem land were interested in ways of incorporating important cultural aspects into housing design. Key issues identified include avoidance laws and their associated behaviours, and sorcery, which were investigated with relation to visual surveillance, access to houses and yards, landscaping, lighting, ablutions design and security. Fantin found that the Yolngu householders' design considerations were often complex and contradictory in nature but that designers had a responsibility to learn and understand in order to design appropriate environments that satisfied their clients' needs.

Keys (2003) specifically investigates the social and physical properties of a single women's camp in Yuendumu, Central Australia. In particular, the ability to visually survey social and environmental conditions was highly valued by the Warlpiri women. It was found that the houses that had been designed in Yuendumu made it particularly hard to observe outside conditions. The older women's practice of sitting on the ground made it increasingly difficult to see outside. An analysis using AccuRate to determine the thermal performance effects of lowering the window height to the ground for the CRRC3K design was conducted and the results are presented in Table 15.

Table 15: Rated energy requirements from varying the window heights of the CRRC3K design from the base design height down to ground level maintaining eave heights

Minimum window height [m]	Rated energy requirements [MJ/m².annum]
0.6	223.9
0.5	224.1
0.4	224.3
0.3	224.5
0.2	224.5
0.1	224.6
0.0	224.7

It can be seen from the results of the variable window height analysis that there was little impact on the overall performance of the house based on varying the window heights. That was primarily due to the fact that the windows were designed to retain their shading characteristics as they were lowered. On the north and south sides this does not vary much as the depth of the verandas is substantial enough to provide continuous shading. As such the windows could be extended from the ground to the roof without affecting the thermal performance of the house. On the east and west sides the windows are protected by permanent eaves. While the variable height of windows does not make a difference, the visibility out of the windows will be affected for anyone not sitting on the ground. This can be corrected by extending the eaves or other variations.

5.3 Health

There is a direct link between the temperature of the environment and the health impact on individuals, particularly groups that are at risk such as children, the elderly and the sick. The effects of extreme temperatures are generally referred to as heat stress and can include heat stroke, exhaustion and cramps (New South Wales Government 2002). The human body can only function well when its temperature is maintained within a narrow temperature range. When heat gain exceeds heat loss, the body's core temperature rises and heat related disorders may occur. The consequences of heat stress can be severe. It is estimated that 35,000 people lost their lives as a consequence of the European heat wave of 2003. In France alone, 14,802 people died – more than 19 times the death toll from the SARS epidemic worldwide (Canada 2004). In Australia, heat waves kill more people than any other weather-related disaster and are projected to increase in severity and frequency with climate change (Isted 2004). It was found that in the Murdi Paaki region of NSW the primary cause of hospitalisation was dehydration during the summer period (New South Wales Government 2002). Heat stress can also induce irritation, anger and other emotions that can lead to rash actions (Leveritt 2004).

The housing for health program developed in the late 1980s is a methodology that is designed to improve the living conditions for Aboriginal Australians. The program in part consists of two surveys that have been used by FaCS to produce the NIHG as discussed in Section 3.2.2: *National Indigenous Housing Guide*. The data presented in Table 16 is from the NIHG. It demonstrates that there are a significant number of houses in which temperatures exceed 30ºC. This is beyond the comfort levels and is impinging on the health of the occupants. It can also be seen that 25% of houses did not have any form of cooling climate control.

Table 16: Housing for Health survey data showing the number of houses that exceed extreme temperatures that have direct links to health impacts

	Total number of houses surveyed	Number of houses	Percentage of houses
House temperature less than 30°C, when outside temperature was greater than 30°C	311	83	27%
Maximum summer temperature regularly greater than 40°C	787	561	71%
Cooling system (ceiling fans or air conditioning)	787	594	75%
Ducted air conditioning	594	17	3%
Air conditioning not ducted	594	101	17%
Ducted evaporative cooling	594	63	11%
Evaporative cooling not ducted	594	21	4%
Ceiling fans	594	392	66%
No cooling system	787	193	25%

Source: Family and Community Services 2005

Ferguson-Hill (2002) examined the management of heat-related illness in children for the north-west Kimberley region of Western Australia. Simple strategies are suggested in the paper, including increasing public health education, providing shade through tree planting and water resource planning to provide easy access to water.

5.4 Cultural workshop

A workshop was held in Alice Springs on the 25th of September by Zane Hughes, through project partners Batchelor Institute of Indigenous Tertiary Education (BIITE). There were 16 attendees in the workshop. As a component of the workshop a simple questionnaire was used to gain some base information specific to the links between thermal performance and cultural sensitivities.

There were 5 sections in the questionnaire:

Section A	House
Section B	Climate control – summer
Section C	Climate control – winter
Section D	Cultural sensitivity
Section E	General satisfaction

The overall results of the combined responses from the 16 participants are represented in the main body of the report. A copy of the questionnaire and the individual anonymous responses are in Appendix C – Workshop Questionnaire and Results.

5.4.1 House

The house section was designed to obtain some base data on the houses occupied by the workshop participants. Construction materials, coverings and verandas are presented in Table 17. In Table 18 the number of bedrooms is investigated to determine average house size.

Table 17: House building materials of the workshop participants

External Walls		Internal Walls	
Large Concrete blocks	9	Large Concrete blocks	8
Skinny Concrete blocks	5	Skinny Concrete blocks	4
Steel frame	1	Steel frame	2
Concrete sheeting		Concrete sheeting	
Mud bricks		Mud bricks	
Other	1 (Mixed)	Other	1 (Mixed)
Floor		**Roof**	
Concrete Slab	14	Metal Desk	15
Elevated Floor	1	Concrete	
Other	1 (Earth)	Other	1 (Mixed)
Floor Covering		**Verandas**	
Carpet		Front and back	10
Tiles	10	All the way around	4
Bare Concrete	5	None	2
Other	1 (None)	Other	

Table 18: House size of the workshop participants

1 Bedrooms	1
2 Bedrooms	5
3 Bedrooms	7
4 Bedrooms	3
More	

From the data it is evident that the CRRC3K IHANT design that was investigated earlier in Section 4. Modelling methodologies could be representative of the designs occupied by the workshop participants.

5.4.2 Climate control – summer

The summer climate control section was designed to gain some basic understanding of the active climate control patterns of the residents. Table 19 details the different methods of climate control in the homes while Table 20 indicates the participants' satisfaction with the house's thermal performance. Table 21 details the climate controlled zones while Table 22 states the climate controlled periods of the day.

Table 19: Methods of active climate control – cooling

How do you keep cool in the summer?	
Evaporative air conditioning (whole house)	4
Refrigerative air Conditioning (single rooms)	7
Ceiling fans	3
Opening the windows and doors for breezes	2
Spend the majority of the time under the verandas	
Other	

Table 20: Rating the thermal performance of the workshop participants' homes

Is your home cool during the summer WITHOUT air conditioning?	
It is very cold	
It is cold	
It is ok	4
It is hot	6
It is very hot	6

Table 21: Climate controlled zones

What rooms in your house are air conditioned?			
All	1	Living Room	9
None	2	Bedroom (main)	4
Kitchen		Bedroom (others)	7

Table 22: Active climate control periods

If you use air conditioning, what time of the day do you use it most?	
All day	1
Breakfast	
Morning	
Lunch	2
Afternoon	4
Dinner	3
Evening	2
Night	4

From the group it can be seen that refrigerative air conditioners are more prevalent than evaporative systems, and that ceiling fans are limited in number considering that most of the designs in this report include the cheapest form of climate control. It could also be derived from Table 20 that passive climate control is relatively limited in the homes.

There is a mild contradiction between the active climate control periods of the participants and those assumed by the ERSs as indicated in Section 4.1 Energy rating schemes. While air conditioning is primarily used during the evening as assumed by NatHERS it is also used during the night time and relatively little during the morning periods.

5.4.3 Climate control – winter

The winter climate control section was designed to gain some basic understanding of the active climate control patterns of the residents. Table 23 details the different methods of climate control in the homes while Table 24 indicates the participant's satisfaction with the house's thermal performance. Table 25 details the climate controlled zones while Table 26 states the climate controlled periods of the day.

Table 23: Methods of active climate control – heating

How do you keep warm in the winter?	
Open fires (outside)	16
Bar heaters (single rooms)	2
Heater fans	
Reverse cycle air conditioners	7
Blankets	10
Other	1 (fire inside)

Table 24: Rating the thermal performance of the workshop participants' homes

Is your home warm during the winter WITHOUT heating?	
It is very cold	8
It is cold	6
It is ok	2
It is hot	
It is very hot	

Table 25: Climate controlled zones

What rooms in your house are heated?			
All		Bedroom (main)	10
Living Room	12	Bedroom (others)	8
Kitchen			

Table 26: Active climate control periods

If you use heating, what time of the day do you use it most?	
All day	2
Breakfast	3
Morning	1
Lunch	
Afternoon	
Dinner	3
Evening	2
Night	5

From the data it is again evident that the passive design for heating is quite poor for the participants' homes. The active heating periods correlate closely with those assumed by the ERSs as indicated in Section 4.1 Energy rating schemes.

