Effectiveness of Maerogel Roofing System on Indoor Temperature of Residential Buildings

by

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ABSTRACT

Malaysia which located in tropical region near to the equator is exposed to long hours of sunshine and experiencing high temperature and relative humidity throughout the year. To cope with this problem, installing air-conditioning in their house seems to be the current best solution in providing the thermal comfort. In tropical countries, 75% of the heat generation in a house come from the roof. Based on previous research, installing insulation on roof has successfully given positive impacts on indoor temperature reduction. It was discovered that Maerogel is the current best solid insulation material where it has the lowest thermal conductivity of 0.02 W/m.K. However, current usage of Maerogel was only restricted in aeronautics, military, vessels and piping insulation. Thus, this research is an initial attempt to investigate the effectiveness of Maerogel as an insulator in the roofing system on indoor temperature of residential buildings. The analysis of the Maerogel's efficiency is first done by using computer simulation, Ecotect Analysis 2011. Three identical model houses were designed with the same building materials. Each roof was equipped with the insulation materials to be tested which are aluminium foil, Rockwool and Maerogel respectively. To demonstrate the effectiveness of Maerogel in real condition as roof insulator in comparison with aluminium foil and Rockwool, three identical small-scale houses were built. For simulation and experimental field data measurement, the indoor, outdoor and roof surface temperatures of each experimental houses are taken every 1 hour for 7 hot days. Finally, the reduction in electricity consumption by installing Maerogel roof insulation is quantified. The results obtained from all stages of this research shows that Maerogel induced the highest outdoor-indoor temperature differences up to 8.1 °C compared to aluminium foil and Rockwool. From the energy saving cost analysis, it was shown that Maerogel reduced the energy cost in comparison with non insulated roof the highest by 89%. These results support the effectiveness of Maerogel as roof insulation in residential building. It is recommended to demonstrate the installation of Maerogel in real house and further analysis on cost benefit analysis to be done in future research.

CERTIFICATION OF APPROVAL

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Approved by,

____

(Prof. Ir. Dr. Muhd. Fadhil Nuruddin)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

September, 2014

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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(NURUL HUDA BT AHMAD ZAIDI)

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Global warming has become one of the most current issue widely discussed by scientists and is recognised all over the world. In fact, Malaysia's Government had also launched the National Climate Change Policy on August 30, 2010 in accordance to this issue with the objective to reduce the greenhouse gases based on the intensity of carbon up to 40% by 2020 as compared to year 2005 [1]. The term global warming refers to the increase of the Earth's average surface temperature [2]. This phenomenon occurs due to the presence of gases called greenhouse gases (GHGs) in the atmosphere, which traps the heat from escaping to the space [3]. A gradual increase in the overall temperature of Earth due to greenhouse effect will cause tropical countries to experience high levels of heat radiation from the sun, which leads to discomfort to humans and their surroundings. The geographical location of Malaysia that is situated in a tropical region near to the equator makes it exposed to long hours of sunshine and experience high temperatures and relative humidity throughout the year [4]. It was recorded that the daily air temperature in Malaysia varies from 24°C up to maximum of 38°C as shown in Figure 1.1.

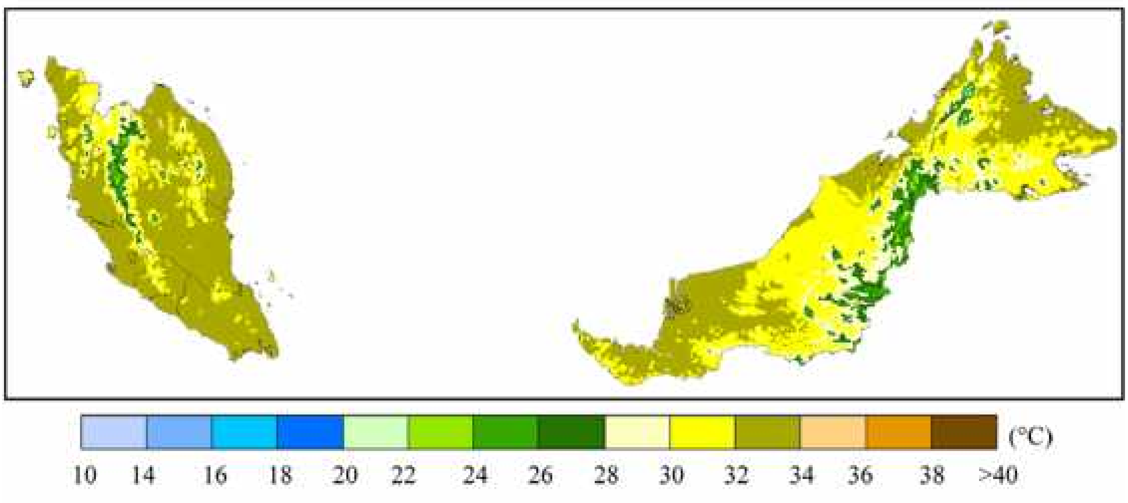

FIGURE 1.1: Maximum temperature experienced by states in Malaysia [5]

These environmental features consequently contribute to large consumption of energy in a building. About 25% of the energy used is in electricity form in order to provide thermal comfort to the consumers. In 2005, it was recorded that buildings consumed 2914 Mtoe of energy and thus constituted as the largest uses of electricity [6]. Buildings are generally grouped into residential and non-residential building. The non residential groups are further categorised into commercial and industrial buildings. The residential and industrial sectors account for two-thirds of the energy use respectively. As shown in Figure 1.2, about 44.23% of electricity consumed in a house is used for cooling. In average, more than 56% of the houses have installed air conditioning [7]. Air conditioning is a major consumer of energy and accounted for 50% of the electricity cost in a house. Meanwhile, Tenaga Nasional Berhad (TNB) had announced the new electricity tariff for domestic consumer starting effectively from 1st January 2014 [8].

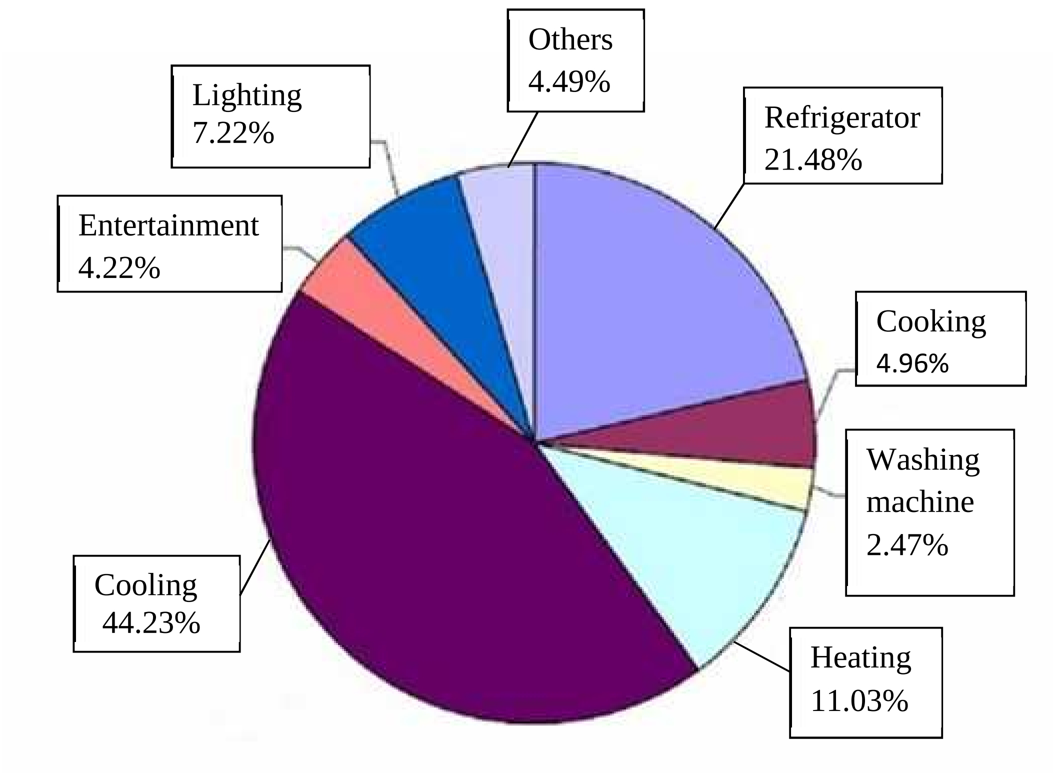

FIGURE 1.2: Average electricity consumption breakdown (%) [9]

In tropical countries, 70% of the heat generation in a house come from the roof. This explains why downstairs is often cooler then the upstairs of double-storey houses during hot weather. Numerous of researches have been done to study the effectiveness of insulation materials used on roofing system that give significant impact on indoor temperature. As stated by the Malaysian Insulation Manufacturers Group (MIMG), it was proved that insulation can reduce indoor temperatures by 3°C to 5°C based on a study in local climate [10]. Through recent researches and studies, it was discovered that Maerogel is the current best insulator materials due to its lowest thermal conductivity. It is the purpose of this quantitative proposed research study to analyze the effect of Maerogel as an insulator in the roofing system on the temperature of a room in a building.

