# Design and Development of an Innovative Flat Plate Solar Collector

By

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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Approved by,

_________________________

(Dr Syed Ihtsham Ul-Haq Gilani)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
December 2010

## CERTIFICATION OF ORIGINALITY

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

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RAUDHAH BINTI AB MAJID

# ABSTRACT

Over the past few years, considerable progress has been made in reducing the energy consumption for space heating. This is mostly achieved by using the energy conservation and traditional solar technologies. Solar collector has already been designed but innovation can be made to the current design to make it perform better and reach a very low level of energy consumption. The efficiency of the existing solar collector is on the lower side because of solar losses from the absorber plate to the surrounding and a major part of absorbed energy is lost to the sky because of the radiation and convection losses from top of the absorber plate.

With the transparent insulation technology such as transparent honeycomb, the performance of the solar collector can be improved. The prototype would be use to make an experiment evaluating the new design effectiveness in improving the flat plate performances. The addition of transparent honeycomb insulator would suppress the connection current between absorber plate and glazing, thus reducing the top convection losses, without much affecting the heat gains.

This report contains Introduction which explains the project background, problem statement, and limitations of the project. Literature review contains the study of flat plate collector, transparent insulation technology and the transparent honeycomb. Methodology discussed the procedures involved in doing this project and the Gantt chart for the project. Results & discussion contain the design parameter that has been taken into consideration for the project, calculation made for the prototype, the design of the prototype with results from experiments. Conclusion was made based on what have been learnt from the report, recommendation for the project and lastly references used throughout the project.

## ACKNOWLEDGEMENTS

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# NOMENCLATURE

| | |
|---|---|
| $A$ | collector area, $m^2$ |
| $F_R$ | collector heat removal factor |
| $I$ | intensity of solar radiation, $W/m^2$ |
| $T_c$ | collector average temperature, $^{\circ}C$ |
| $T_i$ | inlet fluid temperature, $^{\circ}C$ |
| $T_a$ | ambient temperature, $^{\circ}C$ |
| $U_L$ | collector overall heat loss coefficient, W/m |
| $Q_i$ | collector heat input, W |
| $Q_u$ | useful energy gain, W |
| $Q_o$ | heat loss, W |

**Greek Symbols**

| | |
|---|---|
| $\eta$ | collector efficiency |
| $\tau$ | transmission coefficient of glazing |
| $\alpha$ | absorption coefficient of plate |

**Subscripts**

| | |
|---|---|
| $m$ | mass flow rate of fluid through the collector, kg/s |

# CHAPTER 1

# INTRODUCTION

## 1.1 PROJECT BACKGROUND

Solar thermal has been used for a long time, at least as far as Archimedes’ use of a concave mirror to heat water in 214 BC. As a term, `solar thermal’ encompasses all the thermal uses of solar energy, and represents a number of different technology options [1]. Solar Energy is the energy from the Sun. The Sun is a big ball of heat and light resulting from nuclear fusion and fission at its core. The nuclear reaction releases energy that travels outward to the surface of the Sun. Along the way to the surface the energy transforms so that by the time it is released it is primarily light energy. The two major types of solar energy that make it to Earth are heat and light. Solar energy is often called "alternative energy" to fossil fuel energy sources such as oil and coal. One example of our use of solar heat energy is for water heating systems. A solar panel is used to collect heat. The heat is transferred to pipes inside the solar panel and water is heated as it passes through the pipes [2]. The hot water, heated by the Sun, can then be used for showers, cleaning, or heating your home. Alternative energy has many benefits such as renewable and non-polluting.

Applications of solar energy systems, such as desalination, solar industrial processes and absorption solar cooling and air conditioning, require collectors of high efficiency which may be attained by reducing the heat loss coefficients of the collector. This goal can be achieved by using either an evacuated tube collector or flat plate collector equipped with transparent insulation materials. Evacuated tube collectors are relatively expensive and require high technology in comparison with flat plate collectors. However, transparent insulation materials are not expensive and have high optical transmission to solar radiation besides having excellent mechanical strength. The main types of transparent insulation materials are honeycomb structures of circular, rectangular and hexagonal cross sections. Transparent insulation materials, or convection suppression devices, are usually inserted in the air gap between the plate and the glazing cover of the flat plate collector.

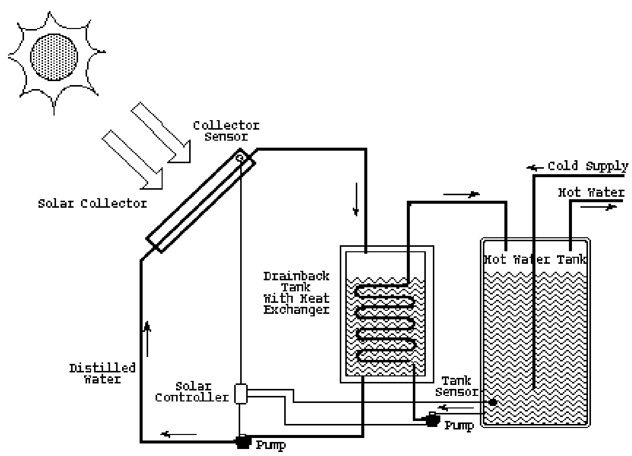


Figure 1.1 Solar water heater system [3]

## 1.2 PROBLEM STATEMENT

Solar collector has already been designed and developed for the last few decades but the major problem with the existing designs is that they lose heat at a very fast rate during the off-solar hours. The main advantage of the new design would be not only high efficiency during sunshine hours but also a good insulator during off-sun hours.

## 1.3 OBJECTIVES

The objectives of this project are as follows:

1. To design a new solar collector for improve insulation and overall efficiency.
2. To develop the prototype using the available sources.
3. To test the solar collector performance with and without the use of honeycomb transparent insulator.

## 1.4 SCOPE OF STUDY

1. Research on the design of the flat plate type of solar collector based on the variety of sources such as books, journals, reports and internet.

2. Design a new flat plate solar collector based on the research done that will be able to enhance the efficiency of the solar collector.

3. Develop the prototype based on the approved design and make experiment using the prototype. Analyze the result by comparing the characteristics of the new design of solar collector with the existing one.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 FLAT PLATE SOLAR COLLECTOR

Solar collector absorbs solar radiation and then converts it into heat and transfer the heat to the solar system. The majority of solar collectors that are sold in many countries are of a flat-plate variety. A simple flat plate collector consists of an absorber surface (usually a dark, thermally conducting surface); a trap for reradiation losses from the absorber surface (such as glass which transmits shorter wavelength solar radiation but blocks the longer wavelength radiation from the absorber); a heat transfer medium such as air, water, etc; and some thermal insulation behind the absorber surface. Flat plate collectors are used typically for temperature requirements up to 75°C although higher temperatures can be obtained from the high efficiency collectors [4].

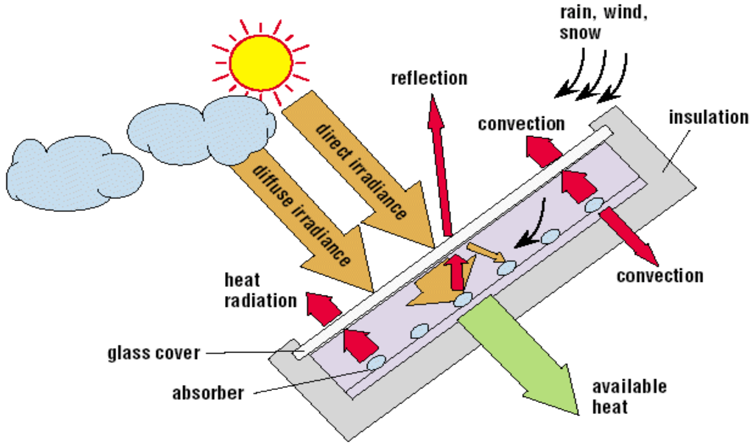

Figure 2.1 Process at a flat plate collector [5]

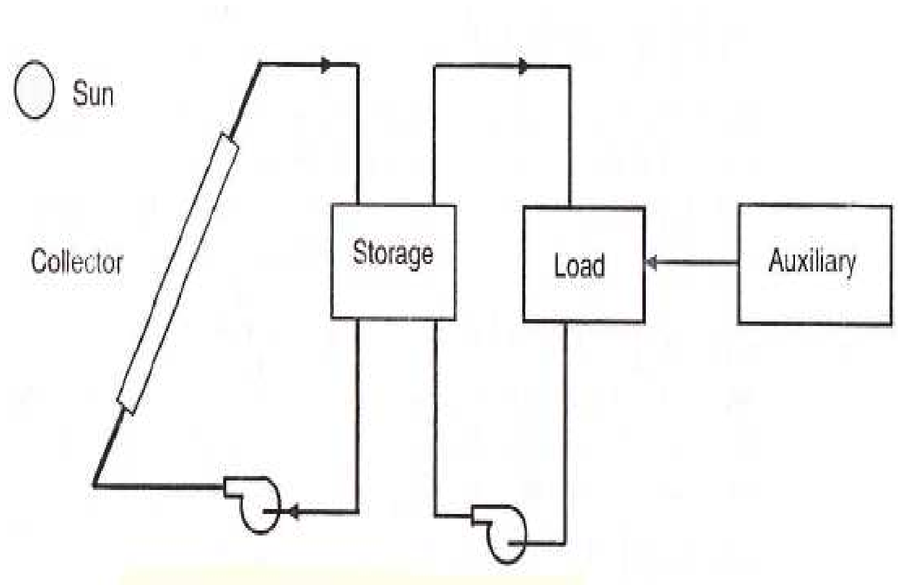


Figure 2.2 Flat plate solar collector system schematic [6]

### 2.1.1 Components of a typical flat plate solar collector

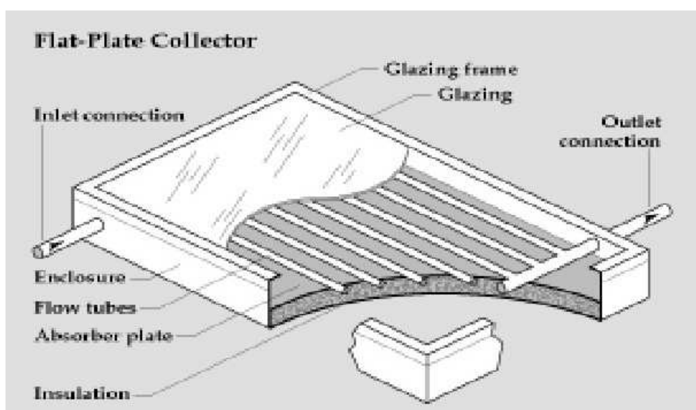


Figure 2.3 Cross-section of a basic flat plate solar collector [7]

Absorber plate: It is usually made of copper, steel or plastic. The surface is covered with a flat black material of high surface is covered with a flat black material of high absorptance. If copper or steel is used it is possible to apply a selective coating that maximizes the absorptance of solar energy and minimizes the radiation emitted by plate.

