International Conference on Mechanical, Industrial and Energy Engineering 2014
26-27 December, 2014, Khulna, BANGLADESH

ICMIEE-PI-140393

Thermal Performance of a New Residential House Wall System

Fayez Aldawi [1], *Firoz Alam* [2,*] , *Harun Chowdhury* [2]
[1] Department of Mechanical Engineering and Industrial Engineering, Yanbu Industrial College, Yanbu, SAUDI ARABIA
[2] School of Aerospace, Mechanical and Manufacturing Engineering, RMIT University, Melbourne, AUSTRALIA

ABSTRACT
The residential housing sector consumes a significant amount of fossil fuel energy and thereby the sector generates a large percentage of greenhouse gas emissions that contribute to global warming and climate change. At present, approximately 40% of the total household energy used is required for space heating/cooling and a substantial amount of that energy is lost through the house walls. Additionally, the floor space area and volumetric dimension of modern residential houses are increasing at a constant rate in most developed countries including Australia. This additional space also requires energy for heating and cooling. Therefore, the energy consumption for heating and cooling and greenhouse gas emissions will be increasing rapidly. A continuous upward energy consumption trend in residential housing sector worldwide will continue for years to come unless energy efficient and carbon neutral house wall systems are developed. One of the biggest challenges is to develop a smart house wall system made of thermal mass and insulation materials that can provide reduced energy needs for on-going heating and cooling with lower carbon footprint as most house wall construction materials are very energy intensive and have large carbon footprints. In order to develop a new energy smart house wall system, a study has been undertaken on thermal performance of two house wall systems (one is currently used conventional brick veneer house wall and other is an alternative house wall). The thermal performance (heat gain or loss through the wall) has been determined using computational modelling and experimental measurements. The economic analysis of both house wall systems has also been carried out. The effects of various climate conditions on these two house wall systems have also been determined. The findings indicate that the new house wall system provides better thermal efficiency than that of currently used conventional house wall.

Keywords: House wall system, thermal performance, energy efficiency, thermal mass, insulation material.

1. Introduction

The expansion of global economy and population growth has led to the expansion of cities and urbanisation. This expansion has dramatically increased not only the demand for new buildings and houses but also energy need. For example, in 2020, the energy consumption in the Australian residential house sector will be almost 467 PJ compared to 299 PJ in 1990 which means the demand will increase by over 50%. The number of residential houses is expected to be around 10 million in 2020 compared to 6 million in 1990. In most developed countries including Australia, the demand for residential buildings has been rapidly increasing due to population growth [1, 2]. More buildings and houses need more energy. Fig 1a illustrates the increasing trend for the Australian housing sector energy consumption for coming years. Additionally, the average floor space of new Australian residential houses is increasing progressively. As a result, the energy consumption is also increasing for the additional space heating and cooling. This additional energy consumption leads to higher CO_2 emissions (see Fig 1b) [3].

Each residential household consumes nearly 40% of the total energy for ongoing heating and cooling as shown in Fig. 2. Therefore, heating and cooling are considered to be an important factor for the reduction of energy consumption. Governments and regulatory authorise in many countries including Australia have formulated policies and enacted laws to improve energy efficiency in the residential housing sector [4, 5].

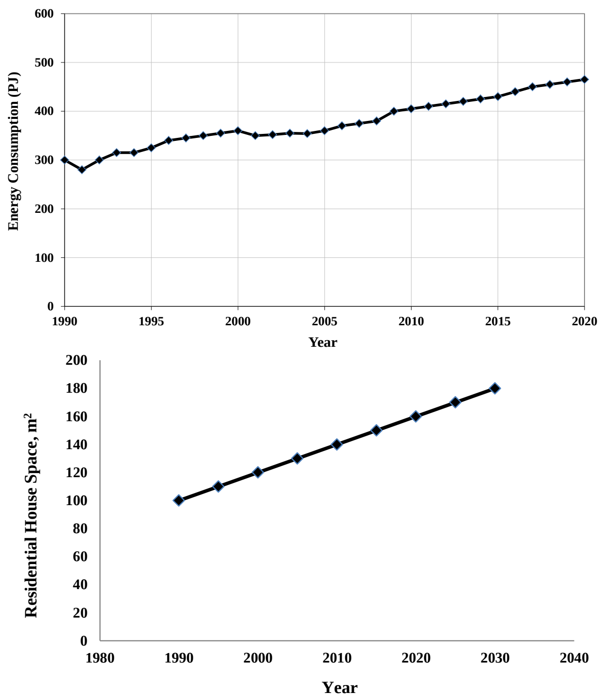

Fig.1 (a) Australian housing sector energy consumption; (b) residential house space increasing