1.2 Problem Statement

The government of Malaysia via Ministry of Natural Resources and Environment Malaysia is dedicated in addressing climate change issues in an integrated manner. Climate change due to global warming has been a serious concern to Malaysia's environment and Earth as a whole. There are three programs implemented in the launching of the National Climate Change Policy, which are Energy Efficiency, Renewable Energy and Solid Management. These programs are implemented in order to reduce the greenhouse gases based on the intensity of carbon up to 40% by 2020 as compared to year 2005. One of the main focuses of the ministry is energy efficiency. Unfortunately, the carbon emitted from Energy Sector is the highest as compared to Industrial, Agriculture, Land Uses and Solid Waste Sectors. Based on the study, the carbon emitted from Energy Sector in Malaysia had an increment from 147 million tonnes in year 2000 up to 217 million tonnes in year 2007 [1].

Buildings consumed about 40% of energy and it is one of the major causes of greenhouse gases emission [6]. A huge amount of energy consumed in buildings is because of the usage of electrical appliance mainly for heating, ventilation, and air-conditioning (HVAC). There are many complaints received by people living in tropical country as such in Malaysia, on heat they experienced in their house where as far as one knows should be the most comfortable place. A roof performs multiple functions with the primary objective of providing protection against something to persons inside a building as such as bright sunshine. However, it wasn't that effective in protecting occupants from the effect of high temperature. Hence, air conditioning will be the solution to this problem of uncomfortable condition.

The current warm climate in Malaysia does not allow the occupants to use energy efficiently. The occupants spend a significant amount of time staying in a building and they will opt to use air-conditioners and fans frequently for long duration to make the environment in the room cooler and more hospitable. Consequently, both applications of air conditioning and long hours usage of fans with regards to reduce the indoor temperature consume a lot of energy in their processes and in return contribute to high percentage of greenhouse gases emission.

The ambient temperature was always considered as a normal cycle of change and a part of life before the invention of air-conditioning. As people started to accept these cycles as normal in nature, they seem to forget the facts in building thermal design. Many Malaysians may think of insulation as only necessary in cold weather. However, they did not realise the truth that a well-insulated house is able to experience a perceptible drop in temperature, too [10].

Apart from that, continuing with this current warm indoor temperature will leads to high electricity usage as well as high electricity bills. In fact, the increment in electricity tariff announced recently by TNB is likely to lead to higher electricity bill. This tariff hike by TNB is likely to burden the consumer especially Malaysian families who are already depressed with the price increase on other daily essential goods and services. Coping with these higher costs of living will not be easy for the consumer.

There are many researches that have been done on roof insulation and results on material used give positive impacts on reduction of indoor temperature. However, the reduction in indoor temperature by existing insulation materials does not significantly reduce in energy consumption by air-conditioner. With the new discovery in materials engineering, through a lot of researches it was proved that the Maerogel is the current best insulator. However, there are still no appropriate experiments and theoretical studies that have been documented to verify the effectiveness of Maerogel as the roof insulator in reducing the indoor temperature.

1.3 Objectives of the Study

This research aims to investigate the effectiveness of Maerogel as an insulator in the roofing system of a house. The specific objectives of this proposed research are:

1. To determine the effectiveness of Maerogel as insulation material on roofing system in comparison with aluminium foil and stone wool.
2. To determine the effect of thickness of Maerogel insulation material on indoor temperature.
3. To establish the reduction factor of electricity consumption by installing Maerogel as roof insulator.

1.4 Scope of the Study

The scope of study for this research can be divided into three phases. The three phases involve are:

1. Simulation the installation of Maerogel insulation material on roofing system by using the computer software.
2. Installation of Maerogel insulation material on the roof system at the experimental houses.
3. Calculation of the Energy Saving Cost.

This study will focus on residential buildings within Malaysia. Simulation analysis and field measurement will be done using model houses. The modelled houses are designated with the same design parameters of standard construction of residential houses in Malaysia where concrete bricks for walls, plaster board for ceiling and concrete tiles for roof material. For field measurement, the dimensions of each experimental house are 600 cm length by 600 cm width by 600 cm height with 45° roof truss. They are built as small-scale houses due to cost and time limitation. Outdoor and indoor temperatures of each experimental house will be collected throughout the experiment. The field measurement will be conducted throughout the day time and data is taken for 7 hot days since Malaysia experiencing averagely the same temperature throughout the year.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The purpose of this literature review is to provide a general overview of roof insulation material with effect to indoor temperature of a house. It introduces the framework for the case study which consist the main focus of this proposed research described earlier in the background of study. The first part of this chapter gives a brief description of thermal comfort of tropical climate and roofing system in Malaysia. Next, the way heat is transferred into the house is explained. Finally, a brief overview of existing insulation materials and Maerogel are given.

2.2 Thermal Comfort of Tropical Climate

A comfortable living environment is important for a healthy and productive life. Thermal comfort is the term referring to that “condition of mind which expresses satisfaction with the thermal environment” [11]. As for the term ‘thermal environment’, it is defined as the surrounding environment within which the occupant lives in. The state of comfort is influenced by both psychological well being and environmental conditions [12]. Environmental conditions is said to be the air temperature, radiant temperature humidity and air movement, which are in turn influenced by psychological well being such as clothing and activity. Figure 2.1 shows the illustration of factors that effect on thermal comfort.

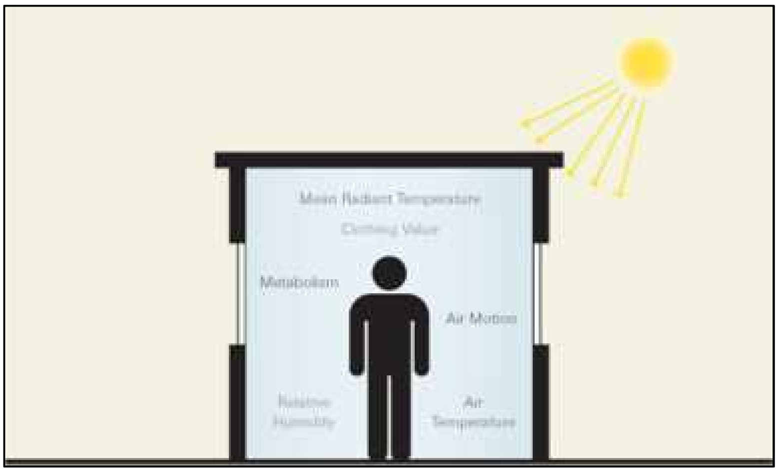

FIGURE 2.1: Factors that influence on thermal comfort

The International Standard ISO 7730 that is use to describe the comfortable thermal environment indoors, uses the predicted mean vote (PMV) and predicted percentage of dissatisfied (PPD) first developed by Fanger [13]. Predicted mean vote is the numerical value for the mean subjective response to the thermal environment quantified by an adapted American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) 7-point psycho-physical scale as shown in Table 2.1.

This scale is deduced from the knowledge of six thermal variables, which are the metabolic rate (*M*) and clothing insulation (I_c) of the subjects, the temperature of the air (t_a) and surrounding surfaces (the radiant temperature,t_r), the water vapour pressure (p_a) and the relative velocity of the air (v_a). Through further experiments, Fanger later determined the relationship between PMV and PDD. The votes outside the range of 1 (slightly cool) to +1 (slightly warm) are considered as the dissatisfied. The example of this relationship is shown in Figure 2.2.

