STUDY OF HYBRID SOLAR AIR CONDITIONING

By

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14983

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CERTIFICATION OF APPROVAL

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in partial fulfillment of the requirements for the
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Approved by,

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TRONOH, PERAK

JANUARY 2015

CERTIFICATION OF ORIGINALITY

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

(ARIFF RAHMAN BIN ISHAK)

ACKNOWLEDGEMENT

بِسْمِ ٱللهِ ٱلْرَّحْمَنِ ٱلرَّحِيمِ

With the Name of Allah the Most Gracious, the Most Merciful

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ABSTRACT

In this progress report, it addresses several researches on the hybrid solar air conditioner with its critical component and mechanism. Some calculation has been made to determine the betterment of the proposed system of the solar air conditioner. Nowadays, the necessity of having air conditioner at our home was highly demand at home and in public areas due to the large demand for comfort in the thermal environment of living space in modern society. Since the demand of the air conditioner had increase from year to year and the air conditioner had consumed big amount of electricity to operate, a new system of air conditioner has been discovered and developed which is by adding solar energy.

Air-conditioner consumes almost 50% of the primary energy supplied to a building. The cooler the temperature, the bigger the energy or electricity needed to run the air-conditioner. 60 % of the power consumed by the air conditioner is used by the compressor whereas the other 40% is used to operate other components in air conditioning. Therefore, by decreasing the consumption of electricity by the compressor may decrease the power consumption of an air-conditioner.

This report discusses a new system of air-conditioning to decrease the power consumption that uses the heat energy from the solar collector to support and enhance the heating of refrigerant, thus decrease the work load of the compressor. It focuses on the new system of the air conditioner which is a solar collector, added after the compressor in the air conditioner cycle. The collector used for the experimentations is discussed and evacuated tube solar collector is selected and the refrigerant used is R407. The project showing that the propose design can reduce the power consumption by the air conditioner by about 30% lower than conventional air conditioner.

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CHAPTER 1:

INTRODUCTION

1.1 Background of Study

1.1.1 Conventional & Integrated system of Solar Air Conditioner

Every air conditioner has a compressor inside it. The refrigerant gas inside is compressed and pumped. When the refrigerant compressed, it produces heat. Then the compressed refrigerant is pumped to the condenser coil which blow by a fan and the heat is dissipated out to the atmosphere. In the process, the refrigerant converts to liquid form and pumped towards expansion valve. A temperature sensor is connecting to the expansion valve which works together with thermostat settings. Expansion valve control the appropriate amount of refrigerant to evaporator (cooling coils) where the liquid refrigerant change back into gas form. The liquid change back into gaseous state due to expansion produces chillness when energy is absorbed from the surrounding.

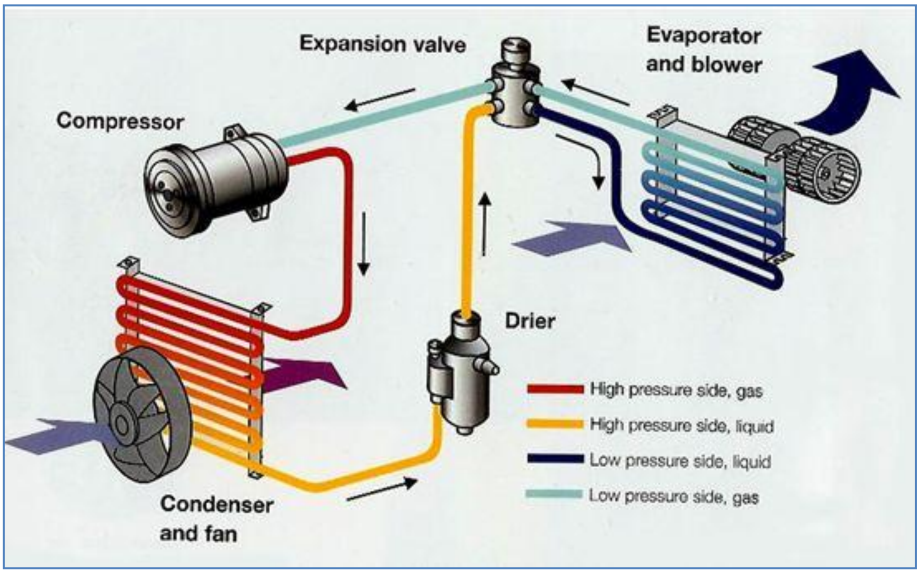

Figure 1.1: Main component of an air conditioner.
Source: http://www.machine-history.com/Solar%20Powered%20Air%20Conditioning.
Retrieved 25 Feb 2015.

Air which passes through fins (attached to coils) will be cooled and blown into the room. The refrigerant in cooling coils then enters back into the compressor and compression process repeat again. The cycle will be continuing until the shutting down of the compressor. This is the system of a regular air conditioning system.

For the integrated system of the solar air conditioner, it is actually use the basic equipment as the conventional air conditioning system with a solar collector is placed between the compressor and the condensing coils. There are many type of application mechanism of solar energy in the air conditioner system which some of them explained in the literature review. The function of the solar collector is to support or enhance the workload by the compressor by pressurize and heat the refrigerant. The higher the temperature it gets the better. The use of the solar collector is because of its ability to heat the organic substance to over 350 $°C$ using the power from the sun to superheat the refrigerant which cannot be done by the electricity. The advantage of having this is because it can increases the ability of the gas to change back into liquid quicker. If in conventional AC, the refrigerant convert into liquid at the third condensing coil, in Solar AC it start at the first condensing coil. Therefore, when the refrigerant reach the expansions devise, it is already almost liquid thus increase its ability to absorb heat, making it delivering cooler drier air to the building.

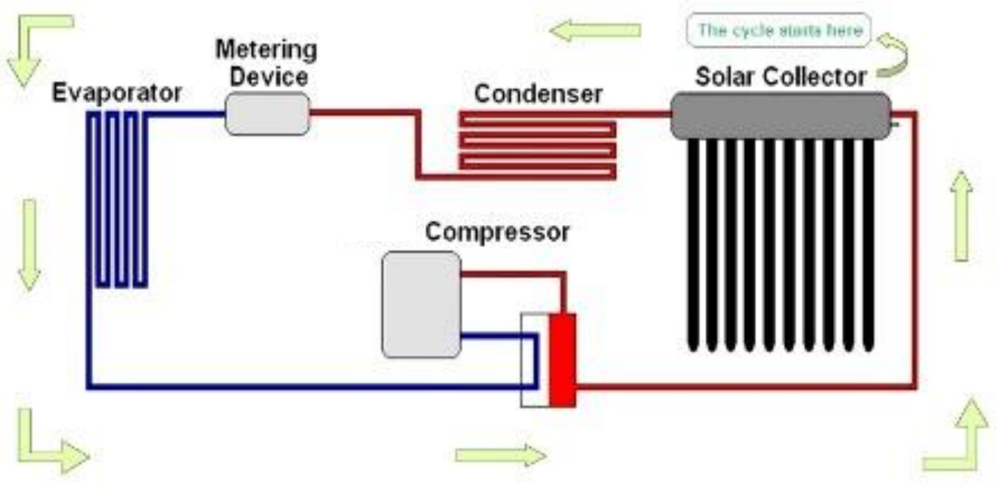

Figure 1.2: System of Solar air-conditioner.

1.1.2 Evacuated tube Solar Collector

Solar powered system needs **s**olar collector which working by absorbing radiation from the sunlight and converting them into heat. This can be imagining by a dark or black coloured object, placed under the sun. As time goes by, the object becomes hotter due to absorbed sunlight. The mechanism of the solar thermal collector is working in the same way but with the aid from materials that are specially designed to maximise the efficiency of that absorption.

Figure 1.3: Evacuated tube Solar Collector.

Evacuated tube is one of the available solar collectors. In a study carried by N.N. Wadaskar [1] it is proven that evacuated tube solar collector works better than any other solar collector. This is because the collar collector use vacuum tube as its main component, which then the vacuum will act as the best prevention of heat loss through convection.

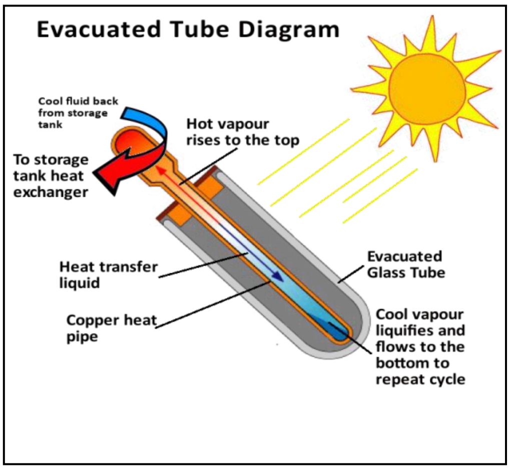

Figure 1.4: Vertical cross-section of the evacuated tube.

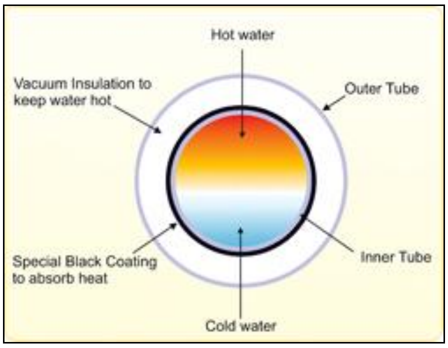

Figure 1.5: Horizontal cross-section of the evacuated tube.

From the figure above it has shown that there is vacuum between the gaps of the two glass tubes. It will minimise the heat loss from the inner tube. On the inner tube it was applied black coating to absorb the solar energy and supply to the water. The water which is facing the solar will heat and becomes lighter and start to move to the top of the tube. At the same time, the cold water which is heavy moves downwards of the tube. The phenomenon will be continuously and is called as natural Thermosyphon circulation, which experienced in every tube.

Thermosyphon Systems: The system involve of water which flows when water becomes hotter, thus rise to the tube of the tank or tube as the cooler water will sinks. This system did not involve any pump or equipment to operate and are more reliable.

