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Energy Consumption of Insulated Material Using Thermal Effect Analysis

M. A. Fadzil[1,*], *M. A.* Norliyati [1], *M. A.* Hilmi[1], *A. R.* Ridzuan[1], *M. H.* Wan Ibrahim[2], and *R. Z.* Assrul [1]

[1]Institut of Infrastructure Engineering and Sustainable Management (IIESM), Faculty of Civil Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia
[2]Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Johor, Malaysia

Abstract. Wall is one of the structures elements that resist direct heat from the atmosphere. Modification on several structures is relevance to reduce filtrate thermal movement on wall. Insulation material seems to be suitable to be implemented since its purpose meets the heat resistance requirement. Insulation material applied as to generate positive impact in energy saving through reduction in total building energy consumption. Fiberglass is one of the insulation materials that can be used to insulate a space from heat and sound. Fiberglass is flammable insulation material with R Value rated of R-2.9 to R-3.8 which meets the requirement in minimizing heat transfer. Finite element software, ABAQUS v6.13 employed for analyze non insulated wall and other insulated wall with different wall thicknesses. The several calculations related to overall heat movement, total energy consumption per unit area of wall, life cycle cost analysis and determination of optimal insulation thickness is calculated due to show the potential of the implementation in minimize heat transfer and generate potential energy saving in building operation. It is hoped that the study can contribute to better understanding on the potential building wall retrofitting works in increasing building serviceability and creating potential benefits for building owner.

1 Introduction

A constructed building relatively contribute to the effect of global warming, as a result, there are an issues in building energy consumption and carbon emission [1]. Based on the geological location and condition, Malaysia is experiencing warm and humid climate condition throughout a year. Due to that condition, Malaysia building having an impact which is high intensity of solar radiation and high daily air temperature [2] world climate change is considered to have strong effects on building needs and requirement as the cooling needs are related to temperature conditions and weather variations. [3].
Refer to the previous study, most of the buildings prefer to assign maximum cooling load to accommodate the comfort level [4]. Therefore, the energy demand especially in cooling

[*]Corresponding author: fadiil2013@yahoo.com

load has increase and currently burdens the building owner. Furthermore, these directly will give great impact towards air pollutant and carbon emission in reflected heat and heat generated from the cooling devices.

It is estimated that buildings consume at least 40% of energy and 16% of water used annually [5]. Energy growth in most develop countries has accounted that about 13.6% of total energy consumption and 48% of electricity consumption consumed in commercial and residential buildings [6]. More than 40% of the energy consumed by Malaysian buildings can be reduced by proper energy efficiency practice and application of suitable sustainable technology to all building in Malaysia [7]. This is next lead to the existence of MS 1525 2007 which is the Energy Efficiency code of practice as a guideline for energy efficient measure in Malaysia buildings.

Modification and renovation can be made by installation of thermal insulation material. Thermal insulation is applicable in facing the climatic problem and to reduce the air pollution forms from heat reflect and air conditioning operation. In reflected to the R-Value of the importance of thermal insulation material where an insulated material consists of high resistance value. Majority of the material R-Value of the wall is attributable to the insulation. R-value is influenced by the surface material that installed as wall surface including wall installed with insulation surfaces [8]. The main purpose of insulation material is to retards the heat movement on two different surfaces with different temperature, less electricity or energy is required the desired inside temperature [9].

An analysis tool such as ABAQUS v6.13 was used in this study. Finite element method is a numerical method to solve an integral or differential equation. How it works is by predicting the piecewise continuous function for the solution and obtaining the parameters of the function to minimize the error in the solution. The intention of this study is to determine heat movement inside the specimen to generate the different between two specimens with and without insulation material.

2 Analytical studies

A complete analysis using ABAQUS v6.13 requires a description of the material, the model configuration, temperature on both outside and inside, duration of surface to be thermally tested, and boundary condition. The modeling analyzed based on 3m x 6m wall panel as shown in Fig. 1.