TABLE 2.1: The ASHRAE comfort scale

Description	Numerical Value
Hot	-3
Warm	-2
Slightly Warm	-1
Neutral	0
Slightly Cold	1
Cool	2
Cold	3

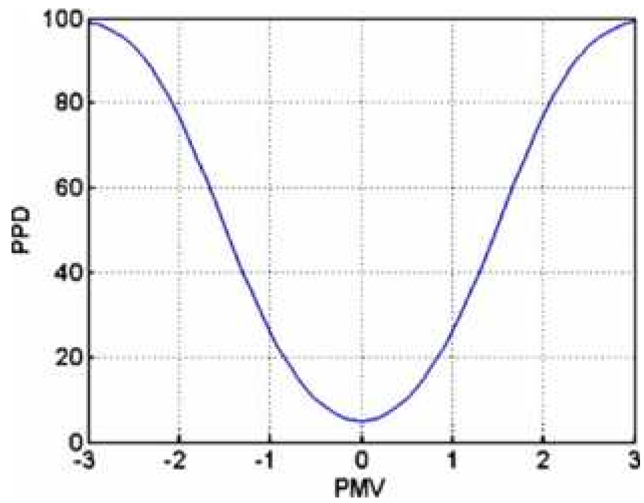

FIGURE 2.2: Predicted Percentage of Dissatisfied vs. Predicted Mean Vote Graph

People in different locations may have different comfort preferences in terms of acclimatization to a particular climate [12]. There are numbers of surveys done by researches using subjects in a tropical context which relate observed sensation on the ASHRAE scale to the physical environment [14]. Surveys of thermal comfort in the field result people in warmer climate may have a tolerance to higher temperature as compared to people in colder climate due to long hours of exposure. As such, people in Malaysia may have the tendency to always be in a shaded place or to seek a location where there is exposure to air flow since Malaysia is a tropical country that has warm climate throughout the year.

The acceptable thermal comfort condition for tropical region country such as Malaysia would be temperature within range of 26.0°C to 30.7°C, humidity in between 30% to 70%. However, for air movement, it varies depending on location and orientation of the building [15]. It is important to keep the indoor conditions thermally comfortable in tropical climate countries because increment in indoor temperature will make the occupants uncomfortable [16]. The differences of human behaviour on thermal comfort in different climate condition and season proved that the design for a building must comply with the locality of the building [17]. The design of building as such as the choice of wall thickness, cool surfaces, and exposure to radiation can make significant contribution to indoor comfort [12]. A good understanding of surrounding climate conditions will result in choosing the suitable building materials.

2.3 Roofing System

The roof is most exposed to the sun as compared to other parts of a building [17]. Solar radiation absorbed by roof surfaces will consequently raise the surface temperature and drives heat transfers toward the interior of buildings. The amount of solar radiation can reach up to 1 kW/m^2 during clear sky condition and the absorption by roof surfaces could be between 20% and 90% of incident solar radiation in its fabric [18]. The surface temperature is greatly affected by solar radiation, where the highest value recorded is at noon on horizontal surfaces.

Residential buildings in Malaysia specifically low rise buildings are having a higher cooling demanding. This is due to the problem of heat gain that passes through the building, where 70% of the heat gain is represents by roof elements [19]. Terrace house accounts for 44% of the buildings in urban areas as of 2000, where commonly these buildings were built by cement or clay brick for walls and using cement and clay tiles for roof [20, 21].

Apart from that, there was no insulation materials have been installed on roofing system of these buildings at that time. Based on the survey that has been by Allen, common types of roof used for Malaysian houses are concrete and clay tiles [22]. The design of a roof plays vital roles in controlling the absorption of solar radiation and its effect on indoor temperature. Otherwise, improper roof design will cause high transmission of solar radiation and thus creating uncomfortable environment to their occupants.

2.4 Heat Transfer

A building gets heated through three methods, which are conduction, radiation and convection as shown in Figure 2.3 [24]. It was recorded that 87% of heat transfer from the roof to indoor space is through radiation and the remaining percentage of heat is transferred through conduction and convection [25]. Roof tiles was first get heated from the Sun through radiant heat. The heat then travels through the roof tiles through conduction method. After that, the hot roof tiles will heats up the air in the attic space through both radiation and convection. Eventually the ceiling boards and plaster ceiling gets heated and finally the room below gets hot through radiation, conduction and convection from the ceiling. These heat processes occurring in a building will give effect on the indoor temperature as well as the thermal comfort experienced by its occupant [25].

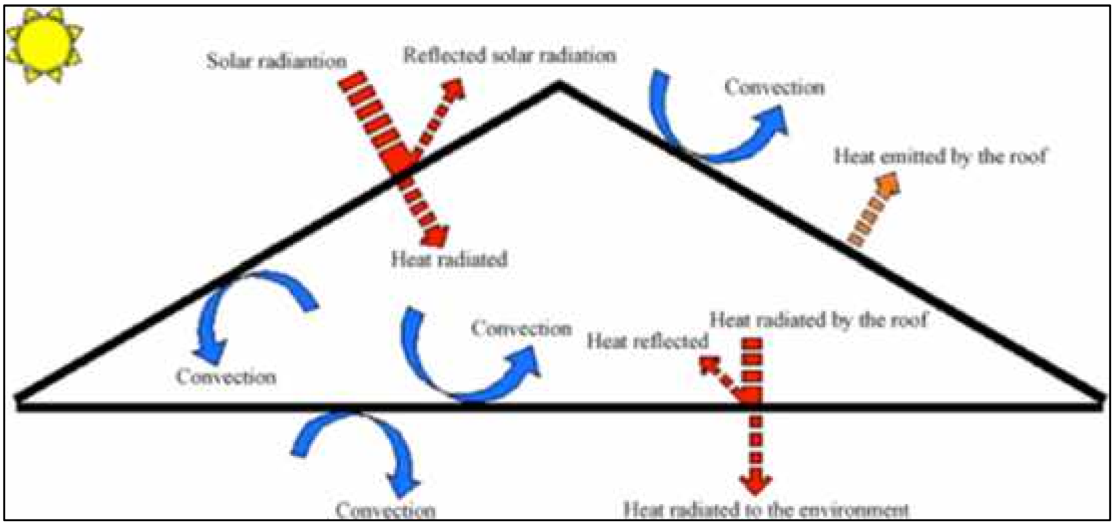

FIGURE 2.3: Heat processes in a building

2.4.1 Conduction

Conduction process takes place when there is flow of heat within two materials in contact. This occurs due to difference in temperature between the materials where thermal energy spreads from hotter regions to cooler regions of a solid or stationary fluid [26]. When the outside temperature is higher than the indoor temperature, thus there is heat gain from outside the building. Heat transfer rate through conduction can be expressed using Fourier's Law shown below [27]:

$$q_c = k \frac{d}{d}$$

where k = thermal conductivity of the material

A = area (perpendicular to the heat flow)

d = temperature gradient

d =thickness

In a building, heat is mainly lost or gained through the windows, walls and roof as shown in Figure 2.4 below [28].

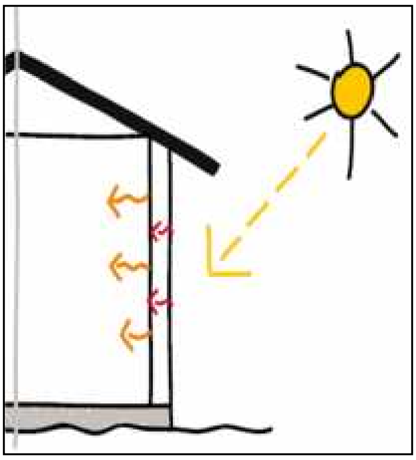

FIGURE 2.4: Illustration of Conduction into a building [29]

2.4.2 Radiation

Radiation heat transfer process takes place through space in form of electromagnetic energy [30]. Differ from conduction and convection where they need medium to transfer the energy, radiation does not need any medium and energy can be transferred even in a vacuum [28]. Heat transfer rate through radiation can be expressed using Stefan-Boltzmann law shown below [27]:

$$P = e \quad (T^4 - T_c^4)$$

where P = net radiated power

σ = Stefan-Boltzman constant, ($5.6703x\ 10^{-8}$ watt /m^2K^2)

A = radiating area

T = temperature of radiator

T_c =temperature of surrounding

An example of radiation heat transfer in a building is when sunlight enters an air-conditioned room through a single pane window; heat energy is generated in the room as shown in Figure 2.5.

