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INVESTIGATION ON THERMAL PERFORMANCE OF PROSPECTIVE GREEN MATERIALS AS BUILDING WALL INSULATION

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Report

Projek Sarjana Muda

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DECLARATION

I declare that this thesis entitled “Investigation on Thermal Performance of Prospective Green Materials as Building Wall Insulation” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ………………………

Name : ………………………

Date : ………………………

APPROVAL

I hereby declare that I have read this report and in my opinion this report is sufficient in terms of scope and quality as a partial fulfillment of bachelor degree of Mechanical Engineering.

Signature :………………………

Supervisor Name :………………………

Date :………………………

DEDICATION

To my beloved mother and father

ABSTRACT

The building construction industry is recently changing focus in using sustainable and green materials. With the abundance of the resources, it is beneficial to utilize the application and observing its potential as wall insulation materials. This study is hoped to provide some prospect in using green materials as wall insulation. Building insulation is defined as any object in a building, such as roof and wall are used as insulation for any purpose. Thermal insulator in buildings is an important factor to achieve thermal comfort for its occupants. By installing the insulator in a building, it will reduce the unwanted heat loss or gain and can also decrease the energy demands of heating and cooling systems. Besides that, the study tends to set as a benchmark study for further application of green materials in building construction. In this project, green waste materials is chosen to analysis and perform the heat transfer test. Green materials used in this study are coconut fibres, cellulose and sugar cane wastes. The objective of this study is to analysis the behaviour and thermal insulation of the selected green materials. The measurement is conducted by installing the green materials samples in mini house model and infrared camera is used to record the temperature gradient in the mini house model under different conditions. Thermal conductivity of each insulator is calculate to determine the thermal behaviour of these insulators.

ABSTRAK

Industri pembinaan bangunan baru-baru ini mengubah tumpuan dalam menggunakan bahan-bahan mampan dan hijau. Dengan adanya sumber yang banyak, aplikasi dan potensinya sebagai bahan penebat dinding telah dipehartikan. Kajian ini diharapkan dapat menyediakan beberapa prospek dalam menggunakan bahan hijau sebagai penebat dinding. Penebat bangunan ditakrifkan sebagai sebarang objek di dalam bangunan, seperti penebat di bumbung dan dinding untuk mencapai tujuan tertentu. Penebat haba dalam bangunan merupakan faktor penting untuk mencapai keselesaan terma bagi penghuninya. Dengan memasang penebat di bangunan, ia akan mengurangkan kehilangan atau kenaikan haba yang tidak diingini dan juga dapat mengurangkan permintaan terhadap tenaga pemanasan dan penyejukan. Di samping itu, kajian ini cenderung kepada penggunaan bahan hijau dalam pembinaan bangunan. Dalam projek ini, bahan buangan hijau dipilih untuk dianalisis dan melaksanakan ujian pemindahan haba. Bahan-bahan hijau yang digunakan dalam kajian ini adalah sisa-sisa kelapa, selulosa dan sisa tebu. Objektif kajian ini adalah untuk menganalisis tingkah balas dan penebat haba bahan-bahan hijau terpilih. Pengukuran dilakukan dengan memasang sampel bahan hijau dalam model rumah dan kamera inframerah digunakan untuk merekam kecerunan suhu dalam model rumah dalam keadaan yang berbeza. Kekonduksian haba bagi setiap penebat akan dikira untuk menentukan tahap kelakuan haba penebat tersebut.

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LIST OF SYMBOLS

k	-	Thermal conductivity
ρ	-	Density
c	-	specific heat capacity
Q	-	Rate of heat conduction
ΔT	-	Temperature different
d / L	-	Material thickness
R	-	Thermal resistance of the material
K	-	Kelvin
℃	-	Degree Celsius
κ	-	Thermal diffusivity
C_p	-	Specific heat
m	-	meter
W	-	Watt
kg	-	kilogram
k_{ave}	-	Average thermal conductivity
T	-	Temperature
A	-	Surface area of heat transfer
Re	-	Reynolds Number

LIST OF ABBREVIATIONS

3I	-	3 cm insulation layer
7I	-	7 cm insulation layer
CBAGB	-	Chemical treated bagasse fibre
CBAGP	-	Heat treated bagasse fibre
CFI	-	Cellulose fibre insulation
ExSTNI	-	External Surface Temperature No Insulation
GR	-	Green roof
GFO	-	Green facade optimization
HHW	-	Household waste
InSTNI	-	Internal Surface Temperature No Insulation
LCA	-	Life cycle analysis
NHIW	-	Non-hazardous industrial waste
NI	-	No insulation
SEM	-	Scanning Electron Microscope
UHI	-	Urban heat island
WG	-	White gravel

CHAPTER 1

INTRODUCTION

1.1 Background of Problem

Building insulation is defined as any object in a building, such as roof and wall are used as insulation for any purpose (Asdrubali, 2015). Majority of insulation in buildings is for thermal insulation purpose in Malaysia. Thermal insulator in buildings is one of the most important factor to achieve thermal comfort for its occupants. By installing the insulator in a building, it will reduce the unwanted heat loss or heat gain and also decrease the energy demands for heating or cooling systems. Generally, insulation can just refer to the insulation materials applied to slow down the heat transfer process from the outer wall to the inner wall, such as cellulose, rock wool, glass wool, wood fibre, plant fibre, cement, polystyrene, urethane foam and plant straw. Figure 1.1 shows the example of extruded polystyrene foam as wall insulation in building.

Figure 1.1: Extruded polystyrene foam as building wall insulation (KIMMU, 2017).

In Malaysia, the problem faced is the hot weather, where the greatest source of heat energy is mainly from solar radiation. Through the windows and doors, solar radiation is able to enter the buildings directly and heat up the wall to a higher temperature than the ambient and increasing the heat transfer through the building envelope and cause the room become hot and uncomfortable (Baker, 2013). In order to stay in comfortable room, refrigerated air conditioning is employed to solve the hot situation, then it is particularly important to seal the building envelope. Due to the dehumidification of air infiltration inside the room, it can significantly cause the wastes of energy. In Malaysia, most of the building designs are based on effective cross ventilation instead of installed air conditioning system to provide convective cooling to the room. Building construction and correct way of insulated materials installation on the wall of the buildings will ensure low conduction of heat transfer. This requires attention from contractor and designer.

The lesser the natural air flow into the building, the more mechanical ventilation required to ensure the thermal comfort of the occupants. High humidity in a room can be significant issue related to lack of airflow, construction material failure, condensation and encouraging growth of microbial such as bacteria and mould. These problems are incorporated with actively or passively air exchange systems. The higher the density of a material, the better it will conduct heat. For example, air is low density medium, hence, air is a very poor heat conductor and therefore can be a good insulator. Principle of insulation is to reduce the heat transfer conductive by using air spaces between fibres, plastic bubbles or foam and building's wall cavities. This is beneficial in an actively heated or cooled building, but can be a liability in a passively cooled building.

In this project, green waste materials is chosen to analyse and perform the heat transfer test. Green material is defined as biodegradable waste material, such as grass, plants, tree trimmings and fibre waste that can be diverted from landfills for recycling (Peterson, 2017). Statistic shows that millions tons of green waste is disposed of in landfilled every year instead of being recycled or fully used. Beside shortens the life of landfills, landfilling green materials also contributes to Green House Gases emission. By applying green material in the building development, it may provide sustainable utilization of waste resources. Utilize of green material not only reduce the quantity of wastes, but also reduce the harmfulness to the environment. For example, in thermal energy storage system (TES) development in Pahang, Malaysia, in order to absorb the heat from outer wall to inner wall of a building, a form of green material is used as an insulator. The potential of heat absorber of the insulator is measured by its R-value. The greater the value of R-value, the better the heat insulation of the green material (Ali, 2013).

1.2 Problem Statement

The purpose of this study is to investigate the potential of waste or green materials as wall insulation for building. This study suits well with the current trend in building construction industry where the focus is on using environmental friendly and sustainable materials. This study will be conducted to find solutions to the following questions:

1. How is the thermal performance of green materials as wall insulation?
2. What are the effects of green materials as wall insulation on internal condition?
3. How efficient is the green materials as wall insulation compare to other types of wall insulation?

1.3 Objectives

The objectives of this project are:

1. To evaluate the thermal performance of green materials as wall insulation for residential housing.
2. To conduct a comparative analysis of the different green materials on how the interior and exterior of the house heats and cools.

1.4 Scope of Research

The scopes of this project are:

1. The experimental investigation will be conducted by using a mini house model.
2. The study will observe the temperature different between internal and external condition by installing different types of green materials.
3. For the temperature distribution during certain condition, the image will be recorded by using thermal infrared camera.
4. The heat transfer analysis will include the calculation of thermal conduction between the wall and green materials from outer surface to inner surface of the room.

1.5 Project Organization

Project organization is a structure that facilitates the coordination and implementation of the activities in the project. The main reason is to create a clear guideline and tidy structure when conduct the project (Diaz, 2007). Proper structured project organization can reduce confusion and uncertainty during project initiation phase is one of the main objectives of the project organization preparation. Proper design of project organization chart is essential to the project success. Figure 1.2 shows the project organization chart for Final Year Project.

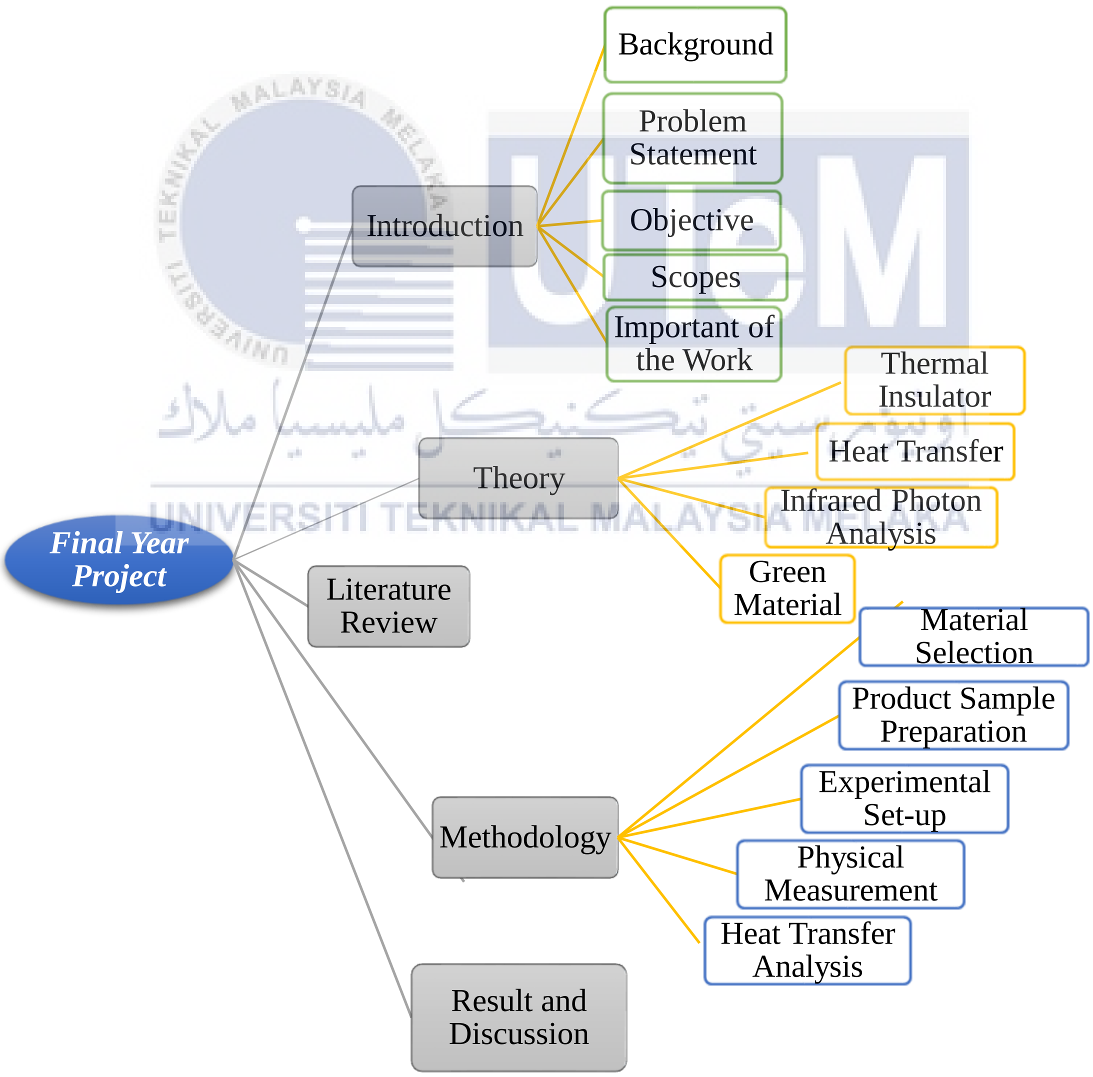


Figure 1.2: Project organization chart for Final Year Project.

1.6 Important of the Work

The building construction industry is recently changing focus in using sustainable and green materials. With the abundance of the source, it is beneficial to utilize the application and observing its potential as wall insulation materials. This study is hoped to provide some prospect in using green materials as wall insulation. Besides that, the study tends to set as a benchmark study for further application of green materials in building construction.

CHAPTER 2

THEORY

This chapter consists of all the theories and principles related to this study. The theories and principles such as thermal comfort, heat conduction and infrared photon analysis are thoroughly research and compiled for better understanding of this study.

2.1 Thermal Insulator

Thermal insulation is defined as reduction of heat transfer between mediums which in thermal contact or under the influence of radioactive. Heat flow is an inevitable consequence of contact between objects with temperature different (Cengel, 2015). Purpose of thermal insulation in a building is to provide a district of insulation where heat transfer conduction is reduced and thermal radiation is reflected to avoid lower temperature medium absorb the heat. The insulating capability of a material is measured by its thermal conductivity (k). Low thermal conductivity is equivalent to high insulating capability. Product density (ρ) and specific heat capacity (c) are also important properties of insulating materials need to be consider in thermal engineering.

Materials chosen for wall insulation must have a low thermal conductivity in order to reduce the heat transfer throughout the wall. Thermal conductivity of a material is measured in watt per meter per kelvin ($W\ m^{-1}\ K^{-1}$). Thickness of the insulation also affect the total heat resist, by increasing the thickness of insulation, thermal resistance of the insulation also increases.

Large proportion of global energy consumption used to heat or cool the building is one of the problem facing by world today is maintaining acceptable temperatures in buildings. Building insulations also commonly use the principle of small trapped air-cells, such as fiberglass, cellulose, wool, polystyrene foam, urethane foam, cotton, vermiculite, green materials fibre and others. When the wall of the building is well insulated, the particular building has few features, which are:

1. Energy-efficient, thus saving the cost in long-term.
2. Provides more uniform temperatures in the building. This is due to less temperature gradient transfer from both vertically and horizontally of exterior walls, windows and roots to the interior walls, thus producing a comfortable interior environment when the outside temperatures of the building are extremely hot.
3. Has minimal recurring expense. Unlike heating and cooling equipment, wall insulation is permanently install and does not require regularly maintenance, upkeep, or adjustment.
4. Lowers the carbon footprint of a building and reduce the greenhouse effect.

Besides insulating the heat, many forms of thermal insulation materials will also reduce the noise and vibration from the surrounding environment and also from other rooms inside the building, thus providing a comfortable environment to its occupants.

2.2 Heat Conduction in Plane Wall

In this project, heat transfer through the wall of the mini house model will be studied in order to understand the flow of heat and the parameter that affect the wall insulator. In this section, the theories of heat conduction, thermal conductivity and thermal resistance will be studied before the analysis start.

2.2.1 Heat Conduction

Heat transfer is defined as energy transfer between material bodies as a result of temperature difference (Cengel, 2015). This energy transfer is defined as heat exchange. There are three modes where heat can be transferred from one place to another, which are conduction, convection and radiation.

In this project, the heat transfer between the outer walls to inner wall of the building is involve conduction heat transfer. Conduction is a process that heat is carried by means of collisions between rapidly moving air molecules closer to the hot end of a body of medium and the slower molecules closer to the cold end (Cengel, 2015). During the collision, some of the kinetic energy of the fast-moving molecules passes to the slower molecules. Heat flows through the body of medium from the hot end to the cold end after the collisions between molecules. Heat can conduct through different medium, which are solids, liquids and gases. Generally, heat conduction take place where there is a temperature gradient in the solid wall. When the molecules collide, heat conduction energy transfer from high energetic to less energetic molecules. Heat flow in direction of deceasing temperature, which is from higher temperature to lower temperature since higher temperature are associated with higher molecular energy. Conductive heat transfer can be expressed by Fourier's Law. Consider steady heat conduction through a large plane wall of thickness $\Delta x = L$, the surface area of the plane wall is A, and the temperature difference across the wall is $\Delta T = T_2 - T_1$, the energy balance for the wall can be expressed in Eq. 2.1:

$$Q = \frac{kA\Delta T}{L} \tag{2.1}$$

where; Q = Rate of heat conduction (W/m^2), k = Thermal conductivity of the medium (W/mK), A = Surface area of heat transfer (m^2), ΔT = Temperature different between two mediums (°K), L = Material thickness (m).

2.2.2 Thermal Conductivity

Thermal conductivity, k is measure of the ability of a material to conduct heat. In other word, thermal conductivity is defined as the rate of heat transfer through a unit thickness of material per unit area per unit temperature difference (Cengel, 2015). When rate of heat flow is involved, then numerical value of the thermal conductivity will indicate how fast the heat will flow through the mediums. In general, thermal conductivity is strongly temperature dependent. Unit for thermal conductivity is watts per meter per Kelvin (W/mK), with symbol k. In solid medium, heat transfer conduction can be realized through the support of photons, electrons and phonons. Material and temperature is the main factors that will affect the thermal conductivity. Thus, thermal conductivity is a second order tensor, however, in a material with cubic isotropy, it reduces to a scalar. Thermal conductivity of a material can be calculated by using Eq. 2.2.

$$k = \frac{d}{R} \tag{2.2}$$

where; k = Thermal conductivity of the medium (W/mK), d = Material thickness (m), R = Thermal resistance of the material (K/W).

2.2.3 Thermal Resistance

Thermal resistance is a heat property and a measurement of a temperature different by which the wall is resist to the heat flow. Thermal resistance of a medium depends on the geometry and thermal properties of the medium. By rearranging the heat conduction equation, the thermal resistance equation in heat conduction can be written as Eq. 2.3.

$$R, \text{wall} = \frac{L}{kA} \tag{2.3}$$

where; $R_{,\ wall}$ = Thermal resistance of the materials wall (K/W), L = Material thickness (m), k = Thermal conductivity of the medium (W/mK), A = Surface area of heat transfer (m^2).

2.3 Infrared Photon Analysis

In this project, thermal imager or infrared camera is used to measure the thermal distribution of the heat from the house model. Infrared camera is a device that forming an image on the screen by using infrared radiation. This process of measurement is known as thermography. There are four basic laws of infrared radiation, which are Kirchhoff's law of thermal radiation, Stefan-Boltzmann law, Planck's law and Wien's displacement law (Babb, 2014). Infrared camera operates at 14,000 nanometre of wavelength, instead of 400 nanometre to 700 nanometre of visible light camera, therefore, infrared radiation is invisible. Infrared also carries radiant energy like electromagnetic radiation, and behave like a wave and its quantum particles or also known as photon. In year 1800, Sir William Herschel discovered the invisible radiation in the spectrum, which has lower energy compare to the red light and only can be detected by thermometer. Further experimentation led to Herschel's conclusion that more than half of the solar energy is arrive at the Earth's surface in the form of infrared. Earth's climate is critically affected by the balance between absorbed and emitted infrared radiation.

Nowadays, infrared radiation is applied in industrial, scientific and also medical applications, such as night vision devices, sensor equipped telescopes and infrared thermal imaging cameras. Thermal infrared imaging camera is used widely in military and research purposes. Appliance in military include night vision, tracking and surveillance. For research purposes, infrared imaging camera is used in thermal efficiency analysis, industrial facility inspections, weather forecasting, environmental monitoring and remote temperature sensing (Fluke, 2017).

2.3.1 Thermography

In this project, thermography method is used to determine the thermal distribution of the house model with the installation of different green material's insulator under different conditions. Thermography help to determine the temperature profile of the house model. Figure 2.1 shows the thermography inspections done by Department of Energy in Washington to detect thermal defect and air leakage in building development (Energy Saver, 2017).

Figure 2.1: Thermography inspections done by Department of Energy in Washington (Energy Saver, 2017).

2.4 Green Material

Green material is fabricated by using natural wastes and didn't contain harmful materials to the environment and ecosystem. Yard trimmings, wood wastes, natural fibre products, construction and demolition wood wastes is considered as green materials. Green material does not include food material, bio solids, mixed demolition wastes and mixed solid wastes. In this project, green material knowledge is applied on the buildings and known as green buildings. Green building technology is defined as the practice of increasing efficiency with which buildings used resources and in the same time reducing the building impacts on human health and environment (Shukla, 2014).

With the continuous development, natural resources must be fully used in order to decrease the pollution and global warming that are facing in Malaysia. With the application of green building, huge amount of money can be saved in term of utility bill and avoid the used of non-renewable energy that polluted the environment. Common types of green materials used in the green buildings technology is wool bricks, sustainable concrete, solar tiles, paper insulator and triple glazed window. Table 2.1 shows the merits and demerits of the green buildings (Shukla, 2014).

Table 2.1: Merits and demerits of the green buildings.

Green Building	
Merits	**Demerits**
✓ Efficient technologies	✓ High initial installation cost
✓ Easy to maintenance	✓ Availability of materials
✓ Return on investment	✓ Longer time to construct
✓ Improved indoor air quality	✓ High skill constructor to install
✓ Energy and water efficiency	
✓ Waste reduction	
✓ Temperature moderation	

Selected green materials must have few criteria and properties in order to be a good insulator in green building. Figure 2.2 shows the properties needed in a green material in order to be a good thermal insulator.

Figure 2.2: Properties needed in a green material (Eco-Friendly Building Materials, 2010).

In this project, three different types of green materials are selected as the case to study, fabricate into small brick, install in the mini house model and perform the thermography analysis. Cellulose, coconut fibre and sugar cane waste are chosen to conduct the thermal insulation analysis. These green materials are chosen due to their properties that fulfil the green material thermal insulator.

In this project, corn starch is used as the adhesive to stick the fibre together to form a strong shape. Corn starch is chosen due to its natural adhesive properties and its natural resource. When mix when liquid, corn starch will become non-Newtonian fluid and make itself sticky. So, corn starch mixture can be a substitute for conventional glue which have chemical addition.

CHAPTER 3

LITERATURE REVIEW

In this chapter, several journals papers and technical reports which are related to this field of study are reviewed and summarized. The relevant journals are selected based on the scope of this study which covers the green material wall insulator. At the end of the chapter, important information from the journals papers is summarized.

3.1 Study of Green Roofs by Anna, Frans, Mengyu, Michiel and Nick (2017).

This study is about the impact of climate change and also the implement of green roofs in reducing the negative impacts of extreme heat. Implementation of green roof is common nowadays in building due to their functions and favourable effects. Some common green roof are roof garden, isolation and runoff peak delay. In this study, literature study is focused on temperature measurement of green roof, which cover cooling effect of green roof to indoor environment and effect on root surface temperature. Studies showed potential benefit of green roof for indoor comfort of the building, such as energy saving. The results based on monitoring results from an extensive, sedum-covered green roof in Utrecht is presented at the end of this research (Anna et.al, 2017).

3.1.1 Methodology

Utrecht has been chosen to conduct the study with the moderate sea climate at this site. Seven 7m x 7m x 7.5m green roots is installed on a one-story school building's rooftop. Part of the installation is conventional white gravel (WG) roof as a baseline for comparison.

The vegetation of green roofs was a mixture of six sedum species, which are S. floriferum “Weihenstephaner gold”, S. album “Coral carpet”, S. reflexum, S. spurium “Fuldaglut”, S. sexangulare, S. album superbum. Figure 3.1 shows the perceptual representation of the sedum species which are installed in each roof.

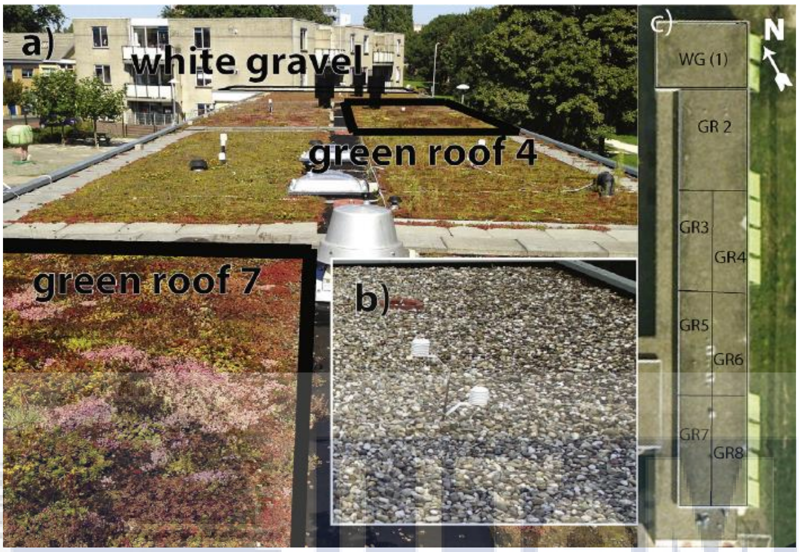


Figure 3.1: Perceptual representation of the sedum species which are installed in each roof.