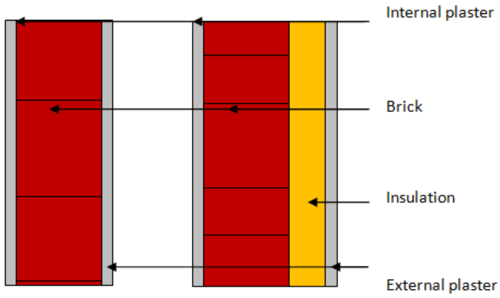

Fig. 1. Test Set up

Data such as absolute zero, Stefan Boltzmann constant, emissivity, material thermal conductivity, and specific heat of all related material will influence the result accuracy. Each data is important in thermal analysis work. Therefore, data such as surface contact between two materials is important in analysis since it will influence result of the analysis.

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In finite element analysis the structural component is divided into detail shape of meshing forms. The smaller the meshing is made, the more accurate data possessed. Meshing work is done individually on every material. However, there were limitation numbers in meshing element where it will affect the analysis process.

For this study, analysis is conducted on four different samples which are non insulated wall and another 3 insulated wall with 25mm, 50mm and 75mm thicknesses. Detail of material properties used in analysis are shown in Table 1.

Table 1. Material properties

Properties	Cement Plaster	Clay Brick	Fiberglass (Insulation Material)
Density (ρ), (kg/m^3)	1860	2243	16
Thermal Conductivity (k), (W/mK)	0.72	0.60	0.04
Specific Heat (c), (J/kgK)	840	900	1000
Emissivity (ε)	0.54	0.45	0.75

Heat is applied from both external and internal wall surface due to replace heat from outside heat radiation and room heat temperature. The indoor air kept at a fixed design temperature T_i.

While on the external wall surface is subjected to an outdoor air temperature T_o. During the analysis, wall is exposed to heat in 25200 sec since normally wall is exposed to extreme heat radiation from 11 am to 6 pm. The emissivity, ε of the material is important due to response towards heat. Heat applied on external wall surface is 37^{o}C while 21^{o}C applied on internal wall surface to response as room temperature. Heat transfer coefficient which combine both convection and radiation effects are considered for both inside and outside wall surfaces with assumption of the surrounding surfaces to be at the same temperature as the ambient air.

First analysis is conducted between non insulated wall and insulated wall due for the purpose to define differential heat transmission characteristic and to determine the response of insulation material towards thermal activity. Then, analysis is continued with different insulation thickness. The purpose of the analysis is to determine the heat transfer and heat release differential influenced from the thickness adjustment.

Result of heat transfer is analyzed and illustrated in heat contour and temperature on each heat transfer phase which segregated with different colour from maximum temperature, red to the minimum temperature represent by blue colour contour as shown in Fig. 2 and Fig. 3.

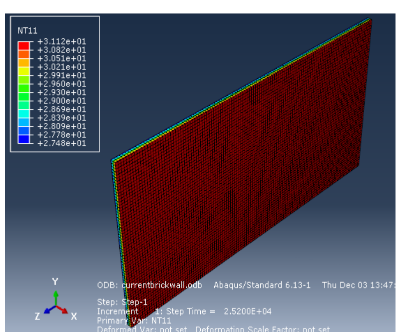

Fig. 2. Non isolated material

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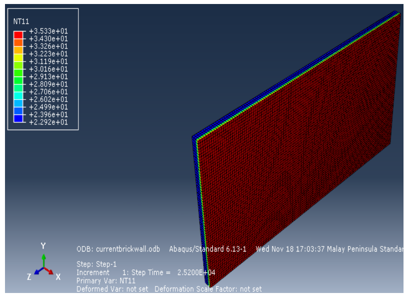


Fig. 3. Isolated material

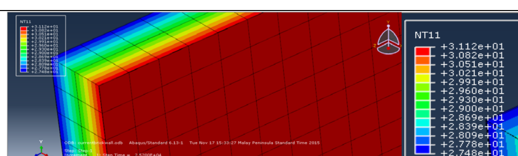
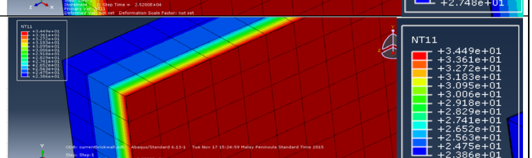
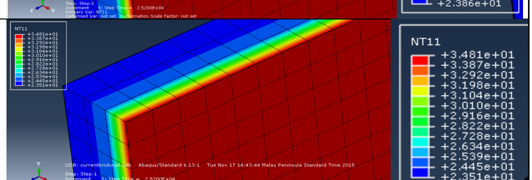
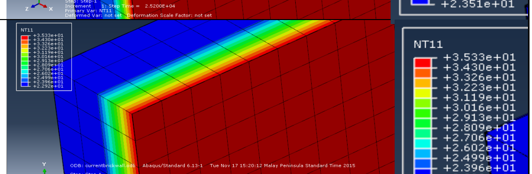
From the results obtained through the analysis, data will be examined mathematically towards its impact on energy consumption, and it reflection on energy savings. Lastly, the determination of Profit Worth Factor, PWF is measured to identify the effectiveness of the implementation investment on N period of time. From the PWF data measured, the optimal thickness which relevance to be implemented is obtained due to identify the relevance of implementation towards the investment made.