* Corresponding author. Tel.: +61 3 9925 6103
E-mail address: firoz.alam@rmit.edu.au

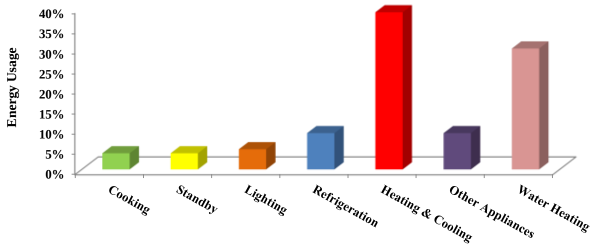

Fig.2 Australian household energy usages at residential buildings

Many researchers have investigated sustainable house construction systems using various wall materials, but scant information is available for zero carbon wall structure. The present state of knowledge is still inadequate for such a treatment because most researchers in the past have focused on energy savings in the building operation. Researchers paid little focus on energy saving by improving house construction systems using smart materials [6-10]. In this study, we have undertaken thermal performance modelling of two residential house wall systems: a conventionally used house wall system (namely brick veneer) and a non-conventional house wall system. The thermal performance modelling was conducted using commercially available software.

2. Energy load and climate zone

2.1 Energy loads for Australian localities

According to the state and territory government regulations since 2008, all the new residential houses must comply with certain minimum energy consumption measured against a star rating for ongoing heating and cooling. Australia's 69 micro climate zones have been rated with a star rating for their ongoing needs for heating and cooling. These scale ratings are called Star Energy Rating at a scale of 0 to 10. For example, to comply with 6 star energy rating, the residential house located in Melbourne metropolitan should not require more than 114 MJ/m² per year for the space heating and cooling [4]. Fig 3 illustrates the star energy rating for the required heating and cooling energy of Australian cities [4].

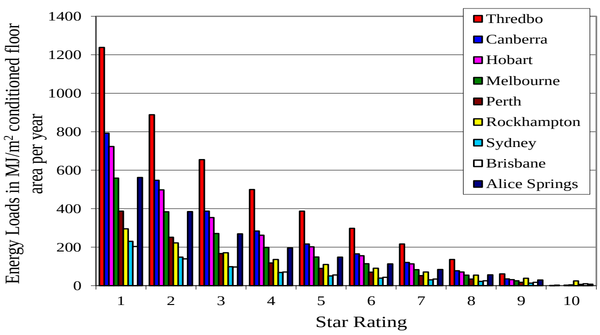

Fig.3 Star energy ratings for different cities across Australia

2.2 Australian climate zones

The climate in Australia varies significantly starting from arid, middle, tropical and subtropical zones. Australian climate zones are classified into six main climate zones based on climate conditions, metrological data and solar radiation. However, for better representation and energy consumption estimation, the entire country has been subdivided into 69 micro climate zones with a certain amount of energy required for heating and cooling. The energy requirement for the conventional and the new house wall systems were modelled for 6 major cities. These cities are Melbourne, Brisbane, Darwin, Hobart, Adelaide and Sydney. These cities experience moderate, tropical, subtropical, arid climates and humid climates (see Table 1).