5.4.4 Cultural sensitivity

This section examines the cultural sensitivity of the participants' homes in a limited fashion through general questions regarding traditional lifestyles and satisfaction. Table 27 shows which traditional lifestyle components participants would most like built into potential house designs. Table 28 shows the average numbers in each of the participants' homes while Table 29 questions the ability of the house to cope with these resident numbers. Table 31 examines the role of cultural sensitivity in the broader context while Table 32 questions a perceived shift between traditional and western cultures.

Table 27: Preferred traditional lifestyle components

Generally, what elements of the traditional lifestyle do you want built into your house design?
9 responded in the area of gender based spaces, 3 responses were based on age areas and 4 responses were around internal food preparation areas

Table 28: Typical household numbers

How many people usually stay in the house at night?
12, 9, 6, 15, 6, 8, 10, 12, 13, 8, 10, 9, 8, 7, 12, 6

Table 29: House size satisfaction

Is the house big enough to accommodate everyone?	
Yes	3
No	12

Table 30: Broader preferred house improvements

What is the aspect that would most improve your house? (chose only 1 response)	
Thermal performance	
Maintenance	4
Size	
Gardens	
Security	3
Floor plan	
Outdoor space (living)	
Windbreaks	
Cultural sensitivity	9

Table 31: Preference of floor plan type

Would you prefer a different house floor plan – emphasis on	
Separation	6
Security	3
Ventilation	1
Orientation	3
Connection to outside	
Thermal performance	
Lines of sight	1
External cooking yard	2

Table 32: Cultural shift indication

Generally, do you feel there is a shift from the 'traditional' to 'western' lifestyles?	
Yes	11
No	2
Not sure	3

In the sample database of 16 participants, the majority of households are exceeding the typical occupation design limits. The average resident number is over 9 people. The majority of respondents stated that in terms of the traditional lifestyles a gender- or age-separation design would be the most desired improvement. Again, in the broader context cultural sensitivity is the most desired aspect to be built into the designs, but maintenance and security also rated highly.

6. Stakeholder engagement

Two meetings were held to inform, reorganise and focus the research project with relevant stakeholders. The first meeting was held on the 20th of December 2004 and the second was held on 23rd of September 2005.

6.1 Stakeholder meeting 1 – December 2004

Date: 20-12-04
Time: 1500
Location: Charles Darwin University, Engineering Conference Room
Present: Friso De Boer (CDU), Michael Duell (CDU), Gary Boyle (NTG), Zane Hughes (BIITE)
Audio conference: Martin Anda (Murdoch), Rachel Gibson (FaCS), Robert Letheby (FaCS)
Minutes: Asma Akram (CDU)

The stakeholder meeting was organised to bring together all the interested to discuss the direction of the project. The meeting used a PowerPoint presentation to direct conversation around a range of issues including each of the 5 milestones – existing knowledge, the BCA, modelling methodologies, cultural sensitivities and potential knowledge gaps – as well as the BIITE project proposals and future research of the project.

There is a new development in the BCA that it will potentially be applied to desert regions in the NT. Currently the BCA only applies to metropolitan centres and 500m off the Stuart Highway. The effect of imposing the BCA on desert regions would require all buildings to adhere to the strict BCA regulations. Current standardised designs do not adhere to these regulations. The standardised designs would have to be further redesigned and brought up to scratch. The NT government is interested in the development of this issue as currently under IHANT there are approximately 20 standardised designs built every year as well as through the National Aboriginal Housing Scheme (NAHS) program. Gary Boyle floated the figure that it could cost upwards of 20%–30% of the cost of a house to satisfy the current DTS criteria. There are still questions arising as to how long the BCA amendment process might take. The issue of what level the designs are brought up to was also raised. If it were going to cost a considerable amount for the DTS criteria to be met what effect would using the energy rating schemes have? Would a lifecycle analysis further influence the decision? It was decided that Gary and Martin Anda would discuss this issue further and inform the group of the details. There was potential for future work investigating these issues.

The stringency increases to the BCA were investigated by CDU and have been reported in this document. The summary of the main analysis is in Section3.3 Energy efficiency stringency with the corresponding submitted conference paper available in Appendix F – Embodied Energy Analysis.

It was also mentioned that through Zane Hughes' work of educating Aboriginal people with regards to the thermal performance of their homes, a basic design guide could be produced to help in the decision process.

Through the discussion of the modelling methodologies the fact that AccuRATE was based on houses on the east coast of Australia was suggestive of poor performance in hot arid and tropical regions. Gary Boyle also raised the potential of future data logging in the desert.

Data logging was conducted on a number of designs including the WWAC house in Laverton (Section 4.2 Full-scale modelling) and a transportable design by Murray River North in Alice Springs. The data logging was conducted by Gary James, an employee of Murdoch University, and a project partner. The transportable design data logging was inconclusive and was not included in this report.

The issue of cultural sensitivity was also raised as being too large for the thermal performance project to adequately analyse. It was identified that there was a thermal performance aspect built into current government policy through the 9 healthy living practices and it was best to focus on this. Through this it was decided to concentrate on a few particular aspects such as men's and women's areas and others which directly related to technical aspects of the design.

In the knowledge gap sections it was identified that the majority of thermal comfort studies had been conducted in the UK/Europe or the USA. This would have dramatic influences on the psychological implications of the studies. The particular levels of expectation and adaptation were also highlighted as being critical factors in thermal comfort. As an aside from this it was highlighted that this project should focus solely on temperature to keep a constant scientific focus throughout this project.

It would also be useful to compare the IHANT and NAHS building programs. IHANT has been focusing on standardised designs while NAHS promotes the use of independent architects. Each has advantages and disadvantages; the standardised designs are not of a very high level but are cheap so that more may be produced depending on demand while the independently designed buildings suit the users' requirements but are more expensive and typically the intellectual property has remained with the architects. It was also identified that architects with apparently little knowledge in hot arid regions/deserts were often used.

While many future research opportunities were highlighted throughout the meeting the common theme was that there would have to be an integrated approach between all the parties.

Future research opportunities:

- BCA amendment impacts
- Development of a whole of life rating scheme for BCA
- Basic design guide for Aboriginal people
- Future data logging in desert regions for AccuRATE modelling tool
- Comparison of IHANT and NAHS building programs
- Australian desert thermal comfort tests
- Redevelopment of standardised designs

Discussions were held with Tess McPeake from FaCS regarding the NIHG as the fundamental design guide for Aboriginal people. Further discussions with the CEO of the WWAC revealed that there was limited knowledge of the NIHG and further that a version that was able to be personalised would be highly beneficial.

6.2 Stakeholder meeting 2 – September 2005

Date: 23-09-05

Time: 1000

Location: Charles Darwin University, Engineering Conference Room.

Present: Friso De Boer (CDU), Michael Duell (CDU), Gary Boyle (NTG), Alicia Harris (Qantec-McWilliam), Amanda (Qantec-McWilliam)

Apologies: Zane Hughes (BIITE), Glenn Marshall (CSAT), Col Pascoe (Qantec-McWilliam), Tess McPeake (FaCS) and Tracey Walker (FaCS)

Minutes: Maeline Tanonef (CDU)

The final stakeholder meeting was used to disseminate the results as it was held during the final stages of the project. A brief overview of the first milestone findings, including desert design, the BCA and the embodied energy analysis, were presented before analysing the second milestone results. The second milestone results included modelling methodologies and cultural sensitivity. The minutes of the meeting can be found in Appendix E – Minutes of September 2005 Stakeholder Meeting.

The presentation and discussion followed the modelling methodology as presented in this report. Of the several variations to the base design studied, of particular interest was the orientation variation. Qantec-McWilliam were the project managers for an IHANT delivery of houses to Hermannsburg, NT. It was identified on a trip to the settlement that the houses being built were skew to the plans to meet the cultural requirements of the residents. The majority of the houses were orientated around the 270º mark consistent with the minimum rated energy requirements as determined by the modelling methodology.

The results of the project were welcomed and Col Pascoe, through Alicia Harris, expressed enthusiasm in implementing the data into current designs.

Gary Boyle, representing the NTG, was enthusiastic about the idea of identifying a range of novel housing solutions to address the knowledge gaps identified including thermal performance and cultural sensitivity. The next step identified was to brainstorm a way forward with such a large goal.

The NTG were also instrumental in organising the upcoming *Thermal, cost and social impact assessment of household air conditioners in remote communities* Desert Knowledge CRC project.

7. Knowledge gaps

There have been a number of knowledge gaps identified by the project. These range from specific technical design issues to issues that are design considerations before and after the thermal performance consideration. The energy use from active climate control has direct impacts on the settlement's ability to provide power. However, the effects of altering housing design to incorporate cultural sensitivity or shifts will have an over-riding impact on the thermal performance of the housing. This is seen as an issue of great significance.

7.1 Settlement energy use

Thermal performance of buildings has a large influence on the settlement's ability to provide power. The settlement energy use depends on two factors: base energy consumption and peak energy demand. The settlement's power supply must be able to handle the base load of the infrastructure, community buildings and housing. The peak loads come from intensive energy consumption by one or more components. Based on simple analysis as well as anecdotal evidence it would appear that the peak loads are driven by active climate control, both heating and cooling in the settlements.

