ENERGY PROJECTION ANALYSIS OF SOLAR ENERGY FOR WATER PUMP SYSTEM USING GRIDLINE POWER WITH FOCUS ON CONTROL SYSTEM

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(Ahmad Basirul Subha Alias)
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Energy Projection Analysis of Solar Energy for Water Pump System Using Gridline Power with Focus on Control System

CHRISTOPHER CHAN SING KONG

Report submitted in fulfilment of requirements
for the award of the degree of
Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering
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JUNE 2013

SUPERVISOR'S DECLARATION

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STUDENT'S DECLARATION

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

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I specially dedicate to my parent, family and those who have help guided and motivated me for this project.

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ABSTRACT

Experiment is undertaken to determine the possibilities of creating a solar powered pump system to reduce the power wastage in an Evacuated Tube Solar Collector water circulation system at Pekan campus (3˚ 30' N, 103˚ 25' E) Faculty of Mechanical Engineering, University Malaysia Pahang. The experiment kicks off by creating a test rig to hold the solar panel in place and creating a cut-in cut-out (CiCo) system to help reduce the pump energy consumption. CiCo system is developed to cut-in and cut-out the pump based on the temperature difference between the Evacuator outlet and the storage tank. Malaysia lies in the equatorial zone with an average daily solar insolation of more than 900 W/m^2 and can reach a maximum of 1200 W/m^2 for most of the year. Due to different weather pattern which will block and reduce the solar isolation, CiCo system can help reduce the power consumption of the pump when the temperature has reach the threshold set in the codding set in PIC18F4550 detected by two thermostat LM35DZ. G.T. Power RC Wattmeter is connected to a solar panel to determine the total energy output of the panel. A multifunctional mini ammeter is connected to the pump to measure the energy consumption of the pump with or without connecting the CiCo system. Based on the experiment the maximum panel required to create a solar powered pump system without using the CiCo system is 18 panels. However when connected to CiCo system the number of panel required is decreased to five panels. This show the minimum required panel if UMP decided to create a solar powered pump system in the campus.

ABSTRAK

Eksperimen ini dijalankan untuk menentukan kemungkinan mewujudkan sistem pam tenaga solar untuk mengurangkan pembaziran tenaga dalam sistem peredaran air ETSC di kampus Pekan (3˚ 30' N, 103˚ 25' E) Fakulti Kejuruteraan Mekanikal, Universiti Malaysia Pahang. Eksperimen ini bermula dengan mewujudkan satu pelantar ujian untuk panel solar dan mewujudkan sistem buka dan tutup pam (CiCo) untuk membantu mengurangkan penggunaan tenaga pam. Sistem CiCo direka untuk buka dan tutup pam berdasarkan perbezaan suhu di dalam ETSC dan juga tangki simpanan. Malaysia terletak di zon khatulistiwa dengan purata kuasa solar harian lebih daripada 900W/m^2 dan boleh mencapai 1200 W/m^2 bagi keseluruhan tahun. Disebabkan corak cuaca yang berbeza yang akan menghalang dan mengurangkan kuasa solar, sistem CiCo ini boleh membantu mengurangkan penggunaan tenaga pam apabila suhu telah mencapai had yang ditetapkan dalam PIC18F4550 yang dikesan oleh dua buah termostat LM35DZ. G.T. RC alat pengukur watt disambungkan kepada panel solar untuk menentukan jumlah tenaga panel. Sebuah ammeter pelbagai fungsi disambungkan kepada pam untuk mengukur penggunaan tenaga pam tanpa menyambung sistem CiCo dan menyambung system CiCo. Berdasarkan eksperimen panel maksimum yang diperlukan untuk mewujudkan satu sistem pam solar tanpa menggunakan sistem CiCo ialah 18 panel. Walau bagaimanapun apabila disambung kepada sistem CiCo bilangan panel yang diperlukan dikurangkan kepada lima panel sahaja. Ini menunjuk had minimum yang diperlukan jikalau pihak UMP hendak mewujudkan system pam kuasa solar.

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η	Efficiency of the system
GT	Global solar radiation, W/m^2
n	Leap year/ Non leap year + Day
β	Angle made by the plane surface with the horizontal
I_{sc}	Solar constant
δ	Declination angle
ω_{st}	Hour angle
N_{MAX}	Monthly average of maximum possible sunshine hours per day, in hours
H_O	Monthly average of daily extra-terrestrial radiation on a horizontal surface, $kJ/m^2.day$
H_g	Monthly average of daily global radiation on a horizontal surface, $kJ/m^2.day$
a, b	Regression coefficients which vary from site to site
H_d	Monthly diffuse radiation, $kJ/m^2.day$
H_b	Monthly beam radiation, $kJ/m^2.day$
β_{opt}	Optimum angle
I_c	Solar radiation at collector, W/m^2
P_m	Power output, W
E	Input light, W/m^2
A_c	Area of solar cell, m^2

LIST OF ABBREVIATIONS

ETSC	Evacuated Tube Solar Collector
ETC	Evacuated Tube Collector
UMP	Universiti Malaysia Pahang
ETC	Evacuated Tube Collector
PV	Photovoltaic
FKM	Fakulti Kejuruteraan Mekanikal
CiCo	Cut-in Cut-out
AC	Alternating Current
DC	Direct Current
adc	Analog
TEMP	Temperature

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

The sun is the centre of our solar system. Without sun, it is impossible for a human or living creature to live in this world. During recent years the issue about global warming has become a hot topic among mankind. One of the main contributors towards global warming is the burning of fossil fuel to generate power. To help save Mother Earth, many ideas and design have been brought up to utilize the renewable energy around us such as solar panel, wind turbine geothermal power plant, hydro power station etc.

For a country like Malaysia which sits at the equator of the Earth, harnessing the power of the sun is well encouraged in this country. Malaysia practically haves sunlight shining on it every day without the effect of changing seasons and reduction in daylight time. Photovoltaic (PV) panel and Evacuated Tube Solar Collector (ETSC) is just some of the solar panels available in the market. PV panel converts sunlight directly to electric current and ETSC hat up working fluid with solar energy.

The current ESTC that have been installed in University Malaysia Pahang Pekan Campus uses a pump which runs on AC power from the grid line. The Author approach to this design is to create a pump cut-in and cut-out system based on temperature difference at the ETSC outlet and the storage tank to help reduce the pump energy consumption. To further improve the design, the Author would conduct an energy projection analysis to determine the minimum panel required to create a solar powered pump system.

1.2 PROBLEM STATEMENT

Evacuated tube solar collector (ESTC) is used as the primary solar collector in University Malaysia Pahang Pekan Campus. However during hot weather, the systems will experience high stagnant temperature. The present ESTC water pump is supplied by grid line electricity and run continuously without any regards towards the weather condition.

This system posted a few problems toward the faculty. When there is an electricity outage, the pump will lose its power and stop functioning. The evacuated tube solar collector will face the risk of breaking if the stagnant temperature is too high due to pressure build up by the steam in the collector.

The current pump system is also operated by timer system which causes energy wastage. The pump will continue to operate even when the weather is bad due to rain or cloud. A system must be created to detect the changing in temperature at the Evacuator tube solar collector outlet and within the storage tank, to turn on the pump when necessary to ensure there is no energy wastage and to ensure that the evacuated tube collector will be able to perform at its best condition.

To create a much more environmentally friendly system, a decision is made to reduce or remove the reliance on grid line electricity by introducing the solar PV panel as the main source of electricity power. To minimize the cost for panel installation an energy projection analysis is needed to determine the minimum solar panel required to ensure that the pump can operate when needed.

1.3 PROJECT OBJECTIVES

The main objectives of "Energy Projection Analysis of Solar Energy for Water Pump System Using Gridline Power with Focus on Control System" projects are:

i. To develop an energy projection analysis of solar energy for water pump system using gridline power with focus on control system
ii. To design, analysis and fabricate the bracket for solar panel.
iii. To design and fabricate a control system to control the pump cut-in and cut-out based on the temperature differences.
iv. To determine the minimum solar panel required to create a solar powered pump system.

1.4 PROJECT SCOPE

This project is focused to design and build a solar powered pump system that act as a cooling system for the solar collector to ensure it does not overheat.

Therefore, this project will cover the scope as follows.

i. To design and fabricate a temperature control system for the pump.
ii. To calculate the optimum tilt angle for fix panel in Pekan.
iii. Design, analysis and fabricate a test rig to hold the solar panel at fix angle.
iv. To monitor the PV panel output to determine the minimum required panel for the pump system.
v. To monitor the pump energy usage on and off the CiCo system to determine the amount of power saved.
vi. To collect the data from 9.00 a.m. to 6.00 p.m. to gain the required data for analysis.

1.5 GRANTT CHART

Figure 1.1: Grantt Chart for PSM1

PROJECT ACTIVITY	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
Discussion With Supervisor	■													
Verify The Project Title, Scope And Objective	■	■												
Literature Review	■	■	■	■	■	■	■	■	■	■	■			
Calculation For Tilt Angle				■										
Draft Design for Test Rig				■										
Selecting Suitable Control System				■	■									
Market Survey On Component					■	■								
Fabrication Of Control Circuit							■							
Test Run Of Control Circuit							■							
Report Writing							■	■	■	■	■	■	■	■
Submit Draft and Log Book											■			
Presentation FYP 1													■	

Figure 1.2: Grantt chart for PSM2

PROJECT ACTIVITY	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15
Fabricating of Test Rig															
System set-up															
Testing on System and equipment															
Data Collection															
Analysis Data															
Report Writing															
Submit Draft and Log Book															
Presentation FYP 2															

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This literature review explores about the major scopes in this report which are solar energy, evacuated tube solar collector, photovoltaic panel and solar pump system. The literature review provides a background to the study being proposed. The background may consider previous findings, rationale of the relevant study, methodology or research methods, and theoretical background. Most of the literature reviews have been extracted from journals, books and web site. This is important because this helps avoid the same mistakes made by the previous study. Therefore, with these literature reviews, the project can be run smoothly.

2.2 RENEWABLE ENERGY

Renewable energy is the sources of energy which will always be available. Based on the law of thermodynamics energy is considered to be finite. Renewable energy is the form of energy which would one day finish, however due to the abundance of supply there is no foreseeable end in our or our children's lifetimes. While this energy must be finite, due to entropy and the laws of thermodynamics, the supply is so large that there is no foreseeable end in our or our children's lifetimes. (The Franklin Institute, 2012)

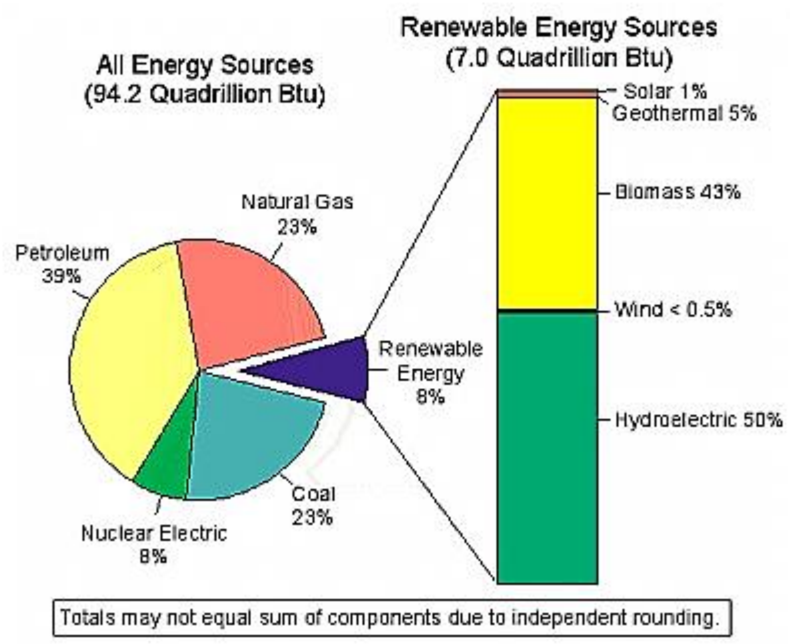

Figure 2.1: World Energy Sources

Source: The Franklin Institute (2012)

Figures 2.1 show the types of energy sources uses through the world and their percentage. Renewable energy only supply around 8 % of the energy source. This is mainly because the high initial cost if compare with the other major energy sources supply such as fossil fuels and uranium. However, as the world run out of our supply of fossil fuels and uranium or the cost of these fuels rises for economic or political reasons, the cost of renewable energy may become much more competitive.

The other important advantage of renewable energy is that it produces much less pollution. Some people believe that if the true costs of pollution, like the medical costs of cancer, were factored into the cost of fossil fuels and uranium, that renewable energy is already cost effective and should be used much more often.

Another requirement to make renewable energy more competitive is more research. The United States government has cut funding for research into solar and other renewable energy. This has left the United States even more likely to be dependent on oil imports far into the future.

2.3 SOLAR ENERGY

The sun is the centre of our solar system. It has been burning and supplying us with solar energy for an average of 4.5 billion years. Astronomers believe the sun has enough fuel supply to burn another 5 billion years. (Elish, 2006).This solar energy is considered one of the best renewable energy because of its sustainability. Lives on earth start from the radiation receive from the sun. This energy is generated when the hydrogen in the sun's core fuse together to become helium. During the process of fusion part of the mass of the hydrogen converted into energy. In a sense, the sun is a huge fusion reactor. (Deutsche Gesellschaft Fur Sonnenenergie , 2012).

The distance between the earth and the sun changes constantly through the year between 1.47×10^8 km and 1.52×10^8 km as shown in Figure 2.2. This causes the amount of solar radiation or irradiance varies between 1325W/m^2 and 1412W/m^2.The average value is denoted as the solar constant:

Solar constant: E_a = 1367W/m^2

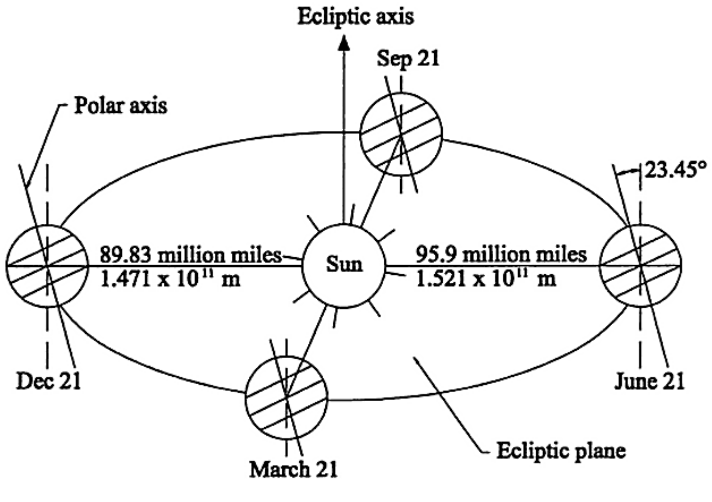

Figure 2.2: Distance of earth from sun

Source: Goswami, Kreith, & Kreider (2000)

Solar radiation or better known as insolation varies according to condition. Although cloud and weather also affect the amount of insolation, however since it is unpredictable and irregular, thus it is difficult to predict the amount of insolation receive accurately. The two major reason of changing in solar radiation which is fixed are the location as the earth rotates on its axis around the earth together with the angle and duration of solar intensity at the given area. One of the ways to determine the amount of solar radiation is by using Lambert's Law, which is the name for an 18th century German scientist, Johann Lambert. Lambert developed a formula where the intensity of irradiance can be calculated using the angle of the sun's zenith angle or the angle of the sun from 90° directly overhead. By using Lambert's law one can calculate the amount of solar radiation based on the latitude. (Petersen, Sack, & Gabler, 2011)

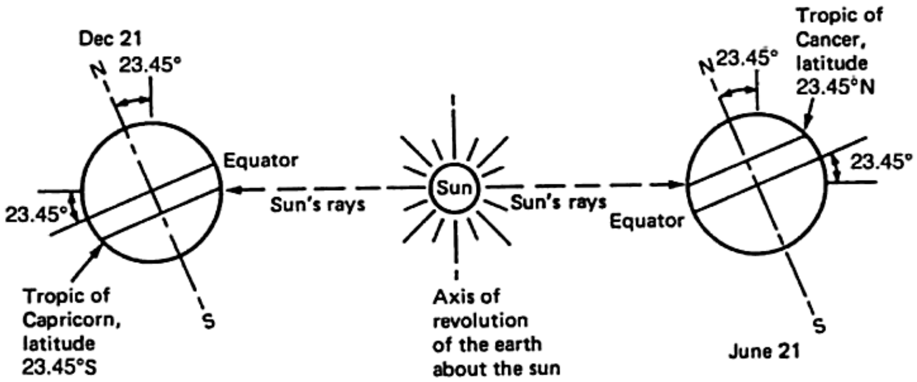

Figure 2.3: The Earth rotates around the sun at axis 23.45°

Source: Goswami, Kreith, & Kreider (2000)

Malaysia is a blessed country for it is placed near the equator. This mean Malaysia is a very suitable place to develop its solar project. There is no changing of season to affect the amount of solar radiation collected. The only thing influences the variation in solar radiation are the cloud and the monsoon. University Malaysia Pahang Pekan Campus is placed at latitude: 3.54° and Longitude: 103.44°. (Zwiefelhofer, 2012)

Tilted angle and the direction where the solar panel is pointing are very important to obtain the most energy from the sun. To optimize the system, solar panel should face true north in the southern hemisphere and true south in the northern hemisphere. The angle between the earth-sun line and the plane through the equator is called solar declination, δ. The solar declination is estimated using Eq. (2.1):

$$\delta = 23.45 \sin\left(360 \frac{284+n}{365}\right) \tag{2.1}$$

Source: Teliat, Falayi, & Rabiu (2001)

Where

n = the day number during a year with January 1 being n = 1.

n = Leap year/ Non leap year + Day

Table 2.1: number of n for each month

Months	**Non Leap Year**	**Leap Year**	**Date Equal To Monthly Average**
January	0	0	17
February	31	31	16
March	59	60	16
April	90	91	15
May	120	121	15
June	151	152	11
July	181	182	17
August	212	213	16
September	243	244	15
October	273	274	15
November	304	305	14
December	334	335	10

Source: Klein (1977)

Table 2.2 shows the average sunlight hours receive by Malaysia based on month. Each month Malaysia receives different amounts of sunlight hour since it is not on the equator but slightly above it. Based on Malaysian Meteorological Department, Malaysia receives an average of 6 hours of sun per day. Table 2.2 shows the amount of time within a month where one can expect the high amount of solar radiation.

Table 2.2: Average sunlight hours/day in every month

Month	Average Sunlight Hours/ Day
January	6.2
February	7.4
March	6.5
April	6.3
May	6.3
June	6.6
July	6.5
August	6.3
September	5.6
October	5.3
November	4.9
December	5.4

2.4 EVACUATED TUBE SOLAR COLLECTOR (ETSC)

ETSC is one of the solar thermal water systems available in the market. It can save money and reduce pollution compared to conventional energy sources. Solar thermal systems are cheap and efficient compared to solar photovoltaic systems, as making sunlight into heat is easier than making sunlight into electricity. Typical new thermal absorption coatings absorb 98 % of solar energy while commercial PV systems do well to change 15 % of incoming solar into electricity. (Wenham, 2006). Even when grid electrical power is available, solar hot water systems can pay for themselves in electrical energy savings. Solar water heating is a way consumer can save money in a “Green” way. (NRCan, 2003)

Evacuated tube collectors (ETC) are the most efficient (conversion efficiency of over 90 %). The collectors are usually made of parallel rows of transparent glass tubes. Each tube contains a glass outer tube and inner glass or metal tube attached to a fin as the absorber. Air is removed, or evacuated, from the space between the two tubes to form a vacuum, which eliminates conductive and convective heat loss.