3 Results and discussions

3.1 Full finite element analysis result

From the analysis result, it is shown that heat flow is reducing by installation of insulation material. Refer to Table 2, the temperature start to reduce at the fiberglass portion.

Table 2. Thermal reaction on wall

Insulation Thickness	Thermal Contour Activity
Non Insulated wall	
25mm Insulation	
50mm insulation	
75mm insulation	

Other than that, it is shown that there were different heats flow contour characteristic throughout the analysis result for all 4 type of walls.

3.2 Thermal effect between non insulated and insulated wall

Resulting from the analysis as shown in Fig. 2 and Fig. 3, there were different thermal contour shapes illustrated from the simulation. Thermal activity that react on non insulated wall shown that the thermal movement is equal from external plaster layer to internal plaster layer while the insulated walls contour shown that heat transfer activity is slow and constant starting form insulation layer and continued to external layer. The heat stored on the last layer of the insulated wall is lesser than non insulated wall. During nighttimes, less energy is required for cooling purposes where the heat released on the internal area is lower than temperature release in common non insulated wall. Fig. 4 and Fig. 5 show contour illustration for non isolated wall and isolated wall respectively.

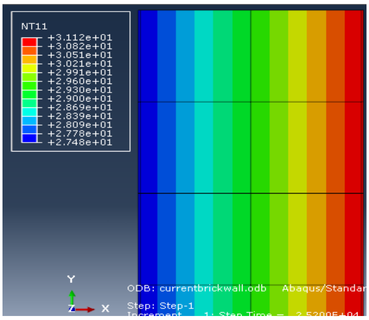


Fig. 4. Non insulated wall

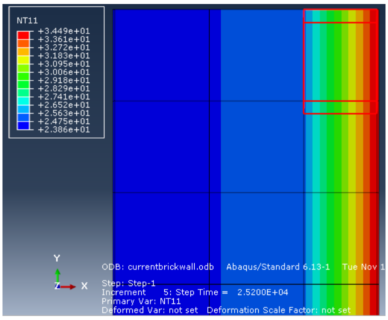


Fig. 5 Insulated wall

Fig. 6 shows that the heat flow of insulated wall start to reduce at insulation layer and the heat flow released to the brick and internal layer are lower than temperature of non insulated wall. Non insulated wall is having a constant heat reduction and the percentage of temperature reduce is smaller than insulated wall. The introduction of insulation can effectively reduce energy cooling demand and peak load of the cooling system. By adding insulation on wall structure energy cooling load demand and peak load will decrease by 12%.

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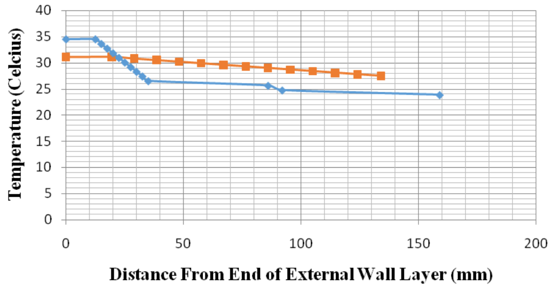


Fig. 6 Graph of temperature versus wall thickness for non insulated and insulated wall

3.3 Thermal radiation impact on walls

Fig. 7 shows the percentage temperature versus insulation thickness graph of the walls reaction after having a natural outside temperature of 37°C on the external surface. From the graph, it shown that by introduction of insulation layer, the heat stored on the external plaster layer is higher when the thickness of insulation increase. In these cases, result shows that heat radiated or reflected to the environment is decreases parallel to the increment of fibreglass insulation layer thickness.