Passive design concepts can greatly reduce the energy demands of active climate control. Passive cooling and passive heating for the CRRC3K and Laverton designs have been studied in detail. It was found in the modelling analysis of the CRRC3K design and the data logging of the Laverton design that they have both been over engineered towards passive cooling for the summer period rather than passive heating for the winter period.

7.1.1 Active cooling

There are two major forms of active cooling prevalent in desert regions of Australia, evaporative and refrigerative cooling. Typically evaporative air conditioners use a substantial amount of water but are low on electricity consumption while refrigerative air conditioners use little water but substantial amounts of electricity. In Section 2.1 Active energy consumption, Glenn Marshall states that there is a growing move towards refrigerative air conditioning in settlements, both small and large.

A DKCRC project has been set up that will form a network of associated researchers and will analyse the effects of the shift to refrigerative air conditioners using the Areyonga community as a case study. Power loads, maintenance requirements and external effects on the air conditioners will be analysed and detailed. Local Environmental Health Workers will be closely involved with installation of monitoring equipment, downloading and interpretation of data and collection of usage pattern data from householders.

General outcomes of the air conditioning project would be:

- Greater understanding of the thermal, social and cost effects of air conditioning on household and settlement power supplies
- A reduction of government exposure to configuration changes and escalating costs in remote settlements (DKCRC Core Project 5 – intention 2)
- To link the effects of air conditioning to energy consumption and effects on community electricity generation infrastructure (DKCRC Core project 5 – intention 3)
- Impact on potential policy implementation from active to passive climate control in remote communities.

Specific outcomes of the air conditioning project would be:

- The minimisation of costs to households and the NTG particularly with the potential fuel cost escalation
- The minimisation of the percentage of settlement energy consumption representing household air conditioning
- The affordability of air conditioners
- Behavioural and social expectation levels of air conditioners
- Reduction of the amount refrigerative reverse cycles are used in winter for heating purposes
- Reduction of peak load impacts on community power stations
- Reduction of cost and frequency of maintenance requirements of refrigerative air conditioners
- Identification of anecdotal social impacts and the effect of external environment factors on the performance of air conditioners.

7.1.2 Active heating

The DKCRC air conditioning project detailed in the previous section extends until the end of 2005/2006 summer. However, as has been identified in Section 4.1 Energy rating schemes, the analysed houses are over-designed towards passive cooling and underperform during the winter period. The winter loads potentially are the greatest concern towards peak energy consumption.

There are questions regarding the use and electricity consumption of heating implements in houses as there are a number of alternatives. Bar heaters are simple and effective devices but consume large amounts of electricity and are also potentially dangerous. The anecdotally prevalent refrigerative air conditioners in settlements can also come in the form of split systems or reverse cycle air conditioners that can double as heaters. The use, effectiveness and electricity consumption of these devices is not known. Table 33 indicates the number of heating devices present in houses surveyed in the Housing for Health surveys conducted by FaCS.

Table 33: Housing for Health survey data indicating the number of houses that exceed minimum comfort levels and the type of active heating devices present in the house

	Total number of houses surveyed	Number of houses	Percentage of houses
Air temperature less than or equal to 20°C at survey	787	140	18%
House temperature greater than 20°C, when outside temperature was less than 20°C	140	37	26%
	Total number of houses surveyed	**Number of houses**	**Percentage of houses**
Minimum winter temperatures regularly less than 10°C	786	256	33%
Ducted reverse cycle heating	274	4	1%
Reverse cycle heating not ducted	274	44	16%
Open fire	274	37	14%
Combustion heater (wood or solid fuel)	274	139	51%
Ducted gas heating	274	2	1%
Gas heating not ducted	274	9	3%
Plug-in electric heaters	274	39	14%
No heaters	787	513	65%

Source: Family and Community Services 2005

A project examining the impacts and the use of reverse cycle air conditioners to heat houses could reveal a potential cost saving and improved standard of living scenario for desert communities. If reverse cycle air conditioners are used for heating purposes during the winter period and consume less power than bar heaters or other forms of smaller but more energy intensive heating devices then the peak power demands of remote communities could be reduced over the year while providing a higher standard of living through improved active climate control.

7.2 Behavioural/Social/Cultural sensitivity

The purpose of a house is to be functional to the resident. This means not only providing protection from the elements but also a design that is culturally sensitive. The effects of altering housing design to incorporate cultural sensitivity or shifts will have an over-riding impact on the thermal performance of the housing. It was found in the limited workshop held by BIITE in late September that the majority of the participants would prefer to see more cultural sensitivity built into the house designs, primarily in the form of gender- or age-separation zones.

7.2.1 Cultural design

The aim of the CRM designs was the development of a range of quality designs that took into consideration general cultural sensitivities (Jardine-Orr 2004), however the designs are claimed to have lost cultural sensitivity during the design process (Z Hughes, pers. comm., 2004). The issue of the way or the extent to which a house is being used by the resident is fundamental to the purpose of the house. Memmott (2003), in his review of books on Aboriginal housing, states that there are no books produced from an architectural perspective that incorporate specific design principles. Memmott highlights studies from the 1970s that have raised the issue but still not addressed it.

7.2.2 Cultural shifts

Lee and Morris (2005) state that as part of the best practice for effective cross-cultural considerations, it must be recognised that 'consultation is being undertaken in culturally, environmentally and economically changing contexts'. A culturally shifting environment has significant impact on housing, given the life span of a house is up to 40 years, particularly the structural components that place the most limitations on thermal performance improvement.

Key's (2003) development of design principles for appropriate housing for the Warlpiri people of Yuendumu in the 1990s led to two distinct factors: Aboriginal and non-Aboriginal living environments and material culture.

One might conclude that a Western style house has no real place in a central Australian Aboriginal settlement, but this concern is not shared by Warlpiri women themselves who were generally united in wanting proper white-fella houses. This desire relates to issues of cultural change and social identity.

Keys 2003

In particular, Keys found that the Warlpiri women had become highly sensitised to mainstream media coverage (2003). The preference to have proper white-fella houses overrode other factors such as climatic considerations. While this is only one example, the issue of cultural shifts, to the author's knowledge, has only been investigated in a limited fashion. There is a necessity to design for the current requirements of the residents but also their future requirements, which may include cultural shifts.

During the workshop held by Zane Hughes, the question of shifting cultural requirements was posed. It was found that the majority of participants indeed felt that there was a shift from traditional to western lifestyles. This will have a significant effect on the housing styles and designs provided both in the long and short term, particularly given that the houses can be used over a number of generations.

7.3 Housing shortage

During a DKCRC Core project 5 meeting held in September 2005, Gary Boyle, who represents the NTG, stated that one of the biggest issues his department was facing was how to address the massive shortage of housing. In particular, labour shortages for construction and maintenance in remote areas make this a difficult problem to tackle. The solution could be viewed as comprising two components: a short term and a longer term solution.

The short term solution could potentially be to use transportable houses to get housing to the areas where it is most required. This solution does not necessarily discount all the compounding issues as modification can be made to the designs to incorporate variability. However, maintenance issues and long-term community development are not addressed.

The CRM developed by IHANT a number of years ago appears to present a longer term solution in that it would address the housing shortage while providing culturally sensitive designs to individuals and encourage community development through training of local building teams. It is beyond the scope of this project to determine the relative success of the IHANT program.

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Appendix A – Transportable Design Competition Winner

Your Kinda House?
Regional Housing Concept Design Competition

Category: **Transportable – Rural & Remote (T1)**

Entrant: Clem Lester

Practice: Clem Lester Architects

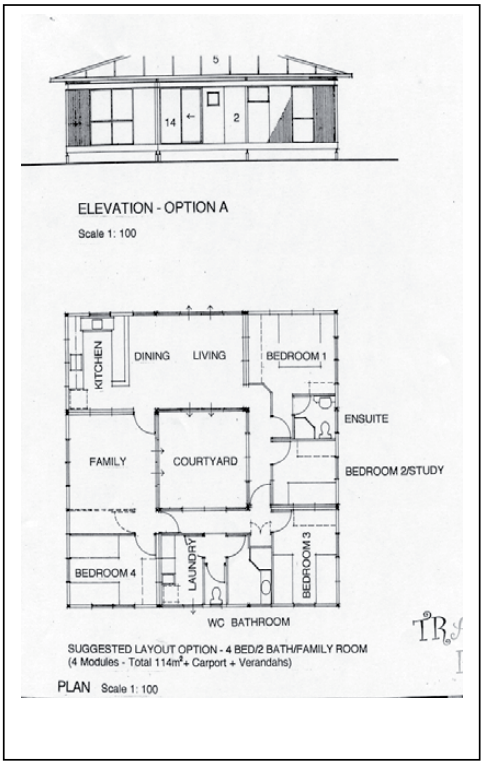
Cost Estimate: $140,000

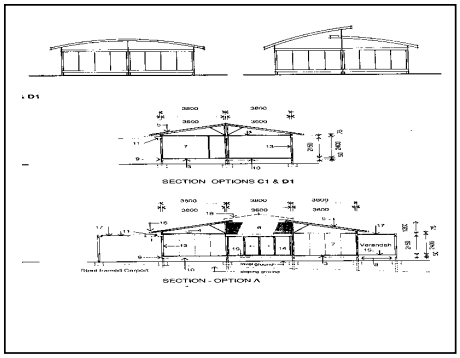
Overview:

- Concept revolves around a series of transportable modules.
- Modules have ability to be arranged in a variety of configurations to allow for options in planning designs to best suit a particular situation.
- The modular system also allows for a 'staged' development of the house.
- Modules are designed for single storey use – but have potential to be adapted for 2-storey construction with further development.
- Each module would be transported to site, with roof, associated framing, solar hot water units stored inside the modules.
- Floors can be concrete on sand pads, or steel framing for sloping sites.

