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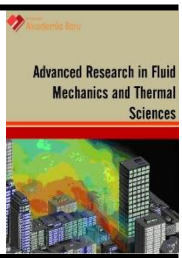

Energy Saving by Applying Different Wall Thermal Insulations on a Room at Malaysian Institution

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ABSTRACT

In a hot and humid climate country, many passive methods have been presented to reduce cooling load of buildings. Nowadays, energy saving has become one of the popular topics over the world. The global warming has caused the high electricity consumption due to the high cooling load demand of the buildings. Where found exterior wall is an important source of heat transfer for the room because wall works as a store for heat. The aim of this study is to evaluate cooling load based on different types of wall thermal insulation. Three different types of material have been selected for wall insulation which are Polyethylene Aluminium Single Bubble (PASB), Expanded Polystyrene (EPS) foam and Rockwool, as well as without insulation. The insulating materials are placed on the front wall of a test room built with dimension 1.2m x 0.8m x 0.8m. Two measuring equipment have been used through this study, Anemometer to measure the air temperature, and Infrared Thermometer to measure the surface temperature of the walls. The data show that rockwool is a better insulation material to reduce the heating load inside the room, the potential temperature reduction inside the room was around 3.85%, where PASB insulation reduced only 2.49% and EPS insulation reduced only 0.89%, which is not much effective as compared to Rockwool. The results show that Rockwool has a potential saving of RM40 per month based on the prototype dimensions without using air condition unit.

1. Introduction

Malaysia is a hot and humid tropical country with a mean temperature between 26°C and 34°C. The daily temperature range is higher than the seasonal temperature range with humidity of 70% – 90% throughout the whole year. However, thermal insulation is the reduction of the transfer of heat between objects in thermal contact. In the modern era, thermal insulation in building is a quite important factor to achieve thermal comfort and reduce heat gain or heat loss which can decrease the heating load and cooling load of the buildings [1-7]. The effectiveness of the thermal insulation is evaluated by its resistance value [8]. Venkiteswaran *et al.,* [9] has researched the passive methods for reducing the cooling load which are wall thermal insulation by polystyrene, white painted roof

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and single low emissivity window glazing, and found that when all three methods applied together could produce the highest reduction in temperature and cooling load.

2. Literature Review

2.1 Thermal Insulation

Many researchers also studied on how to optimize the indoor thermal comfort and energy efficiency by installing the external wall thermal insulation, including Hu *et al.,* [10] studied the use of polystyrene for external brick wall insulation, Ding *et al.,* [11] studied the use of vitrified microsphere inorganic thermal insulation on brick wall, Cao *et al.,* [12] studied the use of composite polystyrene granule thermal insulation mortar in external wall, Noerwasito *et al.,* [13] studied the optimum polystyrene thickness on brick wall, Kumar *et al.,* [14] studied the improvement of energy efficiency by using various type of glasses and building materials, Halim *et al.,* [15] has studied the use of pitch and wall insulation on air-conditioned rooms, while Pruteanu *et al.,* [16] and Mishra *et al., [*17] have studied about the expanded and extruded polystyrene rigid foam board on masonry wall. However, these papers [18-19] state that the performance of two most popular energy-efficient retrofitting measures, installation of insulation material and high reflectivity coating on the building wall. The researchers have found that the insulation board with 50mm thickness could give a satisfactory result. However, the thickness with more than 50mm could only get a limit additional profit.

Wang *et al.,* [20] has studied the influence of the position of the thermal insulation in a building on indoor thermal comfort and energy consumption in Chongqing, China. The researchers found that the building with internal insulation have a very poor thermal stability. Yongson *et al.,* [21] found that the position of the air conditioner in the room could affect the thermal comfort also. The direction of the airflow could change the path with the components and occupants of the room. Meaning that occupants should be positioned on a plane so that could be closer to the blower in order to feel cooler.

