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Life Cycle Analysis of Energy Efficient Measures in Desert Housing Designs

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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 2 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 1. The total ventilation levels of the standard housing designs shown in Table 1 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 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 2 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 2. 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 2 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 2.
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 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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