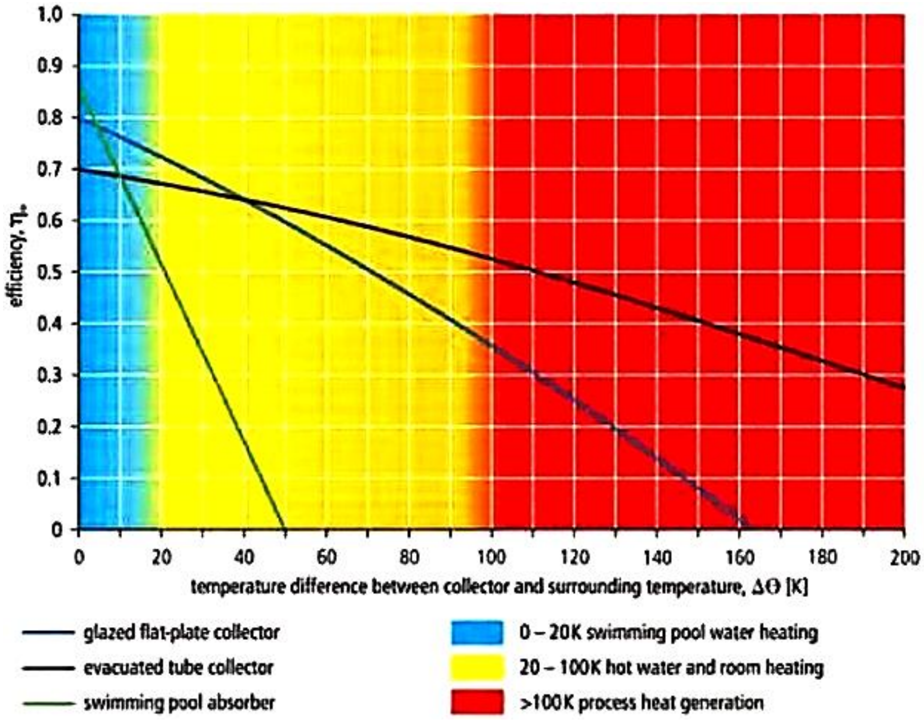

Figure 2.4: Efficiency Characteristic Curves for Different Types of Solar Collector and Their Areas of Application (at irradiation of $1000W/m^2K$)

Source: Earthscan (2012)

Figure 2.4 shows the amount of efficiency produce by different type of collector. ETSC shows the optimum amount of efficiency graph since the amount of efficiency drop is the smallest. For this project water will be used as the working fluid in the ETSC. Since the efficiency of ETSC is the highest overall between 27°C to 100°C which is for the average Malaysia room temperature and boiling point of water. ESTC is the best solar collector in Malaysia. Since the working fluid used is water, thus it will evaporate at 100°C. A control system will be design and fabricated in this project to ensure that the temperature inside the ETSC never reaches boiling point to protect it from damages.

2.5 PHOTOVOLTAIC

There are three types of solar photovoltaic panel in the market which is monocrystalline, polycrystalline and amorphous thin film. Different types of panel have different type of advantages and disadvantages which is shown in Table 2.3.

Table 2.3: Description, advantages and disadvantages of different type of solar panel

Type	**Description**	**Advantages**	**Disadvantages**
Monocrystalline	▪ Composed of cells cut from a piece of continuous crystal ▪ Black in colour	▪ Longer life span ▪ Performs better than a similarly rated polycrystalline solar panel at lower light and lower temperature conditions. ▪ Space efficient ▪ Efficiency rate around 12 % to 19 %	▪ Slightly more expensive than polycrystalline
Polycrystalline	▪ Blue in colour	▪ Cost less due to simpler making process ▪ Good in hotter weather ▪ Efficiency rate around 13 % to 16 %	▪ Not as efficient due to less pure silicon ▪ Need a larger area to produce same power output as monocrystalline
Thin-Film or Amorphous	▪ Not crystalline silicon	▪ Use least amount of silicon ▪ Can be made flexible and lightweight	▪ Less stable than crystalline, causing degradation over time ▪ Efficiency at 6 % - 9 %

Source: M & Rahman, 2012 and Energy Informative (2013)

2.6 PHOTOVOLTAIC CELL EFFICIENCY

Solar cell efficiency or also known as modulus of efficiency for the solar panel is the ratio of the electrical output of a solar cell to the incident energy receives from the sun. The energy conversion efficiency (η) of a solar cell is the percentage of the panel surface which is exposed to sunlight that is able to produce power. This is calculated by using Eq. (2.2).

$$\eta = \frac{P_m}{E \times A_c} \tag{2.2}$$

Where

η = modulus of efficiency, %

P_m = power output, W

E = input light, W/m^2

A_c = area of solar cell, m^2

The efficiency of each type of panel is different based on the environmental condition and location. Based on (Energy Informative, 2013) it shows that monocrystalline panel has an efficiency of 12 % - 19 %. Polycrystalline have an efficiency of 13 % - 16 % while thin films have an efficiency of 6 % - 9 %. This is mainly due to the material used to develop the panel. However the temperature and weather condition of each place will have different effects on the life span and efficiency of the panel.

2.7 TYPE OF PV SYSTEM

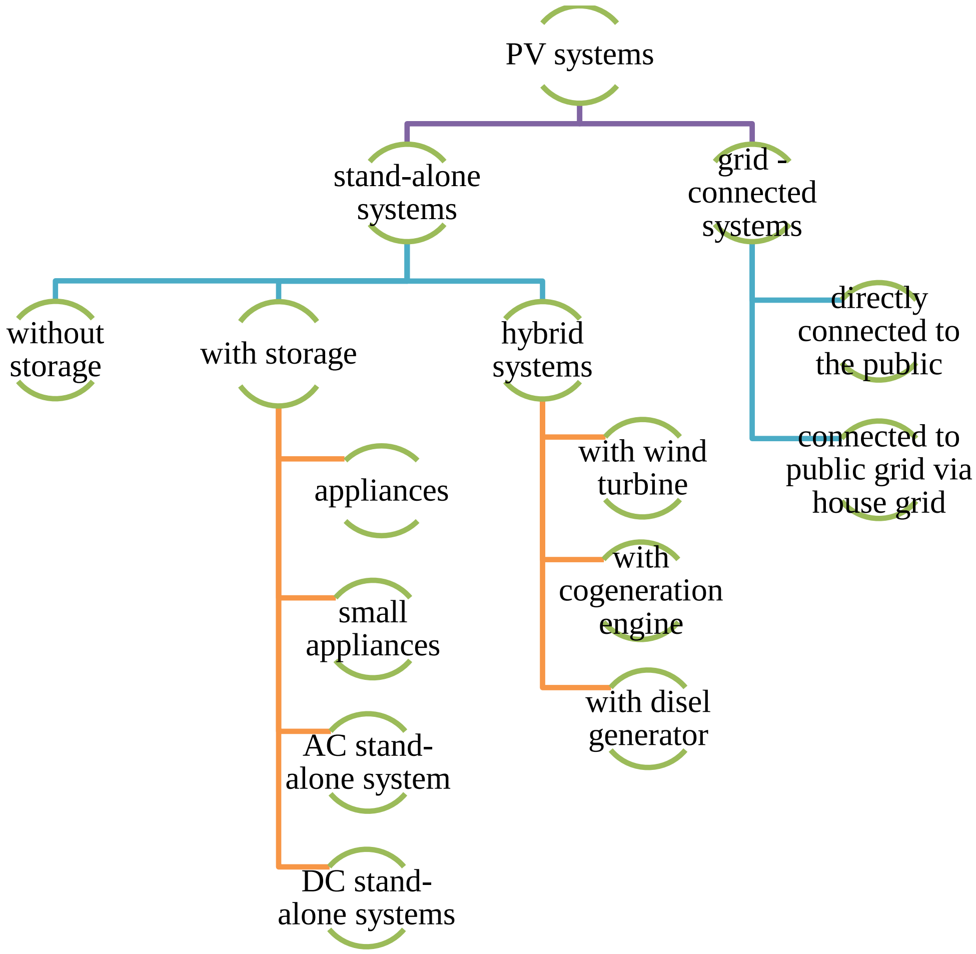

Figure 2.5: Type of PV system

Source: Deutsche Gesellschaft Fur Sonnenenergie (2012)

Figure 2.5 shows the type of PV system which is available and its subcategories. Photovoltaic system is categories into two distinct groups which is stand-alone systems and grid-connected systems. Energy produces in stand-alone system is usually coincided with the energy demand. However due to variable such as cloud and night time the energy produced is usually stored in batteries. Some of the system is connected with other power generator which then will be called hybrid systems. Grid-connected system occur when the energy produced is supplied into the grid and when there is a need of power will get it back from the grid. This system is greatly encouraged in

European country especially Germany where there is a premium feed in traffic for solar energy. (Yang, 2007)

Photovoltaic cells coupled with a solar circulator pump act as fast response sensors to solar energy, only running the pump when solar energy is available to heat the water. Electricity savings are realized exactly at peak air conditioning demand times, when the sun is shining. The timer based controller previously needed to turn the pump on and off can be eliminated. Properly matched to a pump, a direct coupled system will run whenever the sun is shining above a certain level; which is precisely the time that the solar thermal system will have the energy to give to the central storage tank. A directly coupled DC centrifugal pump would dispense with the electronic controller, the temperature sensors and the dependence of the solar thermal system on any type of grid electricity. Besides being economical, this simplicity has been cited as a selling point with North American consumers. (NAHB Research Center, 1998)

2.8 HOW SOLAR WATER HEATING WORKS

Solar thermal water heating systems use collectors to absorb the suns energy and transfer that energy a working fluid, which is then used to heat the water in a storage tank. All solar hot water systems have a means of collecting the solar heat, storing the heat, delivering hot water and controlling operation. (Deutsche Gesellschaft Fur Sonnenenergie, 2012). Some simple systems use basic physics-hot water rising-as the control. The placement of a solar water heating is the collector units are on the roof, while the storage tank is in the building below. A pump circulates the working fluid between the tank and the solar collectors when the working fluid at solar collector is higher than the water in the storage tank. (Smith & Fralick, 2012)

2.9 CIRCULATOR PUMP CONTROL

When there is high solar energy, the water must be circulated to efficiently and quickly remove the heat from the solar collectors to the storage tank, larger temperature differences between the working fluid and the solar collector absorbing surfaces mean more efficient heat transfer can be obtained. If the temperature difference between the solar collector and storage tank is large, then the rate of heat transfer is also large. But if the temperature difference is small, then no heat transfer will be able to take place. This condition happen at night, where there is little temperature difference therefore circulating pump is not required during this time. (Sukhatme & Nayak, 2009)

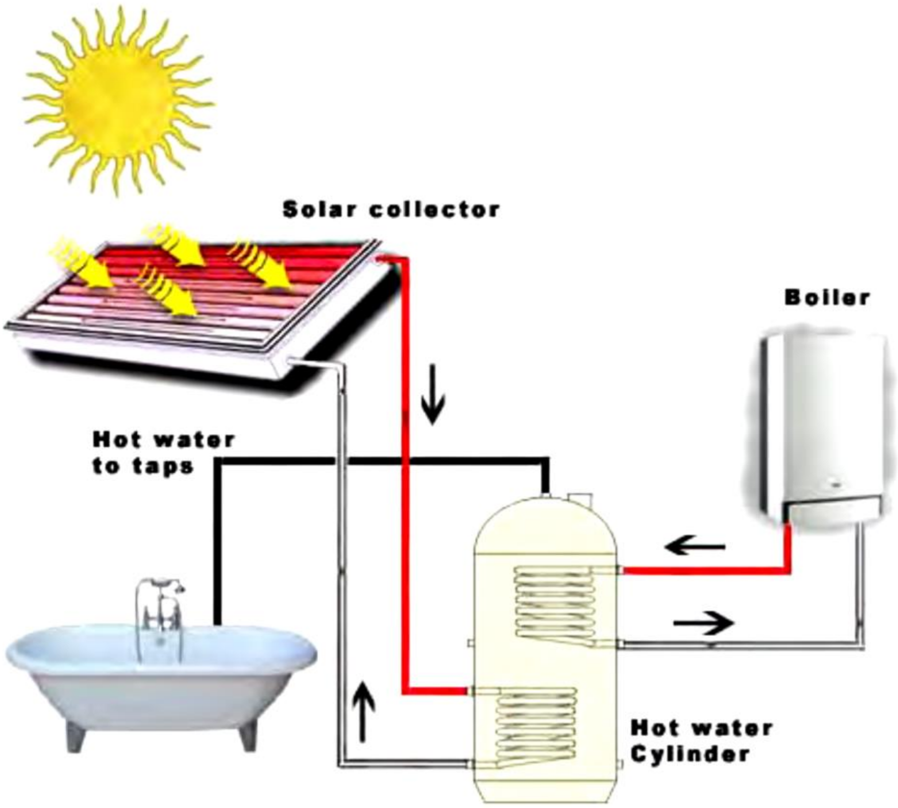

Figure 2.6: Typical solar hot water system with collector, tank, pump and heat exchanger.

Source: Gillies (2012)

In certain type of collectors, such as flat-plate, the working fluid might become cooler than the water in the central storage tank with the changes in weather, so that the solar collector turns into a heat radiator at night and in bad weather condition. In this case, circulating the water would cool the hot water from the tank and cost energy wastage. Thus a temperature sensors and a control unit are used to ensure that the pump only runs when a positive heat gain can be made by circulating water to the solar collector. Fouling of the temperature probes, software problems, and electrical disruptions to the controller is the main reason why temperature sensors and electronic controllers are the most problematic parts of a solar thermal system (Beckman, Thorton, Long, & Wood, 1994) and (Duffie & Beckman, 1991)

2.10 CONCLUSION

Based on the previous studies, the aim of the current experimental work is to study the amount of solar panel needed to power a pump system for an ETSC at Pekan and to determine the efficiency of the control system.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter explains details about the methodology of the whole system and flow of step that used in "Energy Projection Analysis of Solar Energy for Water Pump System Using Gridline Power with Focus on Control System". This chapter also describes further more about the planning of the whole project that is included about software and hardware development.

This chapter will discuss about the whole planning for Final Year Project (FYP) which include the planning for the setup of the project and the process involve in the project.

3.2 FLOW CHART

To ensure that the project is conducted within the time frame given and within scope a flow chart must be drawn out. Figure 3.1 shows the flow chart of the overall project for the whole year. By following the flow chat, the project is conducted smoothly and without any major problem.

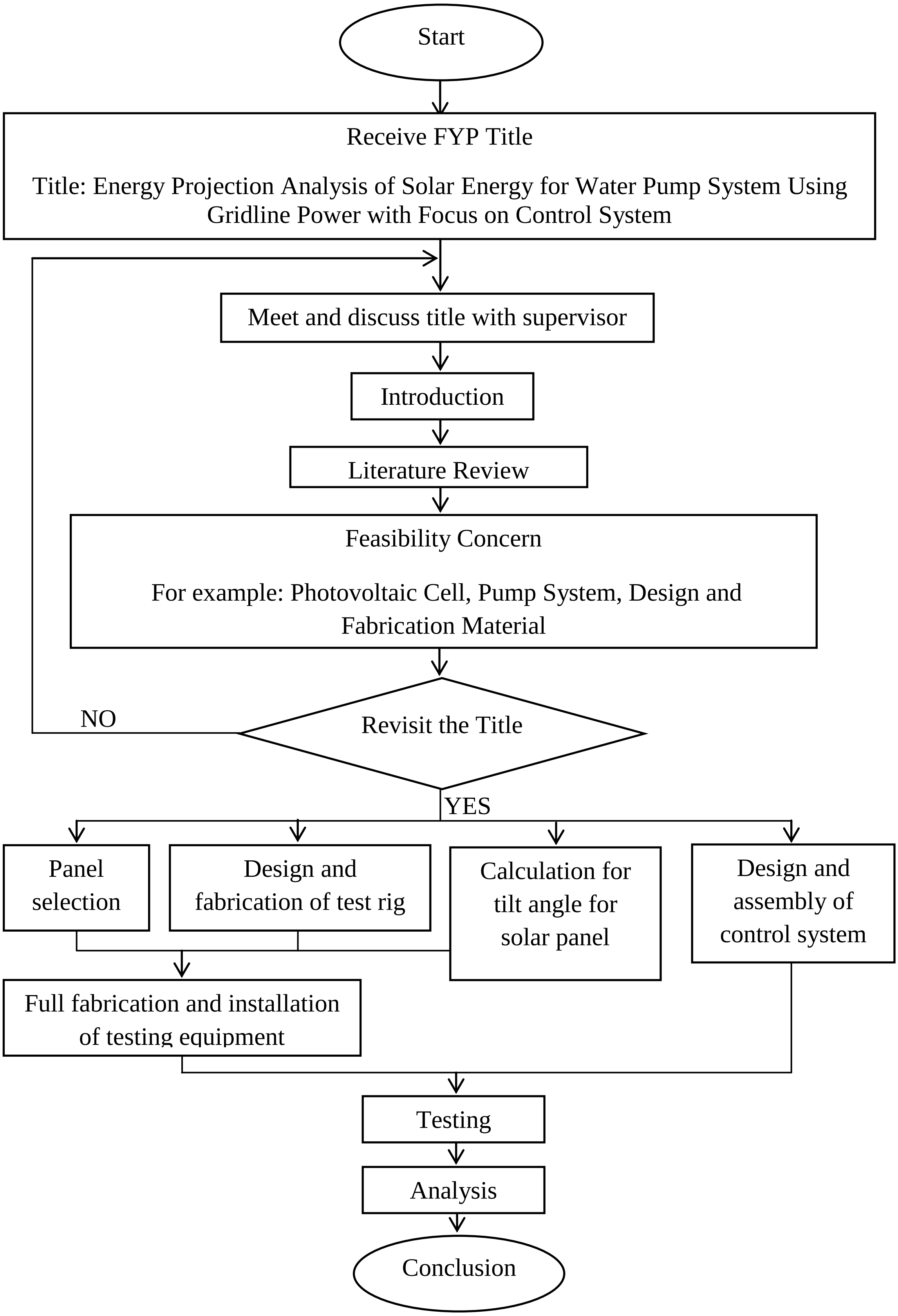

Figure 3.1: Flowchart for PSM Project

3.3 SYSTEM OVERVIEW FOR A SOLAR POWERED PUMP SYSTEM

To create a solar powered pump system firstly an understanding on what is the equipment and system are required. This system consists of two different types which involve the photovoltaic system and pump system. The photovoltaic system is used to capture the solar energy from the sun convert it into electricity. The photovoltaic cell used is monocrystalline cell due to its many advantages which will be discussed later on. The PV panel is used to charge the 24 V battery through a 10 A Solar PV Intelligent Controller which is shown in Figure 3.2. 10 A Solar PV Intelligent Controller is used to control the voltage and current input towards the battery to protect the battery from overload and increase the overall battery life span.