To prevent the overheating of the building wall in the extremely hot summer, the walls that facing the South were painted with light color to avoid absorption of the solar heat. While for the opposite wall of the building, the walls should be painted with darker color to maximize the heat absorption factor in order to retain heat during the winter season. The design showed the color and the quality of the surface of the building walls are the most important factors [22]. Nyers *et al.,* [23] and Ma *et al.,* [24] show that by increasing the thickness of the polystyrene as a wall thermal insulation layer would increase the material cost but it could reduce the cost of exploitation. Besides that, Bojic *et al.,* [25] shows that a 5cm thick of polystyrene board insulation that facing inside the wall slabs could reduce the annual cooling load by 6.22%. Based on the study conducted by Muhieldeen *et al.,* [26 & 27], the optimum thickness of the Rockwool insulation to reduce the indoor temperature without wasting over insulating cost is between 50 mm and 100 mm.

The solar heat gain through the wall could led to increase of indoor temperature that will lower down the thermal comfort inside the building and subsequently increase the cooling load demand. As a matter of choice, wall thermal insulation could be installed in the building in order to reduce the heat transfer rate from outdoor to indoor through the wall. This means that wall insulated buildings could save electricity bills effectively. The main objective of this study is to evaluate cooling load reduction based on different types of wall thermal insulation.

In this study, based on Malaysian's weather, Malaysia receives nearly 10 hours of solar radiation per day. The total radiation received annually by Malaysia is above 4.31 kWh/m^2. Therefore, artificial cooling such as air conditioning requires more energy to provide thermal comfort due to the increase of indoor temperature. Therefore, there is a need to use insulation material on the wall to reduce the indoor temperature as well as reduce the energy consumption.

3. R-value

Wall is one of the important parts of a building as it occupied the largest area of the building envelope. Therefore, the thermal insulation value of the wall is crucial to have thermal comfort indoor environment and energy saving. Insulation performance is measured in R-values, which quantify the thermal resistance of a building. The greater the R-values, the higher the insulating performance. The R-value of the thermal insulation is highly depending on the type of insulation, thickness, and thermal conductivity. As shown in Figure 1, bulk insulation reduces the heat transmitted to the room by trapping dry air in bulky materials. Large amounts of air could be trapped in the medium and reduce the ability for heat to be transferred by conduction efficiently due to the poor thermal conductivity of air. The small pockets of trapped air could reduce the ability to transfer heat by convection as compared to rather than a large and contiguous volume of air.

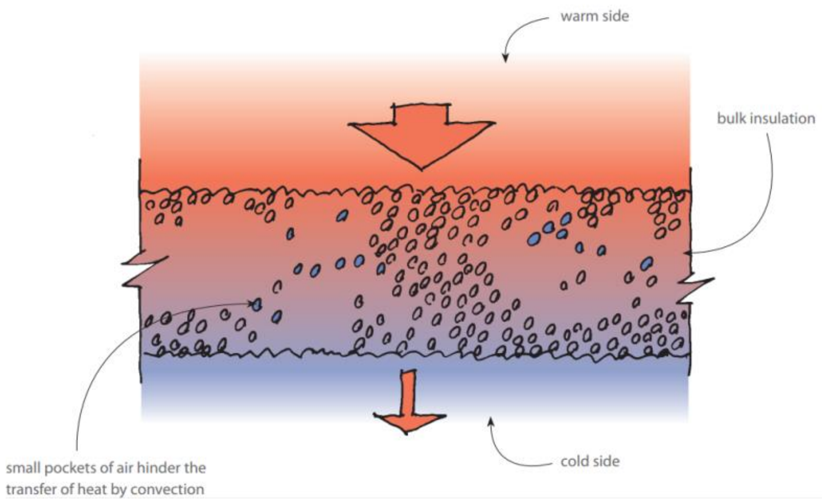


Fig. 1. Mechanism of heat transfer through insulation layer

As shown in the material properties, Table 3, Rockwool has the highest thermal conductivity among the insulations however it could reduce the indoor air temperature the most. This can be explained by using the thermal resistance equation below:

$$R = \frac{L}{k} \quad (1)$$

Where R is the thermal resistance of the insulation ($m^2.K/W$), L is the thickness of the insulation (m), k is the thermal conductivity of the insulation ($W/m.K$).

