Investigation of energy performance of a rammed earth built residential house in sub-tropical, tropical and temperate climates of Australia

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Abstract

Purpose / Context - This paper will examine the predicted energy consumption (MJ/m^2) of a residential house made of rammed earth in sub-tropical, tropical and temperate climates of Australia using design data of the building fabric and glazing.

Methodology - To improve energy performance of this building project, thermal simulation and comprehensive simulated data analysis were conducted, using BERSPro and according to the NatHERS Technical Note. This includes detailed analysis of heating and cooling energy (MJ/m^2). Different constructions, including rammed earth wall, lightweight wall and heavy weight wall were used as building fabrics to achieve a cost effective, energy efficient and sustainable solution

Results- Thermal performance of rammed earth is similar to other constructions in sub-tropical and tropical climate. No insulation is required for a rammed earth built house in tropical climate for the proposed floor plan. However, it requires more insulation with rammed earth in external walls to achieve NCC-complaint 6 star rating in temperate climate.

Key Findings / Implications – The research highlighted that the rammed earth in external walls of the proposed house achieved minimum 5 stars in sub-tropical climate and minimum 6 stars in tropical climate without any changes of other building elements i.e. insulation, glazing, awning. On the other hand, rammed earth house in temperate climate didn't achieve 6 stars without changing other building elements.

Originality - Two research questions are highlighted in this study (a) What would be the thermal performance of the rammed earth compared to other constructions in these three climate zones (b) What are the changes required to any building element for energy performance improvement of this building project? A comparative study for a rammed earth house has not being conducted before this research in climate zones 1, 2 and 6 using the NatHERS Technical Note and BERSPro software.

Keywords - Energy, Rammed earth, house, climate, Star rating

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1. Introduction

Buildings worldwide account for a surprisingly high 40% of global energy consumption (Energy Efficiency in Buildings, 2009). Both residential and commercial buildings account for approximately 23% of Australia's greenhouse gas emissions (Building and Construction, 2011). In 2014, Space conditioning accounted for 40% of residential energy use in Australia (Energy Rating, 2015). Building fabric, specially type of building construction and glazing play a key role to reduce the energy consumption of the building. Ciancio and Beckett (2009) highlighted the use of sustainable building material such as rammed earth wall to reduce the use of HVAC and to achieve a comfortable living space. Rammed earth walls have low thermal resistance but high thermal mass compared to light weight construction. However, thermal resistance is not only responsible for comfortable living (Allinson & Hall, 2007; Faure & Le Roux, 2012). Studies in NSW, Australia and in West Argentina, Galcia and Spain (Page et al. 2011; Larsen et al. 2002; Orosa & Oliveira 2012) indicated that the high thermal mass but low thermal resistance provides better thermal performance and lower heating and cooling demand than high thermal resistance material.

Energy consumption of a rammed earth built office building was studied in Churles Sturt University in NSW, Australia using questionnaire survey and simulation (Taylor et al. 2008). A case study of rammed earth built small commercial office was investigated in climate zones 1,2 and 6 of Australia using Energyplus thermal simulation which demonstrated that rammed earth was a better performer than some wall types in sub-tropical, tropical and temperate climates (Hasan & Dutta, 2015). A hypothetical un-insulated rammed earth built house was investigated by AccuRate software in climate zone 3, 5 and 7 of Australia. (Dong et al. 2014). However, a comprehensive study on rammed earth built house and its energy consumption scenario and compliance with building code was not investigated in a subtropical, tropical and temperate climate using NatHERS Technote and BERSPro.

In this study, energy performance in terms of heating and cooling energy total (MJ/m^2) of a rammed earth (R value 0.32 m^2.K/W and thermal mass 1285 KJ/m^3K) built house was examined using design data of the building fabric and BERSPro simulation. As per Queensland development code (QDC MP4.1) and as per Part 3.12 of the National Construction Code, NCC 2016, a new built house building must achieve 6 Stars. To serve this purpose, design compliance for energy efficiency of a single storey residential house was examined in BERSPro v4.2 thermal simulation with different construction details in external walls including lightweight, heavy weight and rammed earth construction. The energy performance of the rammed earth built house was also compared with light weight and heavy weight constructions in sub-tropical (climate zone 2), tropical (climate zone 1) and temperate climate (climate zone 6) of Australia.

