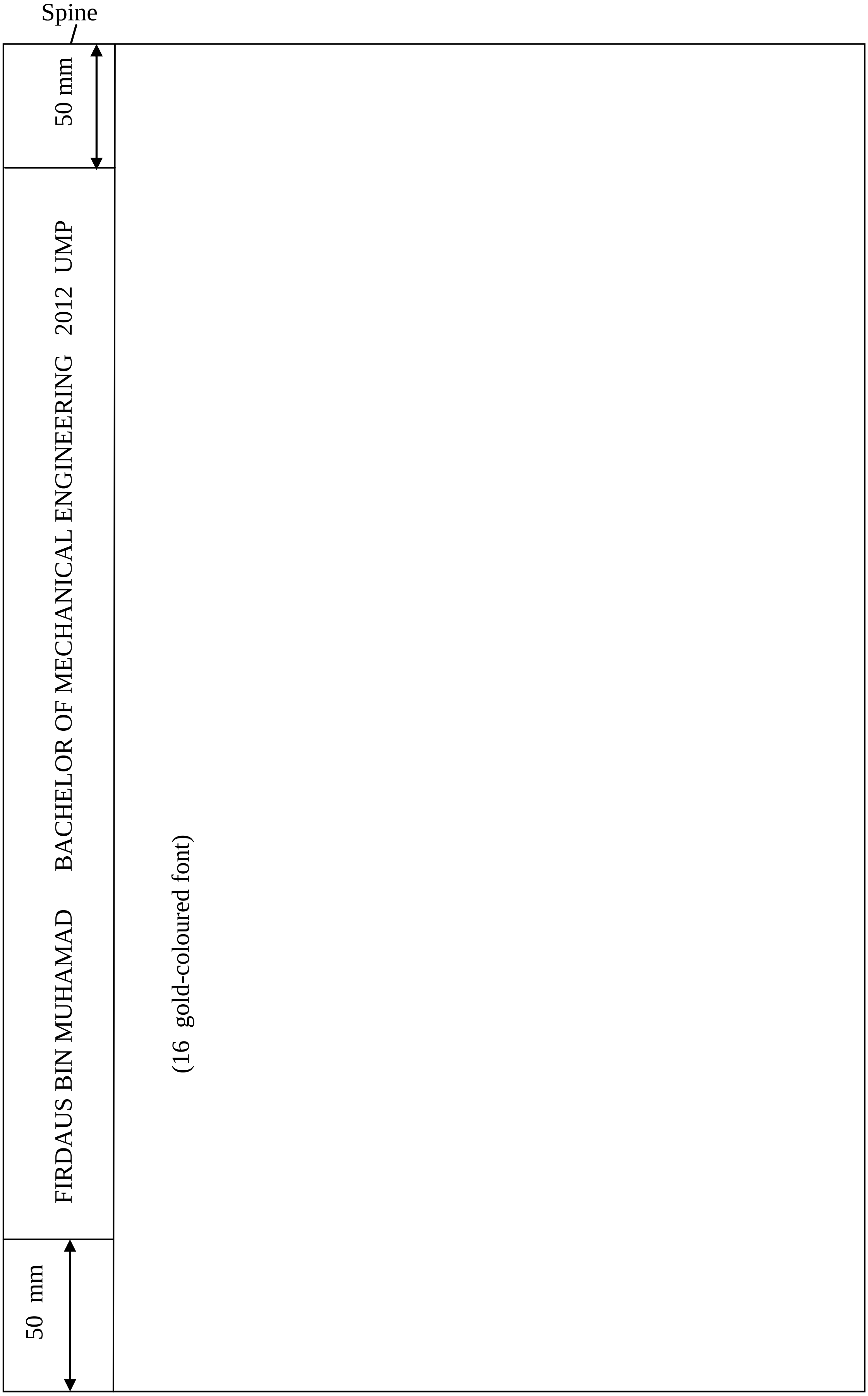
DEVELOPMENT OF SOLAR OVEN INCORPORATING THERMAL ENERGY STORAGE APPLICATION

FIRDAUS BIN MUHAMAD

UNIVERSITI MALAYSIA PAHANG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34310 BAGAN SERAI	(Nama Penyelia)
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DEVELOPMENT OF SOLAR OVEN INCORPORATING THERMAL ENERGY STORAGE APPLICATION

FIRDAUS BIN MUHAMAD

Thesis submitted in partial fulfilment of the requirements for the award of Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

JUNE 2012

UNIVERSITI MALAYSIA PAHANG

FACULTY OF MECHANICAL ENGINEERING

I certify that the project entitled "*Development of Solar Oven Incorporating Thermal Energy Storage Application*" is written by *Firdaus Bin Muhamad*. I have examined the final copy of this project and in my opinion it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. I herewith recommend that it be accepted in partial fulfilment of the requirements for the degree of Bachelor of Mechanical Engineering.

MDM. NORHAIDA BINTI ABDUL RAZAK ____________________

Examiner Signature

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project report and in my opinion this project is satisfactory in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering

Signature :
Name of Supervisor : MR. AMIR BIN ABDUL RAZAK
Position : LECTURER
Date : 22 JUNE 2012

STUDENT'S DECLARATION

I hereby declare that the work in this report is my own except for quotations and summaries which have been duly acknowledged. The report has not been accepted for any degree and is not concurrently submitted for award of other degree.

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Name : FIRDAUS BIN MUHAMAD

ID Number : MA 09015

Date : 22 JUNE 2012

Dedicated to my respected father, Mr. Muhamad Bin Bunaim, my beloved mother, Mrs. Siti Fatimah Binti Amri, my lovely fiancée Ms. Siti Sarah Binti Nijar and all my friends.

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ABSTRACT

This project is about developed and fabricated a functional solar oven incorporating with thermal storage application. This report is to study the performance and characteristic of the oven using different parameter such as aluminum panel, aluminum wall inside the oven and thermal energy storage application. The structural three dimensional solid modeling of this oven was developed using the SOLIDWORK drawing software. The data were collected from four experiments which is used difference parameter for each experiment. Steel bar is used as a product to be measured to find the efficiency of the oven. Another temperatures parameter involved was an aluminum tray which is where the steel bar was placed during the experiment, oven temperature itself and river rock that used as thermal energy storage application. The comparisons of parameter’s temperature for each experiment were discussed in chapter 4 and the result shown that the thermal energy storage application was successful increase the oven efficiency.

Key words: Solar oven; solar oven efficiency; phase change material; latent heat storage; sensible heat storage.

ABSTRAK

Projek ini bertujuan untuk membangunkan dan mereka cipta satu ketuhar menggunakan kuasa solar yang menggabungkan penggunaan aplikasi penyimpanan tenaga haba. Laporan ini adalah untuk mengkaji prestasi dan ciri ketuhar menggunakan parameter berbeza seperti panel aluminium, dinding aluminium di dalam ketuhar dan aplikasi penyimpanan tenaga haba. Model tiga dimensi struktur ketuhar ini dibangunkan menggunakan perisian lukisan SOLIDWORK. Data dikutip dari empat eksperimen yang menggunakan parameter berbeza untuk setiap eksperimen. Bar keluli digunakan sebagai satu produk yang diukur untuk mencari kecekapan ketuhar. Selain daripada bar keluli, parameter suhu lain yang terlibat adalah dulang aluminium dimana bar keluli diletakkan semasa eksperimen, suhu ketuhar sendiri dan batu sungai yang digunakan sebagai aplikasi penyimpanan tenaga haba. Perbandingan suhu parameter bagi setiap eksperimen telah dibincangkan dalam bab 4 dan hasilnya menunjukkan bahawa aplikasi penyimpanan tenaga haba telah berjaya meningkatkan kecekapan ketuhar.

Kata kunci: Ketuhar solar; kecekapan ketuhar solar; fasa perubahan material; penyimpanan haba pendam; simpan haba yang waras.

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LIST OF SYMBOLS

°C	Degree Celsius
A	Area
I	Radiation
Ti	Initial Temperature
Tf	Final Temperature
η	Efficiency
$t\Delta$	Time Different

LIST OF ABBREVIATIONS

PCM	Phase Change Material

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

This final year project title is Development of Solar Oven Incorporating Thermal Energy Storage Application. This project is intended to see the performance improvement resulted from optimization and modification to the feature and characteristic of the solar oven.

A solar oven or solar cooker is a device which uses sunlight as its energy source. They use no fuel and they cost nothing to run. Solar cookers are a form of outdoor cooking and are often used in situations where minimal fuel consumption is important, or the danger of accidental fires is high. Common solar cooker solely dependent on the sun radiation which is an inconsistent variable from the effect of changing weather and directly causing the oven cannot function at optimal performance. To overcome this problem, solar oven with the application of thermal energy storage will be produced and hope it is could maintain the heat distribution in the oven even in sudden decrease of solar radiation.

1.2 PROBLEM STATEMENT

Solar oven generally solely depending on the sun radiation which is not consistent variable from the effect of changing weather and this situation will directly cause the oven cannot be a function at optimal efficiency. Cooking with the sun has become a potentially viable substitute for fuel-wood in food preparation in much of the developing world. Solar cooking is one possible solution but its acceptance has been limited partially due to some barriers. Solar cooker cannot cook the food under low radiation condition. That drawback can be solved by the storage unit associated with in a solar cooker. So that food can be cooked at low radiation condition. Therefore, in this paper, an attempt has been taken to summarize the investigation of the solar cooking system incorporating with thermal energy storage.

1.3 PROJECT OBJECTIVES

The first objective of this project is to design and fabricate a functional solar oven. This solar oven will be fabricated using wood as a main body. The container part from aluminum inside the solar oven will act as rack to hold the food container and energy storage application.

The second objective is to integrate thermal energy storage into the design to store energy and for longer and better heat distribution in the oven. This application will prevent oven from losing heat during the drop of solar radiation due to changing weather condition.

The last objective of this project is to study the characteristics and performance of the system. After the fabrication process done, the solar oven will be tested and go through analysis to determine the performance such as cooking rate and temperature rate.

1.4 PROJECT SCOPE

In this project, the fabrication and analysis was held in the Mechanical Laboratory and the area of the UMP. The scopes of the study are as follows:

Design a solar oven that incorporates thermal energy storage. The design is made by doing some modification of the available design in the market. The design also needs to meet specific specification such as the solar oven unit can be rotated vertically to optimize heat radiation through into the oven.

Review on type of thermal energy storage available and feasibility to be used in the solar oven. There are two types of thermal energy storage in consideration between latent heat storage like phase change material or sensible heat storage such as stone.

Fabrication the solar oven system using selected material. Fabrication will be held in the Mechanical Laboratory. All the material is provided by Material Store and some material need to be buying separately in the market.

Conduct a performance analysis of the solar oven to determine the efficiency, maximum heat temperature and cooking rate. It is important to determine these performances in order to achieve the objective of this project and overcome the problem statement.

CHAPTER 2

LITERATURE REVIEW

2.1 SOLAR OVEN

Solar cookers, as their name indicates, are devices that use solar energy to raise the temperature of food to cook it. These solar devices are based on the simple principles of reflection, concentration, glazing, absorption and the greenhouse effect to store energy in order to increase the temperature. Various types of solar cookers exist, harnessing one or more of these principles (Jaramillo et al., 2007). The vast majorities of the solar cookers presently in use are relatively cheap and used low technology devices. Solar cooker cost nothing to operate and use no fuel, and because of that many nonprofits organizations are promoting their use worldwide to help reduce fuel costs for low income people, reduce air pollution and slow deforestation and desertification that caused by the use of firewood for cooking.

Solar cooking radically decreases the world's dependence on fuel wood and dung as the primary cooking fuels while benefiting the environment, raising the standard of living, and improving the health of the poor worldwide. Energy consumption for cooking in developing countries is a major component of the total energy consumption, including commercial and non-commercial energy sources (Sharma, Chen, Murty, & Shukla, 2009). The exploding population throughout the developing world has hastened the ever increasing need for firewood, severely enhancing the degradation of land and creating massive deforestation which often leads to desertification. Solar cooking is the innovative methodologies which harness the power of free sunlight to decrease a family's use of fuel wood and charcoal by up to 70%, while improving their quality of life.

2.1.1 Advantages of solar cookers

Solar cookers use no fuel, which means that their users do not need to fetch or pay for firewood, gas, electricity, or other fuels. Solar cooker use solar energy which is free, environmentally clean, and therefore is recognized as one of the most promising alternative energy recourses options (Sharma, Chen, et al., 2009). Generally cooking required temperature around 90-100ºC and solar ovens can easily attain these temperature.

Solar cookers do not produce any smoke as a product of combustion. The indoor concentration of health-damaging pollutants from a typical wood-fired cooking stove creates carbon monoxide and other noxious fumes at anywhere between seven and 500 times over the allowable limits.

The simple hot box model can be and has been used to cook, bake, and roast practically all types of meals. Besides cooking, the solar oven can do a variety of jobs such as dry agricultural products, heat and pasteurize water, make tea and coffee, and heat irons for ironing clothes (Nandwani, 1996).

Unlike cooking over an open fire, children cannot be burned by touching many types of solar cookers, which are made from cardboard or plastic and do not get hot. Unlike all fuel based cooking arrangements, these solar cookers are not fire hazards. It is also free of pollution and indirectly reduces emission of pollutants such as SO2, fly ash, smoke, and the main greenhouse gas, CO2 (Nandwani, 1996).

Another advantages is the cost to made this oven for a family size oven (0.25 m^2) with reasonable durability and efficiency which used outer box made from wood, two window panes, may cost around RM 100-150 for materials cost, and it can be made at home using only hand tools (Nandwani, 1996).

2.1.2 Disadvantages of solar cookers

Solar cookers are less usable in cloudy weather and at high latitudes (Nandwani, 1996), so some fuel-based backup heat source must still be available in these conditions. Also, solar cooking provides hot food during or shortly after the hottest part of the day, rather than the evening when most people like to eat. The "integrated solar cooking" concept accepts these limitations, and includes a fuel efficient stove and an insulated heat storage container to provide a complete solution.

Many solar cookers take longer time to cook food than a fuel based oven. Using these solar cookers therefore requires that food preparation be started several hours before the meal. However, it requires less hands-on time cooking, so this is often considered a reasonable trade-off (Nandwani, 1996).