Here a table about matter that absorber plate may be made from:

Table 2.1 Characteristics of absorptive coating

| Material | Absorptance (α) | Emittance (ε) | Break down temperature | Comments |
|---|---|---|---|---|
| Black silicon paint | 0/86-0.94 | 0.83-0.89 | 350°C | Silicone binder |
| Black silicon paint | 0.9 | 0.5 | | Stable at high temperature |
| Black copper over copper | 0.85-0.9 | 0.08-0.12 | 450 | Patinates with moisture |
| Black chorome over nickel | 0.92-0.94 | 0.07-0.12 | 450 | Stable at high temperature |

Flow passages: The flow passages conduct the working fluid through collector. If the working fluid is a liquid, the flow passage is usually a tube that is attached to or is a part of absorber plate. If the working fluid is air, the flow passage should be below the absorber plate to minimize heat loss.

Cover plate: To reduce convective and radiative heat losses from the absorber, one or two transparent covers are generally placed above the absorber plate. They usually are made from glass or plastic.

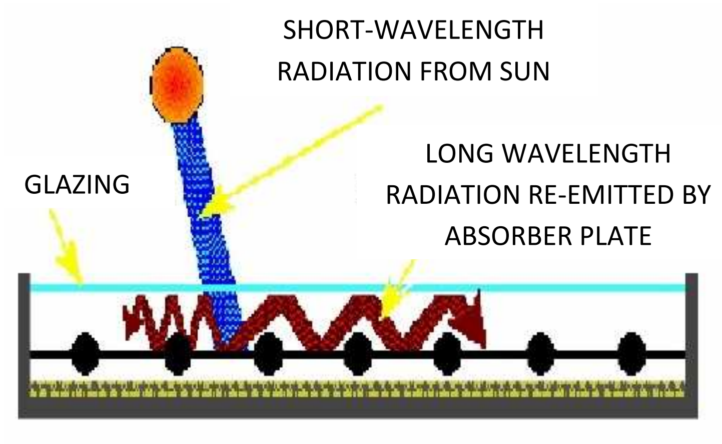


Figure 2.4 Cross-section view of flat plate solar collector [7]

Insulation: These are some materials such as fiberglass and they are placed at the back and sides of the collector to reduce heat losses.

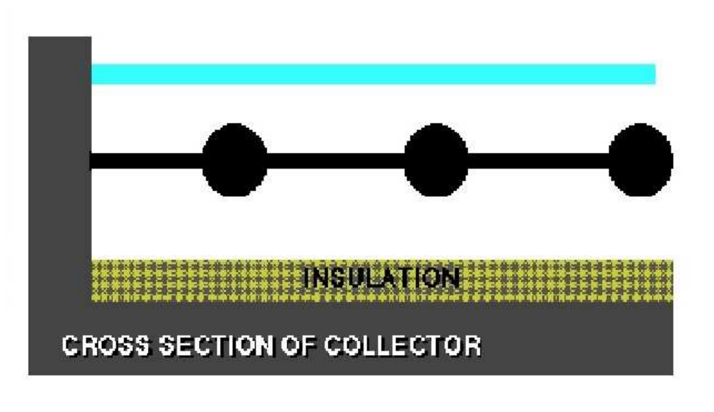


Figure 2.5 Cross-section view of an insulation part of flat plate solar collector [7]

Enclosure: A box that the collector is enclosed in holds the components together, protect them from weather, facilitates installation of the collector on a roof or appropriate frame.

### 2.1.2 Types of solar collectors

Flat-plate collectors could be classified into three groups according to their operating temperatures- low, medium and high [8].

i. Low temperature flat-plate collectors

Employed in systems which require only small temperature rises, usually in order of 2 to 10°C. They are normally used for heating up swimming pools and the collectors are extruded from ultra-violet resistant synthetic rubber or plastic materials

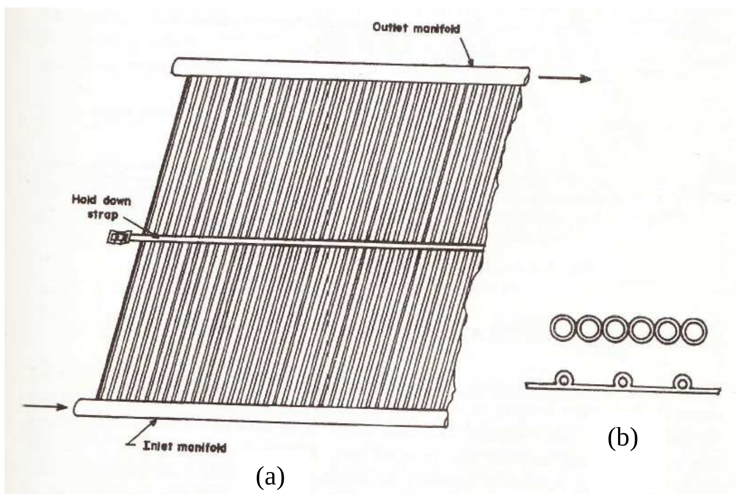


Figure 2.6 Extruded mat type of low temperature swimming pool solar collector: (a) isometric view; (b) cross-sectional views of two different types of extrusions [8].

ii. Medium temperature flat-plate collectors

They are most commonly employed for domestic hot water heating in the range of 50 to 70°C. It consists of a series of metal tubes laid parallel to one another and bonded onto flat metal sheet which is painted black on top surface to increase its absorptivity towards solar radiation. The tubes are jointed at the ends by larger diameter manifolds or header pipes to allow water or other heat transfer fluid to be circulated through the collector.

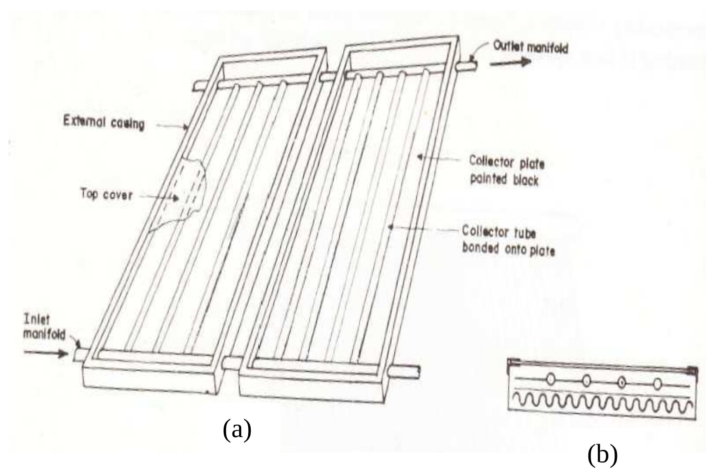


Figure 2.7 Flat-plate type of medium temperature solar collector: (a) isometric view; (b) cross-sectional view [8].

iii. High temperature flat-plate collectors

Employed in applications such as for process heating or for the provision of small scale power production which require collector operating temperatures in excess of 100°C, sometimes up to 250°C. A more sophisticated design approach is needed to reduce heat losses from the collector to the ambient. Such collectors require more effective insulation such as vacuum in the air space between the heat-absorbing plate and the glazing. A special surface coating is applied to the collector plate instead of the normal black paint to increase its absorptivity towards solar radiation.

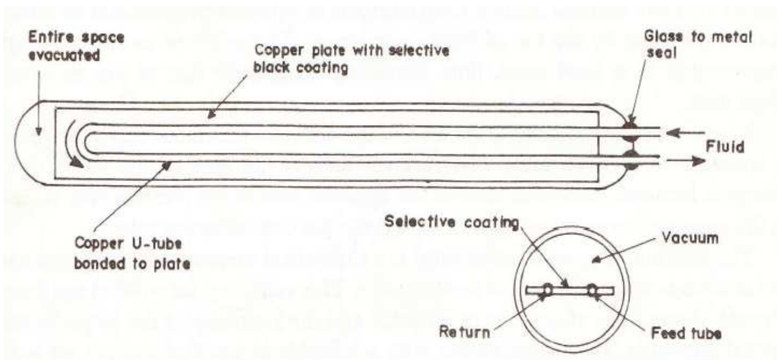


Figure 2.8 Corning evacuated cube high temperature solar collector [8].

## 2.2 COLLECTOR PERFORMANCE

Figure 2.9 shows a schematic drawing of the heat flow through a collector. It is necessary to define step by step the singular heat flow equations in order to find the governing equations of the collector system.

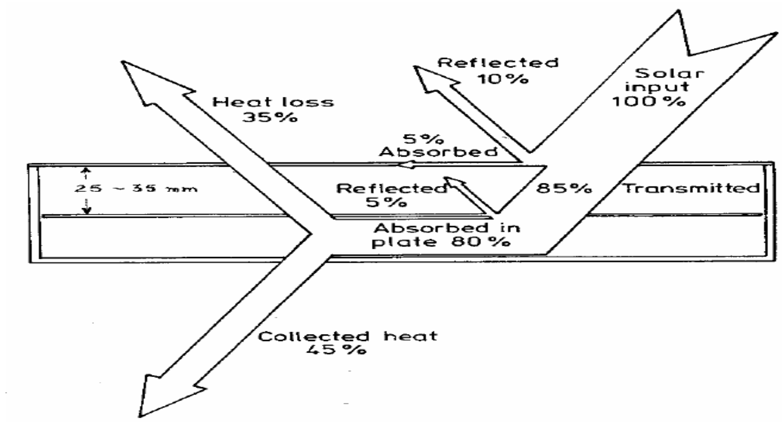


Figure 2.9 Heat flow through a Flat Plate solar collector [9]

Figure 2.10 shows the schematic of a typical solar system employing a flat plate solar collector and a storage tank.