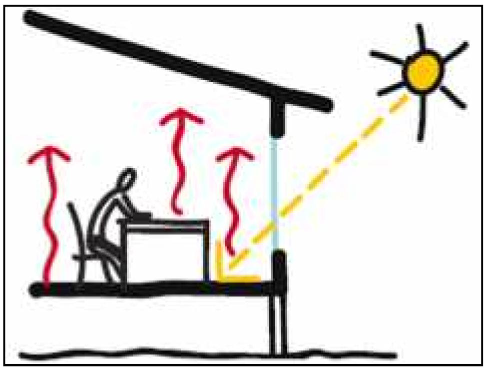

FIGURE 2.5: Illustration of Radiation into a Building [29]

2.4.3 Convection

Convection heat transfer occurs in a moving fluid from one particle to another particle [32]. Such examples of moving fluid are water and air. Heat transfer rate through convection can be expressed using Newton’s Law of cooling shown below:

$$q_{c} = h_c A(T_s T_f)$$

where h_c = surface heat transfer coefficient

A = surface area

T_s = surface temperature

T_f = fluid temperature

Natural convection heat transfer in a house occurs when cold air enters the room, it mixes with warm air. As hot air rises and cool air sinks, heat energy is transferred to the cooler air thus lowered the overall temperature of the room as shown in Figure 8 below.

FIGURE 2.6: Illustration of Convection into a Building [29]

2.5 Insulation Materials

Insulation materials used in building acts as thermal insulation materials, which function to reduce heat transfer into the building through conduction, radiation or convection. They are implemented in building to provide thermal comfort as well as to reduce energy consumption. Insulation materials used in building usually have thermal conductivity value (*k*) of about 0.05 to 0.07 W / m.K [33].

There are numbers of insulation materials types available in market nowadays. However, improper selection and installation of insulation materials in building may not result in maximum thermal performance of insulation. Insulation materials are usually chosen based on its thermal resistance, R-value [34]. R-value is the reciprocal of U-value, which is the thermal transmittance [35]. U-value is expressed as below:

$$U = \frac{1}{R} = \frac{Q_A}{\Delta T} = \frac{k}{L}$$

Where k = the material's thermal conductivity

L = the material’s thickness.

This value is calculated based on the thickness of the insulation and its chemical properties [35]. It was stated that the higher the R-value, the higher the resistance to heat flow [14]. Amount of heat flow reduction between insulation with different R-value is shown in Table 2.2 below.

TABLE 2.2: Relationship between R-value and Heat Flow Reduction [34]

Insulation R-value	Amount of Heat Flow Reduction	Improvement in Energy Efficiency vs. R-8 Insulation
R-8	90%	-
R-12	93%	3%
R-16	95%	5%
R-20	96%	6%
R-32	97%	7%

Few common thermal insulation materials available in Malaysia market are fibreglass, aluminium foil, stone wool and cellulose insulation [23][36]. The thermal resistance, cost and advantages of these commonly used thermal insulation materials is tabulated in Table 2.3 below.

TABLE 2.3: Commonly Used Thermal Insulation Materials Available in Malaysia [23][36]

Insulation Material	Price/ Sq. Ft	R-value/ inch	Environmentally Friendly	Flammable	Notes
Fibreglass	RM 19.80	R-3.1	Yes	No	Does not absorb water
Aluminium Foil	RM 5.99	-	Yes	No	Light and easily installed
Stone Wool	RM 3.50	R-3.1	Yes	No	Does not melt or support combustion.
Cellulose	RM 4.00	R-3.7	Yes	Yes	Contains the highest amount of recycled content.

2.6 Maerogel

Maerogel is the short name for Malaysian aerogel and was first discovered by a Malaysian scientist from Universiti Teknologi Malaysia (UTM), Prof. Dr. Halimaton Hamdan [37]. Aerogel is regarded as the lightest known solid materials and the finest insulation material available. Among all, silica aerogel is the most common and widely used as compared to other types [38]. It was first invented in 1931 by Samuel Stephens Krestler but the usage has been limited due to its high cost of production, which is approximately RM 15,000/kg.

With the new discovery of Maerogel made up from rice husks as shown in Figure 2.7 below, this new process has cuts the cost of producing aerogel by 80%, where it cost about RM330/kg only. Thus, make it possible to be used as common material with widely used. The extraordinary properties of silica aerogel with high specific surface area, high porosity, low density, low dielectric constant and excellent heat insulation properties have attracts more attention and leads to many research works [37]. One of the useful applications of Maerogel is that it acts as an excellent thermal insulator, which provides seven-fold better insulation than fibreglass [38].

With thermal conductivity of 0.02 W/m.K and able to remain intact up to temperature over 600°C, Maerogel is specifically an excellent insulation material for extreme high temperature condition [39]. It was stated that Maerogel could also significantly reduce energy needs for air conditioning and heating. However, there are still no appropriate experiments and theoretical studies that have been documented to verify the reduction in energy consumption used by air-conditioning and heating induced by Maerogel. Previously Maerogel is widely used in aeronautics, military, vessels and piping insulation [40].

FIGURE 2.7: Maerogel

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter describes the proposed methodology that will be adopted throughout this research including modelling, sampling, data collection and analysis. This proposed research will be done in three stages which are:

1. Simulation the installation of Maerogel insulation material on roofing system
2. Installation of Maerogel insulation material on the roof system at the experimental houses
3. Calculation of Energy Saving Cost

All these stages will be conducted based on the methodology and are explained in detail in this chapter.

3.2 Simulation Using Computer Software (Ecotect)

The main aim of this is to investigate the effectiveness of Maerogel as an insulator in the roofing system of a building. To verify this objective, analysis is first done by using a simulation of sustainable design analysis software, Ecotect. Modelled house in Ecotect simulation and the cross section of roof attic is shown in Figure 3.1. In the roof attic, there will be 10 mm plasterboard followed by 50 mm insulation with remaining of air gap as shown in Figure 3.2. The modelled houses are designated with the same design parameters of standard construction of the experimental houses where concrete bricks for walls, plaster board for ceiling and concrete tiles for roof material. The input data for the field study modelling in Ecotech are building construction materials and local climate data of Kuala Lumpur, Malaysia. There are 2 parameters need to be recorded:

1. Indoor Temperature
2. Outdoor Temperature

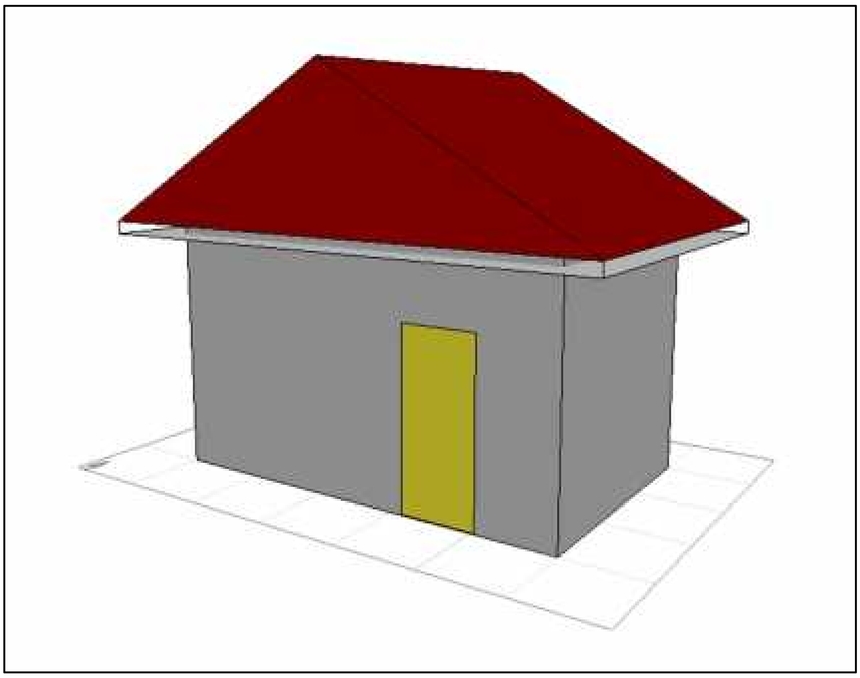

FIGURE 3.1:House Model using Ecotect

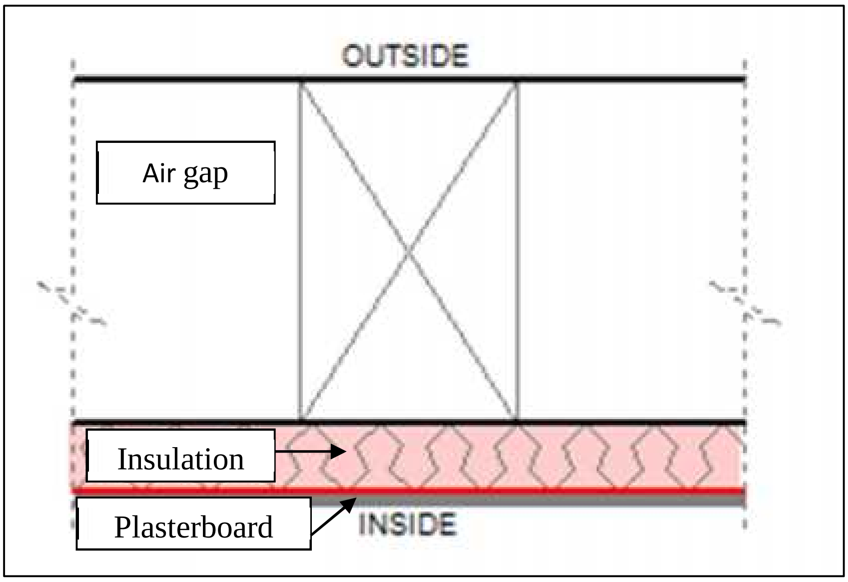

FIGURE 3.2: Cross-section of Roof Attic

The advantages of using computer simulation are that it can be done many times without having limitation of cost and time. Thus, provides many data and compliment the data obtained from real condition experiments.