Steel framed modules with:

- - colorbond external cladding or western red cedar, or ecoply.
- - internal walls and ceiling in plasterboard.
- -Floor in insulated modular panels, clad in fibre cement sheet.
- - All floor, external walls, ceiling and roof to have insulation between panels.
- - Carport, Veranda/Sunhoods are steel framed. Timber decking to veranda.





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Your Kinda House?

Regional Housing Concept Design Competition

Category: **Transportable – Rural & remote (T2)**

Entrant: Christopher James

Practice: Christopher James Residential Design Specialists

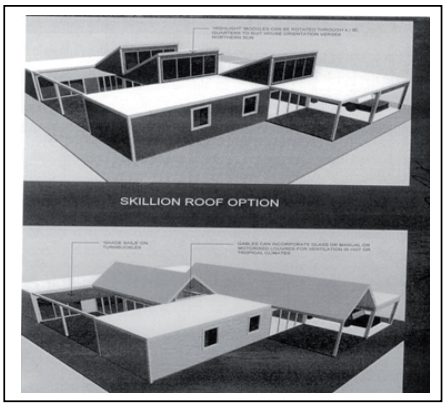
Cost Estimate: $130,620

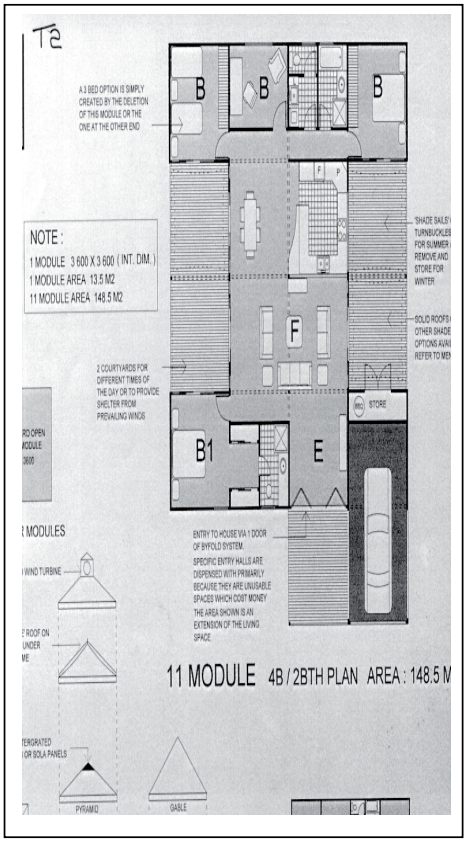
Overview:

- House centred around outdoor living area.
- Ability to open whole house to central outdoor area.
- Modular system in a repetitive format.
- Concept of pre-packaged product which is easily transported and easy to erect by unskilled labour.

Materials used include:

- FLOOR – concrete slab/or suspended floor on platform option.
- WALLS – steel framing with external/internal cladding options in colorbond, gyprock, weatherboards or sandwich panel.
- ROOF – colorbond steel or sandwich panel.
- WINDOWS – double glazing with dust proof seals.





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AN OVERVIEW OF THE WINNING EXHIBIT – T2

The concept relies heavily on the premise that the area surrounding the house in the form of decking or outdoor living area is as integral a part of the environment as the rooms themselves.

The ability to 'open up' the whole house to these areas, which may be covered or uncovered, or a proportion of both is fundamental to our climate and the Australian way of life.

The uninterrupted flow of traffic and indeed the 'visual connection' between the areas via bi-fold doors and full height glass can necessitate a smaller more economical, 'greener' house that is about 'lifestyle' rather than the real estate–driven philosophy of a commodity that must be 'big' and 'brick' to be valuable.

These elevated deck areas, roofed, unroofed, partially shaded or designed to admit winter sun and exclude summer sun are the climate control for our lifestyle – not the air conditioning knob that is so much a part of economically unsustainable development today.

The deck areas and design flexibility of this modular system will enable the retention of trees and natural flora which are the essence of the emerging ecotourism industry with its associated sustainable accommodation needs.

The concept is a flat-pack, pre-cut, pre-finished, pre-packaged product easily transported that is well designed and will achieve low cost through high volume production of minimal components.

It is a structure that can be erected by unskilled labour without tools or power in remote locations with construction times less than 10% of conventional methods.

A module of 13.5m^2 supported on 4 adjustable columns or legs for 'terrain management' with its own floor and roof repeated as many times as necessary to achieve the level of accommodation required. A big house or project is merely the repetition of one component or module.

THE MODULE

The module could be anything but the one chosen is a square 3600 x 3600 because:

- One module is a bedroom/a dining room/a kitchen/ a wet area
- Two modules is a living room/a family room/ or car accommodation
- This size involves minimal 'engineering' impositions
- 3600 is dividable by 300, 400, 900, 1200 & 1800 which has 'material' and 'standards' economies.
- If delivered as assembled modules instead of flat-pack components it meets transport requirements.

A menu of options for the design combined with a mixed used of roof shapes can provide aesthetic diversity, maximise passive solar benefits where northerly aspects conflict with views or other orientation criteria and the need for internal special requirements usually driven by economies or budget.

A standard roof format also enables the economic development of technologies such as integrated photocells/solar panels or wind turbines to run what is already an efficient passive solar structure.

THE MATERIALS

FLOORS – deck or panel flooring supported on platforms with 4 adjustable steel legs for terrain management. Traditional concrete slabs where requested or appropriate although these are possibly incompatible with the ultimate aims of the modular concept in some instances.

WALL PANELS – Lightweight engineered steel frames clad in traditional materials such as custom orb/fibro/weatherboard/gyprock or plasterboard with various insulation options

OR Foam 'sandwich panel' walls utilising traditional materials mentioned above or the development of a specific product utilising 'new age' materials and integrated 'snap-together' plumbing and wiring systems.

WINDOWS & DOORS – Minimal size and style options with the main emphasis on new high technology glass options/double glazing and dust-proof seals and track mechanisms.

ROOF MODULES – Colorbond steel/foam 'sandwich panel'/lightweight monolithic structures/self supporting with high insulation 'R' values and integrated lighting.

Your Kinda House?
Regional Housing Concept Design Competition

Category: **Transportable-Rural & remote (T3)**

Entrant: Finn Pedersen

Design Team: Finn Pedersen, Adrian Iredale, Ross Brewin, John Belviso

Company: Iredale Pedersen Hook Architects

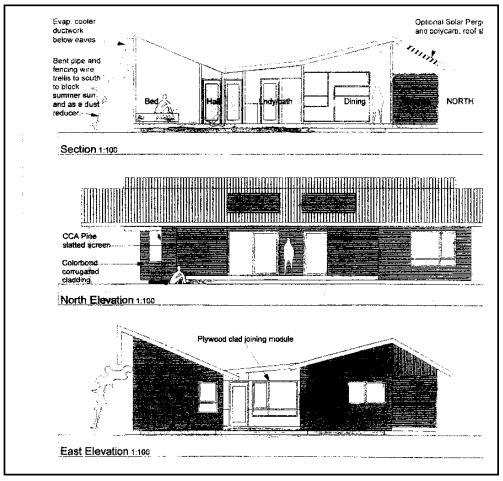
Cost Estimate: $135,000 - $160,400

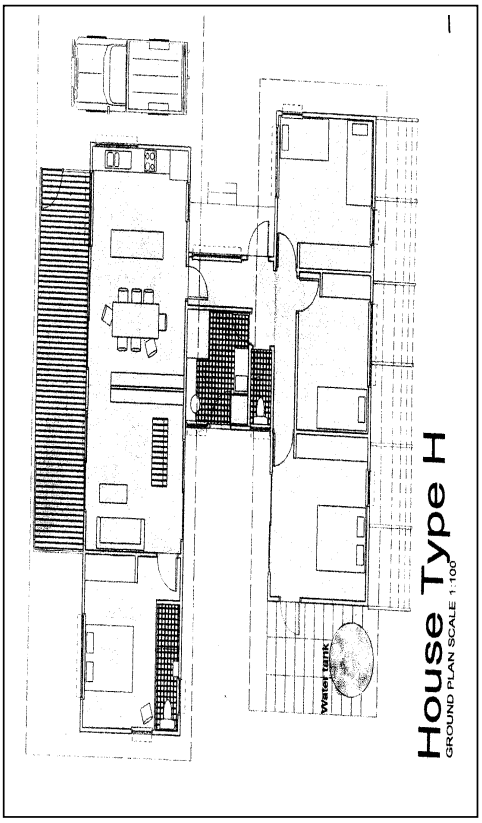
Overview:

- Concept of modular base units – identical in plan.
- Option for single or double storey options.
- System can be designed to reflect the local climatic conditions.
- Use of veranda/awning/roof/timber slatted screens to provide shade and privacy to outdoor areas.
- Choice of customised roof forms.