2. Methodology

NatHERS-accredited software calculates the energy required for artificial heating and cooling, based on standardized assumptions of occupancy, internal heat loads and thermostats (NatHERS, 2016). This allows relative comparisons between buildings with 6 Stars (out of 10) representing a house that will be uncomfortable less than a house that scores 4.5 Stars. BERSPro Version 4.2 that uses Chenath V2.13 and simulation engine 2.2, has been used in this study to investigate the energy performance of a rammed earth built house.

First, all architectural design data including floor plan, elevations, sections, site plan, wall and roof constructions, glazing (all external glass doors and windows) and finishes were collected. The floor plan of the house is shown in Figure 1.

For the house in a sub-tropical climate, the location selected was Brisbane (-27°S 153°E), the tropical climate location was Cairns (-17°S 146°E) and the temperate climate location was Melbourne (-38°S 145°E). The initial assumptions for the house are listed in Table 1. Regulatory credits of 1.5

Stars apply for a complying outdoor living area with minimum R1.5 insulated roof and 1 kW PV panel as per QDC MP4.1. All glazing were sliding windows and doors. Using construction details as per Table 2, 2D modelling and zoning of the designed building in BERSPro V4.2 software was conducted (Figure 2). The zoning procedure followed the NatHERS Technical Note 1.2.

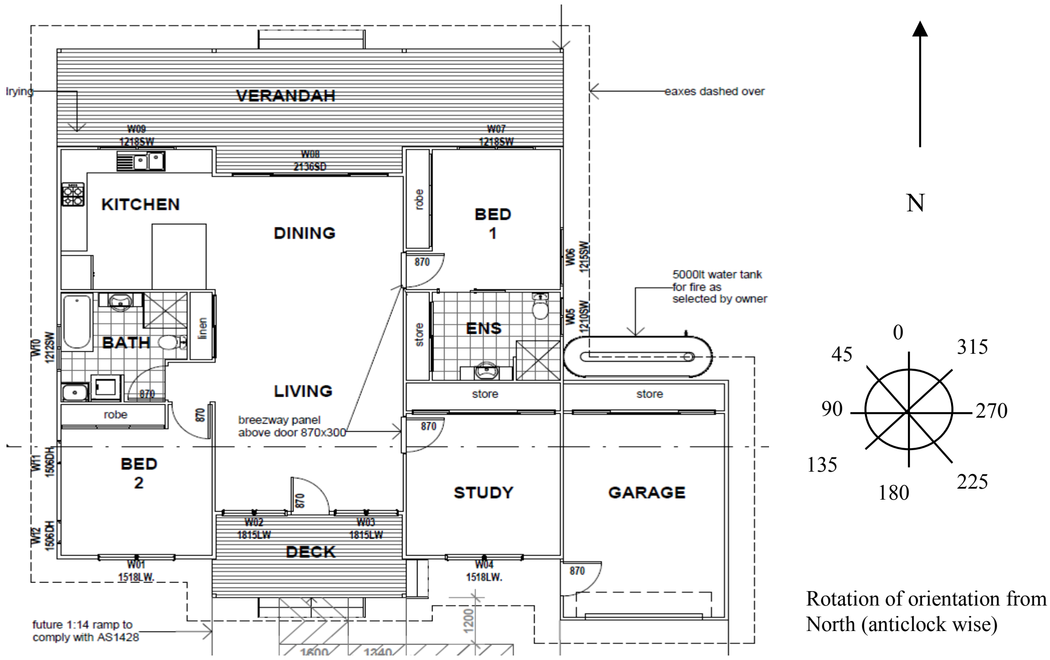

Figure 1: Floor plan of the house

Table 1: Initial assumptions for the house (climate zones 1 and 2, Queensland)

Element	**Description**
Floor area	House 116 m^2, Veranda 32 m^2, Garage 24 m^2, Deck 9 m^2
Complying outdoor living area	+ 1kW solar panel = 1.5 Star credit
Roof	Metal, R1.0 insulation with foil-backed, including verandah
Glazing	Low e medium tint glass in aluminium frame (Uw 4.66, SHGCw 0.44)
Windows and doors	All sliding, 45% opening
Ceiling fans	No ceiling fans
External colours	Medium colour external walls and roof (solar absorptance 0.5)

The star credits were not required for climate zone 1, tropical Queensland.