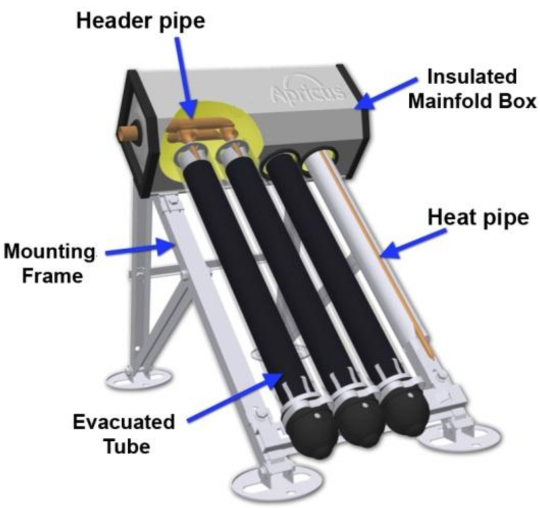

Figure 1.6: Critical Component of the evacuated tube.

The performance of the solar water heater is depending on type of collector use. There are four option provided with evacuated tube as the extracting heat unit.. They are heat pipe, U-tube, pipe in pipe and direct water flow. The mechanisms of transferring heat are different in each of the unit. The most common usage is by using heat pipe and U-tube. The performance of the solar water heater is depend on type of collector use. After being tested side by side, it was found that the convection heat pipe performance is the best (Ong.K.S, 2012).

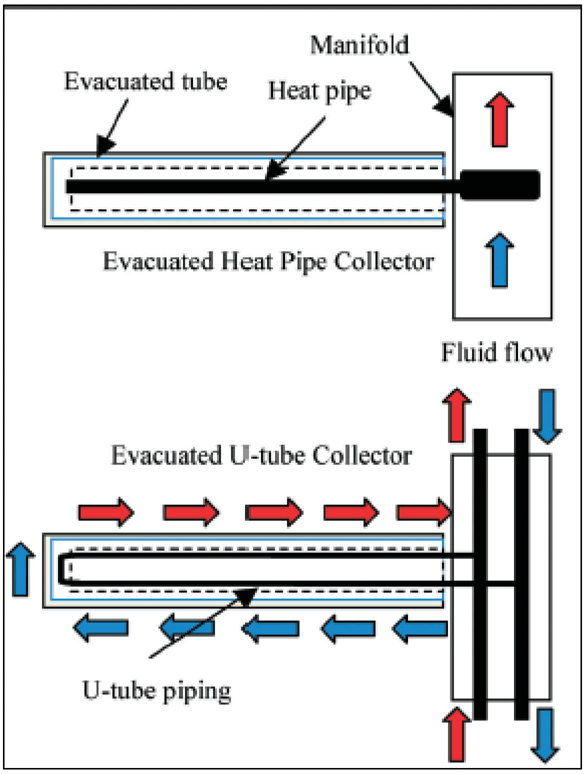

Figure 1.7: Differences in Mechanism of Heat Pipe and U-tube.

1.1.3 **Refrigerant R407**

Previously, chlorodifluoromethane (R22 of HCFC22) has been used as refrigerant for industrial cooling, air conditioning, refrigeration and heating applications. The use of R22 was better since it has low ozone depletion compared to CFC11 and CFC12. Even though HFCs such as R22 give less effect on the ozone layer, they still contain ozone-destroying chlorine. Furthermore R22 is one of the green house effect gas, and the by product of the manufacturing of R22 is (HFC23) which contributes to the global warming of the earth. This is the reason why the usage of R22 is being phased out with another ozone-friendly refrigerant.

Starting January 1, 2010, manufacturers was no longer allowed to manufacture equipment which contains R22 only for servicing equipment which is existing use R22 as its refrigerant. Targeted by January 1, 2020, R22 was no longer being use even to servicing existing equipment. In order to achieve this target, development and investigation of refrigerants had been made to find alternatives for R22 such as manufacturing R407C and R410A.

One of the successful finding is R407C. R407C made up of non-ozone depleting blend of three HFC refrigerants which is R32, R125 and R134A. It has been produce to have properties which is closely possible as R22 in pressure and making the usage transition from R22 to R407C runs smoothly. On the other hand, the production of R410A is to provide in system size and efficiency by higher the system pressure and benefits in transport properties and thermodynamic. This is because it has higher refrigeration capacity and pressure than R22.

Properties/Performance	R407C	R410A	Remarks
Ozone depletion potential, ODP (CFC11=1.0)	0	0	ODP value for R22=0.055. The lower the value, the better the environmental performance
Global warming potential, GWP (CO2=1.0 [100 year integrated time horizon])	1600	1725	GWP value for R22 is 1600. The lower the value, the better the environmental performance.
Maximum allowable concentration in the workplace (ppm)	1000	1000	
Flammable	No	No	
Toxicity	Very Low	Very Low	

Table 1.1: Properties and performance of R407C and R410A. Source: *DuPont Fluorochemicals*.

There is one disadvantages of R407C is it may experience multiple significant leaks and recharges which then effect the refrigerant composition to changes then lead to have minor impact on the effectiveness and heat transfer performance.

As conclusion, refrigerant R407C is less hazardous than R22 and its have similar and even better performance than R22. It has the same designation (A1) in ASHRAE Standard 34 – Designation and Safety Classification of Refrigerants.

1.2 Problem Statement

In living environment, thermal comfort is very significant not only for health but also for occupants as far as productivity is concerned. In fact, comfort conditions importantly influence rest or working efficiency for it affects production and social costs. Therefore, comfort conditions are essential for the well-being, productivity and efficiency of inhabitants.

Air-conditioning is one of a temperature control equipment to change air temperature from thermal discomfort to thermal comfort and maintains the comfortable level of a closed environment's temperature.

Normal air conditioner use high electricity by the system to be operated. This may impacts to the high cost of electricity. Therefore, a hybrid solar air conditioning is the solution for the problem since it uses renewable energy as the power source. This technology would help the compressor to save energy and eventually, the energy used to condition the air would be decreased.

1.3 Objective

The objectives for this project are;

i. Design a hybrid solar air conditioner cycle incorporating the existing A/C cycle.

ii. To study the air conditioning cycle and the power consumption in a normal vapour compressing air conditioner.

iii. To compare the conventional air conditioner and hybrid solar air conditioner energy consumption and its appropriate savings.

1.4 Scope of Study

The scopes of study for this project are the effects of air conditioner in global environment and the renewable energy power generated, the cycle of the air conditioner system and its power consuming, the analysis of energy consumption of the solar air conditioner in an building and the evacuated tube collector as the solar heat absorber.

CHAPTER 2:

LITERATURE REVIEW

2.1 Effectiveness of evacuated tube:

An investigation has been carried out by N.N. Wadaskar [1]which is to develop, design and determine high-efficient solar collectors and apply them for solar energy power generation, solar air conditioning and solar energy industrial hot water system. The experiment was then compared between evacuated solar collector and flat plate solar collector.

In general vacuum tube collectors are used in solar process heat systems. Another possibility is to use transparent insulated flat plate collectors. A critical point however, is that most of the common transparent insulating materials cannot withstand high temperatures because they consist of plastics. Thus, temperature resistive collector covers combining a high transitivity with a low U-value are required. One possibility is to use capillaries made of glass instead of plastics. At the same radiation intensity by comparing the heat gain of both the flat plate and vacuum tube solar collector having same capacity tank, mass flow rate and absorber area. It find out that vacuum tube collector is 16.12% more efficient than flat plate solar collector [1].

Since a collector that is used for thermal heat application need to allowed stagnation temperature of more than 300 ℃, all of the components of the collectors such as insulations material, absorber coating need to withstand this high temperature, evacuated tube collectors was the only choice for this application. This is because the use of vacuum barrier help to prevent heat lost due to convection.

It is a different situation for the flat plate collector. In addition to thermal losses the air inside the collector, usually at atmospheric pressure, is transferring energy mainly by convection as well as conduction. Therefore collector itself has to be insulated against the surrounding. Whereas the rare of the collector can be easily insulated with the variety of temperature and humidity resistance opaque materials available in the market, the front of the collector is more problematic since it is exposed to solar radiation. Transparent Insulation Materials (TIM) combining high transmittance for solar radiation with low heat conductance is required. Various experiments had been done to present and compare the performance for the evacuated tube and the flat plate collector.

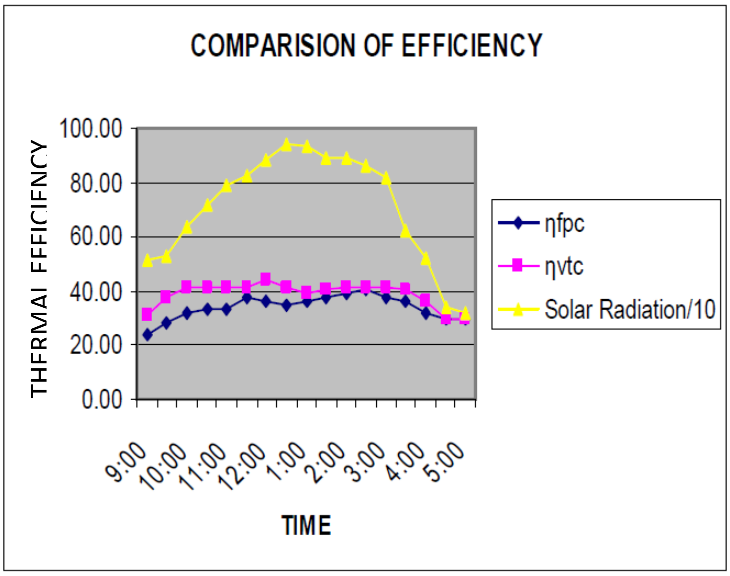

Figure 2.1: Thermal efficiency comparison between evacuated tube and flat plate [1].

Figure showing the graph to Comparison of efficiency of both vacuum tube and flat plate solar collector by using temperature difference of inlet and outlet of these collector in the interval of an hour on date 27/04/2009 at the same radiation intensity.

As a conclusion, comparisons of theoretical results of the different collector show that for the use in high temperature application vacuum tubes are superior to the transparent insulated flat plate collector.