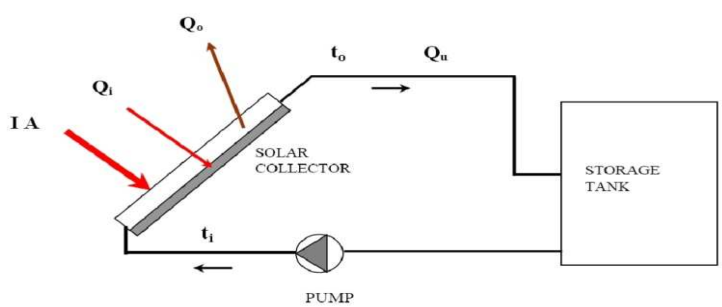


Figure 2.10 Typical solar energy collection system [10]

If **I** is the intensity of solar radiation, in W/m$^2$, incident on the aperture plane of the solar collector having a collector surface area of **A**, m$^2$, then the amount of solar radiation received by the collector is:

$$Q_i = I \cdot A \qquad [2.1]$$

However, as it is shown Figure 2.9, a part of this radiation is reflected back to the sky, another component is absorbed by the glazing and the rest is transmitted through the glazing and reaches the absorber plate as short wave radiation [11].

Therefore the conversion factor indicates the percentage of the solar rays penetrating the transparent cover of the collector (transmission) and the percentage being absorbed.

Basically, it is the product of the rate of transmission of the cover and the absorption rate of the absorber.

Thus,

$$Q_i = I\,(\tau\alpha)\,.\,A \qquad [2.2]$$

As the collector absorbs heat its temperature is getting higher than that of the surrounding and heat is lost to the atmosphere by convection and radiation. The rate of heat loss ($Q_o$) depends on the collector overall heat transfer coefficient ($U_L$) and the collector temperature.

$$Q_o = U_L\,A\left(T_c - T_a\right) \qquad [2.3]$$

Thus, the rate of useful energy extracted by the collector ($Q_u$), expressed as a rate of extraction under steady state conditions, and is proportional to the rate of useful energy absorbed by the collector, less the amount lost by the collector to its surroundings.

This is expressed as follows:

$$Q_u = Q_i - Q_o = I\,\tau\alpha\,.\,U_L\,A\left(T_c - T_a\right) \qquad [2.4]$$

It is also known that the rate of extraction of heat from the collector may be measured by means of the amount of heat carried away in the fluid passed through it, that is:

$$Q_u = mc_p\,(T_o - T_i) \qquad [2.5]$$

Equation 4.4 proves to be somewhat inconvenient because of the difficulty in defining the collector average temperature. It is convenient to define a quantity that relates the actual energy gain of a collector to the useful gain if the whole energy gains of a collector to the useful gain if the whole collector surface were at the fluid inlet temperature. This quantity is known as "the collector heat removal factor ($F_R$)" and is expressed as:

$$F_R = \frac{mc_p(T_0 - T_i)}{A[I\tau\alpha - U_L(T_i - T_a)]} \qquad [2.6]$$

The maximum possible useful energy gain in a solar collector occurs when the whole collector is at the inlet fluid temperature. The actual useful energy gain (Qu), is found by multiplying the collector heat removal factor ($F_R$) by the maximum possible useful energy gain. This allows the rewriting of equation (2.4):

$$Q_u = F_R A\,[I\tau\alpha - U_L(T_i - T_a)] \qquad [2.7]$$

Equation 4.7 is a widely used relationship for measuring collector energy gain and is generally known as the "Hottel-Whillier-Bliss equation".

A measure of a flat plate collector performance is the collector efficiency (η) defined as the ratio of the useful energy gain ($Q_u$) to the incident solar energy over a particular time period:

$$\eta = \frac{\int Q_u \, dt}{A \int I \, dt} \qquad [2.8]$$

The instantaneous thermal efficiency of the collector is:

$$\eta = \frac{Q_u}{AI} \qquad [2.9]$$

$$\eta = \frac{F_R A \left[ I\tau\alpha - U_L (T_i - T_a) \right]}{AI} \qquad [2.10]$$

$$\eta = \mathrm{F_R}\tau\alpha - \mathrm{F_R U_L}\ \frac{T_i - T_a}{I} \qquad [2.11]$$

## 2.3 TRANSPARENT INSULATION

In simple terms, transparent insulation can probably be best described as a mechanism which allows us to harness solar gains through controlled utilization of the greenhouse effect, but which prevents most thermal losses in a manner similar to conventional (opaque) insulation.

For this project, the parameter that will be improved is the use of transparent insulation materials. Transparent insulation materials (TIM) represent a new class of thermal insulation where air gaps and evacuated spaces are used to reduce the unwanted heat losses. It consists of a transparent cellular (honeycomb) array immersed in an air layer. The air layers are similar to conventional insulation materials with regard to the placement of air gaps in the transparent solid media. TIM are solar transparent, yet they provide good thermal insulation. The fundamental physical principle used in TIM is the wavelength difference between solar radiation which is received by the absorber and IR radiation which is emitted by the absorber.

The optical transmissivity of transparent insulation material when installed appropriately in front of a suitable absorber (usually a darkened and preferably matt surface) will allow incident solar energy across most of the spectrum to fall on the absorber which will subsequently re-radiate some of this energy at a higher wavelength, within thermal range. The increase in wavelength however, prevents most of this thermal energy from being transmitted back through the transparent insulation [12].

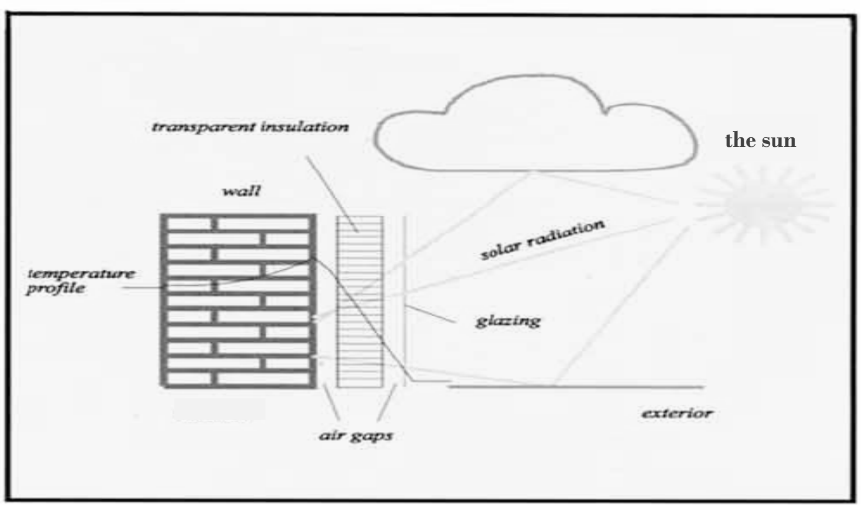


Figure 2.11 General principles of transparent insulation [12]

## 2.4 TRANSPARENT HONEYCOMB

Honeycomb transparent insulation was first developed in the early 1960's in order to enhance the insulation value of glazed systems, with minimum loss of light transmittance. Honeycomb transparent insulations are transparent-walled honeycombs, with open-ended cells whose axes are oriented parallel to the normal vector of the plane of the glazing. Honeycomb transparent insulation materials achieve high light transmittance because the cell walls are perpendicular to the plane of the glazing, and thus, any light that reflects from the cell wall continues in the forward direction. Thus these materials avoid the reflection-loss penalty that is incurred when extra glazings are inserted in the standard plane-parallel orientation [13].

Honeycomb transparent insulation materials provide insulation value by suppressing both convection and radiant heat. Honeycomb transparent insulation materials are typically made from transparent plastics such as acrylic, polycarbonate, or polypropylene. They are manufactured by a number of different techniques, including capillary bundling, extrusion, and film-fabrication. Their properties (such as light transmittance, insulation value, rigidity, weight, etc.) strongly depend on how they were manufactured.

A honeycomb reduces the plate's free convective losses but also decreases the solar energy transmitted to the plate for absorption. Cane et al. [13], using heat transfer experimental apparatus, obtained a significant suppression in convection losses when compared with an air layer of the same thickness without honeycomb. A substantial decrease in both radioactive and free convective losses will greatly improve the efficiency and, consequently, can give performance comparable with a vacuum tube collector. In 1961, Francia [13] introduced the use of honeycomb, made of circular glass cylinders, in a concentrating collector. Since then, the applicability of honeycomb has been extended to flat plate collectors, integrated collector storage solar hot water systems and, recently, to solar cookers as a 6% improvement in efficiency and yearly energy savings of about 1485 MJ are reported.

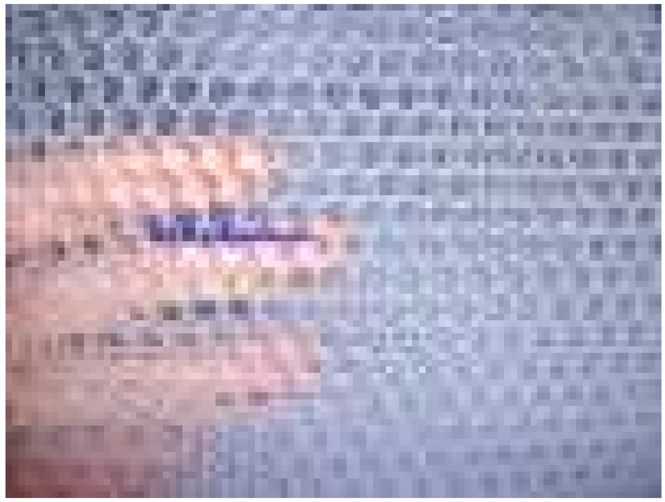

Figure 2.12 Example of transparent honeycomb [14]

# CHAPTER 3

# METHODOLOGY

## 3.1 METHODOLOGY DESCRIPTION

First, research on the topic is done and all relevant journals and books related to the project are collected. Research is done regarding the chosen topic to get the better knowledge of the topic. The information is obtained from the reading materials such as journals, books, and internet.