3.3 Experimental Houses Model

In the second phase of this proposed research, three small-scale experimental houses are built to demonstrate the real condition of Maerogel's effectiveness as roof insulator. Each experimental house is identical to each other where it was built using concrete brick as wall and using red color of roof tiles. The dimensions of each experimental house are 600 cm length by 600 cm width by 600 cm height with 45° roof truss. Figure 3.3, 3.4 & 3.5 below shows the small scale experimental houses used for field measurement.

FIGURE 3.3: Identical Small Scale Houses

FIGURE 3.4: Front View of Experimental House

FIGURE 3.5: Side View of Experimental House

As observed in figures provided, there were no windows built on the wall of experimental houses. This is to create air-tight condition so that experimental houses could focus on properties of the insulation materials only. All three experimental houses are located at open spaces in order to allow maximum exposure to the sun radiation throughout the experiment with fewer disturbances. Apart from that, the wider area of the roof is positioned to face the North and South. This position suit the real condition of the actual house in Malaysia where it will minimize the roof’s area that will be exposed to the sun. As the sun rises in the East and sets in the West, orienting the long axis of the roof east-west can minimize the heat gain due to sun radiation. In Figure 3.5 and 3.6, the orientation of the roof’s model and the schematic diagram of heat generation through the roof are shown respectively.

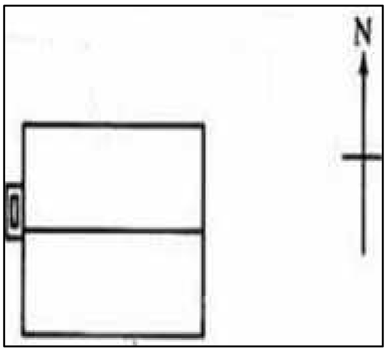

FIGURE 3.6: Roof Orientation of Experimental House

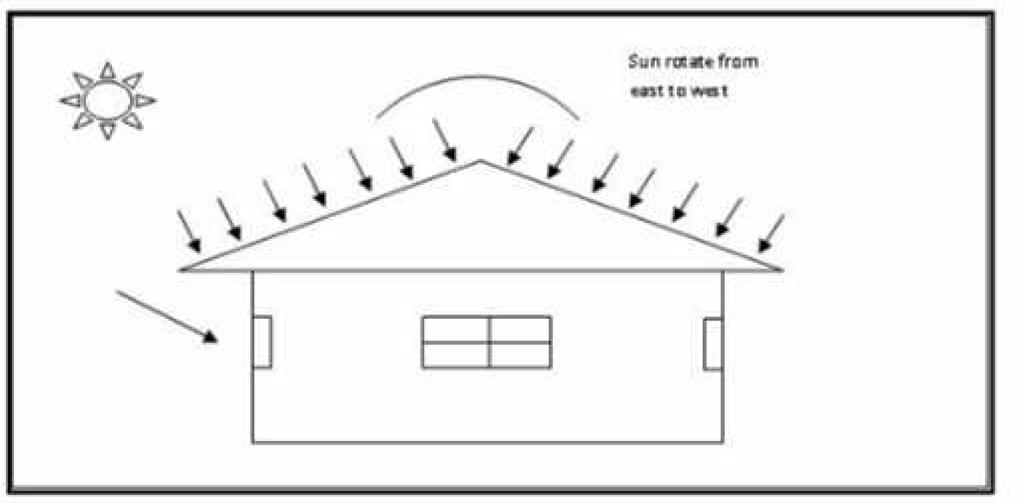

FIGURE 3.7: Heat Generation through Roof

3.3.1 Experimental Set Up

Each roof of the experimental houses will be installed with Maerogel, aluminum foil and stone wool respectively. The thickness of Maerogel that are going to be used is tabulated in Table 3.1 below.

TABLE 3.1: Thickness of Insulation Materials Used

Insulation Materials	Experimental House	Thickness (mm)
Aluminium	House Model 1 (H1)	20
Rockwool	House Model 2 (H2)	50
Maerogel	House Model 3 (H3)	12

The insulation materials are installed at the bottom of the roof truss as shown in Figure 3.7, 3.8 and 3.9 below.

FIGURE 3.8: Aluminium Insulated House

FIGURE 3.9: Rockwool Insulated House

FIGURE 3.10: Maerogel Insulated House

3.3.2 Preparation of Apparatus

Throughout the experiment, the parameters will be measured using Hygro-Thermometer as shown in Figure 3.10 below. It can measure temperature and relative humidity simultaneously. However, in this project only the temperatures are measured. The probes are hanging in the middle of the experimental house as to get the indoor temperature accurately. Temperature readings for each experimental house are taken every 1 hour for 3 days.

FIGURE 3.11: Hygro-Thermometer

3.4 Calculation of Energy Saving Cost

As for the last stage of this research, for finding the reduction factor of electricity consumption by installing Maerogel as roof insulator, the influence of different insulation materials on total energy saving cost and net energy over 5,10 and 20 years lifetime period is studied. Energy rate per kWh is calculated from dividing total annual energy cost in RM by total annual energy consumption in kWh. Energy saving cost is the residuum between energy cost before and after using insulation in lifetime period. Annual energy cost over the life time is calculated by Eq.1. below [41].

$$C_I = C_E . E . \frac{(g+1)^{n-1}}{g} . (g+1)$$

Where C_I = annual energy cost over the lifetime

C_E = cost of electricity (RM/kWh)

E = total annual energy consumption of air conditioner (kWh)

g = inflation ratio in percentage

For calculating Eq (1), it is necessary to mention that the Energy Cost is calculated based on current TNB electricity tariff. Inflation rate at this research has been assumed 4%. This inflation rate only belongs to annual increasing price in electricity tariff. The electricity consumption will be calculated through the usage of air-conditioner. Duration of an air-conditioner usage during daytime is taken as 6 hours where normal living usually start to switch it on at 11 am. The kilowatt-hour usage is based on 1 Horsepower type of air-conditioner. It will later be converted into electricity cost based on TNB electricity tariff. Table 3.2 below shows the current electricity tariff in and pricing rates in Malaysia given by Tenaga Nasional Berhad (TNB) for residential houses.

TABLE 3.2: Electricity Tariff and Pricing Rates given by Tenaga Nasional Berhad [31]

TARIFF A – DOMESTIC TARIFF	UNIT	RATES
For the first 200 kWh (1-200 kWh) per month	sen/kWh	21.8
For the first 100 kWh (201-300 kWh) per month	sen/kWh	33.4
For the first 100 kWh (301-400 kWh) per month	sen/kWh	40.0
For the first 100 kWh (401-500 kWh) per month	sen/kWh	40.2
For the first 100 kWh (501-600 kWh) per month	sen/kWh	41.6
For the first 100 kWh (601-700 kWh) per month	sen/kWh	42.6
For the first 100 kWh (701-800 kWh) per month	sen/kWh	43.7
For the first 100 kWh (801-900 kWh) per month	sen/kWh	45.3
For the first 100 kWh (901 kWh onwards) per month	sen/kWh	45.4
** The minimum monthly charge is RM3.OO*		

Also, installation cost, maintenance cost, rate of interest for investment amount and interest rate of saving resulted from less payment after insulation has not been considered. Full energy cost analysis done is presented in the appendix.

