THERMAL PERFORMANCE AND ECONOMIC ANALYSIS OF SOLAR PHOTOVOLTAIC WATER HEATER UNDER THE MALAYSIAN CLIMATIC CONDITION

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ABSTRACT

The solar energy is one of the highest reliable renewable energy resources. Solar water heater (SWH) system as a considerable application of solar energy has been studied by many researchers. There have been several innovations in the design of SWH through decades of research, and still there is a significant potential to improve the efficiency and optimize the cost of SWH through new and innovative designs. In this study, the modified design of the solar energy absorber of flat plate collector through a water heating system has achieved a commendable success experimentally. The Hottel-Whillier-Bliss equation and Annual Worth method were applied to determine the thermal performance and economic impact of the modified flat plate collector. The design of the sheet and tube was focused on this study. For designing these compartments the copper tube and aluminium sheet have been selected as the most appropriate materials. A solar PV panel was utilized to supply power for running the controller circuit and the water pump. The experiments were carried out for two months of June and July as the sunniest days in Malaysian climate. The results show the maximum water temperature of 45°C in the storage tank, have been obtained on a clear day operation. Similarly, this modified design of the solar water heater has achieved around 5% more thermal efficiency than the previous designs. The thermal efficiency has been found to decrease rapidly when the ambient temperature increases. The estimated thermal efficiency was 75% in the month June and 76% in the month July. The average daily collector heat loss in two months was 8.50 W/m^2K (-13.05 W/m^2C), which is considered a very low heat loss. Economically, the calculated payback period of the system is 5 years which is highly advantages for residential buildings.

ABSTRAK

Tenaga solar adalah salah satu sumber tenaga tertinggi boleh diperbaharui. Sistem pemanas air suria (SWH) telah dikaji oleh ramai penyelidik sebagai aplikasi yang besar tenaga solar. Terdapat beberapa inovasi dalam reka bentuk SWH setelah berdekad penyelidikan, dan masih terdapat potensi yang besar untuk meningkatkan kecekapan dan mengoptimumkan kos SWH melalui reka bentuk dan inovatif baru. Dalam kajian ini, reka bentuk yang telah diubahsuai penyerap tenaga solar pengumpul plat rata melalui system pemanasan air telah mencapai kejayaan yang membanggakan secara uji kaji. Persamaan Hottel-Whillier-Bliss dan kaedah Annual Worth telah digunakan untuk menentukan prestasi terma dan kesan ekonomi pengumpul plat rata yang diubahsuai. Reka bentuk lembaran dan tiub telah diberi tumpuan dalam kajian ini.Untuk bentuk petak-tiub tembaga dan keping aluminium telah dipilih sebagai bahan yang paling sesuai. Satu panel PV solar telah digunakan untuk membekalkan kuasa untuk menjalankan litar pengawal dan pam air. Eksperimen telah dijalankan selama dua bulan iaitu bulan Jun dan Julai ketika cuaca paling cerah di Malaysia. Keputusan menunjukkan suhu air maksimum 45°C dalam tangki simpanan, yangdiperolehi pada hari yang cerah. Reka bentuk pemanas air solar yang telah diubahsuai ini telah mencapai 5% lebih kecekapan termal daripada reka bentuk sebelumnya. Kecekapan termal telah ditemui berkurang dengan pesat apabila suhu ambient meningkat. Anggaran kecekapan termal adalah 75% pada bulan Jun dan 76% pada bulan Julai. Purata kehilangan haba pengumpul harian dalam tempoh dua bulan ialah 8.50 W/m^2K (-13.05 W/m^2C), yang dianggap kehilangan haba yang sangat rendah. Dari segi ekonomi, tempoh bayar balik yang dikira system adalah 5 tahun yang sangat bermanfaat untuk bangunan kediaman.