Figure 3.2: 10A Solar PV Intelligent Controller

The power from the battery is converted from 24 V DC to 240 V AC through a modified sine wave inverter. The main purpose of converting the power source is to power the AC pump. Figure 3.3(b) shows the inverter used. A cheaper and more economical modified sine wave inverter is chosen since it fulfils the requirement of the pump energy consumption. This modified sine wave inverter is also equipped with low voltage disconnecter which will protect the battery from over discharge. This function is also used to act as a switch to change the power supply from the battery to gridline power with the help of a 240 V AC relay. When the inverter stop produces power the relay will switch off the power form the battery and switch on the power supply from the gridline. Figure 3.3(a) shows the position of the relay in the circuit box.

(a) (b)

Figure 3.3: Component of Photovoltaic System

(a) Position of circuit and relay and (b) Modified Sine wave inverter

The pump system is used to pump working fluid to the ETSC to protect it from high stagnant temperature. Heat energy is then transferred to a storage tank which is shown in Figure 3.4(a) via a heat exchanger inside the tank. The excess heat energy which is not absorbed by the storage tank is then expelled to the atmosphere through a radiator which is shown in Figure 3.4(b) before entering the storage tank for working fluid. A cut-in cut-out system (CiCo) is designed based on the requirement set by the project scope to control the pump status.

(a) (b)

Figure 3.4: Component of Pump System

(a) Storage Tank and (b) Radiator

3.4 CALCULATION FOR TILT ANGLE

Where,

n = Leap year/ Non leap year + Day (3.1)

Pekan = Latitude (ϕ): 3° 30′ 0″ N (3.54), Longitude (φ): 103° 25′ 0″ E (103.43),

Sample for March 2013, (2013 is a leap year)

n = 75 get from Table 2.1,

β = 0 (Slope is the angle made by the plane surface with the horizontal),

I_{sc} = 1367W/m^2 (Solar constant)

For declination angle, *δ* is the angle that made by line joining the centre of the sun and the earth with its projection on the equatorial plane. As shown in Eq. (3.2).

$$\delta = 23.45 \sin\left(360 \frac{284 + n}{365}\right) \quad (3.2)$$

$$\delta = 23.45 \sin\left(360 \frac{284+75}{365}\right)$$

$$\delta = -2.4173$$

The *hour angle,* ω_{st} is an angular measure of time and is equivalent to 15^{o} per hour.

$$\omega_{st} = \cos^{-1}[-\tan(\phi-\beta)\tan\delta] \quad (3.3)$$

Source: Sukhatme & Nayak (2009)

$$\omega_{st} = \cos^{-1}[-\tan(3.54-0)\tan(-2.4173)]$$

$$\omega_{st} = 89.9974$$

Since 15^{o} is equivalent to one hour, monthly average of maximum possible sunshine hours per day (in hours)

$$N_{max}=\frac{2}{15}\cos^{-1}[-\tan\phi\tan\delta] \quad (3.4)$$

Source: Sukhatme & Nayak, (2009)

$$N_{max}=\frac{2}{15}\cos^{-1}[-\tan(3.54)\tan(-2.4173)]$$

$$N_{max} = 11.9800 \text{ hours}$$

In the above computation, H_o is monthly average of daily extra-terrestrial radiation on a horizontal surface, (kJ/m^2.day)
From Eq. (3.3),

$$H_o=\frac{24\times3600}{1000\times\pi}I_{sc}\times\left[1+0.033\cos\frac{360n}{365}\right]\times\left[\left\{\sin\emptyset\sin\delta\frac{2\pi\omega_{st}}{360}\right\}+\{\cos\emptyset\cos\delta\sin\omega_{st}\}\right] \quad (3.5)$$

Source: Teliat, Falayi, & Rabiu (2001)

$$H_o=\frac{24\times3600}{1000\times\pi}1367\left[1+0.033\cos\frac{360(75)}{365}\right]\times[\left\{\sin(3.54)\sin(-2.4173)\frac{2\pi(89.9974)}{360}\right\}+$$
$$\{\cos(3.54)\cos(-2.4173)\sin(89.9974)\}]$$

$$H_o= 37676.3404 \text{ kJ/m}^2\text{.day}$$

Therefore, from Eq. (3.3) and Eq. (3.5), H_g is monthly average of daily global radiation on a horizontal surface, (kJ/m^2.day)

Where, a=0.22; b=0.47, is a constant for Kuantan, Pahang.
N is average sunlight hours/day in every month from Table 2.2

$$\frac{H_g}{H_o} = a + b\frac{N}{N_{max}} \tag{3.6}$$

Obtained from M. M. Rahman (1999)

$$\frac{H_g}{40905.6487} = 0.22 + 0.47\frac{6.5}{11.9800}$$

H_g = 17896.54 kJ/m^2.day

Using Eq. (3.5) and (3.6), monthly diffuse radiation, H_d is shown as Eq. (3.7)

$$\frac{H_d}{H_g} = 1.35 - 1.61[\frac{H_g}{H_o}] \tag{3.7}$$

Source: Emanuele (2013)

$$\frac{H_d}{17667} = 1.35 - 1.61[\frac{17896.54}{37676.3404}]$$

H_d = 10473.74 kJ/m^2.day

By substitute Eq. (3.6) and (3.7) into monthly beam radiation, H_b is derived as below:

$$H_b = H_g - H_d \tag{3.8}$$

H_b = 17896.54 – 10473.74

H_b = 7422.802 kJ/m^2.day

When,

0.000277776619339184 kWh = 1 kJ

Therefore,

$$H_b = 2.062\ kW/m^2.day$$

The calculations are shown in Table 3.1, with calculation of declination angles for the middle days of the month. The values obtained for the optimum tilt are in approximate agreement with the bracket tilt angle for ETSC.

Table 3.1: Calculation for Optimum Tilt Angle for ETSC in Pekan

	Hb	**n**	**δ deg**	**(Ø-δ) Deg**	**Hb*tan (Ø-δ) kWh/m²**
January	2.002	17	-20.917	24.45696	0.910
February	2.580	47	-12.9546	16.49461	0.748
March	2.062	75	-2.41773	5.957735	0.215
April	1.909	105	9.414893	-5.87489	-0.196
May	1.861	135	18.79192	-15.2519	-0.507
June	1.970	162	23.08591	-19.5459	-0.699
July	1.927	198	21.18369	-17.6437	-0.613
August	1.871	228	13.45496	-9.91496	-0.327
September	1.610	258	2.216887	1.323113	0.037
October	1.528	288	-9.5994	13.1394	0.357
November	1.395	318	-18.912	22.45195	0.577
December	1.630	344	-23.0496	26.58963	0.816
Total	22.346			Total	1.316

For this monthly beam radiation obtained from Emanuele (2013), the optimum tilt, β is given by the expression

$$\beta = \tan^{-1}\left[\frac{\sum H_b \tan(\varphi - \delta)}{\sum H_b}\right] \tag{3.9}$$

And optimum tilt angle average, β is given by the expression

$$\beta_{opt} = \frac{\beta_1 + \beta_2}{2} \tag{3.10}$$

Using Eq. (3.9), overall optimum tilt angle for whole year,

$$\beta_{opt} = \tan^{-1}[\frac{1.316}{22.346}] = 3.37° \approx 4°$$

Using Eq. (3.9), optimum tilt angle from month January to March,

$$\beta_{opt} = \tan^{-1}[\frac{1.873}{6.644}] = 15.74°$$

Using Eq. (3.9), optimum tilt angle from month September to December,

$$\beta_{opt} = \tan^{-1}[\frac{1.786}{6.163}] = 16.16°$$

Using Eq. (3.10), optimum tilt angle average for September to March,

$$\beta_{opt} = \frac{16.42 + 17.66}{2} = 15.95° \approx 16°$$

Using Eq. (3.10), optimum tilt angle average for whole year,

$$\beta_{opt} = \frac{16 + 4}{2} = 10°$$

There is not much effect on the amount of solar energy collected in the month of April until August due of high solar radiation. However for the month of September until March, the monsoon season brings heavy cloud and rain which will decrease the efficiency of the solar panel. More consideration on the tilt angle must be made in these months. To ensure that system continues running, it is critical that the system receive the best angle for the solar radiation collection. Thus based from the calculation above, to ensure that the solar panel will receive the optimum amount of solar energy, the optimum angle is at 10°.

3.5 MATERIAL SELECTION

Three different types of material are chosen for analysis using Solidwork 2012 Simulation based on the material availability in the market. Mild steel is widely used in many industries including construction for its cheaper price and high strength. On the other hand, aluminium is well known for its properties and high weight to strength ratio and widely use is aviation industry. The final material chosen is brass. Brass has higher strength than copper since it is the combination of copper and zinc. The brass will not corrode since it has high corrosion resistance which will reduce the maintenance required on the test rig if compare with mild steel. Table 3.2 shows the material properties of mild steel, aluminium and brass.

Table 3.2: Material Properties of Mild Steel, Aluminium and Brass

Material Properties	**ASTM-A36**	**Alloy 6061-T6**	**Brass**
Ultimate Tensile Strength, MPa	400	260	585
Yield strength, MPa	250	325	435
Modulus of elasticity, GPa	200	73	120
Density, kg/m^3	7860	2800	8740

Source: Ferdinand et.al, (2008)

3.6 PANEL SELECTION

The most suitable panel must be chosen for the use in Universiti Malaysia Pahang to help reduce the space and stress that the panel will impose on the test rig. Three different types of solar panel which are available in the market are monocrystalline, polycrystalline and thin film or amorphous. Each has its own advantages and disadvantages which is listed in Table 3.3.

Table 3.3: Advantages and Disadvantages of PV Panel

Type	Advantages	Disadvantages
Monocrystalline	▪ Longer life span ▪ Performs better than a similarly rated polycrystalline solar panel at lower light and lower temperature conditions. ▪ Space efficient ▪ Efficiency rate around 12 % to 19 %	▪ Slightly more expensive than polycrystalline
Polycrystalline	▪ Cost less due to simpler making process ▪ Good in hotter weather ▪ Efficiency rate around 13 % to 16 %	▪ Not as efficient due to less pure silicon ▪ Need a larger area to produce same power output as monocrystalline
Thin-Film or Amorphous	▪ Use least amount of silicon ▪ Can be made flexible and lightweight	▪ Less stable than crystalline, causing degradation over time ▪ Efficiency at 6 % -9 %

Based on Table 3.3, monocrystalline has the highest amount of efficiency followed by polycrystalline and finally thin film. The size of monocrystalline panel is the smallest. This way the weight of the panels can be reduce thus reducing the stress on the structure. When comparing monocrystalline with polycrystalline at low temperature and low light condition, monocrystaline produces more power. This characteristic can greatly help the power production between the months of September to March. During this period of time, cloud and rain will reduce the temperature and light intensity. However ETSC which is not influenced by the ambient condition will still receive the solar radiation thus causing the temperature difference between the ETSC outlet and the storage tank to increase. Monocrystalline can help reduce the amount of panel required to run the pump during this time if compare with polycrystalline since it has higher efficiency at low temperature and low light condition. During the month of April to August, the solar radiation is higher thus its loss in efficiency is covered up by the increase in peak solar radiation time. The panel will have a longer time to collect energy to cover up the loss in efficiency. Therefore there is no need for any extra panels to be installed during this period of time.

3.7 DESIGN OF TEST RIG

In this project, three solar panels are used in the energy projection analysis to determine the minimum panel required for a solar powered pump system. Two out of the three panels will be connected to a solar charger to charge the battery. The remaining panel will be connected to a G.T.RC Wattmeter to determine the panel output. A bracket is designed and fabricated to hold the panel in position. The weight of one photovoltaic panel is 6.1 kg. Since the test rig needs to withstand 3 panels thus it has to at least be able to withstand 18.3 kg. Some factor must take into consideration during the designing process such as the test rig needs to be able to withstand 18.3 kg and it needs to be able to change its tilt angle based on the calculation in Chapter 3.4.

Solidwork 2012 is used as the main platform to design and analysis the structure of the test rig as shown in Figure 3.5. The usage of software is critical during the designing process to minimise the wastage of raw material that will occur if the test rig is built through a primitive method of trial and error. To ensure that the structure is up to the job the simulation and analysis is conducted in Solidwork 2012.

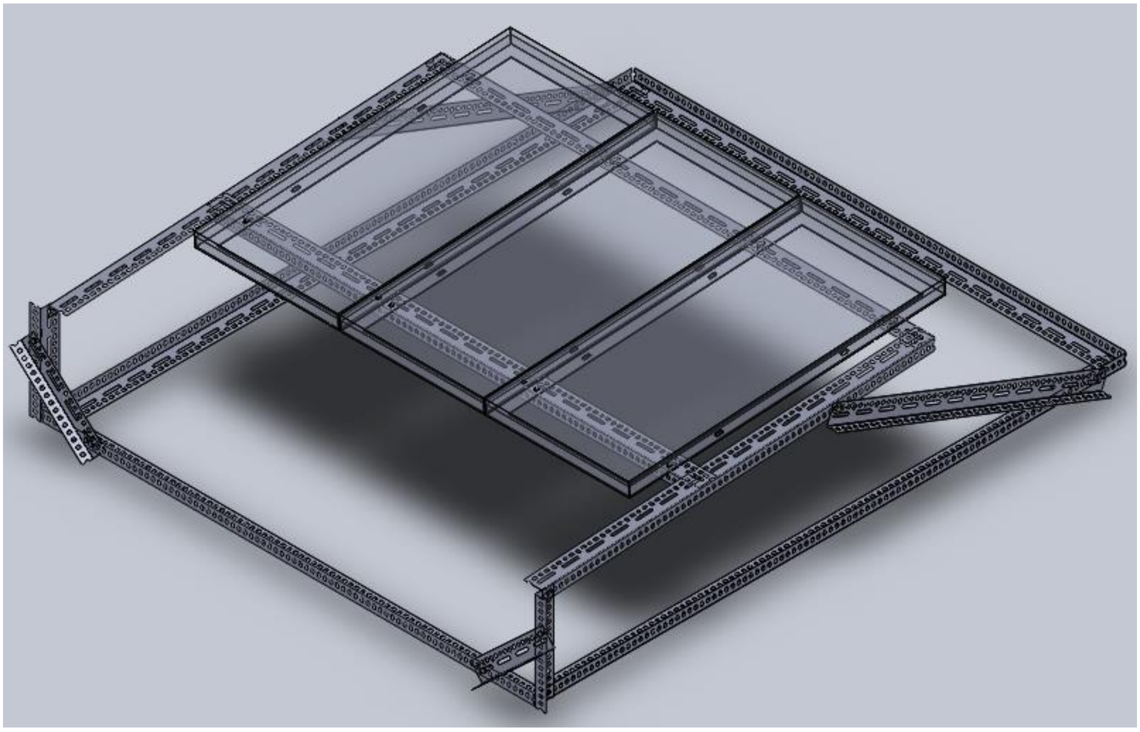

Figure 3.5: Sketch for Design Panel Bracket

3.8 CONTROL SYSTEM

A microprocessor and thermostat is used to determine the pump status according to the temperature. This system is designed to determine the condition when to on or off the pump based on the temperature difference at the ETSC outlet and the storage tank. The pump will only on if the temperature at the Evacuator tube solar collector outlet is higher than 40°C and at least 8°C higher than the temperature in the water storage tank. Figure 3.6 shows the flow chart of the control system.

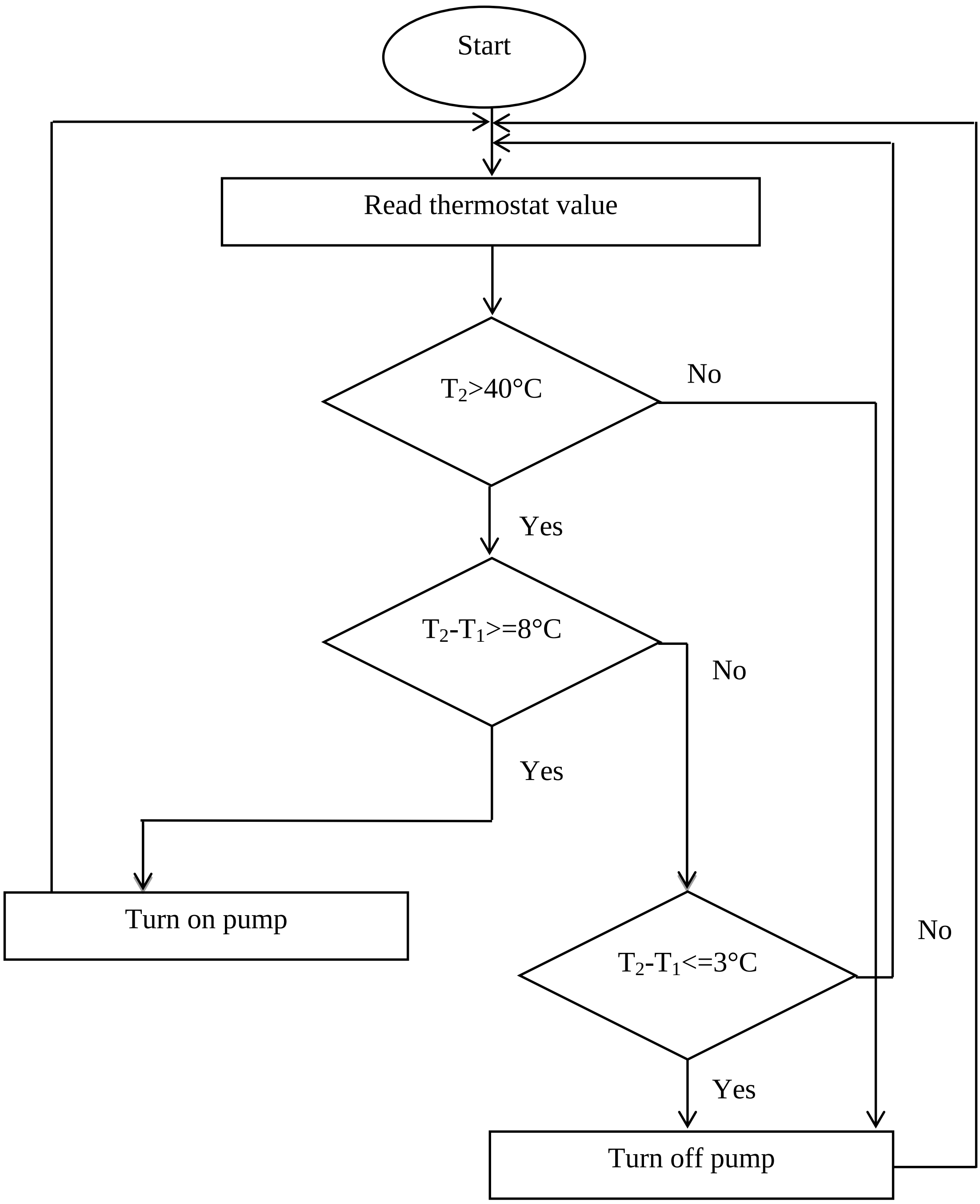

Figure 3.6: Flow Chart for Control System

3.9 ELECTRICAL COMPONENT

3.9.1 Programmable Intelligence Computer PIC18F4550

Figure 3.7 shows PIC18F4550 which is used as the microprocessor in the CiCo system. It received analog signal from the temperature sensor and control the pump cut-in and cut-out with the help of relay which act as the switch. This PIC is very widely used because it is ideal for low power (Nano Watt) and connectivity applications, large amounts of RAM memory for buffering and enhanced flash program memory. This makes it ideal for embedded control and monitoring applications that require periodic connection by using a personal computer via USB for data upload / download and / or firmware updates.