CHAPTER 4

RESULTS & DISCUSSION

4.1 Introduction

In this section, the results obtained from the simulation, field measurement and energy cost saving analysis are evaluated. Data from both modelled house in Ecotect and experimental houses with different insulation materials are collected within 7 and 3 days respectively per house. Both simulation and field measurement experiments were conducted simultaneously and the evaluation on the measured parameters is based on hourly data. Both experimental house data collected for 10 hours started at 9.00 am until 5.00 pm with time interval of 1 hour. The results collected from field measurement were furthered used for Energy Cost Saving analysis in third methodology.

4.2 Effectiveness of Maerogel in Comparison with Aluminium and Rockwool

The effectiveness of Maerogel in comparison with Aluminium and Rockwool is first done using simulation analysis, Ecotect. Comparison on indoor temperature between Maerogel, aluminium and rockwool is made based on the result from the simulations using the same design parameters. Table 4.1 presents the insulations installed in the house model variations with the same thickness of 50 mm.

TABLE 4.1: Insulation installed in the house model variations

House Model	Insulation
A	Aluminium
B	Rockwool
C	Maerogel

Figure 4.1 below shows the Temperature (°C) versus Time (Day) of Model A. The blue line indicates the outdoor temperature while the red line indicates the indoor temperature. Based on the graph, it can be said that daily outdoor temperatures peak in between 9.00 am to 5.00 pm because of the position of the sun which leads to maximum solar radiation. The highest outdoor-indoor temperature difference was 7.4°C which was obtained at 1.00 pm in Day 2.

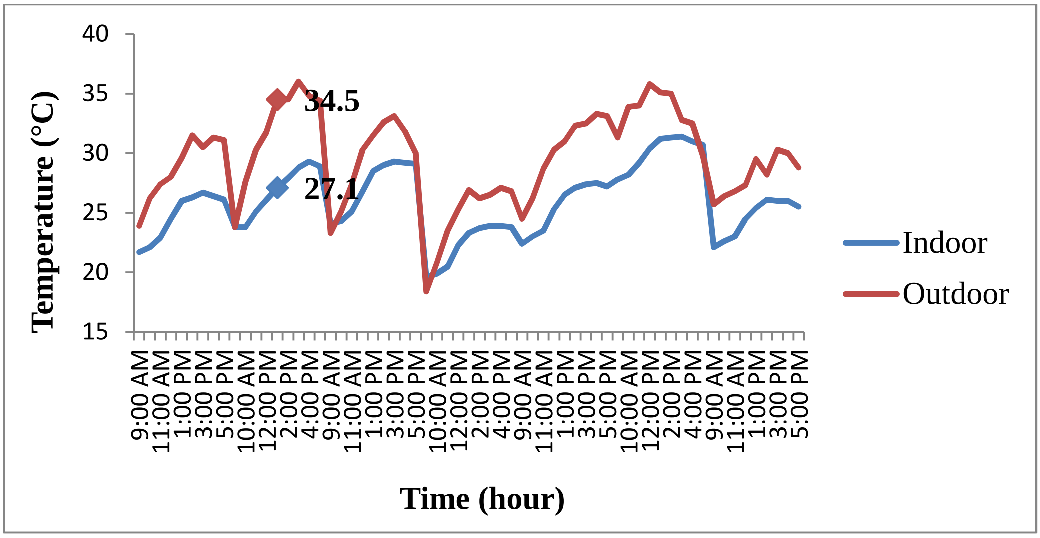

Figure 4.1: Outdoor Indoor Temperature for Aluminium Insulated House (Model A)

Figure 4.2 below shows the Temperature (°C) versus Time (Day) of Model B. The highest outdoor-indoor temperature recorded was 7.5°C obtained at 3.00pm in Day 2. In comparison with Model A, the outdoor-indoor temperature difference obtained at this time was 7.2°C, which is 0.3°C, compared to Model B. Thus, Model B is more effective than Model A in retarding heat into the house.

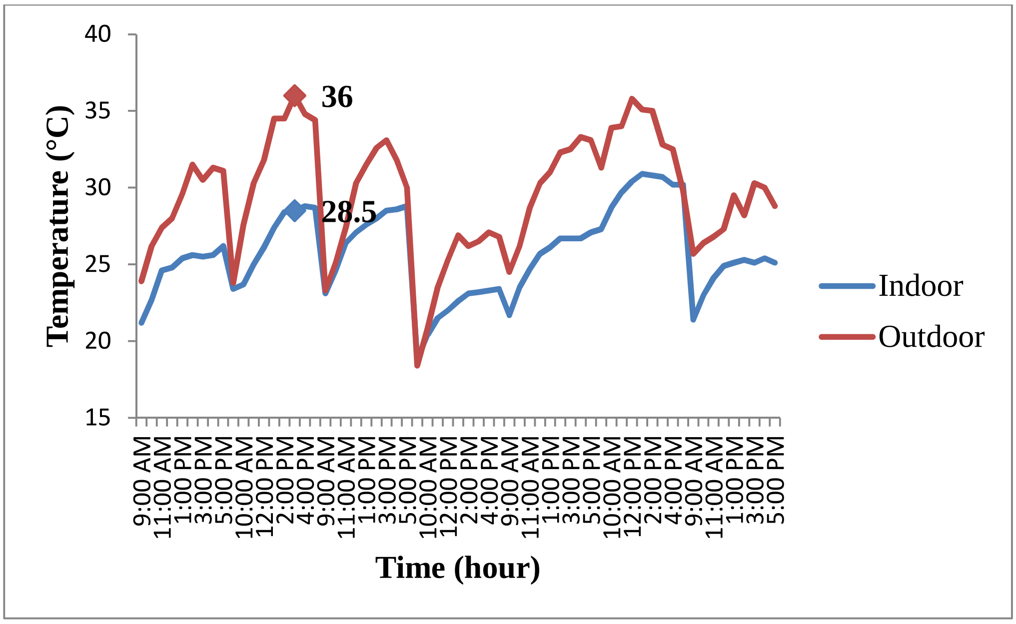

Figure 4.2: Outdoor Indoor Temperature for Rockwool Insulated House (Model B)

Figure 4.3 below shows the Temperature (°C) versus Time (Day) of Model C. The highest outdoor-indoor temperature recorded was 8.2°C obtained at 1.00pm in Day 2. At this time, the outdoor-indoor temperature obtained at Model B was 7.1°C, which is 1.1°C lower, compared to Model C. Therefore, Model C provides better thermal performances than Model B. In addition, the outdoor-indoor temperature differences obtained for Model A and Model B was 7.4°C and 7.1°C, which are 0.8°C and 1.1°C lower than Model C respectively.

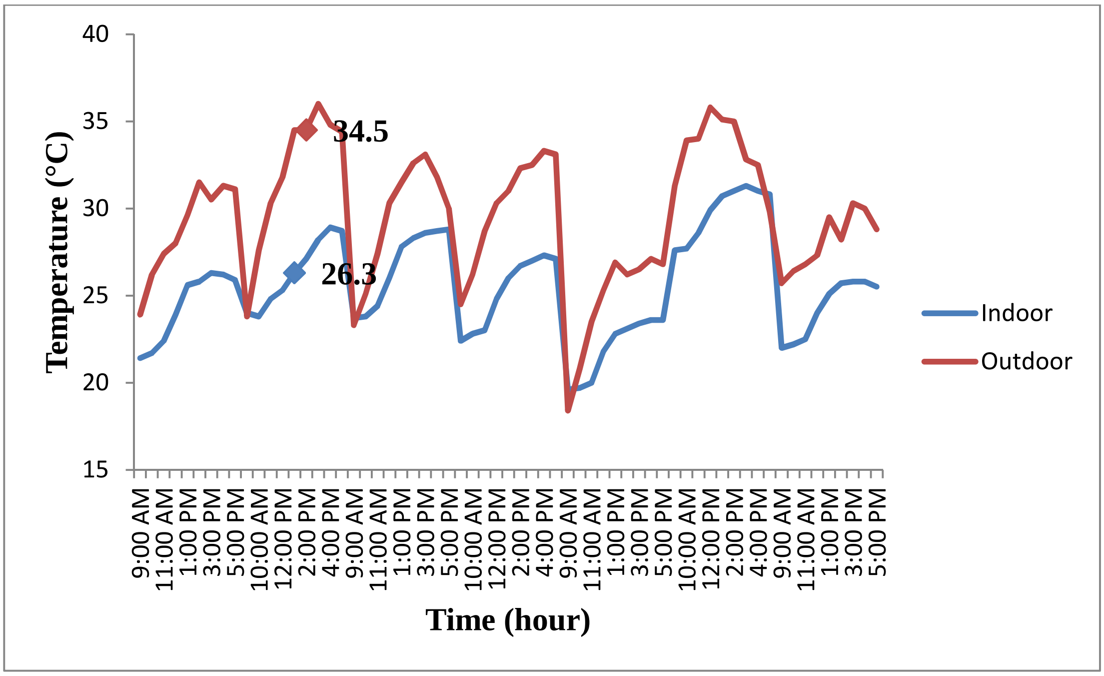

Figure 4.3: Outdoor Indoor Temperature for Maerogel Insulated House (Model C)

Figure 4.4 and Table 4.2 show the comparison of outdoor-indoor temperature differences of all model houses from 9.00am to 5.00pm. Based on the graph, the temperature differences were taken from 9.00am to 5.00pm where the difference is at the biggest margin for all set of experiment. By focusing the data within the time range, the performance of all insulation materials can be compare. From 9.00am till 10.00am, the performance between all house models is averagely the same. However, approaching 11.00am till 3.00pm, Maerogel Insulated House starts to show huge gap on the temperature difference as compared to Aluminium and Rockwool. The highest temperature differences obtained by Model C, Maerogel insulated house as recorded was 8.6°C at 1pm where the temperature is at peak due to Sun location.