Materials include:

- - Steel framed sub-floor with (treated-pine) joists.
- - Plywood floor base internally.
- - Pine insulated walls in pine framing.
- - External cladding in options of marine grade plywood, colorbond, or painted fibre cement sheets.
- Windows in plantation timber.
- Minimisation of mechanical ventilation through passive solar design principles.





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Your Kinda House?
Regional Housing Concept Design Competition

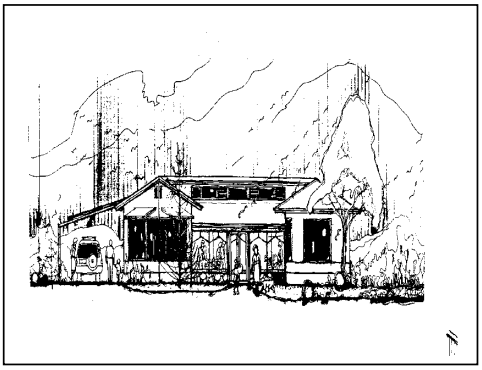
Category: **Transportable – Rural & remote (T4)**

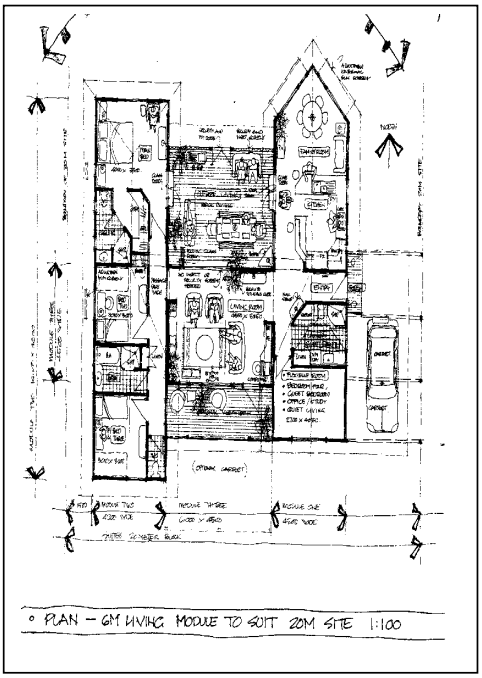
Entrant: Allan Davies

Practice: Allan J Davies Architect

Cost Estimate: $149,313

Overview:





- View of transportable house as a non-standard product, except for compliance with transport requirements of dimensions and weight.
- Factory production allows for variations in the design types and materials.
- Six metre central living room module allows design to be used in a standard town site.
- Insect screened outdoor room with fully insulated room allows house to be opened up for cross-ventilation and entertaining at all times of the year.
- Master bedroom isolated from main part of house for shift workers.
- Concrete floors.
- External walls in colorbond mini orb above dado and Hardiflex to lower level.
- Internal walls in gyprock and colorbond mini orb to living areas and outdoor room.
- Insulated walls/roof.
- Paved outdoor room.

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Your Kinda House?
Regional Housing Concept Design Competition

Category: **Transportable – Rural & remote (T5)**

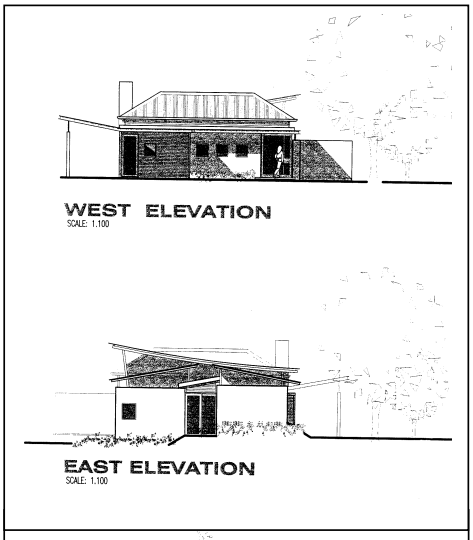
Entrant: Kim Miller

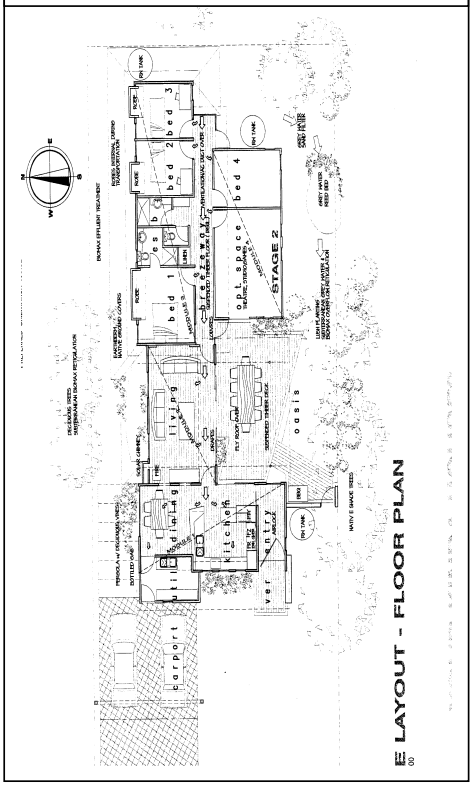
Practice: Commercial Design Management

Cost Estimate: $133,372

Overview:

- Series of 'eskies' – insulated boxes
- Insulated modules protected from environmental conditions and linked via interconnecting breezeway.
- Ability to open/close to allow wind and sun in at appropriate times of the day and year.
- Pre-fabricated components
- Simple to erect with minimum skilled labour requirements.
- Create minimum disruption to the surrounding environment.
- Solar chimney for air flow.
- Use of interconnecting breezeways for cross ventilation.
- Central duct to channel cross ventilation.
- Use of natural breezes via 'Oasis'.
- Fly roofs open and close to allow heat in and out.
- Use of grey water
- Compost toilets
- Solar Panels and photo voltaic cells to north roof
- Ceiling - Sandwich panels with colorbond custom orb external skin.
- Floors – pre-cast concrete floors





Presented by: Goldfields Esperance Development Commission & the Australia Unlimited Taskforce

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Appendix B – CFD Research Proposal

Proposal to ISA Technologies for a research supercomputer fellowshipputting science behind architectural practices

Aim: To investigate the proposed benefits of night purging through natural and forced convection in the desert built environment.

Background: Passive cooling and heating is becoming a major factor in the design of Australian homes. The benefits of thermal mass and natural ventilation are well recognised scientifically, economically and anecdotally. Night purging is a combination of these design principles using convection to remove heat from the internal structure of the building through ventilation expelling the air outside. The most common example of night purging utilises the simple geometry of a room with a low and high opening to the cooler night environment. Convection will warm the interior air causing it to expel itself through the higher opening and draw fresh, cooler air into the room through the lower opening, reducing the temperature of the ambient air and the thermal mass. This process can be accelerated through forced ventilation, rapidly expelling air by use of a fan at the higher opening.

The problems: While this passive design technique is currently being employed in many designs and has been used extensively in traditional housing in India through ground heat pumps the benefits of this Australian configuration are unknown. In the hot desert conditions there is often a very limited period of time where the ambient temperature dips to an acceptable temperature due to the latent heat in the surrounding environment and stable atmosphere.

There are questions about the requirements and the proposed benefits of night purging in geometrically complex housing designs using a limited number of openings for night purging, the amount of heat dissipated through forced and natural convection and the implications of user interference with the system.

Application: This research would be conducted as a component of a proposed Australian Research Council Linkage grant in conjunction with the Indigenous Housing Authority of the Northern Territory (IHANT) standardised housing designs managed through the Northern Territory Government (NTG) Department of Community Development, Sport and Cultural Affairs (DCDSCA). A general review of housing stock is being conducted by the Desert Built Environment Research Group (DBERG) and Charles Darwin University (CDU) with contractual research into embodied energy being finalised and formalised research into Building Code of Australia (BCA) modelling software (AccuRATE) about to begin.

The objectives:

1. To simulate forced and natural night purging in a simple geometric structure reflecting the common housing designs and environmental parameters of the Australian desert regions.
2. To investigate the proposed benefits of night purging purposely built into a house design Kalgoorlie Sustainable House designed by Ramm Building Designs (2005).

3. Investigate the necessary conditions for adequate heat transfer in the Kalgoorlie Sustainable House through variation of parameters.
4. Develop a design guideline for integrating night purging into other housing designs most notably IHANT.

The method: It is proposed to model the simulations using commercially available software packages – primarily computational fluid dynamics (CFD) packages. Currently Charles Darwin University has a licence for Fluent but may soon be transferring across to CFX. These packages have the capability to adequately model house geometry and resulting heat transfer/fluid flow regimes simulating night purging.

The project would begin with a geometrically simple 2 dimensional problem capable of being modelled on a desktop PC. The geometrically complex 3 dimensional Kalgoorlie Sustainable House would then be modelled using ISA's computational ability due to the large mesh required. This simulation would reflect the current environmental parameters of the house.

The third simulation would aim to optimise the benefits of the night purging through variation of the associated parameters. Natural and forced convection would be investigated through the rate and length of forced convection linked to external temperatures. The openings number, dimensions and location required to facilitate night purging would also be investigated within normal housing design variation.