Comparison of Output Temperature of VTC & FPC

VTC output = 12,772 kJ per day
FPC output = 10.712kJ per day
% Increase in heat gain = (VTC o/p –FPC o/p)/ VTC o/p
= (12,772-10,712)/12,772
= 0.1612
= 16.12%
VTC is 16.12% more efficient than FPC

Pay Back Period of VTC is 2.48 years and Pay Back Period of FPC is 3.697 years.

Another study also had been conducted by Hidetoshi Aoki from Japan on the performances of the evacuated tubes solar collector in various conditions. The aim of the study is to investigate whether the performance of the evacuated tube was at optimum temperature indoor and outdoor environment.

A hybrid solar collector had been used to produce warm water and air simultaneously and the results had been recorded. When comparing the result by using artificial light solar light source and the open air light, the efficiency of the hybrid solar collector showed similar values. The maximum overall solar collection efficiency was 74%-79% [3]. This proving that evacuated tube is an efficient equipment to be use as solar collector.

2.2 Performance of Heat Pipe Solar Water Heaters

Research has been done by Ong K. S. Et. Al. to differentiate the performance between the mechanism of heat transfer in solar collector which are Heat Pipe and U-tube. The research has been done at outdoor test and conducted on several solar collector under natural and forced convection. This experiment would guide us to compare the performances since the experiment has been carried out side-by-side simultaneously. It was found that the natural convection perform by the heat pipe is the best among them. (Ong. K.S., 2012) [2].

Table 2.1: Details and tests results of solar water heater [2]

System	U-Tube (A)	Heat Pipe (B)	Heat Pipe (C)
Storage tank volume (m3)	0.10	0.27	0.20
Collector surface area (m2)	1.28	3.13	3.13
Total no of tubes/pipes	16	30	30
Area/volume ratio (m2/m3)	12.8	11.6	15.7
Max temperature achieved (^oC)	72	100	82
Overnight temperature drop (^oC)	4.5-9.0	2.5-11.5	2.5-6.0
Daily system efficiency at ∑H = 4.5 kW/m2 (%)	53	65	41
Daily water temperature rise at ∑H = 4.5 kW/m2 (^oC)	25	30	25
Expected daily water temperature rise at ∑H = 4.5 kW/m2 adjusted for area/volume ratio = 11.6	27.0	30.0	18.5

2.3 Energy-Efficient Hybrid Solar-Assisted Air Conditioning System:

An investigation has been carried in order to improve the performance of the solar air conditioner. A new system is proposed which is the application of the new discharge bypass line together with an inline solenoid valve. It was installed after the compressor which will act as the mass flow rate regulator of the refrigerant vapour passing through a hot water storage tank. Furthermore, a variable speed drive is attached to the condenser fan which then controls the air flow rate and synchronise the speed with the opening of the valve to gain optimum efficiency of the operation.

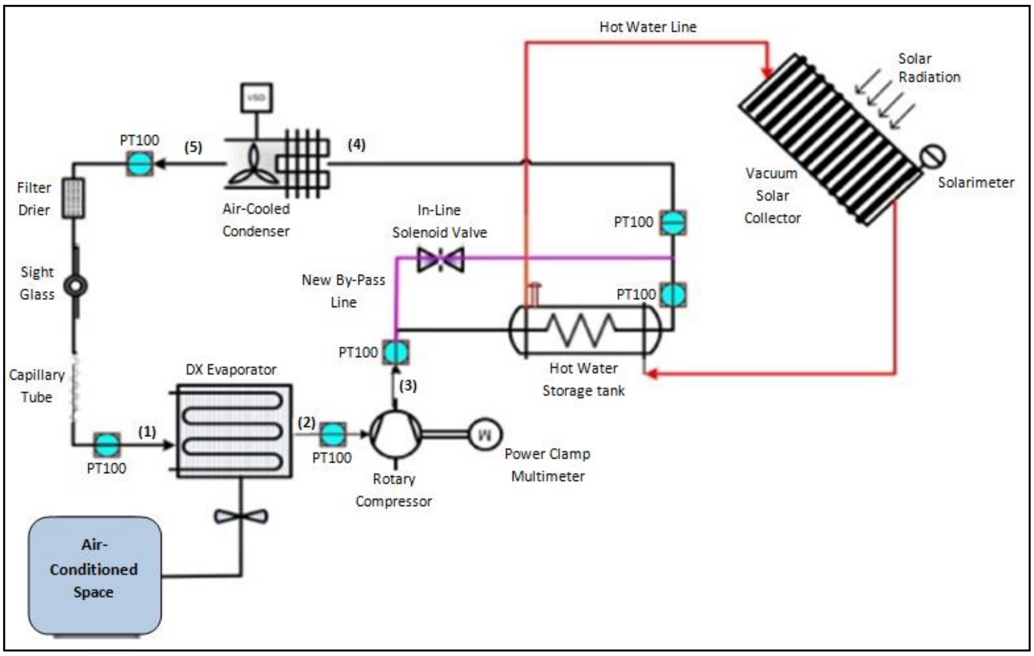

Figure 2.2: Energy-Efficient Hybrid Solar-Assisted Air Conditioning System.

The system has been fully instrumented to examine its performance under different operation conditions, and as the results, it was showed that the system had gained energy savings up to 14% more than regular solar air conditioning system [4].

2.4 Hot-Water Absorption Chiller Air Conditioner using Solar Energy:

Another investigation also has been carried out by Chaoyang Ji Et. Al, which also about the usage of solar energy for betterment of the air-conditioner performance. The purposed design was a bit different with the previous system of air-conditioner.

In the project, there were three sub systems which include in the air-conditioner cycle. The systems are:

i. The Form of Solar Hot Water Supply System.
   This design of water storage had been design to ensure the quality of the water and sustaining the efficiency of the system.

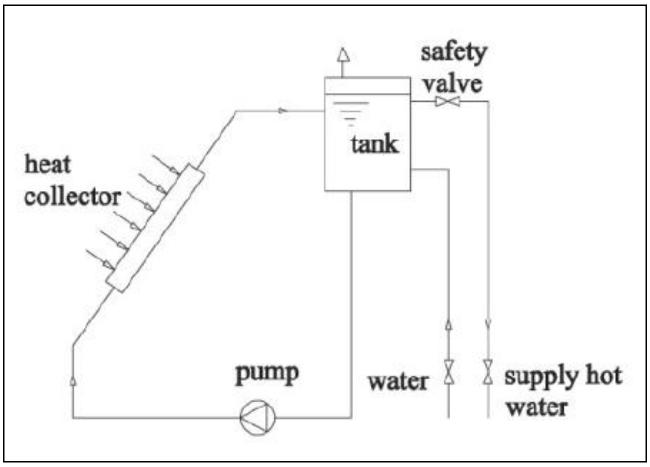

Figure 2.3: System of solar hot water supply (heat recovery machine).

ii. Connection between the Heat Recovery Machine and Air Conditioning System.
   This sub system is made to make sure the system can run by independent circuit with air cooled condenser or water cooled condenser.

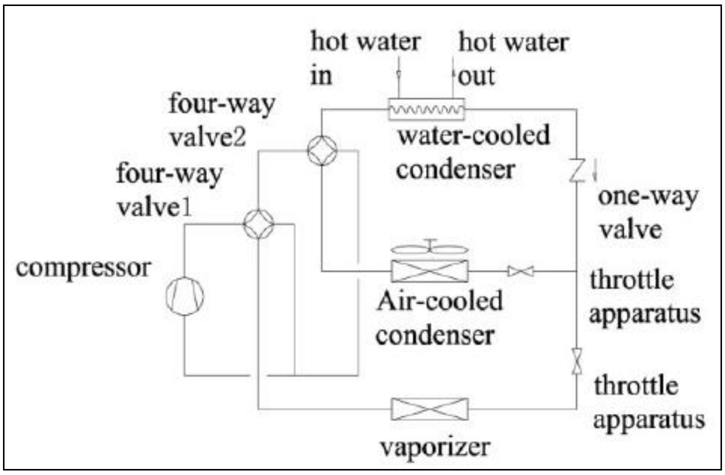

Figure 2.4: Connection between the Heat Recovery Machine and Air Conditioning System.

iii. Connection between the Heat Storage Equipment and Air Conditioning System.

The water will circulate between the tank and condenser. Through convection the water on the top will heated up by the heat absorbs from the condenser. After duration of time, we can get hot water from the tank.

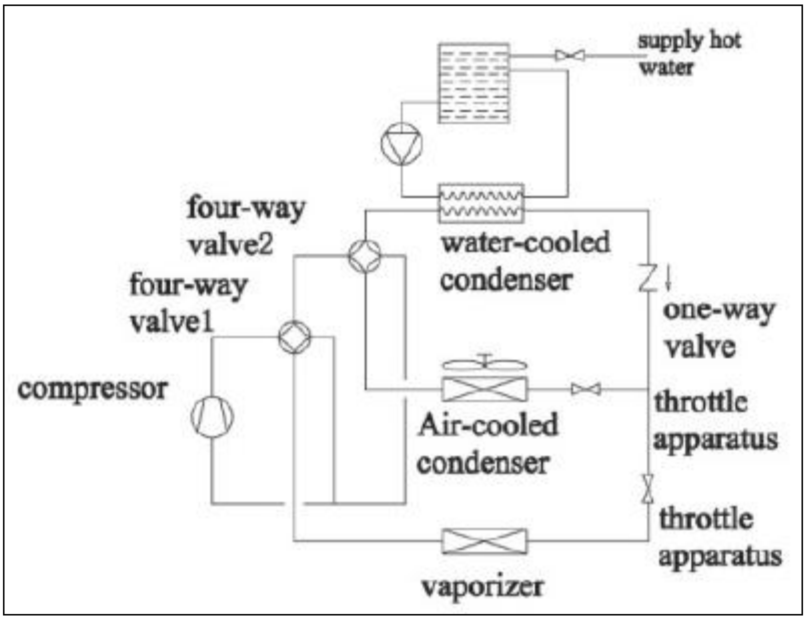

Figure 2.5: Connection between the Heat Storage Equipment and Air Conditioning System.

From the design, it can prove that, energy can be saves up to 21.4% more than solar electric auxiliary water heater [5]. The system utilizes the heat produce by the process of the condenser to provide heat to the water supply. Therefore, a system of air conditioner which also utilizes the heat from the condenser also can be made to reduce the work load for the compressor and saves energy.