Table 1 Climatic weather zones for different cities and states in Australia

City	State	Weather description
Melbourne	VIC	Mid warm to warm summer, cold winter
Brisbane	QLD	Warm humid summer
Darwin	NT	Hot humid summer
Hobart	TAS	Mid warm summer
Adelaide	SA	Warm summer, cool winter
Sydney	NSW	Warm summer, mid cool winter

2.3 Importance of thermal masses

Thermal mass of a house envelope minimizes the effect of temperature fluctuations. Generally high density materials have higher thermal masses. For example, concrete and bricks have higher thermal mass as they have higher specific density and absorb and keep heat during day or night and release it gradually in 7-8 hours. High thermal mass materials take a longer time to release the heat content once the heat source is removed. On the other hand, lightweight materials with lower specific density such as timber or weatherboard have low thermal mass requiring a shorter time to release the heat content. It takes less time (2-3 hours) to store or release heat as shown in Fig 4. Therefore, the appropriate of high thermal masses for the house wall system can provide a comfortable house environment and reduce energy required for heating and cooling. In this study, the new house wall possesses higher thermal masses than the conventional brick veneer house wall system as the new house wall system is made of insulated reinforced concrete [12]. Table 2 shows thermal properties for common building materials used in Australia.

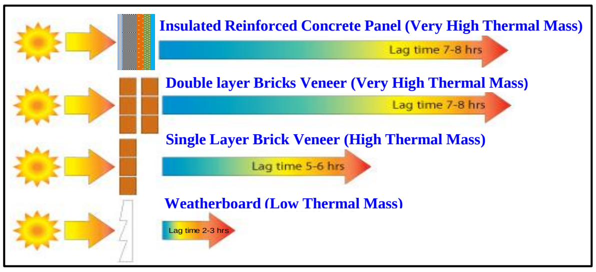

Fig.4 Heat flow through different house envelopes' thermal masses

Table 2 Building materials thermal properties

Material	Volumetric heat capacity (kJ/m³.K)	Thermal conductivity (W/m.K)
Concrete	2112	0.80
Glass	2108	0.65
Brick veneer	1484	0.80
Timber (hard)	1414	0.15
Render	900	0.25
Timber (soft)	1057	0.13
Plasterboard	924	0.25
Glass fibre batt	10.6	0.034
Polystyrene	5.5	0.035

3. Thermal performance modelling procedure

3.1 Description of simulated house

The house selected for this study is an average size residential house built in Australia. The house has three bedrooms with the total floor area and physical volume of approximately 161.33 m² and 460 m3 respectively. The house consists of living or dining area, kitchen, three bedrooms, two bathrooms, an alfresco area and a laundry. The total area of external walls, windows, floors and roof are 113 m², 32.9 m², 100.2 m² and 124.9 m² respectively. The roof slope angle is around 20º, a widely used roof inclination angle for most houses built in Australia. Windows are standard in dimensions and consist of a single glass and aluminum frame. Fig 5 illustrates a plan view of the house [13].