Five different types of wall constructions as shown in Table 2 were used in this study.

Table 2: Base case constructions for external walls used for climate zones 1, 2 and 6

External wall construction type	Added insulation
300 mm Rammed earth	no insulation
190 mm concrete	no insulation and no lining
Cavity panel metal cladding	no insulation
200 mm Straw Board	no insulation
Brick veneer wall	no insulation

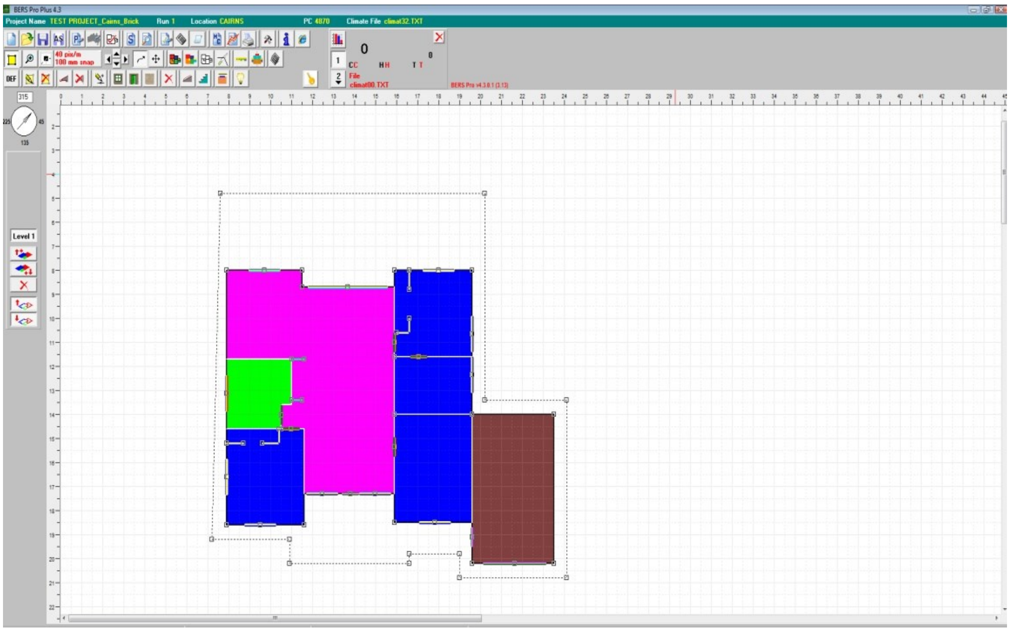

Figure 2: 2D model of the house in BERSPro v4.2

The building orientation was rotated at 0, 45, 90, 180, 225, 270 and 315 deg. In each case, the energy number (MJ/m^2) was examined and the rammed earth house was compared with other constructions. A minimum of 4.5 Stars in climate zone 2 (sub-tropical) was obtained for each construction in the worst orientation. This allowed the maximum regulatory star credit of 1.5 Stars. This insulation was then the base design for further orientation analysis and comparison. In climate zone 1 (tropical) the added insulation for worst orientation for any construction was determined to achieve 6 Stars. No wall insulation was added to the external walls if it was not required.

The initial design for the climate zone 6 (temperate) was as per Table 3. The design was allowing more sunlight by removing the veranda from the north side and using low e clear glass instead of using low e tint glass. The house was simulated using the various wall construction types shown in Table 2 to achieve 6 Stars requirement as per NCC. If any construction type didn't achieve 6 Stars without insulation, then insulation was added for the worst orientation to reach 6 Stars. The results of the rammed earth-built house were compared with other constructions. The process described is outlined in Figure 3.