40 - Pin

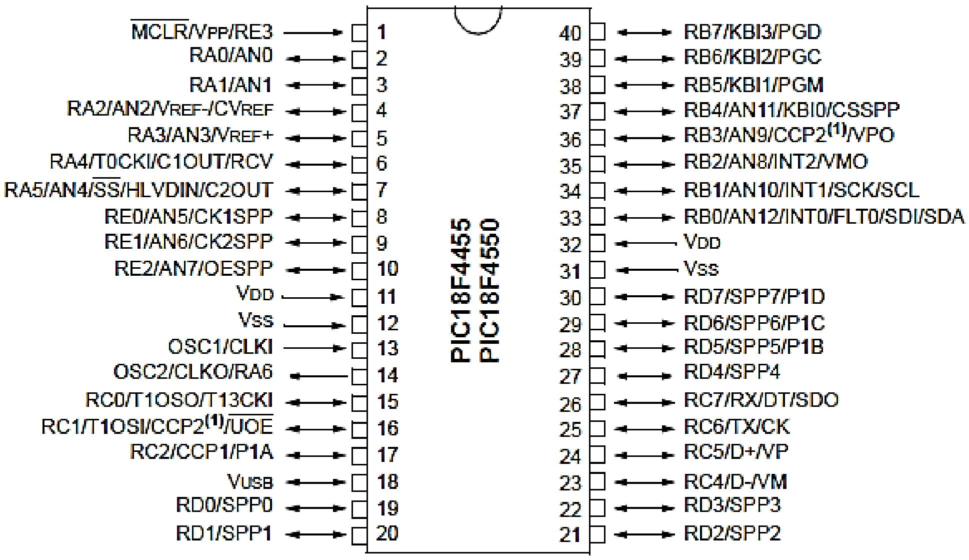

Figure3.7:PIC18F4550

Source: (Microchip – PIC18F4550 Datasheet)

3.9.2 Thermostat LM35DZ

Figure 3.8 shows LM35DZ which is a precision integrated-circuit temperature sensor, whose output is linearly proportional to the Celsius temperature. It does not require any external calibration or trimming. Since in this experiment there is no need to measure any extreme temperature, this device is perfect since it can measure temperature between -55°C to 155°C. It has an accuracy level of 0.5°C at + 25°C. LM35DZ has three pins that is positive, negative and adc pin. Adc pin will send analog signal to the control circuit to determine the temperature of the ETSC outlet and the storage tank inlet.

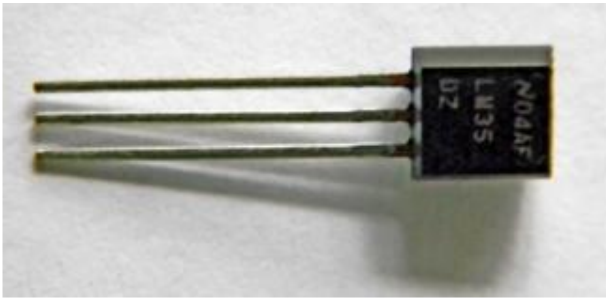

Figure 3.8: LM35DZ

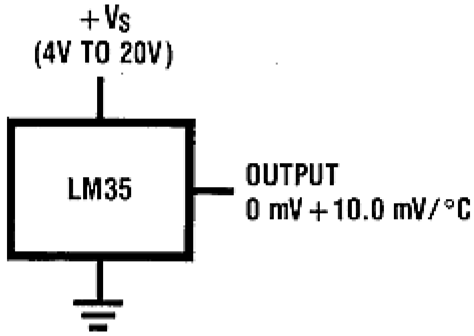

Figure 3.9: LM35DZ connection

Source: (National Semiconductor –LM35DZ Datasheet)

3.10 DATA ACQUSITION EQUIPMENT

3.10.1 G.T. Power RC Wattmeter

Figure 3.10 shows a G.T. RC Power Wattmeter which is used to determine the panel output. The G.T. RC Power Wattmeter is perfect for measuring all the important information. This particular watt meter is able to handle current up to 130 A. It constantly displays the actual values for the voltage (V), current (A) and power (W). The unit also calculates and displays the amount of current discharged (mAh). By recording the panel output a power analysis can be conducted to determine the power output of the panel and the minimum required panel to power the pump.

Specifications:

- Operates from 4.8 V to 60 V
- 0 V with optional auxiliary battery
- Measures: 0 Amps to 130 Amps (resolution 0.01A)
- Measures: 0 V to 60 V (resolution 0.01A)
- Measures: 0 W to 6554 W (resolution 0.1W)
- Measures: 0 Ah to 65 Ah (resolution 0.001 Ah)
- Measures: 0 Watt Hours to 6554 Watt Hours (resolution 0.1 Wh)
- Blue backlit LCD display: 16 x 2
- Dimensions: 85 x 42 x 25 mm
- Weight: 85 g
- Tough casing

Figure 3.10: G.T. Power RC Wattmeter

3.10.2 Multifunctional Mini Ammeter (D02A)

Figure 3.11 shows a Multifunctional Mini Ammeter (D02A) which is used to collect the energy consumption of the pump. This product provides the power connection for the electric devices and records data on the operations of the connected device. It provides reading on the LCD display which includes voltage, real-time running power, electricity consumption, electricity cost, and operational time. At the same time, it provides analysis of real-time running power and gives an alert automatically once abnormal operation occurs. This helps using and maintaining any devices scientifically as well as saving power with reducing waste.

- Measure if there is complete circuit and if the socket is in working condition
- Observe the real-time voltage fluctuations of power Measure Voltage, Watt and accumulated power consumption
- LED Work Indicator with LCD Reading Display
- Adaptable voltage: 160 V - 280 V AC Peak load: 15 A Power measurement: 1 W - 3000 W Operating temperature: -10^{o}C - 60^{o}C Humidity range: 10 % - 95 %
- Power consumption: 0.001 kWh - 999.9 kWh

Figure 3.11: Multifunctional Mini Ammeter (D02A)

3.11 CIRCUIT DIAGRAM

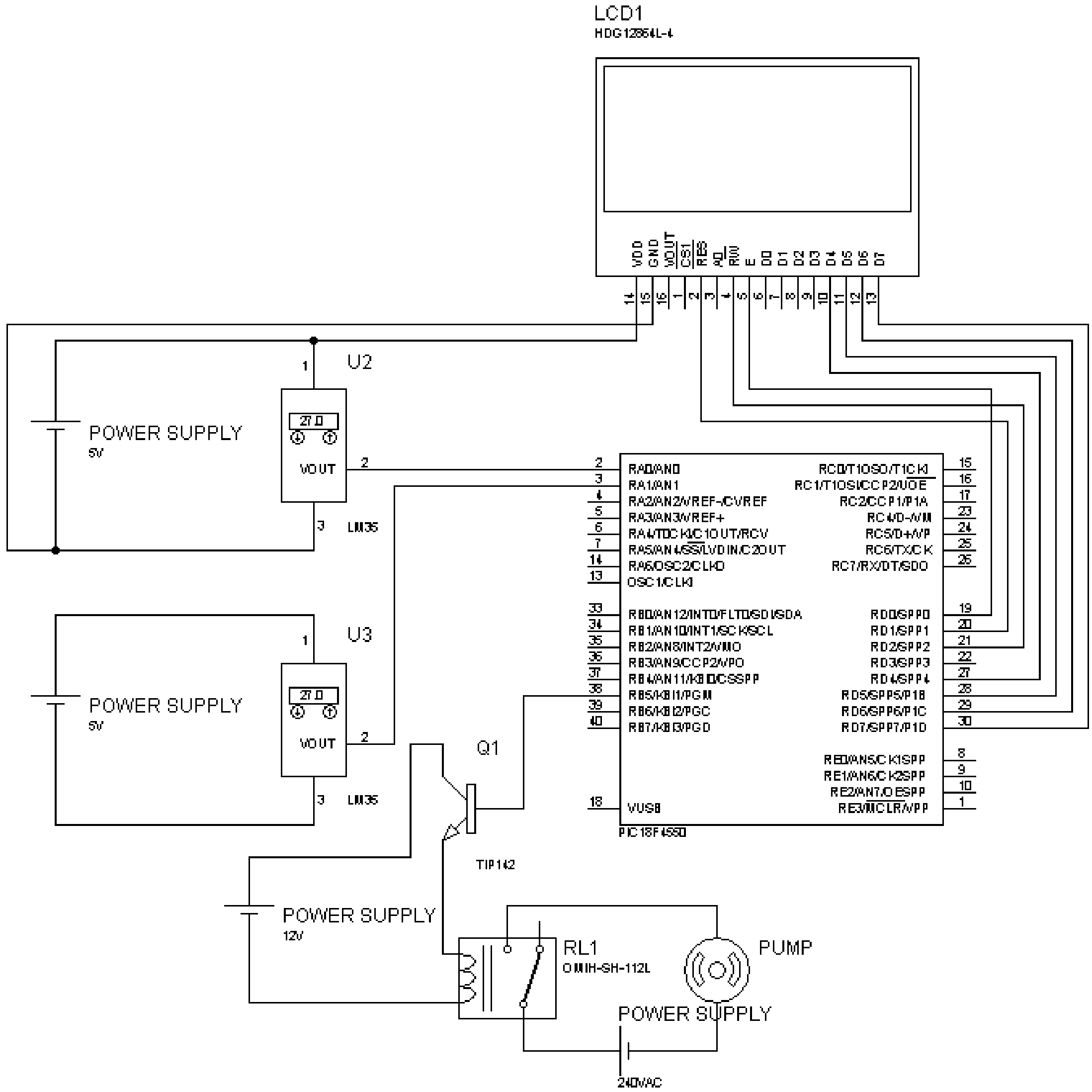

Figure 3.12: Circuit Diagram for CiCo System

Figure 3.12 shows the circuit diagram design for the cut-in cut-out (CiCo) system. 12 V DC is supplied to the circuit. The PIC18F4550 receive the signal from LM35DZ temperature sensor via pin (A0) and pin (A1) where it will do the decoding and give out the appropriate command. The real time temperature reading of both ETSC outlet and storage tank will be displayed on the LCD screen. The command to turn on the pump is sent by the PIC to an NPN transistor TIP142T via pin (B5) where it will act as a switch to turn on the relay when it receives an electrical input. A 12 V DC relay is used to control the 240 V AC power supply for the pump.

3.12 FLUSHING CODING FOR PIC18F4550

The main component in CiCo system is the coding for the microprocessor. The coding used in CiCo system is written in C language which is a common language for computer programming. PIC C Compiler version 4.093 is used to write the program coding. First of all, the coding start with the header file, target the microcontroller is set as PIC18F4550 and hardware is configured. The hardware clock is set at 20MHZ. The coding continues by defining the variable like (A11), (A12) and relay at its individual port. All pins at PORT B and C are set as output. The output will continue to reset after the end of each loop.

The program will start off by reading the adc input at (A11) and (A12). (A11) is defined as temperature sensor at the tank and set as “Temp1” on the LCD display screen. (A12) is defined as temperature sensor at ETSC outlet and set as “Temp 2” at the LCD display. To reduce the sensitivity of the system delay of 100ms is set to reduce the amount of data needed to be processed by the microchip. The coding of the project is shown in Appendix A.

CHAPTER 4

RESULT AND DISCUSSION

4.1 TEST RIG MATERIAL SELECTION

A linear displacement analysis is conducted on the test rig using Solidwork 2012 Simulation Analysis. The test rig is tested under three different material conditions which is Mild Steel ASTM-A36, Aluminium Alloy 6061-T6 and Brass in order to test the effect of different type of material on the strength of the test rig and to choose the best material for fabricating the test rig.

A force of 59.841 N is evenly distributed on the surface of each solar panel to mimic the weight of the solar panel acting on the test rig. The boundary condition of the bottom of the test rig is fixed into position to simulate the condition of the test rig placed on the ground. The boundary condition set on the test rig is shown in Figure 4.1.

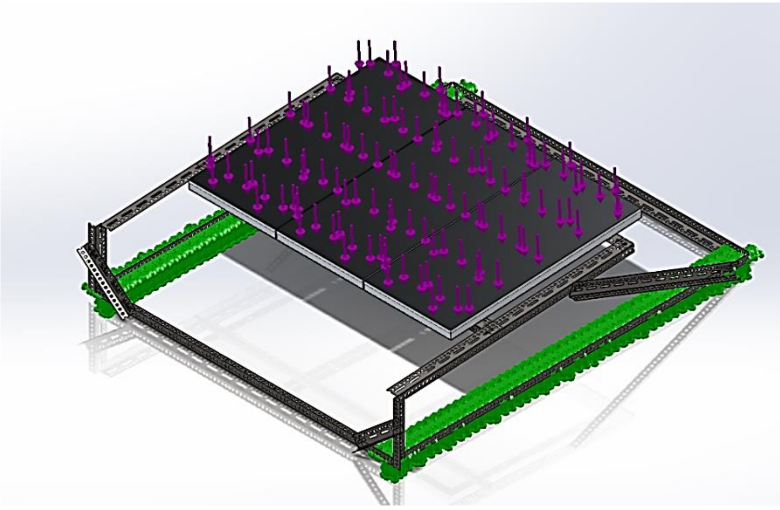

Figure 4.1: Condition Set on the Test Rig for Testing

4.1.1 Solidwork 2012 Displacement Analysis Result

Figure 4.2, 4.3 and 4.4 shows the result of displacement analysis that has been conducted on the material mild steel, aluminium alloy and brass.

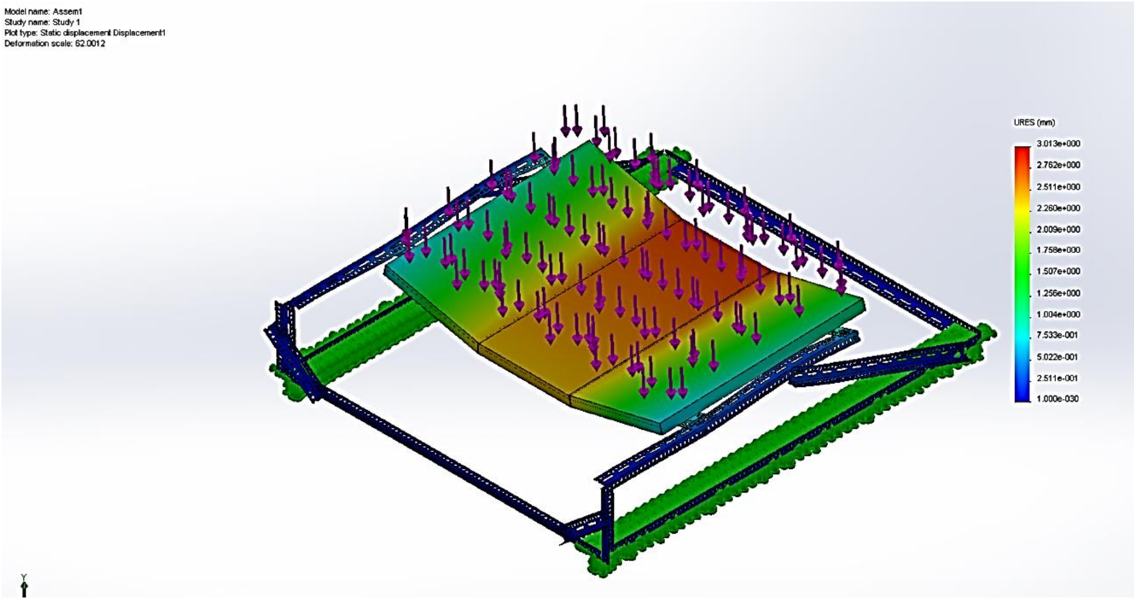

Figure 4.2: Displacement Analysis of Mild Steel ASTM-A36

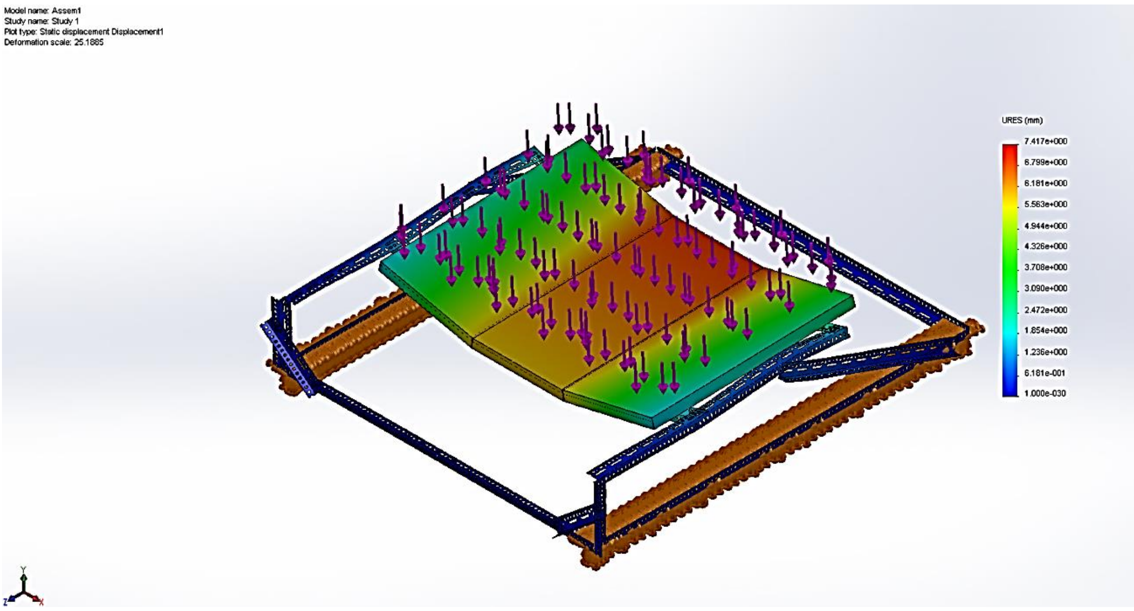

Figure 4.3: Displacement Analysis of Aluminium Alloy 6061-T6

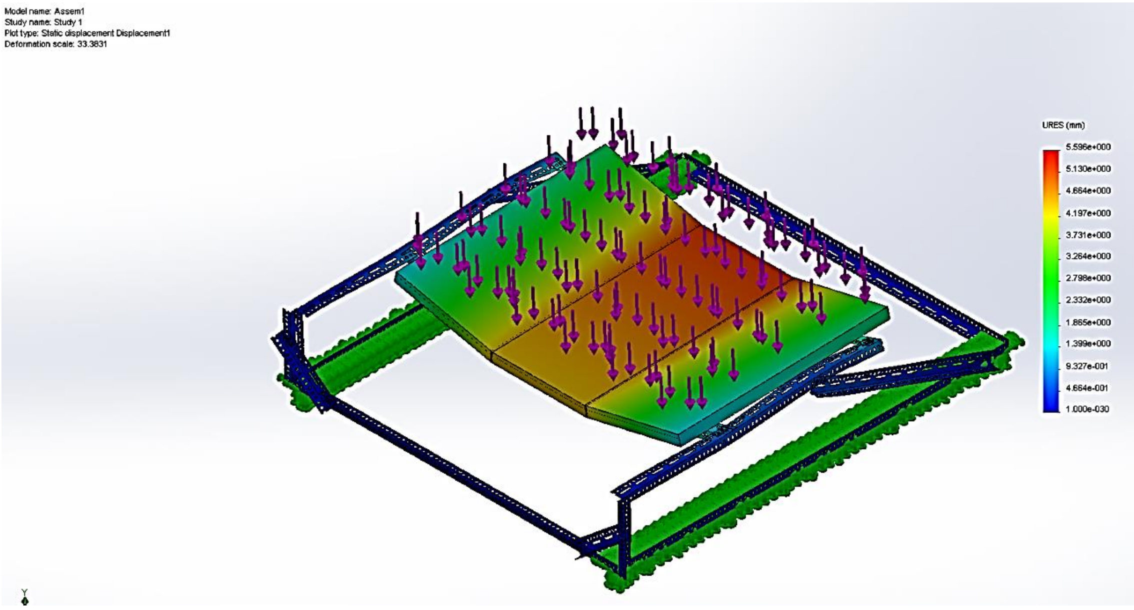

Figure 4.4: Displacement Analysis of Brass

The maximum value of the displacement is shown in the Table 4.1. It shows the amount of displacement of mild steel is the lowest follow by brass and finally by aluminium alloy. The larger amount of displacement will increase the chances of damage occurring on the panel. This analysis clearly shows that mild steel will bring us the best result in maintaining the integrity of the structure and reduce the chances of damage towards the solar panel.