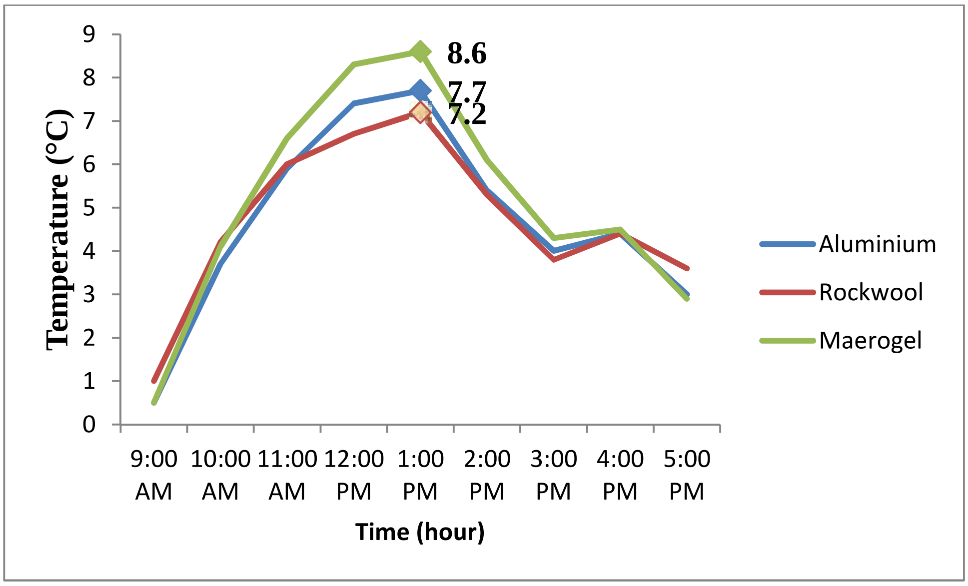

FIGURE 4.4: Outdoor-Indoor Temperature Differences between Insulation Materials

TABLE 4.2: Outdoor-Indoor Temperature Differences between Insulation Materials

Time(hour)	**Outdoor-Indoor Temperature Differences**		
	Aluminium	**Rockwool**	**Maerogel**
9:00 AM	0.5	1	0.5
10:00 AM	3.7	4.2	4.1
11:00 AM	5.9	6	6.6
12:00 PM	7.4	6.7	8.3
1:00 PM	7.7	7.2	8.6
2:00 PM	5.4	5.3	6.1
3:00 PM	4	3.8	4.3
4:00 PM	4.4	4.4	4.5
5.00 PM	3	3.6	2.9
Average	**4.67**	**4.69**	**5.1**

From Table 8, Maerogel induced the highest outdoor-indoor temperature difference followed by Rockwool and Aluminium. Based on the entire graphs above, it was shown that Maerogel performance is better than Aluminium and Rockwool since the outdoor-indoor temperature differences among these insulation materials varies up to ±1.1°C. It is this research objective to determine the effectiveness of Maerogel as roof insulation in comparison with Aluminium and Stone wool. From all the graphs, it can be concluded that Maerogel as roofing insulation is more effective than Aluminium and Stone Wool.

Thermal analysis on indoor temperature using these 3 insulation materials using Ecotect is very helpful in saving time and cost since it can be done many times. However, there are certain limitations when using Ecotect where the weather data available in the software the latest is 2011. Besides that, this thermal analysis in Ecotect is done only based on mathematical equation. Thus, field measurement on experimental houses is going to be conducted in order to determine the effectiveness of Maerogel in with comparison with Aluminium and Stone Wool. In real condition analysis, the indoor temperature is related to many different factors. Figure 4.5 below shows the outdoor-indoor temperature profiles of experimental houses.

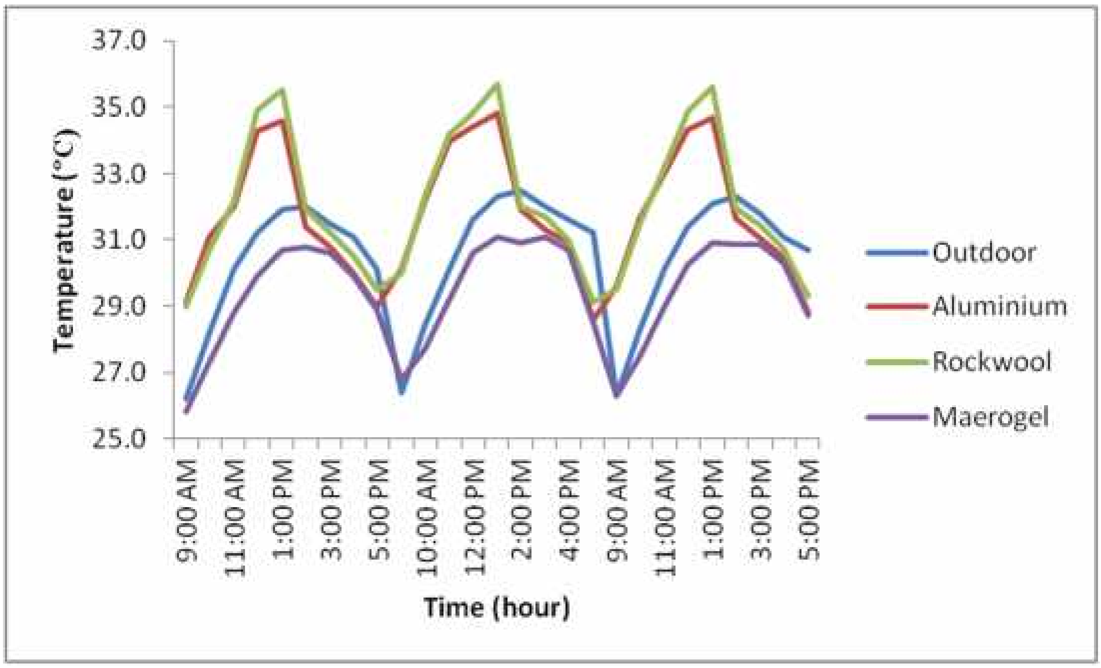

FIGURE 4.5: Outdoor-Indoor Temperature Profiles of Experimental Houses

From the field measurement, the results obtained were not as expected since the indoor temperature of Aluminium & Rockwool insulated houses were higher than the indoor temperature. Maerogel is the only one who induced reduction in temperature. This happened due to high relative humidity in the Aluminium & Rockwool insulated houses which cause the indoor temperature to be higher than the outdoor where the relative humidity varies from 60 to 70±% whereas Maerogel insulating houses relative humidity is only 50%. However, this result is enough to prove the effectiveness of Maerogel as roof insulator in comparison with Aluminium & Rockwool and supports the results obtained from the Ecotect simulation.

4.3 Effect of Thickness of Maerogel

The effect of thickness of Maerogel was also analysed from data obtained in Ecotect simulation. Different thickness of Maerogel however induced the same indoor temperature. This result was also supported by other products of Aerogel where difference thickness of aerogels results in equal thermal performance. Theoretically, thicker material will results in lower thermal resistance. Thus analysis is done based on energy cost to verify the effect of thickness of Maerogel. From Figure 4.5, it is shown that 0.07 m thick Maerogel produced the lowest energy cost for each 5, 10 and 20 years lifetime. The differences can be clearly seen on energy cost at 20 years lifetime where the gap between 0.05m and 0.07m is huge. This can be concluded that increased thickness of Maerogel leads to reduced energy cost.