Small meteorological station is installed on the green roof during monitoring period, which include air temperature sensor, solar radiation, wind speed and rainfall sensor. All data is recorded at five minutes intervals. Accuracy of the sensors, manufacturer as well as the types of sensors used in this study is listed in Figure 3.2.

Variable	Sensor manufacturer and type	Accuracy
Air temperature	EKOPOWER thermometer TS 21	<0.1 °C
Soil temperature	EKOPOWER thermometer TS 21	<0.1 °C
Soil moisture	*ECH$_2$O* EC-20	<0.04 m^3m^{-3}
Rainfall	EKOPOWER rain collector 7852 M	<0.2 mm
Runoff	STS pressure transmitter ATM/N	<0.5%
Wind speed	EKOPOWER anemometer MAX40	<0.1 ms^{-1}
Solar radiation	EKOPOWER solar radiation sensor 6450	<3% (0° to ±70° incident angle) ±10% (±85° incident angle)

Figure 3.2: Sensors specification.

Due to relatively dry and warm summer and spring, several green roofs in Utrecht had dried out. Two similar weather patterns, which are 2012 and 2013 are compared to evaluate the thermal behaviour of the wilted and dried out green roof. In this study, variability in weather conditions is dealt in three ways because day to day variability is visible although both selected seasons had similar weather patterns. First, same fifteen days of these two years is chosen to minimise the influence of different sunrise and sunset times. Second, only the differences between the green roof and conventional white gravel root temperature is concerned. The temperatures variation was measured between the time intervals. Lastly, differences for each hour of the day over whole fifteen-day period for selected seasons is arranged. With this arrangement, diurnal pattern with smaller influences of a day to day variability can be analyse (Anna et.al, 2017).

3.1.2 Result and Discussion

The temperature differences from August 2012 to August 2013 was observed. Temperature differences is based on the differences between dry green roof temperature and well prospering green roof temperature. Figure 3.3 shows the average temperature gradient between green roof and white gravel roof for one-hour intervals of the day.

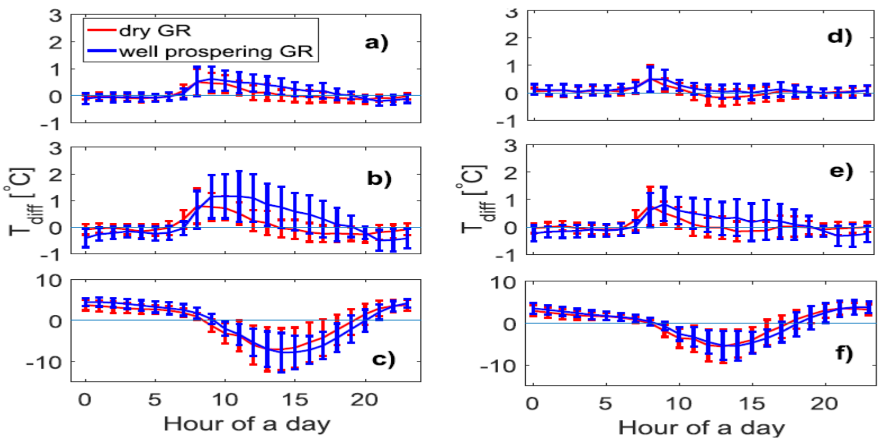


Figure 3.3: Average temperature gradient between green roof and white gravel roof for one-hour intervals of the day.

Figure 3.3, Part a shows the diurnal pattern 30cm above well prospering (blue line) and dry (red line) green roofs. At this level, temperature difference between green roof and white gravel was not significant. For well prospering green roof, there is slight warming effect during the day with highest value reached 0.5 ℃. Figure xx Part b and c shows the diurnal pattern of temperature difference 15cm above roof surface, where dry green roof showed very small differences and well prospering green roofs showed lower temperature compare to white gravel, with cooling effect between 0 ℃ to 0.5 ℃. During the day, well prospering green roofs reached positive temperature difference values. This proved that the white gravel was cooler than green roof. Based on previous research, green roofs have a lower temperature than white gravel roofs, but at night time, conventional roof are generally slightly cooler than the green roof.

3.1.3 Conclusion

In this research, two green roofs were compare with the conventional white gravel roof. Results showed that under normal condition, the sedum-covered green roof show slightly warm effect on its surrounding during the day and immediate cool down the surrounding at night time.

3.2 An Experimental Method to Quantitatively Analyse the Effect of Thermal Insulation Thickness on the Summer Performance of a Vertical Green Wall by Olivieri (2017).

Research has demonstrated that green walls can be an effective strategy to cool interiors in the summer. The presence of vegetation greatly contributes to the reduction of solar radiation and dispersion through the envelope to the interior by translates into a lower energy load for both heating and cooling and also mitigate the thermal conditions at outdoor areas. During the hottest hours of the day, bare walls accumulate and release more heat to the environment than green walls. Several research has demonstrated that by using green walls, it can reduce the urban heat island effect (UHI), improves indoor thermal comfort and also has a positive effect on the filtration of air borne pollutants. With regard to reducing a building's energy demand, the majority of research has focused on hot climates or summer conditions. The green wall was monitored and compared with a bare wall during the summer, which is characterized by daytime temperatures range from 35 ℃ to 50 ℃. The results of the study showed that the vegetation layer partially blocked solar radiation, thereby regulating the temperature, where reduced external surface temperature of the green wall yielded a 6 ℃ decrease in temperature on the internal surface. As a consequence, the green wall always maintained a lower indoor ambient temperature than the bare wall, a difference that ranged from 2 ℃ during the night time to almost 6 ℃ during the peak day time exterior temperature. Despite this, indoor temperatures of about 45 ℃ are still far from a comfortable temperature, which means that although the cooling load was reduced, there was still a need for mechanical cooling, such as fan and air conditioning system.

3.2.1 Methodology

The monitoring periods considered in this research are July of both 2011 and 2012. Monitoring was carried out in a full scale experimental building in Colmenar Viejo (883 m above sea level, 40°39'N, 3°45'W), which is a town located approximately 40 km north of Madrid in a mountainous area characterized by a continental Mediterranean climate with hot and dry summers. Figure 3.4 shows the experimental building in this research.

Figure 3.4: Experimental building in this research.

Local weather conditions during the monitoring periods were recorded by a weather station as shown in Figure 3.5, which is installed 100 m from the experimental building. Global irradiance, air temperature, relative humidity, wind, and rainfall were taken for every 5 minutes intervals. The accuracy of the thermometers and hygrometers in this research is ±0. 2K and ±2%, respectively. Table 3.1 shows the important differences can be noted in the temperature and relative humidity registered in July in 2011 and 2012. The number of hours is shown in percentage with relation to the total number of hours of the monitoring periods.

Figure 3.5: Weather station to monitor the weather conditions.

Table 3.1: Local weather conditions during the monitoring periods.

	Global irradiance [W/m^2]		Temperature [°C]			Relative humidity [%]	
	>800	>1000	>26	>30	<15	<20	>50
July 2011	33%	8%	34%	13%	3%	5%	22%
July 2012	32%	5%	68%	31%	2%	38%	15%

Based on the result obtained, the horizontal global irradiance exceeded 800 W/m^2, in 33% of daylight hours and 1000 W/m^2, in 8% of daylight hours in July 2011. For July 2012, the horizontal global irradiance exceeded 800 W/m^2, in 32% of daylight hours and 1000 W/m^2, in 5% of daylight hours. Based on the reading, the area was receives high solar radiation.

In July 2011, the outdoor temperature was over 26 °C only in 34% of the hours and above 30 °C in 13% of the hours, while in July 2012 it was over 26 °C in 68% of the hours and above 30 °C in 31% of the hours. In both years, the temperature fell below 15 °C very rarely. In July 2011, the relative humidity was below 20% only in 5% of the hours and over 50% in 22% of the hours. On the other hand, in July 2012, the relative humidity was below 20% in 38% of the hours and over 50% in 15% of the hours. The data show a climate that is fundamentally characterized by hot summers with low relative humidity. Based on the data, it is clear that the summer of 2012 was hotter than the summer of 2011.

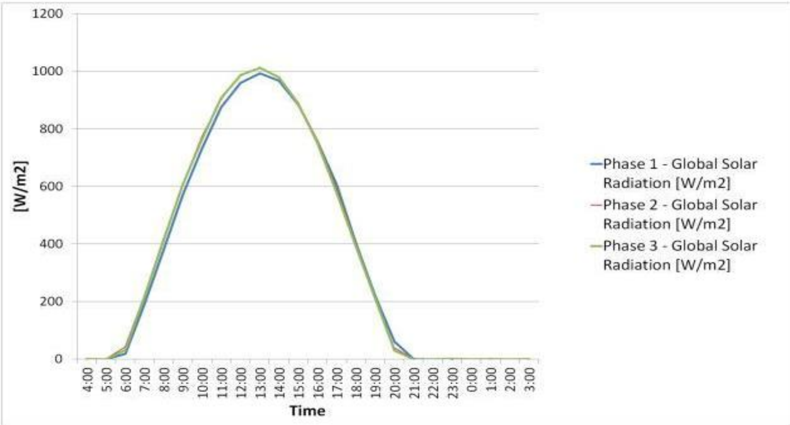
During the monitoring period, three days is selected for both 2011 and 2012 and compared the thermal behaviour of the southern wall during the three monitoring phases in order to identify the influence of the thermal insulation thickness. For this goal, the following details were analysed:

1. The oscillation of the interior and exterior surface temperatures,
2. Difference between the interior and exterior surface temperature,
3. The difference between the interior surface temperature and the temperature on the panel surface.

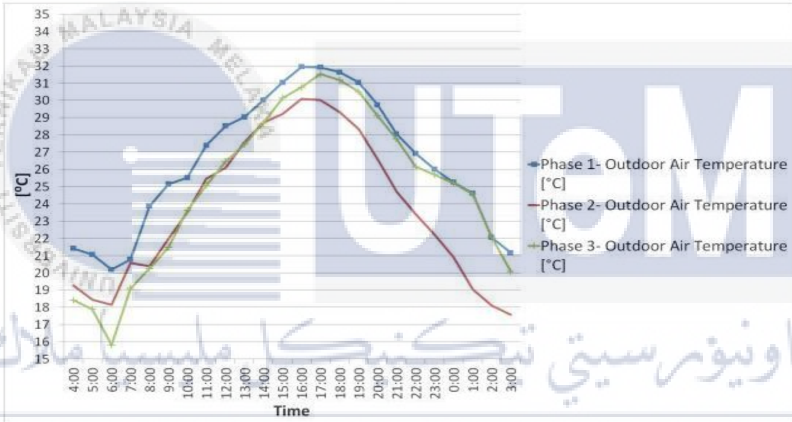
During phase 1, the maximum and minimum temperatures registered on the external surface of the module (External Surface Temperature No Insulation = ExSTNI) were 22. 5 ℃ and 14. 6 ℃ respectively, yielding a thermal oscillation of 7. 9 ℃. For the internal surface temperature (Internal Surface Temperature No Insulation InSTNI), the maximum was 21. 7 ℃ while the minimum was 17. 5 ℃, with an oscillation of 4. 2 ℃.

In phase 2, a layer of thermal insulation was attached to the internal side of the vegetation panel. In this case, the maximum external surface temperature (External Surface Temperature 3 cm Insulation = ExST3I) was 23. 6 ℃ and the minimum was 14. 3 ℃, with an oscillation of 9. 3 ℃. This variation reduces to 4. 1 ℃ for the internal surface temperature (Internal Surface Temperature 3 cm Insulation = InST3I), with a maximum of 23. 3 ℃ and a minimum of 19. 2 ℃.

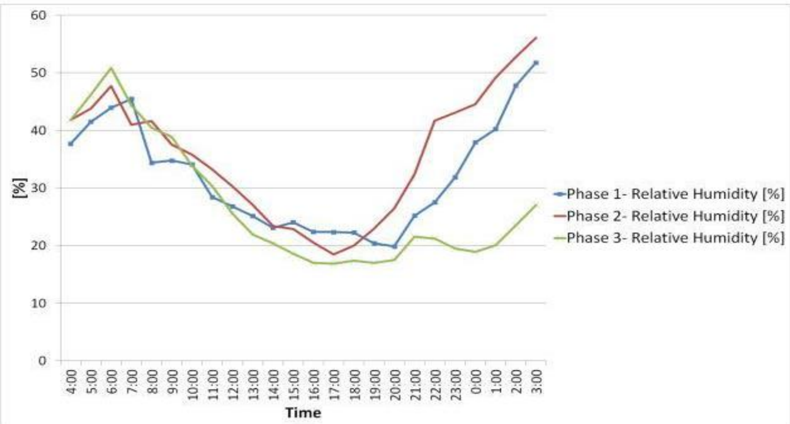
In phase 3, which was characterized by 7 cm of thermal insulation attached to the interior of the south wall, the maximum external surface temperature (External Surface Temperature 7 cm Insulation = ExST7I) was 23. 3 ℃ and the minimum was 11. 7 ℃, with a thermal oscillation of 11. 6 ℃. However, the thermal oscillation of the internal surface reduced to 3. 9 ℃, with a maximum of 23. 3 ℃ and a minimum of 19. 4 ℃. It is clear from the data that for the non-insulated wall, the thermal oscillation of the internal surface temperature is only 37% lower than the external temperature. This increases to 52% for 3 cm of thermal insulation and reaches 77% for 7 cm of insulation. It is therefore evident how the insulation layer attenuates the temperature variation, minimizing night-time cooling in particular. This data is illustrated in Figure 3.6, Part a, b, and c and summarized in Table 3.2.



(a)



(b)



(c)

Figure 3.6: Weather conditions during the three selected days: irradiation (a), temperature (b) and relative humidity (c).

Table 3.2: Maximum and minimum superficial temperatures, in the exterior and the internal layer of the vegetal facade during the three selected days.

	Max (ExST)	Min (ExST)	ΔExST [max-min]	Max (InST)	Min (InST)	ΔInST [max-min]	Reduction
	[℃]	[℃]	[℃]	[℃]	[℃]	[℃]	[%]
NI	22.5	14.6	7.9	21.7	17.5	4.2	37
3I	23.6	14.3	9.3	23.3	19.2	4.1	52
7I	23.3	11.7	11.6	23.3	19.4	3.9	77

where; NI (No Insulation layer, phase 1); 3I (3 cm insulation layer, phase 2); 7I (7 cm insulation layer, phase 23).

3.2.2 Result and Discussion

The main goal of this research was to understand the behaviour of insulation material in a vertical green wall. The insulation effect is related to the insulation capacity of the different layers, which depend on their different compositions, such as the thickness and materials of the substrate layer, the air in the plant layer, other possible intermediate air layers, etc. It is well known that there are no studies of green walls that extensively analyse the insulating effects linked to the substrate layer and the thickness of the insulation. This is therefore a very important aspect of this research.

The thermal behaviour of green technological devices, such as green facade, walls and roofs is still unknown in many cases. It is therefore of interest to use a simulation tool to evaluate and establish the right thermal transmittance values and other technical standards such as thermal comfort temperature for different climate conditions. As a consequence, the behaviour of the green wall was studied as a function of the insulation thickness (varying from 3 to 13 cm). Figure 3.7 shows the results for the green wall behaviour.

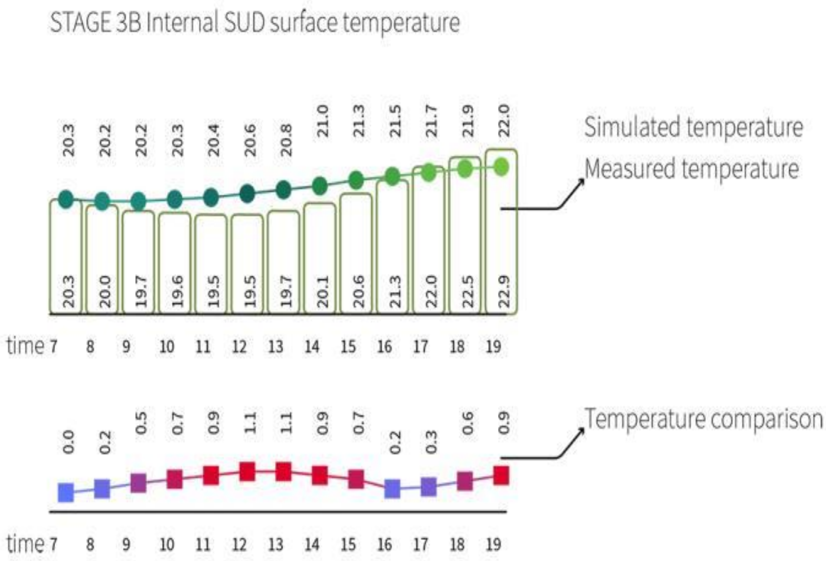


Figure 3.7: Results for the green wall behaviour.

Analysing the temperature behaviour in Figure 3.7, it is clear that there is a cut-off thickness that makes the thermal function of the green wall's insulation almost useless. It is important to understand the amount of insulation that optimizes the capacity of the green wall to correctly manage thermal fluxes and therefore to determine the limiting thickness of the insulation beyond which there is no benefit directly connected to the thickness of the insulation.

Carefully observing the trends in the figure, it can be seen how slight variations in the simulated temperature can be seen for thicknesses greater than 3 cm, while the curve is completely flat for values above 9 cm. This result agrees to the conclusion that in buildings with low insulation levels, the total load in the element with the addition of the green is lower than that of a building with high insulation levels. This represents an important aspect for energy efficiency renovations and urban comfort because when a green system is installed in an existing building with low insulation levels, the energy performance of the building becomes similar to a new building with high insulation level.

3.2.3 Conclusion

The main goal of this research was to understand the importance of insulation thickness in a green facade. A new parametric optimization methodology called GFO (green facade optimization) was therefore developed and validated using real data monitored in an experimental box located near Madrid, Spain. The GFO methodology was developed to find all the unknown variables that well-known thermal simulation tools need to simulate the thermal behaviour of green facades. Comparison of the simulations to experimental data allowed the model to be validated. The model was then used to simulate the behaviour of the green wall, varying the insulation thickness from 3 cm to 13 cm.

The experimental data show that thermal insulation reduces temperature variations inside the building, minimizing night-time cooling in particular, and that this effect increases with increasing insulation thickness. For the non-insulated wall, the thermal oscillation of the internal surface temperature is only 37% lower than the external temperature. This increases to 52% for 3 cm of thermal insulation and reaches 77% reduction from the oscillation recorded on the external surface for 7 cm of insulation. Regarding the temperature on the panel surface, the results confirm that the potential effect of cooling due to the green surface is well attenuated by a 7 cm thick layer of insulation: the reduction in attenuation is around 33% during afternoon hours and reaches values between 60 and 75% from the early morning to midday. As a result of this attenuation, and even though the effect of the vegetation is seen despite the presence of thermal insulation, the thermal insulation ensures that the internal temperature remains higher. This effect could be mitigated by the use of natural ventilation at night. In addition, the GFO methodology showed an efficient insulation thickness up to 9 cm, above which more insulation becomes redundant and inefficient because the green facade has the same thermal behaviour regardless of external conditions. In fact, for an insulation depth of 3 cm, there is a lapse rate about 3 ℃ during the day that decreases to about 2 ℃ for 6 cm and about 1 ℃ for 9 cm. Starting from a 10-cm insulation thickness, there is a temperature difference less than 1 ℃ during the day, an effect that can be disregarded. This represents an interesting result because the correct insulation depth of green wall can be considered economically feasible and should be implemented, as it will provide higher rates of comfort accompanied by lower air conditioning energy costs. In fact, optimum envelope components and optimum insulation thicknesses in green walls have the potential to reduce building energy consumption and therefore reduce CO_2 emissions. In this context, the effect of the optimum insulation thickness on the environment due to optimum energy consumption can be defined by architects and designers in the initial design stages for more sustainable planning.

3.3 Application of Coconut Fibres as Outer Eco-insulation to Control Solar Heat Radiation on Horizontal Concrete Slab Rooftop by Danny, Wanda and Anik (2015).

Due to the fast growing of economic and industry in Indonesia, hundreds of shops and office houses have been built in the central business districts and most of the rooftops are not cover with insulator as a heat barrier to the solar radiation. This research is conducted at Subrajaya, which has a tropical warm humid climate zone over the year. In this paper, coconut fibres are act as thermal insulator that is install in concrete slab roofing and experimental measurements on roof surface and indoor temperature is conducted monthly. Coconut fibres is chosen due to its natural sustainable insulator and achieved few aspects, which are practicing to respect natural materials within the built environment, promoting less hazardous roofing insulator material, limiting the impacts on the urban built atmosphere and preserving cooling energy demand by mitigating the flat concrete rooftop surface thermal onto the room. Most of the horizontal exposed concrete rooftop is equipped with air conditioning system and cause millions of watt-hours of cooling to ensure thermal comfort in the room. Table 3.3 shows the maximum and minimum average outdoor temperature in Subrajaya from 1993 to 2005.

Table 3.3: Maximum and minimum average outdoor temperature in Subrajaya from 1993 to 2005.

	1993		1995		1996		1997		1998		1999		2001		2002		2003		2004		2005	
Month	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
1	33.2	23.3	34.3	23.1	33.2	23.5	33.3	23.2	36.1	23.8	33.0	23.2	34 4	23.2	34.2	21.7	35.2	22.7	34.3	22 9	33.3	24.6
2	33.5	23.2	33.6	23.0	32.9	23.3	34.0	24.3	34.7	23.3	33.3	23.5	34 4	23.4	33.6	23.3	33.9	22 9	33.9	23.2	33.2	23.9
3	32.7	23.9	33.6	22.4	33.7	23.5	34.4	23.1	35.2	23.9	33.4	23.3	34.3	22.9	34.6	23.1	34.7	22.2	34.7	23.2	33.3	24.3
4	32.9	24.0	34.3	22.6	33.9	23.7	33.6	23.6	35.2	24.4	33.3	23.9	34.3	23.4	34.8	23.4	34.9	23.9	34.8	23.8	32.6	24.3
5	33.2	24.3	33.9	22.7	33.6	22.4	33.7	23.5	34.4	24.2	32.9	23.4	34.3	22.0	34.0	23.3	34.2	22.6	34.2	22 5	32.6	24.6
6	32.8	23.6	33.8	23.0	32.8	23.7	32.7	21.2	33.7	24.1	33.2	23.6	33.2	22.2	33.8	21.5	33.6	21.0	33.7	21.5	32.5	24.5
7	32.7	21.3	33.1	21.1	33.0	22.2	32.9	20.0	33.4	23.5	32.0	22.1	32.8	19.7	33.7	20.9	33.5	20.2	33.6	21.3	32.0	22.9
8	32.3	22.2	33.0	20.8	33.3	22.1	32.0	20.0	34.1	23.0	33.0	21.2	33.1	20.6	33.2	20.0	34.0	19.8	33.4	20.3	32.4	22.7
9	33.6	22.5	34.9	21.6	34.7	22.9	34.3	21.1	34.7	22.0	33.8	20.8	35.2	22.9	34.1	21.5	35.6	20.1	34.5	21.5	33.6	24.2
10	35.3	23.5	35.6	22.6	35.3	23.9	36.4	20.1	34.6	23.9	34.7	22.7	35.4	23. 5	36.9	21.9	36.3	22 9	36.7	22.3	34.4	24.0
11	35.3	24.2	35.4	22.9	34.9	23.5	36.3	22.9	34.5	24.0	33.8	23.7	35.3	23.5	36.8	23.3	37.0	22.5	37 0	23.1	34.5	23.8
12	34.5	23.8	34.0	22.8	34.1	23.7	36.0	23.6	34.8	23.7	33.8	23.7	34 2	23.1	35.9	23.3	34.7	22.9	35.3	23.0	32 7	23.9
Ave	33.5	23.3	34.1	22.4	33.8	23.2	34.1	22.2	34.6	23.7	33.4	22.9	34.2	22.5	34.6	22.3	34.8	22.0	34.7	22.4	33.1	24.0

Source : Surabaya Weather Station, (1993-2005)

There are various types of insulation used for building, but most of the insulators are chemical based. In modern country, non-eco-friendly roof insulator materials is used to cover the rooftop, such as thermoplastics polymer-based materials and elastomeric-based coatings.

3.3.1 Methodology

This research is conducted at Petra Christian University at two-story building rooftop and coconut fibres used as eco-insulation to flat concrete rooftop materials. Figure 3.8 shows the coconut fibres in the test model.

The dimension for the test model is 100 x 100 x 100cm and 50cm above the ground. The measurement is done by using data logger with thermocouple probes. Two models is prepared where one model acted as reference model with original flat concrete rooftop and second model was covered by cm of coconut fibres. Experiments on both models is started from May 2014 until July 2014. All temperature was recorded by data logger for 10 minutes intervals and graph is generated by using Microsoft excel.