2.5 PV Solar Powered Air Conditioner:

Tanaka X Et.al, had produce a solar air conditioner which use photovoltaic (PV) as the power source. There are two systems, one is bi-directional system and the other one is uni-directional system. They had confirmed that from the system, it saves up to 50% of the power consumed by the air conditioner during summer [6]. The concept was a little bit difference in the power source. Previously, solar collector was used as the heat resources to heat the refrigerant and support the work load by the compressor. This concept had use the solar energy to convert them into electricity and supply the electricity to the compressor that need high electricity consumption for refrigeration process.

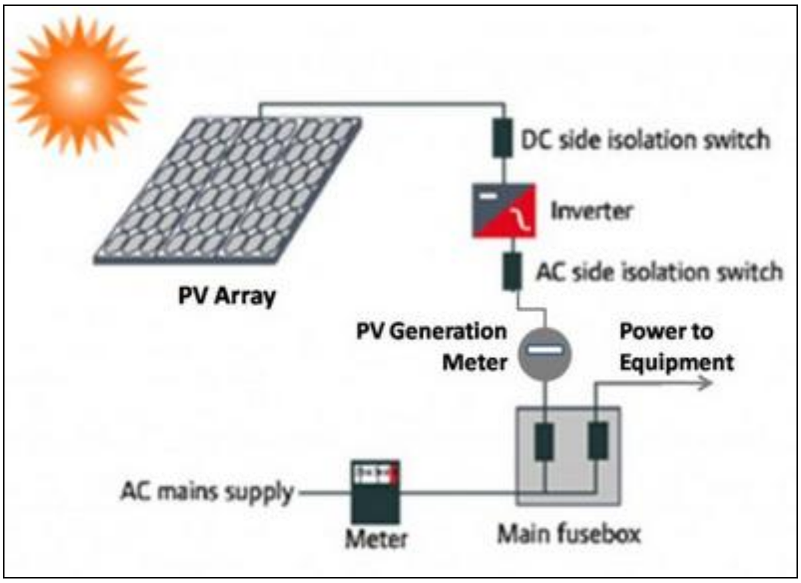

Figure 2.6: PV solar system to provide electricity.

CHAPTER 3:

METHODOLOGY

3.1 Project Activities

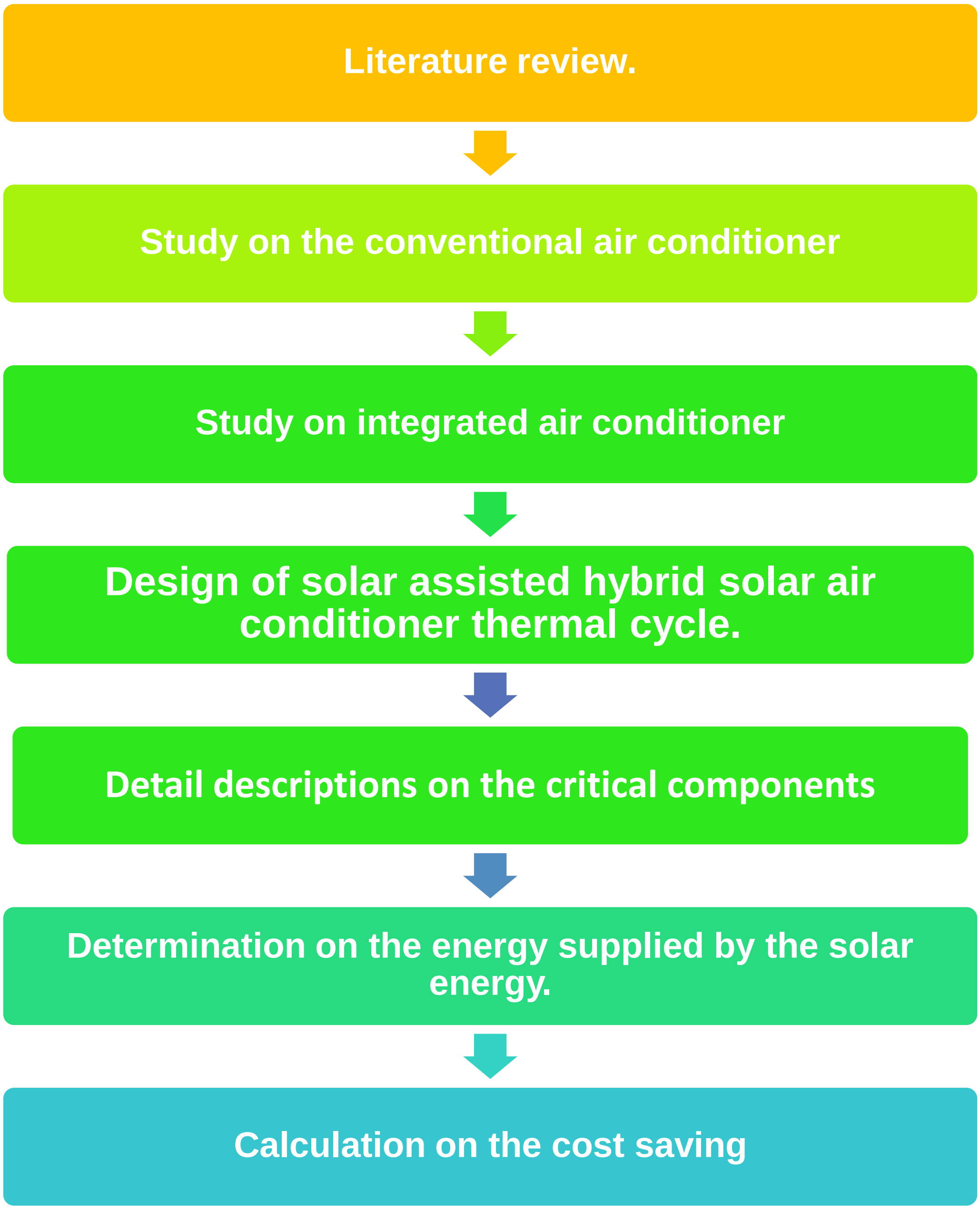

Figure 3.1: Final Year Project Activities

3.2 Solar Hybrid Air Conditioner

A hybrid solar air conditioner was chosen as a reference which from company named ECOLINESOLAR, a company which produce many type of hybrid solar air conditioner which is located at Batu Caves (refer APPENDIX II). The working principle of the air – conditioner is driven by electricity and with solar energy as an auxiliary power. It use R407C as its refrigerant and evacuated tube as the solar collector.

Figure 3.2: Purchased Ecoline Solar Air Conditioner

The performance, description and the details dimension of the solar hybrid air conditioner is use to be the reference value to investigate the components and the energy saving of the hybrid solar air conditioner.

The solar air conditioner has two units which are the indoor unit and outdoor unit. The indoor unit include the evaporator and electronics unit and the outdoor unit includes the compressor, condenser, solar collector and expansion valve. The component used in Ecoline Solar Air Conditioner almost the same with the system in the project.

3.3 Equipment Specification:

3.3.1 Solar Air Conditioner and solar collector

MODEL	Indoor			STA-018SPWM-FC
	Outdoor			STA-018SPWM-C
Cooling Capacity		Btu/Hr		18000
		KW		5.1
Electrical Parts				
Voltage, Frequency, Phase		V~, Hz, Ph		220~240, 50/60, 1
Power Input	Cooling	W		1,113
Operating Current	Cooling	A		5.06
Performance				
EER		Btu/W		16.1
COP		W/W		5.1
Air Flow Volume	Indoor	m3/h		750
Noise Level	Indoor (Hi/Med/Lo)	dB (A)		43~49
	Outdoor	dB (A)		54
Net Dimensions & Weight				
Indoor Unit	W x H x D	mm		900x280x202
Outdoor Unit	W x H x D	mm		820x605x300
Net Weight	Indoor/Outdoor	kg		11/40
Packing Dimensions & Gross Weight				
Indoor Unit	W x H x D	mm (+/-10)		985x365x298
Outdoor Unit	W x H x D	mm (+/-10)		950x640x426
Gross Weight	Indoor/Outdoor	kg (+/-0.5)		14/44
Piping Connection				
Liquid Side		inch		1/4
Gas Side		inch		1/2
Solar Panel				
Net Dimensions				
Collector Frame	L x W x H	mm		1650x970x167
Glass Tube	Length / Diameter	mm		1600mm / 47
Packing Dimensions & Gross Weight				
Collector Frame	L x W x H	mm		1800x990x170
Glass Tube	L x W x H	mm		1630x390x260
Gross Weight	Frame& Tubes	kg		50

Figure 3.3: Specification of the purchased Solar Air Conditioner

3.3.2 Refrigerant R407C

Thermophysical properties of refrigerants: R407C

General:	
Composition	R32/R125/R134a (23/25/52)
Family	HFC
Main application fields (in compliance with the legislation in force)	Air conditioning
Molar mass	86,2 kg/kmol

Thermophysical properties:	
Normal boiling point (at 0.1013 MPa)	–43,8°C
Critical temperature	86,1°C
Critical pression	4,63 MPa

Properties at 0℃ (at saturation)*			
	Unit (SI)	**Liquid**	**Vapour**
Pressure	MPa	0,57	0,46
Specific Volume	dm^3/kg	0,81	50,77
Specific heat capacity • at constant pressure • at constant volume	 kJ/(kg K) kJ/(kg K)	 1,41 0,87	 0,96 0,77
Viscosity	10^{-6} Pa s	209,09	11,41
Thermal conductivity	W/(m K)	0,103	0,012
Surface tension	N/m	0,011	
Heat of vaporization	°C	5,59	
Pressure	kJ/kg	1208,9	

* These data are derived from the brochure Thermodynamic and physical Properties of R407C published by the IIR. You can order it on line.

Environmental properties:	
ODP (R11=1)	0
GWP (CO2=1)	1526

The GWP used as a reference here is the GWP of CO2 over an integration period of 100 years.