Some solar cooker designs are affected by strong winds, which can slow the cooking process, cool the food, and disturb the reflector. In these cases it is necessary to anchor the reflector with string and weights. Irregular availability of solar radiation also makes the solar cooker at disadvantages. Solar energy is intermittent by its nature; there is no sun at night. Its total available value is seasonal and is dependent on the meteorological conditions of the location (Sharma, Chen, et al., 2009).

Another problem is traditional cooking and eating habits (Nandwani, 1996). Cooks may need to learn special cooking techniques to fry common foods, such as fried eggs or flatbreads like chapattis and tortillas. It may not be possible to safely or completely cook some thick foods, such as large roasts, loaves of bread, or pots of soup, particularly in small panel cookers; the cook may need to divide these into smaller portions before cooking.

2.2 TYPE OF SOLAR COOKER

Solar cookers have been classified into four main categories which are concentrator type cookers, solar ovens, box type cookers and indirect solar cookers. Even these four main categories have been further subdivided into different categories which shown in Figure 2.1. A lot of developments and modifications have been made of various types of solar cookers but characteristically modifications have been made to box type cookers due to its straightforwardness and users responsive.

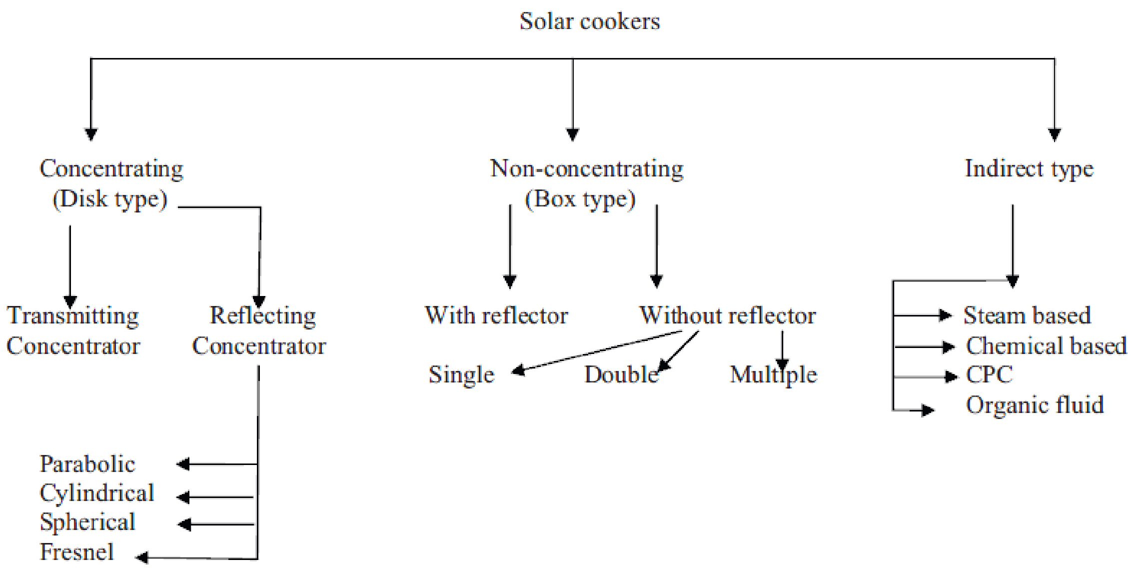


Figure 2.1: Type of solar cooker

(Saxena, Pandey, & Srivastav, 2011)

2.2.1 Parabolic cookers

A parabolic cooker can get even hotter, up to 204°C, which is hot enough to fry food or bake bread. This slightly more complicated design uses curved, reflective surfaces to focus lots of sunlight into a small area. They concentrate solar beam radiation on a cooking pot. In order to keep a good performance, a solar tracking system is required (Jaramillo et al., 2007). It works a lot like a stove, and it is big, sometimes up to several feet across. Like other types of solar cookers, there are many different designs of parabolic solar cookers. It can also use different materials like aluminum foil, Mylar and small mirror tiles as a reflector. A pot of food sits on an arm that holds it in the center of the curved reflectors, suspended slightly above the bottom point of the oven, where all the light is concentrated. This small point gets so hot and the molecules vibrate so much that the heat waves move upward in a steady stream to strike the bottom of the pot. Parabolic solar cookers can boil water much quicker than solar box cookers because of the intense concentrated light rays focused into a small area. This is also known as 'spot heat'.

Figure 2.2: Parabolic type cookers

2.2.2 Box cookers

Solar box cookers or known as solar ovens. They are insulated boxes with six or more faces, a glass cover at the top and usually include one or more adjustable reflective surfaces designed to increase the density of the solar energy collected. This category exploits both direct and diffuse solar radiation. In most cases, they require a minor intervention by the user in order to obtain a good exposure to solar energy (Jaramillo et al., 2007). Cooking containers and the inside bottom of the cooker should be dark-colour or black. Inside walls should be reflective to reduce radiate heat loss and bounce the light towards the pots and the dark bottom, which is in contact with the pots. The box should have insulated sides. Thermal insulation for the solar box cooker must be able to withstand temperatures up to 150°C without melting or out-gassing. Crumpled newspaper, wool, rags, dry grass, sheets of cardboard, etc. can be used to insulate the walls of the cooker. The solar box cooker typically reaches a temperature of 150°C. This temperature is not hot as a standard oven, but still hot enough to cook food over a somewhat longer period of time. The cooker can be used to warm food and drinks and can also be used to pasteurize water or milk.

Figure 2.3: Box type solar cookers

2.2.3 Panel cookers

Panel solar cookers are very inexpensive solar cookers that use reflective panels to direct sunlight to a cooking pot that is enclosed in a clear plastic bag. This type of solar cooker is popular because it is easy to make and can produce fairly good results. It is often produced locally by pasting a reflective material, such as aluminum foil, onto a cut and folded backing, usually corrugated cardboard. It is lightweight and folds for storage. This type of solar cookers can be homemade by using umbrella that wrapping by aluminum foil inside the umbrella and also can used car windshield reflector as a panel cooker. A solar panel cooker generally does not reach the kind of temperatures that a box oven does. This type of solar cooker is considered as a low to moderate temperature solar cooker, easily reaching temperatures high enough to pasteurize water or cook grains such as rice. On a sunny day, it can collect enough solar energy to cook rice, meat or vegetables to feed a family with up to three or four children. Typically, panel cooker will cook between 90°C and 150°C.

Figure 2.4: Panel type solar cookers

2.3 PRINCIPLE OF SOLAR BOX COOKING DESIGN

The basic purpose of a solar box cooker is to heat things up, cook food, purify water, and sterilize water and milk. A solar box cooks because the interior of the box is heated by the energy of the sun. Sunlight, both direct and reflected, enters the solar box through the glass or plastic top. It turns to heat energy when it is absorbed by the dark absorber plate and cooking pots. This heat input causes the temperature inside of the solar box cooker to rise until the heat loss of the cooker is equal to the solar heat gain. At this point, temperatures sufficient for cooking food and pasteurizing water are easily achieved. There are three heating principles that need to be considered in design the solar over which is:

2.3.1 Heat gain

(i) **Greenhouse effect:** This effect results in the heating of enclosed spaces into which the sun shines through a transparent material such as glass or plastic. Visible light easily passes through the glass and is absorbed and reflected by materials within the enclosed space. The light energy that is absorbed by dark pots and the dark absorber plate underneath the pots is converted into longer wavelength heat energy and radiates from the interior materials. Most of this radiant energy, because it is of a longer wavelength, cannot pass back out through the glass and is therefore trapped within the enclosed space. The reflected light is either absorbed by other materials within the space or, because it doesn't change wavelength, passes back out through the glass. Critical to solar cooker performance, the heat that is collected by the dark metal absorber plate and pots is conducted through those materials to heat and cook the food.

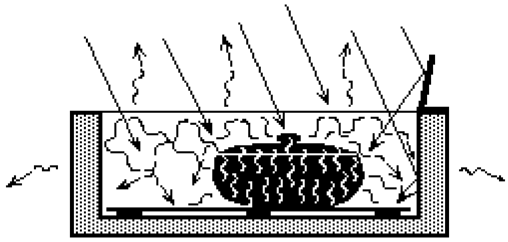


Figure 2.5: Greenhouse effect

(ii) **Glass orientation:** The more directly the glass faces the sun, the greater the solar heat gain. Although the glass is the same size on box 1 and box 2, more sun shines through the glass on box 2 because it faces the sun more directly. Note that box 2 also has more wall area through which to lose heat.

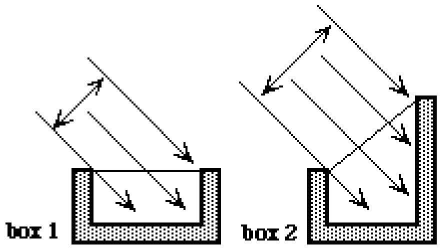


Figure 2.6: Glass orientation

(iii) **Reflectors:** Single or multiple reflectors bounce additional sunlight through the glass and into the solar box. This additional input of solar energy results in higher cooker temperatures.

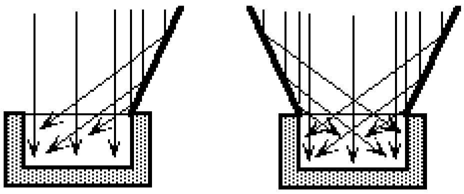


Figure 2.7: Reflector

2.3.2 Heat loss

The Second Law of Thermodynamics states that heat always travels from hot to cold. Heat within a solar box cooker is lost in three fundamental ways:

(i) **Conduction:** The handle of a metal pan on a stove or fire becomes hot through the transfer of heat from the fire through the materials of the pan, to the materials of the handle. In the same way, heat within a solar box is lost when it travels through the molecules of tin foil, glass, cardboard, air, and insulation, to the air outside of the box.

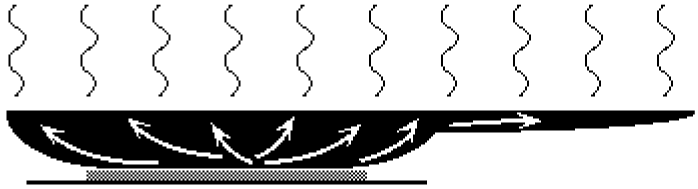


Figure 2.8: Heat conducted through the pan to the handle

The solar heated absorber plate conducts heat to the bottoms of the pots. To prevent loss of this heat via conduction through the bottom of the cooker, the absorber plate is raised from the bottom using small insulating spacers as in Figure 2.8.

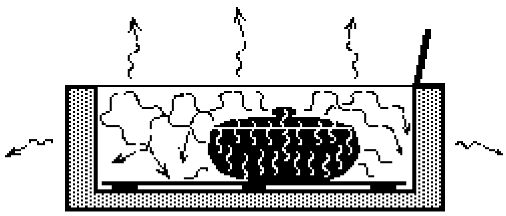


Figure 2.9: Heat radiates from warm cookware

(ii) **Radiation:** Things that are warm or hot like fires, stoves, or pots and food within a solar box cooker, give off heat waves, or radiate heat to their surroundings. These heat waves are radiated from warm objects through air or space. Most of the radiant heat given off by the warm pots within a solar box is reflected from the foil and glass back to the pots and bottom tray. Although the transparent glazing does trap most of the radiant heat, some does escape directly through the glazing. Glass traps radiant heat better than most plastics.

(iii) **Convection:** Molecules of air move in and out of the box through cracks. Heated air molecules within a solar box escape, primarily through the cracks around the top lid, a side "oven door" opening, or construction that imperfections. Cooler air from outside the box also enters through these openings. To prevent this problem, all opening section must be sealed properly.

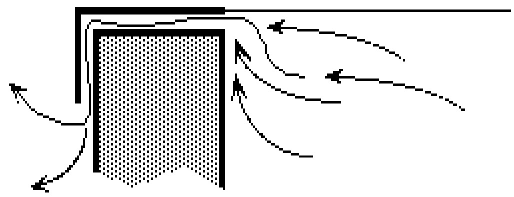


Figure 2.10: Heated air may escape through crack

2.3.3 Heat storage

As the density and weight of the materials within the insulated shell of a solar box cooker increase, the capacity of the box to hold heat increases. The interior of a box including heavy materials such as rocks, bricks, heavy pans, water, or heavy foods will take longer to heat up because of this additional heat storage capacity. The incoming energy is stored as heat in these heavy materials, slowing down the heating of the air in the box. These dense materials, charged with heat, will radiate that heat within the box, keeping it warm for a longer period at the day's end.

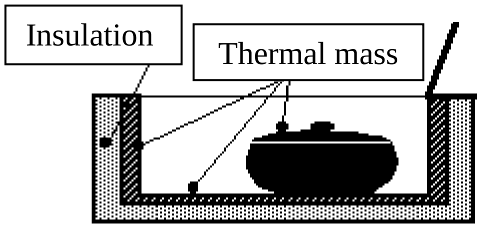


Figure 2.11: Thermal mass inside of the solar box cookers

Source: Mark Aalfs, Solar Cookers International (2011)

2.4 THERMAL ENERGY STORAGE

Heat storage systems rely on the materials within them to store thermal energy. These materials can be classified as sensible heat storage materials or phase-change materials (PCM). Thermal energy storage can be stored as a change in internal energy of a material as sensible heat, latent heat and thermochemical or combination of these. An overview of major technique of storage of solar thermal energy is shown in Figure 2.12 below.