Figure 3.8: Coconut fibres in the test model.

3.3.2 Result and Discussion

Both rooftop surface temperature and room model temperature are recorded hourly and 24 hours graph is generated. Figure 3.9 shows the average rooftop surface and indoor room temperature.

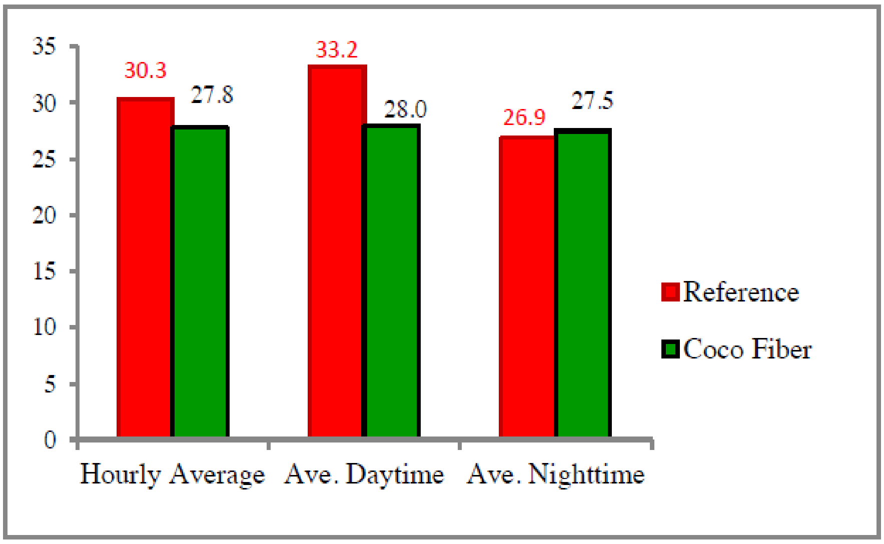


Figure 3.9: Average rooftop surface and indoor room temperature May-July 2014.

Based on the result, the average concrete roof surface temperature reach 41.8 ℃ at noon, while average roof concrete surface covered by coconut fibres only reached 28.7 ℃ at noon. The maximum air temperature in room reached 35.5 ℃ at 2pm, while the room concrete covered by coconut fibres only reached 32.4 ℃. Figure 3.10 shows the average indoor room air temperature for May-July 2014.

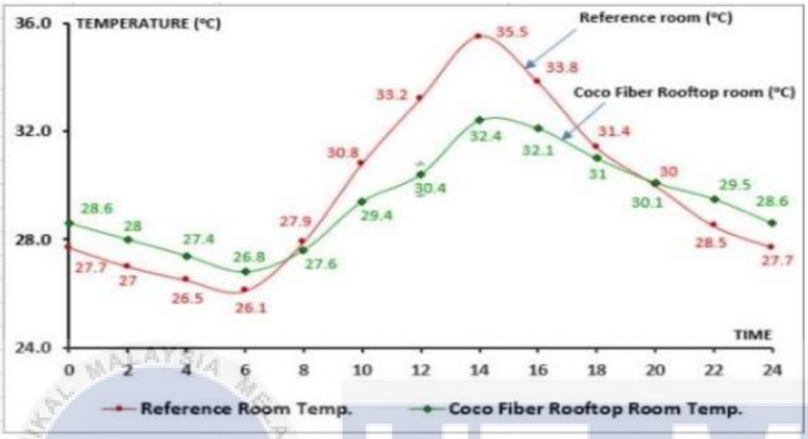


Figure 3.10: Average indoor room air temperature for May-July 2014.

Based on the data, the average daytime dry bulb indoor air temperature with coconut fibres insulator was 30 ℃ and the average dry bulb room air temperature for flat bare concrete rooftop was 31.2 ℃. Figure 3.11 shows the different of average indoor room air temperature between daytime and night time.

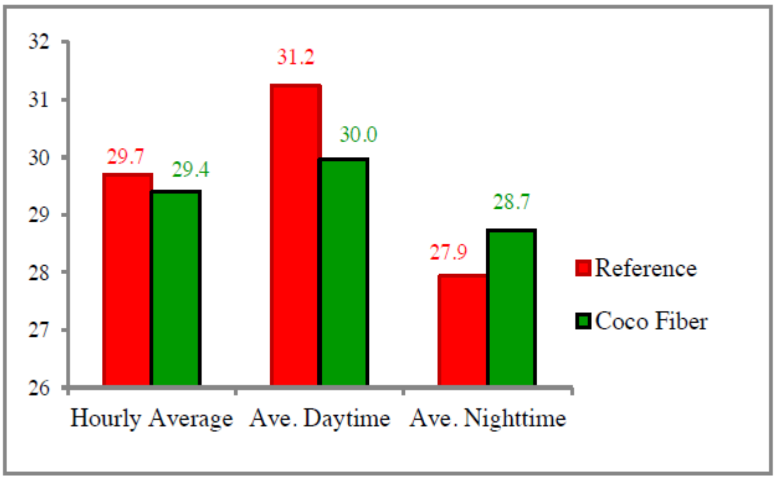


Figure 3.11: Different of average indoor room air temperature between daytime and night time.

3.3.3 Conclusion

Based on the data obtained, coconut fibres as outer insulation on concrete rooftops have lower surface heat fluxes during the day. Coconut fibres as insulator on the building will experience lower indoor air temperature during daytime. Besides that, coconut fibres insulator made from natural sources, therefore it can be decomposed and be recycled. For energy saving, by install the coconut fibres rooftop, it can reduce an average indoor air temperature by 1.2 ℃. Based on Danny et. al (2015), for every increasing or reducing of 1 ℃ room air temperature, the cutback for electrical utility in air conditioning system is roughly 3%. Based on the research, by installing coconut fibres rooftop, it could save energy consumption on average 3% and 9% maximum.

3.4 Sugar Cane Bagasse Fibres Reinforces Cement Composite: Thermal Considerations by Cristel, Nady, Fernando, Silvio, Ketty and Marie (2010).

The purpose of this paper is to study the thermal properties of cement composites that reinforces by vegetable bagasse fibres. This research is generally focused on the thermal behaviour of the cement-vegetable fibres composite in order to reduce the electricity consumption. Bagasse is the solid lignocellulose residue left after the extraction of juice from the sugar cane stalk. Few advantages why the vegetable fibres was chosen to be studies is because they are environmental friendly, cheap and their natural ability to insulate the thermal conduction. In developing countries, tropical plants and agricultural wastes is used to replace the expensive synthetic fibres. In this research, bagasse fibre reinforced cement composites has been applied in construction in India.

3.4.1 Methodology

Main material used is this research is bagasse fibres which supply by Montebello Sugar Cane Factory. First, the fibres was cut into small part with 0.4 to 1mm diameter. Thermal and chemical treatments have been performed to treat the bagasse fibres. Heat treatment is a process that involve pyrolysis under control atmosphere for 2 hours at 200 ℃. For chemical treatment, the bagasse fibres is attack by 5% by mass alkaline solution of $Ca(OH)_2$. Proportions of the compound is based on Portland cement, which are 50% sand, 30% limestone powder, 3% and 1.5% bentonite, 4% cellulose pulp, 5% silica fume and 7.5% butyl acrylate. Thermal conductivity of the sample was measured by using thermal conduct meter "CT-metre" with a thermal probe. While, specific heat of the cement composites under air atmosphere is measured by isothermal calorimeter. The measurement was carried out at least two times a week. Isothermal calorimeter consists of four parts, which are calorimeter to detect the signal comes from, power module to provide steady power supply, controller as interface transforming the voltage into digital signal and computer where records and processes the signal (Cristel et.al, 2010). Thermopiles that consists of thermocouples was connected at the outer surface of the well wall, to read the temperature different in the heat exchange between the cell and block. The signal will enter the controller and computer will process the signal then generate the temperature line and heat flux line which represent the heat flux between the wells.

3.4.2 Result and Discussion

The thermal conductivity of the matrix without fibre is about 0.6188W/mK. Based on the experiment, increment of fibre content will decrease the thermal conductivity. The effect of thermal fibres treatment is more significant compare to alkaline based treatment. The most insulating composite is 3% wrtc of bagasse fibres with thermal conductivity is 25%

lower compare to the matrix composite. Raw and treated bagasse fibres was observed by using Scanning Electron Microscope, SEM and the surface of the fibres is shown in Figure 3.12.

Figure 3.13 shows the evolution of the thermal conductivity based on the fibre content and fibre treatment, where control specimen represents raw bagasse fibres, CBAGP represent heat treated bagasse fibres and CBAGB represent chemical treated bagasse fibres. Thermal conductivity of the fibres is obtained based on the experimental values. Thermal conductivity of the fibres is shown is Table 3.4.

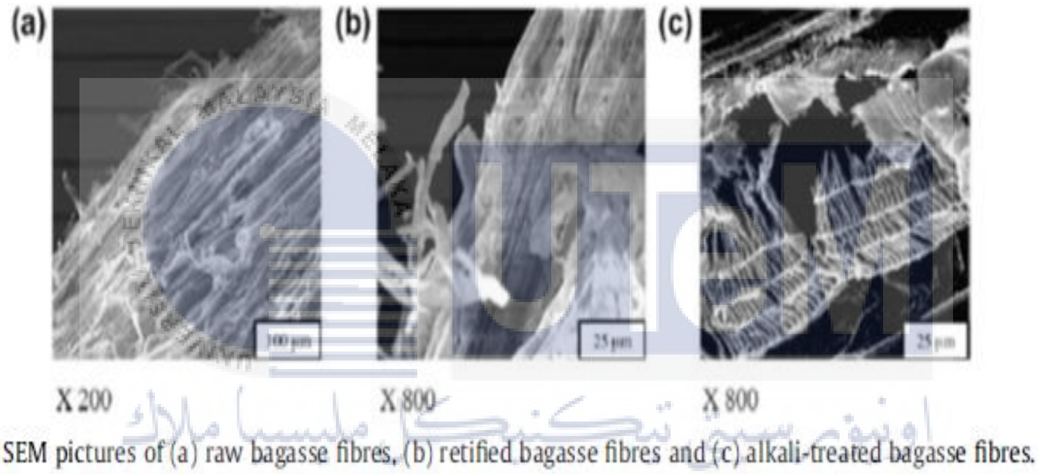


Figure 3.12: Surface of raw and treated bagasse fibres observed by SEM.

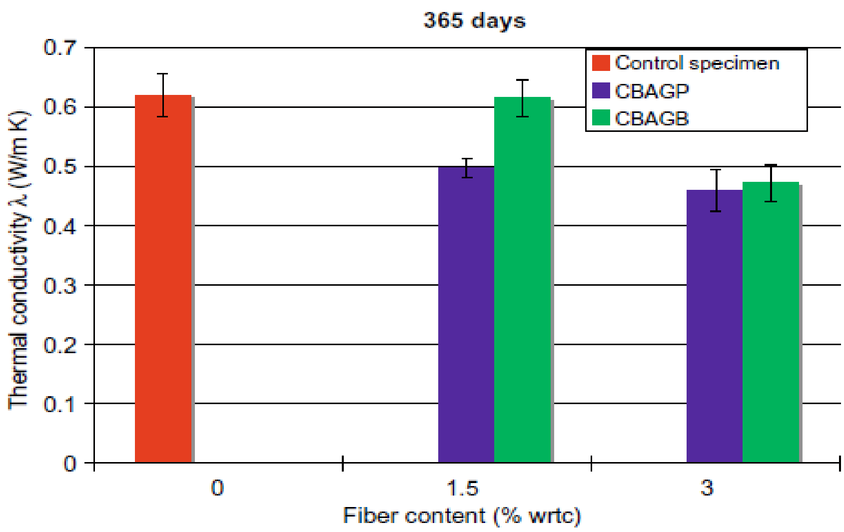


Figure 3.13: Evolution of the thermal conductivity based on the fibre content and fibre treatment.

Table 3.4: Thermal conductivity of bagasse fibres.

	Retified bagasse fibres		Alkaline bagasse fibres	
% f	1.5	3	1.5	3
v_f	0.1909	0.2818	0.2115	0.2096
$\rho_{composite}$ (g/cm^3)	1.6155	1.4561	1.5744	1.6024
k_f (W/m K)	0.1781		0.1092	

Thermal diffusivity of the composites is the most important parameter to determine the potential of the fibres been as wall insulator in building. Thermal diffusivity, κ of a composite can be calculated by using the following equation:

$$\kappa = \frac{k}{\rho Cp} \tag{3.1}$$

where; k is thermal conductivity (W/mK), C_p is specific heat (J/kg K) and ρ is density of the material (kg/cm^3).

Thermal diffusivity is to measure the rapidity of heat propagation through a material. By increasing the fibre content, the thermal diffusivity of the composites can be decreased. Table 3.5 shows thermal diffusivity for both thermal and chemical treated composites. Based on the result, the optimal fibre content is 1.5% wrtc heat treated bagasse fibres because it allows the highest thermal diffusivities.

Table 3.5: Thermal diffusivity for both thermal and chemical treated composites.

Composites	Control	CBAGP1.5	CBAGP3	CBAGB1.5	CBAGB3
K x 10^6 m^{2}s^{-1}	1.1771	1.5856	1.4228	1.5504	1.3114

3.4.3 Conclusion

In construction for energy saving, thermal conductivity of the fibres/cement composites is the important parameter. In this research, weight fraction and treatment of the bagasse fibres is focused. Heat treated bagasse fibres are weaker heat conductor compare to chemical treated bagasse fibres. So, heat treated bagasse fibres is preferred to be used as wall insulator. Result showed that with 1.5% wrtc of heat treated bagasse fibres, it is possible to construct a good wall insulator.

3.5 A Review on the Properties of Cellulose Fibre Insulation by Pablo, Antoine, Virginie and Christine (2016).

In this paper, the properties of cellulose fibre insulation (CFI) has been studied and analysed. Due to the increment greenhouse gaseous emissions, energy efficiency in buildings is one of the important factor in contributing to the reduction greenhouse gaseous emissions. 30% to 40% of world-wide energy consumption is came from building and construction sector, where most of the energy is used to heat and cool buildings. Nowadays, many countries are looking to improve the building's energy efficiency by install insulation materials and technologies, with directives of European directive 2010/31/EU, which states that new constructions in 2020 will have to consume "nearly zero-energy" (Pablo et. al, 2016). One of the reason of installing thermal insulator in building envelope are to prevent heat gain or loss and provide thermal comfort for the indoor. The main factor that characterizes an insulation material's effectiveness is thermal conductivity. The lower the thermal conductivity of a material, the higher the effective it is as an insulator. The traditional insulation materials can be found in market include fibreglass, polystyrene, stone wool and polyurethane foam. These traditional insulation materials are made with non-renewable resources and have a high embodied energy. Speaking of renewable and sustainable sources, one such material is CFI. Cellulose fibre insulator is comprising mostly of recycled paper and increasing in popularity of using cellulose as wall insulator is due to its eco-friendly nature, acoustic properties and favourable thermal (Pablo et. al, 2016). Composition of treated ground paper fibres with inorganic additives is known as cellulose fibre insulator. Recycled newspaper is the main source for the cellulose fibres.

3.5.1 Methodology

In a typical cellulose fibre insulation (CFI) production process, first, old newspaper is sorted to remove any foreign objects, such as stapler, plastics and also low quality or humid paper. Figure 3.14 shows the manufacture process of cellulose fibre insulator. Based on Figure 3.14, the process of manufacture a cellulose fibre insulator is listed as below:

1. Feeding conveyor used to passes the newspaper,
2. Shredder is used to torn the newspaper into smaller pieces (2cm to 4 cm in diameter),
3. To remove any remaining metallic elements, such as stapler, the fibres is then pass through a cyclone separator,
4. The fines from the shredded paper are blown through a filtering unit,
5. The material then goes through a high-pressured air fiberizer to reduce the paper into low density cotton like flakes,
6. A second cyclone separator is used to removes the fines created from the fiberizer. In this stage that the powdered additives, which are mixture of borax and boric acid are dispersed and mixed with the fibres.
7. Final stage of the process will deal with compact packing. In this step, the fibres are filled in bags and then mechanically compacted into three times its normal density, which is around 130 kg/m^3, to reduce transport costs.

8. The bags are then weighed and transported to supplier or construction sites.

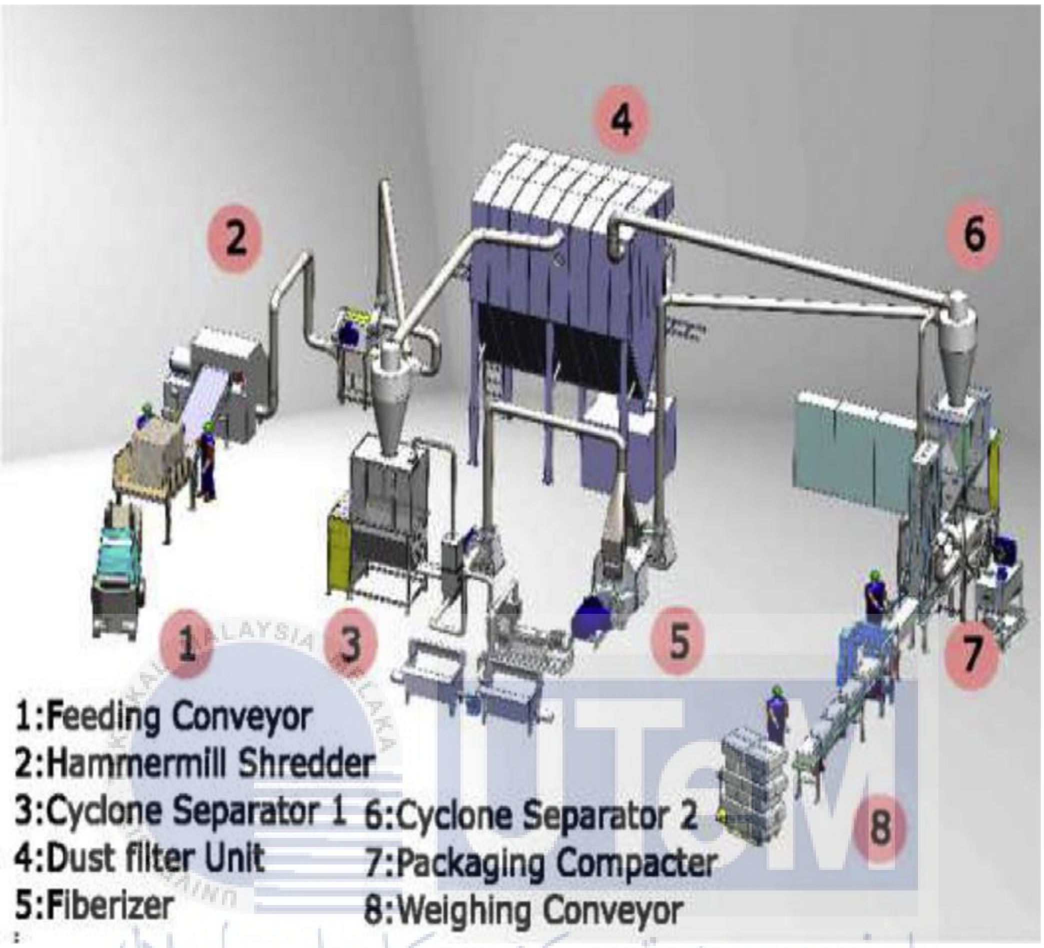


Figure 3.14: Manufacture process of cellulose fibre insulator. (Pablo et. al, 2016)

3.5.2 Result and Discussion

Blown density and design density of the loose fibres are important factors need to distinguish. The blown density is the declared density after installation in horizontal or vertical applications, while design density is determined via cyclic humidity testing and impact testing. Impact testing is deal with subjecting the loose cellulose samples to a series of vibrations. In cyclic humidity tests, the samples are subjected to periodic variations of relative humidity. According to Pablo et. al (2015), the design density can be calculated using by multi-plying a factor which takes into account both types of settling as shown in Eq. 3.2:

$$D = \frac{100}{100 - S} Di \tag{3.2}$$

where; D is design density, D_i is installed density and S is the sum of both the settling from drop impact tests and cyclic humidity testing.

The study found that the average blown density is 34.8 kg/m^3 for horizontal applications. Result shows that average 21.5% losses in thickness from settling, where drop impact tests contributed 10.5% and 11% was from cyclic humidity testing. For horizontal applications, density of loose-fill CFI varies widely due to compressibility of loose-fill CFI. Study shows that installed density varying between 50kg/m^3 to 90 kg/m^3. To prevent settling, 10% of increment in density was recommended after filling the wall cavity in order, with a minimum density of 57 kg/m^3. Density of cellulose fibre insulator is increasing linearly with relative humidity and wall thickness. Figure 3.15 shows the relationship between thickness and density of cellulose fibre insulation.

Thermal conductivity for typical CFI is around 0.040 W/mK, however, its properties and performance are depending on method of installation and manufacturing. Besides that, different sources and quality of newspapers also can affect thermal performance.

The high flammability of cellulosic fibres requires them to be treated before installation in order to achieve acceptable levels of combustion and smouldering resistance. A three-component formulation using borax, boric acid, and aluminium sulphate was also studied. Varying dosage from 12% 18% and 24% increases the possible proportions of these constituents which allow both smouldering and combustion resistance to be obtained.

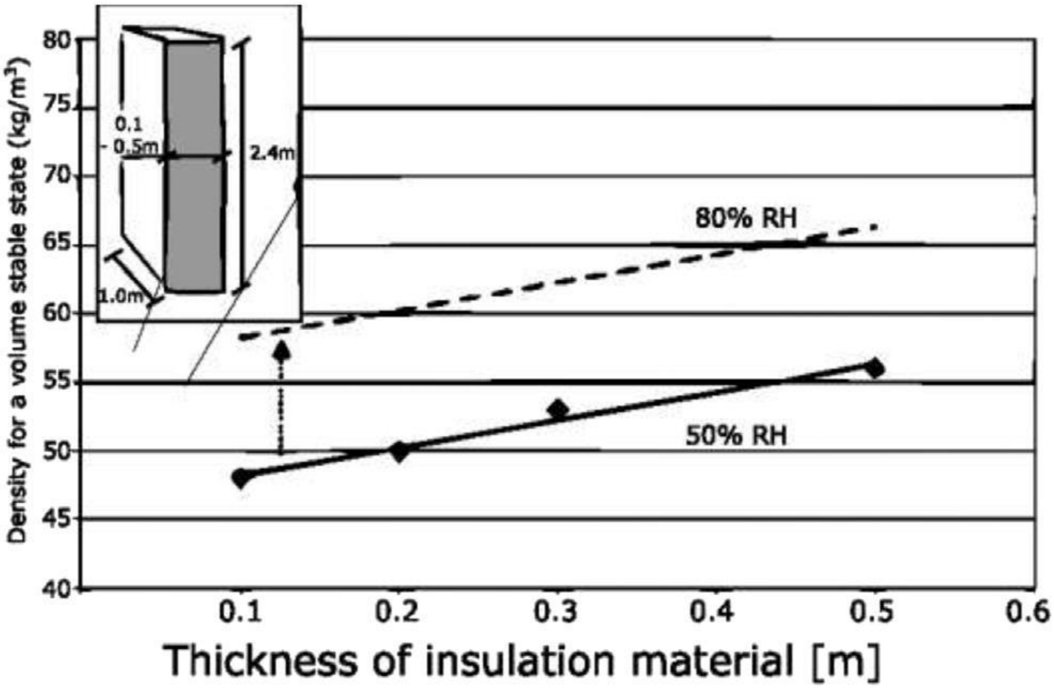


Figure 3.15: Relationship between thickness and density of cellulose fibre insulation.

CFI has a low embodied energy compare to traditional insulation materials. A comparative analysis of three impact categories of the life cycle analysis (LCA) of common insulation materials. Different types of materials required different amount to provide a specific value of thermal resistance since the materials have different densities and thermal conductivities. Table 3.6 shows the comparison of life cycle analysis between common building materials.

Table 3.6: Comparison of life cycle analysis between common building materials.

	Building product density (kg/ m^3)	Thermal conductivity (W/ mK)	Primary energy demand (MJ-Eq/kg)	Global warming potential (kg CO_2-Eq/kg)	Water demand (l/ kg)
EPS foam slab	30	30	0.0375	105.486	7.336
Rock wool	60	60	0.04	26.393	1.511
Polyurethane	30	30	0.032	103.782	6.788

rigid					
foam					
Cork slab	150	150	0.049	51.517	0.807
Cellulose fibre	50	50	0.04	10.487	1.831
Wood wool	180	180	0.07	20.267	0.124

3.5.3 Conclusion

CFI is considered as an eco-friendly insulation material that have the similar characteristics in terms of thermal insulation and properties compare to others non-renewable materials. But, CFI presents some disadvantages compared to less eco-friendly insulation materials and thus the need for more optimization and development. First, there is a need to have a better understanding of the material's sources. Research shown that performance of CFI after installation, there is still many works need to be done on the manufacture and installation methods in order to further optimize the material. One of the challenge faced by CFI is that CFI manufacturers have many different suppliers for newsprint, where each of them may use different compositions of paper and methods of manufacture the newspaper. Besides that, changes in the formulation of CFI could be envisioned by using environmentally friendly additives with antifungal and fire-retardant properties that could replace some of the non-environmental friendly additives used currently. Innovations of the cellulose fibre insulator can become more prevalent and contribute to more eco-friendly construction projects.