Table 3: Initial assumptions for the house (climate zone 6, Victoria)

Element	Description
Floor area	House 116 m^2, Garage 24 m^2, Deck 9 m^2
Complying outdoor living area	Verandah removed to allow more sunlight for the house
Roof	Metal, R1.0 insulation with foil-backed
Glazing	Low e clear glass in aluminium frame (Uw 4.7, SHGCw 0.63)
Windows and doors	All sliding, 45% opening
Ceiling Fans	No fans
External Colours	Medium colour to external walls and roof (solar absorptance 0.5)

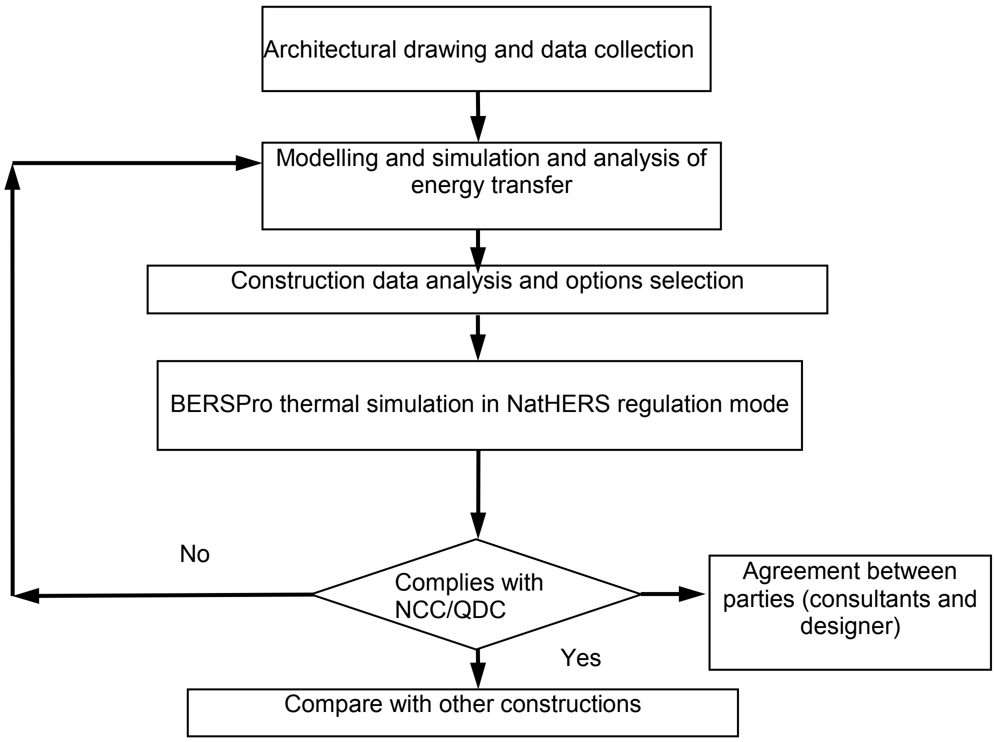

Figure 3: Methodology for obtaining a NCC/QDC-compliant solution

3. Results and discussion

3.1 Rammed Earth built house in Sub-tropical climate

From Figure 4, it was observed that rammed earth walls in the proposed house demonstrated energy numbers between 47 MJ/m^2 and 54 MJ/m^2 in all orientations. The performance numbers were equivalent to 5.5 Stars (48 MJ/m^2) and 5 Stars (55 MJ/m^2) energy rating. The changes of building elements from the base case were shown in Table 4. Rammed earth walls which didn't require any insulation to achieve minimum 5 stars had the better energy performance than the concrete wall and brick veneer wall.

Brick veener wall with no insulation showed the worst energy performance of all wall types. Cavity walls and straw board both required minimum R2.0 insulation to achieve minimum 5 Stars (55 MJ/m^2) to maximum 6 Stars (43 MJ/m^2) requirement, which demonstrated better energy performance than any other wall types. Insulation in these walls enhanced the energy efficiency star rating (e.g. from 4 Stars to 6 Stars).

Table 4: Changes of building elements from the base case for sub-tropical climate

External wall construction type	Changes from base case of Table 2
300 mm rammed earth	No changes
190 mm concrete	No changes
Cavity panel metal cladding	+ **R2.0 wall insulation**
200 mm straw board	+ **R2.0 wall insulation**
Brick veneer wall	No changes

The difference between rammed earth and cavity walls with insulation R2.0 was around 10MJ/m^2. If insulation is added to rammed earth walls, then it can provide similar energy numbers to the insulated cavity walls. From the base case (Table 1 for climate zone 2 and Table 2) and Figure 4, it was obvious that rammed earth walls without any insulation was an alternative option to obtain energy efficient building fabric in sub-tropical climate compared to other constructions types.