Table 4.1: Maximum Displacement for Each Material

Material Properties	ASTM-A36	Alloy 6061-T6	Brass
Maximum Displacement, (mm)	3.013	7.417	5.596

4.1.2 Safety Factor Analysis

Figure 4.5, Figure 4.6 and Figure 4.7shows the stress applied on the test rig for mild steel ASTM-A36, Aluminium Alloy 6061-T6 and Brass.

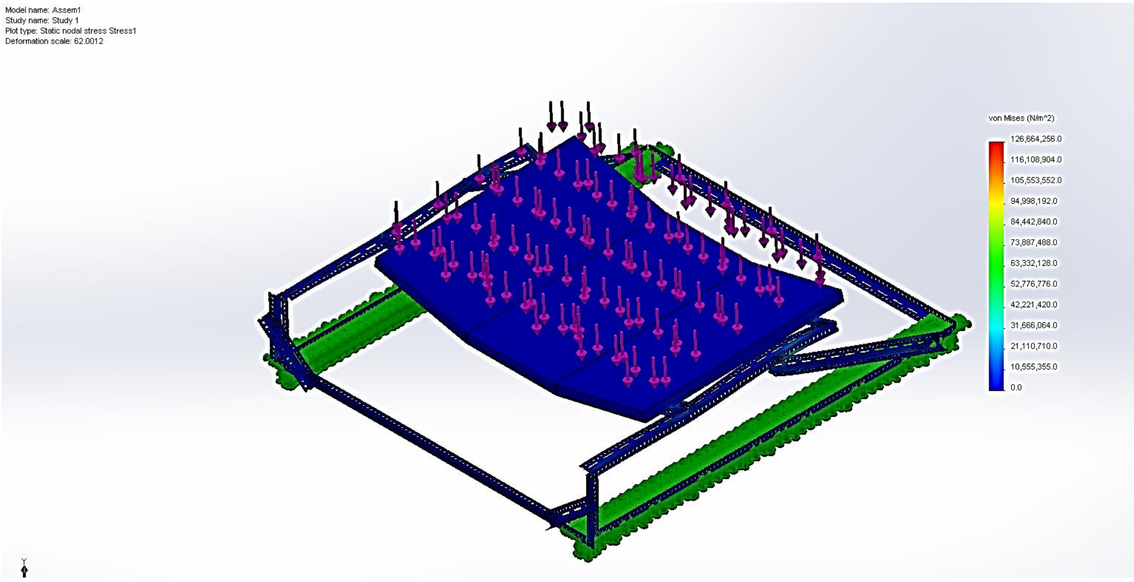

Figure 4.5: Stress Analysis of Mild Steel ASTM-A36

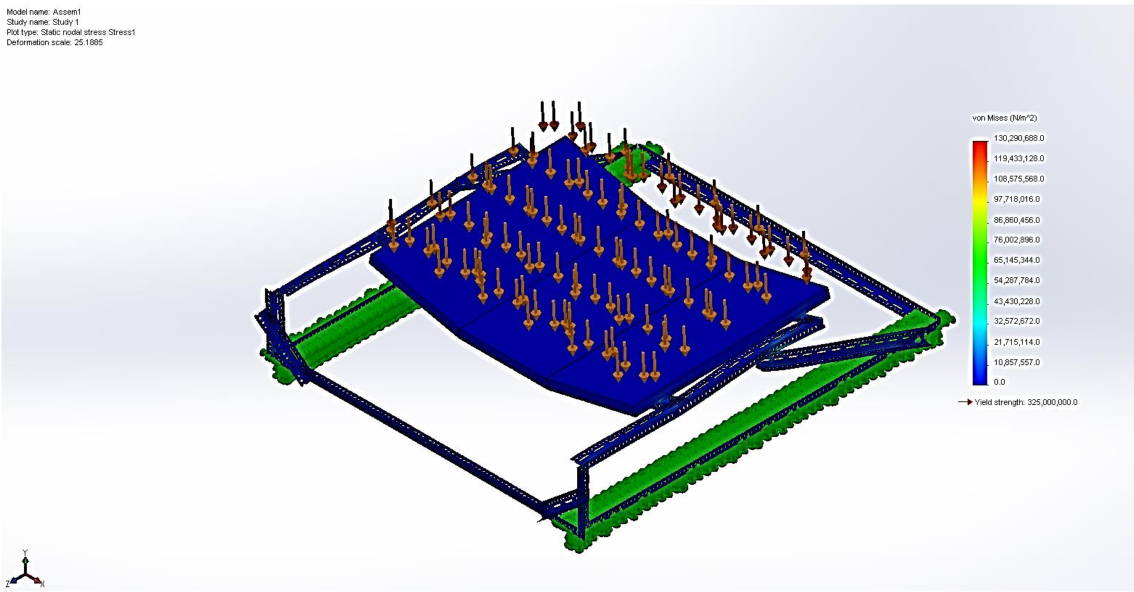

Figure 4.6: Stress Analysis of Aluminium Alloy 6061-T6

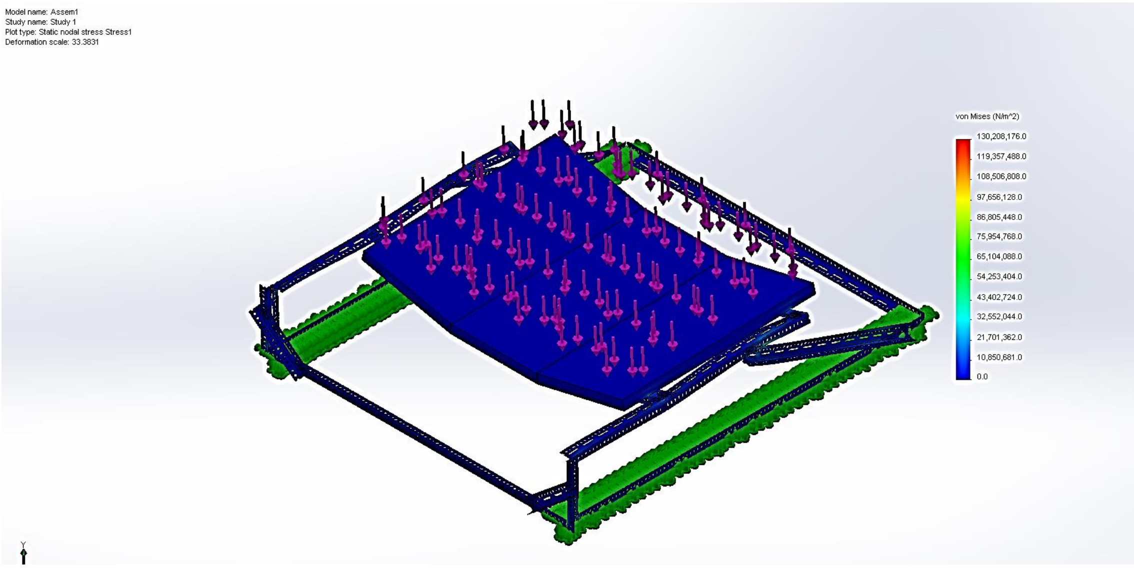

Figure 4.7: Stress Analysis of Brass

Table 4.2: Test Rig Properties

Material	**ASTM-A36**	**Alloy 6061-T6**	**Brass**
Maximum Stress, Pa	$12.7 \text{x} 10^7$	$13.0 \text{x} 10^7$	$13.0 \text{x} 10^7$
Ultimate Tensile Strength, Pa	$4.00 \text{ x} 10^8$	$2.60 \text{ x} 10^8$	$5.85 \text{ x} 10^8$
Safety Factor	3.14	2.00	4.23
Price of (1 x 1 x 0.125) inch x 12 feet of material, USD	1.75	1.40	9.22

Source: Online Metal Store, (2013)

The maximum stress which is applied on the test rig is recorded in Table 4.2. Based on the result of stress analysis shown in the Table 4.2, it proves that the stress on the structure is lower than the ultimate tensile strength of the material. Therefore the test rig made from those materials will not fail under those weights and condition. The calculation for the safety factor is conducted to determine the safest material for the job. The formula used is shown below.

Sample calculation ASTM-A36 using Eq. (4.1):

$$\text{Safety Factor, S.F} = \frac{\text{ultimate tensile strength}}{\text{maximum stress}} \qquad (4.1)$$

$$\text{S.F} = \frac{4.00\times10^{8}}{12.7\times10^{7}}$$

$$\text{S.F} = 3.14$$

From the result shown in Table 4.2, brass has the highest safety factor follow by Mild Steel ASTM-A36 and finally Aluminium Alloy 6061-T6.

Based on the analysis above, mild steel ASTM-A36 is the best material out of the three. This is because it has a low displacement value which mean less damage will occur on the panel. Although brass has a higher safety factor, since the price of brass is very expensive which is five times the prices of mild steel and the displacement for brass is high, thus brass is not suitable. Aluminium is not chosen since its displacement is very high and it has a low safety factor.

4.2 PERFORMANCE EVALUATION

4.2.1 Data Collection Method

The data collection method is used to determine the minimum solar panel required to run the pump and to amount of energy that can be saved when using CiCo system. Figure 4.3 shows the 50 watt monocrystalline solar panels and the test rig fabricated which is used in this project. Based on calculation conducted in Chapter 3, the solar panel is placed on the test rig at a tilted angle 10° for optimum solar radiation collection. It is then connected to a power analyser to determine the voltage, ampere, power and energy output of the solar panel. A 24 V light bulb is used as the load for the system.

The data collection for the pump system is divided into two. One is when it runs on timer system and the other one is when it used the CiCo system to control the pump cut-in and cut-out. For this project to ensure the pump receives a continuous supply of energy, the pump is connected to the grid line. The energy consumption of the pump is then collected by using a Multifunctional Mini Ammeter.

The value of the voltage, ampere, power and energy from the solar panel, the energy consumption of the pump with the temperature at the solar Evacuator outlet and storage tank temperature are recorded at an interval of 15 minutes from 9.00 a.m. to 6.00 p.m.

Figure 4.8: Test Rig of Solar Panel Used

4.2.2 Effect Of Weather On Solar Panel Efficiency

4.2.2.1 Solar Energy against Panel Power Output on Cloudy-Sunny Day

Table 4.3 shows the modulus of efficiency while Figure 4.9 shows the solar energy and panel power output on the 3 April 2013. The weather on that day is cloudy in the morning until 11.00 a.m. and sunny for the rest of the day until 6.00 p.m. The peak power produced by the panel is in between 11.00 a.m. to 3.00 p.m.

Table 4.3: Modulus of efficiency at given time on cloudy-sunny day

Time	**9.00**	**10.00**	**11.00**	**12.00**	**1.00**	**2.00**	**3.00**	**4.00**	**5.00**	**6.00**
Panel power output, W	6.2	24.5	33.1	34.8	34.1	34.5	32.5	24.5	16	0.5
Solar radiation, W/m^2	435	652	802	919	931	893	829	652	499	174
Modulus efficiency, %	3.33	8.79	9.65	8.86	8.57	9.04	9.17	8.79	7.50	0.67

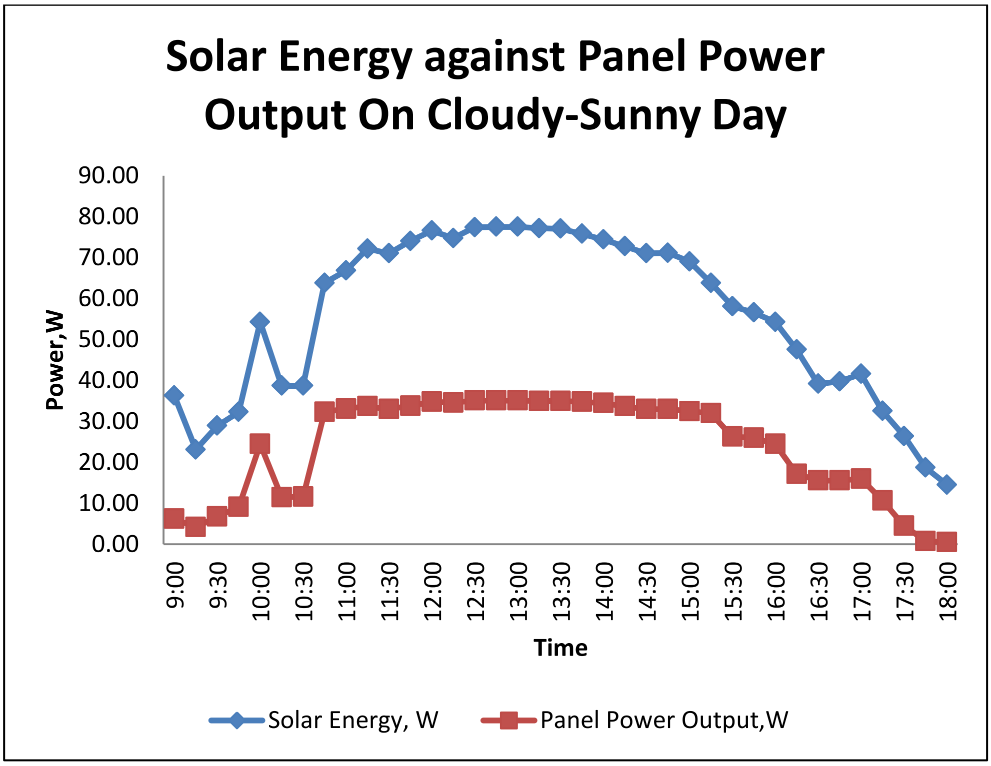

Figure 4.9: Solar energy against panel power output on cloudy-sunny day

Sample calculation using Eq. (2.1):

$$\eta = \frac{P_m}{E \times A_c} \tag{2.1}$$

3 April 2013, 9.00 a.m.:

P_m = 6.2 W
E = 435 W/m^2
A_c = 0.4275 m^2

$$\eta = \frac{6.2\ \text{W}}{435\ \text{W/m}^2 \times 0.4275\ \text{m}^2}$$

$$\eta = 3.33\ \%$$

Figure 4.9 shows that the cloudy weather will cause the efficiency of panel to decrease. The peak energy give out by the sun is between 12.00 p.m. to 1.30 p.m. This is because at that time the sun rays enter perpendicularly into the panel. Table 4.3 shows that the modulus efficiency in the afternoon are lower and gradually increase towards the evening before decreasing again due to the lack of sunlight. The solar energy that reaches the panel increase gradually towards the afternoon, however the power output of the panel remains constant. This causes the modulus of efficiency to decrease. This condition is the same for in the evening where the solar energy decreases and the panel output remain constant. Therefore the modulus of efficiency in the evening is higher than the afternoon.

4.2.2.2 Solar Energy against Panel Power Output on Sunny Day

Table 4.4 shows the modulus of efficiency while Figure 4.10 above shows the solar energy and panel power output on the 12 April 2013 at that given day. The weather on that day is sunny in the morning until 1.30 p.m., cloudy until 3.00 p.m. and sunny for the rest of the day until 6.00 p.m.

Table 4.4: Modulus of efficiency at given time on sunny day

Time	**9.00**	**10.00**	**11.00**	**12.00**	**1.00**	**2.00**	**3.00**	**4.00**	**5.00**	**6.00**
Panel power output, W	9.8	26.9	34.5	33.7	35	33.0	34.2	27.6	6.6	0.3
Solar radiation, W/m^2	426	610	809	816	951	852	833	586	322	225
Modulus efficiency, %	5.38	10.32	9.98	9.66	8.61	9.06	9.60	11.01	4.79	0.31

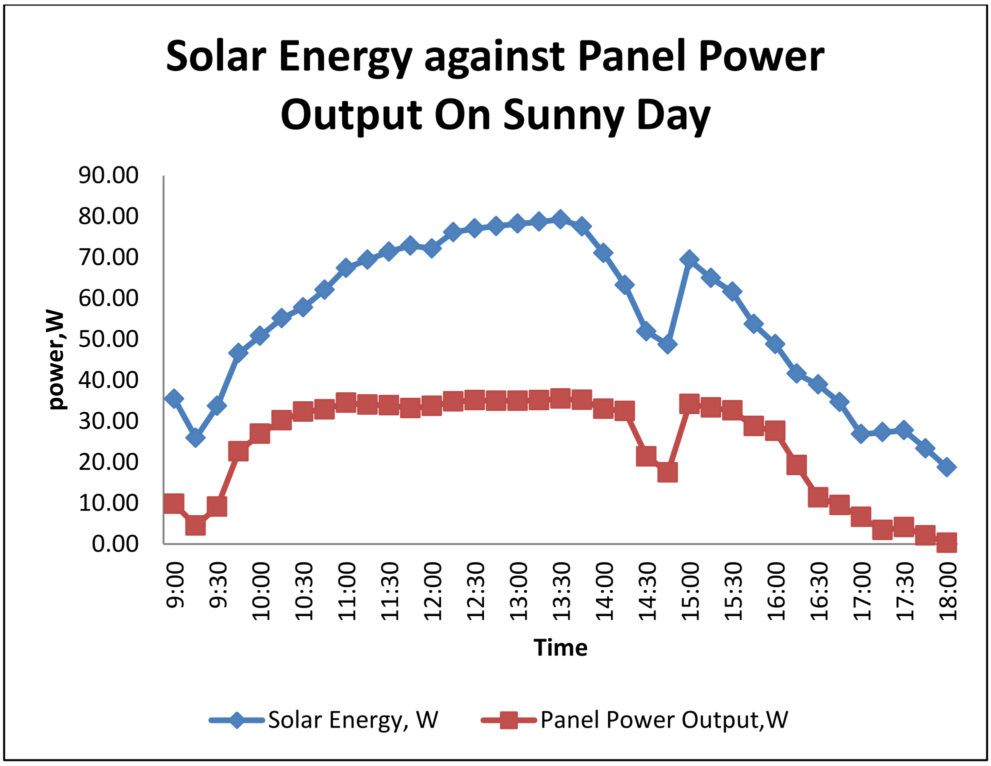

Figure 4.10: Solar energy against panel power output on sunny day

Figure 4.10 shows that the peak energy give out by the sun is between 12.00 p.m. till 1.30 p.m. Since the results obtain for the peak solar radiation in Table 4.3 is almost the same with Table 4.4, thus a conclusion can be drawn that 12.00 p.m. to 1.30 p.m. has the peak solar energy. Figure 4.10 also produce the same result as Figure 4.11 where the peak energy produce by the panel is between 11.00 a.m. till 3.00 p.m. The result from Table 4.3 is also supported by result in Table 4.4 when the modulus of efficiency in the morning and evening is higher than in the afternoon.