Safety Group: A1

Table 3.1: Thermo physical properties of refrigerants R407C

3.4 Basic Equation

3.4.1 Net refrigeration capacity

The net refrigeration Capacity (TR) can be obtained from following equation:

$$\text{Net refrigeration Capacity (TR)} = \frac{m^\circ \, C_p \, (\Delta T)}{3024} \qquad (1)$$

Where 3024 is of refrigeration is the amount of cooling obtained by one ton ice melting in one day.

The following equations describe the thermal performance of a solar collector under steady state conditions:

$$\text{Efficiency} = \frac{m^\circ \, C_p \, (\Delta T)}{I_T A_P} \qquad (2)$$

Where, m° = mass flow rate, kg/hr; C_p= specific heat, kcal/kg ºC; ΔT = temperature difference, ºC; I_T = solar radiation, kWh/m^2; A_P = aperture area, m^2.

3.4.2 Performances calculations

The efficiency of energy by the air conditioner can be obtained from three of following ratio:

$$\text{Coefficient of performance (COP)} = \frac{kW\ refrigeration\ effect}{kW\ input} \qquad (3)$$

$$\text{Energy efficiency ratio (EER)} = \frac{\frac{Btu}{h}\ refrigeration\ effect}{Watt\ input} \qquad (4)$$

$$\text{Power per Ton (kW/Ton)} = \frac{kW\ input}{Tons\ \ refrigeration\ effect} \qquad (5)$$

3.4.3. Analysis of the refrigeration cycle

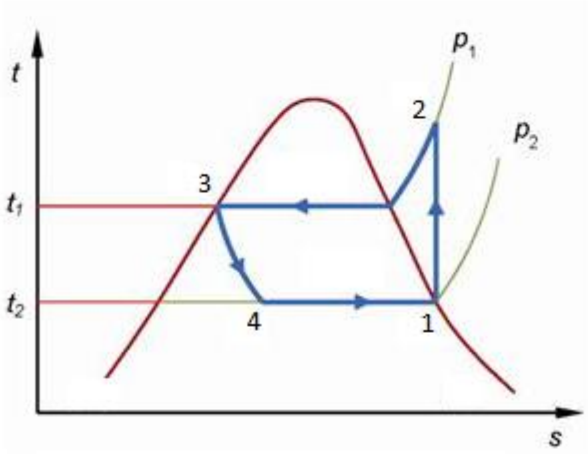

Figure 3.5: Ideal T-S diagram refrigeration cycle

The *compressor power consumption* is obtained from the formula :

$$\dot{Q}_{cp} = \dot{m}(h_{2r} - h_1) = \frac{\dot{m}(h_{2is} - h_1)}{\eta_{is}} \quad (6)$$

While the *effective compressor power consumption* is given by :

$$\dot{Q}_{eff} = \frac{\dot{Q}_{cp}}{\eta_M} = \frac{\dot{m}(h_{2is} - h_1)}{\eta_{is} \cdot \eta_M} \quad (7)$$

Where h_i is the specific enthalpy at state i, η_{is} and η_M are respectively the isentropic and the mechanical efficiencies of the compressor, and $\dot{m}$ the mass flow rate of the refrigerant. The indexes r and is are respectively for reversible and isentropic transformations.

The *condenser capacity* is obtained from :

$$\dot{Q}_{con} = \dot{m}(h_{2r} - h_3) \quad (8)$$

The *isentropic efficiency* is given by :

$$\dot{\eta_{is}} = \frac{(h_{is} - h_1)}{(h_{2r} - h_1)} \quad (9)$$

The *power transfer at the evaporator* is given by :

$$\dot{Q}_{ev} = \dot{m}(h_1 - h_4) \quad (10)$$

The *process of expansion valve* is assumed to be a throttling process, therefore:

$$h_4 = h_3 \tag{11}$$

h_4 and h_3 represent respectively the specific enthalpies of inlet and outlet valve fluids.

The *power balance of the cycle* can be written as follows :

$$\dot{Q}_{con} = \dot{Q}_{ev} + \dot{Q}_{eff} \tag{12}$$

The mass flows of liquid refrigerant and *volumetric efficiency* of the machine are respectively given by :

$$\dot{m} = \frac{\dot{V}_b}{\dot{V}_1}\eta_v \text{ and } \dot{m} = \frac{\dot{V}_a}{\dot{V}_b} \tag{13}$$

$$\dot{V}_b = \frac{\pi D^2 nNC}{4\times 60} \text{ and } \dot{V}_b = \dot{m}\cdot V_1 \tag{14}$$

Where $\dot{V}_a$ and $\dot{V}_b$ are respectively the volumetric rates aspired and generated by the compressor; V_1 is the volumetric mass; n the number of piston; N the rotational speed; C the distance travelled by piston, and D the diameter of the piston.

Coefficient of performance of the refrigeration cycle:

$$COP_F = \frac{\dot{Q}_{ev}}{\dot{Q}_{eff}} = \frac{(h_1 - h_4)}{(h_{2is} - h_1)}\eta_{eff} \tag{15}$$

Efficiency of the refrigeration cycle:

$$\eta_f = COP_F\left(\frac{\theta_c - \theta_0}{\theta_0}\right) = \frac{(h_1 - h_4)}{(h_{2is} - h_1)}\eta_{eff}\left(\frac{\theta_c - \theta_0}{\theta_0}\right) \tag{16}$$

Where θ_0 and θ_c are respectively the evaporating and condensing temperatures of the refrigerant.

Coefficient of the performance of the calorific cycle:

$$COP_F = \frac{\dot{Q}_{con}}{\dot{Q}_{eff}} = \frac{(h_{2r} - h_3)}{(h_{2is} - h_1)} \eta_{eff} \tag{17}$$

Efficiency of the calorific cycle:

$$\eta_C = COP_C \left(\frac{\theta_c - \theta_0}{\theta_0}\right) = \frac{(h_1 - h_4)}{(h_{2is} - h_1)} \eta_{eff} \left(\frac{\theta_c - \theta_0}{\theta_0}\right) \tag{18}$$

3.4.4 Saving Performance

$$Energy\ saving = 1 - \frac{h_x - h_1}{h_2 - h_1}\ x\ 100\% \tag{19}$$

3.5 Project Timeline FYP I & FYP II

FYP I															
NO	SUBJECT	WEEK													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	FYP Topic Selection	■													
2	Project Introduction		■ *												
3	Extended Proposal			■	■	■	■								
4	Finalise & Extended Proposal Submission						■								
5	Proposal Defence Preparation							■	■	■					
6	Designing solar power generator into the air conditioner								■	■	*				
7	Proposal Defence Preparation & Evaluation								■	■					
8	Monitor the analysis of the air conditioner performance.										■	■	■		
9	Finalise of Interim Draft Report													■	
10	Finalise of Interim Report														■

Figure 3.6: Gantt Chart for FYP I

FYP II																
NO	SUBJECT	WEEK														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Survey on Air Conditioner in Market	■	■	■	■	■										
2	Detail description on the critical component						■	■	■ *							
3	Calculations on the performance and saving									■ *	■					
4	Submission of Progress Report										■					
5	Pre-Sedex											■				
6	Submission of Draft Final Report											■				
7	Finalise of Technical Paper												■	■	■	■
8	Finalise of Dissertation												■	■	■	■
9	Viva															■
10	Finalise & Submission of project dissertation (hard bound)															■

Figure 3.7: Gantt chart for FYP II

3.6 Project Key-Milestone

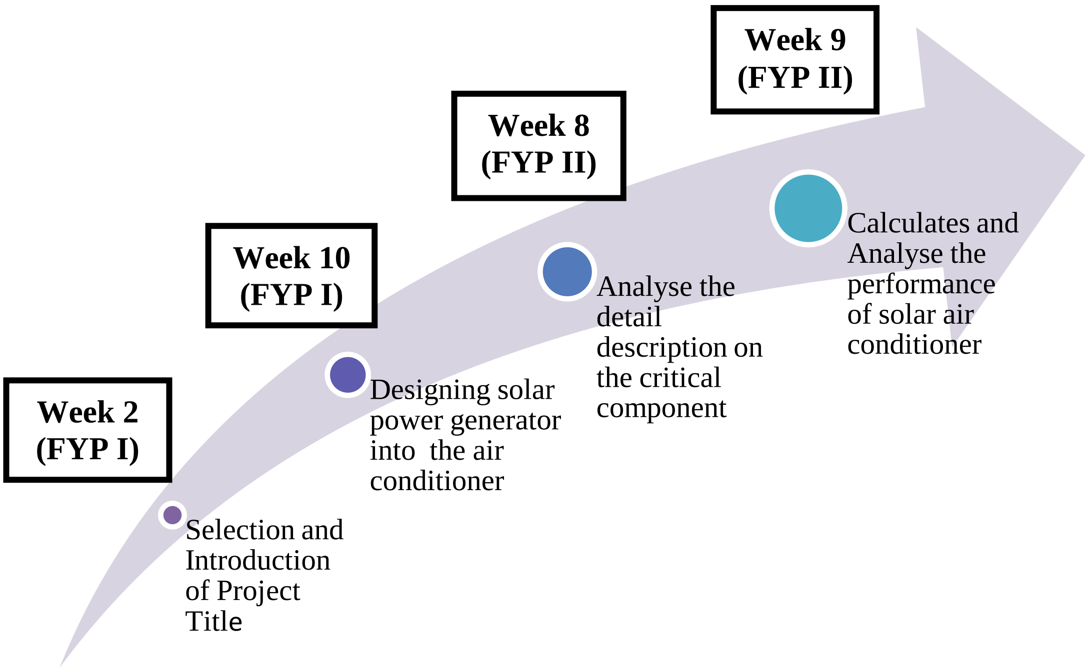

Figure 3.9: Key-Milestones for the project

CHAPTER 4:

RESULT AND DISCUSSION

4.1 Result

From the literature, we can conclude that the most efficiency and suitable type of solar air conditioner to be is evacuated tube as the solar collector. This is because by using evacuated tube, it is more suitable for our project which is to further heat up the refrigerants which pass through the compressor. We can see that evacuated is less expensive and less complicated than the PV cell powered air conditioner. Besides that, the efficiency of evacuated tube is more efficient to be compared to the flat plate collector. Evacuated tube can withstand high temperature up to 300^{o}C because all of the components of the collectors such as insulations material, absorber coating need to withstand this high temperature. At the same radiation intensity by comparing the heat gain of both the flat plate and vacuum tube solar collector having same capacity tank, mass flow rate and absorber area. It find out that vacuum tube collector is 16.12% more efficient than flat plate solar collector (Wadaskar, 2009).