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NOMENCLATURE

A/F	sinking fund factor
A/P	capital recovery factor
AW	annual worth
A_{rc}	annual running cost
A_0	collector area (m^2)
A_c	area of pv collector (m^2)
C_{afic}	change of aluminium foil insulation cover
c	thermal capacity (J/kg °C)
E	radiation intensity
EWH	electric water heater
F	amount of money accumulate
f	factor in collector top heat loss coefficient
H_{erc}	heating element replacement cost
h_w	wind convection heat transfer coefficient (W/m^2 K)
I_c	initial cost
I_{lc}	installation cost
i	interest rate
k	global losses factor (W/m^2 °C)
k_{bi}	thermal conductivity of collector back insulation (W/m K)
n_l	day of year
N	life time
N_l	number of glass covers
P	amount of money
PV	photovoltaic
q_t	thermal losses (W/m^2)

q_{opt}	optical losses (W/m^2)
Q_l	latitude
Q_a	heat derived from the absorption surface (W/m^2)
Q_u	useful energy gain (W)
R_c	running cost
SWH	solar water heater
T	temperature
T_{a1}	average temperature of the environment (°C)
T_m	average temperature of the absorption surface (°C)
T_p	mean plate temperature (°C)
U_b	collector plate bottom heat loss coefficient (W/m^2 K)
U_c	collector plate overall heat loss coefficient (W/m^2 K)
U_t	collector plate bop heat loss coefficient (W/m^2 K)
v	wind velocity (m/s).
x_{bf}	collector back insulation thickness (m)

Greek symbols

α	absorption factor
β	collector slope (degree)
Δ	gradient
δ	inclination angle (degree)
ε_g	emissivity of glass
ε_p	emissivity of collector plate
τ	transmission factor
σ	Stefan-Boltzmann constant (5.669×10^{-8} $(W/m^2)/K^4$)
η	efficiency
η_0	total efficiency

Subscripts

e	output
electrical	
i	input
max	maximum
th	thermal
u	usable

CHAPTER 1: INTRODUCTION

1.1 Background

Energy has the greatest impact on the socio-economic development of a country. Recently there has been a total increase of 44.2% over the projection period for 2006-2030 in energy demand due to the economic and technological developments over the world (Rahman & Lee, 2006). The global economy grew at 3.3% per year over the past 30 years and during this period the electrical energy demand has increased by 3.6%. The electrical energy production of the world was 17,450 TWh in 2004 and it is estimated that the world will consume 31,657 TWh in 2030. According to the International Energy Outlook, the world energy consumption will increase from $1.38\times l0^{23}$ kWh in 2006 to 1.62×10^{23} kWh in 2015 and 2.0×10^{23} kWh in 2030. A major share of the energy comes from fossil fuel and it is a well-known fact that burning fossil fuels releases gaseous pollutants which are responsible for the global warming and greenhouse gas effects. Consequently, these phenomena will result in a global climate change, stratospheric ozone depletion, loss of biodiversity, hydrological systems change and the supplies of freshwater, land degradation and stresses on food-producing systems (Saidur et at., 2010).

Cheap and abundant energy is crucial for human being to survive as the growth of modern industry and the explosive increase in world population have made additional and extensive demand on the supply of energy, thus, an equal increase in demand of food production is necessarily required through the manufacturing industries which entirely depend on fuel respectively.

While the industrial economy might be able to withstand spiraling fuel costs but there would come a time when the supply would be grossly insufficient to meet the increasing energy demand due to the decreasing available fossil fuels (Ong, 1994). Experts have predicted a world-wide acute shortage of fuel in the future, although they have yet to agree upon the time when the conventional non-renewable fuel reserves, such as, coal, oil, natural gas and even nuclear sources would be seriously depleted. The sources of energy are as shown in Figure 1.1. There are two types of energies, namely, Renewable energy and Non-renewable energy as the accepted concept in our society (Panwar et al., 2011).

Figure 1.1 categorizes various sources of energy under renewable and non-renewable energy resources. Biomass, biogas, solar ray, wind, water and geothermal energies are grouped under renewable resources because they are non-exhaustible with a great abundance. Wave, tidal and ocean thermal gradient resources are under water power. Fossil fuels like coal, oil and natural gas are grouped with nuclear fusion and nuclear fission under non-renewable resources because they can be depleted and there are major obstacles to their utilization.

