Energy and Environmental Benefits of Applying Roof Insulation to Office Buildings in Malaysia

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Abstract: - Buildings in developed countries today consume a large portion of primary energy, which leads to more CO_2 production and environmental pollution compared to other human enterprises or industries. This study estimated the energy saving and emission reduction potentially achieved by applying selected roof insulation, using Integrated Environmental Solutions (IES) simulation software. It was found that through the application of extrude-polystyrene, glass fiber quilt and rock wool roof thermal insulation, the energy saving of 33485 to 37292 kWh can be achieved. It estimated that applying selected insulation materials have the emission reduction of 17311 $kgCO_2$.

Key-Words: - Building simulation, Emission reduction, Energy saving, Office building, Thermal insulation

1 Introduction

Energy is increasingly costly and the condition is worsened by global warming due to greenhouse gas emissions. Many countries are beginning to take measures to improve energy efficiency in the building sector in response to the increasing global concern about the impact of energy consumption on the environment [1].Efficient use of energy in buildings will greatly help to reduce overall energy consumption as well as related emissions into the atmosphere, due to the fact that the building sub-sector consumes about 8 – 50% of the total energy and materials worldwide [2].

90% of the energy consumed in Malaysia is in the form of electricity. These continuing trends will result in Malaysian buildings consuming almost as much as the industrial and transportation sectors combined. This is very alarming as Malaysia is known to have one of the most rapidly developing building industries in the world [3].

Table 1 shows that more than 50% of the energy used in commercial buildings are utilized by lighting and air-conditioning. It is sensible and obvious that lighting and air-conditioning systems are maintained for maximum performance and minimum energy consumption. This leads to the assumption that there is an enormous potential in energy savings that may result from energy efficient practices in buildings.

2 Passive Cooling Principles in Tropical Climate

Roofs are an integral component of the building envelope feature, which are very vulnerable to solar radiation as well as a host of different environmental factors. This will lead to the indoor conditions for occupants to be affected. A lot of heat is gained or lost through roofs especially in buildings built with big roof areas such as shopping malls, amphitheatres, and closed stadiums. Among the possible modifications include the implementation of a compact cellular roof layout with minimal exposure to the sun, high roofs, double roofs, vaulted roofs or roofs with domes, ventilated and micro ventilated roofs. Other methods that are beginning to gain popularity are the implementation of white-washed external roof surfaces with the purpose of reducing

Description	Residential	Hotels	Shopping Complexes	Offices
Lighting	25.3	18	51.9	42.5
Air Conditioning	8.3	38.5	44.9	51.8
Total	33.6	56.5	96.8	94.3

Table1 Energy consumption according to building type in Malaysia

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the amount of solar absorption, the usage of materials such as concrete that have a high specific heat capacity to reduce peak load demands, and the use of vegetation on roofs to provide humidity and shade.. Such measures may contribute to as much as a 6 ◦C drop in the indoor temperature [4].Al-Sanea [5] compared the thermal performance of different roofs and showed that a slightly better thermal performance was achieved by placing the insulation closer to the inside surface of the roof; however, this exposed the water proofing membrane to larger temperature fluctuations. In another study, the most suitable location of roof insulation was investigated from the point view of maximum load leveling. It was concluded that the best load leveling was obtained when insulation layers of the same thickness were placed, first outdoors, second in the middle and the third layer at the indoor roof surface [6].

2.1 Thermal roof insulation systems

There has been growing attention paid to the importance of thermal insulation of late, due to the fact that there is an average of 60% of heat energy being leaked through roofs. As such, it can be deduced that effective roof insulation can result in the saving of cooling loads as well as heating loads. ‘Thermal insulation’ is also commonly used interchangeably with the term ‘transmittive barrier’. The use of polystyrene, fiberglass, rock wool or mineral-wool is common in the roof insulation of buildings in the dry desert climatic conditions experienced in the regions of the Middle-East and Asia. A reduction of the heating and cooling loads of more than 50% can be seen when polystyrene or polyurethane insulation layers are used compared to a similar but un-insulated building roof [7]. Different configurations of roof insulation systems utilizing five various types of insulation materials, including polyurethane, polystyrene, polyethylene, sand and rubber along with two different reflector materials (aluminum 1100-H14 and galvanized steel sheets) were tested through a series of laboratory experiments. The shape of the reflector apparently had negligible effects barring any forced convection [8]. The insulation system, as shown in Fig.1, was tested on an occupied building in Sri Lanka, where tropical climatic conditions are prevalent. The type of insulation that was used was a form of expanded cellular polyethylene with a thermal conductivity of 0.034W/m2 K. The results indicated that a 25mm-thick insulation produced a reduction in the soffit temperature of about 10 ◦C[9].