The option for the heat transfer mechanism from the evacuated tube to heatting the refrigerant choosed is heat pipe type. This is the best mechanism of the convection of heat because it involve two different type of liquid, which are refrigerant R407C and liquid in the solar collector pipe glass will not being mixing with the refrigerant. Besides that, the performance based on the experiment between the heat pipe and the u-tube showing, heat pipe is better. (Ong. K.S., 2012).

Below is the outcome from the design of the hybrid solar air conditioner. It involves installation of the solar collector (evacuated tube) after the compressor in the system.

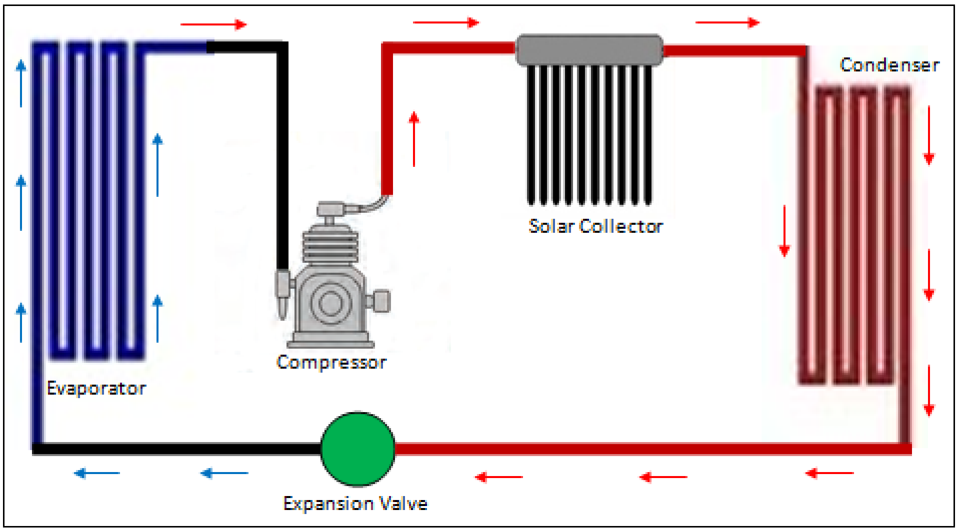

Figure 4.1: Schematic diagram of the designed system hybrid solar air conditioner

In the Hybrid solar air conditioner system, the solar collector is installed after the compressor in the system, in order to reduce the work load by the compressor. Its function is to produce essential temperature required for the refrigerant before entering the condenser. Therefore, the compressor can be sized solely with the heat provided by the solar collector, which allow the system to reduce about 30% of energy consumption by the compressor. However, it should be noted that, the temperature of the refrigerant will be higher especially in partial load conditions because heat has been added by the solar collector. Thus, it will reduce the coefficient of performance (COP).

To overcome this from happened; the temperature of refrigerant leaving the condenser should be lowered. The temperature of the optimum temperature for the refrigerant leaving the condenser is setup the same with the conventional air conditioner system to balance back the COP. There are two places that can control the optimum temperature which is before entering condenser and after leaving condenser. In principle, a proper control strategy for the refrigerant temperature entering the condenser can lead to more energy-efficient operations [Vakiloroaya et al., 2013].

Comparison between the PV and the TS diagram of the conventional refrigeration cycle and the designed hybrid solar air conditioner refrigeration cycle.

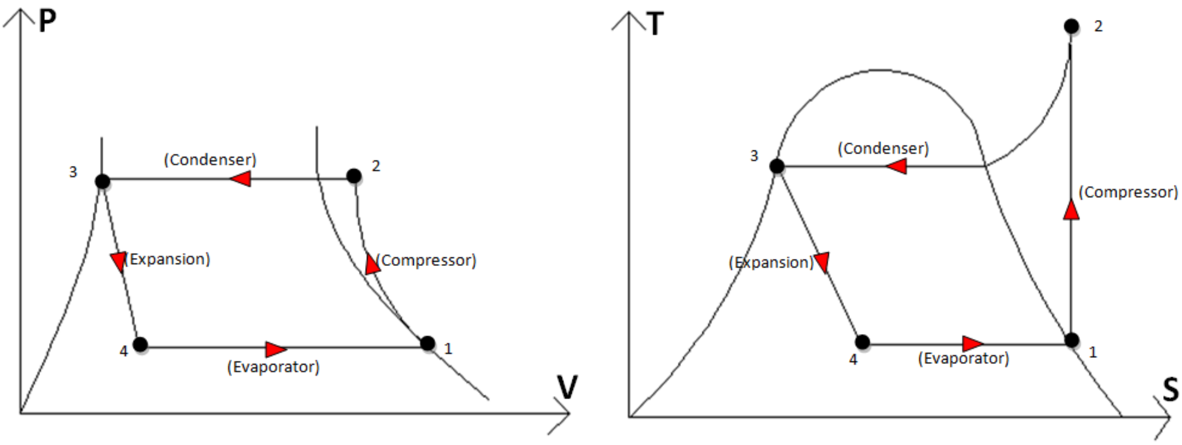

Figure 4.2: PV and TS diagram of Conventional AC Refrigeration Cycle

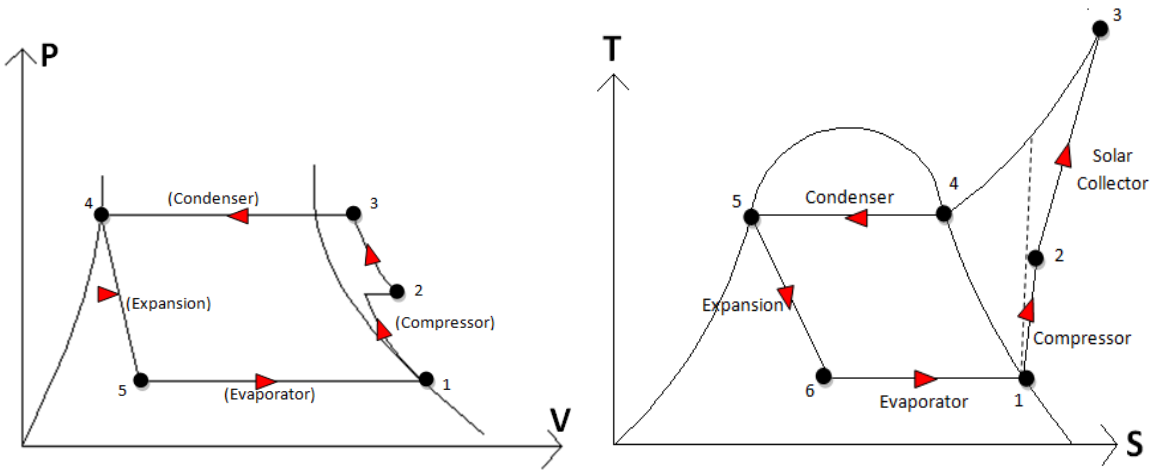

Figure 4.3: PV and TS diagram of Designed Hybrid Solar AC Refrigeration Cycle

From the design it can be seen that the pattern of the increment in the pressure of refrigerant after it pass through the compressor. Compared to the conventional air conditioner, the pressure of the refrigerant increase by step since the heating process is firstly done by the compressor and next taken by the heat convection by the solar collector. This is where the reduction of the power consumption takes place. The solar collector support the heating of the refrigerant instead of the compressor use high electricity to achieve high temperature of the refrigerant.

The location of UTP has been determining using software in the internet based on UTP longitude and latitude which are (4.385; 100.978). The location has been used to determine the amount of solar radiation emit at UTP. 1st January 2015 has been choosing as reference date to determine the amount of radiation.

Software use:

Location of UTP (longitude; latitude): http://www.worldatlas.com/aatlas/imageg.htm

Solar Radiation: http://suncalc.net/#/51.508,-0.125,2/2015.04.17/11:55

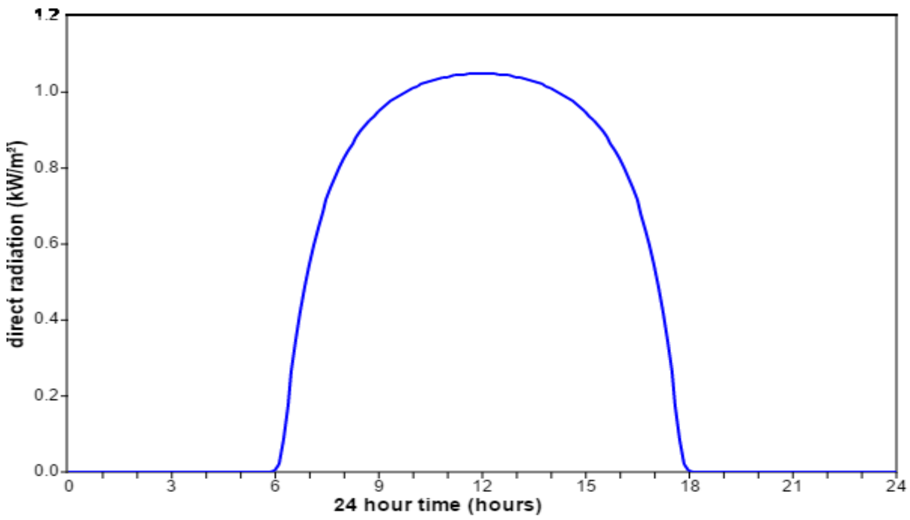

Figure 4.4: Sun Radiation at UTP (Longitude: 4.385; Latitude: 100.978) on 1st January 2015

As determined by the software which have the databank on the solar radiation in the world, it show that the pattern and the amount of solar radiation at UTP on 1st January 2015. From the solar radiation pattern, we can see that the radiation start to emit by 6.00 am. The peak of solar radiation is at 12.00 noon since UTP located at the Equator. Then, the solar radiations continue to decrease and absent at 6.00 pm. The viscosity of the solar radiation would determine the workload by the compressor of the hybrid solar air conditioner.