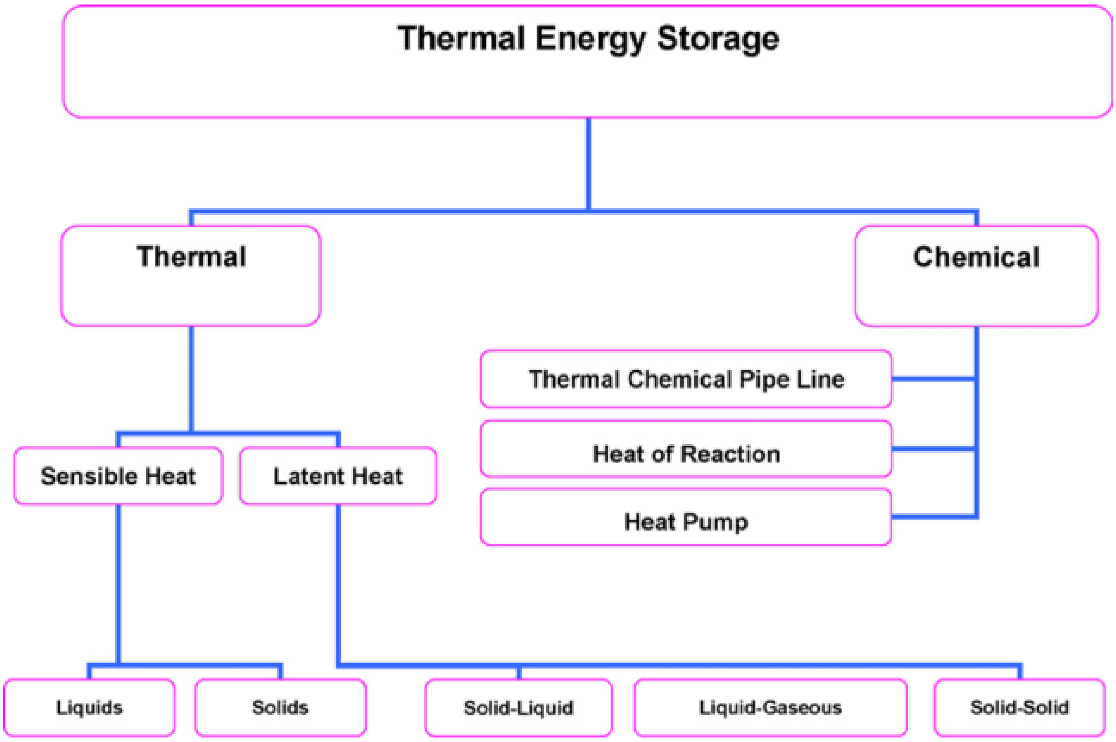


Figure 2.12: Different types of thermal storage of solar energy

(Sharma, Tyagi, Chen, & Buddhi, 2009)

Figure shown above is the type of thermal storage of solar energy. For this project it will only review on sensible and latent heat storage for thermal energy storage in solar oven application.

2.4.1 Latent Heat Storage (Phase change material)

Phase change materials (PCM) are latent heat storage materials. The thermal energy transfer occurs when a material changes from solid to liquid, or liquid to solid. This is called a change in state, these solid–liquid PCMs perform like conventional storage materials, and their temperature rises as they absorb heat. Unlike conventional (sensible) storage materials, PCM absorbs and release heat at a nearly constant temperature. They store 5–14 times more heat per unit volume than sensible storage materials such as water, masonry, or rock. A large number of PCMs are known to melt with a heat of fusion in any required range. However, for their employment as latent heat storage materials these materials must exhibit certain desirable thermodynamic, kinetic and chemical properties. Moreover, economic considerations and easy availability of these materials has to be kept in mind. Figure 2.13 below show the type of PCM.

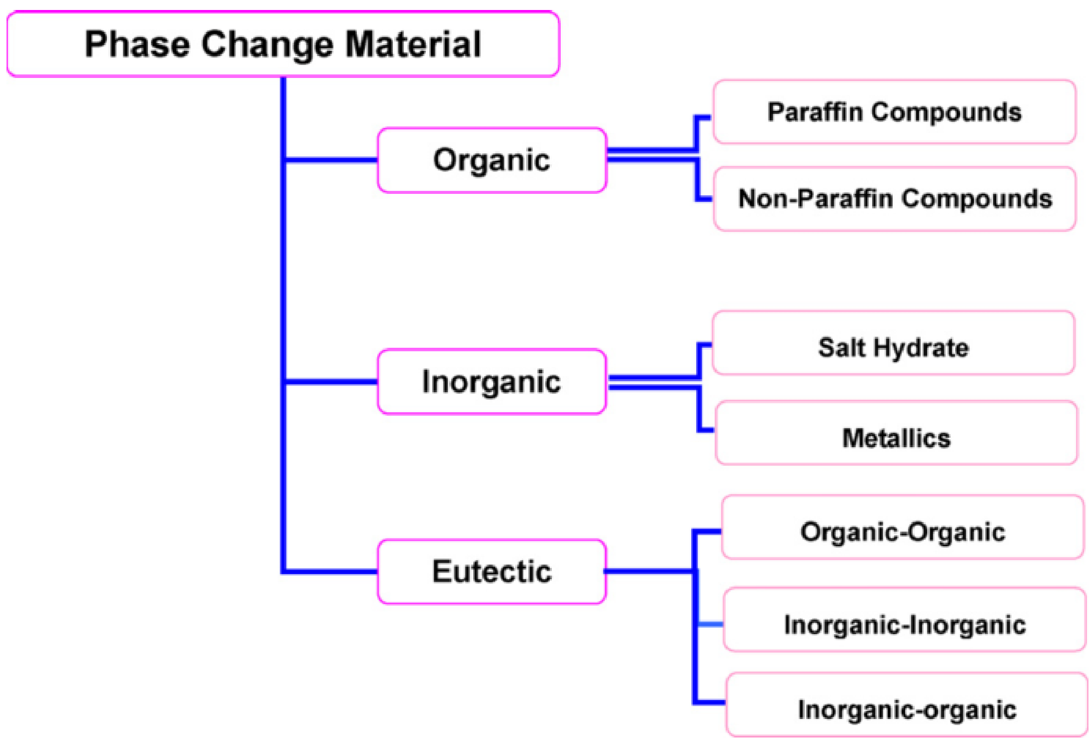


Figure 2.13: Type of PCMs

(Sharma, Tyagi, et al., 2009).

A large number of solid–liquid PCMs have been investigated for heating and cooling applications The PCM to be used in the design of any thermal storage systems should pass desirable thermo physical, kinetics and chemical properties which are given in Table 2.1. The ideal phase change material to be used for latent heat storage system must meet the following requirements: high sensitive heat capacity and heat of fusion; stable composition; high density and heat conductivity; chemical inert; non-toxic and non-inflammable; reasonable and inexpensive.

In the nature, the salt hydrates, paraffin and paraffin waxes, fatty acids and some other compounds have a high latent heat of fusion in the temperature range from 0 ºC to 150 ºC that is interesting for solar applications. Recently, the incorporation of PCM in different applications has grown interest to the researcher. The PCM review article are available for any one application except solar cookers. Therefore, in this paper, an attempt has been taken to summarize the investigation of the solar cooking system incorporating with PCMs. This paper is a compilation of much of practical information on few selected PCMs used in a box-type solar cooker and concentrator solar cooker. This review will help to find the design, development of suitable PCM storage unit for solar cookers.

Table 2.1: Two type of PCMs

Source: Kenisarin, M; Mahkamov, K (2007

Organic phase change material	**Inorganic phase change material**
Paraffin (CnH2n+2) and fatty acids (CH3 (CH2)2nCOOH).	Salt hydrates (M_nH_2O)
Advantages	
Freeze without much supercooling. Ability to melt congruently. Self nucleating properties. Compatibility with conventional material of construction. No segregation. Chemically stable. High heat of fusion. Safe and non-reactive. Recyclable.	High volumetric latent heat storage capacity. Availability and low cost. Sharp melting point. High thermal conductivity. High heat fusion. Non flammable.
Disadvantages	
Low thermal conductivity in their solid state. High heat transfer rates are required during the freezing cycle. Volumetric latent heat storage capacity is low. Flammable, this can be easily alleviated by a proper container. To obtain reliable phase change points, most manufacturers use technical grade paraffins which are essentially paraffin mixture(s) and are completely refined of oil, resulting in high costs.	Change of volume is very high. Super cooling is major problem in solid–liquid transition. Nucleating agents are needed and they often become inoperative after repeated cycling.

Table 2.2: Main desirable properties of phase change materials

(Abhat. A 1983)

Thermal properties	Suitable phase-transition temperature High latent heat of transition Good heat transfer
Physical properties	Favorable phase equilibrium High density Small volume change Low vapor pressure
Kinetic properties	No super cooling Sufficient crystallization rate
Chemical properties	Long-term chemical stability Compatibility with materials of construction
Economics	Abundant Available Cost effective

Recently, Chen (Sharma, Tyagi, et al., 2009) investigated theoretically on the PCMs used as the heat storage media for box-type solar cookers. The selected PCMs are magnesium nitrate hex hydrate, stearic acid, acetamide, acetanilide and erythritol; refer to Table 2.3. For a two dimensional simulation model based on the enthalpy approach, calculations have been made for the melt fraction with conduction only. Different material such as glass, stainless steel, tin, and aluminum mixed, aluminum and copper are used as the heat exchanger container materials in the numerical calculations. It is also found that the initial temperature of PCM does not have very important effects on the melting time, while the boundary wall temperature play an important role during the melting and has a strong effect on the melt fraction.

Table 2.3: Thermo physical of selected PCMs

(Sharma, Tyagi, et al., 2009)

Properties		Steric acid	Acetamide	Acetanilide	Erythritol
Melting temperature (ºC)		55.1	82	118.9	118
Latent heat fusion (kJ/kg)		198	283	222	339.8
Density (kg/m³)	**Solid**	965	1159	1210	1400
	Liquid	848	998	1020	1300
Specific heat (kJ/kg.ºC)	**Solid**	1.6	1.94	2	1.38
	Liquid	2.2	1.94	2	2,76
Price (RM/kg)		56	520	NA	NA

The results also show that the effect of the thickness of container material on the melt fraction is insignificant. The results obtained in this paper show that acetamide and stearic acid, should be used as storage media in a box type solar cooker to cook and, or to keep food warm in the late evening with different heat exchanger container materials. The large value of thermal conductivity of heat exchanger container material did not make a significant contribution on the melt fraction except for at very low thermal conductivities.

2.4.2 Sensible heat storage

Sensible heat storage is a heat storage system that uses a heat storage medium, and where the additional or removal of heat results in a change in temperature. The term is used in contrast to a latent heat, which is the amount of energy exchanged that is hidden, meaning it cannot be observed as a change of temperature. For example, during a phase change such as the melting of ice, the temperature of the system containing the ice and the liquid is constant until all ice has melted. Typical materials in a sensible heat storage device include rock, sand, wood, and water.

Table 2.4: A list of selected solid–liquid materials for sensible heat storage

(Sharma, Tyagi, et al., 2009)

Medium	Fluid type	Temperature range (°C)	Density (kg/m³)	Specific heat (J/kg.K)
Rock		20	2560	879
Brick		20	1600	840
Concrete		20	1900-2300	880
Water		0-100	1000	4190
Caloriea HT43	Oil	12-260	867	2200
Engine oil	Oil	Up to 160	888	1880
Ethanol	Organic liquid	Up to 78	790	2400
Proponal	Organic liquid	Up to 97	800	2500
Butanol	Organic liquid	Up to 118	809	2400
Isotunaol	Organic liquid	Up to 100	808	3000
Isopentamol	Organic liquid	Up to 148	831	2200
Octane	Organic liquid	Up to 126	704	2400

Every material stores energy within it as it is heated. This can be quantified by the heat capacity C, the temperature change ΔT (final temperature - initial temperature), and the amount of additional heat stored ΔQ, such that ΔQ = CΔT. The units for Q, C, and T are joules (J), J K-1, and K, respectively. Clearly, other factors being equal, the higher the heat capacity (C) of a material, the greater will be the energy stored (ΔQ) for a given temperature rise (ΔT).

2.5 GLAZING MATERIALS

Glazing materials include glass, acrylics, fiberglass, and other materials. Although different glazing materials have very specific applications and the use of glass has proven the most diverse. The single pane is the simplest of glass types and has a high solar transmission. Double pane glass is just two panes manufactured into one unit. The spacer creates a dead air space between the panes. This air space increases the resistance to heat transfer. In fact, a large air space can actually encourage convective heat transfer within the unit and produce a heat loss. A rule of thumb for air space is between 1cm and 2 cm (Saxena et al., 2011). Below is several types of glazing material and Table 2.5 show the properties of glazing material.

2.5.1 Regular Transparent Glass

This is the most common type of glazing used for glazed building openings. The thickness of a sheet of glass usually ranges between 3 mm and 5 mm. This type of glazing permits high proportion of visible light penetration (88-90%) as well as penetration of a large proportion of the solar radiation striking it (77-86%). These properties make it the preferred material for south facing windows and greenhouses. It is important to remember that the thermal resistance coefficient of glass is very low ($R=0.18$ W/ºC.m²), which makes the glazing a thermally weak point in the structure's envelope.

2.5.2 Double Glazing

This consists of two sheets of glass with space in between, sometimes filled with air or other gases, or vacuum. The thickness of both the glass and space are variable. These variations have a certain effect, up to a certain limit, on the percentage of radiation allowed to penetrate and on the thermal conductance of the composition (when the thickness of the air space is over 2.5 cm, its marginal effect becomes smaller). The main advantage of this type of cross-section is its ability to reduce heat transfer from one pane to the other, both by conduction and by radiation. Double glazing is more expensive than single glazing but sometimes offers improved performance. Triple glazing (sometimes used) is even more expensive and has a conductance coefficient that is about 20% lower than that of double glazing, but the savings in energy are relatively small compared to its higher cost.

2.5.3 Absorbing Glass

This type of glazing permits penetration of light (about 80%, depending on thickness), but transmits only a relatively small portion of total solar radiation at the different wavelengths striking it (48-65%). The various industrial products belonging to this group are usually made of two layers of glass with a layer of absorbing material between them or of glass coated with one of the various varnishes. These additions absorb different wavelengths of radiation (from ultraviolet to infrared) and their effectiveness varies. Absorbing glass significantly prevents fading of colors, moderates light penetration into the room and reduces overall radiation. However, absorbing the radiation in the glass will raise its temperature, and its heat will be transferred by convection to the air of the building's interior.

Table 2.5: Properties of glazing material

(Comfortable Low Energy Architecture, 2011)

		Glass thickness (mm)	Light penetration (%)	Real solar radiation (%)
Glass	Single, transparent	3	90	86
		5	88	77
	Double, transparent	3	82	71
		5	78	60
	Absorbent	3	84	65
		5	76	48
	Dark	3	62	63
		5	42	44
	Reflective/ Mirror	-	8-34	11-37
Polycarbonate	Single	3	86	89
		5	82	86
	Double	-	73-80	21-60
Corrugated Fiberglass	Absolutely transparent		93	82
	Transducers		87	81
	White		32-66	21-60
Acrylic sheets	Transparent		83	83
	White		20-70	19-67

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter will explain about the project flow diagram, designing process, material selection and fabrication process. It is important to follow the project flow diagram in order to make sure the project goes smoothly. It is also determined the troubleshot the problem during the project running.