Based on the previous works that have been discussed, overall summary of these materials as insulators are shown in Table 3.7.

Table 3.7: Overall summary of previous works.

Author	Material	Properties	Advantages
Application of coconut fibres as outer eco-insulation to control solar heat radiation on horizontal concrete slab rooftop by Danny et. al.	Coconut fibres	• Low surface heat flux. • Low thermal conductivity.	• Recyclable. • Decomposable.
Sugar cane bagasse fibres reinforces cement composite: thermal considerations by Cristel et. al.	Vegetable bagasse fibres	• Moderate thermal conductivity.	• Environmental friendly. • Cheap. • Natural ability to insulate the thermal conduction.
A review on the properties of cellulose fibre insulation by Pablo et. al.	Recycled newspaper	• Low thermal conductivity.	• Eco-friendly materials. • Favourable thermal. • Acoustic properties.

CHAPTER 4

METHODOLOGY

In this chapter, scopes of this research will focus on the physical measurement of thermal distribution of the house model under different conditions using thermal imaging camera. The flow chart of this project is shown in Appendix A. Three different types of green materials will be selected and fabricate into block brick to be install in the house model. There is five main methods that will be applied in this research, which are:

1. Selection of suitable green materials,
2. Preparation of product sample using selected green materials,
3. Experimental Set-up of the product sample in the mini house model,
4. Physical measurement of thermal distribution on house model under different situations,
5. Heat transfer conduction analysis on the green materials.

4.1 Green Materials Selection

In this project, green material selection is important to insulate the wall during building or remodelling. Selected green material in this project is important to meet the requirement of Green Building Standard (Arzeta, 2015). To achieve green standard, the green materials are evaluated based on few criterions, which are:

1. Indoor air quality:

   In order to achieve Green Building Standard, a building that install with green wall materials must provide highest quality of indoor air quality to its occupational. Good indoor air quality must have minimal chemical emissions. Green materials also must resist to moisture in the room, to reduce the likelihood of mould growth.

2. Reusable or renewable resources:

Green materials are made from recycle or renewable waste and sources. By utilized the uses of the wastes, it can significantly reduce deforesting and waste. Besides that, these green material wall insulators usually can be broken down and reused, which complied with Life-Cycle Assessment.

3. Energy efficiency:

Green wall insulator generally will reduce the amount of energy consumption required to keep a room in comfort. Green wall insulator incorporates alternative forms of energy, thermal efficiency as well as energy waste reduction to minimize the energy footprint of the buildings.

4. Water conversation:

In commercial structures, water efficiency is particularly important. Green wall insulator must be manufactured by using the techniques that will not polluted the local water supply.

In this project, few green materials is proposed and final green materials which is selected is sugar cane waste, coconut fibre and cellulose. Three others insulation materials will be provided in Air Conditioning Laboratory, which are cotton, wool and polystyrene to do the comparison of the selected green materials.

4.2 Green Materials Product Sample Preparation

Specific size of green material wall insulator samples need to be prepared in order to slot into the gaps between the Marcraft GT-7500 mini house model. In this section, two different methods will be applied to prepare the sample with two green materials. First method is deal with cellulose wall insulator preparation, while the second method is deal with the harder materials, which is sugar cane waste and coconut fibre. These three materials is collected and cut into small piece, with length around 1cm before crush in a cruncher in laboratory. Before crunching process, first, these materials will been dry under sun for days until totally dried.

4.2.1 Cellulose Sample Preparation

Main reason of choosing cellulose as green wall insulator in this project is due to its sustainable resources and its properties. Household waste (HHW) or also known as non-hazardous industrial waste (NHIW), which includes a large amount of used papers and cardboard. Papers and cardboards only can be can be categories as HHW and NHIW if these materials are composed nearly exclusively of organic matter, it. However, most of the paper and cardboards contain non-organic chemical components, such as ink, metal, plastics and glue which confer its complexity to be categories as NHIW or HHW (Practice Management, 2017). Recycling of paper and cardboards used in this project is old newspapers. Steps of cellulose sample preparation is shown in Figure 4.1.

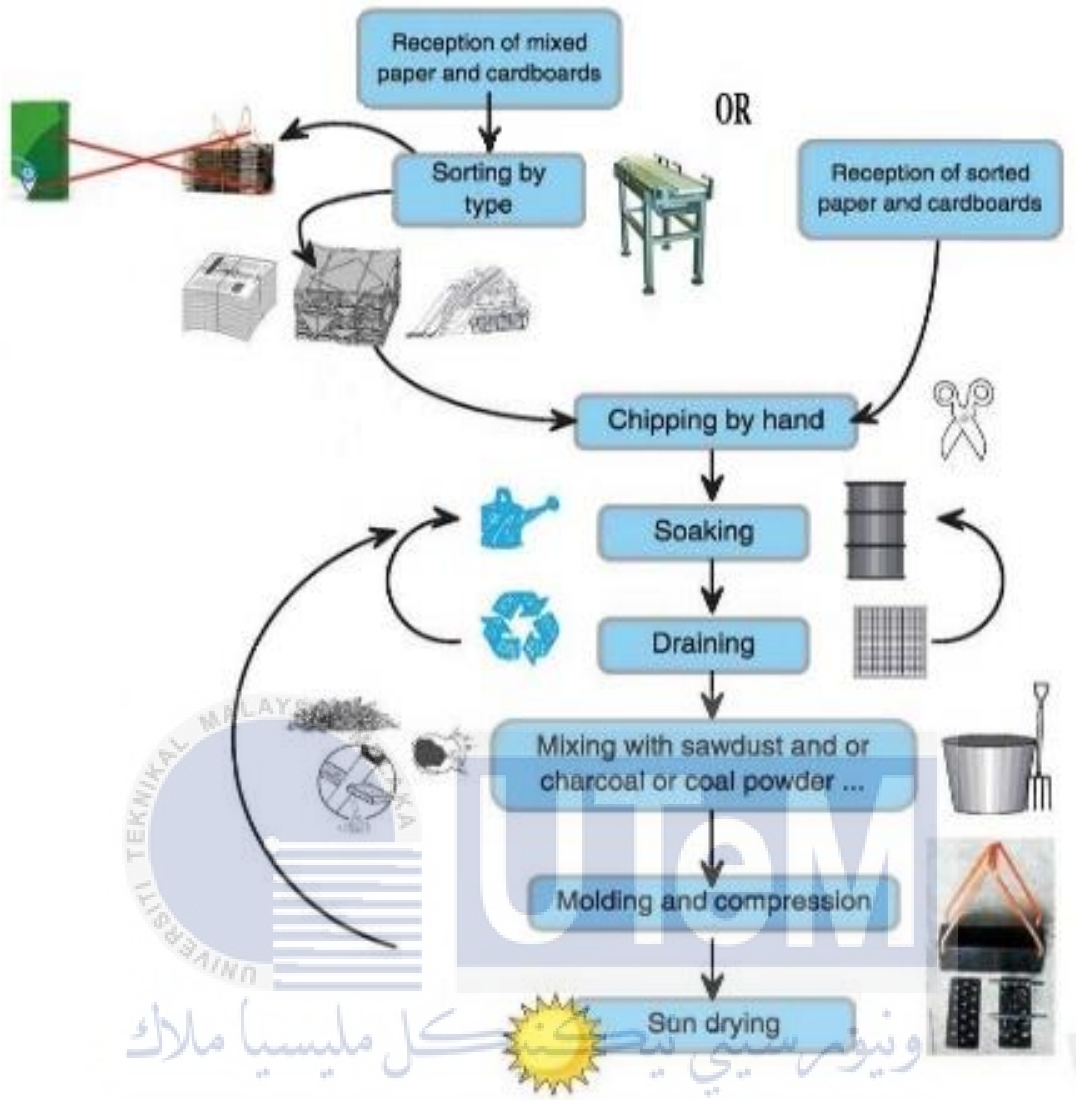


Figure 4.1: Steps of cellulose sample preparation. (Solid Waste Management, 2017)

4.2.2 Sugar Cane Waste and Coconut Fibre Sample Preparation

Sugar cane and coconut water are popular drinks to Malaysian. Due to their non-seasonal characteristics, both ingredients can continuously provide the raw materials for green wall insulator and achieve the sustainable supply. Sugar cane and coconut is harder to fabricate into small sample compare to cellulose because of their hardness. Before mixing with glue to form desired shapes, first, sugar cane and coconut shell need to be crushed by using crusher into small piece. Sample preparation of sugar cane and coconut shell are shown in Figure 4.2.

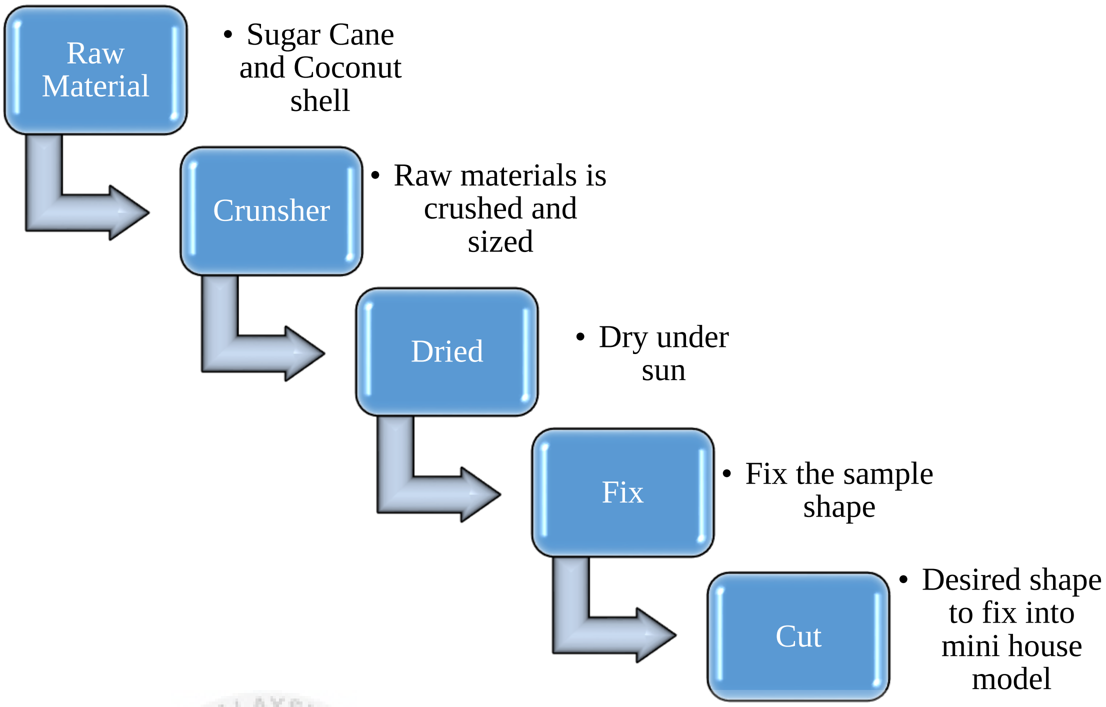


Figure 4.2: Steps of sugar cane and coconut shell sample preparation.

4.2.3 Ratio Contain of Green Material and Glue

In this project, corn starch is used as glue to mix with green raw materials in order to get the desired shape and dimension. Corn starch been chosen due to its natural adhesive properties and suitable to be added into the samples to perform the thermal insulation test. Before adding the corn starch into the raw materials, first, 1 litre of drinking water is added into 350g of corn starch and boil for 2 minutes to get a sticky mixture. Different raw materials required different amount of glue added to get the shapes to slot into Marcraft GT-7500 mini house model. Table 4.1 shows the ratios of raw materials and glue added to get the desired shapes.

Table 4.1: Ratios of raw materials and glue added to get the desired shapes.

Green Material Wall Insulator	Ratio			
	Raw Material		Glue	
Cellulose	Newspapers	6 kg	Corn starch mixture	0 litre
Coconut fibres	Crushed coconut shell	5 kg	Corn starch mixture	3 litres
Sugar cane waste	Crushed sugar cane stalk	5 kg	Corn starch mixture	3 litres

By converging litre into kilogram, the ratio of raw materials to glue are listed in Table 4.2:

Table 4.2: Ration of raw material with glue.

	Raw Material	Glue
Newspapers	100%	0%
Crushed coconut shell	62.5%	37.5%
Crushed sugar cane stalk	62.5%	37.5%

4.3 Experimental Set-up

Thermal insulation of the samples prepared will be tested on the Marcraft GT-7500 mini house model located at Air Conditioning Laboratory. Figure 4.3 shows the mini house model that will be used to test the thermal properties of the green material wall insulators. Lighting system in the mini house model is represent the external heat sources and fan is used to circulate the air flow inside the house model. 12V mini fan is install in mini house model to create the internal air circulation. Mini fan installed is 12V brushless direct current with fan speed of 3000 rpm. Tachometer is used to test the rotational speed of the mini fan. Figure 4.4 shows the sport light used to represent as a sun to generate heat source. The energy produce by the sport light is 1000W. Air velocity in mini house model is 0.33m/s, which is measured by using air velocity meter. Based on experiment conducted by Hsu Cheng Chiang in a 22m x 20m x 10m house model (Chiang, 2007), suggested thermal comfort value for air velocity in a room is around 1.4m/s to 1.7m/s. Reynolds number calculate to determine whether the air velocity in mini house model is in the acceptable range. Reynolds number is calculated by using Eq. 4.1:

$$\mathrm{Re} = \frac{vD}{\nu} \tag{4.1}$$

where: Re = Reynolds number; v = air velocity (m/s); D = Diameter of fan circulate (m); υ = Kinematic viscosity of air at room temperature (1.63×10^{-6} m^2/s).

Table 4.3: Reynolds number for air circulating in actual house and mini house model.

Model	**Air Velocity (m/s)**	**Diameter of fan circulating (m)**	**Reynolds number (Re)**
Actual house model	1.55 (5m down at measuring point)	1.125 (3 blades fan)	1069785.28
Marcraft GT-7500 mini house model	0.67 (5cm away from fan)	0.0525 (4 blades mini fan)	21579.75

Based on the Reynolds number obtained, the air velocity in mini house model is within the acceptable range at the dimension of 50 times smaller than the actual house model.

While, angle of the sport light is set to be 80 ° as the hottest hours in Malaysia are around 1300 to 1400 with average sun altitude varies between 78 ° and 82 ° (Sun Position, 2018). Figure 4.5 shows the position of sport light, which is 180cm height and 100cm away from Marcraft GT-7500 mini house model.

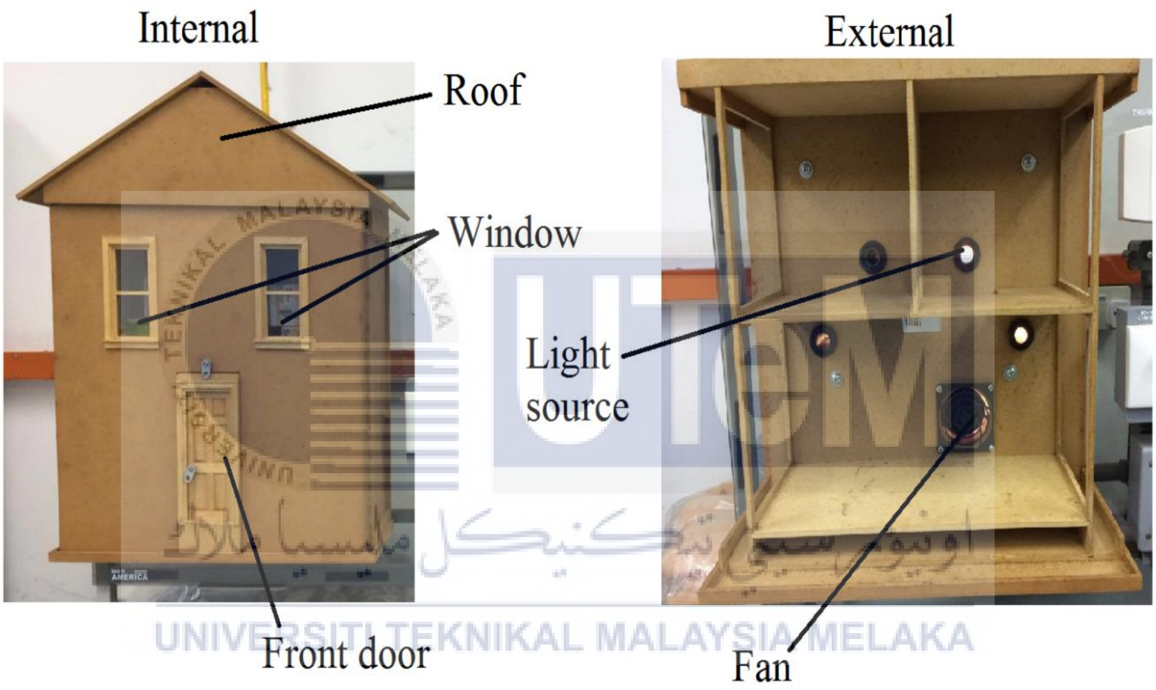


Figure 4.3: Marcraft GT-7500 Mini House Model.

Figure 4.4: Sport light represent as sun to generate heat source.

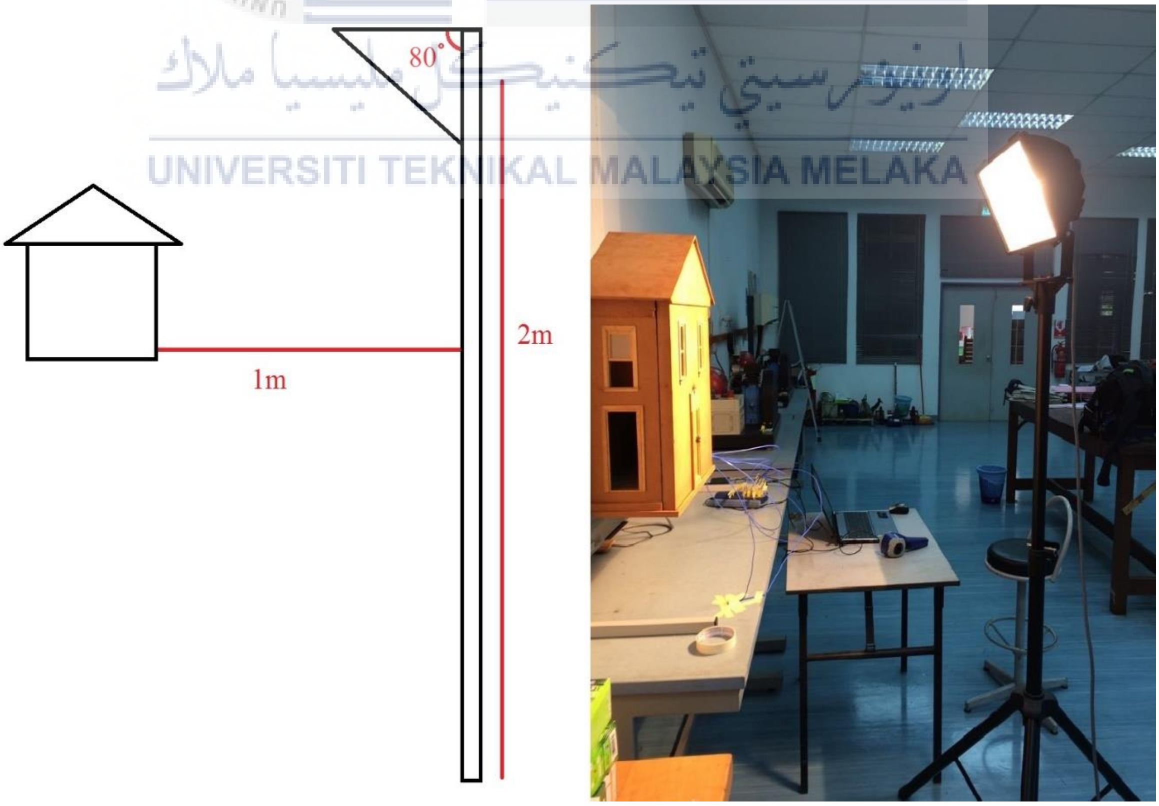


Figure 4.5: Position of sport light.

Initial experiment setup of this research will focus on the green material wall insulators preparation. Three different types of green materials will be crushed and fabricate into block brick to be install in the house model. Before that, the dimensions of the mini house model are measured and presented in this section. Main reason to conduct the measurement is to avoid wastage of materials and energy used during the samples preparation. Figure 4.6 shows the dimensions for each part in mini house model located in air conditioning laboratory.

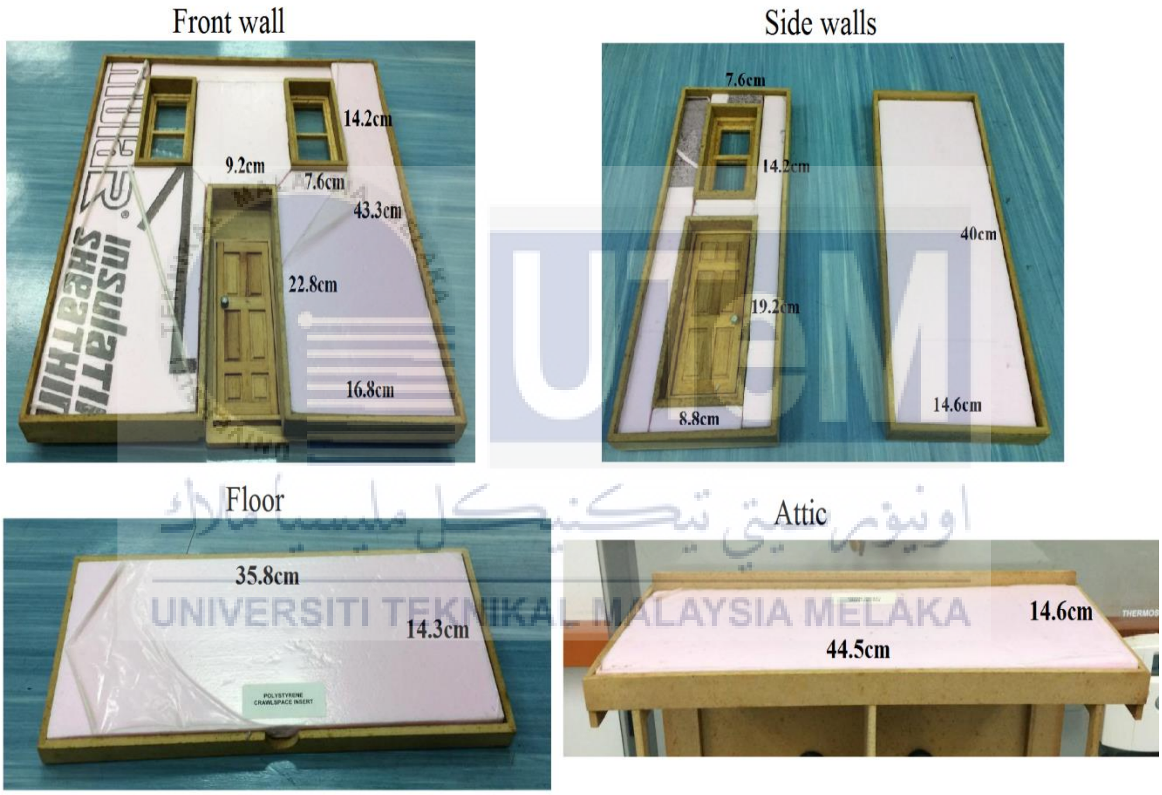


Figure 4.6: Parts and dimensions of mini house model.

After the installation of samples in the mini house model, thermal conduction will be tested under three different condition, which are:

1. With heat source only,
2. With heat source and fan is switched on only,
3. With heat source, fan is switched on and window is opened.

4.4 Physical Measurement Using Thermal Imaging Camera

In this project, thermography method is used to determine the thermal distribution of the house model with the installation of different green material's insulator under different conditions. Infrared thermography is an equipment or method used to detect infrared radiation from an object, by converting the radiation to temperature and displays the temperature distribution profile on the devices. The equipment used in known as infrared thermograph and the method is known as infrared thermography. In this project, thermography method is using to determine the temperature profile of the mini house model. Few important characteristics of infrared thermography equipment is it capture the thermal distribution on an object and display as a visible information, temperature can be measured without contacting to the object and temperature can be measured in real time. Figure 4.7 shows the illustration of how the thermal imagine camera work.