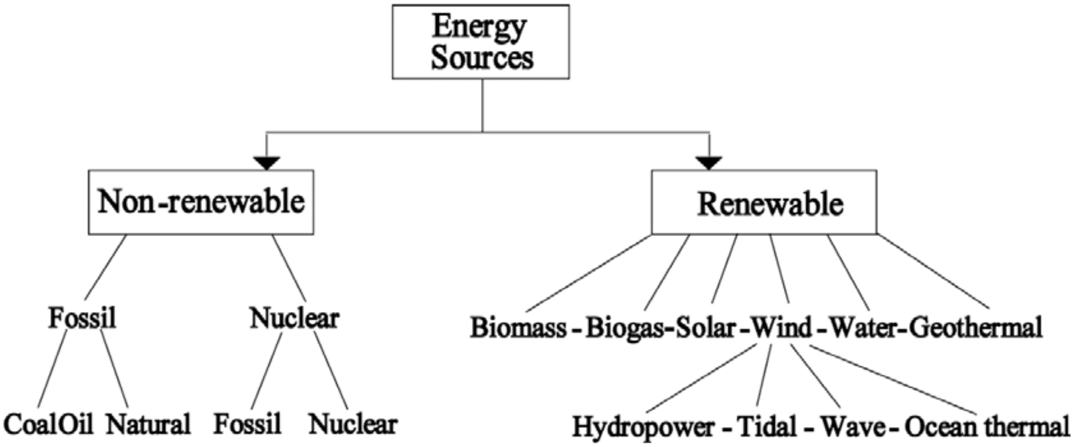


Figure 1.1 Source of energy (Ong, 1994).

Solar energy is radiant energy produces by the sun. Every day the sun radiates or sends out an enormous amount of radiant and heat energy. The sun radiates more energy in one second then people have used since beginning of time. The Sun is a big ball of heat and light resulting from nuclear fusion in its core. The nuclear reaction releases energy that travels outwards to the surface of the Sun. Along the way to the surface, the energy transforms so that by the time it is released it is primarily light energy. The two major types of solar energy that reach to the Earth are heat and light. Solar energy is often called the "alternative energy" to fossil fuel energy sources such as, oil and coal. The development and diffusion of renewable energy resources and technologies will help realize important economic, environmental and social objectives in the next future of the 21st century. Renewable energies are critical components for achieving sustainable development. During the next decades, solar energy is likely to be one of the most promising sources of clean energy. This fact is especially relevant in countries like Spain, Germany, China, USA and some other countries that have abundant sunlight.

The major applications of solar energy can be classified under two categories:

i) Solar thermal system, which converts the solar energy into thermal energy.

ii) Photovoltaic (PV) system, which converts the solar energy into electrical energy. Usually, these systems are used separately. The PV module temperature varies in the range of 300-325 K (27-52 °C) for an ambient air temperature of 297.5 K (24.5°C). The carrier of thermal energy associated with the PV module may be either air or water.

In the solar thermal system, the external electrical energy is required to circulate the working fluid through the system. On the other hand, in the PV system, the electrical efficiency of the system decreases rapidly as the PV module temperature increases. Therefore, in order to achieve a higher electrical efficiency, the PV module should be cooled by removing the heat in some way. In order to eliminate an external electrical source and to cool the PV module, the PV module should be combined with the solar air/water heater collector. This type of system is called solar photovoltaic thermal (PV /T) collector. The PV/T collector produces the thermal and electrical energies simultaneously. Besides the higher overall energy performance, the advantage of the PV /T system lies in the reduction of the demands on physical space and the equipment cost through the use of common frames and brackets as compared to the separated PV and solar thermal systems which are placed side-by-side (Mohsen et al., 2009; Sarhaddi et al., 2010).

According to study done by the international Energy Agency, a 44.2% increase in the global energy consumption is foreseen by 2030, with 70% of the growth in demand coming from the developing countries. Malaysia is one of the developing countries among ASEAN countries, with a GDP of US$15,400 per capita (PPP basis), and a steady GDP growth of 4.6% in 2009. The economy of Malaysia grew at 5% in 2005 and the overall energy demand is expected to increase at an average rate of 6% per annum. In parallel with Malaysia's rapid economic development, the energy consumption grew at the rate of 5.6% from 2000 to 2005 to reach 38.9 Mtoe in 2005. The energy consumption is expected to reach 98.7 Mtoe in 2030, nearly three times the 2002 level (Oh et al., 2010).