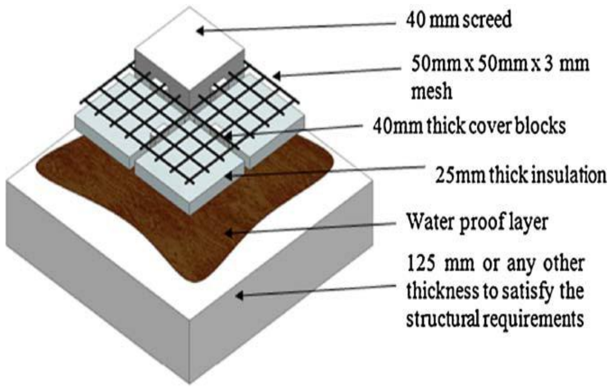

Fig.1 Roof insulation system. Source: (Halwatura & Jayasinghe 2008)

3 Analysis Method

This section explains the simulation software, case study building, climate and passive solar techniques applied in order to minimize emission and enrgy consumption.

3.1 Integrated Environmental Solutions (IES) simulation software

The building energy simulation program IES <VE-Pro> (Integrated Environment Solution) was used for the present study to predict annual energy used by the Chancellery office building.The IES software is a flexible and integrated system geared to assist in the assessment of the productivity of the aspects involved in a sustainable design of a building. It models the dynamic interactions between the building, the external climate, the internal loads and processes, and the building mechanical systems[10]. Weather data in these formats are available through a large number of sites worldwide. Heat gain calculations and thermal simulations are done based on information on heat gains from occupants, lights and equipment. Among the assumptions of this study include the assumption that the building has a rate of occupancy of 9 persons/m^2 with each person producing a sensible heat gain of 70W and latent heat gain of 45W. A lighting power of 18 W/m2 and office equipment load consisting of computers, printers and copy machines of 5, 20 and 9 W/m2 have been used respectively. It is assumed that the daily average rate of ventilationfor all zones, sustained by infiltration through window gaps, has around 0.25 air change per hour.

3.2 An overview of the case study building

The proposed building is the Chancellery office building, an iconic landmark at UKM (University

Kebangsaan Malaysia), as it can be observed, located in Bangi, Malaysia. The selected building is a typical, six-story office building which contains 14848m^2 of assignable, instructional space including office spaces, lobby, meeting rooms and restaurants. The daily occupancy rate of the building is averaged at 65% and daily operating hours range from 10am to 12pm. Fig.2 and 3 exhibits the site plan and 3D view of the building involved in this research. The building being studied is a six-storey building with 14484m² of floor area and a total glass area of 2671 m².

The building envelope (includes exterior and interior walls, basement floor, ceiling and roofs) is a medium through which heat flows in and out of the building. Energy loss calculations through the building envelope require the thermal resistances (U-values) of the different components of the opaque building envelope to be as close as possible to the actual U-value of the building envelope. Tables 2 shows what materials the walls are composed of, windows and other building fabric elements.

Fig.2 Location of the case study building at UKM, Chancellery

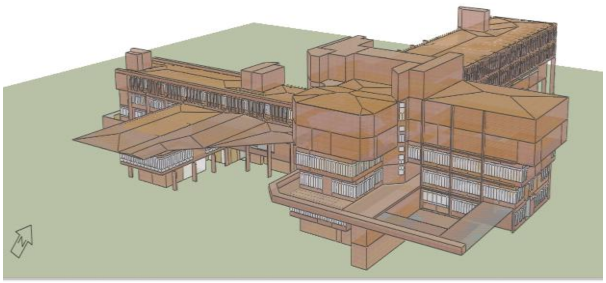

Fig.3 3D view of the Chancellery office building

Table 2 Material properties of the building

Description	Material	Thickness m	Conductivity W/(m·K)	Specific heat capacity J/(kg·K)
External wall	Brickwork Plaster	0.117 0.02	0.84 0.5	800 1000
Internal Ceiling/floors	Cast Concrete Cavity Plaster	0.1 0.012 0.01	1.4 0.5	840 1000
Metal Roof	Steel Bitumen layer Glass wool	0.01 0.005 0.03	50 0.5 0.04	480 1000 670
Flat Roof	Stone Bitumen layer Cast Concrete	0.01 0.005 0.15	0.96 0.5 1.13	1000 1000 1000

3.3 Climate
The energy consumption in buildings is very much related to the climate. Malaysia's geographic coordinates lie between latitude 3.12oN and longitude 101.55oE, with varying temperatures and high humidity; the hottest time is around March. The average Malaysian climate can be described as follows [11]:

- Very small variation in monthly temperatures (less than 8 0C).
- The mean daily temperature of the hottest month (February/March) is 27.8oC
- The coolest month (December) is 25.9oC.
- The daily temperature exceeds the value of 25oC more than 50% of the time
- Monthly humidities exceed 70% with an annual mean value of 83%.
- RH exceeds 55% most of the time
- Wind speeds are quite low with a mean value of 1.2 m/s
- Prevailing winds blow from the North East, East and South East

3.4 Applied passive solar design techniques

In this study, the shape of the roof model is assumed to be similar with base model. The metal layer with a 3° slope above the roof of the model is assumed to provide effective drainage of rain water while increasing roof temperature. The roof modifications included in this study were the application of green roofs and thermal insulation materials. Two types of insulation materials were used in the simulation study. Table 3 shows the properties of the selected roof insulation materials.