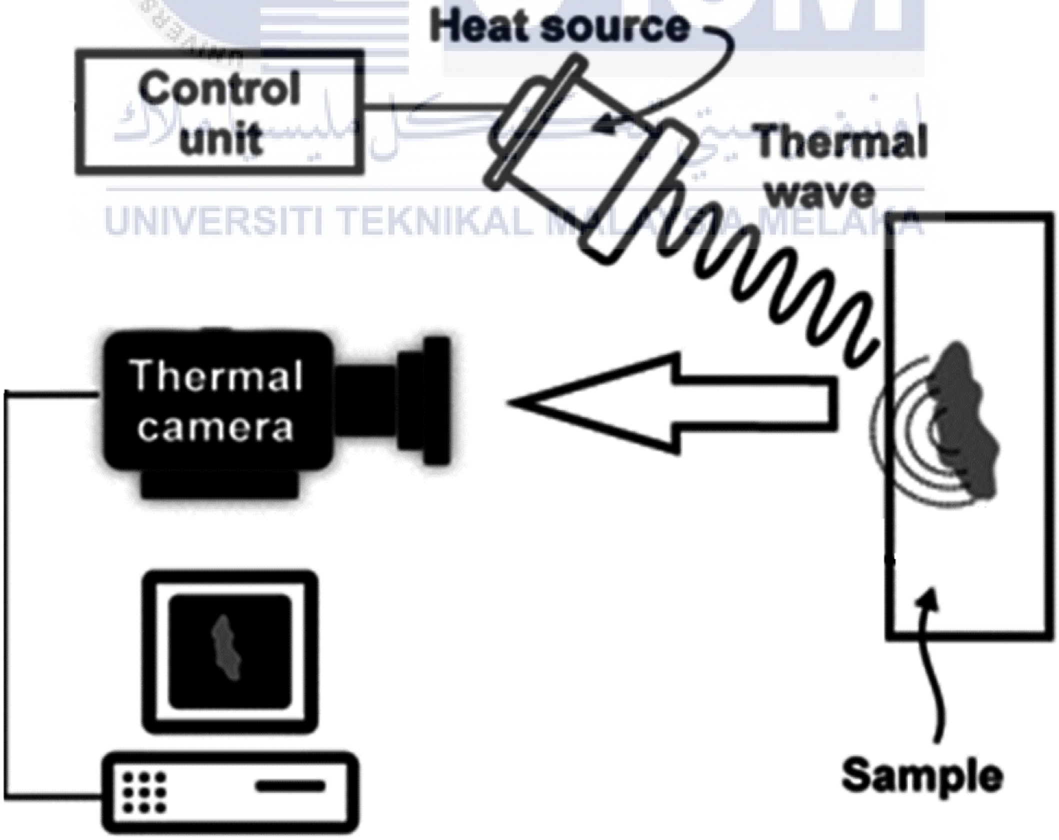


Figure 4.7: Illustration of how the Thermal Imagine Camera work.

4.5 Thermocouple

In this project, dry bulb room temperature inside the mini house model is measured by using a thermocouple. Generally, in a thermocouple there are two important element, which are a temperature sensor and a device that convert the changes in sensor to a numerical value. Temperature sensor will react to the change of the temperature gradient and a digital device will show the digital value for the temperature changes in the room. To monitor room temperature, the specific thermometer used is Pico data logger TC-08, which allow to collect, analysis and displays up to 8 thermocouples. Thermocouples will then install at different regions in the mini house model and monitor the maximum and minimum temperatures over a period of time and the result is recorded to perform heat conduction analysis. Figure 4.8 shows the Pico data logger TC-08 used to measure the temperature change in the mini house model. Figure 4.9 shows the locations (red dots) of thermocouples will be installed.

Figure 4.8: Pico data logger TC-08.

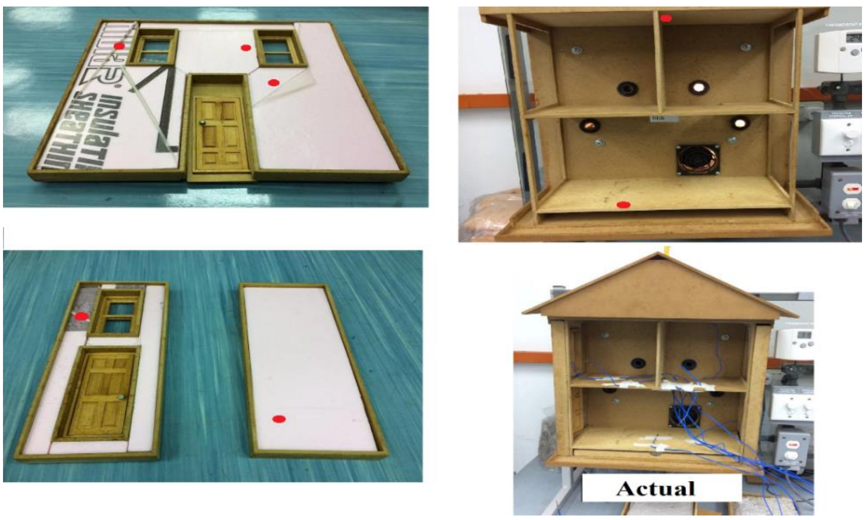


Figure 4.9: Locations (red dots) of thermocouples will be installed.

4.6 Heat Transfer Conduction Analysis

In this section, data obtained from thermal imaging camera will be studied and analysed to determine the behaviour of heat transfer conduction of the mini house model. Thermal conductivity of the green materials will be calculated based on the data obtained from Thermal Imaging Camera and thermocouple. Figure 4.10 shows the process of heat transfer conduction analysis in this project.

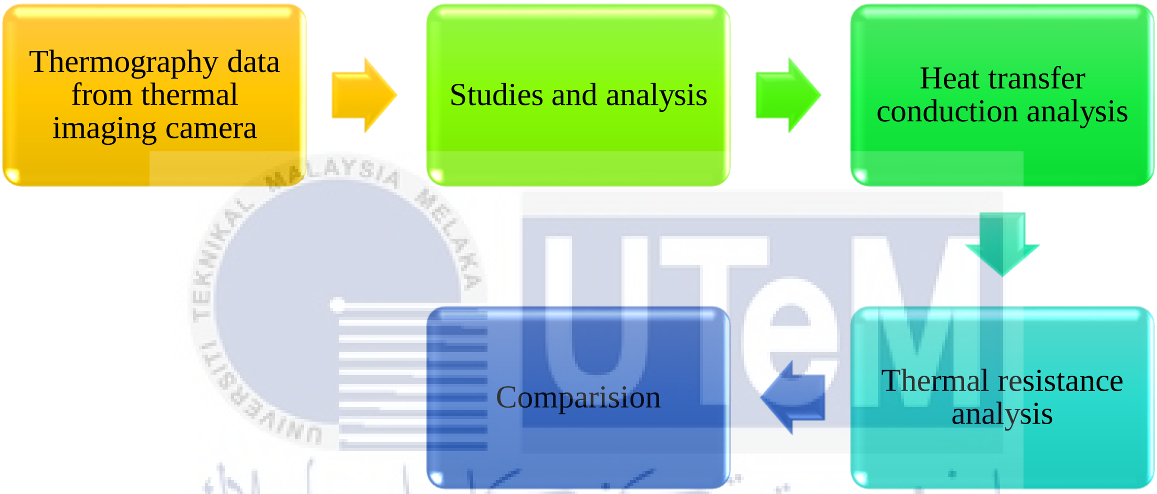


Figure 4.10: Process of heat transfer conduction analysis.

CHAPTER 5

RESULT

In this chapter, result of the testing on the insulator is listed and plotted. Two different temperatures are taken from outdoor and indoor the mini house model for further analysis. In this case, outdoor temperature is set as T_2 and indoor temperature is set as T_1. In this study, 7 different zones been chosen to study the thermal behaviour. Positions of these zone are listed in Table 5.1. These insulators are tested under 3 different conditions as shown in Table 5.2.

Table 5.1: Positions of 7 different zone in Marcraft GT-7500 Mini House Model.

Marking	**Position**
1	Ambient temperature
2	Front wall
3	Floor
4	Bottom wall (right)
5	Top room (left)
6	Top room (right)
7	Top wall (left)
8	Roof

Table 5.2: Three different condition to test the samples.

No.	**Condition**
1.	With heat source only.
2.	With heat source and fan is switched on only.
3.	With heat source, fan is switched on and window is opened.

Area of insulator for each zone is required to calculate the thermal conductivity of each zones. Table 5.3 shows the area of thermal insulator at different zones. Thickness of these thermal insulators are all the same, which are 0.015m.

Table 5.3: Area of insulators at each zone.

Zone	**Area (m^2)**
Bottom room (Front wall)	0.0766
Top room (left)	0.0331
Top room (right)	0.0331
Roof	0.0650
Floor	0.0512
Top side wall (left)	0.0143
Bottom wall (right)	0.0333

Conductive heat transfer can be expressed by Fourier's Law. Consider steady heat conduction through a large plane wall of thickness $\Delta x = L$, the surface area of the plane wall is A, and the temperature difference across the wall is $\Delta T = T_2 - T_1$, the energy balance for the wall can be expressed in Eq. 2.1:

$$Q = \frac{kA\Delta T}{L} \tag{2.1}$$

where; Q = Rate of heat conduction (W/m^3), k = Thermal conductivity of the medium (W/mK), A = Surface area of heat transfer (m^2), ΔT = Temperature different between two mediums (℃K), L = Material thickness (m).

By rearranging Eq. 2.1, thermal conductivity of the insulators can be express as in Eq. 5.1:

$$k = \frac{QL}{A\Delta T} \tag{5.1}$$

Power of the sport light used in this project is 1000W. Time taken to test a sample under 1 conditions are 30 minutes and Pico data logger will record the indoor temperature from start (0 second) until end (29 second). For outdoor temperature of the mini house model, thermal imaging camera is used to snap the thermal image for 4 times, which are at 0 minute, 9 minute, 19 minute and lastly 29 minute. After the data is collected, sport light will be turned off for 15 minutes until the surface of Marcraft GT-7500 Mini House Model cooled down. Same steps are repeated for condition 2 and others samples.

5.1 Polystyrene

Polystyrene insulator is slotted into mini house model to test the thermal behaviour of the insulator. Table 5.4 shows the outdoor and indoor temperature are recorded by using thermocouples and thermal infrared camera.

Table 5.4: Indoor and outdoor temperature for polystyrene under condition 1, 2 and 3.

Condition	Temperature (℃)								
	Position / Time taken	1	2	3	4	5	6	7	8
1.	Indoor Temp.	T_1	T_1	T_1	T_1	T_1	T_1	T_1	T_1
	0 second	31.28	31.56	29.14	30.30	30.25	30.90	31.15	30.78
	9 second	31.82	31.05	30.37	30.99	31.37	32.50	30.75	30.49
	19 second	31.25	31.96	31.11	31.97	32.58	33.66	31.45	30.91
	29 second	32.25	32.87	31.89	32.78	33.51	34.61	32.24	31.69
	Outdoor Temp.	T_2	T_2	T_2	T_2	T_2	T_2	T_2	T_2
	0 second	-	32.9	33.0	31.3	31.4	32.3	32.0	30.9
	9 second	-	42.2	40.3	31.8	42.6	39.2	31.9	41.9
	19 second	-	46.2	43.3	32.8	47.2	47.2	32.8	45.6
	29 second	-	48.2	44.1	33.7	49.2	49.2	33.6	47.8
2.	Indoor Temp.	T_1	T_1	T_1	T_1	T_1	T_1	T_1	T_1
	0 second	28.53	28.79	28.34	27.96	28.17	28.29	28.70	28.31
	9 second	29.83	29.03	27.64	28.14	29.01	29.36	28.10	27.56
	19 second	30.56	30.52	28.19	29.12	30.11	30.33	28.63	27.81
	29 second	30.82	31.95	28.97	30.09	31.22	31.41	29.74	28.59
	Outdoor Temp.	T_2	T_2	T_2	T_2	T_2	T_2	T_2	T_2
	0 second	-	34.4	30.4	32.5	32.6	32.8	30.7	40.6
	9 second	-	37.7	35.4	33.1	34.4	37.1	32.2	41.8
	19 second	-	39.7	39.4	33.8	38.2	39.2	32.8	42.8
	29 second	-	44.1	40.2	34.8	39.5	40.8	34.1	43.9
3.	Indoor Temp.	T_1	T_1	T_1	T_1	T_1	T_1	T_1	T_1
	0 second	29.60	33.95	32.26	32.96	32.08	33.33	29.66	31.83

	9 second	31.32	32.27	31.69	32.36	32.37	33.39	30.09	31.36
	19 second	30.87	33.22	32.66	33.13	33.24	33.98	30.79	31.55
	29 second	31.19	33.88	33.50	33.69	33.84	34.59	31.55	31.99
	Outdoor Temp.	T_2	T_2	T_2	T_2	T_2	T_2	T_2	T_2
	0 second	-	34.6	34.5	34.2	35.1	35.8	30.5	36.8
	9 second	-	38.5	36.7	36.4	38.7	38.8	31.2	38.8
	19 second	-	40.1	38.8	38.5	40.5	41.2	32.0	40.5
	29 second	-	44.8	40.3	39.6	42.2	43.1	32.8	42.6

Calculation:

By substituting indoor temperature (T_1) and outdoor temperature (T_2) into Eq. 5.1, thermal conductivity of polystyrene for each condition are tabulated in Table 5.5.

Table 5.5: Thermal conductivity of polystyrene.

		Thermal Conductivity, W/mK						
Cond.	t	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	**0**	146.14	75.90	650.45	394.06	323.69	1234.06	1923.08
	9	17.56	29.50	556.11	40.35	67.64	912.13	20.23
	19	13.75	24.03	542.71	31.00	33.47	777.00	15.71
	29	12.77	23.99	489.62	28.88	31.06	771.29	14.32
2	**0**	34.91	142.22	99.22	102.30	100.48	524.48	18.78
	9	22.59	37.75	90.82	84.08	58.55	255.84	16.21
	19	21.33	26.13	86.25	56.02	51.09	251.55	15.39
	29	16.12	26.09	85.64	54.73	48.26	240.59	15.07
3	**0**	301.27	130.79	363.27	150.06	183.47	1248.75	46.43
	9	31.43	58.48	111.50	71.59	83.77	945.00	31.02
	19	28.46	47.71	83.88	62.42	62.77	866.90	25.78
	29	17.93	43.08	76.22	54.21	53.25	839.16	21.75

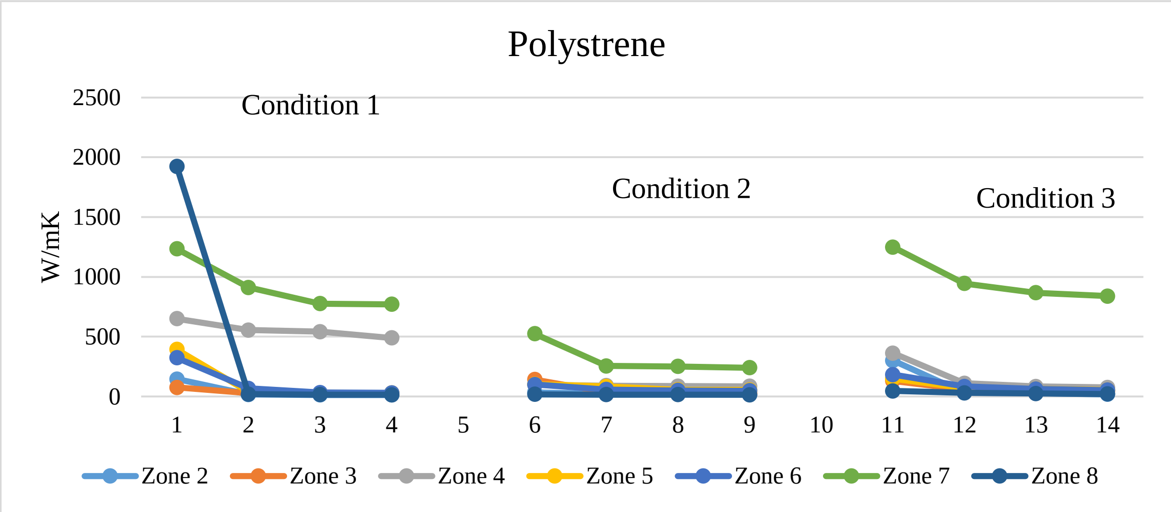


Figure 5.1: Polystyrene insulations tested under different conditions.

Based on the data obtained from Table 5.5, by installing polystyrene thermal insulator at mini house model, condition 2 shows the best result as polystyrene gave the lowest thermal conductivity under condition 2. In condition 2, mini house model is exposed to 1000W of light intensity and internal fan in the mini house model is switched on. Internal air circulation is done by the mini fan and result shows that it did cool down the rooms. In condition 3, window and door which are located at zone 2 and zone 5 are open to allow natural air flow in. Result show that by internal air circulation done by the fan did cooled down the room temperature.

5.2 Fibreglass

Fibreglass insulator is slotted into mini house model to test the thermal behaviour of the insulator. Table 5.6 shows the outdoor and indoor temperature are recorded by using thermocouples and thermal infrared camera.

Table 5.6: Indoor and outdoor temperature for fibreglass under condition 1, 2 and 3.

Condition	Temperature (℃)								
	Position / Time taken	1	2	3	4	5	6	7	8
1.	Indoor Temp.	T_1	T_1	T_1	T_1	T_1	T_1	T_1	T_1
	0 second	28.20	32.42	31.67	30.91	30.50	32.04	30.25	31.76
	9 second	29.33	31.55	31.04	31.21	32.04	33.31	31.69	31.45
	19 second	29.61	31.92	31.21	31.90	32.81	34.12	32.02	31.82
	29 second	30.19	32.64	31.70	32.55	33.55	34.84	32.74	32.54
	Outdoor Temp.	T_2	T_2	T_2	T_2	T_2	T_2	T_2	T_2
	0 second	-	34.0	32.0	31.1	30.8	32.2	30.8	34.6
	9 second	-	40.5	32.1	31.5	36.9	42.3	32.2	39.7
	19 second	-	42.3	32.4	33.0	37.2	43.1	32.9	42.5
	29 second	-	43.8	33.1	33.7	38.7	44.1	33.8	44.5
2.	Indoor Temp.	T_1	T_1	T_1	T_1	T_1	T_1	T_1	T_1
	0 second	29.77	31.62	31.42	29.97	30.98	31.75	31.75	31.07
	9 second	29.44	31.07	30.03	30.33	31.59	32.60	30.88	30.98
	19 second	29.75	31.36	29.78	30.85	32.32	33.31	30.97	31.42
	29 second	30.35	32.00	30.05	31.28	32.94	33.09	31.59	32.05
	Outdoor Temp.	T_2	T_2	T_2	T_2	T_2	T_2	T_2	T_2
	0 second	-	32.8	31.8	30.6	31.2	32.8	32.0	33.1
	9 second	-	40.1	31.0	31.2	34.7	38.2	32.0	40.5
	19 second	-	42.8	30.9	31.8	37.6	39.1	33.5	41.5
	29 second	-	44.2	31.5	32.3	38.4	40.1	34.2	44.0
3.	Indoor Temp.	T_1	T_1	T_1	T_1	T_1	T_1	T_1	T_1
	0 second	29.24	28.97	28.44	28.66	29.03	29.97	28.89	29.05

	9 second	28.97	29.51	28.19	29.08	30.19	32.36	29.52	29.06
	19 second	28.92	30.98	28.74	29.90	31.33	33.58	30.56	29.76
	29 second	29.25	32.21	29.39	30.64	32.38	34.59	31.58	30.75
	Outdoor Temp.	T_2	T_2	T_2	T_2	T_2	T_2	T_2	T_2
	0 second	-	32.9	32.7	29.8	32.9	33.6	30.1	33.6
	9 second	-	38.5	36.5	30.4	35.1	36.6	30.9	36.3
	19 second	-	41.0	38.0	31.9	37.9	38.2	32.1	41.9
	29 second	-	42.3	39.5	32.8	36.0	40.7	33.2	44.6

Calculation:

By substituting indoor temperature (T_1) and outdoor temperature (T_2) into Eq. 5.1, thermal conductivity of fibreglass insulator for each condition are tabulated in Table 5.7.

Table 5.7: Thermal conductivity of fibreglass insulator.

		Thermal Conductivity, W/mK						
Cond.	**t**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	**0**	123.94	887.78	2370.79	1510.57	832.33	2056.77	81.26
	9	21.88	276.39	1553.28	103.23	50.41	1907.18	27.97
	19	18.87	246.19	409.50	93.25	50.46	1191.99	21.61
	29	17.55	209.26	391.70	87.99	48.94	989.58	19.30
2	**0**	165.95	770.97	715.00	2059.87	431.59	1195.80	113.68
	9	21.69	302.03	517.76	145.71	80.92	936.56	24.24
	19	17.12	261.58	474.16	85.83	78.27	414.61	22.89
	29	16.05	202.05	441.62	83.00	64.65	401.90	19.31
3	**0**	49.83	68.77	395.13	125.19	124.84	866.90	50.72
	9	21.78	35.25	341.25	117.10	106.88	760.11	31.87
	19	19.54	31.64	225.23	92.30	98.09	681.14	19.01
	29	19.41	28.98	208.54	68.98	74.17	647.50	16.66

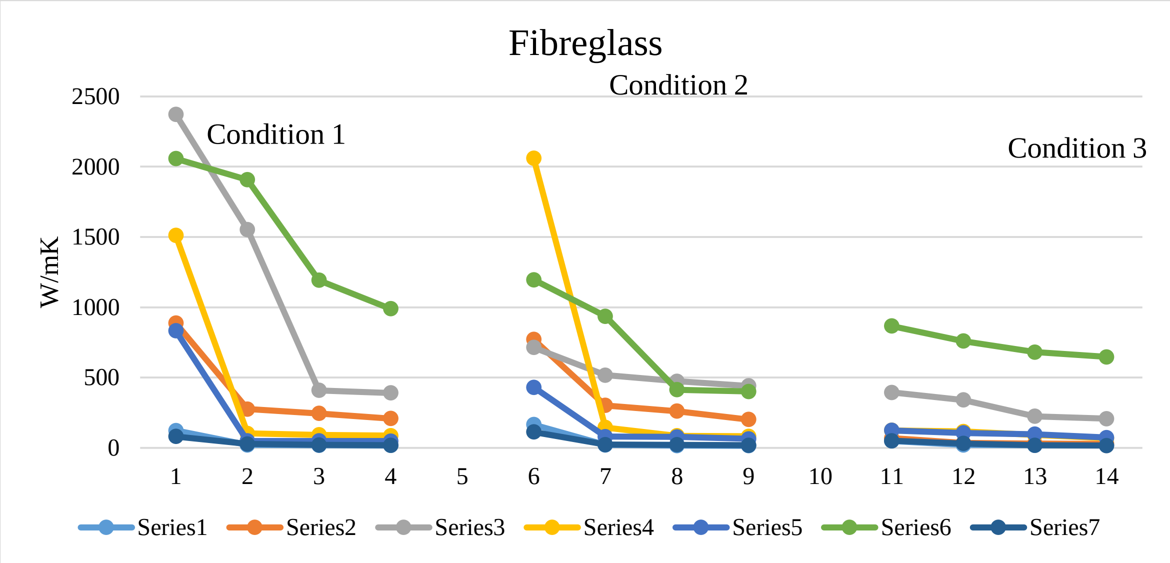


Figure 5.2: Fibreglass insulations tested under different conditions.

Based on the data obtained from Table 5.7, thermal conductivity of fibreglass is relatively low. With internal air circulation by mini fan, the heat transfer by from outdoor to indoor also have relatively decrease. Based on Figure 5.2, condition 2 and condition 3 have relatively low thermal conductivity compare to condition 1. At zone 7 for condition 3, which is right top room has the significant high conduction compare to other zones.

5.3 Cotton

Cotton wall insulator is slotted into mini house model to test the thermal behaviour of the insulator. Table 5.8 shows the outdoor and indoor temperature are recorded by using thermocouples and thermal infrared camera.

Table 5.8: Indoor and outdoor temperature for cotton under condition 1, 2 and 3.

Condition	Temperature (℃)								
	Position / Time taken	1	2	3	4	5	6	7	8
1.	Indoor Temp.	T_1	T_1	T_1	T_1	T_1	T_1	T_1	T_1
	0 second	28.47	29.36	27.54	28.26	28.79	28.74	28.19	29.12
	9 second	28.55	30.10	27.41	28.69	30.33	29.67	28.91	30.37
	19 second	29.33	31.59	27.95	29.57	31.49	30.82	30.03	31.80
	29 second	29.52	32.92	28.67	30.40	32.65	31.95	31.44	33.14
	Outdoor Temp.	T_2	T_2	T_2	T_2	T_2	T_2	T_2	T_2
	0 second	-	31.7	30.1	28.7	31.9	32.2	28.5	32.6
	9 second	-	41.4	36.6	30.6	37.5	39.5	30.2	42.8
	19 second	-	43.1	38.6	32.0	39.1	41.1	32.5	44.3
	29 second	-	44.5	39.5	33.2	40.5	42.8	34.2	45.8
2.	Indoor Temp.	T_1	T_1	T_1	T_1	T_1	T_1	T_1	T_1
	0 second	28.44	31.76	30.46	29.61	30.50	30.63	30.08	31.06
	9 second	29.56	31.31	30.14	30.66	31.43	31.30	31.25	31.43
	19 second	29.71	31.93	30.70	31.58	32.39	32.19	31.88	32.12
	29 second	30.20	32.80	31.41	32.44	33.26	33.06	32.69	33.07
	Outdoor Temp.	T_2	T_2	T_2	T_2	T_2	T_2	T_2	T_2
	0 second	-	34.6	33.7	29.9	32.9	33.3	30.4	33.1
	9 second	-	38.7	35.5	32.5	35.2	36.8	31.9	35.4
	19 second	-	41.9	38.0	34.8	37.5	39.6	32.8	41.2
	29 second	-	43.5	39.8	38.5	39.2	41.0	33.9	44.6
3.	Indoor Temp.	T_1	T_1	T_1	T_1	T_1	T_1	T_1	T_1

	0 second	29.72	32.56	31.30	30.58	31.31	31.62	31.25	31.95
	9 second	31.49	31.70	30.18	30.85	31.89	31.89	31.52	31.79
	19 second	31.05	32.40	30.37	31.58	32.71	32.56	31.90	32.34
	29 second	31.23	33.31	30.90	32.16	33.46	33.27	32.57	33.13
	Outdoor Temp.	T_2	T_2	T_2	T_2	T_2	T_2	T_2	T_2
	0 second	-	34.2	33.1	31.2	33.7	32.1	32.2	34.2
	9 second	-	40.7	37.6	32.1	35.1	35.8	32.8	40.9
	19 second	-	44.2	39.9	33.1	38.1	41.3	33.2	44.5
	29 second	-	45.2	40.9	33.8	39.1	43.1	33.9	45.5

Calculation:

By substituting indoor temperature (T_1) and outdoor temperature (T_2) into Eq. 5.1, thermal conductivity of cotton insulator for each condition are tabulated in Table 5.9.