The R-value was calculated and tabulated in Table 1. The thermal resistance value of the system or material is not only defined by its thermal conductivity, it could be varying by its thickness and thermal conductivity as well. The thermal resistance is directly proportional to the thickness of the insulation and inversely proportional to the thermal conductivity of the insulation. Therefore, Rockwool has the highest R-value and higher performance in energy saving.

Table 1
Thermal resistance of each insulation

Insulation	Thickness (m)	Thermal conductivity ($W/m.K$)	R-value ($m^2.K/W$)
PASB	0.005	0.032	0.156
EPS	0.023	0.033	0.697
Rockwool	0.052	0.044	1.182

4. Methodology

4.1 Test Model

One of the rooms at North Wing UCSI University, Malaysia was selected to be the test room. A wooden room is fabricated based on the laundry room in the North Wing UCSI University campus as shown in Figure 2 and 3.

Fig. 2. Test room

Fig. 3. UCSI laundry room

The dimension of the wooden room was 1.2m x 0.8m x 0.8m which is scaled down by a ratio 0.4 to the actual size of the laundry room. The material of the wooden room is made up of plywood, 9mm thick with a thermal conductivity of 0.13W/m.K with density 620 kg/m^3. The properties of the plywood are shown in the Table 2. The wooden room has 5 sides which are front, back, left, right and top. In order to allow some air circulations inside the room, the bottom of the wooden room was left uncovered and placed on stands while conducting the experiment. The front wall surface of the wooden room which is exposed to the sun the most will be applied with a layer of thermal insulation during the experiment.

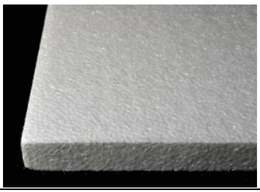
Table 2
Plywood specifications

Property	Value	Unit
Density	620	kg/m^3
Thermal Conductivity	0.13	$W/m.K$
Thickness	9	mm
Shear Modulus	6.96 - 8.55	GPa
Yield Strength	31.0 – 41.0	MPa
Poisson Ratio	0.3	-

4.2 Types of Insulating Materials

Three types of different thermal insulation were selected for conducting the experiment: Polyethylene Aluminium Single Bubble (PASB), Rockwool and Expanded Polystyrene (EPS) board. The properties of the thermal insulations are listed in Table 3.

Table 3
Properties of different types of insulations

Insulation	Types of insulation	Thickness (mm)	Thermal conductivity (W/m.K)	Density (kg/m^3)
PASB 	Reflective insulation	5	0.032	85
Rockwool 	Bulk insulation	52	0.044	90
EPS board 	Rigid foam insulation	23	0.033	15

4.3 Devices

Figure 4 and 5 show the measuring equipment used in the project which are infrared thermometer and anemometer. Infrared thermometer was used to measure the surface temperature of the external wall and internal wall that applied with the insulation layer. While anemometer was used to measure the indoor temperature and surrounding temperature. The tools and devices used in this experiment were listed in Table 4.