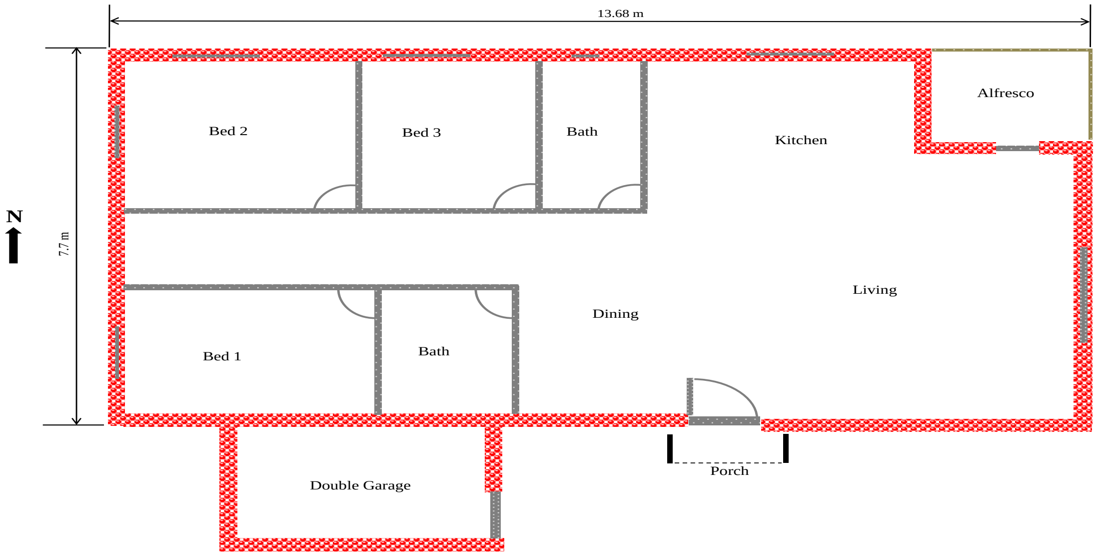

Fig.5 House plan view

The foundation of both house envelopes is the reinforced concrete and classified as “H class concrete slab”. Generally there are two types of reinforced concrete foundations popularly used in Australia. The conventional variety is generally made of reinforced concrete. However, recently a waffle concrete foundation is becoming more popular due to its better insulation properties and lower construction costs [14]. This study considered the reinforced concrete foundation only. Fig 6 shows a typical reinforced concrete floor foundation used for both houses.

Fig.6 Slab on ground

3.2 Energy performance simulation software

The most commonly used thermal performance simulation software in Australian all states and territories is AccuRate software. It was developed by the Commonwealth Scientific and Industrial Research Organization (CSIRO). It is a significantly improved version of the first generation software known as the National House Energy Rating Scheme (NatHERS). It is widely used for the simulation of house energy performance. The simulation also identifies the house energy needs for ongoing heating and cooling on a scale rating of 1 to 10. The higher the star rating, the better it is for energy saving. The software has a large library of physical and thermal data for a wide range of construction materials, and weather data for different climate zones across Australia. The software contains all functions and features of heat transfer equations that are required for all 3 modes of heat transfer (conduction, convection and radiation). It also incorporates the effects of natural ventilation in the house energy rating [15]. The physical data for the non-conventional and conventional house wall systems was fed into the AccuRate software to model the thermal performance.

4. Wall system

4.1 Conventional house wall system

The brick veneer house wall system consists of 110 mm brick veneer and 40 mm air gap from outside. The 90 mm timber frame structure is filled with 2 mm insulation foil. Fibreglass insulation with thickness of 59 mm is inserted in between the external timber structure and the internal plaster board (10mm thick.) The floor foundation is made of 100 mm thick reinforced concrete. The roof structure is made of timber with terracotta/concrete tiles with an angle around 20°. Figs 7 a & b illustrates a typical exterior brick veneer house under construction in an outer Melbourne suburb.

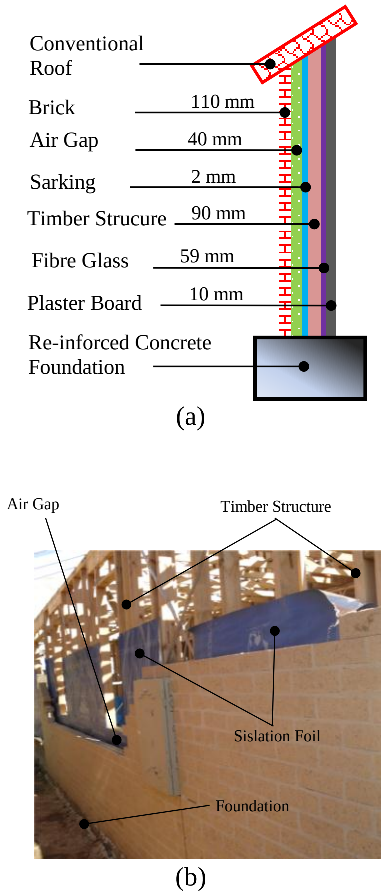

Fig.7 (a) Schematic of house wall; (b) conventional house wall systems near Melbourne

4.2 New house wall system

The new house wall system consists of 10 mm render, a layer of reinforced concrete panel with 150 mm thickness and standard 59 mm polystyrene insulation. The interior part is made of 10 mm plaster board. The physical data for the new and conventional house wall systems was fed into the AccuRate software to model the thermal performance. The schematic of the new wall system is shown in Fig 8. Table 3 provides additional details for both house wall materials and their thicknesses [13].