Through the optimisation of the results general design guidelines could be developed for application to a broader range of housing stock. IHANT produces a range of 3- and 4-bedroom housing designs specifically for the desert regions of the Northern Territory. Night purging would be highly applicable to these designs due to the weather conditions, high electricity costs due to remoteness and robustness of the concept.

Appendix C – Workshop Questionnaire and Results

Alice Springs Creek Questionnaire

Section A: House

1. What is the name of your settlement?

……..

2. What materials is your house made from?

External Walls		*Internal Walls*	
Large concrete blocks		Large concrete blocks	□
Skinny concrete blocks	□	Skinny concrete blocks	□
Steel frame	□	Steel frame	□
Concrete sheeting	□	Concrete sheeting	□
Mud bricks	□	Mud bricks	□
Other	…….	Other	……..
Floor		*Roof*	
Concrete slab	□	Metal desk	□
Elevated floor	□	Concrete	□
Other	…….	Other	……..
Floor Covering		*Verandas*	
Carpet	□	Front and back	□
Tiles	□	All the way around	□
Bare concrete	□	None	□
Other	…….	Other	……..

3. How big is your house?

1 Bedrooms	□
2 Bedrooms	□
3 Bedrooms	□
4 Bedrooms	□
More	□

Section B: Climate Control – Summer

4. How do you keep cool in the summer?

Evaporative air conditioning (whole house)	□
Refrigerative air conditioning (single rooms)	□
Ceiling fans	□
Opening the windows and doors for breezes	□
Spend the majority of the time under the verandas	□
Other	.....

5. Is your home cool during the summer WITHOUT air conditioning?

It is very cold	□
It is cold	□
It is ok	□
It is hot	□
It is very hot	□

6. What rooms in your house are air conditioned?

All	□	Living Room	□
		Kitchen	□
		Bedroom (main)	□
		Bedroom (others)	□

7. If you use air conditioning, what time of the day do you use it most?

All day	□
Breakfast	□
Morning	□
Lunch	□
Afternoon	□
Dinner	□
Evening	□
Night	□

Section C: Climate Control – Winter

8. How do you keep warm in the winter?

Open fires (outside)	□
Bar heaters (single rooms)	□
Heater fans	□
Reverse cycle air conditioners	□
Blankets	□
Other	.....

9. Is your home warm during the winter WITHOUT heating?

It is very cold □
It is cold □
It is ok □
It is hot □
It is very hot □

10. What rooms in your house are heated?

All □
Living room □
Kitchen □
Bedroom (main) □
Bedroom (others) □

11. If you use heating, what time of the day do you use it most?

All day □
Breakfast □
Morning □
Lunch □
Afternoon □
Dinner □
Evening □
Night □

Section D: Cultural Sensitivity

12. Generally, do you feel there is a shift from the 'traditional' to 'western' lifestyles?

Yes □
No □
Not sure □

13. Generally, what elements of the traditional lifestyle do you want put into your house design?

For example: avoidance behaviour

What is the most important?

Section E: General Satisfaction

14. How many people usually stay in the house at night?

……..

15. Is the house big enough to accommodate everyone?

Yes □

No □

If no, what would be the ideal number of people? ……

16. What is the aspect that would most improve your house?

Thermal performance □

Maintenance □

Size □

Gardens □

Security □

Floor Plan □

Outdoor space (living) □

Windbreaks □

Cultural Sensitivity □

17. Would you prefer a different house floor plan – emphasis on?

Separation □

Security □

Ventilation □

Orientation □

Connection to outside □

Thermal performance □

Lines of sight □

External cooking yard □

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
1																		
2.1	a	1		1	1		1	1		1			1		1	1		9
	b		1			1			1		1	1						5
	c													1				1
	d																	
	e																	
	f																1	1
																		16
2.2	a	1		1	1		1	1		1			1		1	1		9
	b		1			1			1		1	1						5
	c													1				1
	d																	
	e																	
	f																1	1
																		16
2.3	a	1	1	1	1	1	1	1	1	1	1	1	1		1	1		14
	b													1				1
	c																1	1
																		16
2.4	a	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		15
	b																	
	c																1	1
																		16
2.5	a																	
	b			1	1			1	1	1	1	1	1	1		1		10
	c	1	1			1	1								1			5
	d																1	1
																		16
2.6	a	1	1	1			1	1			1	1		1	1	1		10
	b				1	1			1				1					4
	c									1							1	2
	d																	
																		16
3	a																1	1
	b	1		1	1			1				1						5
	c		1			1			1	1			1	1		1		7
	d						1				1				1			3
	e																	
																		16
4	a				1	1			1				1					4
	b	1		1				1				1		1	1	1		7
	c						1			1	1							3
	d		1														1	2
	e																	
	f																	
																		16
5	a																	
	b																	
	c		1					1							1	1		4
	d	1		1			1				1	1		1				6
	e				1	1			1	1			1				1	6
																		16
6.1	a				1	1			1				1					4
	b		1														1	2
																		6
6.2	a			1	1	1	1	1	1		1	1	1		1			10
	b																	
	c	1		1	1	1	1	1	1	1	1	1	1	1	1	1		14
	d				1	1			1		1	1	2		1			8
																		32
7	a												1					1
	b																	
	c																	
	d				1	1												2
	e													1	1			2
	f			1				1	1		1							4
	g		1				1											2
	h									1		1	1					3
																		14

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
8	a	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	16
	b								1				1					2
	c	1		1	1	1	1	1	1									7
	d	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	16
	e																1	1
																		42
9	a	1	1	1			1				1	1		1			1	8
	b				1	1		1	1				1		1			6
	c									1						1		2
	d																	
	e																	
10.1	a																	
10.2	a	1		1	1	1	1	1		1	1	1		1	1	1		12
	b																	
	c			1	1	1	1	1	1	1	1	1	1		1			11
	d			1		1		1	1	1	1	1	1	1	1			10
																		33
11	a																	
	b																	
	c																	
	d																	
	e				1	1												2
	f									1	1	1						3
	g	1		1										1	1	1		5
	h		1				1	1	1				1					5
																		15
12	a	1		1	1		1	1	1	1		1	1		1	1		11
	b					1					1			1				3
	c		1														1	2
																		16
13		1	3	2	2	1	3	3	1	1	1	1	1	1	1	1	3	
14		12	9	6	9	6	8	10	12	13	8	10	9	8	12	7	6	145
15	a			1		1				1								3
	b	1	1		1		1	1	1		1	1	1	1	1	1	1	13
	c	4	4		4		5	4	4	5	5	5	4	4	5	4	4	61
16	a				1	1			1				1					4
	b		1							1							1	3
	c																	
	d																	
	e																	
	f																	
	g																	
	h																	
	i	1		1			1	1			1	1		1	1	1		9
																		16
17	a																	
	b				1	1			1				1					4
	c		1							1							1	3
	d															1		1
	e										1			1	1			3
	f											1						1
	g			1			1	1										3
	h	1																1
																		16
18	a	1						1	1	1		1				1		6
	b										1			1	1			3
	c																1	1
	d			1	1	1												3
	e																	
	f																	
	g		1															1
	h	1											1					2
																		16

Appendix D – Minutes of December 2004 Stakeholder Meeting

Minutes

· Local architects have developed / produced housing in Alice Springs
· Been given the designs to use
· Proposed changes out for comment
· 20 – 30% extra per house outweigh benefits in dollars and energy
· Review of building code – House life is only for 7 years
· Parameters for the changes / review – project direction
· Follow up get back to the BCA for date for the submission
· BCA amendments in conjunction for Indigenous housing - Ensure there is an email loop with information being passed to all stakeholders.
· Program: standard design, model through the 3 packages to get results. To get an idea will have to model all three methods to get a complete picture.
· Filling in the gaps hasn't been addressed by the BCA. Used the framework between Brisbane / Melbourne as a standard. Have misconceptions as to it working in the NT.
· Contact external people – Dr ? from the University of South Australia for input.
· Shift in requirements for Indigenous; extend a house design for X years, with he changes for Indigenous people changed over the years.
· May not be able to address the cultural issues in the communities.
· Healthy living practices as a starting point. Speak to people in Indigenous housing to get broad principals.
· Findings from the project will have an impact.
· Separate men and women's areas, is an issue.
· Pick several unique cultural aspects, relate, reinforce, or contradict against the thermal issues.
· Talk to Indigenous housing people to see where things are at.
· Partnership project with BIITE to address cultural sensitivities
· Designs are on constant revision every year
· Compare / anecdotal thermal impact to NAR and standardised.
· Experimental stage may be able to link to the institute of sports.
· Outsiders more vocal then locals when something has changed.
· Geographical comparisons have literature compiled.
· BIITE: Aboriginal company (Wild Goose?) Set up to build the housing. Way to go in Indigenous housing. Begin from start to the end.
· Look at Batchelor. Data-log the houses in the next 12 months and in other communities
· Share the information with Michael and use for educational purposes to responses (Training package)
· BIITE in Alice Springs have a conference next year (May) with 100 people attending.
· Smaller focus group to address cultural sensitivity.
· Survey communities to gather information.
· Cultural sensitivity – intellectual design stays with the architect. Keep the designs as the property of the community.
· Future Research – ½ way through the project.
· Happy with project meeting all the milestones. Working towards smaller projects.
· Michael and Zane look at the cultural sensitivity issues
· Martin, Gary and Michael – BCA
· In-kind issue with regards to the work being done by various stakeholders is consistent with agreement.