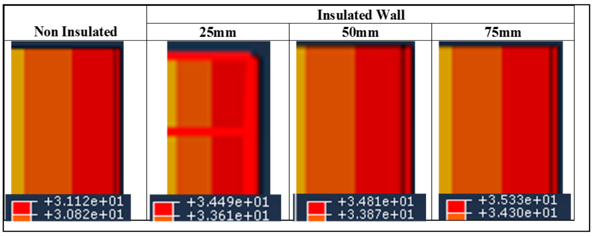


Fig. 7 Heat Radiation on external wall

Based on Fig. 7 and Fig. 8, it is shown that without installation of insulation material, a wall surface can contribute 16% of heat that being reflected back to the atmosphere. While by the adding thermal insulation layer, it is shown that the thermal radiation rates slowly decrease by the increment of insulation thicknesses. By implementing 25mm insulation layer, the heat radiation percentage decrease 56% from non insulated wall in total heat radiation percentage of 7%. The percentage is continuously decreased to 6% on 50mm insulation thickness and 5% on 75mm insulation thickness installation. This show the effectiveness of insulation walls which will react on slowing the thermal movement through the wall.

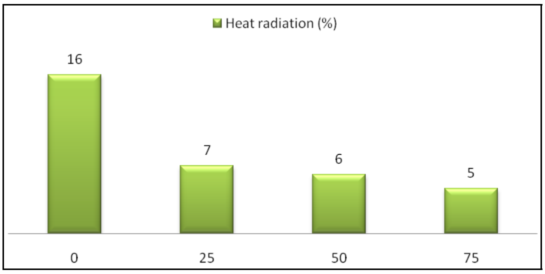


Fig. 8. Heat radiation percentages

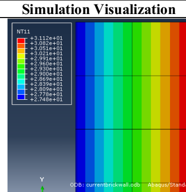
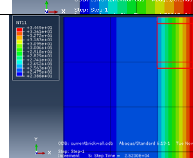
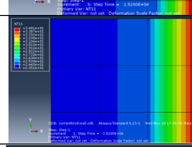
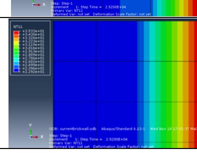
3.4 Thermal Conduction impact on internal area

From the simulation, result of the heat stored at two last layer shown that the temperature reading four all four material is different as shown in Table 3. Temperature recorded in the last layer is 27.48°C. Meanwhile the temperature recorded at all three others insulated walls shown the temperature start decreasing by the increase of insulation thickness. On 25 mm insulation thicknesses, results shown that the temperature is 23.86°C, on 50mm thickness, temperature recorded from the simulation is 23.51°C and lastly, at the thickness of 75mm, temperature stored at the both brick and internal layer is 22.92°C. From these results, it is shown that insulation will give benefit in term of reducing the heat release on the internal area which needs a comfort environment and at these cases, to human thermal comfort level is at 24°C.

Table 3. Thermal conduction temperature

Type of wall	Temperature °C
Non Insulated	27.48
25mm Insulated Wall	23.86
50mm Insulated Wall	23.51
75mm Insulated Wall	22.92

Table 4 Thermal Reaction Characteristic

Type of Wall	Simulation Visualization	Result description
Non insulated		• thickness of dark blue region equal to others temperature region
25mm insulated wall		• Blue region region wider up to 55% of the clay brick thickness
50mm insulated wall		• Dark blue region covering up to 65% of clay brick thickness
75mm insulated wall		• The temperature starts to be consistent at 22.92°C at 80% of clay brick layer. •

Based on the results illustrated generated from the simulation, it review the different thermal reaction on all four examined walls. From Table 4, it can be described that fibreglass insulation material reacts on reducing the heat movement from outside to inside area. In non insulated walls, the dark blue region thickness is almost equal to others region. By adding fibreglass as thermal insulation material the trend of heat movement shows a different contour where the blue or cool temperature region is thicker than other region. The blue cool region starts to cover the clay brick layer. This lastly support the fact on chapter two which described insulation materials is installed as a median to reduce the heat flow and reducing the heat released to the internal area [10] that resulting a major impact on cooling load demand reduction.