Table 5.9: Thermal conductivity of cotton insulator.

		Thermal Conductivity, W/mK						
Cond.	**t**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	**0**	83.68	114.44	1023.75	145.71	130.97	3383.71	66.31
	9	17.33	31.88	235.84	63.20	46.10	813.14	18.57
	19	17.01	27.51	185.37	59.55	44.08	424.68	18.46
	29	16.91	27.05	160.88	57.73	41.77	380.05	18.23
2	**0**	68.95	90.42	1553.28	188.82	169.73	1277.97	113.12
	9	26.50	54.66	244.81	120.20	82.39	1163.77	58.13
	19	19.64	40.13	139.89	88.68	61.16	1140.16	25.42
	29	18.30	34.92	74.33	76.29	57.07	866.90	20.01
3	**0**	119.40	162.76	726.53	189.61	944.11	1104.16	102.56
	9	21.76	39.48	360.36	141.18	115.90	819.49	25.33
	19	16.60	30.74	296.35	84.08	51.85	806.89	18.98
	29	16.47	29.30	274.66	80.35	46.10	788.68	18.66

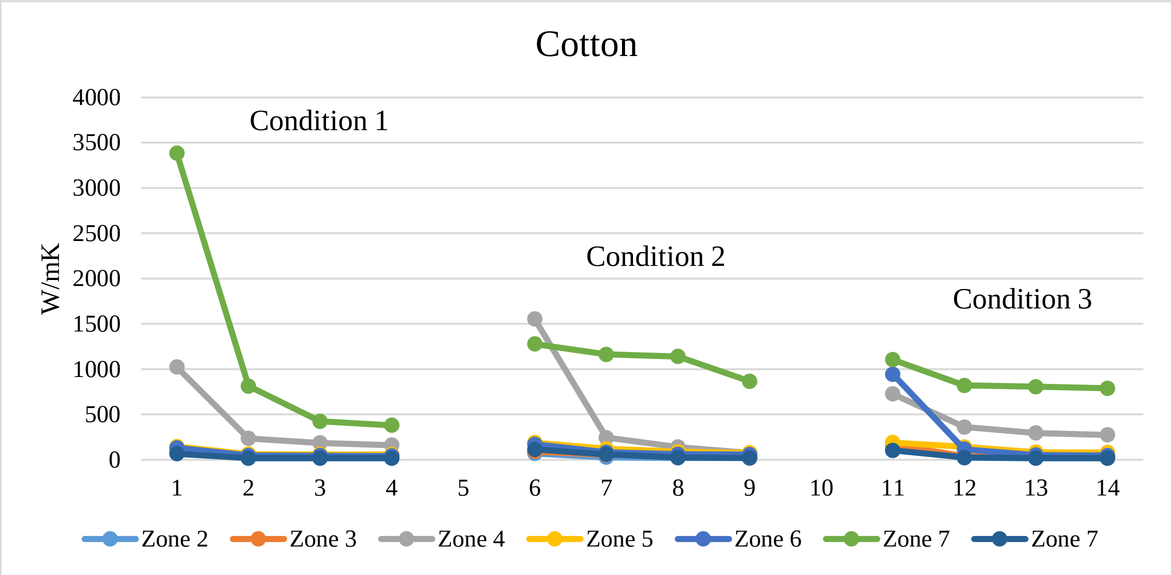


Figure 5.3: Cotton insulations tested under different conditions.

With internal air circulations, thermal conductivity of cotton is relatively decrease. While, natural air flow from outdoor didn't have a significant impact in cooling down the room. At zone 4, which is floor of mini house model, when the side door is opened, there are significant drop in thermal conductivity at that zone. Based on Table 5.9, the highest thermal conductivity is recorded at zone 7, which is left top wall. At this area, there is no direct contact to the radiation of sport light, so the temperature different is very small. At condition 3, zone 4 have significant incensement in thermal conductivity. This is due to the heat flow from external through the gap.

5.4 Wool

Wool insulator is tested in mini house model to determine the thermal behaviour of the insulator. Table 5.10 shows the outdoor and indoor temperature are recorded by using thermocouples and thermal infrared camera.

Table 5.10: Indoor and outdoor temperature for wool under condition 1, 2 and 3.

Condition		Temperature (℃)							
	Position / Time taken	1	2	3	4	5	6	7	8
1.	Indoor Temp.	T_1	T_1	T_1	T_1	T_1	T_1	T_1	T_1
	0 second	29.14	30.04	31.08	29.83	29.98	30.19	30.90	31.16
	9 second	30.69	31.37	30.43	30.81	31.34	31.51	30.66	31.17
	19 second	31.04	32.71	30.73	31.66	32.40	32.48	31.31	31.88
	29 second	30.79	34.04	31.37	32.42	33.41	33.46	32.25	32.75
	Outdoor Temp.	T_2	T_2	T_2	T_2	T_2	T_2	T_2	T_2
	0 second	-	33.0	31.5	31.2	32.3	32.1	31.3	35.8
	9 second	-	39.7	35.9	32.2	35.6	37.1	31.8	42.6
	19 second	-	45.2	39.3	33.6	37.4	39.8	32.9	44.6
	29 second	-	46.6	40.2	34.5	38.9	41.0	33.9	47.3
2.	Indoor Temp.	T_1	T_1	T_1	T_1	T_1	T_1	T_1	T_1
	0 second	28.83	32.04	31.35	30.71	30.69	30.93	31.34	31.28
	9 second	30.36	31.70	30.69	31.16	31.44	31.72	30.93	31.35
	19 second	30.41	32.86	31.32	32.16	32.49	32.76	31.63	32.13
	29 second	30.72	34.20	32.39	33.17	33.60	33.80	32.57	33.12
	Outdoor Temp.	T_2	T_2	T_2	T_2	T_2	T_2	T_2	T_2
	0 second	-	34.2	32.5	31.0	32.3	32.7	32.3	35.1
	9 second	-	40.2	36.5	31.7	35.0	37.6	32.8	42.3
	19 second	-	44.2	38.2	32.9	38.7	39.0	32.8	43.7
	29 second	-	45.6	39.2	34.0	39.9	40.2	33.8	47.2
3.	Indoor Temp.	T_1	T_1	T_1	T_1	T_1	T_1	T_1	T_1
	0 second	29.46	29.37	28.76	28.99	29.18	29.46	29.08	29.40

	9 second	30.33	29.77	28.25	29.28	30.21	29.94	28.57	29.25
	19 second	30.71	31.82	29.00	30.41	31.58	31.15	29.58	30.14
	29 second	30.32	33.72	31.29	31.10	32.46	32.32	32.00	32.23
	Outdoor Temp.	T_2	T_2	T_2	T_2	T_2	T_2	T_2	T_2
	0 second	-	33.1	32.2	30.0	32.3	32.2	30.7	33.2
	9 second	-	38.4	36.8	30.5	35.2	36.1	30.8	37.3
	19 second	-	40.6	37.8	32.5	37.8	38.6	32.5	41.2
	29 second	-	43.8	40.3	32.5	38.2	39.2	34.2	44.0

Calculation:

By substituting indoor temperature (T_1) and outdoor temperature (T_2) into Eq. 5.1, thermal conductivity of wool insulator for each condition are tabulated in Table 5.11.

Table 5.11: Thermal conductivity of wool insulator.

		Thermal Conductivity, W/mK						
Cond.	**t**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	**0**	66.16	697.54	328.80	195.33	237.26	2622.38	49.73
	9	23.51	53.56	324.07	106.38	81.07	920.13	20.19
	19	15.68	34.19	232.19	90.63	61.91	659.72	18.14
	29	15.59	33.18	216.56	82.55	60.10	635.73	15.86
2	**0**	90.66	254.76	1553.28	281.47	256.03	1092.66	60.41
	9	23.04	50.42	834.17	127.30	77.07	560.94	21.07
	19	17.27	42.58	608.72	72.97	72.62	896.54	19.95
	29	17.18	43.02	542.71	71.93	70.81	852.81	16.39
3	**0**	52.50	85.17	445.99	145.25	165.39	647.50	60.73
	9	22.69	34.27	369.22	90.82	73.57	470.38	28.67
	19	22.30	33.29	321.75	78.95	65.87	476.80	20.87
	29	19.43	32.52	215.53	72.86	60.83	359.23	19.61

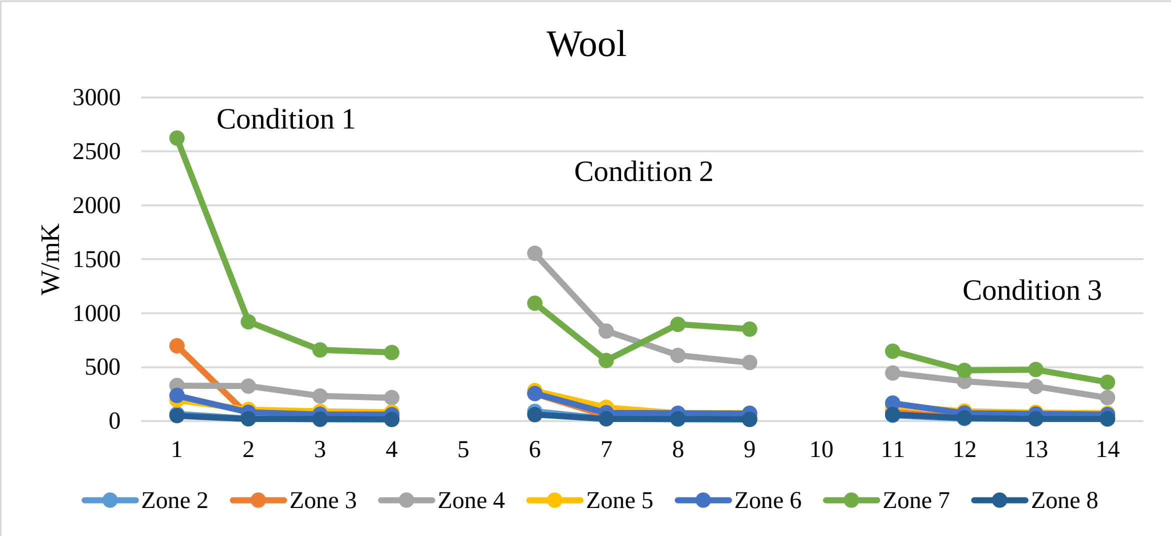


Figure 5.4: Wool insulations tested under different conditions.

With internal air circulation, the internal temperature in condition 2 and condition 3 is lower compare to condition 1. In condition 1, there is only heat source, where sport light is on to act as sun in actual scenario. With external air circulation, overall thermal conductivity in condition 3 is slight lower than condition 2.

5.5 Sugar Cane Fibre

Sugar cane fibre insulator is slotted into mini house model to test the thermal behaviour of the insulator. Table 5.12 shows the outdoor and indoor temperature are recorded by using thermocouples and thermal infrared camera.

Table 5.12: Indoor and outdoor temperature for sugar cane under condition 1, 2 and 3.

Condition	Temperature (℃)								
	Position / Time taken	1	2	3	4	5	6	7	8
1.	Indoor Temp.	T_1	T_1	T_1	T_1	T_1	T_1	T_1	T_1
	0 second	28.66	30.58	29.90	28.80	28.84	29.99	30.08	30.15
	9 second	29.39	30.47	30.07	29.53	29.12	30.51	30.42	30.15
	19 second	30.46	30.52	29.88	30.13	29.73	31.18	30.58	30.49
	29 second	30.91	31.27	30.30	30.80	30.60	31.98	31.27	31.16
	Outdoor Temp.	T_2	T_2	T_2	T_2	T_2	T_2	T_2	T_2
	0 second	-	34.4	31.8	30.1	33.0	35.0	30.2	35.0
	9 second	-	39.3	34.7	31.2	39.3	40.2	31.5	42.4
	19 second	-	41.5	36.4	32.2	42.4	42.3	31.8	45.0
	29 second	-	42.9	37.9	32.9	43.9	44.6	32.9	47.0
2.	Indoor Temp.	T_1	T_1	T_1	T_1	T_1	T_1	T_1	T_1
	0 second	28.73	29.21	29.87	28.20	27.93	29.28	29.12	30.06
	9 second	30.59	27.98	28.74	28.48	28.15	29.54	28.85	29.49
	19 second	30.09	28.61	29.20	29.32	29.06	30.34	29.40	29.65
	29 second	29.35	29.53	29.67	29.94	29.99	31.03	30.44	30.33
	Outdoor Temp.	T_2	T_2	T_2	T_2	T_2	T_2	T_2	T_2
	0 second	-	31.7	31.0	29.2	32.9	32.8	29.6	33.8
	9 second	-	37.3	34.9	30.0	39.7	40.2	30.3	42.8
	19 second	-	38.1	36.6	31.1	41.6	41.8	31.2	44.5
	29 second	-	39.2	36.9	32.1	42.0	42.8	32.6	45.4
3.	Indoor Temp.	T_1	T_1	T_1	T_1	T_1	T_1	T_1	T_1
	0 second	28.09	27.58	27.79	26.81	28.95	27.87	27.52	28.20

	9 second	29.38	27.07	27.12	26.95	31.02	28.80	27.29	27.98
	19 second	30.08	28.49	27.43	27.56	32.15	30.06	28.05	28.28
	29 second	30.62	30.31	28.13	28.34	33.37	31.37	29.20	29.02
	Outdoor Temp.	T_2	T_2	T_2	T_2	T_2	T_2	T_2	T_2
	0 second	-	32.4	29.4	29.2	31.6	31.9	28.0	32.1
	9 second	-	37.7	34.3	30.0	38.0	38.2	30.0	40.5
	19 second	-	39.4	34.8	30.7	39.3	39.5	31.2	40.9
	29 second	-	42.4	36.5	31.5	41.7	42.6	32.5	43.3

Calculation:

By substituting indoor temperature (T_1) and outdoor temperature (T_2) into Eq. 5.1, thermal conductivity of sugar cane fibre for each condition are tabulated in Table 5.13.

Table 5.13: Thermal conductivity of sugar cane fibre.

		Thermal Conductivity, W/mK						
Cond.	**t**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	**0**	51.26	154.19	346.50	108.94	90.45	1741.26	47.58
	9	22.18	63.28	269.73	44.52	46.77	971.25	18.84
	19	17.83	44.93	217.61	35.77	40.75	859.80	15.90
	29	16.84	38.55	214.50	34.07	35.91	643.53	14.57
2	**0**	78.64	259.26	450.45	91.18	128.74	1185.31	61.70
	9	21.01	47.56	296.35	39.24	42.51	723.41	17.34
	19	20.63	39.59	253.06	36.14	39.54	582.75	15.54
	29	20.25	40.52	208.54	37.73	38.50	485.63	15.31
3	**0**	40.63	181.97	188.47	171.01	112.45	1185.31	59.17
	9	18.42	40.80	147.69	64.92	48.21	387.07	18.43
	19	17.95	39.75	143.46	63.38	48.01	333.00	18.29
	29	16.20	35.00	142.55	54.40	40.35	317.86	16.16

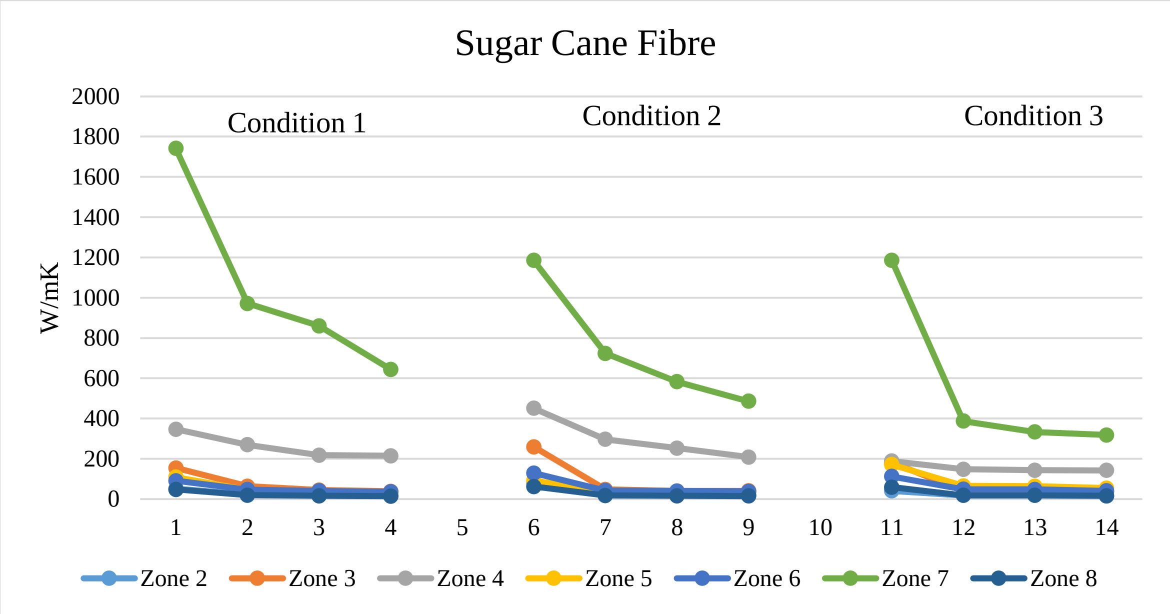


Figure 5.5: Sugar cane fibre insulations tested under different conditions.

Sugar cane fibre insulator has lower thermal conductivity compare to others insulators, such as wool and cotton. From the result, highest thermal conductivity occur at two point, which are zone 7 (left top wall) and zone 4 (bottom wall). This is due to no direct contact to radiation of sport light and only small temperature different between internal and external wall.

5.6 Coconut Shell Fibre

Coconut shell fibre insulator is slotted into mini house model to test the thermal behaviour of the insulator. Table 5.14 shows the outdoor and indoor temperature are recorded by using thermocouples and thermal infrared camera.

Table 5.14: Indoor and outdoor temperature for coconut fibre under condition 1, 2 and 3.

Condition	Temperature (℃)								
	Position / Time taken	1	2	3	4	5	6	7	8
1.	Indoor Temp.	T_1	T_1	T_1	T_1	T_1	T_1	T_1	T_1
	0 second	30.79	30.82	30.64	30.25	30.16	30.77	30.64	30.46
	9 second	31.28	30.21	30.35	30.56	31.10	31.42	31.17	30.60
	19 second	31.43	31.02	31.01	31.43	32.53	32.80	32.37	31.48
	29 second	31.84	32.14	31.96	32.36	33.80	34.02	33.63	32.55
	Outdoor Temp.	T_2	T_2	T_2	T_2	T_2	T_2	T_2	T_2
	0 second	-	33.3	32.9	31.1	33.7	33.9	31.3	34.0
	9 second	-	39.1	36.7	32.8	41.8	42.0	32.1	41.3
	19 second	-	41.7	38.1	33.4	44.2	45.5	33.4	46.2
	29 second	-	42.4	38.6	33.9	45.5	46.5	33.8	47.4
2.	Indoor Temp.	T_1	T_1	T_1	T_1	T_1	T_1	T_1	T_1
	0 second	29.88	33.16	32.29	31.32	32.27	32.57	31.12	32.51
	9 second	32.47	32.10	31.57	31.64	32.64	33.16	33.05	32.49
	19 second	32.22	32.19	31.41	32.01	33.33	33.76	33.29	32.72
	29 second	32.55	32.63	31.71	32.43	34.01	34.38	33.92	33.21
	Outdoor Temp.	T_2	T_2	T_2	T_2	T_2	T_2	T_2	T_2
	0 second	-	36.1	34.7	32.0	37.4	37.7	31.6	34.4
	9 second	-	39.5	37.2	33.4	40.2	42.2	33.3	42.6
	19 second	-	41.0	39.0	33.8	44.1	44.1	33.5	45.6
	29 second	-	41.6	39.2	34.4	45.1	45.2	34.2	46.8
3.	Indoor Temp.	T_1	T_1	T_1	T_1	T_1	T_1	T_1	T_1
	0 second	29.33	28.30	29.84	28.46	29.03	29.72	30.09	30.47

	9 second	30.03	28.35	29.23	29.03	30.30	30.77	30.10	30.36
	19 second	30.11	29.46	29.73	30.95	31.80	32.22	30.98	30.96
	29 second	29.57	30.57	30.44	30.80	33.17	33.45	31.95	31.46
	Outdoor Temp.	T_2	T_2	T_2	T_2	T_2	T_2	T_2	T_2
	0 second	-	37.2	35.9	31.5	40.8	41.0	31.4	43.1
	9 second	-	39.3	37.3	32.2	43.2	43.2	32.3	45.8
	19 second	-	39.7	37.7	32.3	43.5	44.1	33.1	46.2
	29 second	-	40.2	38.8	33.6	44.6	45.3	33.8	47.6

Calculation:

By substituting indoor temperature (T_1) and outdoor temperature (T_2) into Eq. 5.1, thermal conductivity of coconut shell fibre for each condition are tabulated in Table 5.15.

Table 5.15: Thermal conductivity of coconut shell fibre.

		Thermal Conductivity, W/mK						
Cond.	**t**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	**0**	78.96	129.63	529.94	128.01	144.78	1589.32	65.19
	9	22.03	46.14	292.50	42.35	42.83	1127.90	21.57
	19	18.34	44.12	228.66	38.83	35.68	1018.40	15.68
	29	19.09	41.32	201.09	38.73	36.31	617.30	15.54
2	**0**	66.61	121.56	662.43	88.34	88.34	1185.31	122.10
	9	26.46	52.04	255.94	59.94	50.13	995.80	22.83
	19	22.23	38.60	251.65	42.08	43.83	990.00	17.92
	29	21.83	39.11	228.66	40.86	41.88	746.25	16.98
3	**0**	22.00	48.34	333.67	38.50	40.17	800.73	18.27
	9	17.88	36.30	160.88	39.65	36.46	567.00	14.95
	19	19.12	36.76	148.17	38.73	38.15	494.79	15.14
	29	20.33	35.04	142.10	35.13	38.24	476.80	14.30

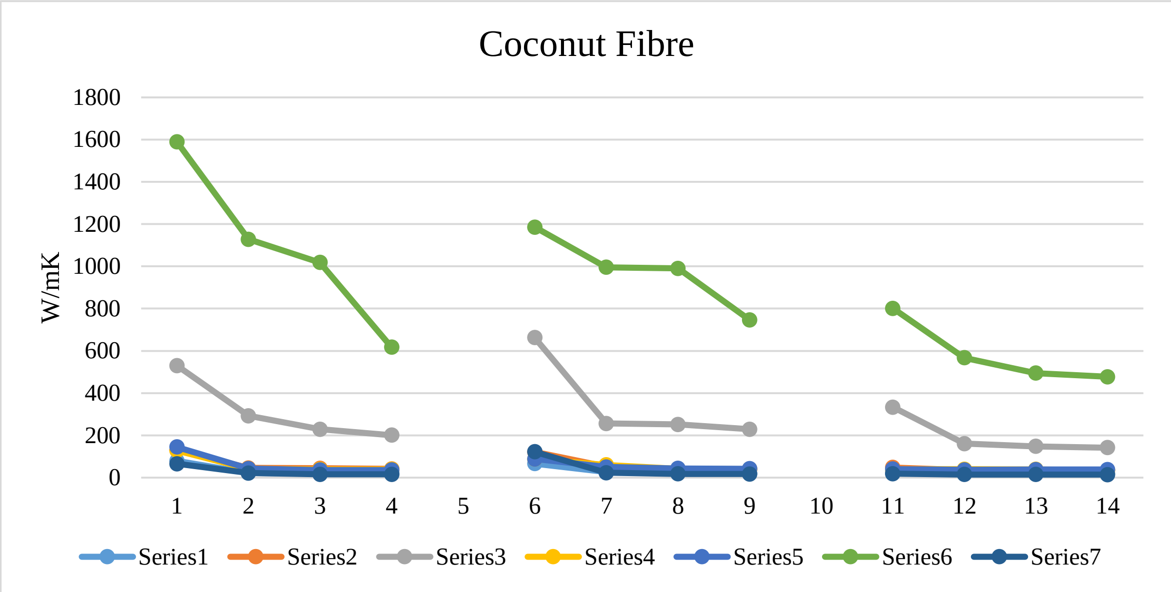


Figure 5.6: Coconut shell fibre insulations tested under different conditions.