3.2 PROJECT FLOW DIAGRAM

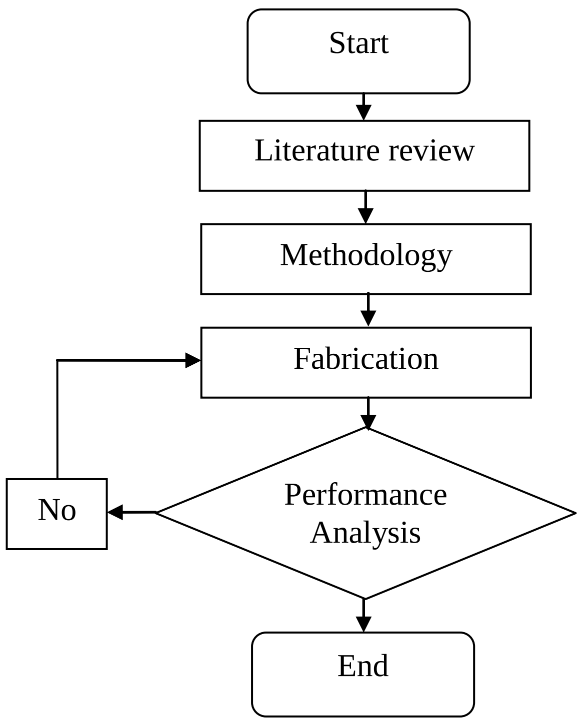


Figure 3.1: Flow chart of methodology

3.3 PROJECT FLOW DETAIL

From the project flow diagram above, the project starts with gathering the information on related of journal, magazines, books, and internet to get a literature review and research about solar oven. In this part, it focuses more on gathering data, function and characteristic of the solar oven and thermal energy storage system. This literature review will guide to decide the right decision before the design and fabrication go on.

After gathering all the relevant information, the project undergoes project methodology. This part consists of the design process, material selection and fabrication process. Design considerations have been made after several designs sketched and one design has been chosen. The selected design sketched then will transfer to solid modelling using the Solidwork program. The design measurement discussed with supervisor before proceed to the fabrication process.

After the best design have been chosen, the next process is gathering information about process to making the solar oven. For the material selection, discussion and analysis have been done to choose the suitable and available material that will be used in the fabrication process. All joining and procedure needs to be detailed in order to make the fabrication process easy and running smooth. This process must choose a proper work piece. It has a various work piece and material to set up the fabrication process such as a sheet of aluminum, plywood, shear machine, glove, arc welding machine, fastening screw set, and a few more equipment. This is important to make sure the fabrication process will go smooth and follow the schedule.

After doing in the gathering process information, the next part is fabrication process. The fabrication process has been used to make the solar oven. The plywood will be used as a main material to produce the main body. To join this plywood, only screw and contact adhesive needs to use as a fastener. During the experiment, if a problem occurs such as unsuccessful joining, the process step back to previous process. After that, the product will be analysis and testing to define the function is good to work.

In the analysis process, the performance of the solar oven will be tested using a thermometer. During the testing, if the product failed to work properly, so it is must go back to redesign or fabrication process again. If the product works properly and meet the project objective, the product is done.

After all the process mentioned above is done. All the material for report writing is gathered. The report writing process will be guided by the Universiti Malaysia Pahang final year project report writing guideline.

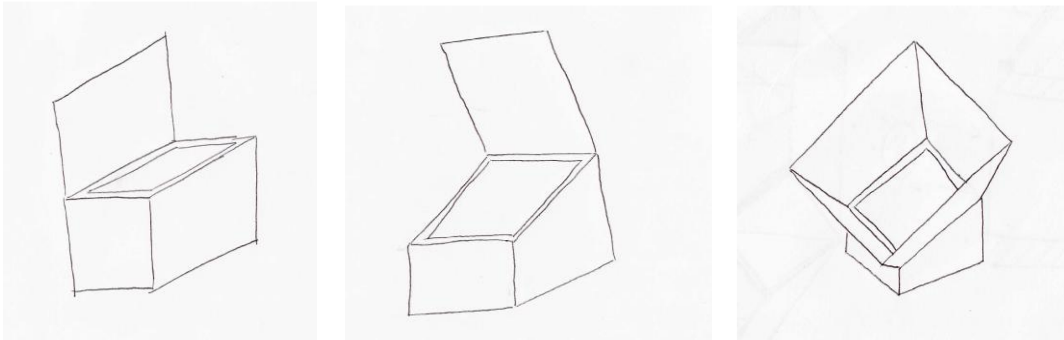
3.4 DESIGNING PROCESS

The design of the Solar Oven must be compliance with several aspects. The design consideration must be done carefully so the design can be fabricated and the parts are all functioning. The aspects that must be considered in designing are:

(i) Strength: Must have certain strengths to ensure that it can load heavy items.
(ii) Ergonomic factors: Product must be user friendly as easy and convenient.
(iii) Glass orientation: The more directly the glass faces the sun, the greater the solar heat gain.
(iv) Reflector: Multiple reflectors to gain more solar radiation incident.
(v) Heat storage: Additional heat storage application.

3.4.1 Sketching Idea

The idea of designing the solar oven is initially to sketch to get the earlier description. From the existing ideas, only three sketching that had been chosen to be considered as the final ideas, which are:



(a) (b) (c)

Figure 3.2: (a) Idea A, (b) Idea B, (c) Idea C

3.4.1.1 Idea A

This idea shown above is the solar oven with a square box type with horizontal glass orientation. This idea is generally used as a homemade solar box cooker. It is because this design can be made by using card box. The design used only one panel to reflect sunlight to the bottom of the box, this design is not too effective because it cannot absorb the optimum heat incident. It is also because of the horizontal glass orientation that not perpendicular to the sunlight in the early of the morning but only gets optimum in the middle of the day.

3.4.1.2 Idea B

This is the design where the glass orientation faces more sunlight in the morning and the middle of the day. The one panel application also gives an advantage in reflecting more solar incident into the box. This type solar cooker is suitable for commercial application. But this design cannot give optimum performance because there are several modifications can be made such as using four panel reflectors.

3.4.1.3 Idea C

This design used four panels to reflect the sunlight into the box. It is also used glass orientation that faces more in the sunlight to gain more heat. This design was chosen as main design in this project, but there are several modifications have been made to make this design more effective and good in performance.

3.4.2 Idea selection

After a design has been selected, the next step in to do dimensioning. The design is separated into part by part and the dimensioning process is firstly sketched on paper. The dimensioning is based on relevant dimensions and also referring to the existence solar oven.

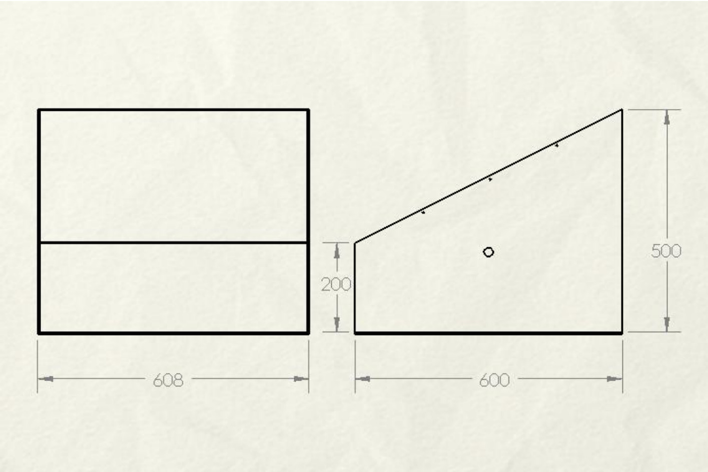


Figure 3.5: Dimension of main body

After dimensioning, the design is drawn using *Solidworks* application, at this stage solid modelling method is used. Part by part solid modelling created according to the dimension done before, after all part created, the 3D model is assembled with each other based on the design. It is important to review model in *Solidworks* in order to determine the problem in joining and fastening before the fabrication process go on.

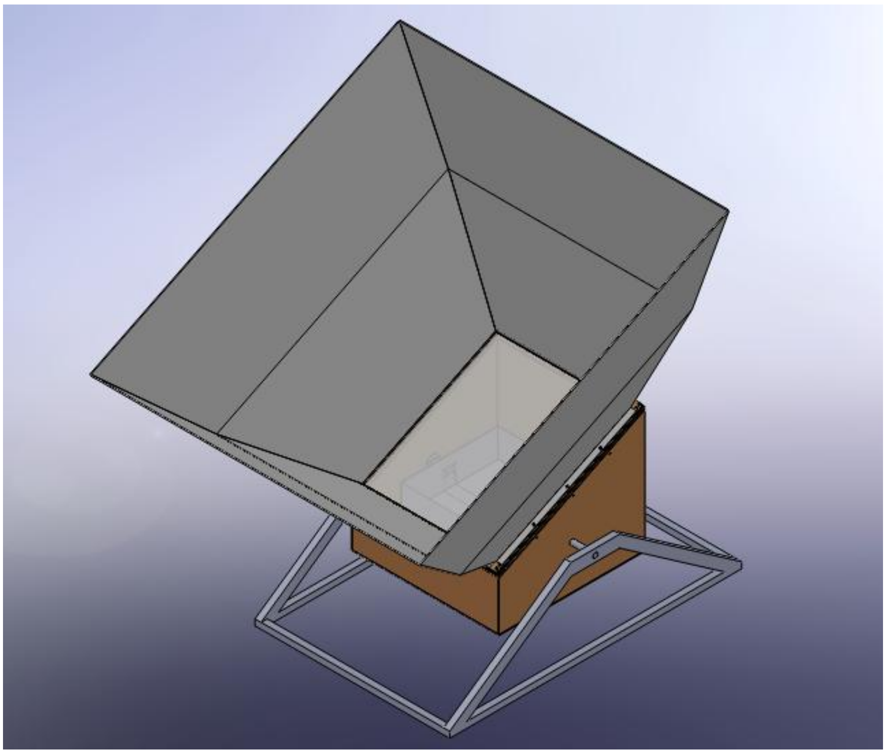


Figure 3.6: Design in Solidwork

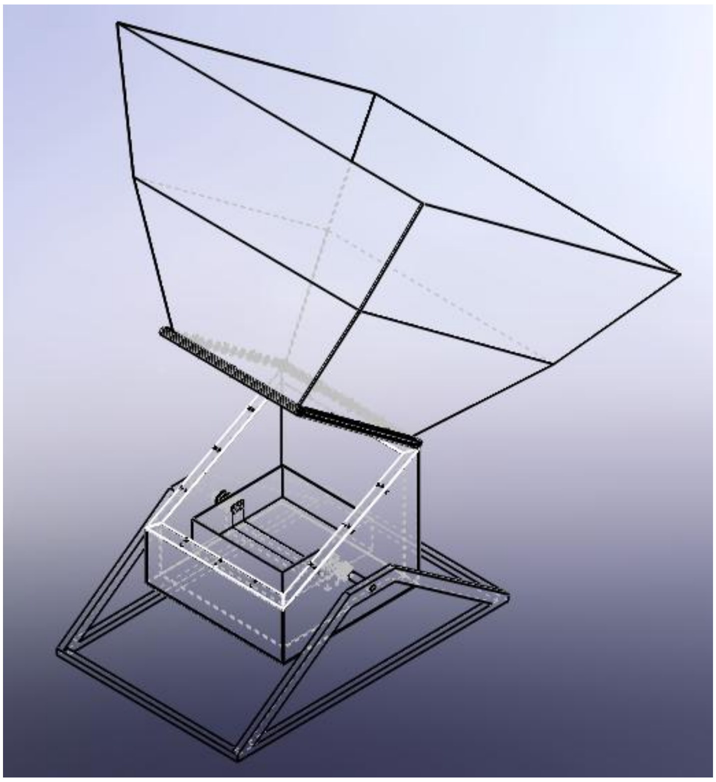


Figure 3.7: Design in wire frame view

3.4.3 Material selection

After a design has been selected, material selection need be done. Several discussions have been made with supervisor before making a decision what material will be used during fabricates the solar oven. This design consists of four main parts which is main body, container, reflector and a holder. The main body of this solar oven used plywood as main material. There are 2 bodies actually which is an inner and outer body where separately 3 cm in order to make space for air. This trapped air will be used as an insulated medium for the wall of the main body.

To cover up the top of this solar oven, double glasses have been used. The reason of using double glazing is because it will trap air between the glasses. So this glass separated by an air filled space to reduce heat transfer across a part of the solar oven body. In other word this glazing system function as insulated glass and seal top cover from escaping heat to the outside.

Container part is made using aluminum and it locates in the main body. The purpose of the container is to place food and thermal energy storage application. There are separate column between food and thermal energy storage. The relevance of using aluminum in making container is because aluminum properties that is good in thermal conductivity. Aluminum also can be used as thermal energy storage.

For the reflector, an aluminum was chosen because of the light weight and easy to cut and shape. Aluminum sheet also has a good heat reflector from the sun direct to the oven. This reflector will bounce additional heat to the oven.

This design for the first sketch do not have holder and just put on the ground to run it. But to make it more in performance, this application was installed to make this solar oven can be moved vertically so it can perpendicular face to the sun. The principle of making solar oven state that more glass facing perpendicular to sunlight will gain more solar incident into the solar oven. It only used steel hollow bar as a main part.

3.4.4 Thermal energy storage application

There are two types of energy storage which is a sensible heat storage and latent heat storage. The difference between these two is the capability of storing heat within the material. Latent heat storage which is known as the phase change material has more capability to store energy compare to sensible heat storage materials. Typical materials in a sensible heat storage device include rock, sand, wood, and water.

It is known that latent heat storage is greater than the sensible heat storage in store heat. A phase change can lead to a much larger quantity of energy stored, compared with sensible storage alone. Although phase change materials can be used to provide more energy storage, they have their limitations. The most critical limitation is that, in order to be most useful, they must have their phase transition in the temperature range at which the system will operate. Glauber salts are commonly used as phase change materials. They are inorganic salt hydrates that undergo melting phase transitions that absorb heat. While these materials are highly efficient at storing heat, their maximum storage capacity, again, is over a limited range (transition temperature from 30 to 48°C). But for this project it is needed transition temperature between 100ºC to 150ºC in order to achieve maximum performance. In addition, there are problems associated with phase separation on melting, and there is a need for super cooling in order to recover all the stored heat. While these materials are inexpensive, their corrosive nature can lead to high storage container costs. However, the energy storage capacity of Glauber salts and related materials is high, and they are used in commercial products.