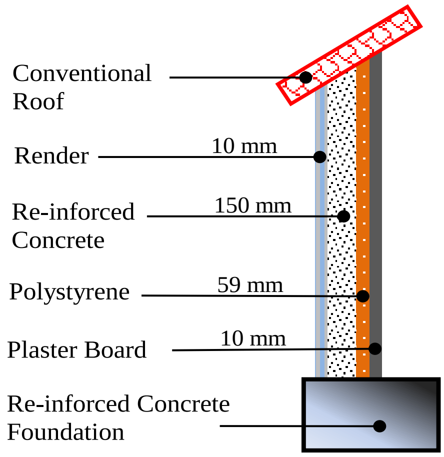

Fig.8. New house wall system

5. Thermal Performance Modelling Results

The two residential house wall systems (conventional and new wall systems) were modelled using AccuRate for 6 cities located in different climate zones. The results obtained show the thermal performances of two house wall systems. The roof structure, foundations, doors and internal walls were all kept constant for both house wall systems. The total energy requirement for the conventional and new house wall systems is shown in Fig 9. With the conventional system, Darwin has the highest total energy needs for the heating and cooling while Brisbane has the lowest energy need. Adelaide and Melbourne have similar energy requirements for the ongoing heating and cooling. Hobart's energy load is in between of other cities. On the other hand, the new house wall system used in this study needs significantly less energy for all six cities. A notably less energy (~ 30%) for the heating and cooling using the new house wall system (envelope) is required for the city of Darwin. Likewise, the heating and cooling energy reductions for other four cities were 28%, 20%, 14%, 20% and 19% (Adelaide, Melbourne, Hobart, Brisbane and Sydney) respectively. Energy required for heating and cooling, and star rating for all six cities are shown in Tables 4 and 5.

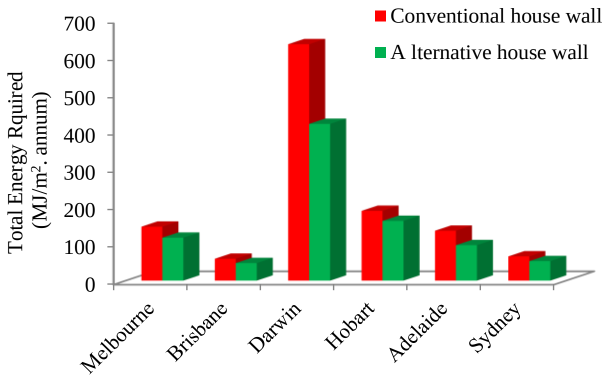

Fig.9 Total energy required for on-going heating and cooling for selected six cities

Table 3 Comparison between conventional and new house envelopes

No.	Items	Conventional house envelope	Thickness (mm)	New house envelope	Thickness (mm)
1	External Wall	Brick veneer (single)	110	Render	10
		Air gap	50	Reinforced concrete panel	150
		Insulation foil	2	Insulation polystyrene	59
		Timber structure	90	Single glass window	3
2	Internal Wall	Plaster board	10	Plaster board	10
3	Ground/Floor	Reinforced concrete slab	100	Reinforced concrete slab	100
4	Roof	Timber with concrete tiles (20°)	90+20	Timber with concrete tiles (20°)	90+20
		Insulation batts + plaster board	20+10	Insulation batts + plaster board	20+10

Table 4 Total energy required for conventional house wall system for selected Australian metropolitan cities

No.	City	State	Heating load MJ/m^2. annum	Cooling load MJ/m^2. annum	Total energy required MJ/m^2. annum	Star rating 0-10
1	Melbourne	VIC	107.2	37.3	144.5	5.1
2	Brisbane	QLD	4.3	54.3	58.6	4.7
3	Darwin	NT	0.0	633.5	633.5	2.1
4	Hobart	TAS	182.6	4.3	186.9	5.3
5	Adelaide	SA	45.3	88.4	133.7	4.8
6	Sydney	NSW	7.9	57.9	65.0	4.1

Table 5 Total energy required for new house wall system for selected Australian metropolitan cities

No.	City	State	Heating load MJ/m^2. annum	Cooling load MJ/m^2. annum	Total energy required MJ/m^2. annum	Star rating 0-10
1	Melbourne	VIC	91.1	33.3	115.0	5.7
2	Brisbane	QLD	2.5	55.0	47.0	4.8
3	Darwin	NT	0.0	423.0	420.0	4.7
4	Hobart	TAS	163	17.3	160.0	5.4
5	Adelaide	SA	37.6	62.5	95.0	5.8
6	Sydney	NSW	3.4	48.4	52.3	4.9