Constraints of the project must be put into consideration and alternatives are generated to get the basic design of the project. The calculation is done to get the parameters for the design. After all the information has been gathered, all the constrained of the project is put into consideration so that the design that will be made is relevant to the project. Calculation such as energy required and area needed is done for the design of the prototype.

The final design is develop the final design based on the information obtained and the calculation that has been done. After the research for the project and all the constrained has been consider, continue with designing the prototype. Several designs will be considered before the final one is chosen.

Based on the final design, the prototype is Develop. All the materials and equipment needed for the project is collected and then continue with building the prototype.

With the prototype that has been produced, make the experiment comparing the flat plate solar collector that has been improved with honeycomb and the normal one. The data from the experiment will be gathered and the analysis will be made based on the data.

A written report of this project will be produced after all activities has been successfully conducted .A report is made to conclude the project outcome and some recommendation will be made based on the results that has been obtained.

## 3.2 PROJECT FLOW

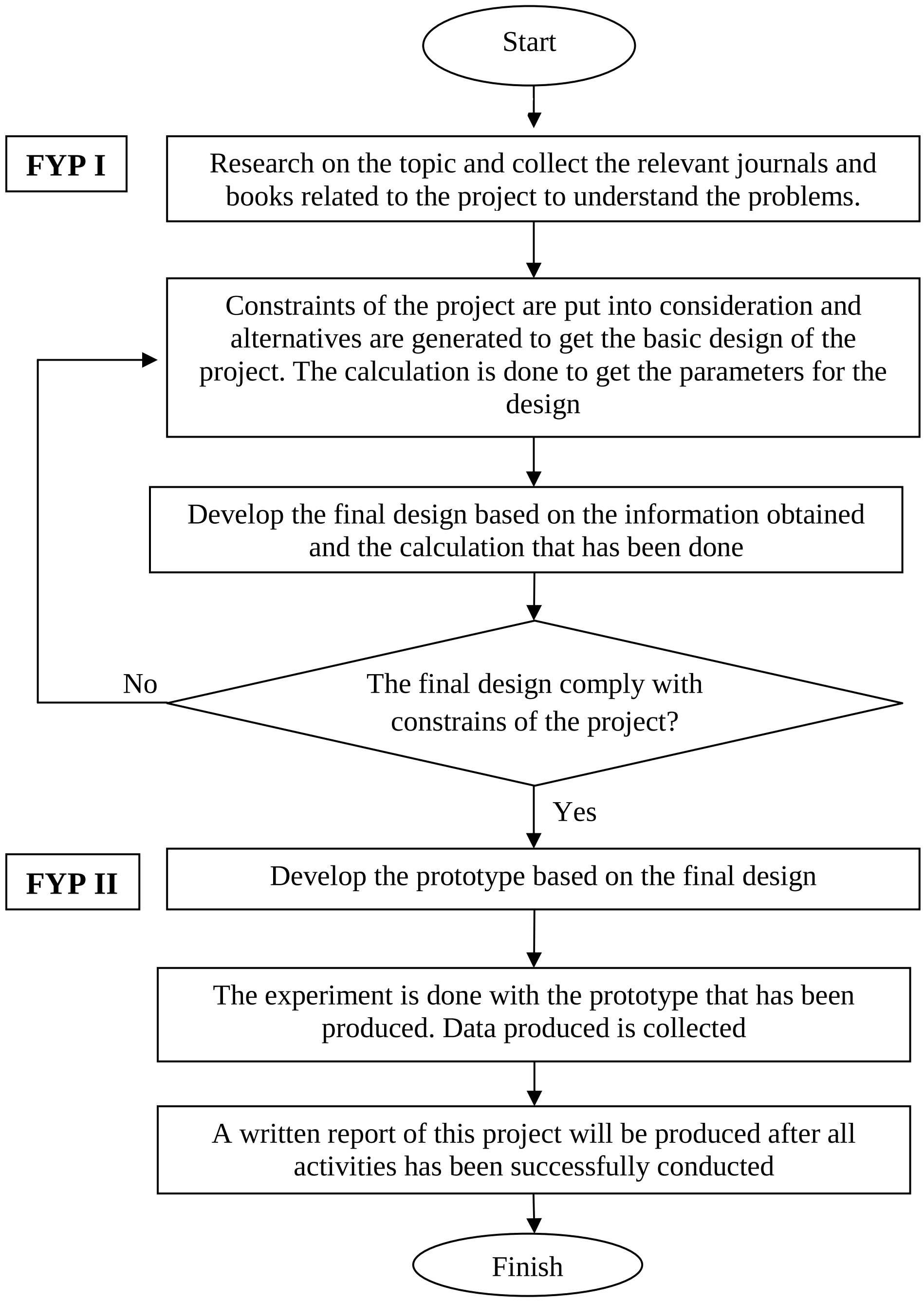


Figure 3.1 Project methodology

## 3.3 GANTT CHART

Gantt Charts are useful tools for analyzing and planning projects as they can help to plan out the tasks that need to be completed, give a basis for scheduling when these tasks will be carried out, allow us to plan the allocation of resources needed to complete the project, and help to work out the critical path for a project when need to complete it by a particular date. When a project is under way, Gantt Charts help to monitor whether the project is on schedule. If it is not, it allows us to pinpoint the remedial action necessary to put it back on schedule. These dependent activities need to be completed in a sequence, with each stage being more-or-less completed before the next activity can begin.

For this project, the Gantt chart with time plan is divided into two since the project needed to be completed within 2 semesters. For first semester, the focus of the project is on doing research, background data collection, early designing of the flat plate collector and the final design of the project (attachment APPENDIX A). For the second semester, the procurement process started to build the prototype and continued with making experiment using the prototype that has been build. Then continued with data analysis and lastly dissertation report is written on the results (attachment APPENDIX B).

## 3.4 PROCEDURE FOR THE EXPERIMENT

Developed a prototype based on the experiment that will be done. The flat plate collector must have a gap between the glazing and the collector so that the transparent honeycomb can be put later for the second experiment

↓

Set the prototype and the equipments needed such as flowmeter, pyranometer, data logger and thermocouple for the first experiment. During the eqperiment, all the parameters such as water temperature, flow rate, collector temperature, solar radiation and volume of water is observed and data is collected.

↓

Continue by developing a trasparent honeycomb that has inlet diameter of about 6mm and thickness of 75mm. The honeycomb should cover the area of 1.6m x 0.8 m. The honeycomb is then put inside the existing solar collector between the glazing and the collector.

↓

The second experiment is conducted with the prototype that has been modified. The parameters involved is observed and collected. The data of the experiment is compared to the previous data and analysis is made from the result.

Figure 3.2 Procedure for the experiment

### 3.5 EQUIPMENTS/ MATERIAL USE

1. Flat Plate Solar Collector - The size of the collector is 1.6m x 0.8 m.

2. Transparent honeycomb Insulation- The transparent honeycomb size is 1.6m x 0.8m with thickness of 75mm.

3. Flow meters - Instrument used to measure linear, nonlinear, mass or volumetric flow rate of a liquid or a gas. The type of flowmeter used for the experiment is rotameter that has a 10-to-1 flow range.

4. Data logger - Electronic device that records data over time or in relation to location either with a built in instrument or sensor or via external instruments and sensors. The data logger used has 4 measurement point.

5. Water tank with insulator – As a medium to put the water that will be used for the experiment. The water tank is made from plastic.

6. Water pump – To give force to the water so that water will be able to circulate through the collector. The flow rate of the pump is 2800L/H and maximum head of 1.8m.

7. Pyranometer - Used to measure broadband solar irradiance on a planar surface and is a sensor that is designed to measure the solar radiation flux density in $W/m^2$ (watts per meter square) from a field of view of 180 degrees. It has the range from 0 $W/m^2$ to 1000 $W/m^2$.

8. Thermocouple - Sensor for measuring temperature. It consists of two dissimilar metals, joined together at one end. When the junction of the two metals is heated or cooled a voltage is produced that can be correlated back to the temperature. The thermocouple alloys are commonly available as wire. The thermocouple use for the experiment is thermocouple probe type J with temperature range from 0°C to 750°C.

## 3.6 DESIGNS FOR PROTOTYPE

**Design for the prototype**

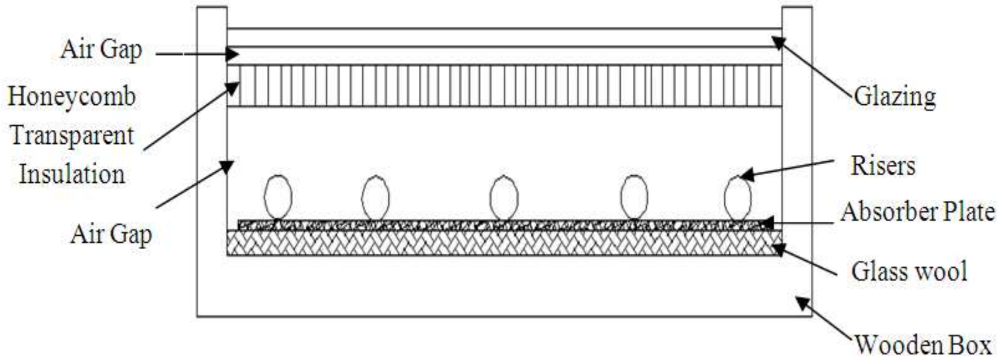


Figure 3.3 Cross-sectional view of the proposed new Flat Plate Collector

For the final design of the prototype, the parts that will be on the prototype includes wood box, glazing, risers with absorber plat that are made form copper, and insulator (refer APPENDIX C).