Appendix E – Minutes of September 2005 Stakeholder Meeting

Thermal Performance in the Desert Built Environment
Presentation by: Michael Duell
23rd Friday 2005
Bld41.35

Attendees: Michael Duell (CDU), Maeline Tanonef (CDU), Alicia Harris (Qantec-McWilliam), Amanda (Qantec-McWilliam), and Gary Boyle (NT Government).

Alicia's background is Structural
Amanda's background is Environmental

In the case study building

- Alicia brought up price issues in houses in the middle of no where are too high and ridicules.

Building Code Australia

- Alicia talked about hoe central remote houses has expanded their bedroom size.
- Which includes the verandas' outside, and installations that may improve energy.

Looking at graphs on Installation Variation:

- Gary asked what is 'none' in the ceiling installation list. He was a bit confused.

'When asked about what people think of the houses?'

- Gary states that the houses should try to meet the cultural needs and that this is a concerning issue.
- Also taking principles to a bit more consideration weather it's the cultural appropriation, more robust. Concrete walls - was a subject that aroused the standards housing and that the modules, rooms become standard…but all comes down to cost effectiveness.
- To add to that Alicia gave an example of 'Numbuare' on how their shading does not have heating and they have cooling issues.
- Gary also says that the western walls should be Corrugated iron, where slabs walls could cause more plumbing issues. Therefore the orientation of the model is important.

63 General Notes:

- Alicia asks if Mr. Cole could have a copy of the orientation of houses slides sent to him.
- Gary suggested that Michael should turn this presentation into a journal, or ask wether Michael could publish the paper?
- All attendees also asked if they could all have an email of the slides.

Meeting Started: 10.00am
Meeting Ends: 11.15am

XXXIII IAHS, September 27-30, 2005, Pretoria, South Africa

Appendix F – Embodied Energy Analysis

Life Cycle Analysis of Energy Efficient Measures in Desert Housing Designs

Michael G. Duell, Lorien A. Martin

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Northern Territory, Australia
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Key words: embodied energy, housing, life cycle analysis

Abstract
Energy conservation has become an issue of global significance, reflected through the growing status of Environmentally Sustainable Design (ESD) in the Australian housing industry. The objective of ESD is to achieve an efficient balance between social, environmental and economic forces [1].
The Australian Building Codes Board (ABCB) has proposed to increase the stringency of the Building Code of Australia (BCA) in partial recognition of ESD principles, including the enhancement of thermal performance requirements and greater acknowledgement of thermal mass in energy rating schemes.
In order to determine its relative merits in desert climates, two standardised house designs utilised by the Indigenous Housing Authority of the Northern Territory (IHANT) were analysed through life cycles, embodied energy, the efficiency of energy saving measures and the resulting active energy consumption. The standardised houses, like others in the NT, are designed for retrofitting within 10 years reducing the time available for savings in operational energy to exceed energy invested in installing these measures. In addition, the spatial distances between population settlements in the NT greatly increase embodied energy values.
It was found that adopting the proposed measures would increase the embodied energy within the houses without markedly reducing the energy requirements of evaporative air conditioners that are the primary source of active climate control. The short lifespan of these houses did not permit sufficient time to pay back the energy investment through operational energy savings. Therefore, for these desert housing designs, implementation of the BCA's proposed energy efficiency measures was found to be out of balance.

Key words: embodied energy, housing, life cycle analysis

Nomenclature

R-Value Thermal resistance (m^2K/W)

1 Introduction

As a reflection of the growing importance of ESD, the ABCB have enhanced their energy efficiency requirements for all new housing constructions. The new regulations focus on improving the thermal performance of roofs, external walls, floors and window glazing required for new homes to meet 'Deemed-to-Satisfy' (DTS) criteria or satisfy the 5 stars of the Nationwide House Energy Rating Scheme (NatHERS) [2]. ESD aims to achieve an efficient balance between social, environmental and economic forces and so embraces a range of principles, including energy conservation, embodied energy and the enhancement of community life.

The Indigenous Housing Authority of the Northern Territory (IHANT) developed the Central Remote Model (CRM) that combines designs that integrate local inhabitants' requirements with a training and employment program and the use of standardised designs to ensure greater construction efficiencies and minimal maintenance requirements. The CRM has had a positive impact in communities, which reach well beyond the long-term energy savings it achieved by using houses designed to meet this region's unique extremes of distance and climate. In the context of ESD, one of the most notable achievements for this project is its social impact. The local training program transferred invaluable skills to the communities involved, and therefore provided community education and employment, as well as a potential workforce for future maintenance projects [3]. There is, however, still a significant shortage in remote Indigenous housing represented by overcrowding and lack of maintenance leading to entrenched health problems [4].

The life cycle of a building's energy use falls into 5 stages: production, erection, operation, maintenance and demolition [5]. Embodied energy comprises the energy required to produce, manufacture and transport building materials [6] and is most significant in the production phase of building construction when energy investments are made. Several studies have found that the embodied energy of most Australian buildings is equal to between 20 and 50 years of annual operational energy, which highlights the significant contribution of embodied energy to a house's life cycle energy consumption [7-9]. The operational energy phase of a building's life cycle in desert regions is represented in part by active climate control, most commonly evaporative air conditioners that require relatively little energy when compared to the total embodied energy values.

In this paper, section 2 details the housing designs analysed and section 3 follows the methodology used to analyse the houses. The analysis compares the addition of insulation and plasterboard to the internal side of all external facing walls to extending verandas around the entire perimeter of the house, which both satisfy the new BCA regulations. Both cases were analysed over the houses' lifecycles using an embodied energy approach to determine the operational energy savings. The two cases were also simulated using NatHERS to compare and contrast results from the two analysis methods. Section 5 discusses the results within the broader context.

2 Housing Designs

IHANT currently uses the housing designs investigated in this study. Design One is a simple three-bedroom house and Design Two is a simple 4-bedroom house, both used in desert areas of the NT, typically a hot and dry climate zone. Design One has a floor area of 108.3 m^2 (conditioned floor area of 81.7m^2) while Design Two a floor area of 136.6m^2 (conditioned floor area of 94.9m^2). There are verandas on the North and South perimeters.

The houses are constructed of 190 series reinforced block work, with concrete slab on ground flooring. Windows are aluminium framed with clear polycarbonate windows. Roofing is custom orb roof sheeting with battens and sisalation, with the roof insulation having an R-Value of 2.5.

3 Methodology

This section outlines the methodology followed through the life cycle analysis of the standardised housing designs used in desert areas of the Northern Territory. In satisfying the DTS criteria of the BCA, only those design changes that would be useful to inhabitants were selected. The addition of full verandas would not only provide extra shading for windows but would also provide additional outdoor living space in a hot climate. Olofsson et al. [10] did not classify low energy buildings as efficient if the low energy was achieved by lower occupancy rates or as a result of 'not providing the services that should make the place pleasant'.

3.1 Deemed-to-Satisfy Criteria (DTS)

The proposed energy efficiency changes are outlined in the BCA regulation document [2], which provides direction through the DTS analysis process. The ventilation levels, glazing of windows, and thermal performance of roofing and external wall structure all require DTS analysis. The ventilation levels are calculated as the ratio of the window area to the floor area of habitable areas and are compared to a minimum acceptable level. This value is then used to calculate the thermal conductance and solar heat gain constants in order to analyse the glazing performance of all windows. The total R-Value of all external walls is also analysed, and when found to be below the minimum acceptable value, the BCA regulation document provides guidance on increasing the R-Value or improving the shading of all external walls [2]. In calculating the amounts of materials needed, a detailed bill of materials and design specifications provided by the building contractor specific to each design were used as well as product specific data provided by the relevant manufacturers.

3.2 Embodied Energy Analysis

The embodied energy incurred through satisfying the BCA thermal resistivity DTS criteria of external walls was calculated and compared to the operating energy of the house over its life cycle. To simplify this process, the embodied energy required to upgrade the houses was compared to the energy savings achieved if evaporative air conditioner use was reduced by 50%. This figure was chosen to be representative of a significant decrease in active climate control use.

3.3 Nationwide Housing Energy Rating Scheme (NatHERS)

NatHERS is a computational modelling program designed to measure the heat transfer and subsequent energy rating of Australian homes used within the BCA. NatHERS version 2.32a was used to assess energy savings achieved through the design changes proposed in this study. The cooling energy savings from NatHERS were compared to those obtained from the embodied energy life cycle analysis and the differences explored. While NatHERS has been found to have a number of shortcomings with respect to ventilation [11], the star ratings shown in Table 35 may increase when analysed with future software packages that do allow for ventilation.

4 Results and Discussion

The results obtained through both an embodied energy analysis and NatHERS energy rating of the standardised designs are presented in the following two sections.