The crucial challenge facing the power sector in Malaysia is the issue of sustainability which is to ensure the security and reliability of the energy supply and the diversification of the various energy resources. In Malaysia, the green technology application is seen as one of the sensible solutions, which are being adopted by many countries around the world in order to address the issues of the energy and the environment simultaneously. The Malaysian government declared the Eighth Malaysian Plan in 2001 where the RE (renewable energy) was regarded as the fifth fuel in the new five-fuel strategy in the energy mix and had set a target of 5% (600 MW) RE contribution in electricity mix by the year 2005. However, the development pace of the RE in Malaysia is rather slow and still in its nascent stage; with its current contribution at around I% only of the total energy mix, even though the fifth fuel policy had been announced a decade ago. The notion is further pursued in the 9th Malaysia Plan (2006-2010) which has also set a target of 5% RE in the country's energy mix (Gan & L i, 2008; Leo, 1996).

1.2 Solar Energy Utilization

The solar hot water heating has been proven to be commercially successful in countries like Israel, Japan, Australia, India and The United States, for providing 60°C hot water for bathing and washing purposes. Generally, solar water heaters operating at 50% efficiency can recover their initial capital costs after about 5 to 8 years of operation. In rural and isolated areas, the solar distillation of brackish or sea water can provide bacteria free water for human and animal consumption. It would be possible to provide about 5 litres of water per square meter of area on good sunny days. The various applications of the solar energy are as shown in Figure 1.2.

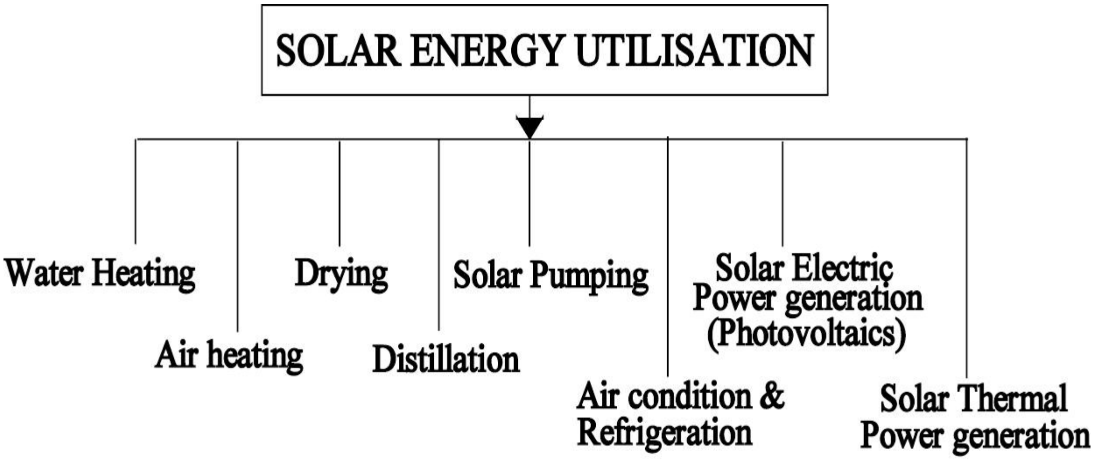


Figure 1.2 Solar energy Utilization (Ong, 1994).

The solar energy can be used for the following purposes:

a) Heating water for domestic, commercial and industrial applications.

b) Heating air for comfortable space heating and for drying agricultural crops.

c) Distilling brackish or saline water for drinking.

d) Pumping water.

e) Powering air conditioning, refrigeration and ice-making machines.

f) Power generation.

Hot air between 50-60°C can be obtained by passing ambient air through the corrugated passages of zinc or aluminium roofing sheets. It is possible to collect about 30% of the available solar energy incident on top of the roof surface in this way. This solar heated hot air can be used for a wide variety of solar drying application, For example, for drying agricultural products, like rice, fruits, tapioca, coffee, tea and pepper and for drying marine products, like fish and prawns (Chwieduk, 2004).