FIGURE 4.5 showed expected result of the power consumption by the conventional air conditioner and the hybrid solar air conditioner. The reduced of the power consumption is based on the sunlight radiation exposure to the solar collector. The higher the sunlight exposure, the higher the temperature output at the solar collector thus more saving.

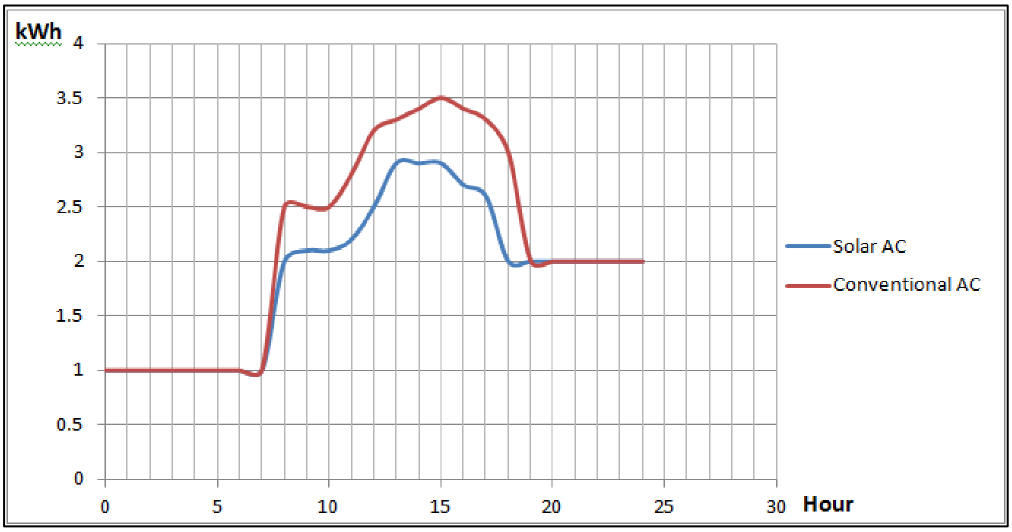

Figure 4.5: Expected Saving chart of solar air conditioner VS conventional air conditioner

Below is calculation on the air conditioning performance and percentage of savings of the hybrid solar air conditioner.

Calculation on Air Conditioning Performance:

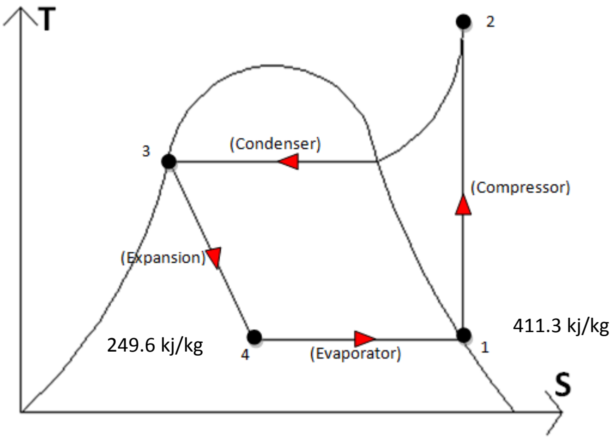

Figure 4.6: TS diagram of Conventional AC Refrigeration Cycle

$$COP = \frac{h_1 - h_4}{h_{2a} - h_1} \rightarrow 5.1 = \frac{411.3 - 249.6}{h_{2a} - 411.3} \quad (3)$$

$$Actual\ Enthalpy, h_{2a} = 443.0\ kJ/kg$$

$$Compressor\ Isentropic\ Efficiency, \eta_c = \frac{h_{2s} - h_1}{h_{2a} - h_1} = \frac{440.9 - 411.3}{443.0 - 411.3} = 0.934$$

$$Compressor\ power = \dot{m}_r(h_{2a} - h_1) \rightarrow 934.0x10^{-3} = \dot{m}_r(443.0 - 411.3)$$

$$Refrigerant\ mass\ flow\ rate, \dot{m}_r = 0.0295\ kg/s$$

Calculation on Solar Hybrid Compressor Energy Saving Performance:

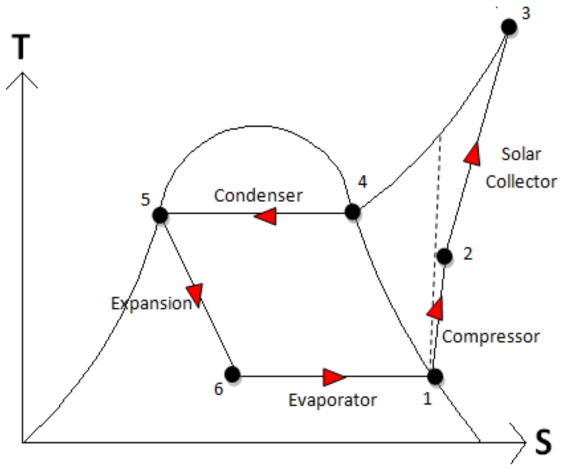

Figure 4.7: TS diagram of Hybrid Solar AC Refrigeration Cycle

Parameter:

$T_2 = 54.1\ ^0C$ [1]; $P_2 = 2191.90 kPa$; $h_x = 426.3 kj/kg$

$$Energy\ saving = 1 - \frac{h_x - h_1}{h_{2s} - h_1}\ x\ 100\% = 1 - \frac{426.3 - 411.3}{440.9 - 411.3}\ x\ 100\% = 27\% \quad (19)$$

Table 4.1: Saving and payback period for Hybrid Solar Air Conditioner

Saving on the power consumption	
Solar System	30% of the conventional usage
Reduced Energy Cost	
Tariff of electricity in UTP	21.8 sent/kWh (first 200kWh) 33.4 cent/kWh (next 100kWh)
Cooling capacity of the air conditioner	5.1 kW
	18000 Btu/h
Usage (hours)/day	9 hours
Usage (days)/month	20 days
Power Consumption on Electricity (Conventional AC)	45.9 kW/day 918 kW/month
Price paid for Conventional AC bill	RM 10/day RM 200/month

Power Consumption on Electricity (Hybrid Solar AC)	37.64 kW/day 752.76 kW/month	
Price paid for Hybrid Solar Air Conditioner bill	RM 8.20/day RM 164.10/month	
Savings	RM 1.80/day RM 35.9/month	
Investment		
System price (Conventional)	RM 2000.00	
System price (Hybrid Solar)	RM 6400.00	
Saving on the bill	RM 430.8/year	
Payback Period	10.2 years	
Return on Investment	9.8 %	
Savings on Electricity Bills		
Savings over	1 year	5 years
Electricity bill (conventional)	RM 2400	Rm12 000
Electricity bill (hybrid solar)	RM 1970	RM 9846
Electricity bill savings	RM 430.8	RM 2154

Based on the calculation on the saving percentage of the hybrid solar air conditioner, it showing that, the power consumption of the system had been reduced to about 30% from the power consumption by the conventional air conditioner. The cooling capacity of the air conditioner parameter has been use to calculate the saving of the cost on the electricity. There are some assumed conditions such as the usage of the air conditioner is 9 hours per day for 20 days per month. The saving of the electricity by the solar collector is calculated and the save cost is determine to calculated the payback period of using the hybrid solar air conditioner.

The payback period takes about 10 years to gain back the capital invested for the hybrid solar air conditioner. Even though the price of the hybrid solar air conditioner was quiet high about triple the price of conventional air conditioner, it has it saving in cost every month. Besides that, the saving in electricity bills for 1 year and for 5 years also calculated. It show the amount of the benefits which user will experienced if use the hybrid solar air conditioner.

4.2 Discussion

Based on the literature, we can describe that a solar air conditioner can save electricity, thus can save cost. In the same time, there are 3 options to support the operation of the air conditioner which is evacuated tube or flat plate as the solar collector, or photovoltaic cell as the power supply.

Photovoltaic cell is not being chosen in the project because the system was more complex and not aligns with our project which is to support the heat up of the refrigerants. Only two option left, which is evacuated tube and flat plate as the solar collector.

From the literature, it was proven that the efficiency of the evacuated tube was more than the efficiency of the flat plate. This is because, the evacuated tube used round cylindrical glass which making the surface area to grab the solar from the sun bigger. Besides that, the evacuated tube design can decrease the grabbed heat loss and can fully utilize the absorbed solar energy.

A next finding is, the best refrigerant to be used in the refrigeration system is R407C. The chemical properties of the R407C was almost the same with the R22 which was used widely before because of its best performance, but it have the advantages that, R407C does not contain any ozone depleting element even a little bit. This property is better especially to sustain the earth climate and environment friendly machine. Before, R22 was used widely because of its performance in transferring heat and it contains less ozone depleting element. Now, a better refrigerant has been created and that is the reason R407C is selected. R407C has no ozone depleting element at all. Therefore, R407C is a best R22 alternative for direct expansion systems operating at high temperatures.

Last but not least is the determination of the efficiency, performance and the saving by the new proposed system. Based on the calculation using the parameter from the Hybrid Solar Air Conditioner System, it has been proven that, the system may reduce the power consumption up to 30% of the power used by the conventional air conditioner. Besides that, some calculations also has been calculated to cheque the revenue if the system was use, and the result is, user can gain their capital in about 3 years time for the investment and after that continuously gain profit from the saving by utilizing the free renewable energy, the solar energy.

CHAPTER 5:

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The objectives of the project have been successfully achieved regarding the study of hybrid solar energy. In a nutshell, the idea of adding the solar collector to reduce the electricity consumption of the air conditioner is realise by reducing the workload by the compressor. The solar collector installed had support to add heating source to the refrigerant which before has to be done by the compressor alone. Besides that, the application of solar energy in the air conditioner can help to reduce the high cost of running an air conditioner and utilize renewable energy for human use.

New cycle for the air conditioner cycle had been created and the study for the power consumption has been done. It has proved that the power consumption for the hybrid solar air conditioner is smaller than the conventional air conditioner and the saving from the designed air conditioner will decrease the cost of electricity for an air conditioner.