Paraffin waxes are also used as phase-change materials. When a paraffin wax melts, it absorbs heat and stores energy. However, there are drawbacks associated with using paraffin waxes as heat storage materials such as oxidation, volatility, flammability, and the large volume change on melting (about 20% increase). Once again, containment costs can be high. It is also not suitable when place together with food in a food container. Paraffin has been often microencapsulated in commercial phase-change materials applications (Sharma, Tyagi, et al., 2009).

Other reasonable and suitable phase change material to be used in this project is acetamide and stearic acid that should be used as storage media in a box type solar cooker to cook and, or to keep food warm in the late evening with different heat exchanger container materials. Acetamide has transition temperature at 82ºC and good in storage heat, but the problem is high cost where for 1 kilogram acetamide it cost RM 520. The second chosen is stearic acid which has transition temperature at 55ºC and price around RM 56 per kilogram, it is good for warming water but not too good for oven application where need high temperature to operate.

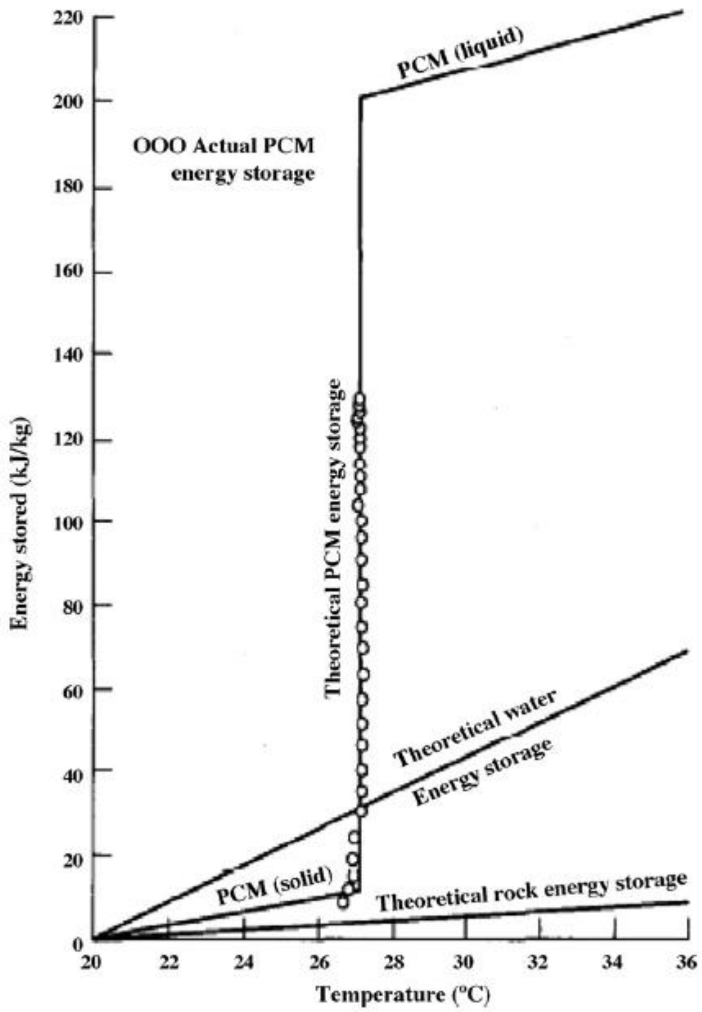


Figure 3.8: Sensible and Latent heat storage diagram

(Sharma, Tyagi, et al., 2009)

From the figure above, it is shown that differentiation between latent heat storage (PCMs) and sensible heat storage (water and rock). PCMs have a constant temperature to store heat energy in it, but for the sensible heat store it is contrasted from PCMs where there is no transition temperature to absorb large energy.

So for this project, it has been decided to use sensible heat storage which is rock as a thermal energy storage application. The type of rock has been chosen is river stone which much known in stove application. This stone has a high melting point and it can store a large heat within it as it is heated. It is known that this stone can store heat but since it is under sensible heat store type, it cannot supply heat to long when the temperature in the solar oven drop in case of sun blocked by cloud and so on. But it is enough since the oven face the sun and environment temperature will give an advantage to slowing down the temperature. So the used on this stone is reasonable and suitable because it is not too long in Malaysia to have blocked the sun with a cloud in sunny day.

3.4.5 Glazing material

Mullick (Sharma, Tyagi, et al., 2009) has considered a double glazed box cooker and a double glazing with suitable thickness and gap in between were found better than a single thick glazing. It is because the transparent cover (glazing) is used to reduce convection losses from the food container through the restraint of the stagnant air layer between the food container and the glass. It also reduces radiation losses from the collector as the glass is transparent to the short wave radiation received from the sun but it is nearly opaque to long-wave thermal radiation emitted by the food container.

3.5 EXPERIMENTAL SETUP

There are four experiments in this project to be done in order to determine the efficiency of the oven. To achieve the objective of this project, the solar radiation needs to be constant which is 1000W/m². This value is same with actual mean solar radiation in Malaysia during the day hour. To make the radiation value in constant, four set spotlight will be used as a source of heat instead of using solar itself. So experiment can be done inside the H-VAC lab and radiation will be constant. Each experiment was carried out for 3 hour heating and 30 minutes cooling. 30 minutes cooling data is to determine the functionality of thermal storage application.

Figure 3.9: Experiment setup

3.5.1 Experiment 1 (Oven only)

This is the first experiment thus was conduct for this project and it was the basic which is only used oven only to measure the temperature data. There are three parameters to be measured which is oven temperature, aluminum tray temperature and steel bar temperature. All temperature parameter is measured using thermocouples. Steel bar is used as a product to be measured and to find the energy efficiency of this oven. The spotlight radiation for this experiment were set to 1000W/m² and measure using Radiometer.

Figure 3.10: Experiment 1 setup

3.5.2 Experiment 2 (Oven with aluminum panel)

This experiment is shown as Figure 3.11 below using the oven and additional aluminum panel to measure the temperature parameter. The used of the aluminum panel is to increase the heat incident directly to the oven and also increase the oven temperature. The parameter need to be measured is same as experiment 1 which is oven temperature, aluminum tray temperature, and steel bar temperature. The spotlight radiation for this experiment were set to 1000W/m² and measure using Radiometer.

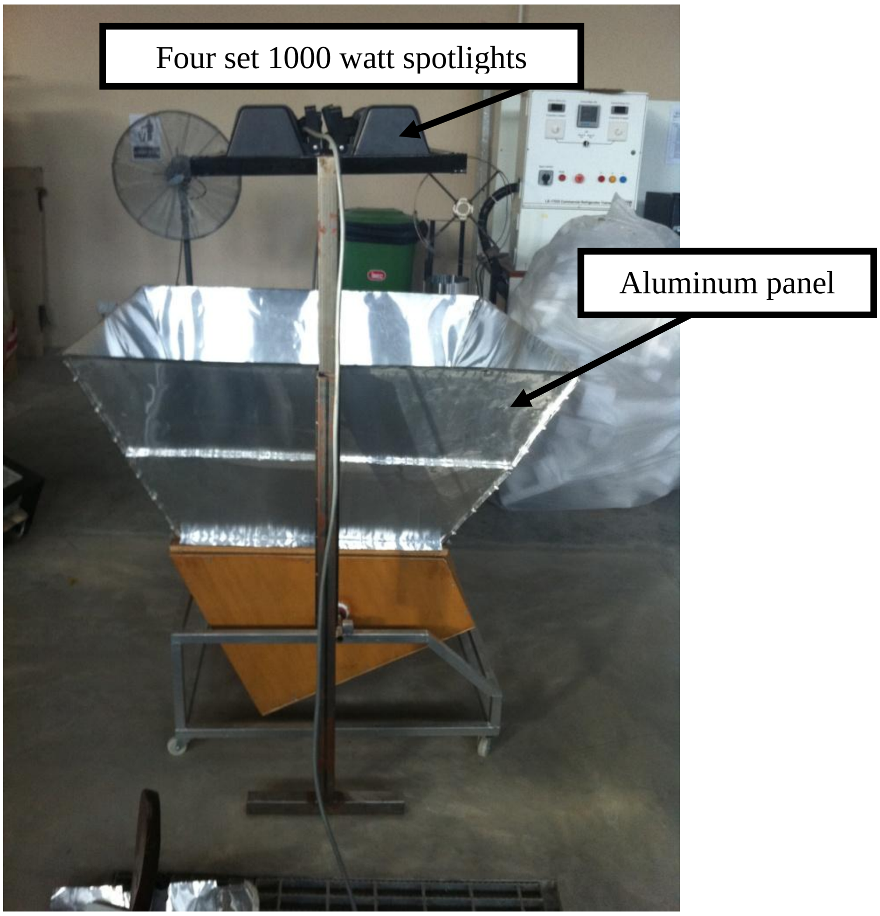
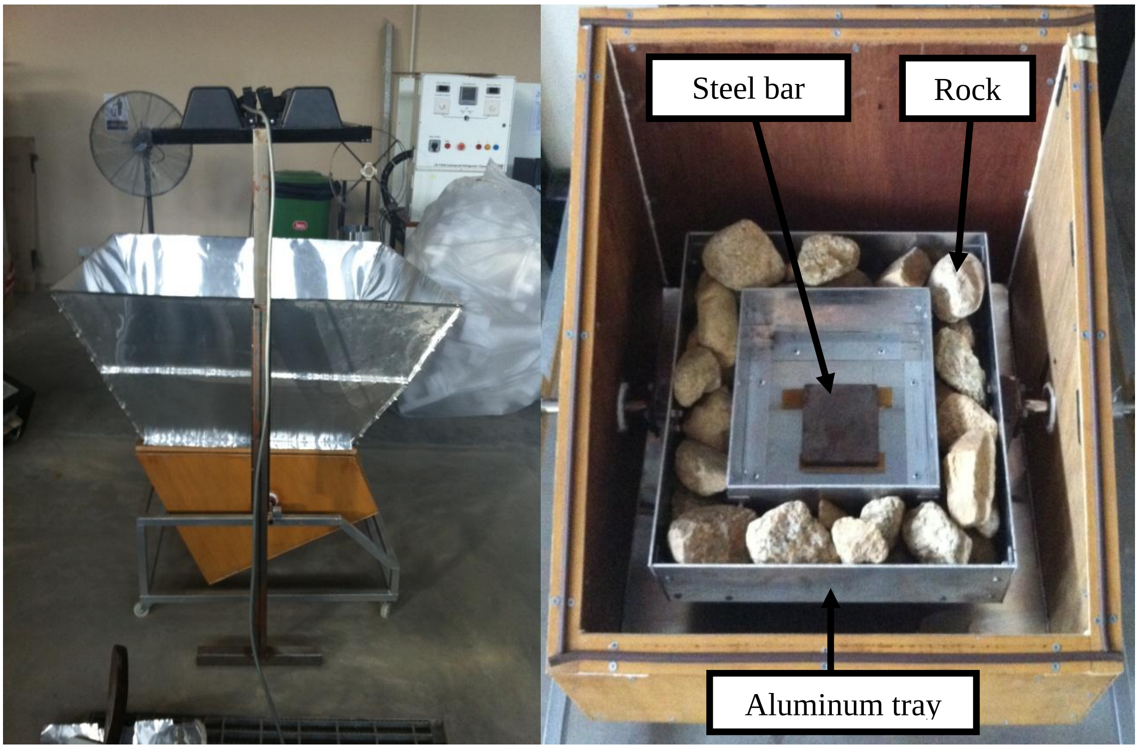


Figure 3.11: Experiment 2 setup

3.5.3 Experiment 3 (Oven with aluminum panel and thermal storage)

Figure 3.12 below shown the experiment 3 that consist of an oven with aluminum panel and additional of thermal energy storage application. After using panel to increase the heat incident, thermal storage application was added to determine the capability of oven to maintain the temperature during the drop of heat source. The temperature parameter to be measured is oven temperature, aluminum tray temperature, steel bar temperature and river rock temperature. The spotlight radiation still constant which is 1000W/m².

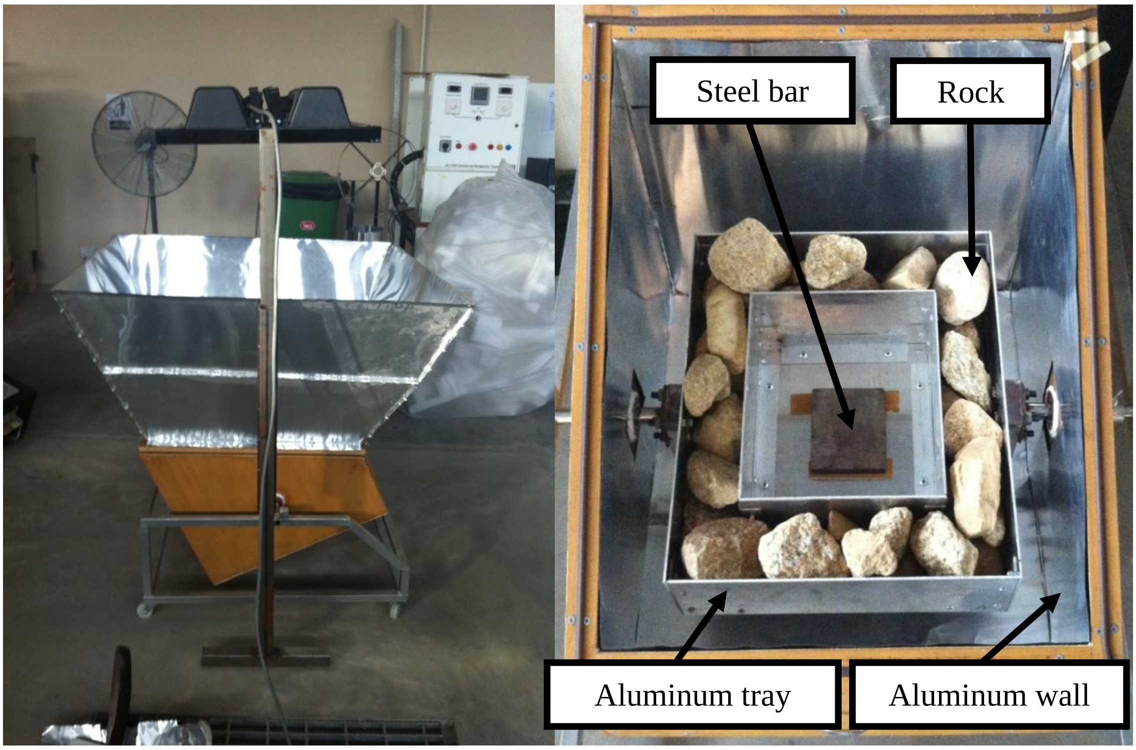


(a) (b)

Figure 3.12: Experiment 3 setup, (a) Oven with panel, (b) Inside the oven

3.5.4 Experiment 4 (Oven with panel, thermal storage and aluminum wall)

The Figure 3.13 below shown the experiment 4 setup which is consist of additional oven parameter such as aluminum panel, thermal energy storage application and aluminum wall. The purpose of using the aluminum wall is to determine whether the overall parameter temperature will increase or not because it is known that aluminum sheet is good at reflecting heat. It is expected in the result that experiment 4 will boost up the heating rate and increase the oven efficiency. Incident radiation from the spotlight is 1000W/m².