- Adding 6cm glass fiber quilt thermal insulation
- Adding 6cm extrude-polystyrene thermal insulation
- Adding 6cm rock-wool thermal insulation

Table **Error! No text of specified style in document.** Data of Roof Insulation Materials

Type of insulation	Thickness (m)	Thermal conductivity W/(m-K)	Density kg/m^3	Specific heat capacity J/(kg-K)
Glass fiber quilt	0.06	0.04	12	840
Extrude polystyrene	0.06	0.029	35	1380
Rock wool	0.06	0.042	30	837

7 Results and Analysis

Based on the building characteristics described, annual electricity consumption of the selected building was calculated by using electricity per hour at the IES. The simulation ran from 1 January to 31 December. Calculations were performed using hourly weather data consistent with conductive, convective, and radiant heat transfer effects.

Annual energy consumption was 2256.4 (MWh) and energy intensity was 244 kWh/m^2/year as shown in Fig.4 According to the code of practice on Energy Efficiency and Use of Renewable Energy for Non-residential Buildings (MS1525), the Building Energy Index (BEI) suggested for office buildings is 136 kWh/m^2/year. The energy performance of the Chancellery office building is still far from the set target. Previous studies have found that 58% of the energy consumed by an average mid-rise office building in Malaysia is utilized by its air conditioning, while 20% was used by lighting followed by office equipment (19%), and others (3%).These findings concur with previous results by Saidur (2009)[12] which indicate that office building air conditioners consumed most energy (57%) followed by lighting appliances (19%), elevators and pumps (18%), and lastly other equipment (6%)[13].

Simulation results indicate that in buildings with roof thermal insulation, the annual cooling load and energy consumption is decreased. Fig.5 and 6 illustrate that the application of extrude-polystyrene, glass fiber quilt and rock wool insulation with thicknesses of 6cm and how they generally assist in the decrease of annual energy consumption. Compared to glass fiber quilt and rock wool, the application of extrude-polystyrene as an insulation material would lead to highest annual energy saving of 37292 kWh.

The yearly energy saving through application of glass fiber quilt and rock wool was 33485 and 33572 kWh respectively.

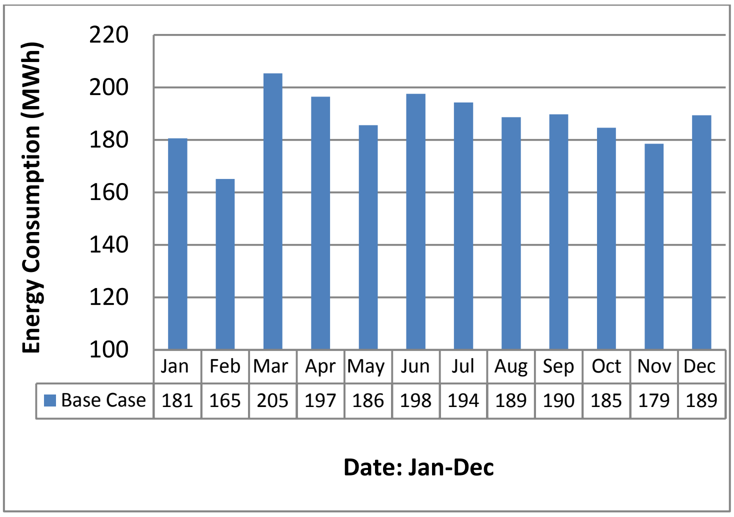

Fig.4 Results of the IES run on Chancellery building energy performance for the base case