Fig. 4. Infrared thermometer

Fig. 5. Anemometer

Table 4
Tools

Item	No.	Function
Infrared thermometer	1	To measure wall surface temperature
Anemometer	2	To measure the air speed and air temperature inside and outside the room
Camera	1	To take photo of the progress
Screw	80	To build the wooden room
Screw driver	1	
Nail	4	To install the insulation
Insulation material	1	PASB
	1	Rockwool
	1	EPS board

4.4 Experimental Setup

Firstly, the wooden room built was placed in the open area in the North Wing UCSI University campus as shown in Figure 6. The front wall surface of the wooden room was made sure to place under condition of fully exposed to the sunlight during the entire experiment. After that, the front wall of the test room is applied with the PASB insulation as shown in Figure 7. The outdoor and indoor temperature of the test room are measured by anemometer. While the surface temperature of the wall and insulation layer were measured by infrared thermometer from 10am to 4pm during the peak hours for one month. There were three different types of thermal insulation proposed in this experiment in order to evaluate their effect and performance for reducing the heat penetrating into the room. Once the measurement was done for the first thermal insulation, it will be removed and placed with the second type of thermal insulation material and same goes for the third thermal insulation material as shown in Figure 8 and 9.

Fig. 6. Completed wooden room

Fig. 7. Test room insulated with PASB

Fig. 8. Test room insulated with EPS board

Fig. 9. Test room insulated with Rockwool

5. Results and Discussion
5.1 Experimental Results

This experiment has been done to study the effect of different types of wall thermal insulation in reducing temperature of buildings. For conducting the experiment, a wooden room was built as prototype model which was related to the size of the UCSI laundry room at North Wing. The work involved were measuring data for three different types of wall insulation and without insulation as well. Measurements for air temperature and walls surface temperature have been done for a period of one month in a sunny condition.

Figure 10 shows that Rockwool insulation with thickness of 52mm has the best reduction in temperature as compared to the PASB and EPS insulation. During the highest outdoor temperature which was 2pm, Rockwool with thickness of 52mm could reduce the indoor temperature the most which was 1.3ºC, following by EPS with thickness of 23mm which could reduce the indoor temperature by 0.84ºC, while PASB with thickness of 5mm does not show significant indoor temperature reduction which was only 0.3ºC.

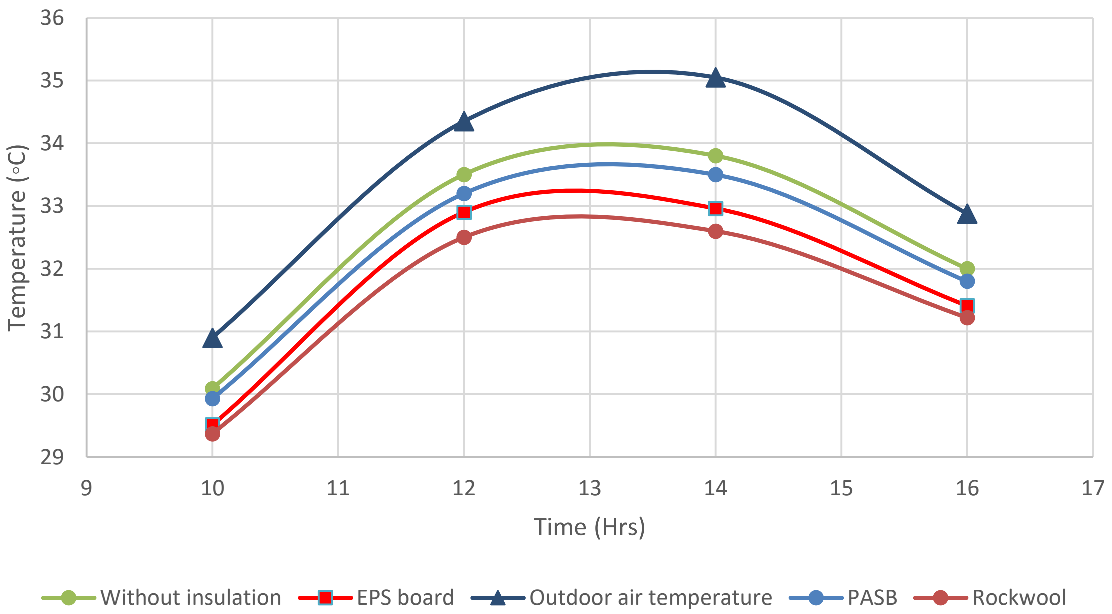


Fig. 10. Temperature distribution inside and outside the room with all insulations