1.3 Solar energy background

The sun's radiation arrives at no cost and is available during any clear day. More energy from the sun falls on the earth in one hour than is used by everyone in the world in one year. "Solar Energy" implies a potential for directly heating or generating electricity by harnessing the energy radiated from the sun. In the broad sense of the term, solar energy also includes wind, wave, biomass, and fossil fuel energy as well. All these forms of energy originated from solar energy. Let us start at the beginning, the sun itself (Mazria, 2011).

The sun is an immense fusion reactor. Its means the hydrogen atoms are combined "Fusion" to produce helium. That is why the sun is very hot. From the sun releases a great quantity of heat, hence, fusion that is called a chain reaction. The amount of 508 million tons of hydrogen and 504 million tons of helium are combined nuclear fusion process into every second. Another reason of the sun extremely hot because the amount of 4 million tons of matter are converted into energy and core temperature. As Albert Einstein found, a very small amount of matter can convert into a very large amount of energy. In fact, by fusion of matter one ounce converted into energy can supply all the energy your home and car would more than, that energy can supply five-thousand other people's homes and cars as well. From the sun energy is preferable to make other sources of energy because solar radiation is abundant and will be available for many more millions of years (Michael, 1993).

Unlike other energy sources, solar radiation cannot be cut off or made more costly. Putting solar radiation to work does not directly pollute the environment as it is a clean and safe source of energy. The only cost is the equipment used to harness the energy while the energy itself is free (Watson, 2011).

Unfortunately, solar energy is not always available on demand. It is unobtainable under heavy clouds or at night. However this shortcoming can be overcome by storing the energy. Solar radiation arrives at a low intensity and must be concentrated to obtain a high temperature (over 250°F [120°C]) for applications (Kreider & Kreith, 2011).

1.4 Objectives of the study

The vision in Malaysia stipulates the overall target of becoming an industrialized country by 2020. Similarly, the Ministry of Energy, Communication and Multimedia (MECM) has elaborated on the vision for the energy sector for 2020. According to MECM vision, every member of the Malaysian society should have access to high quality, secure electrical power and other convenient forms of energy supply in a sustainable, efficient and cost-effective manner. However, Malaysia's energy sources primarily comprise oil, natural gas, hydropower and coal and recently renewable energy sources such as solar power and biomass which are being exploited. In Malaysia, solar energy conversion is a serious consideration. The potential for solar energy generation in Malaysia depends on the availability of the solar resource which varies with locations. It is necessary to carry out a general assessment of the solar energy potential nationwide first and can then be followed by detailed assessment in promising locations. The solar resource is a crucial step in planning a solar energy project and detailed knowledge of the solar resource at a site is needed to estimate the performance of a solar energy project, and keeping these in mind, the objectives of this dissertation are as follows:

- To modify design of flat plate solar water heater absorber.
- To investigate the thermal performance of solar water heaters.
- To investigate the conversion efficiency of the solar PV.
- To study the economic viability of the usage of solar water heaters.

1.5 Scope of the study

Assessment of a solar energy potentiality at various locations in Peninsular Malaysia has been studied by (Islam, 2011). In general, a solar water heater collector need as modified design to provide data for the thermal performance and solar PV efficiency. It is better to analyse the data by using the flat plat collector formula in order to obtain a better performance of the SWH.

The main scopes of this study are as given below:

- The solar water heater performance generally is highly dependent on its absorber design. There are many designs proposed previously in the journal articles. In Malaysia, the flat plates and the evacuated tube solar water heaters are available. This study's main concentration is on the flat plate solar collector because this type of collector is economical in terms of cost and is adjustable to the solar beam angle that can absorb more radiation.
- The performance of a flat plate solar collector can be easily evaluated by the available methods, particularly, in its application in the solar water heater system in homes as well as solar space heating.
- Besides calculating the thermal performance, the solar PV efficiency and useful energy gain of the collector is also done in the present study from which it is found that almost 80% of the solar thermal energy is absorbed in the collector plate. Measurement of the radiant heat reflection and heat loss in the collector surface can be done as well.

- The present work focuses on the validation of the developed model and its economic and environmental impacts on the respective sectors of implementation.

1.6 Outline of the dissertation

This dissertation comprises five chapters with the contents of each chapter being described briefly as here under:

CHAPTER 2: In this chapter present works that have been done and have been equally highlighted. The literature review of this study has been divided into three parts, namely, i) the flat plat solar water heater collector, ii) the thermal performance, and iii) the efficiency of solar PV as compared to electric water heater for economic viability.