6. Conclusions

The paper presents a thermal performance modelling of two house wall systems (conventional and new) for six Australian cities. The study evaluated the total ongoing heating and cooling requirements using two wall systems and compared their energy performances. The following conclusions are drawn from the study:

- The new house wall system provides better thermal performance than the conventional wall systems for all six Australian cities.
- Using the new house wall system energy savings ranging from 14% to 33% various climate zones is achieved. This will reduce the greenhouse gas emission, enhance sustainable environment and energy security. However, further study is required to understand the full potential of the new house wall system.

The thermal performance of the conventional house wall system is poor as it needs more energy for ongoing heating and cooling. However, a retrofit with smart materials can improve its thermal performance.

REFERENCES

[1] F. Alam, A. Akbarzadeh, C. Dixon, T. Theos, 2010, Thermal performance of residential house envelopes, *proceedings of the International Conference on Mechanical, Industrial and Energy Engineering (ICMIEE2010)*, Paper MIE10-158, ISBN: 978-984-33-2300-2. Khulna, Bangladesh.

[2] Report on energy use in the Australian residential sector 1986-2020, 2008, Department of the Environment, Water, Heritage and the Arts, Commonwealth of Australia, Canberra.

[3] F. Alam, M. Khan, M. Rasul, 2008, Comparative study of residential household energy consumption in Australia and USA, *the International Journal of Mechanical Engineering and Materials Science*, Vol. 3 (2), pp 127-132.

[4] F. Alam, M. Rasul, W. Saman, T. Theos, M. Khan, A. Akbarzadeh, 2009, Residential house energy rating in Australia, *Central Region Engineering Conference (CREC)*, ISBN 1-921047-62-3, p 1-6, Rockhampton, Australia.

[5] A. Chowdhary, M. Rasul, M. Khan, F. Alam, 2010, Performance analysis of a novel building material

to achieve superior thermal comfort and energy efficiency in arid climate, *proceedings of the International Engineering Conference on Hot Arid Regions (IECHAR 2010)*, Al-Ahsa, Saudi Arabia.
[6] Y. Chen, A. Athienitis, K. Galal, 2010, Design and thermal performance of a BIPV/T system thermally coupled with a ventilated concrete slab in a low energy solar house: Part 1, BIPV/T system and house energy concept, Solar Energy, 84: 1892–1907.
[7] L. Zhu, R. Hurt, D. Boehm, 2010, Detailed energy saving performance analyses on thermal mass walls demonstrated in a zero energy house, *Energy and Buildings*, 41: 303–310.
[8] M. Kordjamshidi, S. King, 2009, Overcoming problems in house energy ratings in temperate climates: *A proposed new rating framework*, *Energy and Buildings*, 41: 125–132
[9] R. Judkoff, 2008. Increasing Building Energy Efficiency through Advances in Materials, National Renewable Energy Laboratory, *MRS Bulletin*, Vol. 33, p 449 454. USA.
[10] H. Tommerup, J. Rose, S. Svendsen, 2007, Energy-efficient house built according to the energy performance requirements introduced in Denmark, *Energy and Building*, Vol. 39, p 1123-1130.
[11] Australian climatic zones, Australian Government, Bureau of Metrology: http://www.bom.gov.au/climate/environ/travel/map.shtml, accessed April 04, 2012).
[12] K. Gregory, B. Moghtaderi, H. Sugo, A. Page, 2008, Effect of thermal mass on the thermal performance of various Australian residential constructions systems, *Energy and Buildings*, (40) 459-465.
[13] F. Aldawi, F. Alam, H. Moria, 2012, Energy Efficient House Wall System for Arid and Moderate Climatic Regions, Journal paper, accepted after peer review for *Yanbu Journal Engineering and Science* (YJES).
[14] Renovation robot, Australian house foundation, accessed on 15 April 2012, http://www.renovationrobot.com.au/foundations/housefoundations.html
[15] AccuRate Sustainability, Hearne Scientific Software Pty Ltd, technical software for professional, energy thermal performance for residential household.