The reduction of temperature starts to increase significantly with the Roclwool insulation applied on the wall from 1 p.m. onwards. The effectiveness of the Rockwool insulation is more observable at 2 p.m. due to the higher solar radiation and outdoor temperature. The average dry bulb temperature reaches the highest at 2 p.m. which is 35.2^{o}C. The maximum reduction in indoor temperature is recorded at 1.3^{o}C by applying the Rockwool insulation. When using Rockwool insulation, the temperature reduction is almost twice the value of the wall without using any insulation which the indoor temperature is reduced by 2.3^{o}C when no insulation is being used.

The reduction of temperature inside the room becomes less noticeable from 3 p.m. onwards. The temperature is reduced at a range between 0.4^{o}C to 0.8^{o}C. According to study conducted by Qahtan [28], the average dry bulb temperature is declining to 30.0^{o}C at 4 p.m. Therefore, the reduction of temperature is not significant at 4 p.m. due to the low temperature variation of between outdoor and indoor. A significant contribution to both the surface temperature and the indoor temperature is clearly made by direct solar radiation Qahtan, [28].

5.2 Power Consumption Analysis

Table 5 shows the monthly power consumption reduction for each insulation applied. The power consumption was calculated by assuming the air condition units operate for 10 hours a day and there is 30 days in a month. The results show that the application of Rockwool insulation gave the highest power consumption reduction followed by EPS and PASB as justified by the temperature reduction.

Table 5
Energy consumption

Method	Monthly power consumption (kWh)	Monthly power reduction (kWh)	Percentage monthly power reduction (%)
Without insulation	432	-	-
PASB	427	5	1.16
EPS	370	62	14.35
Rockwool	360	72	16.67

The electricity cost was calculated based on the electricity tariff by Tenaga Nasional Berhad. The first 200kWh was 21.80 cent/kWh per month, for the next 100kWh was 33.4 cent/kWh per month. The calculated electricity cost was tabulated in Table 6 of the real room. The results show that by applying Rockwool insulation could save the electricity cost the most while PASB insulation has the least electricity cost saved. This is due to Rockwool insulation has the highest power reduction followed by EPS and PASB insulation.

Table 6
Monthly electricity cost saving of the real room

Method	Monthly power consumption (kWh)	Monthly Electricity cost (RM)	Monthly saving (RM)	Percentage monthly saving (%)
Without insulation	432	241.93	-	-
PASB	427	238.73	3.2	1.32
EPS	370	207.02	34.91	14.43
Rockwool	360	201.17	40.76	16.85

5.3 Comparison between Rockwool and Polystyrene Foam Insulation

The main idea of this paper is to evaluate the different types of wall thermal insulation performance based on the indoor air temperature reduction. The results show that Rockwool with a thickness of 52mm could reduce the indoor temperature by 1.3ºC. The study done by Venkiteswaran *et al.,* [6] in Malaysia showing that by using 50mm thick of polystyrene could reduce the room temperature by 0.81ºC. The results of the using Rockwool as wall insulation were compared with the results by using polystyrene foam insulation that has been conducted in the previous studies under the same of tropical climate in Malaysia. The results show that Rockwool could achieve a 0.49ºC lower as compared to polystyrene foam insulation.

6. Conclusions

In this study, the effect of the insulating materials on temperature reduction for the test room (1.2m x 0.8m x 0.8m) walls was experimentally investigated. The cooling loads for three different types of insulating materials are calculated as well. The experimental results show that the insulating material Rockwool (thickness 52mm) could give the best reduction in temperature which could reduce the inner temperature of the test room by 3.85%, leading to a potential saving of RM40 per month without using air condition units or fan, compared to the results given by EPS insulation (thickness 23mm) which reduced 2.49% and to the PASB insulation (thickness 5mm) which reduced 0.89%.

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