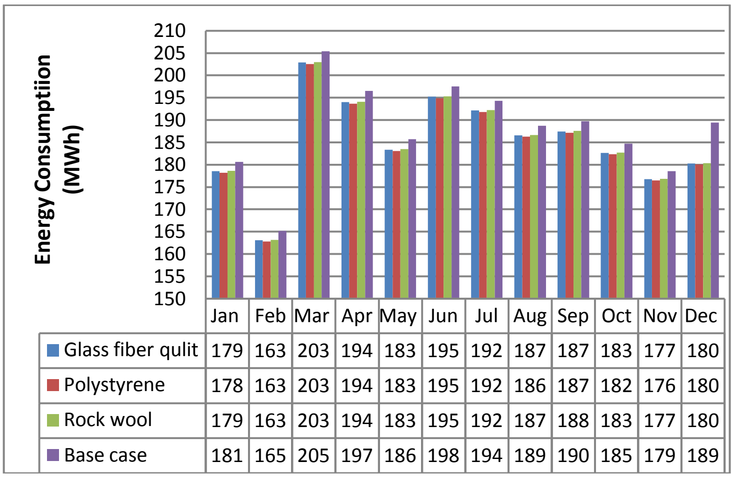

Fig.5 Annual energy consumption, using different roof insulation

Results show that by application of roof thermal insulation the energy consumption and, the emissions are reduced. This can be seen in Figs 7 and 8. It was found that application of 6 cm thickness of extruded polystyrene demonstrated the highest annual emission reduction of 19279 (kg CO2). Glass fiber quilt and extrude-polystyrene as roof insulation materials with 6 cm thickness was found to have the emission reduction of 17311 and 16839 kgCO_2 respectively.

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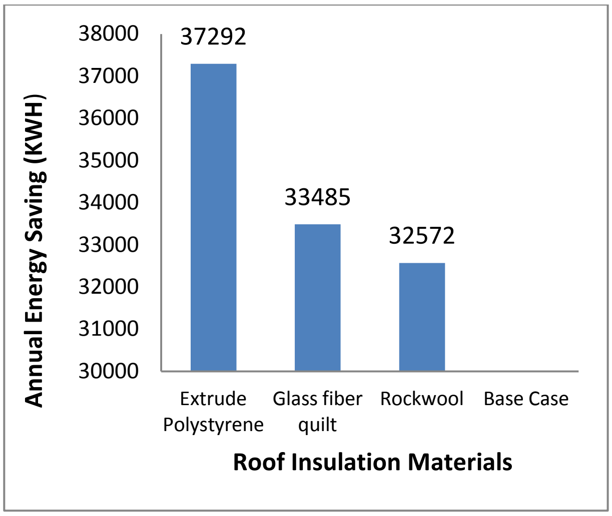

Fig.6 Annual energy saving, using different roof insulation

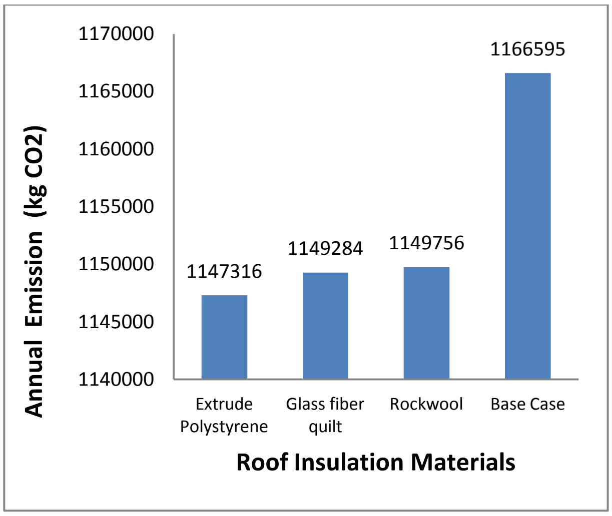

Fig.7 Annual CO_2 emission

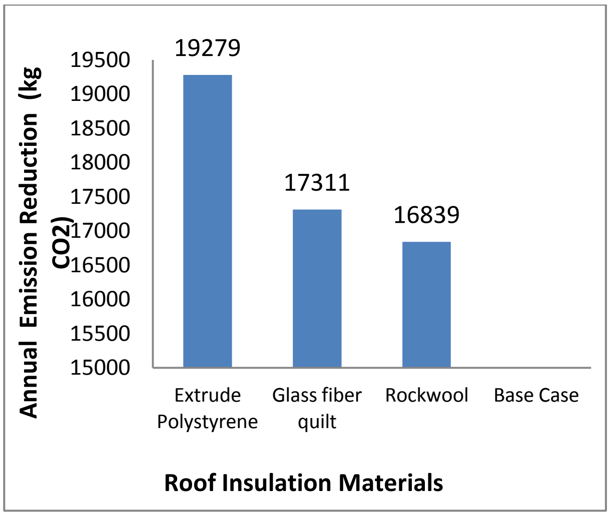

Fig.8 Annual CO_2 emission reduction

4 Conclusion

This paper examined energy consumed and saved after installing roof thermal insulation material to office building in Malaysia. The decrease in electricity consumption was investigated with IES simulation software. The yearly savings in energy consumption by applying extrude-polystyrene, glass fiber quilt and rock wool thermal insulation to roofs of a building were found to be, 37292, 33485 and 33572 KWh respectively.

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