(a) (b)

Figure 3.13: Experiment 4 setup, (a) Oven with panel, (b) Inside the oven

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

The purpose of this chapter is to provide further discussion about the data collected from the experiment. The analysis of the temperature data is obtained from several experiments which are held at H-VAC lab in Faculty of Mechanical Engineering

4.1.1 Experiment method

All experiments are done in H-VAC laboratory using four 1000 watt spotlights as a source of radiation and heat. The radiation value from the spotlight is adjusted to 1000W/m² and measured using Radiometer. The temperature parameter to be measured is oven temperature, steel bar temperature, aluminum tray temperature and rock temperature. The parameter depends on each experiment where the rock and the thermal storage temperature only can be measured in experiment 3 and experiment 4. Overall time for each experiment is 180 minutes heating and 30 minutes cooling periods

4.2 TEMPERATURE DATA

4.2.1 The Experiment 1 data result

Table 4.1 show the experiment 1 data results.

Table 4.1: Experiment 1 (Oven only)

	TEMPERATURE (°C)		
TIME (MIN)	**STEEL BAR**	**OVEN**	**ALUMINUM BOX**
0	30	31	32
5	33	41	38
10	36	47	42
15	39	52	45
20	41	56	48
25	44	60	52
30	47	62	55
35	50	65	57
40	53	67	60
45	55	68	62
50	58	69	64
55	60	70	66
60	62	71	68
65	64	73	69
70	66	74	71
75	68	75	72
80	70	75	73
85	72	76	75
90	74	77	76
95	75	77	76
100	76	78	77
105	78	78	78
110	79	79	79
115	81	79	80
120	82	80	80
125	82	80	81
130	83	81	81
135	84	81	82
140	85	81	82
145	85	82	83
150	86	82	83
155	87	82	83
160	87	82	84
165	88	82	84
170	88	83	84
175	88	83	84
180	88	83	85
185	87	76	81
190	85	71	78
195	83	66	75
200	80	63	72
205	77	60	69
210	75	58	67

From the graph in Figure 4.1, it is show that the highest temperature is steel bar which is 88ºC. Aluminum tray reach maximum temperature at 85ºC and oven only got to the 83ºC. Oven temperature increase leads to 100 minutes then slowly stable when reach 120 minutes during the experiment. But for the steel bar, it is slowly increased to the maximum value at 180 minutes. This is because steel bar has a higher capability to store energy than aluminum tray. Aluminum tray good at handling and transferring heat from the oven to the steel bar.

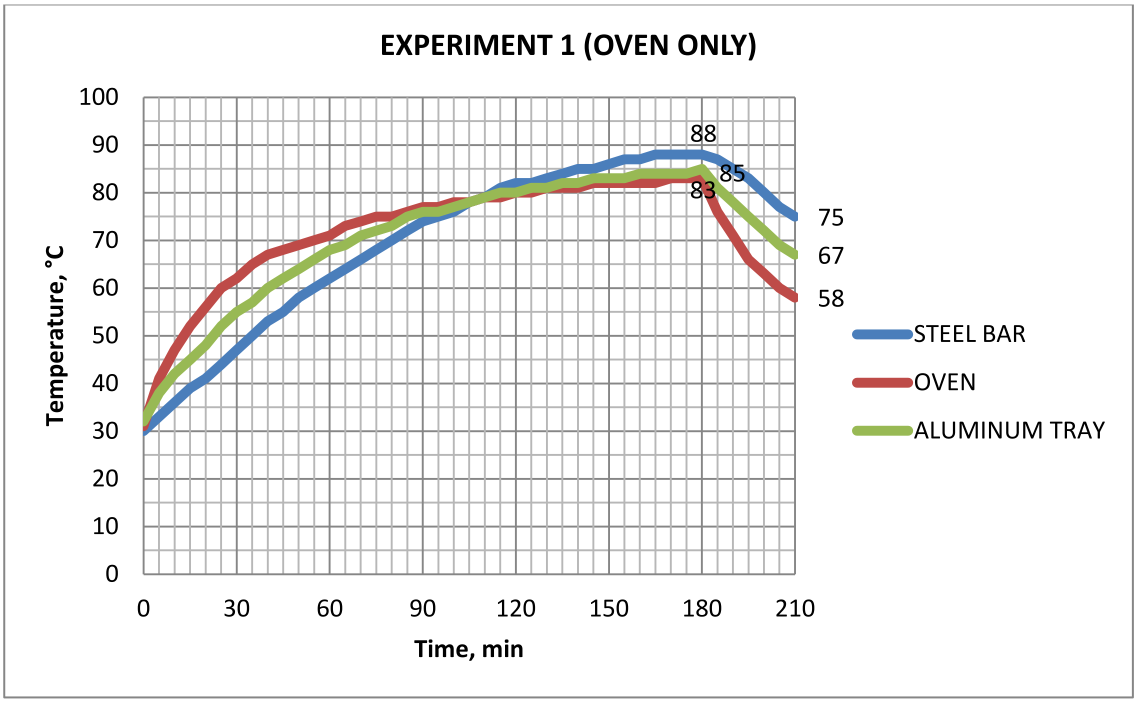


Figure 4.1 : Graph Temperature VS Time for Experiment 1

4.2.2 The Experiment 2 data result

The table 4.2 show the experiment 2 data results.

Table 4.2: Experiment 2 (Oven + Panel)

	TEMPERATURE (°C)		
TIME (MIN)	OVEN	STEEL BAR	ALUMINUM BOX
0	30	32	31
5	46	37	41
10	50	41	44
15	53	44	49
20	56	48	52
25	58	51	56
30	61	54	59
35	63	58	62
40	65	61	65
45	67	64	67
50	69	66	69
55	70	69	71
60	71	72	73
65	72	74	75
70	74	76	76
75	75	78	77
80	76	80	78
85	78	82	79
90	80	84	82
95	82	86	84
100	84	89	86
105	85	91	88
110	86	93	89
115	87	94	90
120	88	96	92
125	89	98	93
130	90	99	94
135	90	101	94
140	91	102	95
145	92	103	96
150	92	104	96
155	92	105	97
160	93	106	97
165	93	106	98
170	93	107	98
175	94	108	99
180	94	108	99
185	88	106	93
190	76	103	88
195	72	101	84
200	68	97	79
205	64	94	75
210	61	90	72

From the graph in Figure 4.2, it is show that the maximum temperature is steel bar which is 108°C. Then it follow by aluminum tray at 99°C and oven temperature at 94°C. Experiment 2 absolutely increased the overall temperature of the parameter measured, this is because of the aluminum panel eventually supply more heat incident to the oven. Oven temperature also increase perpendicular to the time compared to the experiment 1 which is only good at the beginning.

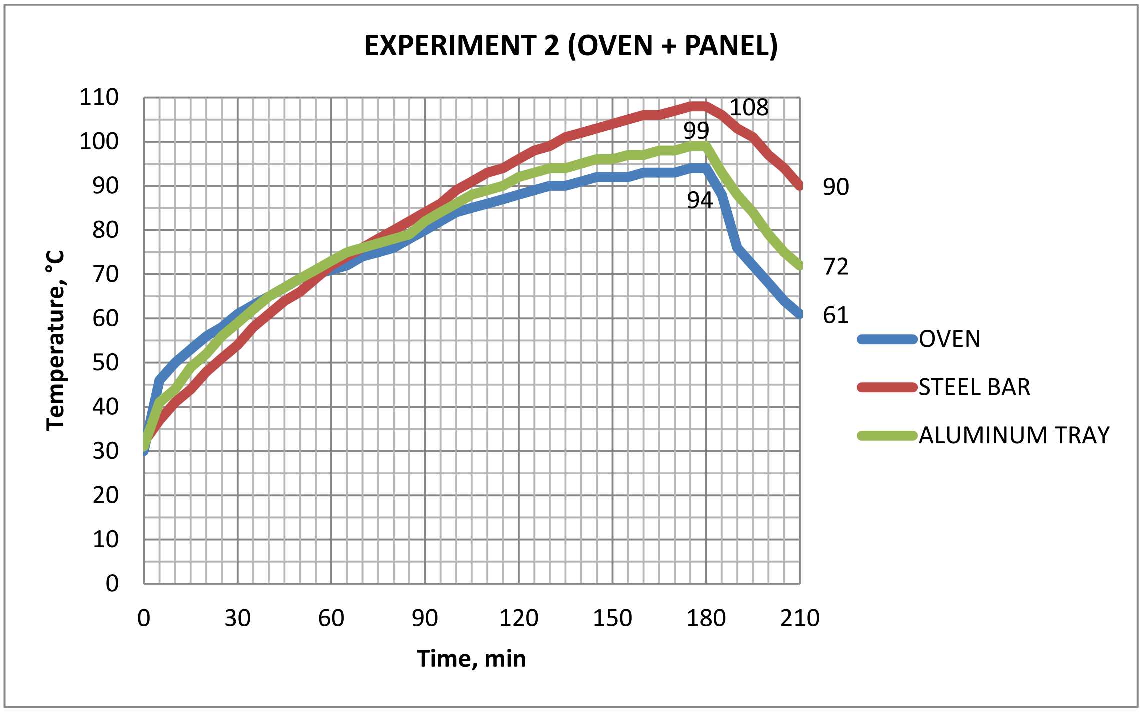


Figure 4.2: Graph Temperature VS Time for Experiment 2

4.2.3 The Experiment 3 data result

The table 4.3 show the experiment 3 data results.

Table 4.3: Experiment 3 (Oven + Panel + Thermal storage)

	TEMPERATURE (°C)			
TIME (MIN)	**STEEL BAR**	**OVEN**	**ROCK**	**ALUMINUM BOX**
0	30	33	30	32
5	34	52	31	40
10	37	59	33	44
15	41	64	35	47
20	45	68	37	51
25	49	72	39	54
30	52	75	41	57
35	55	78	44	59
40	58	80	46	61
45	61	82	48	64
50	64	83	49	66
55	66	85	51	67
60	69	86	53	69
65	71	87	54	71
70	73	87	56	72
75	75	88	57	73
80	77	89	58	74
85	78	90	59	75
90	80	91	60	77
95	81	92	61	78
100	83	93	62	79
105	84	93	63	80
110	85	94	64	80
115	86	94	65	81
120	87	95	66	82
125	88	95	67	83
130	89	96	68	83
135	90	96	69	84
140	91	96	70	85
145	91	97	71	85
150	92	97	72	86
155	92	97	73	86
160	93	97	74	87
165	94	98	74	88
170	94	98	75	88
175	95	98	76	89
180	95	98	77	89
185	94	83	77	84
190	91	77	77	81
195	89	73	77	79
200	86	70	76	76
205	83	67	75	74
210	81	65	74	73

The graph in Figure 4.3 show that the maximum temperature is oven which is 98°C. Steel bar at second highest which is 95°C follow by aluminum tray 89°C and lastly rock at 77°C. It is also shown that oven temperature drastically increase compare to previous experiment. It is because the thermal energy storage application increase the oven temperature. Temperature of steel bar and aluminum tray dropped a little bit because heat energy absorbed by rock during heating processes.

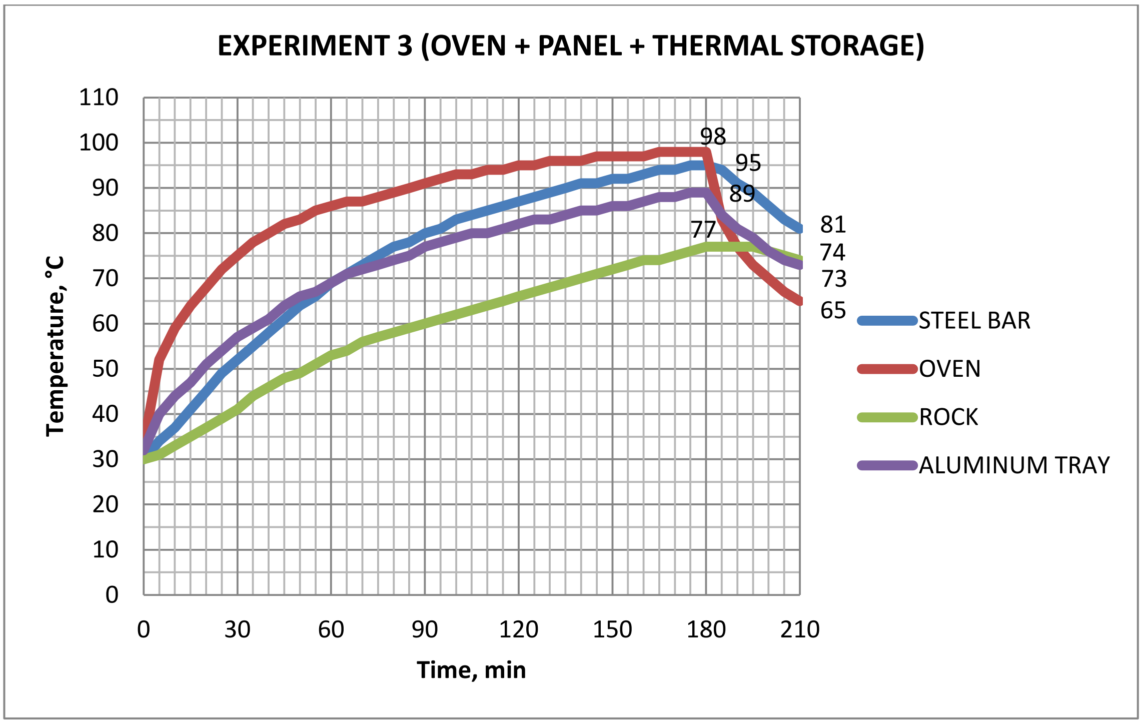


Figure 4.3: Graph Temperature VS Time for Experiment 3

4.2.4 The Experiment 4 data result

The table 4.4 show the experiment 4 data results.