4.2.2.3 Solar Energy against Panel Power Output on Rainy-Sunny Day

Table 4.5 shows the modulus of efficiency while Figure 4.11 shows the solar energy and panel power output on the 10 April 2013. The day starts off with a little rain in the morning until 10.30 a.m. follow with cloudy and sunny weather.

Table 4.5: Modulus of efficiency at given time on rainy-sunny day

Time	**9.00**	**10.00**	**11.00**	**12.00**	**1.00**	**2.00**	**3.00**	**4.00**	**5.00**	**6.00**
Panel power output, W	0.0	1.8	32.7	19.2	29.3	12.6	30.2	26.7	17.7	0.0
Solar radiation, W/m^2	26	252	734	503	665	446	780	606	402	42
Modulus efficiency%	0.00	1.67	10.42	8.93	10.31	6.61	9.06	10.31	10.29	0.00

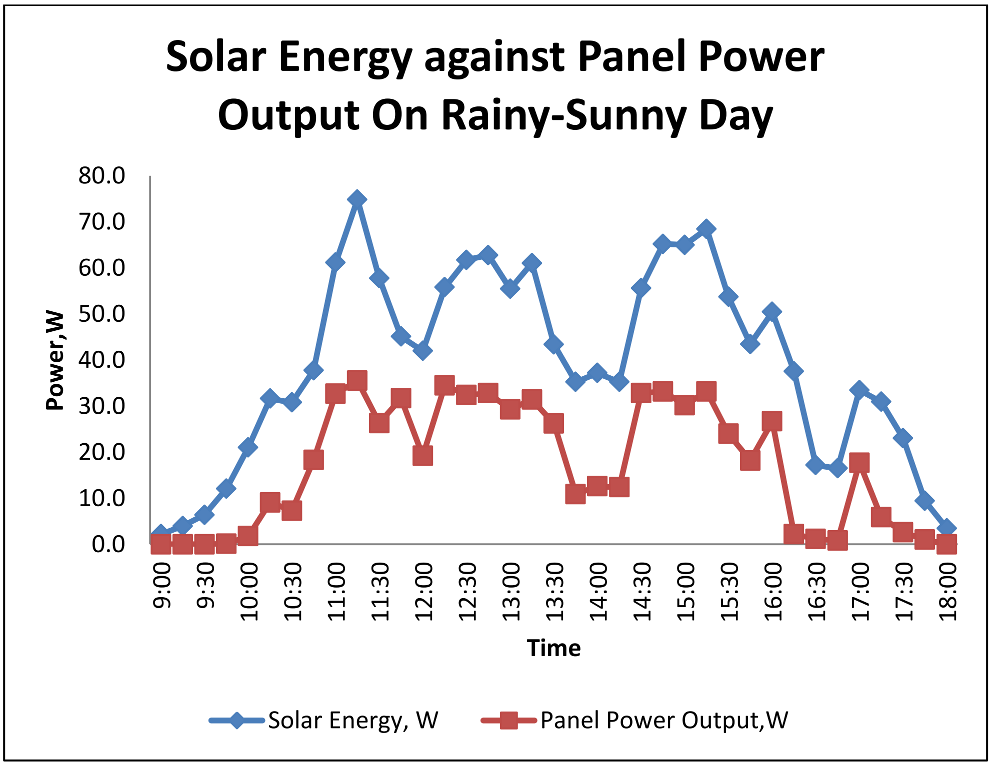

Figure 4.11: Solar energy against panel power output on rainy-sunny day

Since that the weather for that day is not stable, the peak output duration for solar panel can be determined. However through the calculation in Table 4.5, rainy and cloudy weather will cause the efficiency of the panel to decrease.

Raining will cause the output of the panel to decrease to the range almost zero while cloudy weather will block most of the sun radiation thus reducing the performance of the panel. The data from Figure 4.11 is also supported by the modulus of efficiency of the panel calculated in Table 4.5 where at rainy time the efficiency is 0 % while at cloudy time will reduce to 6.61 % where normally if on sunny weather the modulus of efficiency at that time should be at around 9 %.

4.2.3 Energy Analysis for Different Weather Pattern

4.2.3.1 Energy Analysis for Sunny Day

12 April is considered a sunny day. Figure 4.12 shows the energy consumed by the pump at two different days which is at 5 and 12 April. From Figure 4.12 without CiCo system the pump will continuously drain energy from the grid line thus the graph increase in a straight line. On 12 April, when using CiCo system the pump uses less power and in the evening the pump stop uses power all together. This resulted in a smaller increase in the energy consumption, thus forming a small slope shape. Figure 4.12 clearly shows that there is a huge difference between the energy consume by the pump on and off the system.

By incorporating CiCo system approximately 64.52 % of energy consumption on a sunny day can be saved. Based on the Figure 4.12, to change the current system to a solar powered pump system without incorporating CiCo system approximates 10, 50 W monocrystalline solar panels are required. If compared with using CiCo system only four, 50 W monocrystalline solar panels are required.

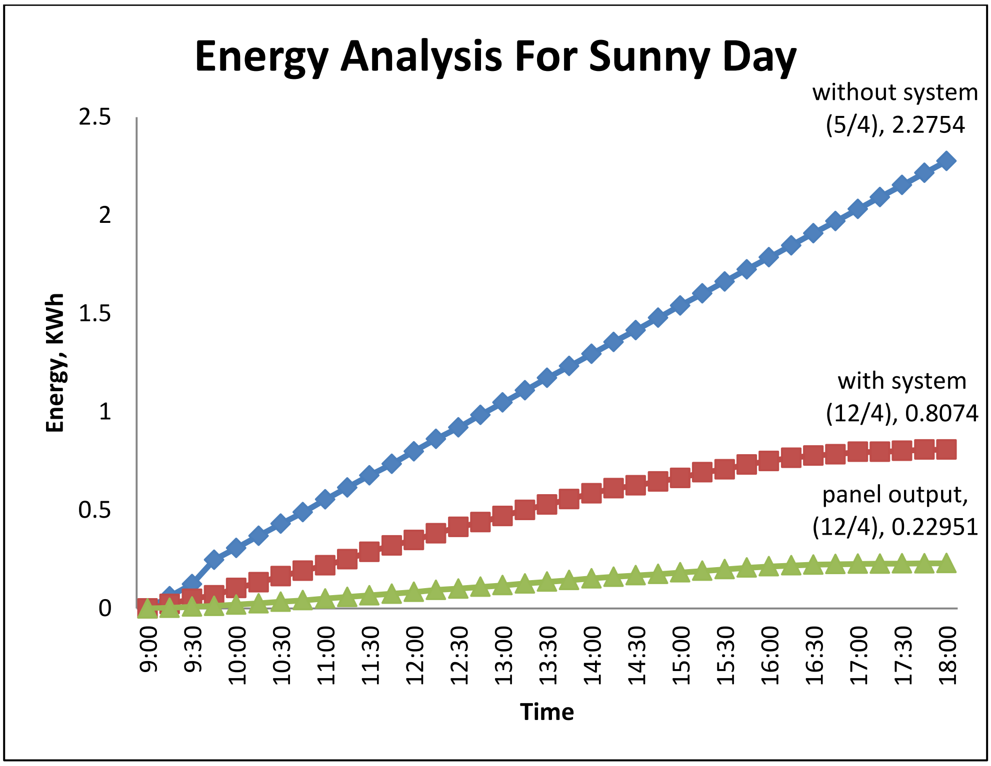

Figure 4.12: Power analysis for sunny day

4.2.3.2 Energy Analysis Rainy-Sunny Day

10 of April is considered a rainy and sunny day. Figure 4.13 shows the power consumed by the pump at two different days which is at 3 and 10 of April. From Figure 4.13 without the CiCo system the pump will continuously drain power even when not needed causing the cumulative energy consumption graph to be in a straight line. On 10 April, when using the CiCo system the pump uses less energy when comparing with the result in Figure 4.12. This is because from 9.00 a.m. to 10.30 a.m. it rains. The pump does not need a lot of energy since it takes a very long time for the evacuated tube to receive enough energy to increase the temperature difference between the ETSC outlet and the storage tank.Which is cause by the reduction of solar energy at that time resulting in a smaller slope for energy consumption graph with CiCo.

By incorporating the system approximately 64.41 % power consumption for raining and cloudy day can be saved. Based on the Figure 4.13, to change the current system to a solar powered pump system without incorporating CiCo system approximates 15, 50 W monocrystalline solar panelsare required. If compared with using CiCo system only five, 50 W monocrystalline solar panels are required.

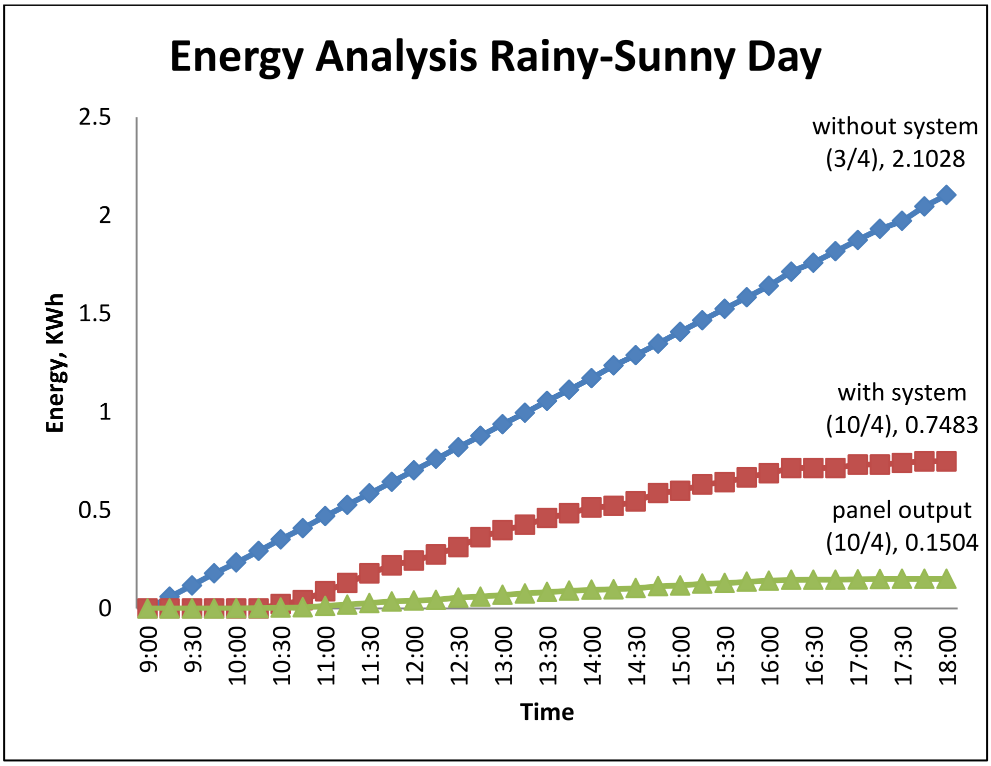

Figure 4.13: Power analysis for rainy-sunny day

4.2.3.3 Energy Analysis For Cloudy Day

11 April is considered a cloudy day. From Figure 4.14 shows the power consumed by the pump at two different days which is at 4 and 10 April. Figure 4.14 shows that without the CiCo system the pump will continuously drain power even when not needed causing the cumulative energy consumption graph to be in a straight line. On 11 April, when using the system the pump uses less power if compare with a sunny day in Figure 4.12.

Cloudy weather causes less sun energy to reach the earth surfaces which thus lower temperature for the ETSC. The weather throughout the day is cloudy. It takes a longer time for the sun to heat the ETSC to reach the cut-in temperature required. Therefore the pump uses less work.

By incorporating the CiCo system approximately 75.02 % energy consumption can be save for cloudy days. Based on the Figure 4.14, to change the current system to a solar powered pump system without incorporating CiCo system approximates 18, 50 W monocrystalline solar panels are required. If compared with using CiCo system only five, 50 W monocrystalline solar panels are required.

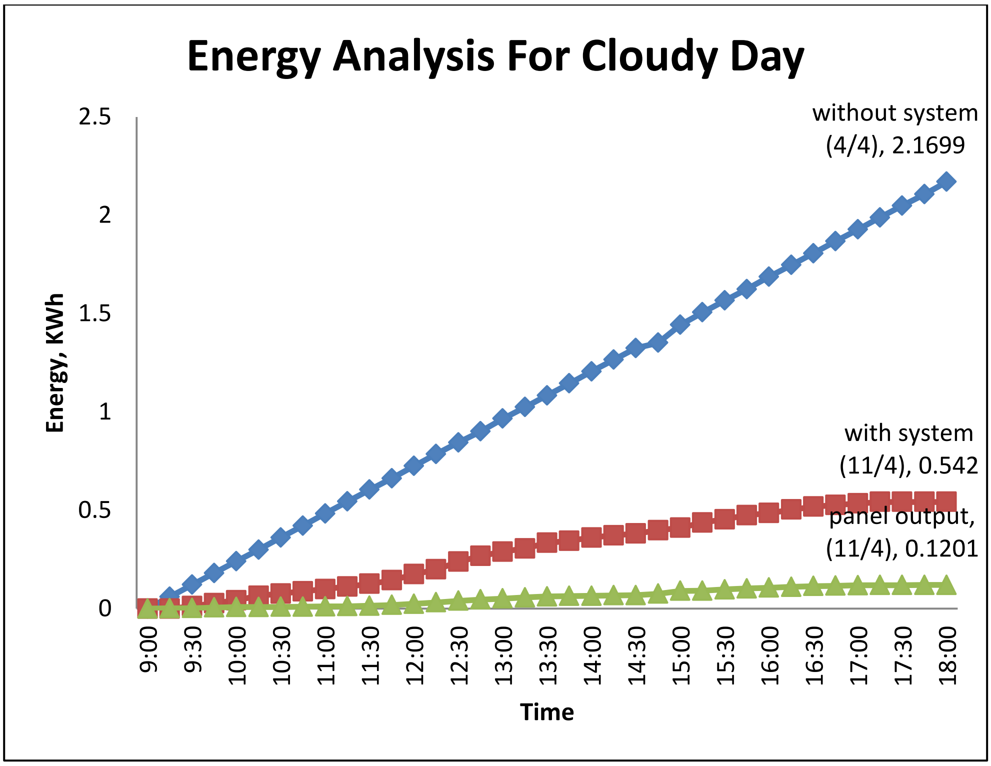

Figure 4.14: Power analysis for cloudy day

4.2.4 Effect of CiCo System Towards Storage Tank Temperature

4.2.4.1 Graph of Temperature VS Time (Without CiCo System)

Figure 4.15 shows the temperature data inside the storage tank for the four days where normal pump operation is conducted. From Figure 4.15 the temperature in the storage tank will continue to increase until 3.00 p.m. and then start to decrease again until 6.00 p.m.

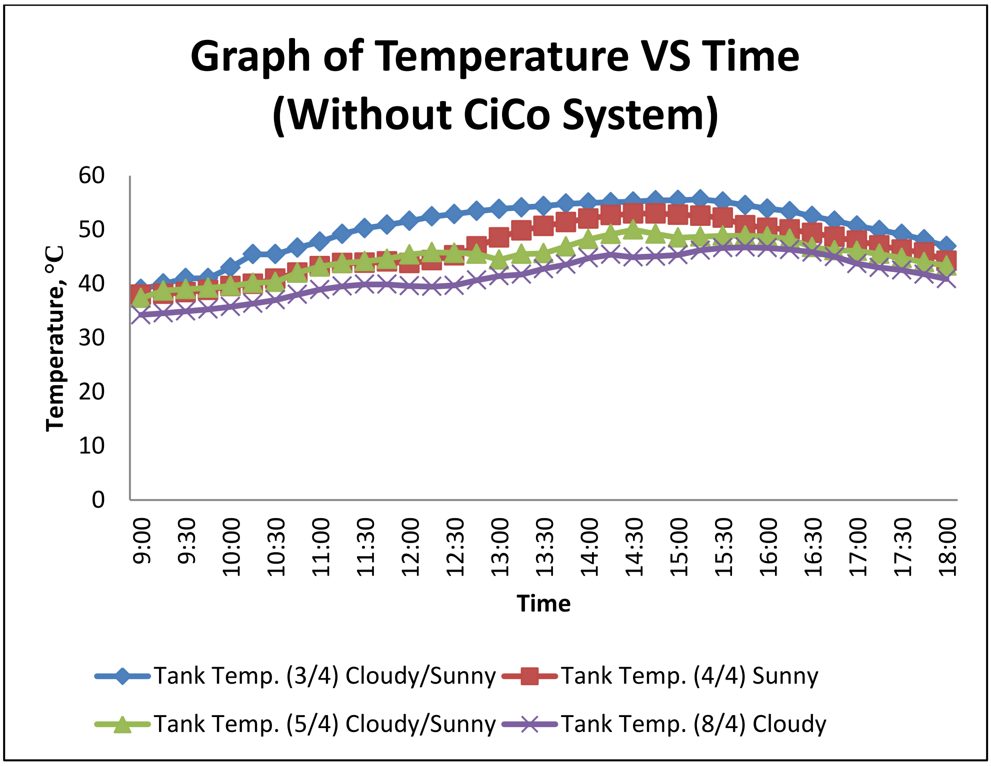

Figure 4.15: Graph of Temperature VS Time (Without CiCo System)

As per discussed in Chapter 3, the working fluid will leave the ETSC and enter the storage tank for heat exchange process to be conducted. Since the heat exchanger efficiency is not 100 % the excess heat will be removed from the radiator. During normal operation, the pump will be switched on for the whole duration of nine hours from 9.00 a.m. to 6.00 p.m. After 3.00 p.m. it takes a longer time for the solar radiation to increase the temperature of the ETSC higher than the storage tank. Since the pump is turned on the whole time the working fluid exiting the ETSC is lower than the storage tank, the working fluid will start to extract the heat from the storage tank. The heat is then removed by the heat exchanger. This cycle will continue until 6.00 p.m. Thus, cause the temperature in the storage tank to drop after 3.00 p.m.

4.2.4.2 Graph of Temperature VS Time (With CiCo System)

Figure 4.16 shows the temperature data inside the storage tank for the four days where CiCo system is fitted on the pump. From Figure 4.16 the temperature in the storage tank will continue to increase until 3.00 p.m. and decrease slightly until 6.00 p.m.