4.1 Embodied Energy Results

Reviewing the standardised houses under the DTS provisions yielded the results shown in Table 34. The total ventilation levels of the standard housing designs shown in Table 34 are greater than the minimum values specified under the upgraded BCA DTS provisions (minimum of 7.5% to be considered as having standard ventilation, or 22.5% to be considered as having high ventilation levels). The total conductance of the windows is within limits, as are the solar heat gain constants indicating that the glazing of all windows is satisfactory. The conductance of walls in both cases is above the maximum total conductance allowed under the new DTS provisions. This result led to the embodied energy analysis of both redesign options.

Table 4.1: Standard designs' DTS provision results

Characteristic	DTS value	Actual Value [12]
Design One		
Total ventilation area to floor area ratio of habitable areas	Min 7.5% for standard or 22.5% for High Ventilation	26.2%
Conductance	Max 193.60W/K	106.10W/K
Solar heat gain value	Max 15.73	4.09
Total conductance of walls	Max 270.50 W/K	395.77 W/K
Design Two		
Total ventilation area to floor area ratio of habitable areas	Min 7.50 % for Standard or 22.5% for High Ventilation	20.09%
Conductance	Max 222.4W/K	135.16W/K
Solar heat gain value	Max 13.90	3.67
Total conductance of walls	Max 304.86 W/K	440.48 W/K

The first, simpler solution, involving the addition of a layer of insulation behind an internal layer of plasterboard utilised galvanized steel vertical batons covered with sisalation (polystyrene insulation backed with aluminium foil) and plasterboard on the internal side of all external facing walls. However, this is not an option consistent with the general robustness of the house, since plasterboard is relatively fragile, it is only considered here as a representative solution. As an alternative, provisions for improving the shading of each house were explored through the extension of existing North and South facing verandas to surround the entire house. The embodied energy values and cost [13] of the two redesign options are shown in Table 35 along with further results.

The values of embodied energy used were supplied by Treloar [14] and were calculated using process data from the Australian Life Cycle Assessment (LCA) database, other public domain databases and an input-output model [15]. These values, however, are not site specific to the NT or to remote communities. Due to the long transportation distances involved, it is expected that the actual values of embodied energy would increase beyond these estimates. The roof sheeting used in the standardised designs was light grey custom orb roof sheeting. The typical absorbtance value of this colour is 0.45. The total R-Value of roofing construction used is 2.2 when the typical surface absorbtance value is less than 0.55. Because the ceiling insulation had a value of R2.5, no further changes were required to the roofing material to meet the new DTS provisions of the BCA.

Anecdotally, the life cycle of these houses is typically very short, averaging less than 10 years before the house either needs to be retrofitted or rebuilt. This is a very short operational energy saving payback period for the initial embodied energy investment in the additional materials. Several other studies examine the energy lifecycle of building designs over 50 year periods [6, 16] allowing energy savings to be made over a longer period of time, which is not possible in this circumstance.
The Australian Bureau of Statistics [17] projects that the residential energy consumption for 2009-2010 will be approximately 19.7GJ/capita (per annum). Based on an average minimum of 5 people per household (in some remote NT Aboriginal communities such as Wadeye, an average of 16 or 17 people live in each house [18]), this is in the range of at least 100GJ per annum. The housing designs examined in this study consumed an average of 2000 GJ of embodied energy in their construction [12]. Based on a household of 5 residents, the operational energy would only exceed the embodied energy of the house after approximately 20 years. . With residents in remote desert areas relying more heavily on air conditioning and for longer occupational periods, the operational energy will increase significantly. Thus, if the use of air conditioners can be reduced, the payback period may decrease as a result of larger operational energy savings. Adjusting the design of each house to satisfy the DTS provisions stipulated in the new BCA guidelines such as through the addition of full verandas will require approximately 400GJ of embodied energy [12].
Desert areas tend to use evaporative air conditioners as the primary form of active climate control. In the desert regions, the Bonair B23 is typical for conditioning houses of this size and runs on approximately 800W [19], consuming an average of 12.6GJ of energy per year (based on 12 hour operating days).
When compared to the amount of energy required to run an evaporative air conditioner, the embodied energy increase incurred is significant. If the DTS provisions result in the evaporative cooler being operated for half the time, then the energy savings are not comparable (saving 6GJ per annum say if the cooler is used for half the time in comparison to 400GJ for a veranda extension). These results contraindicate the implementation of the proposed BCA guidelines.

4.2 NatHERS Energy Rating Results

The NatHERS analyses of the two redesign options are shown in Table 35. Using NatHERS, both houses are currently of a 5 star energy rating; consuming approximately 24GJ of cooling energy (no heating energy is required). Adding insulation does not change this star rating and decreases the total cooling energy consumption slightly. Adding full verandas more than doubles the total cooling energy savings. Theoretically, the cooling energy savings shown in Table 35 would take 60 to 80 years to repay the extended verandas, but up to 200 years to repay the additional insulation to external walls. NatHERS, however, does not account for the convective cooling effect of ventilation of ceiling fans, significant due to the minimal energy consumption of ceiling fans.
The cooling energy loads generated by NatHERS do not correspond to the cooling energy loads of the actual air conditioner type used in these houses. Similarly, the standard set of occupational behaviour patterns used by NatHERS does not correspond to those of these regions specifically. NatHERS also uses weather data for a limited number of locations across Australia. As a result of these assumptions and inaccuracies inherent in NatHERS, the number of years required to repay the initial embodied energy investment is only used as a basis for comparison between the two reconstruction options. Olofsson et al. [10] agrees that although modelling is a useful tool to simulate the ideal performance of a building design, it ignores information about actual site-specific conditions and of course the ‘important aspects of construction, operation and maintenance’.

4.3 Outcomes

Summaries of the two redesign options for the standard housing designs are detailed in Table 35.
It has been assumed that the energy savings due to decreased use of the air conditioner are the same for both options. Based on the lower NatHERS energy consumption result of the full veranda option, it can thus be assumed that the energy savings of this option will be greater than those of the insulated wall option. Based on these results, increasing verandas to surround the full perimeter of the house may be the most expensive option and would require a greater investment in embodied energy, but the energy savings will generally be greater and thus the payback period will be shorter. In this case, only design two has a shorter pay back period based on NatHERS energy savings. This is again a critical factor considering the short life span of the house design.

Table 4.2: Summary of results for the standardised designs

	With additional insulation	With full verandas
Design One		
Embodied energy increase (GJ)	120.65	330
Cost (AUS$) [13]	5341. 00	14604.00
Energy savings of decreased air conditioner use (GJ)	6	6
Embodied Energy Payback Period	20.1 years	55 years
NatHERS Star Rating	5	5
NatHERS cooling energy (GJ)	22	19.62
NatHERS Energy savings (GJ) compared to original	1.90	4.28
NatHERS Payback period	64 years	77 years
Design Two		
Embodied energy increase (GJ)	123.58	366.40
Cost (AUS$) [13]	5460. 00	18276.00
Energy savings of decreased air conditioner use (GJ)	6	6
Embodied Energy Payback Period	21 years	61 years
NatHERS Star Rating	5	5
NatHERS cooling energy (GJ)	23.67	21.76
NatHERS Energy savings (GJ) compared to original	0.62	2.53
NatHERS Payback period	199 years	145 years

5 Concluding remarks

This study examined the life cycle analysis of two IHANT housing designs used in the desert regions of the NT based on the proposed stringency increases to the BCA. The primary alteration to the housing designs satisfying the regulations is full perimeter verandas. This option also satisfies cultural requirements, allowing inhabitants to utilise the veranda as an extended outdoor living space. A roof extension alone may be pursued, which would reduce the embodied energy investment, and thus the energy pay back period of the extension. However, further investigation would be required to assess residential satisfaction and probable utilisation of this option. Other possibilities are to redesign the houses through or promoting vegetation for natural shading.

This study has attempted to provide an indication of the relative merits of the proposed changes to the BCA in reference to NT desert designs. A life cycle analysis encompassing the embodied energy, the energy efficient measures and resulting active energy consumption have shown that upgrading housing designs in desert areas is not worthwhile under the new BCA DTS criteria, as embodied energy investments are unlikely to be repaid within the life-span of these houses, based on the reduced need for evaporative air conditioners. However, there is currently a shift toward the use of refrigerative air conditioners due to the low water quality in desert areas, which degrades evaporative air conditioners [21]. Refrigerative air conditioners use significantly more energy than evaporative air conditioners and will alter the life cycle energy analysis of this paper.

The cost of electricity generation in these remote communities was not factored into the operational energy costs. Remote communities in the NT typically rely on diesel generators, which can cost from $0.20c to $2.00 per kWh when compared to $0.08 to $0.16 per kWh in larger towns supplied by the national electricity grid [20]. These figures will impact on the fiscal context of ESD. The social context of ESD was also only considered in a limited fashion. Broader cultural considerations, occupancy patterns and user consciousness need to be addressed to ensure the ongoing successful implementation of such design changes and to maximize resulting energy savings.

This study will need to further investigate the regular maintenance and retrofitting energy requirements inevitably required after the life cycle to determine their magnitude relative to the initial embodied energy investment and subsequent operational energy use. In this way, a more accurate determination of the downstream effects of the BCA regulations in desert areas may be determined.

It is equally important for a standard methodology of embodied energy analysis to be established [9] so that increasingly accurate studies may be carried out and compared with similar studies nationally and internationally. In this way the results of such studies can be more beneficially applied.

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