Figure 9 below shows the graph of temperature reaction on all walls analyzed during the study. It show different heat flow recorded from both non insulated and insulated wall. Changing the fibreglass thermal insulation of the external wall from 25mm to other 50mm and 75mm reduces the cooling energy demand and peak load by 14% and 16% respectively. It can be seen that the ticker the insulation the greater reduction in both cooling energy demand and cooling load demand.

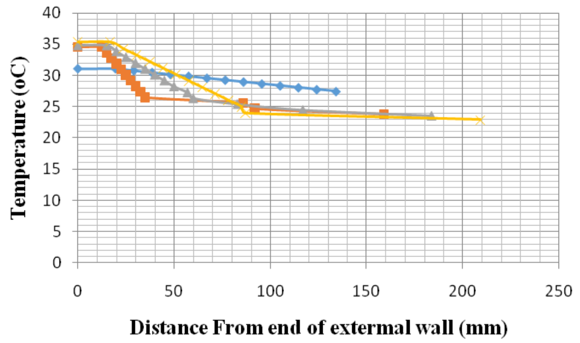


Fig. 9. Graph Thermal temperature reactions on walls

3.5 Annual energy cost for unit wall area

In this study, annual energy cost calculated by considering data such as fuel cost, Cf in RM/kg and its heating value *Hu* in J/kg. From the calculation, annual energy cost per unit area for all four walls is tabulated in Figure 10 below. From previous data description, the annual energy cost is influenced by the thickness of insulation. The thicker it goes, the lower energy cost resulted in the calculation. This calculation leads to the effectiveness of insulation layer installation in promoting energy saving opportunities in buildings wall. Annual energy cost recorded about 50% cost reduction in increment of insulation thickness layer. It is shown in 25mm thickness, the rate of annual energy cost per unit area are RM12.49/m^2 and the cost drop to RM 7.17/unit wall area after addition of 50% insulation thickness to 50mm and lastly at 75mm insulation thickness, the annual energy cost is drop to RM 5.03 per unit wall area. From the simulation, result of the heat stored at two last layer shown that the temperature reading four all four material is different as shown in Table 3.

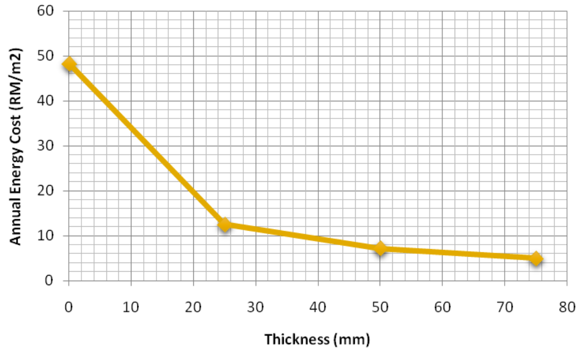


Fig. 10. Graph of Annual energy cost versus insulation thickness

3.6 Energy saving

Refer to Table 5 and Fig. 10, total energy consumption (EA) shows that the total energy consumption has been reduced starting from 25mm Insulation wall at 40.74kWh energy consumption, and continuously reduce to 40.53kWh and 40.33kWh at both 50mm insulation wall and 75mm insulation wall. By reduction of energy consumption, less energy demand is required to accommodate cooling load for the internal area.

Table 5. Total energy consumption

Thickness (mm)	0	25	50	75
ADH	4.5	4.5	4.5	4.5
q	26.67	26.53	26.39	26.26
COP	2.93	2.93	2.93	2.93
EA (kWh)	40.96	40.74	40.53	40.33

Result is be fortified as shown in Fig. 11and Fig. 12 where the energy consumed per air conditioning system and annual energy consumption per air-conditioning system reduce at every walls with insulation materials. Even though the cost involve in implementing insulation wall is high, both graph shown that the guaranteed returns of the investment will give the benefits to the house owner.