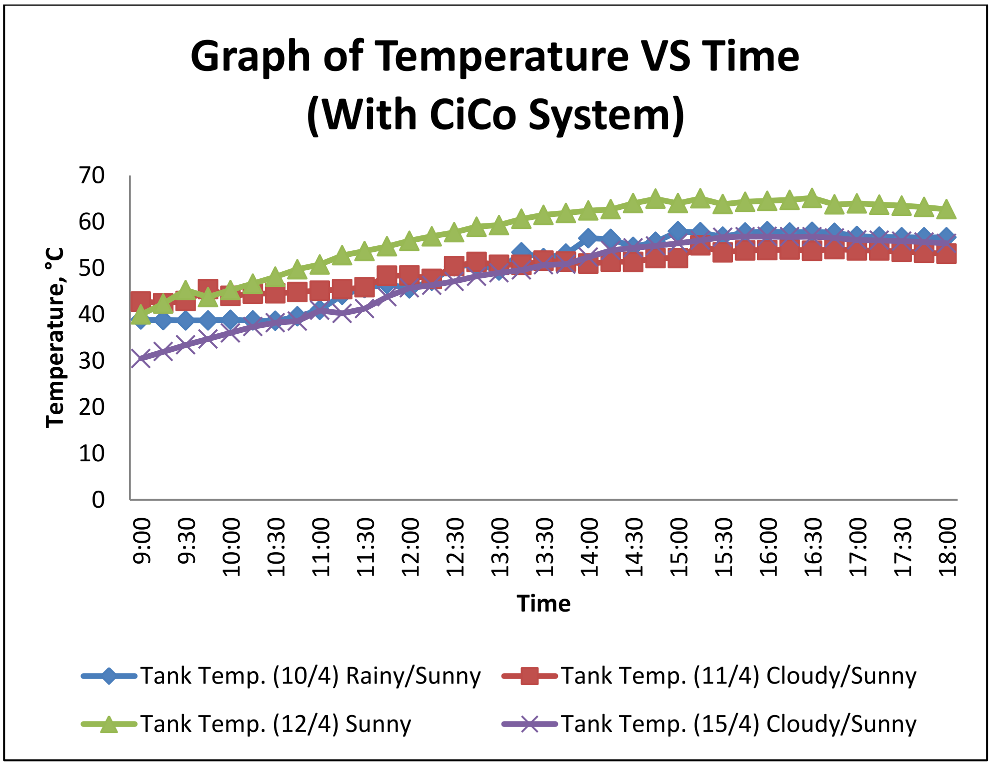

Figure 4.16: Graph of Temperature VS Time (With CiCo System)

As discussed in Chapter 3, after fitting CiCo system, the pump will only start when the temperature of the ETSC outlet is at least 8°C higher than the temperature in the storage tank. From 9.00 a.m. till 3.00 p.m. the solar energy receive by the ETSC is sufficient to increase the temperature in the ETSC higher than the set point set. This will cause an increase in temperature of the storage tank. However, after 3.00 p.m. it takes longer time for the ETSC to achieve the set point. The heats receive from the ETSC after the pump start again is only sufficient to overcome the heat loss from the storage tank to the surrounding. Therefore the result from the graph shows that the temperature after 3.00 p.m. will maintain and only drop slightly.

Figure 4.15 and 4.16 show that the temperature range for without CiCo system is between 40°C to 50°C, however after fitting the CiCo system, the temperature range is higher which is between 50°C to 65°C. From the data obtain, by fitting the CiCo system, the amount of heat stored in the storage tank can be increased.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

As a conclusion, all the objective set in chapter 1 has been successfully achieved during the duration of the data collection. A test rig has been fabricated at an angle of 10°. 10° is determined to be the optimum tilt angle for pecan at the year 2013. Through the analysis, mild steel is determined to be the best material used for the building of the test rig since it has high safety factor and the value of deflection is low.

From the analysis conducted, different weather condition will give different modulus of efficiency for PV panel. Rainy and cloudy will reduce the modulus of efficiency. Even during a sunny day, the modulus of efficiency for morning and evening is higher than in the afternoon due to the PV panel have already reached its maximum output however the solar radiation continue to increase in the afternoon causing a lower modulus of efficiency.

For the result obtained, by incorporating CiCo system, there is a huge save on power consumption of the pump system. On a sunny day, CiCo system is able to reduce the amount of panel needed from 10 panels to only four panels. On a rainy-sunny day, CiCo system is able to reduce the amount of panel required from 15 panels to five panels. On a cloudy day, CiCo system is able to reduce the amount of panel required from 18 panels to five panels.

From the result obtain it also show that, CiCo system is able to increase the final storage tank temperature which is recorded at 6.00 p.m. Without CiCo system, the temperature of the storage tank start to decrease after 3.00 p.m. because the energy absorb by the ETSC is not enough to overcome the amount of energy expel from the radiator causing reverse energy flow from the storage tank into the working fluid via the heat exchanger.

However by incorporating CiCo system, the pump will only turn on when the temperature at the ETSC outlet is higher than the storage tank. This stops the reverse flow of energy and thus reducing the amount of temperature drop in the storage tank. CiCo system increases the final temperature inside the storage tank at 6.00 p.m. which is in the range of 40°C to 50°C without using CiCo system to 50°C to 65°C when using CiCo system.

From this result, it proved that CiCo system is able to reduce the amount of panel required on all weather patterns to power the pump. It also helps increase the final temperature of the storage tank. If also show that if Universiti Malaysia Pahang decided to a fully solar powered pump system they need a minimum of five panels to ensure that the pump are able to perform on all-weather condition.

5.2 RECOMMENDATION

Below shows the recommendation for the future research and development on an energy projection analysis of solar energy for water pump system using gridline power with focus on control system.

1. The fix angle panel used in this project should be changed to the tracking system to increase the efficiency of the PV panel through the day.

2. Other than that, an in depth study should be conducted to determine the best solar PV panel to use in Pekan. A research can be conducted by mounting different type of PV panel to determine the panel which produces the most amount of energy.

3. An experiment on the effect of different angle placement for the fix angle panel can also be conducted to determine whether the tilt angle obtained from the formula is the best for Pekan or changing in angle does not have any significant effect on the power output.

4. Use the help of software and data logger to get a more accurate result. Data logger is able to get data at a fix period of time interval and throughout the day without any human interference and error. Time interval between each data recorded can also be reduced to ensure a more accurate data obtain. It can also help reduce the risk on the researcher since it reduces the exposure of bad weather on the researcher.

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APPENDIX A

The Codding in CiCo System

```
#include <18F4550.h>                        // PIC18F4550 HEADER FILE
#fuses HS,NOWDT,NOLVP,NOPROTECT             // EXTERNAL CLOCK,
                                            // NOWATCH DOG TIMER,
                                            // NO LOW VOLTAGE
                                               PROGRAMMING
#device adc=10                              // USE 10 BIT ADC QUANTIZATION
#use delay (clock=20M)                      // 20 MHZ CRYSTAL
#include <lcd.c>
////////////////////////////////////////////////////////////////////////////////////////////////////
//                                                                                              //
//                              LED && RELAY && SWITCH                                          //
//                                                                                              //
////////////////////////////////////////////////////////////////////////////////////////////////////

#define LED1        PIN_B6              // LED 1
#define LED2        PIN_B7              // LED 2
#define RELAY       PIN_B5              // RELAY
#define sw_1        PIN_B0              // switch 1
#define sw_2        PIN_B1              // switch 2

////////////////////////////////////////////////////////////////////////////////////////////////////
//                                                                                              //
//                                   ANALOG INPUT                                               //
//                                                                                              //
////////////////////////////////////////////////////////////////////////////////////////////////////

#define VR_AI1      PIN_A0              // TEMPERATURE SENSOR TANK
#define VR_AI2      PIN_A1              // TEMPERATURE SENSOR OUTLET
```

```
/////////////////////////////////////////////////////////////////////////////////////////////////////////////////////
//                                                                                                   //
//                              SWITCHING RELAY                                                      //
//                                                                                                   //
/////////////////////////////////////////////////////////////////////////////////////////////////////////////////////

/////////////////////////////////////////////////////////////////////////////////////////////////////////////////////
//                                                                                                   //
//                              LCD DISPLAY                                                          //
//                                                                                                   //
/////////////////////////////////////////////////////////////////////////////////////////////////////////////////////

#define LCD_E       PIN_D0          // PIN E
#define LCD_RS      PIN_D1          // PIN RS
#define LCD_RW      PIN_D2          // PIN RW
#define LCD_D4      PIN_D4          // PIN D4
#define LCD_D5      PIN_D5          // PIN D5
#define LCD_D6      PIN_D6          // PIN D6
#define LCD_D7      PIN_D7          // PIN D7

/////////////////////////////////////////////////////////////////////////////////////////////////////////////////////

void main()
{

/////////////////////////////////////////////////////////////////////////////////////////////////////////////////////
//                                                                                                   //
//                              LOCAL VARIABLE                                                       //
//                                                                                                   //
/////////////////////////////////////////////////////////////////////////////////////////////////////////////////////

int32 AI1;
int32 AI2;
```

```
int32 TEMP1;
int32 TEMP2;

//////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////
//                                                                    //
//                      PORT INITIALIZE                               //
//                                                                    //
//////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////

setup_adc(ADC_CLOCK_INTERNAL);      // SET INTERNAL CLOCK FOR ADC
setup_adc_ports(All_ANALOG);        // SET PORT RA0
set_tris_b(0x00);                   // SET ALL PORT B AS OUTPUT PORT
set_tris_c(0x00);                   // SET ALL PORT B AS OUTPUT PORT
output_b(0x00);                     // RESET PORT B
output_c(0x00);                     // RESET PORT C
lcd_init();                         // INITIALIZE LCD

//////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////
//                                                                    //
//                      MAIN PROGRAM                                  //
//                                                                    //
//////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////

lcd_putc("\f.....HELLO......");
delay_ms(500);
lcd_putc("\f");
lcd_putc("\n.....loading....");
delay_ms(500);
lcd_putc("\f");
lcd_putc("\f     Ready");
delay_ms(200);
```

```
while(TRUE)
{
delay_ms(250);

set_adc_channel(0);                    // POINTS ADC AT CHANNEL 0
delay_ms(100);                         // DELAY TO GET ANALOG VALUE
AI1=read_adc()/2;                      // READ ANALOG INPUT 0

TEMP1=AI1-3;                           // SCALLING TO RANGE 0% TO 100%

set_adc_channel(1);                    // POINTS ADC AT CHANNEL 0
delay_ms(100);                         // DELAY TO GET ANALOG VALUE
AI2=read_adc()/2;
TEMP2=AI2-3;                           // SCALLING TO RANGE 0% TO 100%

printf(lcd_putc,"\fT1=%uC T2=%uC",(int)TEMP1,(int)TEMP2);
// DISPLAY TRUE VALUE AT LCD DISPLAY

if ((TEMP1-TEMP2>=0) && (TEMP1-TEMP2<=3))
{
output_low(LED1);
output_low(LED2);
output_low(RELAY);
lcd_putc("\nEqual");                   //feed message at LCD display
}

else if ((TEMP1-TEMP2>=4) && (TEMP1-TEMP2<=100))
{
output_low(LED1);
output_high(LED2);
output_low(RELAY);
lcd_putc("\nTemp1>2");                 //feed message at LCD display
}
```

```
else if ((TEMP2-TEMP1>=0) && (TEMP2-TEMP1<=3))
{
output_low(LED1);
output_low(LED2);
output_low(RELAY);
lcd_putc("\nEqual");                    //feed message at LCD display
}

else if ((TEMP2-TEMP1>=4) && (TEMP2-TEMP1<=7))
{
output_low(LED1);
output_low(LED2);
lcd_putc("\nEqual");                    //feed message at LCD display
}

else if ((TEMP2-TEMP1>=0) && (TEMP2-TEMP1<=7) && (TEMP2<=40))
{
output_low(LED1);
output_low(LED2);
output_low(RELAY);
lcd_putc("\nEqual");                    //feed message at LCD display
}

else if ((TEMP2-TEMP1>=8) && (TEMP2-TEMP1<=100) && (TEMP2<=40))
{
output_high(LED1);
output_low(LED2);
output_low(RELAY);
lcd_putc("\nTEMP2>1");                  //feed message at LCD display
}
```

```
else if ((TEMP2-TEMP1>=8) && (TEMP2-TEMP1<=100) && (TEMP2>=45))
{
output_high(LED1);
output_low(LED2);
output_high(RELAY);
lcd_putc("\nTEMP2>1 RELAY 0N ");          //feed message at LCD display
}

else
{
output_low(LED1);
output_low(LED2);
lcd_putc("\nEqual");                      //feed message at LCD display
}

}
}
```

APPENDIX B

Raw data collected during the experiment period.

3RD APRIL (WITHOUT SYSTEM, CiCo)									
Time	**Pump Energy consumption, KWh**	**Temp**		**Panel**				**Solar**	
		T1	**T2**	**A**	**V**	**W**	**Wh**	**Energy, W**	**Radiation, W/m^2**
09:00	0.0000	39	41	1.11	3.49	6.2	0.0	36.26	435
09:15	0.0588	40	38	0.97	4.32	4.2	2.0	23.13	277
09:30	0.1165	41	40	1.12	5.71	6.8	4.5	28.94	347
09:45	0.1778	41	39	1.30	7.64	9.1	7.3	32.31	388
10:00	0.2330	43	49	1.92	14.94	24.5	12.9	54.27	652
10:15	0.2920	45	40	1.41	8.05	11.5	16.3	38.70	464
10:30	0.3514	45	49	1.38	8.44	11.6	19.6	38.70	464
10:45	0.4083	47	53	2.01	16.10	32.3	25.1	63.80	766
11:00	0.4687	48	55	2.01	16.06	33.1	31.8	66.83	802
11:15	0.5266	49	54	2.07	16.31	33.7	40.0	72.17	867
11:30	0.5850	50	56	2.07	16.32	33.0	48.2	71.01	852
11:45	0.6429	51	53	1.97	16.32	33.8	56.5	74.03	889
12:00	0.7021	52	55	2.08	16.71	34.8	65.1	76.59	919
12:15	0.7600	52	56	2.07	16.50	34.6	75.5	74.73	897
12:30	0.8201	53	55	2.10	16.70	35.1	87.2	77.40	929
12:45	0.8773	53	55	2.10	16.90	35.1	99.9	77.52	930
13:00	0.9366	54	55	2.20	17.20	35.1	112.5	77.52	931
13:15	0.9945	54	55	2.20	16.50	35.0	125.2	77.17	926
13:30	1.0545	54	55	2.11	16.83	35.0	136.8	77.05	925
13:45	1.1130	55	56	2.08	16.81	34.8	148.3	75.78	910
14:00	1.1715	55	55	2.07	16.71	34.5	157.7	74.38	893
14:15	1.2355	55	55	2.07	16.31	33.7	166.0	72.75	873
14:30	1.2880	55	55	2.08	16.12	33.0	174.1	71.01	853
14:45	1.3470	55	55	2.06	16.42	33.0	182.2	71.13	854
15:00	1.4072	55	54	2.03	16.10	32.5	190.2	69.03	829
15:15	1.4657	56	54	2.01	15.68	32.0	196.7	63.80	766
15:30	1.5240	55	52	1.81	13.33	26.3	201.7	58.11	698
15:45	1.5821	55	51	1.90	14.20	26.0	206.5	56.60	680
16:00	1.6413	54	51	1.84	13.80	24.5	211.2	54.27	652
16:15	1.7130	53	49	1.55	9.90	17.2	215.3	47.53	571
16:30	1.7589	53	48	1.51	9.70	15.6	218.7	39.17	470
16:45	1.8167	52	46	1.49	9.80	15.6	222.1	39.75	477
17:00	1.8742	51	45	1.55	10.30	16.0	225.7	41.61	499
17:15	1.9300	50	44	1.20	8.88	10.7	228.5	32.54	391
17:30	1.9710	49	42	0.99	4.52	4.5	230.7	26.38	317
17:45	2.0450	48	40	0.45	0.68	0.8	232.3	18.71	225
18:00	2.1028	47	38	0.35	0.49	0.5	233.6	14.53	174

4th APRIL (WITHOUT SYSTEM, CiCo)									
Time	**Pump Energy consumption, KWh**	**Temp**		**Panel**				**Solar**	
		T1	**T2**	**A**	**V**	**W**	**Wh**	**Energy, W**	**Radiation, W/m^2**
09:00	0.0000	38	38	1.00	3.70	3.6	0.0	27.3	328
09:15	0.0601	38	39	1.31	7.07	9.1	2.9	33.4	401
09:30	0.1205	38	41	1.42	7.21	9.3	6.0	35.9	431
09:45	0.1799	39	42	1.36	7.08	9.1	8.9	34.2	410
10:00	0.2403	40	43	1.59	7.10	9.5	12.0	36.5	438
10:15	0.2987	40	46	1.40	10.66	17.9	17.3	49.4	593
10:30	0.3611	41	47	1.92	14.94	28.8	23.0	54.3	652
10:45	0.4212	42	49	2.04	15.81	32.1	31.3	62.5	750
11:00	0.4826	43	51	2.06	16.75	34.5	40.2	68.1	818
11:15	0.5442	44	46	1.95	15.43	30.2	46.2	57.9	695
11:30	0.6045	44	42	1.12	7.00	8.7	49.0	32.8	393
11:45	0.6623	44	46	1.42	8.04	11.1	53.3	38.4	461
12:00	0.7242	44	43	1.01	6.90	8.5	57.0	31.3	375
12:15	0.7856	44	48	2.01	15.00	32.1	65.4	62.5	750
12:30	0.8444	45	52	2.08	17.03	35.5	75.8	74.3	892
12:45	0.9000	47	55	2.07	17.50	36.3	87.9	83.3	1000
13:00	0.9652	49	55	2.06	16.98	36.0	99.4	75.2	902
13:15	1.0242	50	55	2.19	16.97	36.1	110.3	80.2	962
13:30	1.0836	51	53	2.13	16.51	34.9	119.3	69.7	837
13:45	1.1444	51	55	2.10	16.75	35.1	128.9	76.7	921
14:00	1.2057	52	55	2.10	16.70	35.0	137.4	76.0	912
14:15	1.2645	53	55	2.07	16.31	33.7	145.6	72.1	865
14:30	1.3238	53	54	2.03	16.13	33.2	153.6	69.0	829
14:45	1.8510	53	53	2.21	15.75	32.2	161.2	65.8	789
15:00	1.4421	53	52	1.71	17.21	31.8	168.7	63.1	758
15:15	1.5057	53	52	1.97	15.90	30.9	174.8	59.3	711
15:30	1.5660	52	49	1.51	9.75	14.9	179.3	41.0	493
15:45	1.6238	51	48	1.93	14.22	27.1	184.5	49.0	589
16:00	1.6867	50	48	2.00	15.41	27.5	188.8	50.2	603
16:15	1.7462	50	47	1.72	12.90	19.5	192.6	44.2	530
16:30	1.8056	49	46	1.60	10.20	14.8	196.2	41.3	495
16:45	1.8673	49	44	1.44	8.74	12.6	199.3	36.0	432
17:00	1.9273	48	43	1.20	8.88	10.7	202.1	32.4	389
17:15	1.9881	47	41	1.09	5.34	5.8	204.6	28.7	345
17:30	2.0483	46	40	0.86	3.49	3.1	206.5	22.7	272
17:45	2.1064	46	38	0.48	4.20	2.0	207.4	10.3	124
18:00	2.1699	44	36	0.42	2.10	0.9	207.8	4.9	59