Table 4.4: Experiment 4 (Oven + Panel + Thermal storage + Aluminum wall)

	TEMPERATURE (°C)			
TIME (MIN)	**STEEL BAR**	**OVEN**	**ROCK**	**ALUMINUM BOX**
0	29	32	32	31
5	41	58	33	41
10	45	64	35	45
15	50	69	37	49
20	54	74	39	52
25	58	77	42	56
30	61	80	44	59
35	65	83	46	61
40	68	85	48	64
45	71	87	51	66
50	74	89	53	68
55	76	90	55	70
60	79	91	57	72
65	81	92	59	74
70	82	93	61	76
75	84	94	63	77
80	86	95	65	79
85	88	95	67	80
90	89	96	68	82
95	90	97	70	83
100	92	97	72	84
105	93	97	73	86
110	94	98	74	87
115	96	98	76	88
120	96	98	77	89
125	97	99	79	90
130	98	99	80	91
135	99	99	81	91
140	100	99	82	92
145	101	99	83	93
150	102	100	85	94
155	103	100	86	95
160	103	101	87	96
165	103	101	88	97
170	104	101	88	98
175	105	102	89	98
180	105	102	90	99
185	98	87	90	95
190	94	82	90	92
195	91	76	90	89
200	88	75	90	87
205	86	72	89	85
210	84	70	88	83

The Figure 4.4 show that the maximum temperature in the oven is steel bar which is 105°C. Oven at second highest is at 102°C, follow by aluminum tray at 99°C and rock at 90°C. It is also shown that the oven temperature increase drastically in 30 minute earlier of the experiment. This is because of the aluminum wall that installed inside the oven. The purpose of aluminum wall is to reflex heat and blocked heat from escaping from the oven. The heat then focusing directly to the center of the oven and that why the steel bar have the highest temperature compare to the previous experiment.

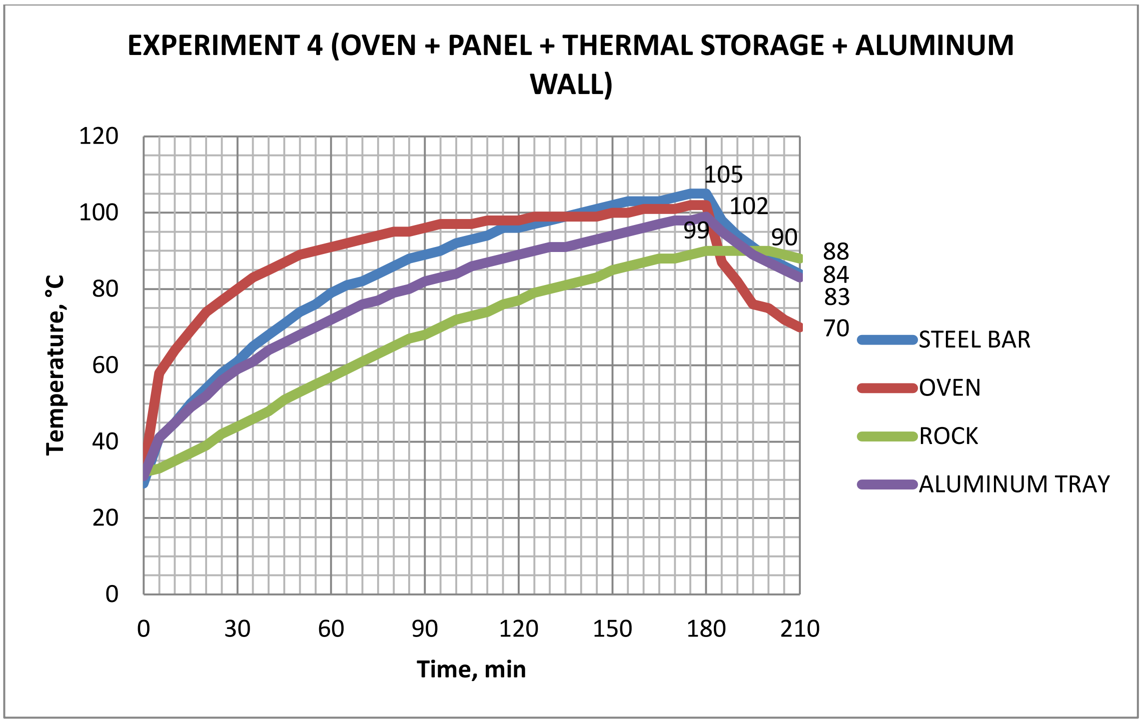


Figure 4.4: Graph Temperature VS Time for Experiment 4

4.3 TEMPERATURE DISCUSSION AND ANALYSIS

4.3.1 Oven temperature

The graph in Figure 4.5 show the oven temperature for overall experiment which is from experiment 1 until experiment 4. From the graph it shown that oven have a maximum temperature at experiment 4 which is 102°C. Experiment 4 have panel, thermal storage and aluminum wall as additional parameter to boost up the oven temperature. The second highest is experiment 3 at 98°C which is only used panel and thermal storage as additional parameter. Experiment 2 that used panel only to gain extra heat from the heat source have only 94°C and lastly experiment 1 which used oven only got maximum temperature at 83°C.

For the temperature drop, experiment 4 and experiment 3 that have thermal storage application prove that this application can hold the temperature from cooling down drastically. After 30 minute cooling period, experiment 4 still hold the temperature at 70°C and for experiment 3 is at 65°C.

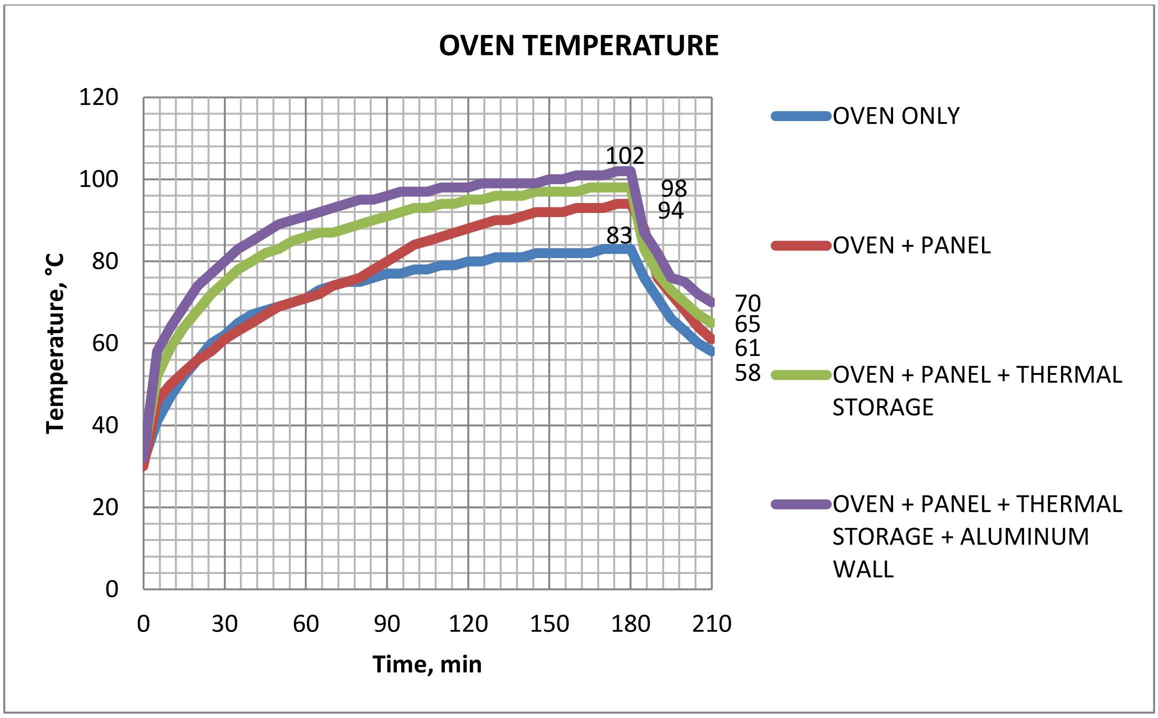


Figure 4.5: Oven temperature

4.3.2 Aluminum tray temperature

Figure 4.6 show that experiment 2 and experiment 4 share the highest temperature at 99°C. The explanation for this situation is for experiment 2 it only have aluminum tray and steel bar to share the heat inside of the oven. It is also used only panel as additional heat gain. But for experiment 4 it is known that additional heat gain is used more than experiment 2 which is thermal storage and aluminum wall were installed for experiment 4. This extra parameter actually can give more heat for the oven but steel bar and aluminum tray need to be share heat inside the oven with thermal energy storage which is 20 kg river rocks. That why the temperature for experiment 4 is as the highest temperature.

But for temperature drop it is clearly shown that experiment 2 drastically dropped from 99°C to 72°C. But it is different for experiment 4 which only got a little temperature drop from 99°C to 83°C. This phenomena prove that thermal storage application can hold the temperature drop during the no heat source situation.

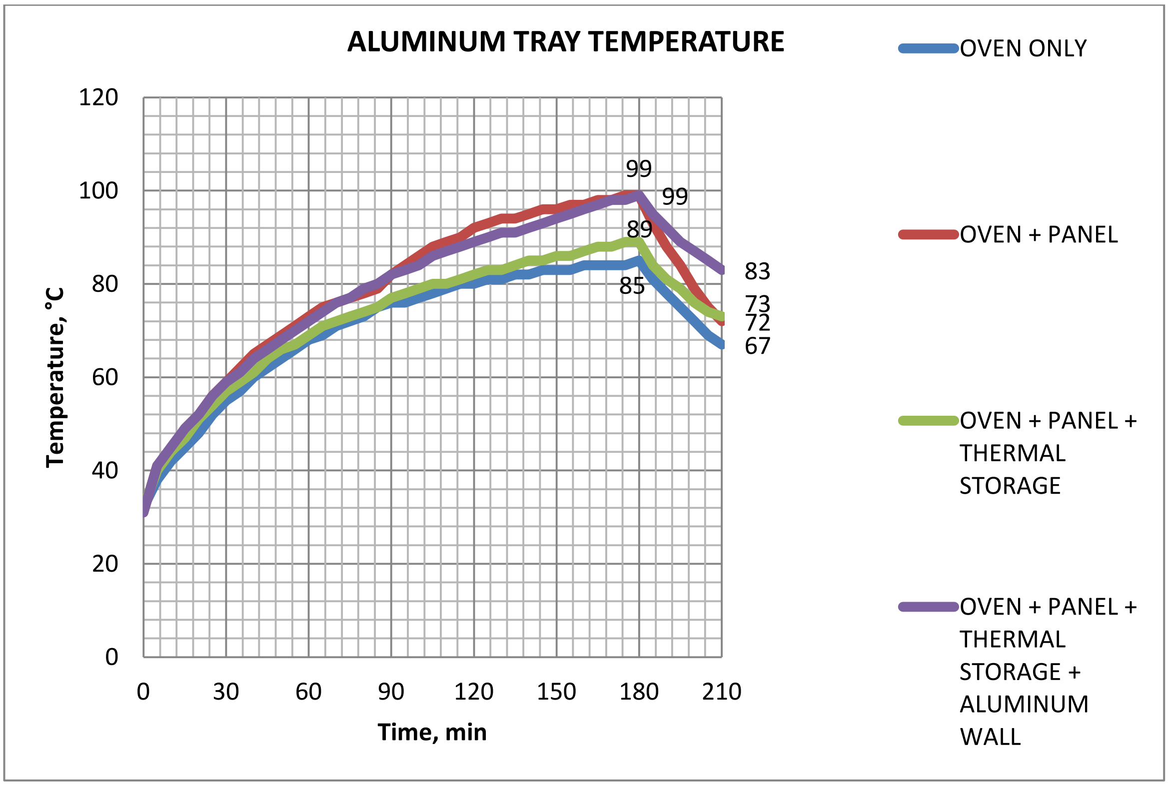


Figure 4.6: Aluminum tray temperature

4.3.3 Steel bar temperature

The graph in Figure 4.7 show the steel bar temperature for experiment 1 until experiment 4. The maximum temperature is at 108°C which is have from experiment 2. The second highest is at experiment 4 which is at 105°C. From the graph behaviour, it shown that experiment 4 lead in earlier time until 120 minute of experiment before experiment 2 take over the heating processes. Experiment 3 having maximum temperature at 95°C and follow by experiment 1 at 88°C. It is expected that experiment 4 will gave the highest temperature to the steel bar but since there were thermal storage application in experiment 4 so heat need to be distributed evenly for all parameter. That why experiment 2 always got the highest temperature in steel bar and aluminum tray.