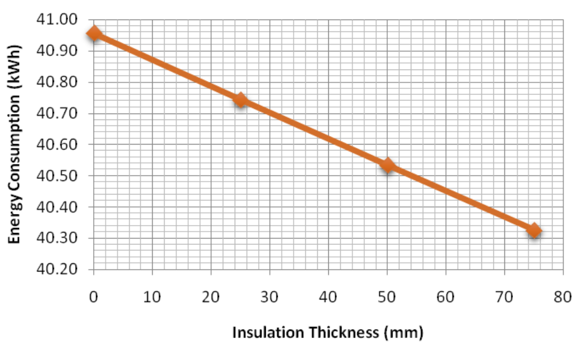


Fig. 11. Graph total energy consumption versus insulation thickness

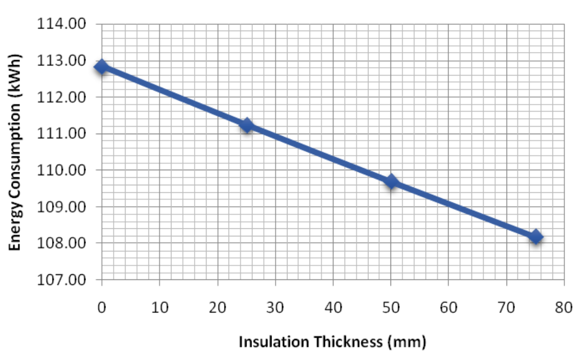


Fig. 12. Graph annual energy consumed per air conditioning unit versus insulation thickness

3.7 Life cycle analysis of implementation and optimum thickness layer

In this study, life cycle cost employed as to determine the relevance of the investment for long term period. Life cycle cost study is computes the cost that reflected by parameters such as heating cost over the lifetime of buildings, the total cost of heating throughout N years where 10 years is estimated and evaluated by using present worth factor (PWF) in calculation of PWF, current interest rate and inflation rate data is important to monitoring the relevance of this investment. In this study, PWF value calculated is 5.04. This PWF data will next influence the determination of insulation cost and yet the optimum thickness that found relevance to applied during N years' time.

The optimal thickness represent the optimal investment that worth to invest and can generate both saving and provide thermal heat reduction in order to reduce cooling demand on internal spaces. In this study, the optimal thickness measured that suits PWF at 10 years duration is 110 mm.

4 Conclusions

From this analytical analysis, the following conclusion can be drawn:

i) Temperature reduces in implementation of thermal insulation material. Heat release to the internal area will be lower than non-insulated wall. Insulation given an impact 13.17% heat reduction.
ii) Heat movement inside structure body is different between non insulated and insulated wall.
iii) Addition of insulation thickness will give continuous positive increasing heat reduction that directly will reduce more cooling demand and cooling load demand.
iv) The annual energy cost per unit area of the wall having 50% cut off after insulate the wall with fibreglass material.
v) The energy consumption used in cooling purposes is reduce on thermal insulation material.
vi) Optimum insulation thickness best to be installed is 110mm.

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References

[1] A. Ismail, M.H. Abdul Samad, A.M.A. Rahman, F.S. Yeok, Cooling potentials and CO2 uptake of Ipomoea Pescaprae installed on the flat roof of a single storey residential building in Malaysia, Procedia - Social and Behavioural Sciences, **35**, 361-368 (2012)
[2] N.A.M. Al-Tamimi, S.F. Syed Fadzil, Thermal performance analysis for ventilated and unventilated glazed rooms in Malaysia (comparing simulated and field data), **20**, 222-229 (2011)
[3] K. Papakostas, T. Mavromatis, N. Kyriakis, Impact of the ambient temperature rise on the energy consumption for heating and cooling in residential buildings of Greece, **35**, 1376-1379 (2010)
[4] T. Kubota, S. Jeong, D.H.C. Toe, Energy consumption and air conditioning usage in residential buildings of Malaysia, Journal of international Development and Cooperation, **17**, 61-69 (2011)
[5] D.M. Roodman, N. Lenssen, A building revolution: How ecology and health concerns are tranforming construction, Worldwatch Paper 124 (2005)

[6] A. Al - Mofleh, S. Taib, Analysis of sectoral energy conservation In Malaysia, Energy, **34**,733-739 (2009)
[7] A. Azni Zain, Integrating sustainable energy in buildings: A case study in Malaysia, *FAU Conference*, Copenhagen, 78-91 (2008)
[8] A. Sami, Al-Sanea, M.F. Zedan, Improving thermal performance of building walls by optimizing insulation layer distribution and thickness for same thermal mass, Applied Energy, **88**, 3113-3124 (2011)
[9] Paul Dunham Close, Thermal insulation of buildings: A Treatise on the principles of thermal building insulation for dwellings and other structures, **01**, 1-3 (2007)
[10] E.F. Strother, W.C. Turner, Thermal Insulation Building Guide, 2-322(1990)