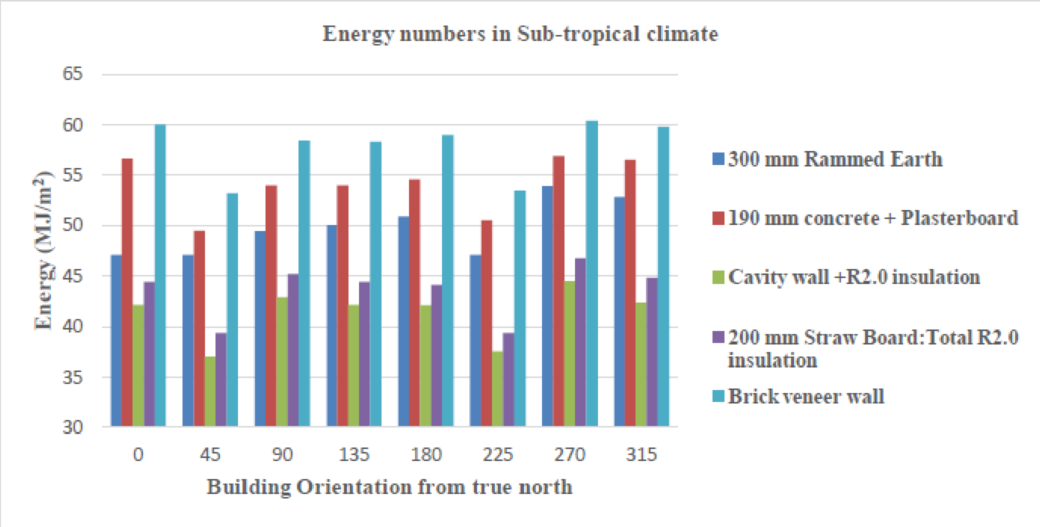

Figure 4: Energy perfromance of the house for different constructions in external walls in sub-tropical climate

3.2 Rammed Earth built house in tropical climate

From Figure 5, it was observed that rammed earth walls demonstrated better energy performance than the concrete walls, cavity walls with insulation, and brick veneer walls.The proposed house with the rammed earth walls demonstrated energy numbers between 106 MJ/m^2 and 118 MJ/m^2 in all orientations. The performance numbers were equivalent to 6.5 Stars (117 MJ/m^2) and 6 Stars (128 MJ/m^2) energy rating. Rammed earth walls achieved minimum 6 stars and maximum 6.5 stars without any added insulation. The changes of building elements from the base case are listed in Table 5. These changes include lowest additional cost options for the worst orientation. Unlike the sub-tropical climate, the building with cavity panel walls (in Table 5) did not need added wall insulation; but the roof required additional R1.0 insulation (total R2.1 insulation) and the glazing needed changing to low e heavy tint glass with aluminium frames (Uw 4.8, SHGCw 0.36).

Table 5: Changed building elements from the base case for tropical climate

External wall construction type	Changes from base case of Table 2
300 mm rammed earth	No changes
190 mm concrete	No changes
Cavity panel metal cladding	**R1.0 insulation to roof** + **low e heavy tint glass**
200 mm straw board	+ **R2.0 wall insulation**
Brick veneer wall	No changes

Figure 5 shows that rammed earth walls in a tropical climate without any insulation, was an efficient alternative building fabric compared to other construction types. Insulated straw board walls showed the best energy performance of any other wall types. However, the straw board with no insulation demonstrated less than 5 Stars energy rating similar to sub-tropical climate. The difference between rammed earth and straw board walls with R2.0 insulation was around 8MJ/m^2. The minimum star rating observed in the tropical climate was 6 Stars, whereas 5 Stars energy rating was observed in the sub-tropical climate.