5th APRIL (WITHOUT SYSTEM, CiCo)									
Time	**Pump Energy consumption, KWh**	**Temp**		**Panel**				**Solar**	
		T1	**T2**	**A**	**V**	**W**	**Wh**	**Energy, W**	**Radiation, W/m²**
09:00	0.0000	37	40	1.16	7.76	9.00	0.0	31.8	382
09:15	0.0614	39	40	1.20	7.17	8.60	1.9	33.0	396
09:30	0.1233	39	41	1.24	7.74	9.60	4.3	33.1	398
09:45	0.2466	39	41	1.39	10.22	14.20	7.1	37.0	444
10:00	0.3074	40	43	1.70	13.53	23.00	12.1	44.9	539
10:15	0.3691	40	41	1.56	12.12	18.90	15.1	38.6	463
10:30	0.4298	40	46	1.96	16.12	31.60	21.4	57.1	685
10:45	0.4889	42	48	1.97	16.09	31.70	30.5	58.7	704
11:00	0.5534	43	48	1.97	16.65	32.80	38.3	59.3	711
11:15	0.6150	44	45	1.04	5.29	5.50	41.8	35.4	425
11:30	0.6765	44	46	1.98	17.02	33.70	46.1	68.0	816
11:45	0.7345	45	49	1.96	17.14	33.60	52.2	59.7	717
12:00	0.7989	45	50	1.41	8.37	11.80	59.1	33.2	399
12:15	0.8624	46	44	1.02	6.47	6.60	62.2	24.1	289
12:30	0.9200	46	50	2.00	15.10	30.20	69.0	28.8	346
12:45	0.9840	46	42	0.57	5.61	3.20	73.0	14.6	176
13:00	1.0470	44	45	1.89	17.14	32.40	76.6	70.7	848
13:15	1.1087	46	45	0.95	8.21	7.80	81.2	22.0	263
13:30	1.1723	46	49	1.93	16.37	31.60	88.4	65.5	787
13:45	1.2325	47	52	1.97	16.29	32.10	96.4	68.1	817
14:00	1.2938	48	53	1.92	16.35	31.40	104.3	70.4	845
14:15	1.3555	49	53	1.96	16.33	32.00	111.5	58.6	703
14:30	1.4154	50	51	2.04	16.67	34.00	118.4	71.0	852
14:45	1.4782	49	45	2.07	17.00	35.20	122.3	56.6	679
15:00	1.5406	49	46	1.99	16.08	32.00	128.7	60.7	728
15:15	1.6017	49	49	1.96	15.77	30.90	135.8	58.1	698
15:30	1.6623	49	49	1.85	15.08	27.90	142.9	53.3	640
15:45	1.7243	49	48	1.81	14.64	26.50	149.4	49.3	591
16:00	1.7855	49	47	1.71	13.22	22.60	155.4	44.6	536
16:15	1.8469	48	46	1.49	9.66	14.40	160.2	38.8	466
16:30	1.9082	47	44	1.32	7.88	10.40	163.2	35.2	423
16:45	1.9695	46	43	1.13	5.84	6.60	165.3	30.2	363
17:00	2.0308	46	42	1.00	4.70	4.70	166.6	26.7	321
17:15	2.0926	46	40	0.80	3.00	2.40	167.5	22.5	270
17:30	2.1534	45	39	0.66	1.97	1.30	167.9	18.7	225
17:45	2.2147	44	39	0.56	1.25	0.70	168.2	16.4	197
18:00	2.2754	43	38	0.39	0.51	0.20	168.3	11.9	143

8th APRIL (WITHOUT SYSTEM, CiCo)									
Time	**Pump Energy consumption, KWh**	**Temp**		**Panel**				**Solar**	
		T1	**T2**	**A**	**V**	**W**	**Wh**	**Energy, W**	**Radiation, W/m^2**
09:00	0.0000	34	35	0.65	1.70	1.1	0.0	20.9	251
09:15	0.0635	35	36	0.73	2.35	1.0	0.1	21.7	261
09:30	0.1267	35	37	0.82	2.98	2.4	1.1	23.1	278
09:45	0.1878	35	38	1.02	4.45	4.5	2.3	28.5	342
10:00	0.2525	36	39	0.93	3.68	3.4	3.5	27.0	324
10:15	0.3145	36	40	1.53	12.17	18.5	8.8	39.7	477
10:30	0.3788	37	41	1.87	14.17	26.5	14.6	50.0	600
10:45	0.4410	38	43	1.63	10.48	17.0	18.9	42.8	513
11:00	0.5044	39	43	1.55	10.30	15.9	22.7	39.9	479
11:15	0.5669	40	42	1.58	10.43	18.3	24.9	37.8	454
11:30	0.6299	40	42	1.16	8.27	9.6	25.9	32.7	392
11:45	0.6932	40	40	0.88	5.90	5.2	26.5	25.9	311
12:00	0.7566	40	39	0.76	5.10	4.7	27.2	25.2	303
12:15	0.8206	39	40	1.19	6.21	7.3	29.0	30.1	362
12:30	0.8830	40	42	1.20	6.23	7.4	31.1	31.1	374
12:45	0.9456	41	46	1.40	7.80	10.9	37.7	43.9	528
13:00	1.0960	41	42	1.43	8.63	12.5	42.8	36.0	433
13:15	1.1350	42	43	1.66	14.05	23.3	46.4	47.7	572
13:30	1.1999	43	49	2.08	17.60	36.5	55.6	85.7	1028
13:45	1.2616	44	46	1.20	6.22	7.4	57.3	31.3	375
14:00	1.3242	45	52	2.06	16.75	34.5	66.7	67.3	808
14:15	1.3870	45	45	2.00	15.75	31.8	75.0	45.4	545
14:30	1.4506	45	45	1.82	13.10	23.7	82.2	53.1	637
14:45	1.5137	45	46	2.01	15.73	31.7	90.1	45.7	548
15:00	1.5766	45	48	2.05	16.10	33.3	98.5	64.7	777
15:15	1.6380	46	49	2.03	16.14	32.8	104.0	62.8	753
15:30	1.7021	47	48	1.81	13.30	25.8	109.5	57.2	686
15:45	1.7655	47	47	1.78	12.80	24.3	113.9	56.3	675
16:00	1.8290	47	46	1.64	10.66	17.5	117.5	48.6	583
16:15	1.8921	46	45	1.99	15.72	31.7	123.4	45.0	540
16:30	1.9554	46	44	1.85	13.74	26.3	129.3	43.7	524
16:45	2.0183	45	41	0.81	3.01	2.1	130.1	18.5	222
17:00	2.0814	44	39	0.85	3.20	2.8	131.5	23.7	284
17:15	2.1444	43	41	0.60	4.20	2.3	132.2	17.2	206
17:30	2.2066	43	38	0.40	4.00	2.2	132.5	16.2	194
17:45	2.2707	42	37	0.30	3.70	1.5	132.6	10.6	127
18:00	2.3335	41	36	0.28	3.20	0.9	132.6	7.7	92

10th APRIL (WITH SYSTEM, CiCo)									
Time	**Pump Energy consumption, KWh**	**Temp**		**Panel**				**Solar**	
		T1	**T2**	**A**	**V**	**W**	**Wh**	**Energy, W**	**Radiation, W/m^2**
09:00	0.0000	39	25	0.18	0.20	0.0	0.0	2.2	26
09:15	0.0000	39	25	0.19	0.19	0.0	0.0	4.0	47
09:30	0.0000	39	26	0.20	0.22	0.0	0.0	6.4	77
09:45	0.0000	39	28	0.35	0.49	0.1	0.0	12.1	145
10:00	0.0000	39	31	0.72	2.34	1.8	0.1	21.0	252
10:15	0.0000	39	36	1.30	7.07	9.1	1.6	31.6	380
10:30	0.0215	39	40	1.19	6.21	7.3	3.3	30.8	370
10:45	0.0410	40	52	1.58	10.42	18.3	5.6	37.8	453
11:00	0.0872	41	48	2.01	16.18	32.7	12.8	61.1	734
11:15	0.1294	44	52	2.08	17.03	35.5	18.9	74.8	899
11:30	0.1780	46	53	1.81	13.33	26.3	27.7	57.8	693
11:45	0.2192	47	54	1.99	15.72	31.7	35.2	45.1	542
12:00	0.2432	46	54	1.72	11.72	19.2	39.2	42.0	503
12:15	0.2746	47	50	2.08	16.70	34.5	43.9	55.8	669
12:30	0.3123	50	64	2.01	16.10	32.4	54.9	61.7	741
12:45	0.3627	51	59	2.03	16.14	32.8	60.0	62.8	753
13:00	0.3978	49	66	1.95	14.97	29.3	68.9	55.4	665
13:15	0.4255	53	69	2.00	15.68	31.4	75.8	61.0	732
13:30	0.4591	52	55	1.84	13.74	26.2	83.8	43.4	520
13:45	0.4846	53	62	1.38	7.98	10.9	90.2	35.2	423
14:00	0.5132	56	64	1.44	8.74	12.6	94.5	37.2	446
14:15	0.5211	56	66	1.42	8.52	12.4	97.2	35.2	423
14:30	0.5451	55	56	2.00	15.98	32.8	102.7	55.6	667
14:45	0.5871	56	57	2.01	16.06	33.2	112.6	65.2	783
15:00	0.5983	58	63	1.91	14.75	30.2	116.8	65.0	780
15:15	0.6304	58	61	2.03	16.13	33.2	125.6	68.5	822
15:30	0.6422	57	89	1.87	13.83	24.0	129.4	53.7	645
15:45	0.6665	58	65	1.63	11.20	18.2	135.8	43.5	522
16:00	0.6883	58	58	1.90	14.20	26.7	141.2	50.4	606
16:15	0.7138	58	64	0.80	2.82	2.2	145.4	37.5	451
16:30	0.7138	58	51	0.67	1.98	1.2	145.7	17.2	206
16:45	0.7138	58	57	0.60	1.46	0.8	145.8	16.5	198
17:00	0.7317	57	63	1.16	6.01	17.7	148.0	33.5	402
17:15	0.7317	57	64	1.11	5.44	5.9	149.0	30.9	371
17:30	0.7399	57	61	0.83	3.16	2.6	149.9	23.0	276
17:45	0.7483	57	51	0.44	0.85	1.0	150.3	9.4	113
18:00	0.7483	57	44	0.18	0.20	0.0	150.4	3.5	42

11th APRIL (WITH SYSTEM, CiCo)									
Time	**Pump Energy consumption, KWh**	**Temp**		**Panel**				**Solar**	
		T1	**T2**	**A**	**V**	**W**	**Wh**	**Energy, W**	**Radiation, W/m^2**
09:00	0.0000	43	50	0.48	4.20	2.0	0.0	13.6	163
09:15	0.0000	42	40	0.75	2.40	1.8	1.0	21.6	259
09:30	0.0120	43	46	1.51	9.75	14.8	2.0	40.4	486
09:45	0.0275	45	55	1.38	8.44	11.6	5.3	39.3	472
10:00	0.0420	44	46	0.86	3.49	3.0	7.4	22.8	273
10:15	0.0645	45	44	0.77	2.71	2.0	8.0	20.5	246
10:30	0.0759	45	47	0.97	4.32	4.2	8.8	24.9	299
10:45	0.0875	45	49	1.00	4.55	4.5	9.8	25.6	307
11:00	0.0987	45	46	0.99	4.52	4.5	10.9	25.2	303
11:15	0.1123	45	45	1.07	5.17	5.5	12.0	27.8	333
11:30	0.1259	46	50	1.37	8.24	11.3	14.0	36.3	435
11:45	0.1439	48	56	1.79	13.18	23.6	18.5	45.0	540
12:00	0.1749	48	53	1.92	14.94	28.8	24.1	54.4	653
12:15	0.1987	48	58	1.75	12.63	22.1	31.3	52.2	626
12:30	0.2380	50	55	2.07	17.50	36.3	39.3	84.4	1013
12:45	0.2677	51	54	1.69	12.03	20.3	45.9	46.0	553
13:00	0.2896	51	51	1.55	10.30	15.9	51.0	39.9	478
13:15	0.3056	51	65	1.95	15.43	30.2	56.4	54.9	658
13:30	0.3338	52	51	1.37	8.07	11.0	61.5	35.1	421
13:45	0.3445	51	63	1.11	5.49	6.0	63.6	28.8	346
14:00	0.3610	51	50	1.09	5.34	5.8	65.1	28.7	345
14:15	0.3725	51	62	1.25	6.85	8.6	66.8	30.7	368
14:30	0.3815	51	46	0.74	2.44	1.8	67.6	21.7	261
14:45	0.3984	52	57	2.00	16.00	32.8	75.3	56.4	677
15:00	0.4102	52	68	1.80	13.10	23.6	89.8	52.5	630
15:15	0.4373	55	61	1.65	14.04	23.2	90.6	47.0	563
15:30	0.4534	53	66	1.79	15.04	26.9	97.1	51.4	616
15:45	0.4747	54	57	1.51	12.16	18.4	102.2	39.4	473
16:00	0.4851	54	73	1.63	13.34	21.7	106.4	37.4	449
16:15	0.5034	54	53	1.20	8.88	10.7	110.0	32.1	385
16:30	0.5175	54	52	1.16	8.27	9.6	114.1	32.8	393
16:45	0.5271	54	53	0.99	6.87	6.8	116.1	26.8	322
17:00	0.5342	54	56	0.89	6.09	5.4	118.1	23.4	281
17:15	0.5420	54	46	0.52	4.26	2.2	118.9	14.6	176
17:30	0.5420	54	49	0.43	4.58	1.9	119.3	12.2	146
17:45	0.5420	53	49	0.33	4.61	1.5	119.8	9.5	114
18:00	0.5420	53	47	0.28	5.03	1.4	120.1	8.1	97

12th APRIL (WITH SYSTEM, CiCo)									
Time	Pump Energy consumption, KWh	Temp		Panel				Solar	
		T1	T2	A	V	W	Wh	Energy, W	Radiation, W/m^2
09:00	0.0000	40	43	1.32	7.40	9.8	0.0	35.45	426
09:15	0.0221	42	44	1.10	4.56	4.5	3.0	25.92	311
09:30	0.0483	45	52	1.21	7.47	9.1	8.2	33.70	404
09:45	0.0661	44	46	1.73	13.00	22.6	12.7	46.60	559
10:00	0.1027	45	48	1.88	14.28	26.9	18.9	50.79	610
10:15	0.1323	47	53	1.96	15.40	30.2	25.9	55.09	661
10:30	0.1632	48	51	2.01	16.06	32.3	33.4	57.76	694
10:45	0.1920	50	53	2.02	16.25	32.9	41.4	62.06	745
11:00	0.2185	51	61	2.06	16.75	34.5	49.7	67.41	809
11:15	0.2505	53	63	2.05	16.57	34.0	58.1	69.38	833
11:30	0.2880	54	59	2.02	16.76	33.9	66.4	71.36	856
11:45	0.3200	55	58	1.96	16.90	33.2	74.8	72.87	875
12:00	0.3473	56	68	2.07	16.31	33.7	83.2	72.17	866
12:15	0.3823	57	61	2.08	16.71	34.8	93.8	76.12	914
12:30	0.4139	58	56	2.10	16.71	35.1	100.4	77.05	925
12:45	0.4380	59	77	2.09	16.70	35.0	109.1	77.63	932
13:00	0.4697	59	67	2.10	16.68	35.0	117.7	78.22	939
13:15	0.5009	61	67	2.10	16.70	35.1	126.3	78.68	945
13:30	0.5285	61	62	2.11	16.83	35.5	135.1	79.26	951
13:45	0.5550	62	64	2.10	16.75	35.2	143.9	77.52	930
14:00	0.5854	62	64	2.07	16.32	33.0	152.5	71.01	852
14:15	0.6110	63	61	2.04	15.81	32.5	161.0	63.22	759
14:30	0.6249	64	63	1.71	12.11	21.4	168.2	51.95	623
14:45	0.6453	65	67	1.64	10.66	17.5	174.6	48.70	585
15:00	0.6637	64	88	2.08	16.42	34.2	182.9	69.38	833
15:15	0.6922	65	74	2.06	16.15	33.3	191.2	64.97	780
15:30	0.7074	64	95	2.05	15.94	32.6	199.3	61.60	739
15:45	0.7320	64	64	1.96	14.70	28.8	206.7	53.69	644
16:00	0.7496	65	67	1.93	14.31	27.6	213.6	48.81	586
16:15	0.7663	65	69	1.70	11.36	19.3	218.7	41.61	500
16:30	0.7778	65	73	1.41	8.05	11.4	222.7	38.93	468
16:45	0.7842	64	81	1.32	7.20	9.5	225.2	34.63	416
17:00	0.7965	64	68	1.17	5.71	6.6	226.9	26.85	322
17:15	0.7965	64	73	0.93	3.68	3.4	227.5	27.31	328
17:30	0.8021	63	69	0.98	4.15	4.1	228.5	27.78	333
17:45	0.8074	63	63	0.79	2.65	2.1	229.2	23.36	281
18:00	0.8074	63	64	0.45	0.68	0.3	229.5	18.71	225

15th APRIL (WITH SYSTEM, CiCo)									
Time	**Pump Energy consumption, KWh**	**Temp**		**Panel**				**Solar**	
		T1	**T2**	**A**	**V**	**W**	**Wh**	**Energy, W**	**Radiation, W/m^2**
09:00	0.0000	30	38	1.15	9.33	10.8	0.0	32.54	391
09:15	0.0503	32	39	0.60	2.82	2.1	3.2	36.73	441
09:30	0.1102	33	40	1.47	12.46	18.3	6.6	40.44	486
09:45	0.1715	35	42	1.62	14.55	23.6	10.6	45.44	546
10:00	0.2331	36	43	1.97	14.82	29.1	14.8	49.74	597
10:15	0.2931	37	45	2.00	16.25	32.7	21.1	61.71	741
10:30	0.3311	38	43	1.11	4.12	5.3	24.7	30.22	363
10:45	0.3441	39	61	1.10	7.45	8.3	32.8	58.92	707
11:00	0.3890	41	45	1.02	6.87	6.8	38.2	27.54	330
11:15	0.3890	40	46	1.07	4.02	5.1	41.7	29.40	353
11:30	0.4157	41	47	2.08	16.55	34.6	48.2	75.08	901
11:45	0.4615	44	50	1.90	17.11	32.6	54.0	56.60	679
12:00	0.5032	46	55	0.89	8.09	5.4	57.1	23.59	283
12:15	0.5197	46	66	2.55	17.80	36.5	67.5	86.00	1032
12:30	0.5409	47	51	2.62	18.10	37.2	79.4	92.05	1105
12:45	0.5690	48	62	2.01	16.06	32.3	90.4	58.11	698
13:00	0.5883	49	51	2.01	18.20	37.3	103.6	95.77	1150
13:15	0.6151	50	47	2.03	17.78	36.2	115.2	87.75	1053
13:30	0.6426	51	54	1.10	7.51	8.5	123.4	60.09	721
13:45	0.6709	51	82	2.08	16.71	34.8	132.9	76.01	913
14:00	0.7049	52	62	2.09	16.58	34.7	141.4	75.78	909
14:15	0.7372	54	58	2.10	16.57	34.9	149.8	73.92	888
14:30	0.7599	54	55	2.09	16.32	34.1	157.8	69.50	835
14:45	0.7942	55	65	2.07	16.78	33.5	165.6	68.22	819
15:00	0.8240	55	78	2.04	16.06	32.6	173.3	65.43	786
15:15	0.8492	56	69	2.03	15.77	32.1	179.6	62.53	751
15:30	0.8839	57	57	2.00	15.30	30.6	185.6	57.41	689
15:45	0.9081	57	59	1.99	15.20	30.3	191.4	56.02	673
16:00	0.9318	57	59	1.94	14.40	27.9	195.9	52.76	633
16:15	0.9481	57	54	1.77	12.10	21.5	200.0	46.95	563
16:30	0.9668	57	54	1.63	10.48	17.0	203.6	42.30	508
16:45	0.9800	57	53	1.07	4.02	5.1	206.2	29.64	356
17:00	0.9828	56	72	1.01	4.45	4.6	208.9	31.61	380
17:15	0.9912	56	66	1.02	4.45	4.5	211.4	28.71	345
17:30	0.9978	56	64	0.81	2.98	2.4	213.4	24.06	289
17:45	1.0080	56	48	0.63	1.69	1.0	215.1	19.29	231
18:00	1.0080	55	54	0.36	0.55	0.1	216.3	14.30	172

APPENDIX C

Test Rig Design