Critical component for the solar equipment also has been discussed. The aspects which are needed to be focus on are the solar collector, type of heat exchange and the refrigerant. The preferable type of solar collector is evacuated tube instead flat plate and photovoltaic cell. The heat transfer mechanism chose for the solar collector is heat pipe, rather than other mechanism such as pipe in pipe and U-flow. Selected refrigerant is R407C instead of R134a. Those combinations have produced a solar hybrid air conditioner which can reduce the energy consumption for about 30% and has payback period for about 3 years of usage. Therefore, the use of hybrid solar air conditioner will benefit much for human being and more greener to the environment.

5.2 Recommendation

However, some recommendation has been noted to further develop the validation of the performance of hybrid solar air conditioner along the completing of the project. Firstly, ANSYS software should be utilise to estimate the output heat which will be emitted by the evacuated tube when expose to the solar radiation. This simulation can be done by using the software but need to be guided by the person in charge of the software.

Besides that, the proposed overall system also can be simulated by using TRNSYS software. The software is better to determine the temperature and pressure of the refrigerant after pass through each of the component of the hybrid solar air conditioner. Again, the process needs to be guide by the person who specialise in the software because the process for the simulation is quite complicated.

Last but not least, to determine the actual result for the propose system, an experiment can be done to have the real situation findings. Actually, the writer plan to do the experiment, but because of having some difficulties with the vendor of the air conditioner and time constraint, the plan need to be postpone and another alternative is done. Based on the result produced from the experiment, the data can be compared to the theoretical or simulation's data.

Appendices:

TEGA

Saturation Table R 407C

Temp. °C	Pressure kPa liquid	Pressure kPa gas	spec. Density kg/m³ liquid	spec. Density kg/m³ gas	spec. Volume m³/kg liquid	spec. Volume m³/kg gas	spec. Enthalpy kJ/kg liquid	spec. Enthalpy kJ/kg latent	spec. Enthalpy kJ/kg gas	spec. Entropy kJ/kg K liquid	spec. Entropy kJ/kg K gas
32	1431,40	1243,10	1106,2	53,921	0,00090398	0,018546	247,59	174,82	422,41	1,1621	1,7407
33	1468,50	1277,70	1101,6	55,534	0,00090779	0,018007	249,17	173,54	422,71	1,1671	1,7396
34	1506,40	1313,10	1096,9	57,19	0,00091167	0,017485	250,75	172,24	422,99	1,1722	1,7385
35	1545,00	1349,20	1092,1	58,893	0,00091563	0,01698	252,34	170,93	423,27	1,1772	1,7373
36	1584,30	1386,10	1087,4	60,643	0,00091966	0,01649	253,94	169,59	423,53	1,1823	1,7362
37	1624,40	1423,70	1082,5	62,442	0,00092377	0,016015	255,54	168,25	423,79	1,1873	1,735
38	1665,20	1462,10	1077,6	64,291	0,00092797	0,015554	257,15	166,89	424,04	1,1924	1,7339
39	1706,70	1501,30	1072,7	66,193	0,00093225	0,015107	258,77	165,50	424,27	1,1975	1,7327
40	1749,00	1541,30	1067,7	68,148	0,00093662	0,014674	260,40	164,10	424,50	1,2025	1,7315
41	1792,10	1582,10	1062,6	70,16	0,00094109	0,014253	262,04	162,67	424,71	1,2076	1,7303
42	1836,00	1623,70	1057,5	72,23	0,00094565	0,013845	263,68	161,24	424,92	1,2127	1,7291
43	1880,60	1666,20	1052,3	74,359	0,00095032	0,013448	265,34	159,77	425,11	1,2178	1,7279
44	1926,10	1709,50	1047,0	76,552	0,00095509	0,013063	267,00	158,29	425,29	1,223	1,7266
45	1972,30	1753,60	1041,7	78,809	0,00095997	0,012689	268,67	156,78	425,45	1,2281	1,7254
46	2019,40	1798,70	1036,3	81,134	0,00096497	0,012325	270,35	155,25	425,60	1,2332	1,7241
47	2067,30	1844,60	1030,8	83,529	0,0009701	0,011972	272,04	153,70	425,74	1,2384	1,7228
48	2116,00	1891,40	1025,3	85,997	0,00097535	0,011628	273,75	152,12	425,87	1,2435	1,7215
49	2165,60	1939,10	1019,6	88,542	0,00098074	0,011294	275,46	150,52	425,98	1,2487	1,7201
50	2216,00	1987,80	1013,9	91,166	0,00098626	0,010969	277,18	148,89	426,07	1,2539	1,7187
51	2267,30	2037,40	1008,1	93,873	0,00099194	0,010653	278,92	147,23	426,15	1,2591	1,7173
52	2319,40	2087,90	1002,2	96,668	0,00099778	0,010345	280,67	145,55	426,22	1,2643	1,7159
53	2372,50	2139,40	996,2	99,553	0,0010038	0,010045	282,43	143,83	426,26	1,2696	1,7144
54	2426,40	2191,90	990,1	102,53	0,00101	0,0097528	284,20	142,09	426,29	1,2748	1,7129
55	2481,20	2245,40	983,9	105,62	0,0010163	0,0094682	285,99	140,30	426,29	1,2801	1,7113
56	2537,00	2300,00	977,6	108,8	0,0010229	0,0091909	287,79	138,49	426,28	1,2854	1,7097
57	2593,60	2355,60	971,2	112,1	0,0010297	0,0089204	289,61	136,64	426,25	1,2908	1,7081
58	2651,20	2412,20	964,6	115,52	0,0010367	0,0086567	291,44	134,75	426,19	1,2961	1,7064
59	2709,80	2469,90	957,9	119,06	0,0010439	0,0083992	293,29	132,82	426,11	1,3015	1,7047
60	2769,20	2528,70	951,1	122,73	0,0010514	0,0081479	295,16	130,85	426,01	1,3069	1,7029
61	2829,70	2588,60	944,1	126,54	0,0010592	0,0079025	297,05	128,82	425,87	1,3124	1,7011
62	2891,10	2649,70	936,9	130,5	0,0010673	0,0076627	298,96	126,76	425,72	1,3179	1,6992
63	2953,50	2711,90	929,6	134,62	0,0010757	0,0074282	300,88	124,65	425,53	1,3235	1,6972
64	3017,00	2775,30	922,1	138,91	0,0010845	0,0071989	302,83	122,48	425,31	1,329	1,6952
65	3081,40	2840,00	914,4	143,38	0,0010936	0,0069744	304,81	120,24	425,05	1,3347	1,6931
66	3146,80	2905,80	906,5	148,05	0,0011032	0,0067546	306,81	117,95	424,76	1,3404	1,6909
67	3213,30	2973,00	898,3	152,93	0,0011132	0,0065391	308,84	115,59	424,43	1,3461	1,6886
68	3280,80	3041,40	889,8	158,04	0,0011238	0,0063277	310,90	113,16	424,06	1,352	1,6862
69	3349,30	3111,20	881,1	163,39	0,0011349	0,0061202	312,99	110,66	423,65	1,3579	1,6838
70	3418,90	3182,30	872,1	169,03	0,0011467	0,0059163	315,12	108,06	423,18	1,3639	1,6811
71	3489,60	3254,90	862,7	174,96	0,0011591	0,0057157	317,29	105,37	422,66	1,3699	1,6784
72	3561,30	3328,90	852,9	181,22	0,0011724	0,005518	319,51	102,56	422,07	1,3761	1,6755
73	3634,10	3404,40	842,7	187,86	0,0011866	0,0053231	321,77	99,65	421,42	1,3824	1,6724
74	3708,00	3481,40	832,0	194,92	0,0012019	0,0051304	324,09	96,61	420,70	1,3889	1,6692
75	3783,00	3560,10	820,8	202,44	0,0012184	0,0049396	326,48	93,41	419,89	1,3955	1,6657
76	3859,10	3640,50	808,8	210,51	0,0012364	0,0047503	328,94	90,04	418,98	1,4022	1,662
77	3936,20	3722,60	796,1	219,21	0,0012561	0,004562	331,48	86,49	417,97	1,4092	1,658
78	4014,40	3806,60	782,5	228,65	0,001278	0,0043735	334,13	82,69	416,82	1,4165	1,6536
79	4093,60	3892,60	767,7	238,98	0,0013025	0,0041844	336,91	78,60	415,51	1,4241	1,6489
80	4173,80	3980,80	751,6	250,41	0,0013305	0,0039934	339,84	74,17	414,01	1,4321	1,6436

These data were collected by application REFPRO7.

Appendix I: Temperature & Pressure Chart for R407C refrigerants

KK SONG AIR-COND (M) SDN BHD

(Co. No. 511749-V)

HQ : M4A-3A(Grd Floor) , Jalan Pandan Indah 4/1A,Pandan Indah , 55100 KL.
Tel: 03-42974118 Fax : 03-42940098
BRANCH : 21,Jalan SBC 1,Taman Sri Batu Caves,68100 Batu Caves,Selangor
Tel : 03-61859696 Fax : 03-61879696

Sir ,
Email drifterof@gmail.com

DATE : 13.03.2015

RE: QUOTATION FOR MAINTENANCE OF AIR-CONDITIONER

We are pleased to submit our quotation as per your inquiry :

No.	Description	Qty	Unit price RM	Total RM
1	To Supply & install split air cond with 10feet copper piping, Pvc drain pipe,bracket,control wiring ,refill gas & testing commisioning **Brand : Ecoline** **Type : 2.0hp wall type solar aircond** **Model : STA 18SPWM**	1 Set	5,800.00	5,800.00
2	Extra copper piping for 2.0hp solar aircond Total : 20feet	20feet	30.00	600.00
3	3 port digital manifold eg brand : field piece to measure temperature	-	-	-
4	Clamp meter to measure voltage brand : kyoritsu,japan	1 Unit	380.00	380.00
	***Not including transpotation**			
		Total RM		**6,780.00**

Term of payment : CASH
We trust the above quotation will meet with your requirement and hope to receive your order soon . Any requiries , please do not hesitate to contact us .
Thank you .

Yours Sincerely ,

Appendix II: Quotation on the Purchased Solar Air Conditioner.

ned & Accepted

LIZA

....

Ms Liza (CHOP & SIGN)
C.c Mr. Song Kok Kim
(012-317 3300)

Appendix II: Quotation for purchasing Ecoline Solar Air Conditioner

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