CHAPTER 3: This is the methodology chapter, where the method to use the Hottel-Whillier-Bliss equation for calculating the thermal performance is carried out. The RETScreen International and MATLAB software has been used for the data analysis. In this chapter annual worth method has been used to calculate the economic viability and its impact in the local environment. Therefore, Sheet and Tube collectors set up has been chosen for this experiment.

CHAPTER 4: This is the discussion chapter in which the results of the modified design solar water heater collector thermal efficiency, solar PV panel efficiency and cost analysis, etc., have been discussed wherein the thermal performance and economic analysis of the collector used in Malaysian weather have been fully discussed.

CHAPTER 5: This chapter consists of the conclusions and suggestions on the subject matter in which the main outcome of the dissertation has been precisely narrated. The main outcomes of the absorber design performance as compared with the electric water heater have been fully described as well. The aggressively challenging suggestions have been proposed for future work.

CHAPTER 2: SOLAR WATER HEATER COLLECTOR

2.1 Introduction

In recent years, solar energy applications have grown rapidly to meet environmental protection requirements and electricity demands. Renewable energy sources like solar, wind, biomass, hydropower and tidal energies offer promising CO_2 free alternatives. Despite the general awareness of the advantages of renewable energy utilization, this source of energy contributed only about 1.6% of the world energy demand in 2012. The trend is estimated to rise up to 2.2% in 2035. The delivered energy is utilized in 4 major industrial sectors, namely construction, agriculture, mining and manufacturing. The highest percentages of energy usage in the industrial sector of a few selected countries around the world as in China is 70%, Malaysia is 48%, Turkey is 35% and USA is 33%. The literature review of this dissertation will give an overview of the present status in the related field and shows the future work of the relevant field. This chapter presents a literature review on the flat plate design, energy performance, solar photovoltaic and economic analyses of Peninsular Malaysia. The most versatile 'Hottel-Whillier' formula has been used for the energy performance of SWH and the economic analysis has been done using the Annual Worth method. A good collection of PhD and Master Theses, journal articles, reports, conference papers, internet sources and books have been used for this study. It should be mentioned that about 80-90% of the journal papers are collected from most pertinent and prestigious peer reviewed internationally referred journals, such as, Energy, Energy Policy, Applied Energy, Renewable and Sustainable Energy Reviews, Renewable Energy, Journal of Solar Energy, Environmental Research and International Journal of Energy Research. Some international high quality masters and PhD theses in the relevant field by (Morrison, 1997; Panapakidis, 2009; Sanjayan, 2006; UFC, 2004a, 2004b) may be considered as strong supports for this work.

Moreover, a substantial amount of the relevant information has been collected through personal communication with the key researchers around the world in this research area.

2.2 Review on modified design of flat plate SWH collector

The solar (water heater) collector is the vital element in the solar energy system as it absorbs the solar radiation and converts it into a useful form of heat energy that can be applied to carry out specific tasks. The most intellectual system has been developed for higher temperature collection form the collector (Farahat et al., 2009).

There are a number of different designs for solar energy collectors but they are mainly either stationary or concentrating. The stationary type includes: Flat Plate Collectors, Evacuated Tube Collectors and Compound Parabolic Collectors while the Concentrating type includes: Parabolic and Cylindrical Trough Collector, Parabolic Dish Reflector and Heliostat Field Collector. Figure 2.1 shows a typical liquid flat plate collector while Table 2.1 shows different types of flat plate collectors (Adnan et al., 2009).