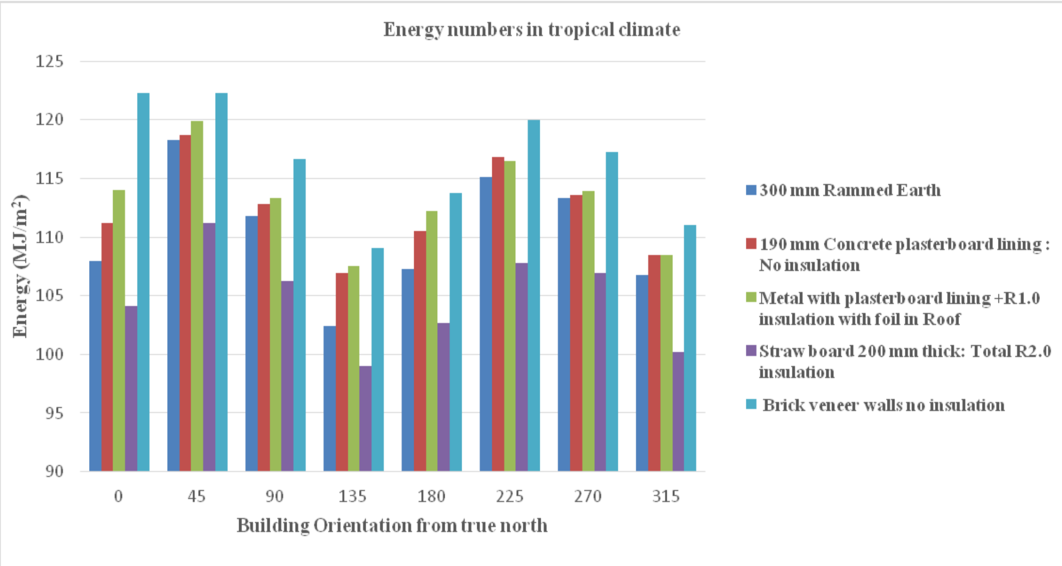

Figure 5: Energy performance of the house for different constructions in tropical climate

3.3 Rammed earth built house in temperate climate

In temperate climate (e.g. Melbourne), the minimum requirement for a new house is 6 Stars. The star credits are not applicable for climate zone 6. Table 6 lists the added insulation required in the temperate climate. The rammed earth wall thickness was reduced 100mm to compensate for the thickness of the added insulation. Without extra insulation in external walls and additional insulation to roof, no constructions achieved minimum 6 stars energy rating (130 MJ/m^2) for the temperate climate. The added insulation are examples including lowest cost options. Different combinations of R-value to walls and ceiling/roof may have given similar results.

Table 6: Changed building elements from the base case for temperate climate

External walls type	Changes from base case (Table 4) to external walls	Changes from base case (Table 4) to other elements
300 mm rammed earth	200 mm rammed earth +R3.0 insulation	R2.0 insulation to roof or ceiling
190 mm concrete	R2.5 insulation	R2.0 insulation to roof or ceiling
Cavity panel metal cladding	R3.0 insulation	R3.5 insulation to roof or ceiling
200 mm straw board	R2.0 insulation	R2.5 insulation to roof or ceiling +R1.0 to garage partition
Brick veneer wall	R2.0 insulation	R3.0 insulation to roof or ceiling +R1.0 to garage partition

The energy numbers for the changes of building elements of the proposed house were illustrated in Figure 6. The rammed earth built house with insulation demonstrated the lowest energy numbers in 90 deg orientation compared to other construction types. The second lowest number for the rammed earth was observed in 315 degree rotation, highlighting the benefit of passive solar design.