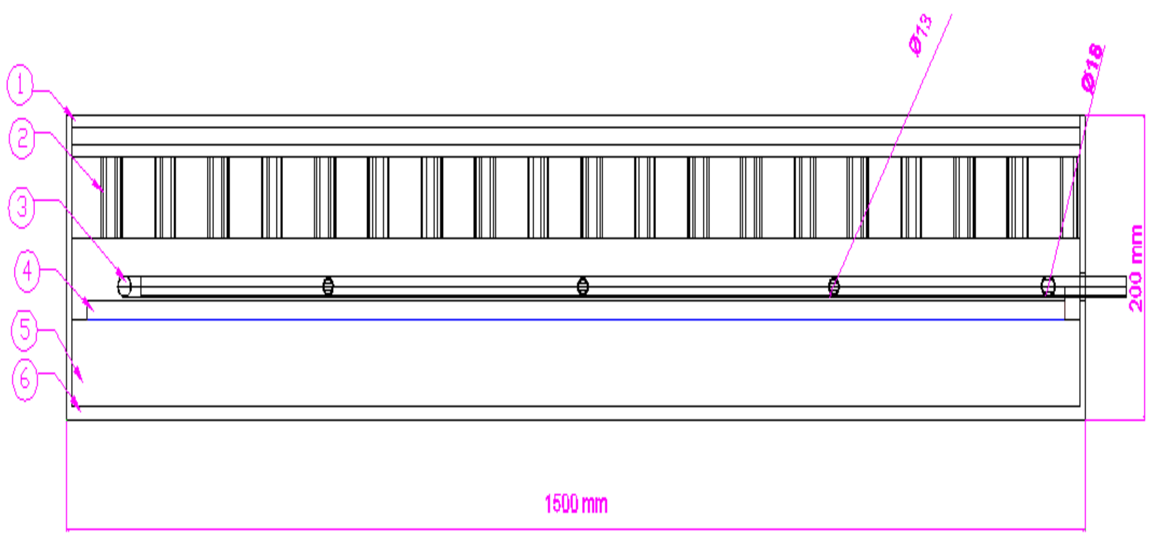


Figure 3.4 Final design of the prototype

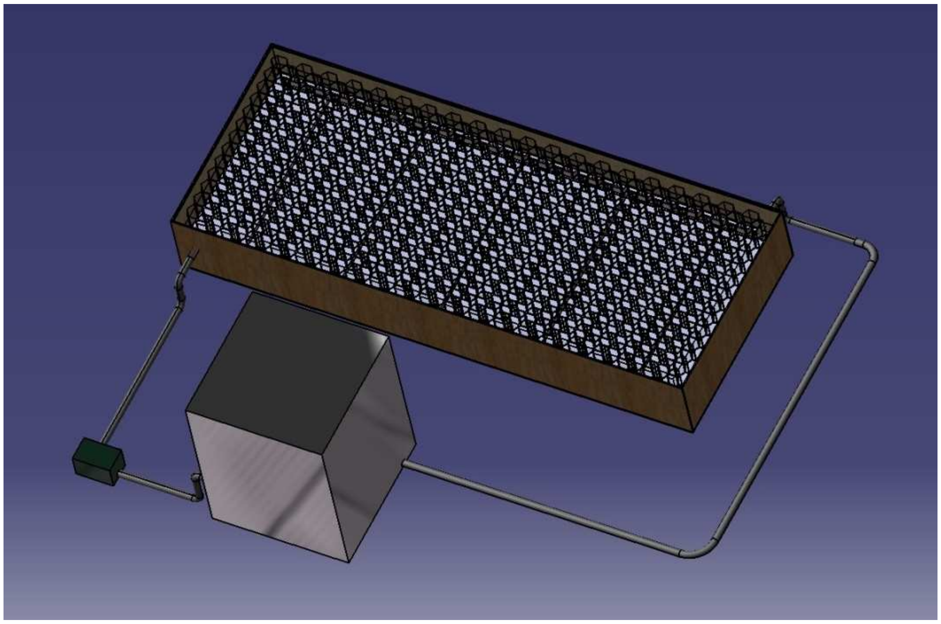

Figure 3.5 Drawing of the system of the flat plate collector

Since the earlier prototype is available in the lab, some of the materials will be taken for the available source to save the cost. All dimensions are recorded to be used in the refurbishment of flat plate collector.

Figure 3.5 Flat Plate Solar Collector available in the lab

## 3.7 EXPERIMENTS

The flat plate collector developed for this study was a low temperature device operating with the temperature range of ambient to 100°C. It absorbed solar energy consisting of both beam and diffused radiation and transferred heat to the working fluid that is water. The flat plate collector of fixed orientation was selected in view of the fact that the construction is easier, cost is low, requires no tracking, is easy to maintain and is widely available compared to concentrating collectors. Similar type of flat plate collectors are commercially used with water as working fluid for heating water of about 100 liters within a day. This system was modifies with the presence of transparent honeycomb as an insulation that will allow the heat to go through the collector but avoid it from being transmitted back to the surrounding to increase the efficiency of the solar collector. The performance of the collector with transparent honeycomb monitored by observing the variations of temperature at different locations and recorded at interval of 60 minutes.

Figure 3.7 Prototype is put outside the room for experiment

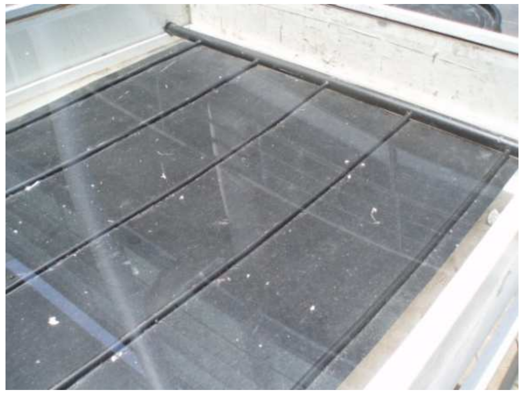

Figure 3.8 Flat plate solar collector without transparent honeycomb

Figure 3.9 Flat plate solar collector with transparent honeycomb


Figure 3.10 Pyranometer used to measure the solar radiation

Figure 3.11 Thermocouple and data logger used for the experiment

Figure 3.12 Flow meter used for the experiment

Figure 3.13 Connector with thermocouple to measure water temperature

# CHAPTER 4

# RESULTS AND DISCUSSION

## 4.1 RESULTS OF EXPERIMENTS

### 4.1.1 Solar collector without transparent honeycomb

Two experiments were done throughout the entire project to test the prototype that has been build. The first experiment was done with the flat plate solar collector without any modification made. The second experiment will be done with the transparent honeycomb being put in between the flat plate solar collector and the glazing. For the first experiment that is the solar collector performance without the transparent honeycomb, the test was conducted on 29$^{th}$ September 2010 (Wednesday) from 8 am to 6 pm.

After all the equipment has been set, the water is allowed to flow through the solar collector with the help of the pump. During the entire experiment, the important parameter is collected on hourly basis for analysis. Some of the parameter includes temperature of water inside the tank, collector temperature, solar radiation, ambient temperature, and glazing temperature. Flow rate of the water and volume of water was also recorded.

Table 4.1 Data recorded for experiment I

| Time, t | Temp of water inside tank, °C | Collector temp, °C | Solar Radiation, W/m² | Ambient temp, °C | Temp water in, °C | Temp water out, °C | Temp glazing, °C |
|---|---|---|---|---|---|---|---|
| 8 | 23.5 | 24.5 | 36.6 | 25.1 | 24 | 23.5 | 27.4 |
| 9 | 26.1 | 27 | 120.3 | 27.3 | 26.7 | 28.1 | 38.8 |
| 10 | 33.7 | 43.6 | 388 | 31.6 | 36.3 | 38 | 38.1 |
| 11 | 39.4 | 45.9 | 374 | 34.9 | 37 | 39.5 | 39.2 |
| 12 | 55.9 | 63.4 | 376 | 35 | 38.5 | 44.2 | 47.6 |
| 1 | 60.2 | 69.5 | 464 | 33.8 | 49 | 56.3 | 49.5 |
| 2 | 63.1 | 72.2 | 455 | 33.2 | 58.4 | 58.5 | 47.5 |
| 3 | 66.2 | 73.1 | 389 | 32 | 61.2 | 64 | 48.9 |
| 4 | 65.5 | 71.6 | 303 | 31.3 | 62 | 64.5 | 47.5 |
| 5 | 63.4 | 58.1 | 298 | 30.6 | 61.5 | 63.4 | 44.5 |
| 6 | 61.2 | 48.3 | 126 | 28.1 | 59.8 | 58.8 | 40.1 |

### 4.1.2 Solar collector with transparent honeycomb

For the second experiment that is the solar collector performance with the transparent honeycomb, the test was conducted on 5th October 2010 (Tuesday) from 8 am to 6 pm. The transparent honeycomb that has been build is put inside the solar collector between the glazing and flat plate. After all the equipment has been set, the water is allowed to flow through the solar collector with the help of the pump. During the entire experiment, the important parameter is collected on hourly basis for analysis. Some of the parameter includes temperature of water inside the tank, collector temperature, solar radiation, ambient temperature, and glazing temperature. Flow rate of the water and volume of water was also recorded.