Based on result obtained, coconut insulator has significant low thermal conductivity when tested in mini house model. Thermal conductivity is slightly decrease when tested under condition 3. Highest region of thermal conductivity is at zone 3 and zone 7, which are top wall and floor of house model.

5.7 Cellulose

Cellulose insulator is slotted into mini house model to test the thermal behaviour of the insulator. Table 5.16 shows the outdoor and indoor temperature are recorded by using thermocouples and thermal infrared camera.

Table 5.16: Indoor and outdoor temperature for cellulose under condition 1, 2 and 3.

Condition	Temperature (℃)								
	Position / Time taken	1	2	3	4	5	6	7	8
1.	Indoor Temp.	T_1	T_1	T_1	T_1	T_1	T_1	T_1	T_1
	0 second	31.66	32.51	31.64	31.80	31.99	32.69	32.75	32.60
	9 second	32.52	32.08	31.57	32.10	33.13	33.49	33.10	32.73
	19 second	33.00	32.61	31.94	32.84	34.47	34.60	33.95	33.57
	29 second	32.68	33.53	32.67	33.62	33.45	35.54	34.83	34.50
	Outdoor Temp.	T_2	T_2	T_2	T_2	T_2	T_2	T_2	T_2
	0 second	-	35.3	33.9	32.1	35.8	36.5	33.1	37.0
	9 second	-	40.4	38.3	33.8	43.4	43.2	34.4	44.6
	19 second	-	42.6	39.9	34.4	47.4	46.5	34.8	48.7
	29 second	-	42.8	40.1	35.2	47.9	47.2	35.4	49.4
2.	Indoor Temp.	T_1	T_1	T_1	T_1	T_1	T_1	T_1	T_1
	0 second	30.58	31.18	31.47	30.66	31.44	31.39	32.04	30.96
	9 second	30.30	31.36	31.32	30.80	32.99	32.77	32.76	31.10
	19 second	31.08	32.13	31.24	31.05	34.48	34.08	33.53	31.83
	29 second	31.33	33.09	31.81	31.61	35.75	35.26	34.75	32.80
	Outdoor Temp.	T_2	T_2	T_2	T_2	T_2	T_2	T_2	T_2
	0 second	-	36.1	34.8	31.8	38.0	38.3	32.9	39.3
	9 second	-	38.7	37.5	31.9	41.7	42.1	33.0	43.0
	19 second	-	40.1	38.5	32.7	44.1	44.6	34.3	45.7
	29 second	-	41.4	39.1	33.3	45.1	45.6	35.8	46.7
3.	Outdoor Temp.	T_1	T_1	T_1	T_1	T_1	T_1	T_1	T_1

	0 second	29.74	32.59	32.33	31.14	31.94	32.40	31.94	32.32
	9 second	32.11	31.90	31.76	31.17	32.82	33.13	32.99	32.42
	19 second	32.01	32.69	32.36	32.35	34.21	34.33	33.73	33.31
	29 second	32.34	33.59	33.25	33.27	35.49	35.53	34.35	34.40
	Indoor Temp.	T_2	T_2	T_2	T_2	T_2	T_2	T_2	T_2
	0 second	-	36.5	35.2	32.1	38.8	39.0	32.9	40.5
	9 second	-	40.6	38.3	33.3	43.2	43.4	34.6	45.5
	19 second	-	40.9	39.1	33.6	43.8	43.6	34.9	47.2
	29 second	-	42.1	40.5	34.4	45.6	45.0	35.7	48.8

Calculation:

By substituting indoor temperature (T_1) and outdoor temperature (T_2) into Eq. 5.1, thermal conductivity of cellulose insulator for each condition are tabulated in Table 5.17.

Table 5.17: Thermal conductivity of cellulose insulator.

		Thermal Conductivity, W/mK						
Cond.	**t**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	**0**	70.19	129.63	1501.50	118.94	118.94	997.00	52.45
	9	23.54	43.53	264.97	44.13	46.67	806.89	19.44
	19	19.60	39.43	288.75	35.05	38.08	634.06	15.25
	29	21.12	36.81	285.10	31.36	38.87	540.26	15.49
2	**0**	39.80	87.98	409.50	69.08	65.58	1219.71	27.67
	9	26.68	47.41	395.13	52.03	48.57	1170.63	19.39
	19	24.57	40.35	273.00	47.11	43.08	1062.27	16.64
	29	23.56	40.19	266.54	48.47	43.83	999.00	16.60
3	**0**	50.08	102.08	469.22	66.06	68.66	1092.66	28.21
	9	22.51	44.80	398.63	43.66	44.13	896.54	17.64
	19	23.85	43.47	360.36	47.25	48.89	777.00	16.61
	29	23.01	40.41	211.48	44.82	47.85	651.52	16.03

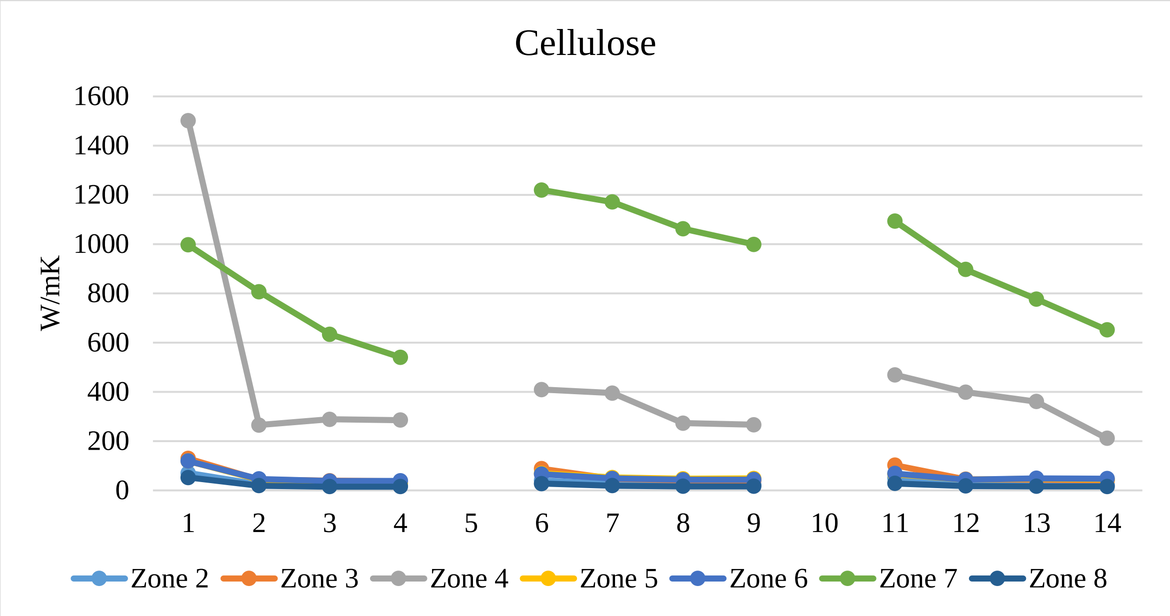


Figure 5.7: Cellulose insulations tested under different conditions.

Thermal conductivity for cellulose insulator in condition 2 and condition 3 is slightly lower than condition 1. Highest region of thermal conductivity is at the top wall of house model. This result is due to no direct exposure to radiation of sport light. Lower thermal conductivity occurs at zone 2, which is the front wall of house model. High temperature different between external and internal wall causes this phenomenon to occur.

5.8 Average Thermal Conductivity of Insulators

Table 5.18 shows the average thermal conductivity for 7 zones in mini house model which are installed by 7 different insulators. Average thermal conductivity is obtained by using Eq. 5.2:

$$k, ave = \frac{T1 + T2}{2} \tag{5.2}$$

where; k $_{ave}$ = Average thermal conductivity of insulators (W/mK), T_1 = Lowest thermal conductivity of the zone (℃) and T_2 = Highest thermal conductivity of the zone (℃),

Table 5.18: Average thermal conductivity for each insulator.

No.	Insulator \ Zone	Thermal Conductivity, W/mK						
		2	3	4	5	6	7	8
1.	Polystyrene	55.36	55.47	250.64	94.14	91.46	738.90	180.31
2.	Fibreglass	42.80	276.74	670.33	381.09	336.80	912.50	37.38
3.	Cotton	36.88	56.94	439.67	107.95	149.27	951.63	41.98
4.	**Wool**	32.17	116.21	499.42	118.04	106.88	766.22	29.30
5.	**Sugar cane waste**	28.49	82.11	239.91	65.10	59.35	784.68	26.57
6.	**Coconut fibres**	29.57	55.74	286.31	52.59	53.06	884.13	30.03
7.	Cellulose	30.71	58.00	427.02	53.99	54.42	1353.9	21.79

Results shows that wool, sugar cane insulator and coconut fibre insulator have relatively lower thermal conductivity compare to other insulators. The lower the thermal conductivity, the largest the temperature different between outdoor temperature and indoor temperature.

CHAPTER 6

CONCLUSION AND RECOMMENDATION

Thermal insulator in buildings is an important factor to achieve thermal comfort for its occupants. By installing the insulator in a building, it will reduce the unwanted heat loss or gain and can also decrease the energy demands of heating and cooling systems. In this project, green waste materials are chosen to analysis and perform the heat transfer test. Green materials used in this study are coconut fibres, cellulose and sugar cane wastes.

The objective of this study is to analysis the behaviour and thermal insulation of the selected green materials. Follow by samples preparations of green wall insulator based on the dimensions obtained on the mini house model. The measurement is conducted by installing the green materials samples in mini house model and infrared camera is used to investigate the thermal behaviour in the mini house model which is install by different types of green wall insulator. Previous study on selected green materials are done and from the researches, these green materials have the low thermal conductivity, which have the potential to be a good wall insulation. Common advantages of these green materials are environmental friendly, low cost and also natural ability to insulate the heat conduction.

In PSM 1, dimensions of the Marcraft GT-7500 mini house model been measured before samples preparations. Different conditions is determined before the experiment carry on in order to do the comparison. Pico data logger, Marcraft GT-7500 mini house model and thermal imaging camera been studies before start the analysis. In PSM 2, measurement of the thermal behaviour of the mini house model under different parameters and green wall insulators by using thermal imaging camera is conducted. Temperature gradient in the mini house model is collected by installing Pico data logger in different areas. Heat conduction analysis is conducted based on the data obtained from thermal imaging camera and thermocouple to determine the performance of the green wall insulators. Results show that the thermal behaviour of wool, sugar cane insulator and coconut fibre insulator is relatively low compare to others insulators, where these materials insulated most of the heat from external wall conducted through internal wall. This result is proven when sugar cane fibre had insulate 12.09 ℃ compare to fibreglass which only insulated 10.09 ℃ with same external wall temperature in condition 3. Analysis of thermal conductivity for cellulose, coconut fibre and sugar cane fibre show that these green insulators can be good wall insulation.

6.1 Recommendation

Based on the results, thermal conductivity of insulators is over thousands. For the next research, thermal conductivity of these insulators are recommended to test by using heat transfer unit, where sample need to be hot extruded into a cylinder shape by using hot compressing composite granule and heat compression machine. Heat transfer of the samples can be tested by using HT10X Heat Transfer Services Unit with HT11 Linear Conduction Device. Comparison can be made between the thermal conductivity obtained from both experiments.

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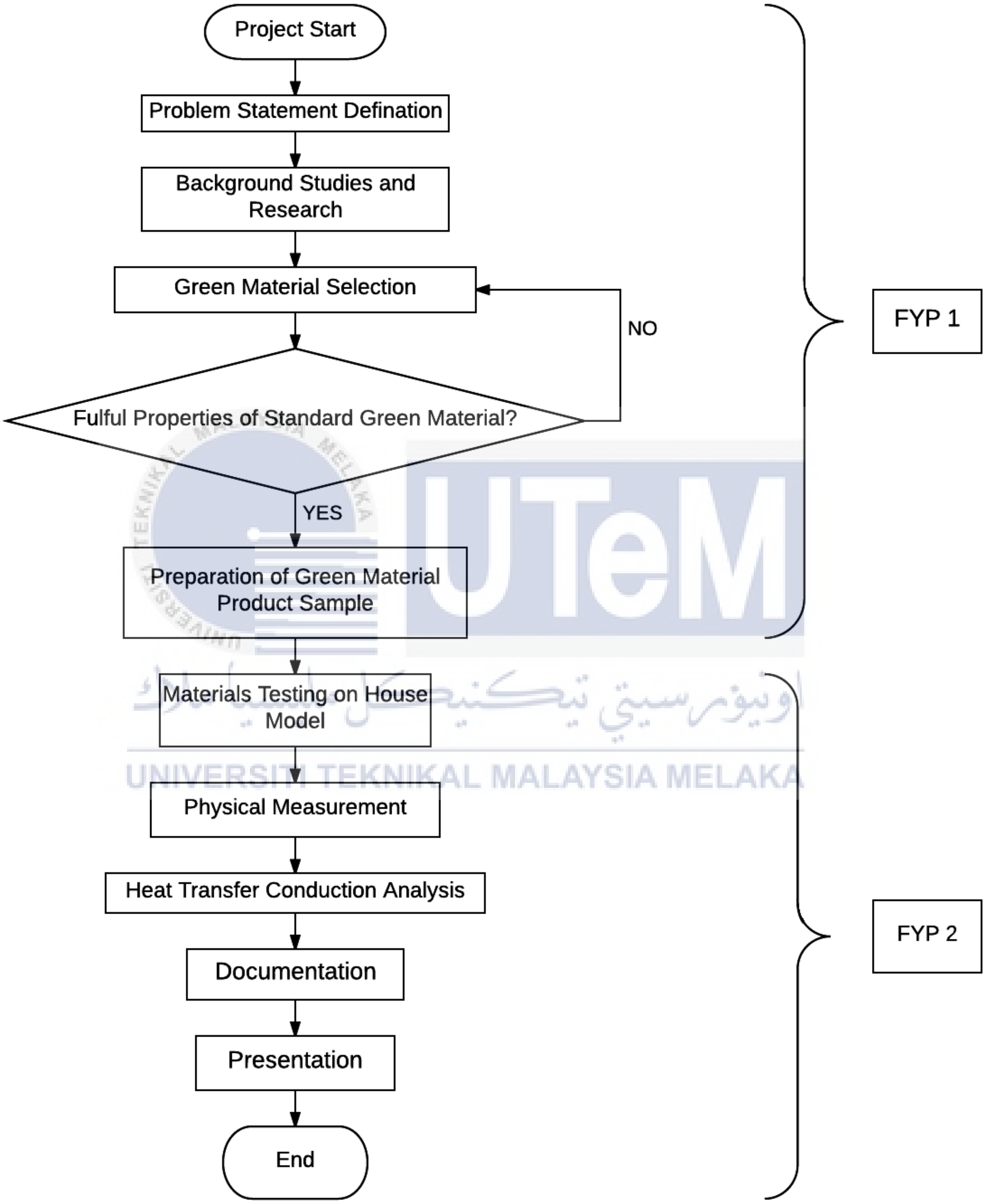
APPENDIX A

PROJECT FLOW CHART

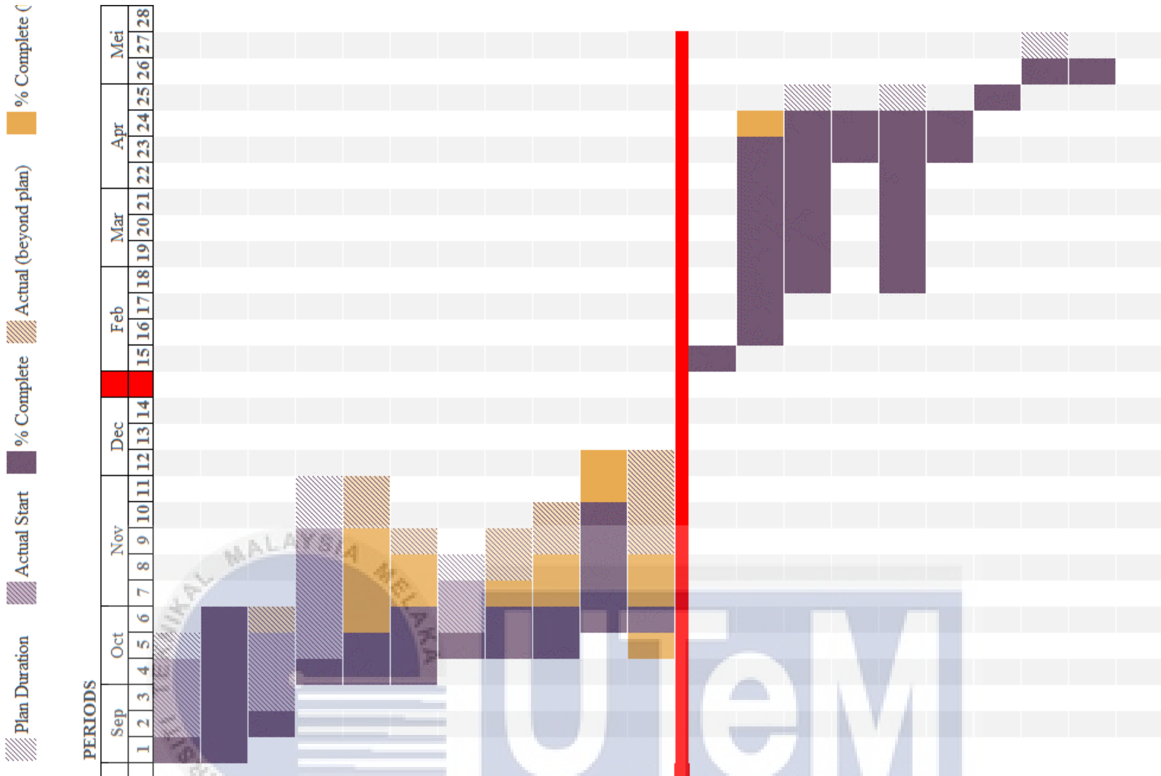


APPENDIX B

PROJECT GANTT CHART

Final Year Project

	ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
1	Project Briefing 1	1	5	1	4	25%
2	Research and Studies	1	6	1	6	100%
3	Gantt Chart preparation	2	4	2	5	35%
4	Green Material Selection	4	8	4	6	10%
5	Report Writing_Chapter 1	4	2	4	8	85%
6	Report Writing_Chapter 2	4	3	4	6	85%
7	Report Writing_Chapter 3	5	4	5	3	50%
8	Report Writing_Chapter 4	5	2	5	5	60%
9	Green Material Block Fabrication	5	2	5	6	75%
10	Presentation Slide Preparation	6	5	6	7	100%
10	FYP 1 Oral Presentation	6	1	5	8	60%
	Prject Briefing 2	15	1	15	1	100%
	Physical Measurement	16	8	16	9	100%
	Report Writing_Chapter 5	18	8	18	7	100%
	Report Writing_Chapter 6	23	2	23	2	100%
	Heat Transfer Conduction Calculation	18	8	18	7	100%
	Report Writing_Chapter 7	23	2	23	2	100%
	Report Writing and Checking	25	1	25	1	100%
	Report Correction	26	2	26	1	100%
	Presentation Slide Preparation	26	1	26	1	100%
	FYP 1 Oral Presentation	29	1	29	1	0%



APPENDIX C

Appendix C1: Sample Reading from Pico Data Logger (Interior Temperature)

Sample: Coconut fiber.

Condition 1:

Time (min)	Outdoor	Front wall	Floor	Bottom room	Top room (left)	Top room (right)	Top wall (left)	Roof
0	29.33	28.30	29.84	28.46	29.03	29.72	30.09	30.47
1	29.31	28.25	29.75	28.50	29.15	29.79	30.11	30.60
2	29.30	28.20	29.64	28.57	29.36	29.94	30.12	30.59
3	29.74	28.18	29.55	28.62	29.54	30.07	30.11	30.53
4	30.02	28.14	29.44	28.68	29.68	30.18	30.07	30.50
5	30.21	28.10	29.34	28.74	29.81	30.29	30.08	30.45
6	30.26	28.09	29.29	28.81	29.93	30.41	30.10	30.40
7	30.25	28.12	29.25	28.88	30.05	30.52	30.09	30.35
8	30.09	28.18	29.24	28.96	30.17	30.64	30.10	30.33
9	30.03	28.25	29.23	29.03	30.30	30.77	30.10	30.36
10	30.12	28.32	29.21	29.11	30.43	30.91	30.13	30.42
11	30.20	28.41	29.22	29.19	30.56	31.04	30.17	30.45
12	30.21	28.51	29.25	29.28	30.71	31.19	30.24	30.52
13	30.30	28.64	29.30	29.37	30.85	31.34	30.33	30.66
14	30.26	28.78	29.36	29.47	31.01	31.48	30.44	30.87
15	30.33	28.95	29.45	29.57	31.17	31.63	30.58	30.99
16	30.22	29.12	29.53	29.67	31.34	31.78	30.70	31.00
17	30.39	29.24	29.60	29.76	31.49	31.93	30.78	30.99
18	30.22	29.35	29.67	29.86	31.65	32.07	30.88	30.99
19	30.11	29.46	29.73	29.95	31.80	32.22	30.98	30.96
20	30.22	29.56	29.78	30.05	31.95	32.36	31.07	30.95
21	30.37	29.64	29.83	30.13	32.09	32.49	31.16	31.01
22	30.36	29.73	29.88	30.21	32.23	32.63	31.25	31.10
23	30.47	29.82	29.93	30.29	32.37	32.75	31.35	31.15
24	30.56	29.89	29.98	30.37	32.51	32.87	31.43	31.15
25	30.39	30.00	30.04	30.44	32.65	32.99	31.57	31.19
26	30.31	30.10	30.11	30.52	32.79	33.13	31.67	31.27
27	30.53	30.19	30.18	30.60	32.93	33.25	31.75	31.32
28	29.93	30.34	30.27	30.69	33.06	33.35	31.85	31.38
29	29.57	30.57	30.44	30.80	33.17	33.45	31.95	31.46

Condition 2:

Time (min)	Outdoor	Front wall	Floor	Bottom room	Top room (left)	Top room (right)	Top wall (left)	Roof
0	30.79	30.82	30.64	30.25	30.16	30.77	30.64	30.46
1	31.18	30.67	30.56	30.21	30.23	30.71	30.70	30.46
2	31.46	30.44	30.45	30.19	30.32	30.67	30.75	30.44
3	31.48	30.30	30.39	30.20	30.41	30.73	30.80	30.43
4	31.50	30.21	30.34	30.23	30.51	30.82	30.85	30.42
5	31.53	30.16	30.32	30.28	30.61	30.92	30.90	30.43
6	31.39	30.14	30.31	30.34	30.72	31.03	30.94	30.46
7	31.49	30.14	30.30	30.40	30.84	31.16	31.01	30.49
8	31.53	30.17	30.33	30.47	30.97	31.28	31.09	30.55
9	31.28	30.21	30.35	30.56	31.10	31.42	31.17	30.60
10	31.32	30.25	30.40	30.64	31.26	31.56	31.31	30.67
11	31.27	30.29	30.43	30.71	31.39	31.70	31.41	30.73
12	31.11	30.39	30.49	30.80	31.53	31.84	31.50	30.81
13	31.44	30.45	30.55	30.88	31.68	31.98	31.63	30.89
14	31.48	30.53	30.63	30.97	31.83	32.12	31.79	30.98
15	31.38	30.64	30.71	31.07	31.97	32.26	31.91	31.08
16	31.27	30.73	30.80	31.16	32.12	32.40	32.04	31.17
17	31.45	30.81	30.85	31.25	32.25	32.53	32.15	31.28
18	31.42	30.92	30.94	31.35	32.39	32.66	32.24	31.38
19	31.43	31.02	31.01	31.43	32.53	32.80	32.37	31.48
20	31.52	31.13	31.13	31.54	32.67	32.94	32.51	31.58
21	31.39	31.22	31.19	31.63	32.80	33.06	32.61	31.69
22	31.58	31.32	31.26	31.71	32.93	33.18	32.73	31.79
23	31.69	31.41	31.35	31.81	33.07	33.31	32.88	31.89
24	31.66	31.52	31.43	31.91	33.19	33.44	32.99	32.01
25	31.86	31.62	31.51	31.99	33.32	33.56	33.11	32.11
26	31.79	31.75	31.60	32.06	33.44	33.68	33.21	32.23
27	31.80	31.90	31.73	32.16	33.57	33.79	33.35	32.34
28	31.76	32.03	31.87	32.28	33.68	33.90	33.50	32.44
29	31.84	32.14	31.96	32.36	33.80	34.02	33.63	32.55

Condition 3:

Time (min)	Outdoor	Front wall	Floor	Bottom room	Top room (left)	Top room (right)	Top wall (left)	Roof
0	29.88	33.16	32.29	31.32	32.27	32.57	33.12	32.51
1	30.19	33.19	32.40	31.43	32.36	32.69	33.26	32.57
2	31.03	33.13	32.35	31.50	32.42	32.81	33.37	32.63
3	31.57	32.92	32.22	31.53	32.45	32.88	33.40	32.62
4	31.64	32.73	32.10	31.55	32.48	32.94	33.38	32.60
5	32.11	32.59	31.93	31.54	32.49	32.96	33.24	32.56
6	32.58	32.42	31.81	31.56	32.53	33.01	33.17	32.53
7	32.19	32.27	31.69	31.57	32.54	33.05	33.11	32.51
8	32.30	32.17	31.61	31.60	32.58	33.09	33.05	32.49
9	32.47	32.10	31.57	31.64	32.64	33.16	33.05	32.49
10	32.51	32.07	31.49	31.64	32.67	33.20	33.00	32.48
11	32.32	32.05	31.43	31.71	32.73	33.25	32.99	32.48
12	32.40	32.07	31.43	31.76	32.81	33.31	33.00	32.51
13	32.58	32.07	31.50	31.83	32.90	33.39	33.11	32.53
14	32.67	32.06	31.51	31.89	32.98	33.47	33.20	32.57
15	32.40	32.09	31.45	31.91	33.05	33.51	33.19	32.59
16	32.72	32.11	31.46	31.93	33.11	33.57	33.19	32.62
17	32.46	32.11	31.43	31.95	33.18	33.64	33.23	32.64
18	32.38	32.16	31.40	31.98	33.25	33.69	33.25	32.68
19	32.22	32.19	31.41	32.01	33.33	33.76	33.29	32.72
20	32.30	32.24	31.44	32.05	33.38	33.81	33.31	32.77
21	32.40	32.30	31.48	32.09	33.44	33.88	33.34	32.82
22	31.92	32.36	31.55	32.10	33.50	33.93	33.38	32.86
23	32.06	32.43	31.60	32.16	33.59	34.00	33.49	32.92
24	32.12	32.48	31.60	32.21	33.65	34.06	33.58	32.96
25	32.46	32.53	31.62	32.28	33.71	34.12	33.62	33.01
26	32.69	32.54	31.64	32.32	33.77	34.19	33.69	33.06
27	32.61	32.56	31.65	32.35	33.85	34.25	33.76	33.11
28	32.79	32.61	31.70	32.38	33.91	34.31	33.83	33.16
29	32.55	32.63	31.71	32.43	34.01	34.38	33.92	33.21

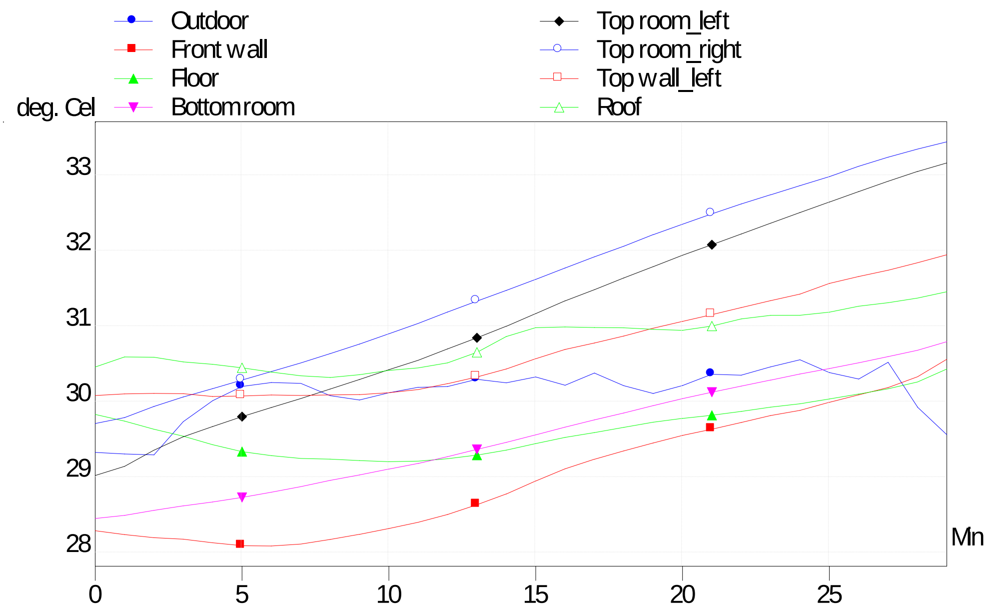


Figure 1: Graph for coconut sample condition 1.

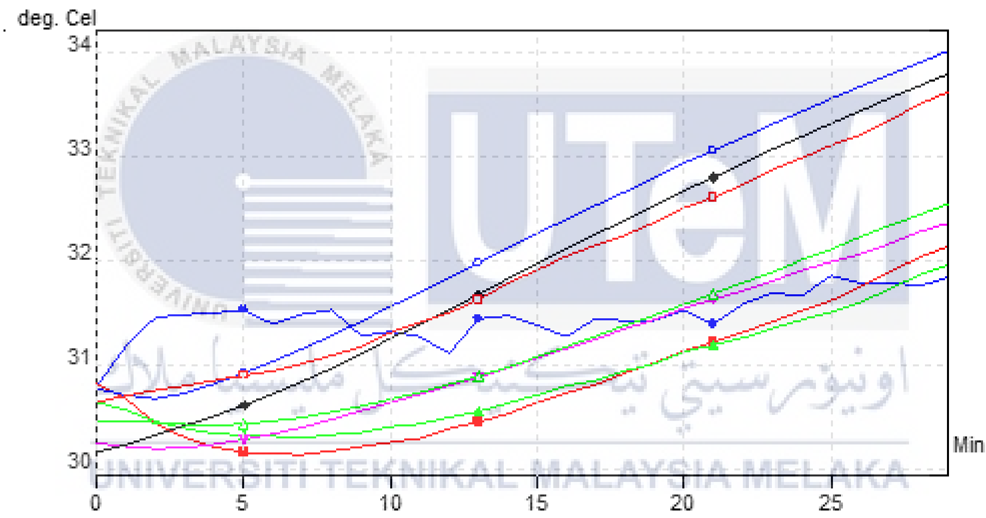


Figure 2: Graph for coconut sample condition 2.

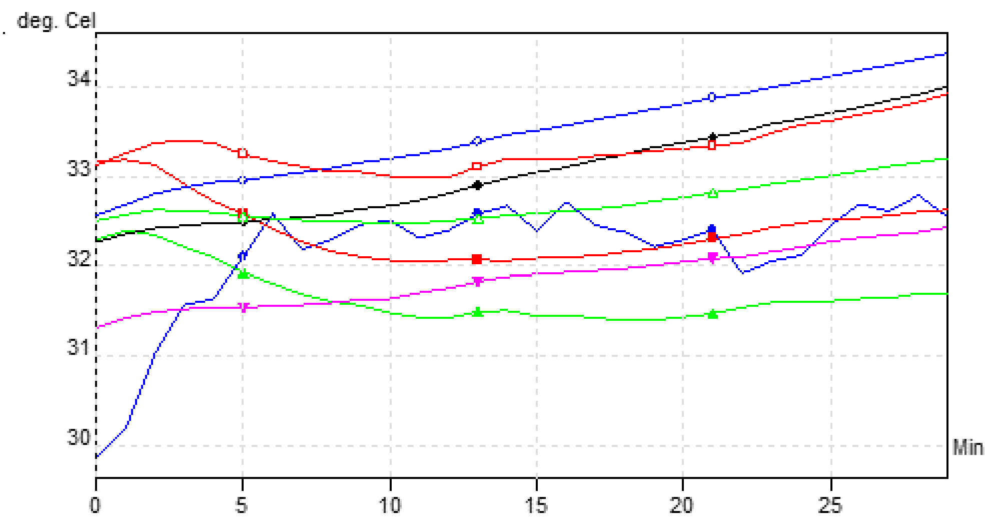
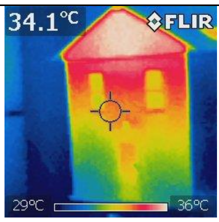
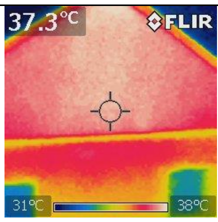
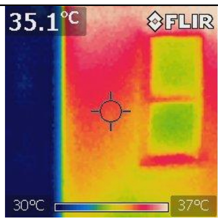
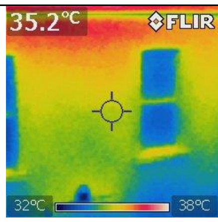
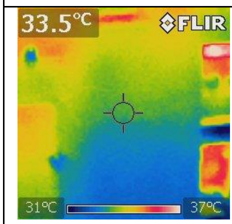
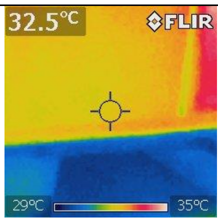
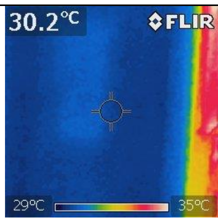
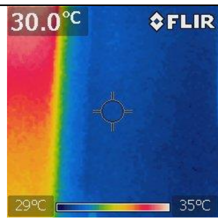
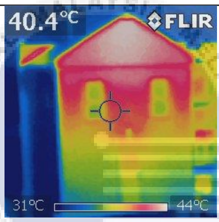
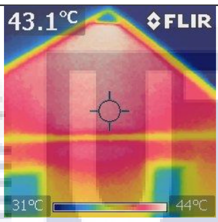
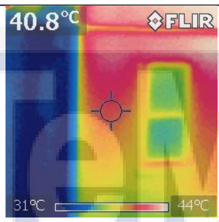
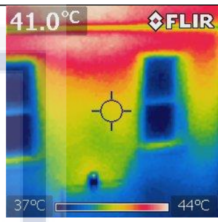
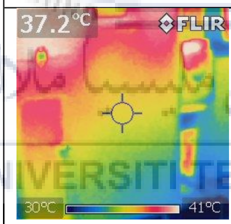
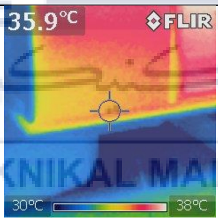
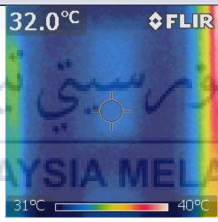
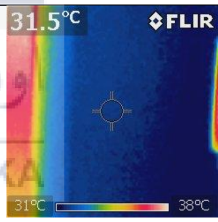
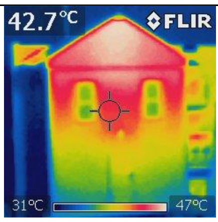
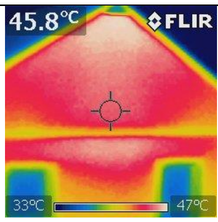
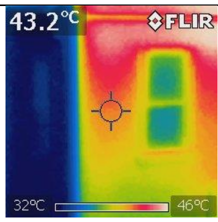
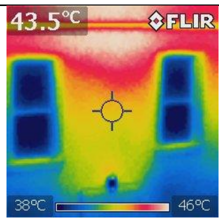
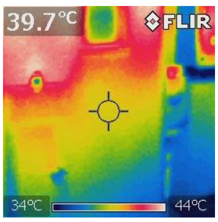
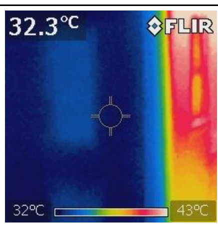
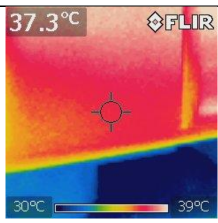
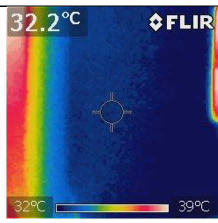


Figure 3: Graph for coconut sample condition 3.

Appendix C2: Thermal Images for Coconut Fibre Insulation.

Condition 1:

Time (second)	Thermal Image			
0				
				
9				
				
19				
				

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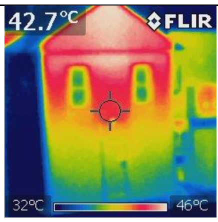
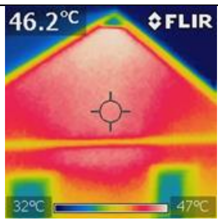
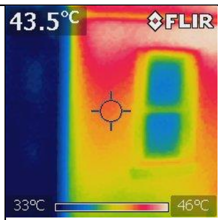
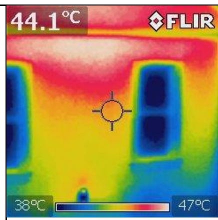
<tr><td rowspan="2">29</td><td>
</td><td>
</td><td>
</td><td>
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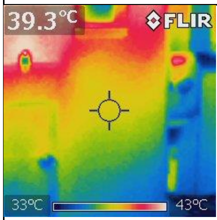
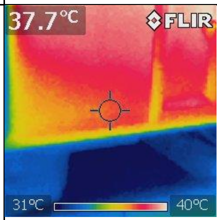
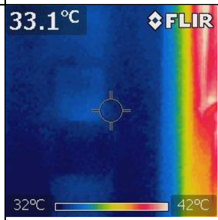
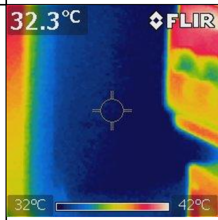
<tr><td>
</td><td>
</td><td>
</td><td>
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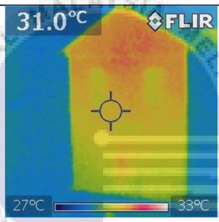
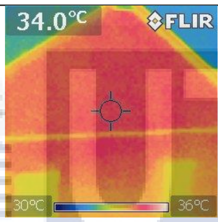
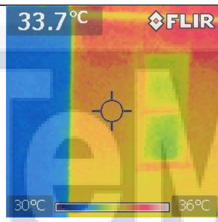
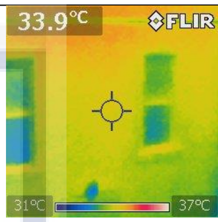
<tr><td rowspan="2">0</td><td>
</td><td>
</td><td>
</td><td>
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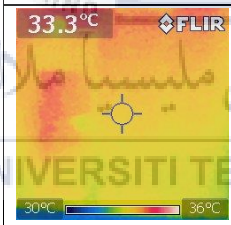
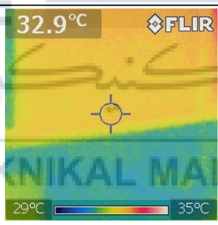
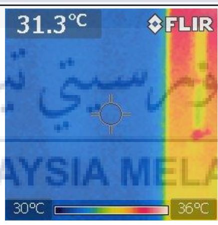
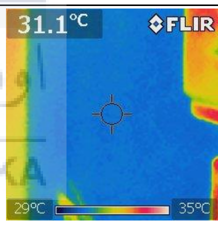
<tr><td>
</td><td>
</td><td>
</td><td>
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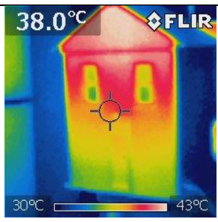
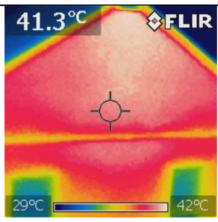
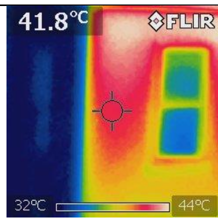
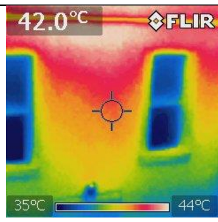
<tr><td rowspan="2">9</td><td>
</td><td>
</td><td>
</td><td>
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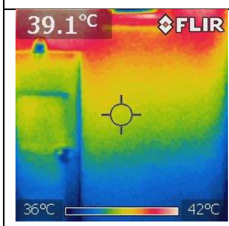
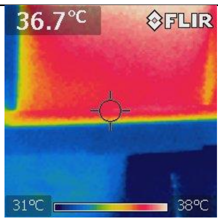
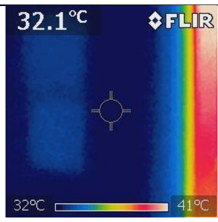
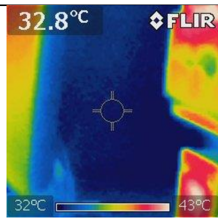
<tr><td>
</td><td>
</td><td>
</td><td>
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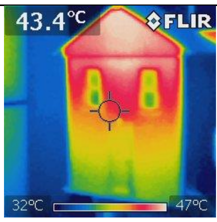
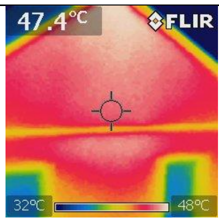
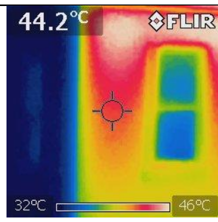
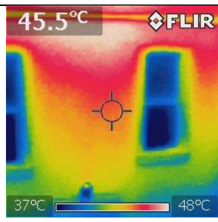
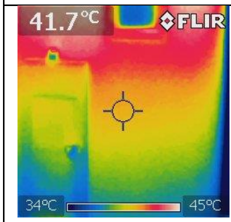
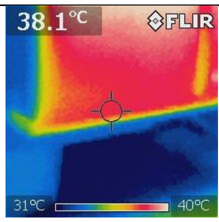
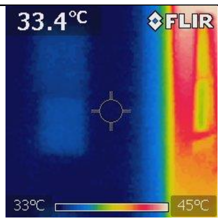
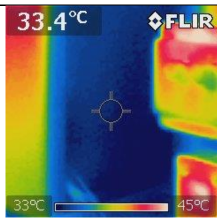
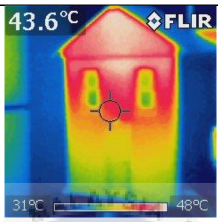
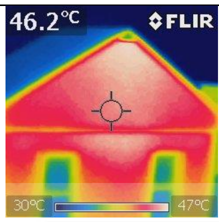
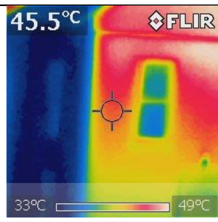
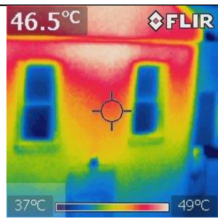
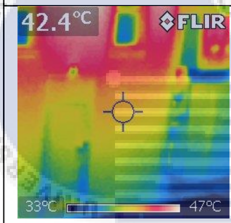
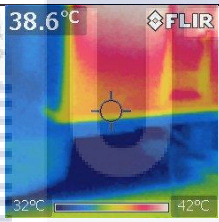
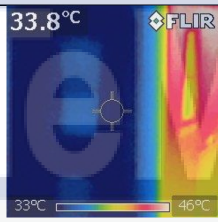
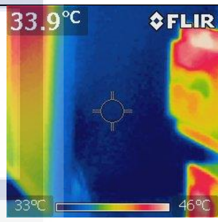
<tr><td rowspan="2">19</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">29</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
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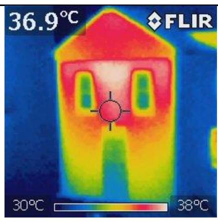
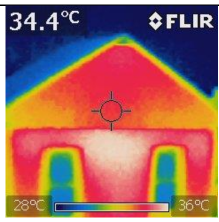
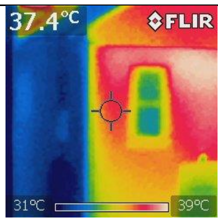
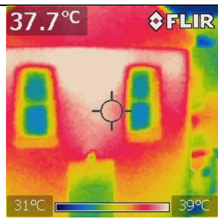
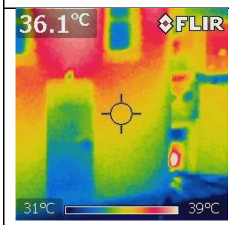
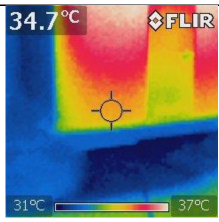
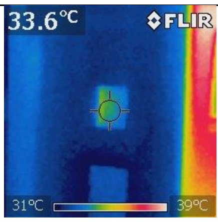
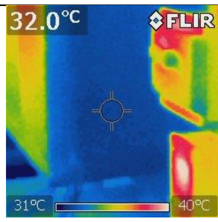
<tr><td rowspan="2">0</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
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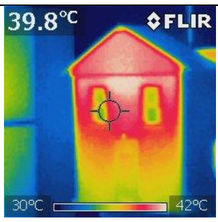
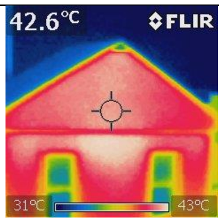
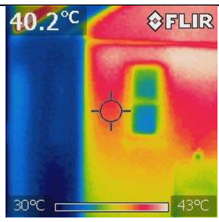
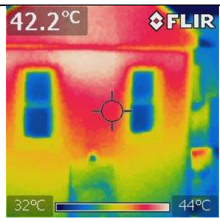
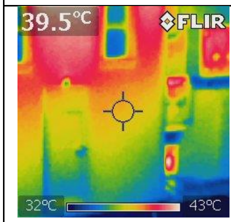
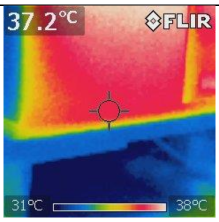
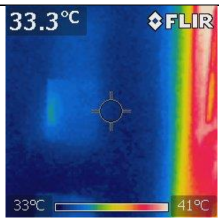
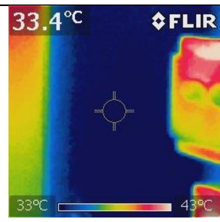
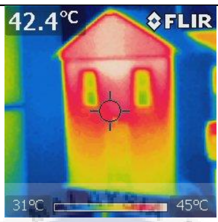
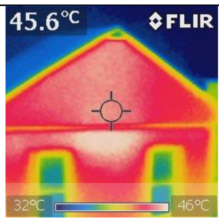
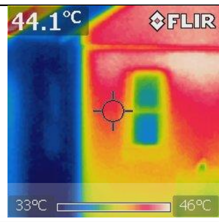
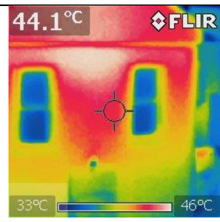
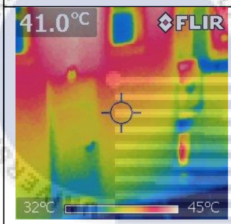
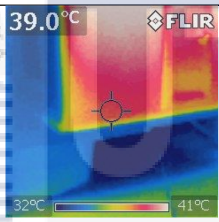
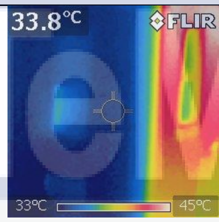
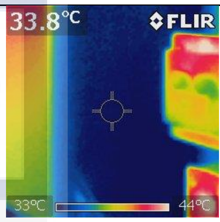
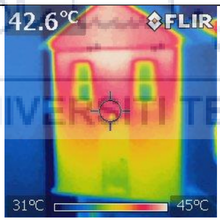
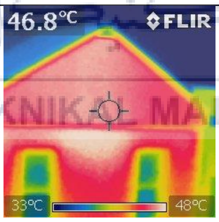
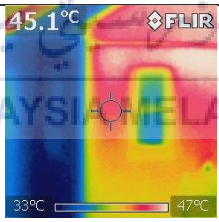
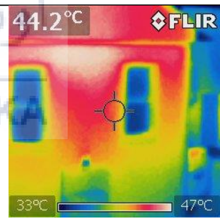
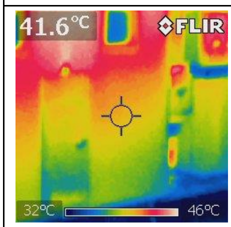
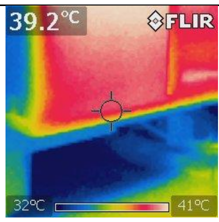
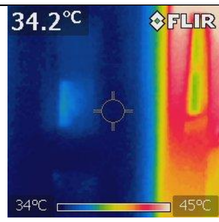
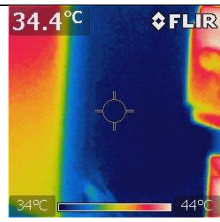
9	39.8°C FLIR 30°C 42°C	42.6°C FLIR 31°C 43°C	40.2°C FLIR 30°C 43°C	42.2°C FLIR 32°C 44°C
	39.5°C FLIR 32°C 43°C	37.2°C FLIR 31°C 38°C	33.3°C FLIR 33°C 41°C	33.4°C FLIR 33°C 43°C
19	42.4°C FLIR 31°C 45°C	45.6°C FLIR 32°C 46°C	44.1°C FLIR 33°C 46°C	44.1°C FLIR 33°C 46°C
	41.0°C FLIR 32°C 45°C	39.0°C FLIR 32°C 41°C	33.8°C FLIR 33°C 45°C	33.8°C FLIR 33°C 44°C
29	42.6°C FLIR 31°C 45°C	46.8°C FLIR 33°C 48°C	45.1°C FLIR 33°C 47°C	44.2°C FLIR 33°C 47°C
	41.6°C FLIR 32°C 46°C	39.2°C FLIR 32°C 41°C	34.2°C FLIR 34°C 45°C	34.4°C FLIR 34°C 44°C