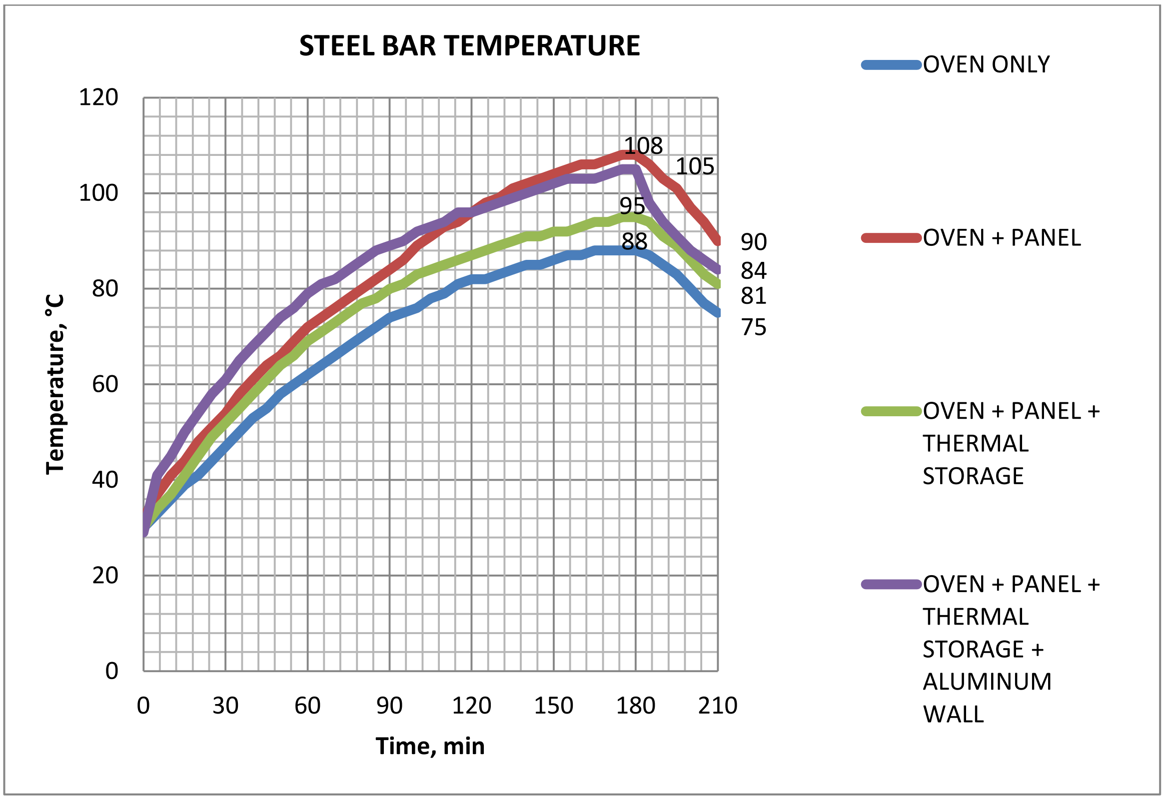


Figure 4.7: Steel bar temperature

But that not important because the different only 3°C. The important thing here is to determine whether the thermal storage application can hold the temperature during the cooling period. And it is proven in experiment 3 and experiment 4 where it can keep the temperature around 80°C to 85°C.

4.3.4 Rock temperature

Figure 4.8 show the rock temperature for all experiment. Only experiment 3 and experiment 4 used rock as thermal energy storage application. From the graph it is shown that experiment 4 that have aluminum wall having the highest temperature compare to experiment 3. The maximum temperature for experiment 4 is 90°C and for experiment 3 is 77°C. It is prove that aluminum wall increase the heating rate for rock during the heating processes.

For cooling period experiment 4 only have 2°C temperature drop and experiment 3 have 3°C temperature drop. So the conclusion that can be made is aluminum wall also helping temperature rock from temperature drop drastically.

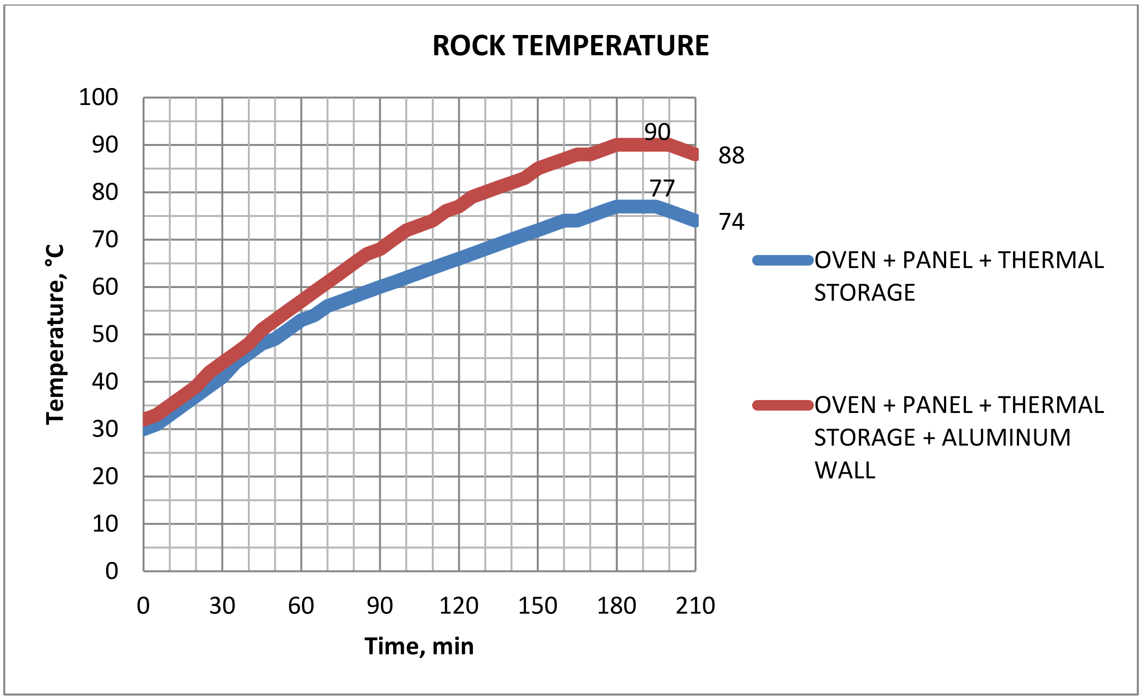


Figure 4.8: Rock temperature

4.4 ENERGY EFFICIENCY

Oven efficiency is calculate from the data collected from the steel bar as the product to be measured. Energy efficiency of a oven can be defined as the ratio of energy output (only the increase of the steel bar due to temperature growth) to the energy input (the energy of solar radiation). Thus the instantaneous energy efficiency of the oven was calculated as follows:

$$\eta = \frac{\frac{m.cp(Tf-Ti)}{\Delta t}}{I.A}$$

The experimental results for oven effiecincy are shown in Figure 4.9 and the calculated energy efficiencie are summarized in graph below.

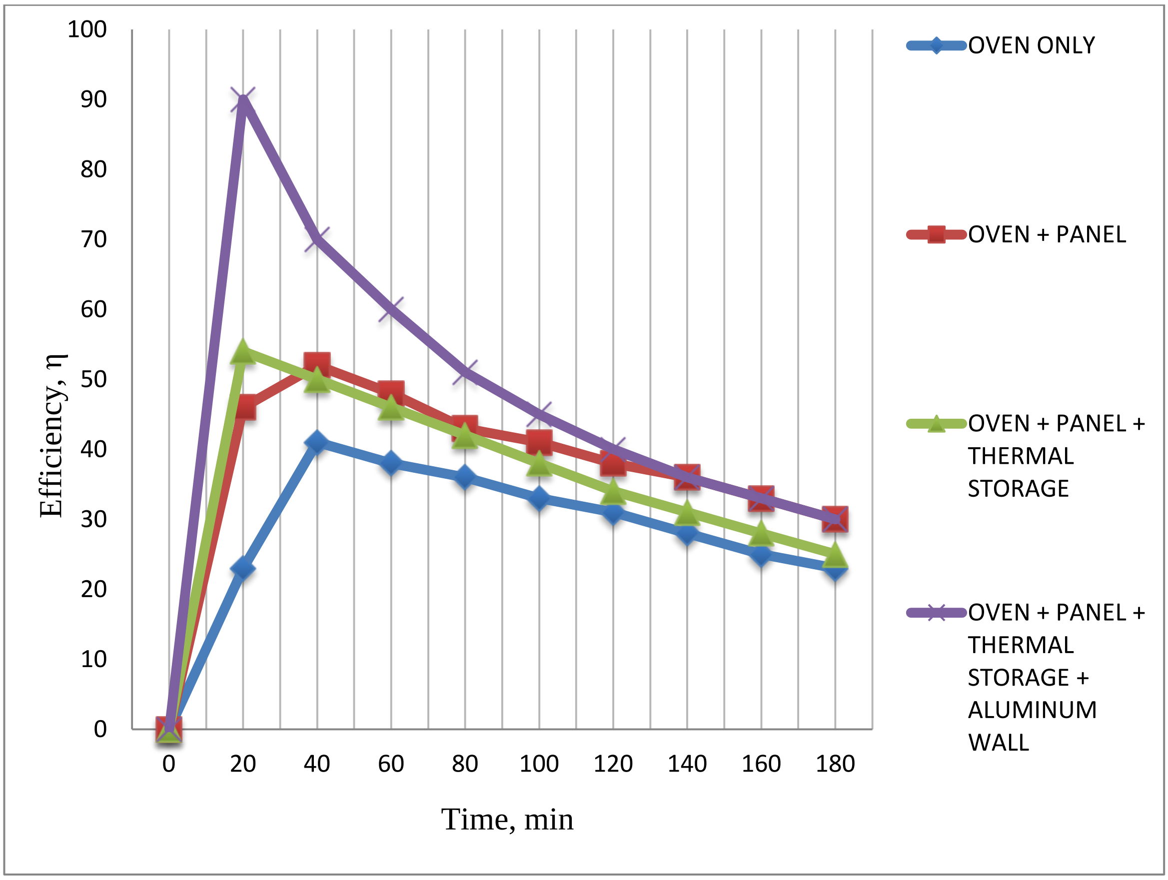


Figure 4.9: Oven efficiency

The oven efficiency is calculated for each 20 minute period of experiment. It is shown that the maximum efficiency is at 20 minute first for experiment 4 which is 90% of efficiency. The efficiency then drastically drop due to increasely of time and temperature different slowly reach the stable condition. Experiment 4 reach 35% of efficieny at the end of heating processes.

CHAPTER 5

CONCLUSSION

5.1 INTRODUCTION

This chapter will conclude the project and briefly discussed about the recommendation that can be applied in the future work. The conclusion obtained according to the result from Chapter 4. In order to study the performance of the oven and the optimum efficiency for the oven, other aspects of future work also will be discussed.

5.2 CONCLUSSION

The objective of this project which is to design and fabricate a functional solar oven, integrate thermal energy storage in the design and study characteristics & performance of the system were achieve after finishing the chapter 4.

From the result and discussion, aluminum panel increase the oven and steel bar temperature. Aluminum wall increase heating rate to boost up oven, aluminum tray and rock temperature. Aluminum panel and aluminum wall also increase the oven efficiency. This can be proven in experiment 2 and experiment 4 where the steel bar and oven temperature is highest in these two experiment.

Thermal storage application hold up oven's, aluminum's and steel bar's temperature when radiation drop. This proven that the using of thermal storage application was useful when the radiation drop and at the same time increase the oven temperature during the heating processes.

5.3 RECOMMENDATION

There are few improvements need to be done for the future research. These improvement is to make the oven get the optimum performance and more efficiency than this project. There are several recommendations which is:

1. Improve oven efficiency by sealing and make sure the oven vacuum when the lid is closing.
2. Improve thermal storage application by using latent heat storage type application such as a phase change material instead of using sensible heat storage.
3. Making the simulation using Computational Fluid Dynamic (CFD) or Solidwork Flow Simulation software to investigate suitable design to get optimum performance.

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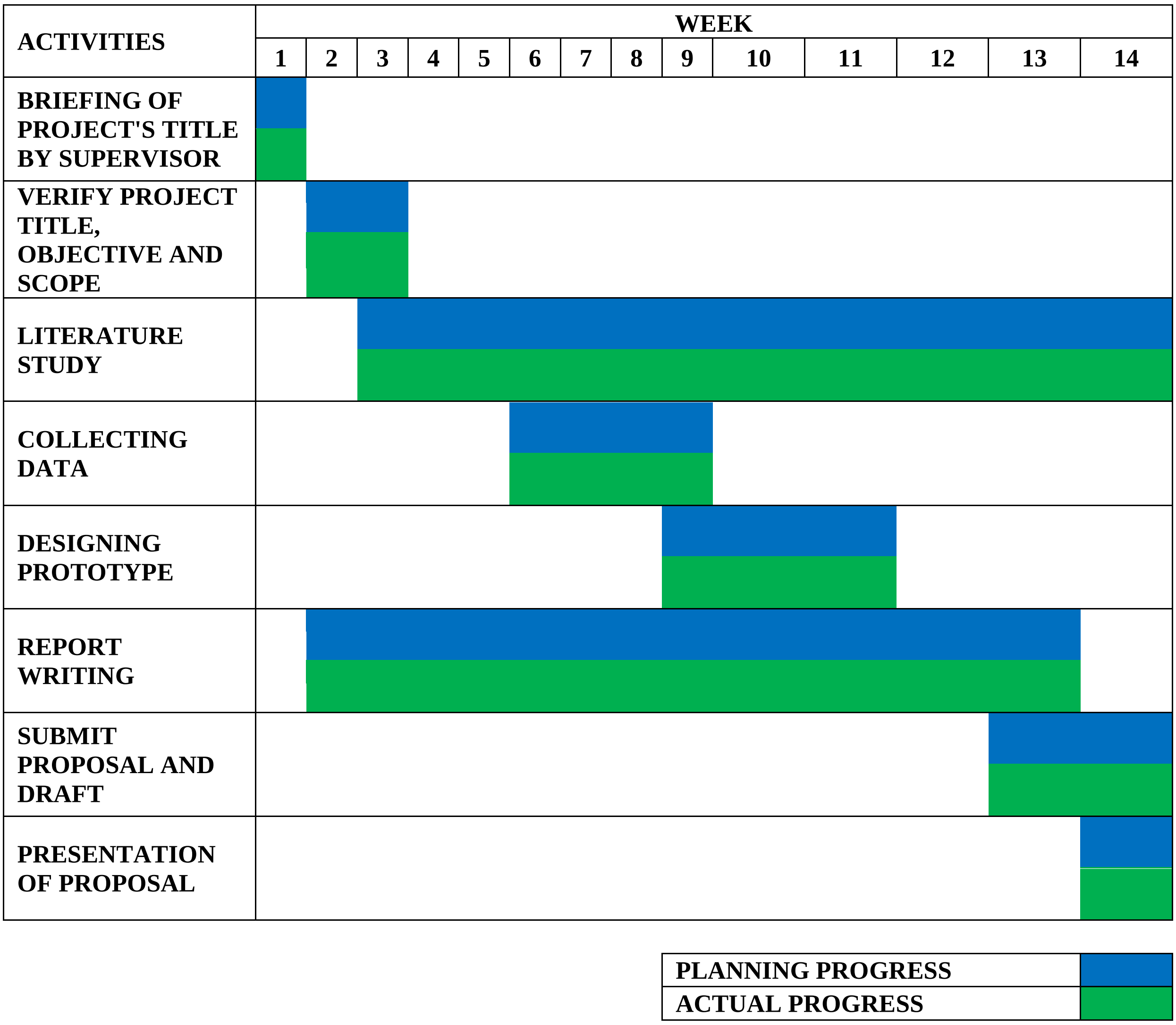
APPENDIX A1

Gantt Chart for Final Year Project 1



APPENDIX A2

Gantt Chart for Final year Project 2