Table 4.2 Data recorded for experiment II

| Time, t | Temp of water inside tank, °C | Collector temp, °C | Solar Radiation, W/m² | Ambient temp, °C | Temp water in, °C | Temp water out, °C | Temp glazing, °C |
|---|---|---|---|---|---|---|---|
| 8 | 23.5 | 24.6 | 33.2 | 25 | 23 | 24.3 | 27.1 |
| 9 | 25 | 27.1 | 155.5 | 26.9 | 24.6 | 25.8 | 28.4 |
| 10 | 29.8 | 44.6 | 247 | 30.9 | 27.9 | 30.3 | 34.2 |
| 11 | 40.5 | 47.9 | 368 | 33.4 | 35 | 36.7 | 40.1 |
| 12 | 57.2 | 59.5 | 402 | 32.6 | 55.1 | 58 | 43.3 |
| 1 | 63.5 | 72.3 | 447 | 33 | 60.2 | 64.6 | 45.6 |
| 2 | 68.3 | 76.2 | 461 | 33.2 | 67.7 | 69.1 | 52.1 |
| 3 | 69.8 | 79.8 | 367 | 31.6 | 68.4 | 71.1 | 53 |
| 4 | 68.5 | 76.6 | 329 | 29 | 68 | 69 | 51.9 |
| 5 | 67.7 | 63.1 | 303 | 27.9 | 66.5 | 67.9 | 51.2 |
| 6 | 65 | 57.1 | 176 | 26 | 64.1 | 66.3 | 48.9 |

Comparison between the data collected for both of the experiments is presented in form of graph

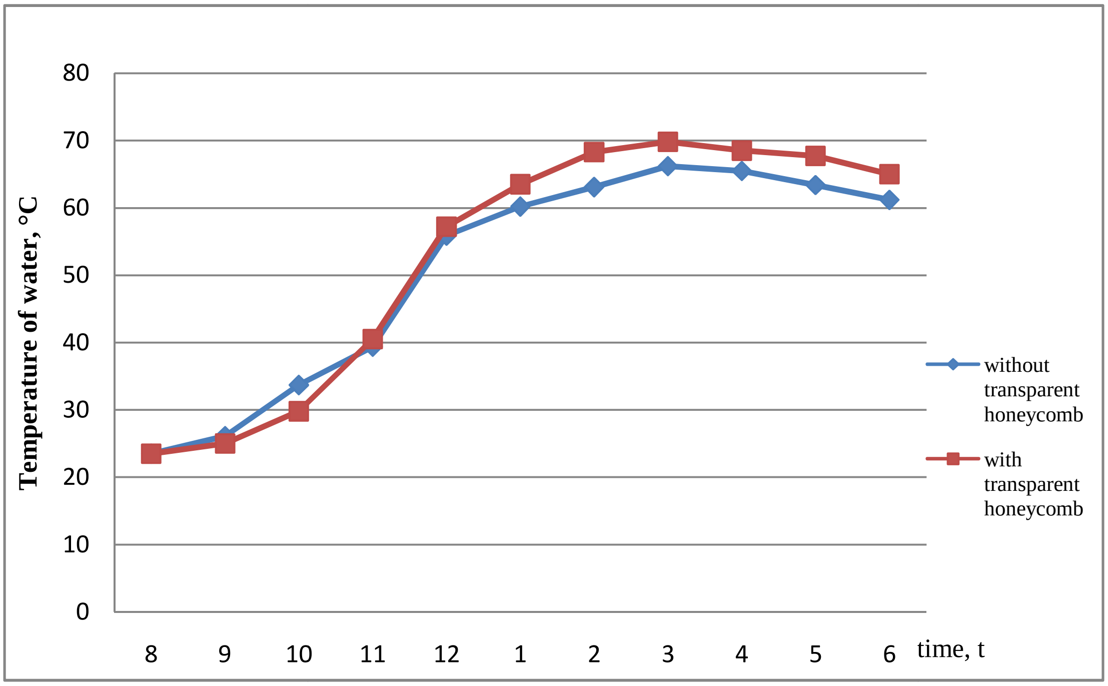


Figure 4.1 Temperature of Water Vs Time

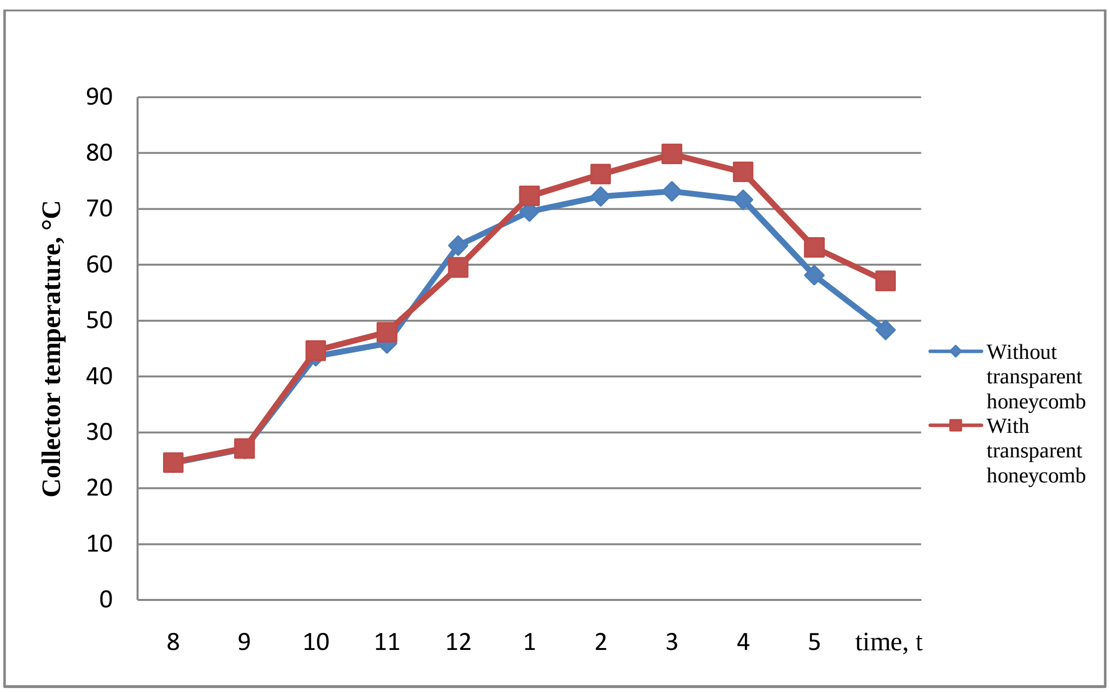


Figure 4.2 Temperature of Collector Vs Time

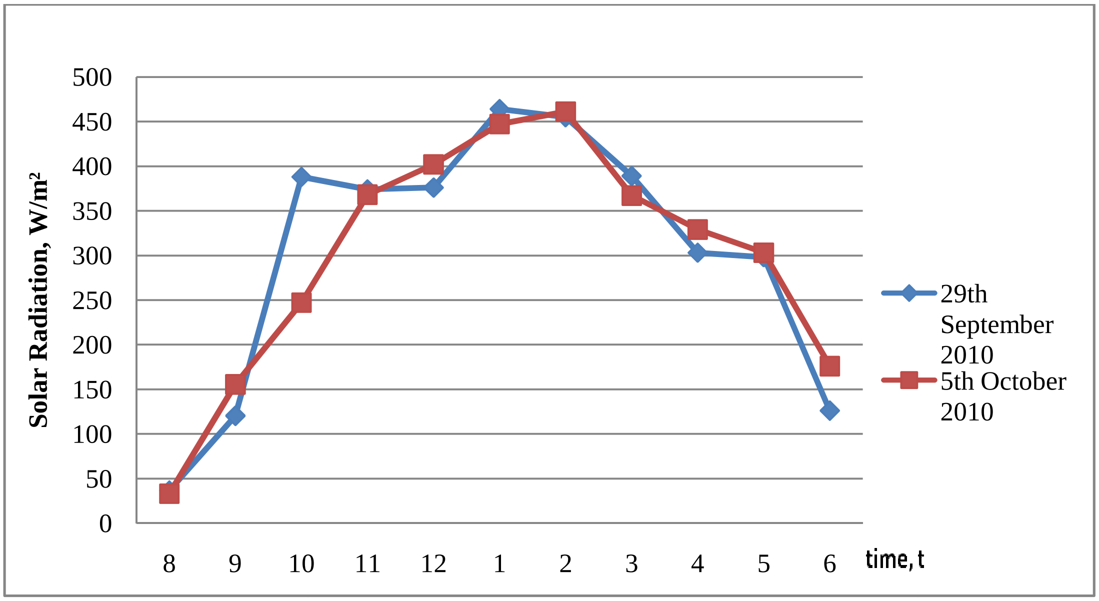


Figure 4.3 Solar Radiation Vs Time

Two experiments were done throughout the entire project. The first experiment was done with the flat plate solar collector without any modification made. The second experiment will be done with the transparent honeycomb being put in between the flat plate solar collector and the glazing. The experiments have been made and the results are recorded. The volume of water used throughout the experiments is 11.07 liters and the flow rate of the water is approximately about 0.5 liters per second. The solar radiation value for the two days is almost identical so the results that have been obtained can be compared. During the first experiment, the temperature of water rises about 42° to 66°C before fall to 61°C after several hours. For the second experiment, the water managed to reach higher temperature that is increased of 46° to 69°C. Although the increase is not very significant, but the water managed to maintain the temperature as by the end of the experiment, the temperature of water is about 65°. The usage of transparent honeycomb has managed to help improve the performance of the collector, thus increases the efficiency of the collector. The transparent honeycomb must be put in the correct position that is parallel with the glazing and collector with the correct thickness to get the maximum benefit.