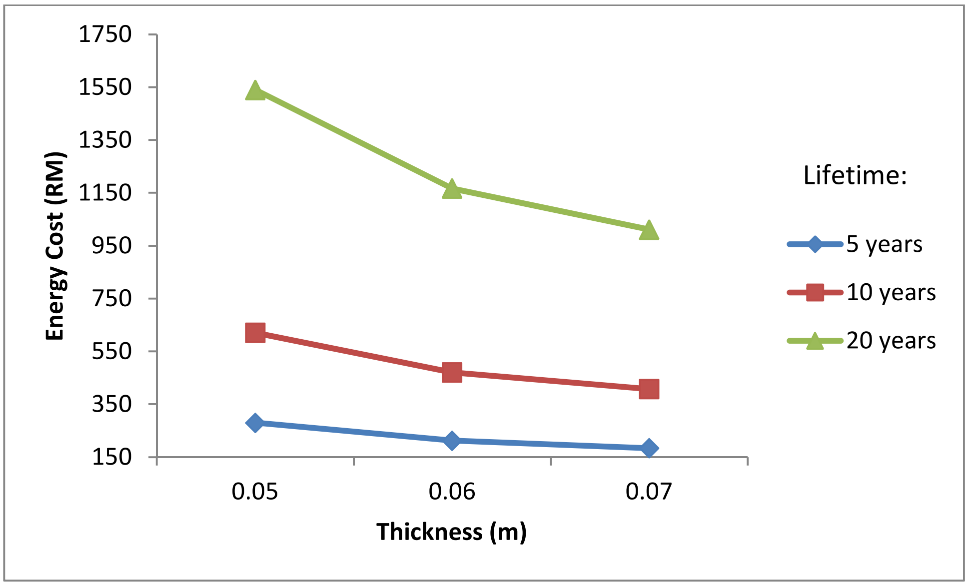

FIGURE 4.5: Energy Cost of Maerogel of Different Thickness

4.4 Energy Saving Cost Analysis

The energy cost for each insulation materials is analysed for 5, 10 and 20 years lifetime as shown in Figure 4.6. From the graph, the highest energy cost is obtained by non-insulated roof and Maerogel produced the lowest energy cost for each lifetime compared to Aluminium and Rockwool. The purpose of analysis of different lifetime is to show the increase of energy cost due to inflation rate of 4% used in the analysis. The differences can be clearly seen on energy cost at 20 years lifetime where the gap of energy cost between Maerogel and non-insulated is huge.

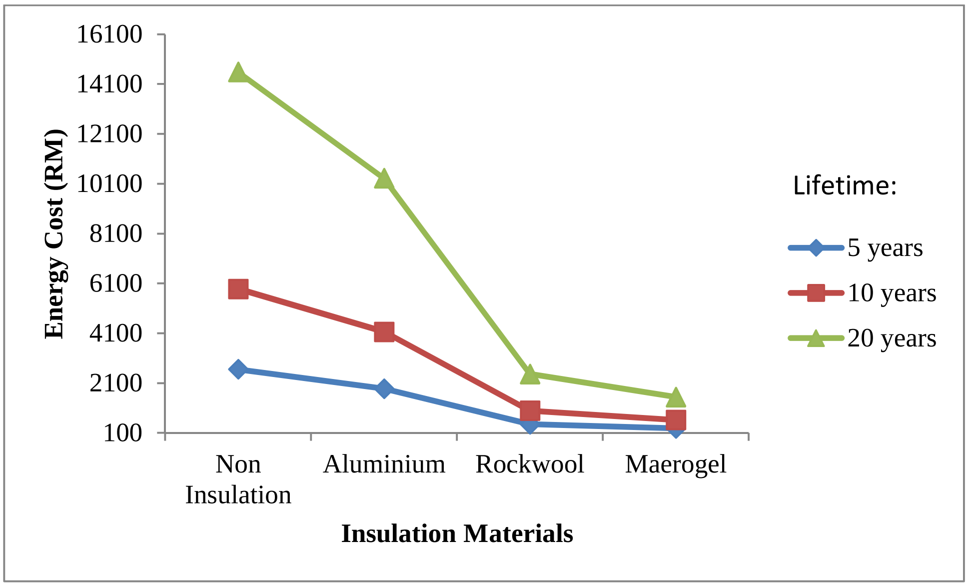

FIGURE 4.6: Energy Cost of Different Roofing System

In Figure 4.7, it shows the reduction of energy cost of different insulation materials in comparison with the non insulated roof. It was shown that Maerogel reduced the energy cost in comparison with non insulated roof the highest by 89% followed by Rockwool and Insulation. This result supports the effectiveness of Maerogel as roofing insulation in comparison with Aluminium and Rockwool.

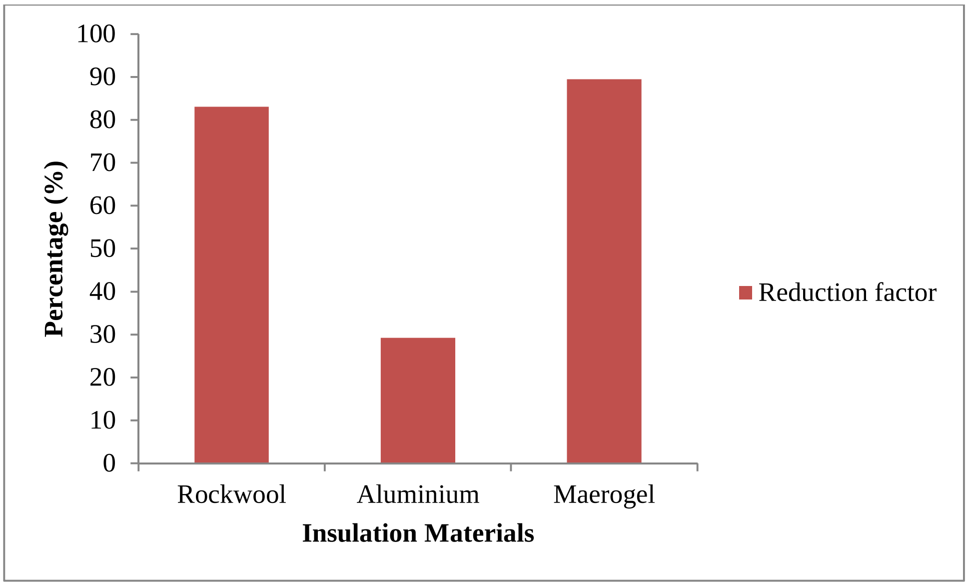

FIGURE 4.7: Reduction of Energy Cost of Different Insulation Materials

CHAPTER 5

CONCLUSIONS & RECOMMENDATIONS

4.1 Introduction

This final chapter will conclude the results of the study. The applications of the research study are also discussed in relation to the aims and objectives of the report as set in Chapter 1. Finally, further work related to this study will be suggested in this chapter in order to strengthen and compliment this report.

4.2 Conclusion

Based on the literature review and methods discussed above, the results of this study are already expected. As stated in the Objective section, this study aims to obtain positive effects of Maerogel roofing system on indoor temperature of residential buildings. From the thermal analysis in Ecotect, it was resulted that Maerogel as roofing insulation is more effective in retarding heat into the house compared to Aluminium Foil and Rockwool and supported with the results obtained from field measurement. Thicker Maerogel does also give effect on energy cost where the energy cost will be lower. The reduction in indoor temperature will definitely reduce the electricity consumption. Based on the energy cost analysis, it was recorded that Maerogel insulated house can induce reduction on electricity cost the highest by 89% in comparison with non-insulated house. Hence, energy efficiency will be obtained for that particular building and at the same time, the living cost can be minimized. All the results obtained are in line with the literature review.

4.3 Recommendation

As to date, simulation the installation of Maerogel insulation material on roofing system in Ecotect for 7 days has been done. From the decreasing value of indoor temperature shown in the graph, it was proved that Maerogel works effectively as insulation on roofing system. Next is to demonstrate the effectiveness of Maerogel as insulation on roofing system in real condition and to calculate the energy saving cost after the insulation. Several recommended future works are recommended in order to strengthen and compliment this research. The recommendations are as follows:

1. Incorporating Maerogel with other materials such as plastic to result in better performance.
2. Conducting a field measurement using the current most used roof type and colour in housing sector on experimental house is highly recommended for future work.
3. Research on the effect of Maerogel roofing system on indoor temperature at night.
4. Further analysis on net energy cost saving from the insulation installed on roofing system based on energy cost and also the insulation cost.

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