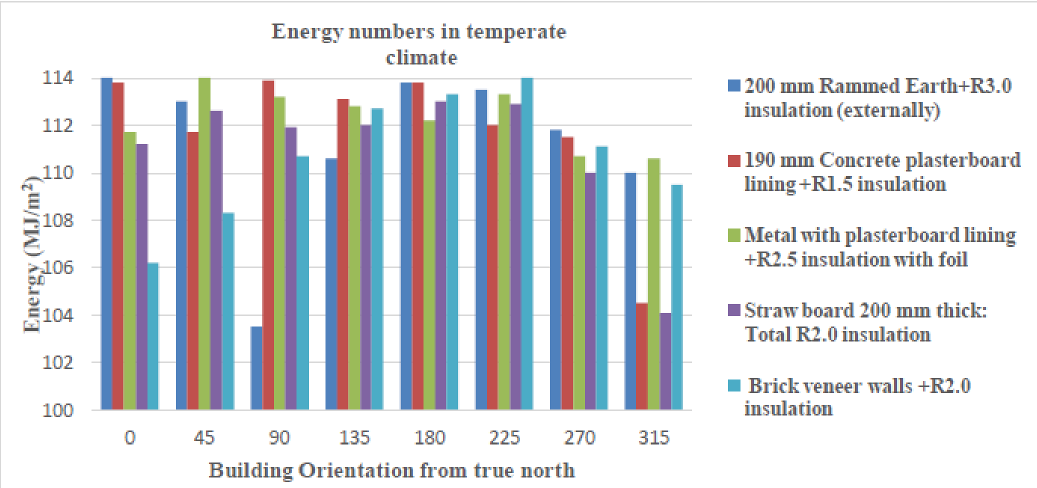

Figure 6: Energy perfromance of the house for different constructions in external walls in temperate climate

From 135 to 270 degree orientation, the energy numbers of all constructions were observed more than 110MJ/m^2. Brick veneer walls demonstrated better energy performance in 0 and 45 degree orientation. Straw board walls showed better energy performance in 0 and 45 degree orientation compared to other constructions. However, more insulation in roof and garage partition walls were required to achieve 6 stars requirement for the house as shown in Table 6.

Overall, external insulation in rammed earth walls depicted the similar energy performance nature compared to other constructions. Though the insulation was required for the rammed earth built house, the insulation requirement for the roof/ceiling in the cavity panel, straw board and brick veneer built house was higher than rammed earth built house as shown in Table 6.

4. Conclusions

For this case-study building, to comply with the Code a number of changes in building elements were required in a temperate climate. Apart from designs with lightweight external wall construction, no changes of other building elements were required for sub-tropical and tropical climates. The building orientation, glazing, insulation in roof and ceiling and overall shading have a significant effect in achieving the desired energy rating and thermal comfort in any climate. The difference between optimum and worst orientation was 0.5 to 1.0 Stars. From the results of different construction types, it can be concluded that no added wall insulation for rammed earth built house provided better energy performance in tropical and sub-tropical climates than in a temperate climate.

The level of added insulation listed was the minimum necessary to comply with the Code requirements. More wall insulation can improve the energy efficiency, but it may be more cost effective to add ceiling insulation or tint glazing depending on orientation and climate.

The 6 Stars for the tropical climate and 5 Stars in the sub-tropical climate can be achieved for a rammed earth built house with no added external wall insulation. Without additional insulation in external walls and roof, a rammed earth built house didn't achieve 6 Stars in a temperate climate. Rammed earth walls were confirmed as an effective, energy efficient construction in sub-tropical and tropical climates because of the diurnal temperature range. In cool temperate climate, rammed earth external walls with external insulation acted as thermal energy storage for passive heating.

Overall, rammed earth demonstrated its thermal potential for use in external walls as an alternative to lightweight and heavy weight constructions. If rammed earth is used correctly in the right climate, thermal mass can delay the heat flow through building envelope, which is effective to reduce cooling demand in tropical and sub-tropical climates, and heating demand for temperate climates. Though the energy performance of rammed earth is better in a tropical climate than a temperate climate, higher thermal discomfort may occur in a tropical climate.

To minimise thermal discomfort, proper use of cross flow ventilation and controlled air movement by ceiling fans are important consideration for the new house design in tropical and sub-tropical climates. No ceiling fans were used in these thermal performance simulations. Use of ceiling fans in combination with a rammed earth built house can compensate for some thermal discomfort in tropical and sub-tropical climates.

A more comprehensive case study on rammed earth is required regarding buildability, availability, cost and thermal comfort in all climate zones of Australia. In terms of environmental impact, rammed earth is a low greenhouse gas emission product. Australian builders, house owners, architects, technologists and governments can work together and establish a sustainable technology plan to encourage people to use this environmentally-friendly construction in newly built houses.

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