In order to get the rate of heat loss of the water, the formula below is used:

$$Q_o = U_L A(T_c - T_a)$$

Table 4.3 Rate of Heat Loss

| Time, t | Rate of heat loss, Q (Watt) | |
|---|---|---|
| | without transparent honeycomb | with transparent honeycomb |
| 8 | -261.12 | -174.08 |
| 9 | -130.56 | 87.04 |
| 10 | 5222.4 | 5962.24 |
| 11 | 4787.2 | 6310.4 |
| 12 | 12359.68 | 11706.88 |
| 1 | 15536.64 | 17103.36 |
| 2 | 16972.8 | 18713.6 |
| 3 | 17886.72 | 20976.64 |
| 4 | 17538.56 | 20715.52 |
| 5 | 11968 | 15319.04 |
| 6 | 8791.04 | 13534.72 |

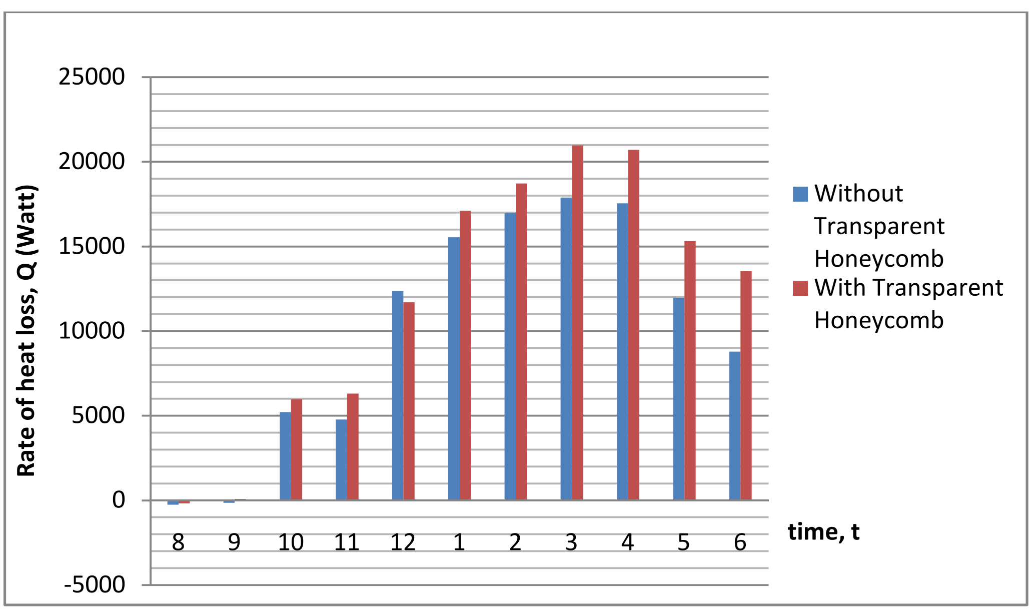


Figure 4. Rate of Heat Loss Vs Time

## 4.2 CALCULATIONS FOR EFFICIENCY

Experiment analysis of flat plate collector efficiency and comparison of performance with transparent honeycomb.

Average Solar radiation received by earth in terms of energy,

(Without transparent honeycomb)

R = 3229.9 $W/m^2/hr$

= 11627640 $Ws/m^2$

Average Solar radiation received by earth in terms of energy,

(With transparent honeycomb)

R = 3288.7 $W/m^2/hr$

= 11839320 $Ws/m^2$

Area of flat plate solar collector,

A= Length x Width

= (1.6 x 0.8) $m^2$

= 1.28 $m^2$

Radiation receive by collector without transparent honeycomb,

R1 = R x A

= 11627640 $Ws/m^2$ x 1.28 $m^2$

= 14883379 Joules

Radiation receive by collector with transparent honeycomb,

R1 = R x A

= 11839320 $Ws/m^2$ x 1.28 $m^2$

= 15154329.6 Joules

Output of the collector without transparent honeycomb,

Q = M x Cp x (T2 – T1)

= 20 kg x4.187x103 KJ/KG ºK x (61.2 – 24) K

= 3115128 Joules

Output of the collector with transparent honeycomb,

Q = M x Cp x (T2 – T1)

= 20kg x 4.187x103 KJ/KG ºK x (65 – 23) K

= 3517080 Joules

Efficiency of collector without transparent honeycomb,

η = Output of the collector / Input Radiation

η = M x Cp x (T2 – T1) / R x A

= 3115128 Joules / 14,883,379 Joules

= 20.93%

Efficiency of collector with transparent honeycomb,

η = Output of the collector / Input Radiation

η = M x Cp x (T2 – T1) / R x A

= 3517080 Joules / 15154329.6 Joules

= 23.21%

Comparison of efficiencies for flat plate collectors without and with transparent honeycomb

Table 4.4 Efficiency of Solar Collector

| **Efficiency of flat plate collector without transparent honeycomb** | **Efficiency of flat plate collector with transparent honeycomb** | **Increase in Percentage of efficiency due to the presence transparent honeycomb** |
|---|---|---|
| 20.93% | 23.21% | 10.89 % |

From the above calculation, we can conclude that by providing the transparent honeycomb to the collector we can improve the efficiency of the system to about 11%

## 4.3. CALCULATIONS FOR PROTOTYPE SCALE

Average solar radiation (MJ/ $m^2$) based on meteorological data for one day for the year 2003 in Ipoh.

Table 4.5 Average solar radiation

| Month | Solar radiation (MJ/$m^2$) |
|---|---|
| January | 13.93 |
| February | 11.38 |
| March | 14.29 |
| April | 12.61 |
| May | 18.87 |
| June | 18.93 |
| July | 17.44 |
| August | 18.19 |
| September | 18.14 |
| October | 16.63 |
| November | 6.74 |
| December | 18.40 |

**Based on the data above, the daily average for solar radiation = 15.46 MJ/$m^2$.**

Amount of water needed for a family of 4,

For 1 person per day, V = 15 gallons (15 gal (US Liq) = 0.056781 $m^3$)

For the entire family, V = (15 x 4) gallons = 60 gallons

$$\mathbf{V = 0.45\ m^3}$$

Energy required to heat a volume of (V) of water

$E_h = \rho V c \; (T_h - T_i)$

$= (1000 \text{ kg/ m}^3)\ (0.450 \text{ m}^3)\ (4190 \text{ J/ kg.K})\ ((50 - 27)\text{K})$

**= 43. 37 MJ**

$\rho$ = water density (kg/m³)

V = water volume ($m^3$)

C = specific heat of water (J/kg.K)

T = temperature (K)

Total energy collected,

$E_s = A_c \eta_m H$

Area of a flat plate collector will be,

$$A_c = \frac{E_s}{\eta_m H}$$

$$= \frac{43.37\ MJ}{(0.3)(\ 15.46\frac{MJ}{m^2})}$$

**= 9.35 m²**

$E_s$= solar energy collected (MJ)

$\eta_m$= mean system efficiency (assume 30% for the flat plate)

H = solar radiation ($MJ/m^2$)

Prototype will have the area of 1.28 $m^2$ (1.6m x 0.8 m)

**The scale of prototype will be 1:7.**

# CHAPTER 5

# CONCLUSIONS AND RECOMMENDATIONS

## 5.1 CONCLUSIONS

Solar collector design can be improved with the use of transparent insulation honeycomb that is put between the glazing and absorber. Honeycomb can reduce the losses of the heat at the top of the solar collector thus increase the efficiency of the flat plate collector. The prototype was build based on the design that has been made. Next, experiments were conducted with the prototype and the transparent honeycomb to test the theory. The results gain from the experiment was analyzed and compared to the previous experiment. A full report was made based on the findings.

The use of honeycomb in solar collectors has the benefit of reducing the top heat loss and also the penalty of decreasing the optical efficiency. From the experiment that has been conducted and data that has been analyzed, it shown that the usage of transparent honeycomb has increases the efficiency of the solar collector for about 10.98% and with further enhancement to the prototype, the value might increase. But, unless proper design of the honeycomb is accomplished, the honeycomb may deteriorate the collector performance. Apart from the honeycomb material and aspect ratios, the proper design involves adequate thickness of honeycomb and appropriate gap thickness above and below the honeycomb must be taken into consideration.

## 5.2 RECOMMENDATIONS

As recommendation, it is suggested that the design of the flat plate collector being improved to include transparent honeycomb. Other final year students should take the opportunity to research further on this subject so that other improvement can be made to the solar collector.

For the transparent honeycomb, research regarding layered honeycomb can be made to determine the effect of the layer to the performance of the flat plate solar collector. Beside that, other area that can be put into consideration for improvement of flat plate solar collector is to put the tracking mechanism on the collector so that it will be able to obtain maximum energy.

Hopefully other students taking final year project subject in the future can continue to do topic on flat plate solar collector and suggest other ways to enhance the performance of the collector.

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## LIST OF APPENDICES

## APPENDIX A: GANTT CHART FOR FYP I

| No | Detail / Week | 1 | 2 | 3 | 4 | 5 | 6 | 7 | | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Selection of project topic and submission of project proposal | ■ | ■ | | | | | | Mid-Sem Break | | | | | | | |
| 2 | Preliminary research work based on the journal and book related to project | | ■ | ■ | ■ | | | | | | | | | | | |
| 3 | Submission of preliminary report | | | | | ■ | | | | | | | | | | |
| 4 | Work on early design for the prototype | | | | | ■ | ■ | ● | | | | | | | | |
| 5 | Submission of progress report | | | | | | | | | ■ | | | | | | |
| 6 | Seminar | | | | | | | | | ■ | | | | | | |
| 7 | Develop final design based on all the info that has been obtained and calculated | | | | | | | | | ■ | ■ | ■ | ■ | ■ | ● | |
| 8 | Submission of interim report final draft | | | | | | | | | | | | | | | ■ |
| 9 | Oral Presentation | During study week | | | | | | | | | | | | | | |

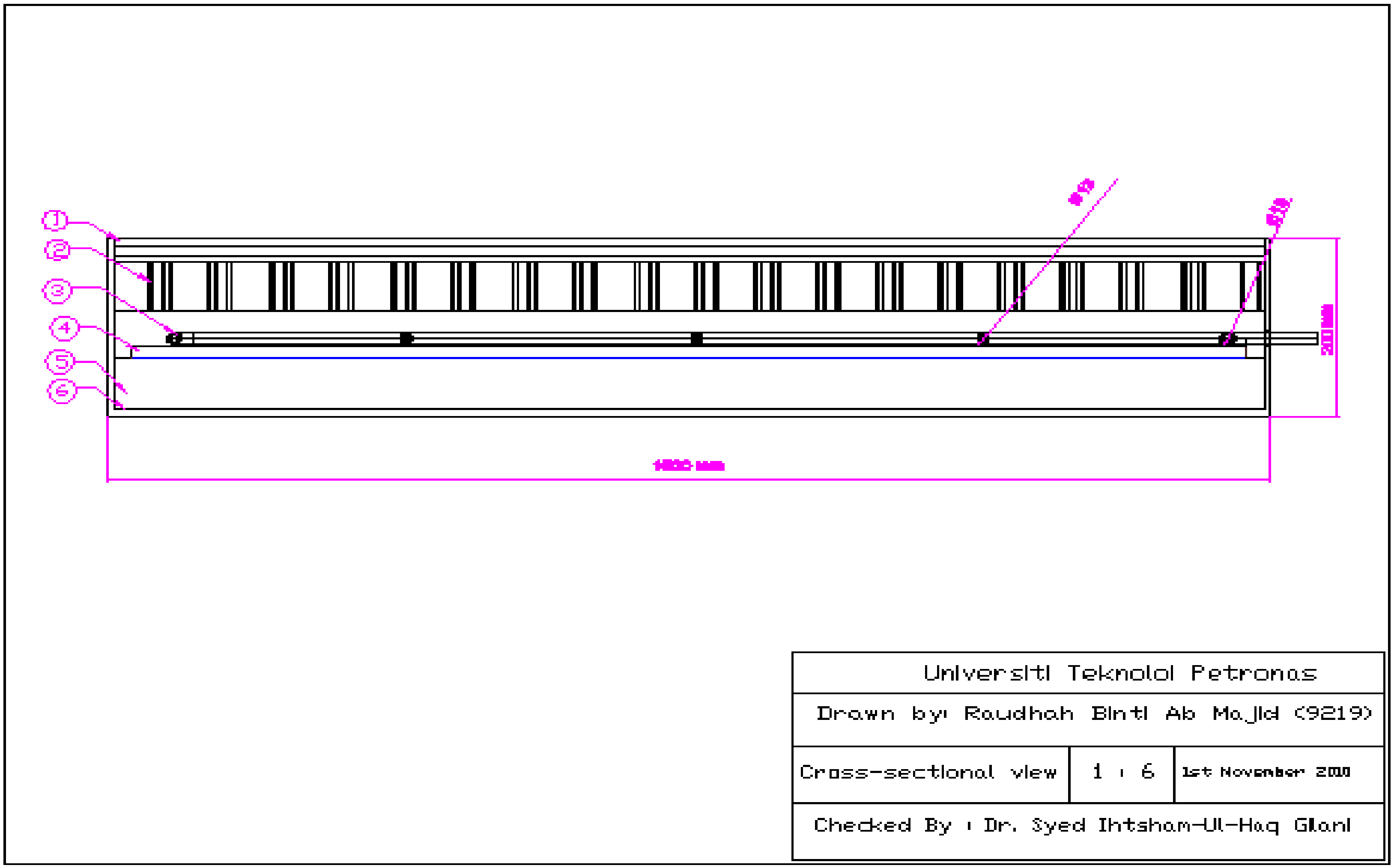
| | |
|---|---|
| ● | Milestone |
| ■ | Process |

## APPENDIX B: GANTT CHART FOR FYP II

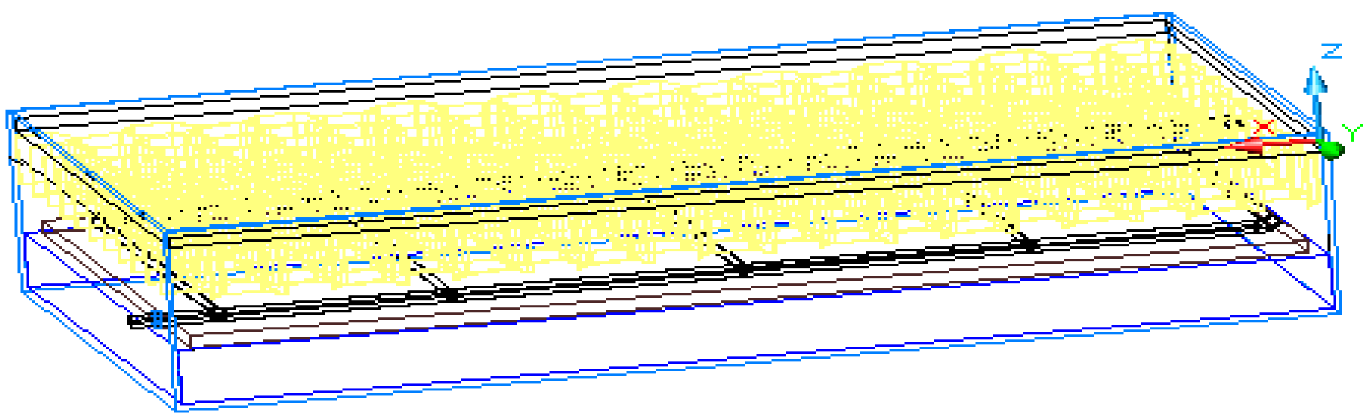
| No | Detail / Week | 1 | 2 | 3 | 4 | 5 | 6 | | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Project work continues | ■ | ■ | ■ | | | | **Mid-Sem Break** | | | | | | | | |
| 2 | Submission of progress report I | | | | ● | | | | | | | | | | | |
| 3 | Project work continues | | | | ■ | ■ | ■ | | | | | | | | | |
| 4 | Submission of progress report II | | | | | | | | | ● | | | | | | |
| 5 | Seminar | | | | | | | | | ● | | | | | | |
| 6 | Project work continues | | | | | | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| 7 | Poster Exhibition | | | | | | | | | | | | ● | | | |
| 8 | Submission of dissertation final draft | | | | | | | | | | | | | | | ● |
| 9 | Oral Presentation | During study week | | | | | | | | | | | | | | |
| 10 | Submission of dissertation (hard bound) | 7 days after oral presentation | | | | | | | | | | | | | | |

| | |
|---|---|
| ● | Milestone |
| ■ | Process |

## APPENDIX C: DRAWING FOR PROTOTYPE (CROSS-SECTIONAL VIEW)



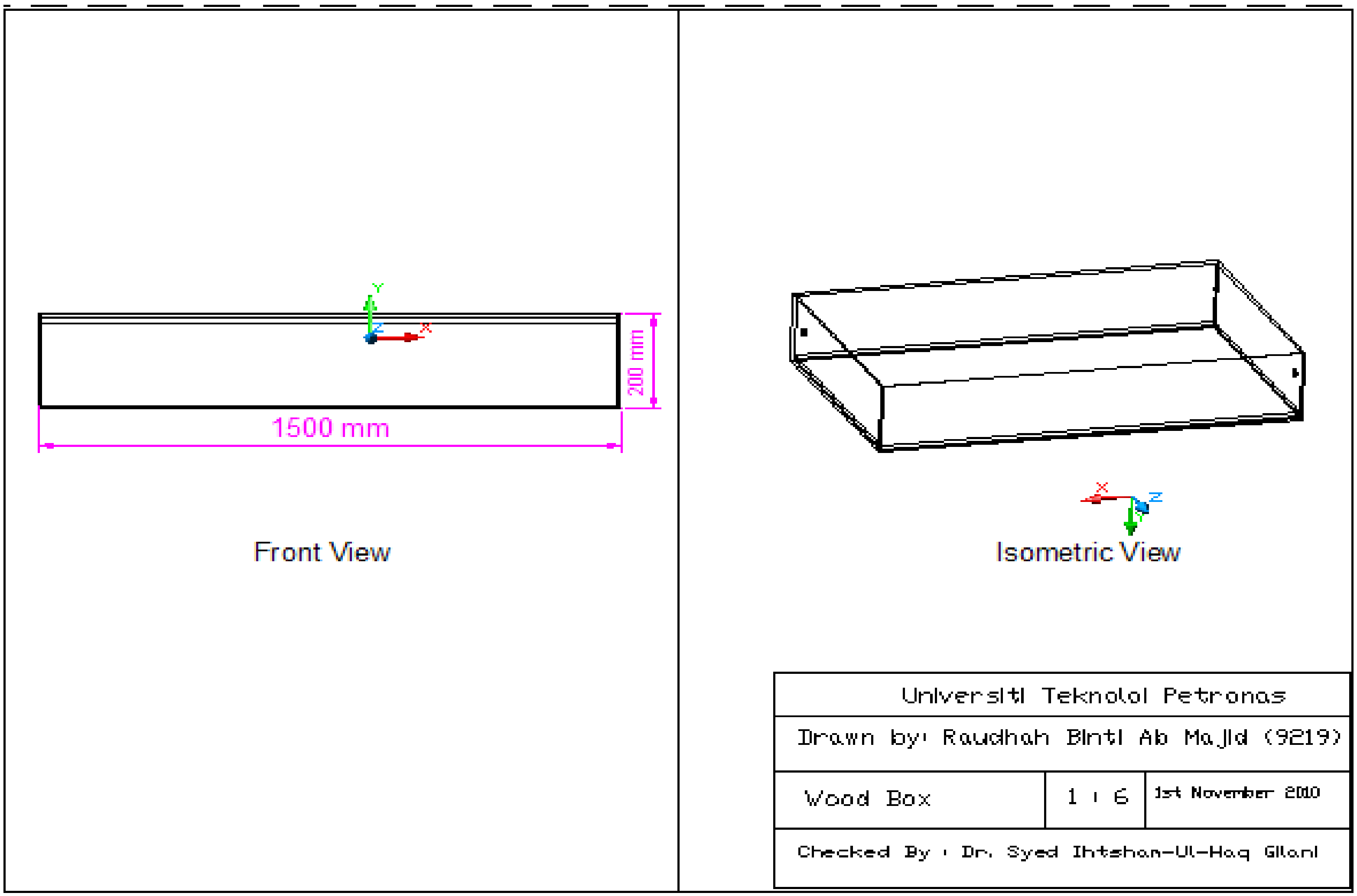
**APPENDIX D: DRAWING FOR PROTOTYPE (ISOMETRIC VIEW)**




Isometric View

| Universiti Teknoloi Petronas | | |
|---|---|---|
| Drawn by: Raudhah Binti Ab Majid (9219) | | |
| Isometric View | 1 : 6 | 1st November 2010 |
| Checked By : Dr. Syed Ihtsham-Ul-Haq Gilani | | |

## APPENDIX E: DRAWING FOR PROTOTYPE (WOOD BOX)



**APPENDIX F: BILL OF MATERIALS**

# Bill of Materials

| Part No | Description | Thickness | Materials |
|---|---|---|---|
| 1 | Glazing | 4 mm | Glass |
| 2 | Transparent Honeycomb | 75 mm | Plastic |
| 3 | Risers | 1 mm | PVC |
| 4 | Absorber | 1 mm | Copper |
| 5 | Insulator | 75 mm | Fiber Glass |
| 6 | Wood Box | 8 mm | Wood |