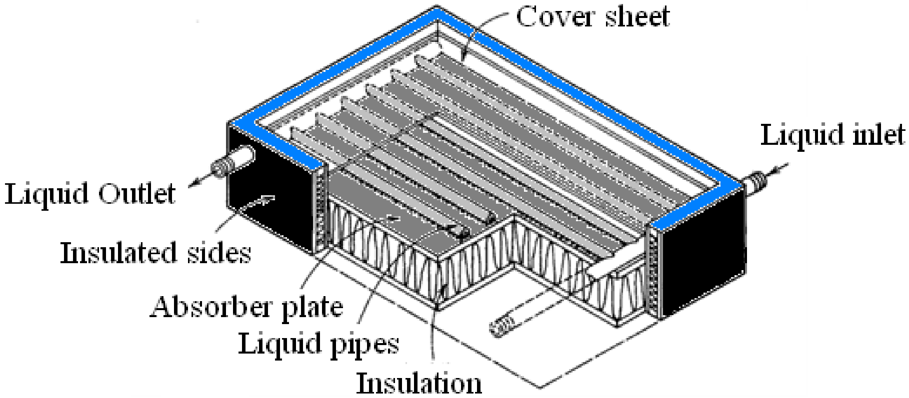
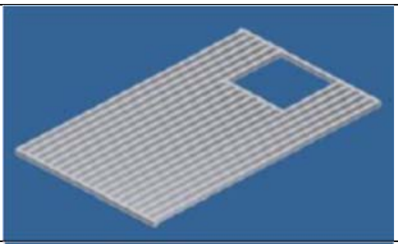
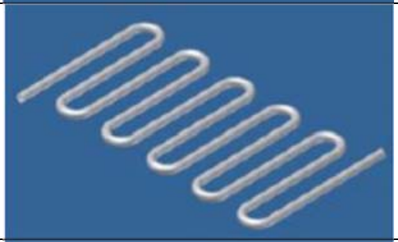
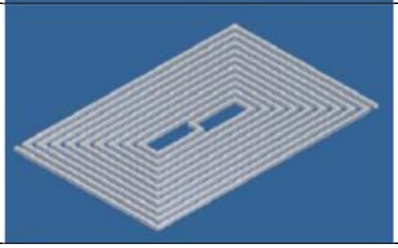


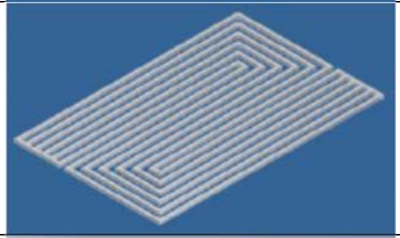
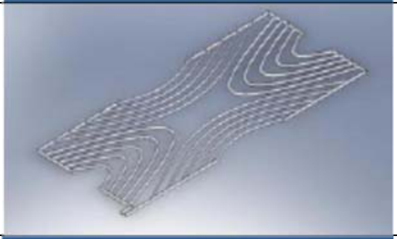
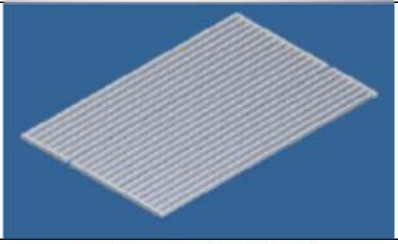
Figure 2.1 A typical liquid flat plate collector (Sarhaddi et al., 2010; Zondag, 2008).

Flat-plate collectors are the most common for residential water heating and space heating purposes. A typical flat-plate collector consists of an absorber, transparent cover sheets and an insulated box as shown in Figure 2.1. The absorber is usually a sheet of high thermal conductivity metal with tubes or ducts either integrated or attached. Its surface is painted or coated to maximize radiant energy absorption and in some cases to minimize radiant emission. The insulated box provides the structure and sealing which reduces heat loss from the back or sides of the collector. The cover sheets, called glazing, allow the sunlight to pass through onto the absorber but insulate the space in the absorber to prevent cool air from flowing into it. However, the glass also reflects a small part of the sunlight, which does not reach the absorber (Grigorios, 2009).

The collector can reach temperatures of up to 200°C when no liquid flows through it and therefore all the materials used must be able to resist such heat. The absorber is usually made of metallic materials, such as, copper, steel or aluminium. The collector housing can be made of plastic, metal or wood, and the glass front cover must be sealed so that the heat does not escape and the collector itself is protected from dirt, insects or humidity. The eight conventional designs of flat plate solar water heater collectors have their thermal efficiency as mentioned below (Adnan et al., 2009; Chong et al., 2012):

Table 2.1 Different types of flat plate collector pipe absorbers and their thermal efficiencies (Adnan et al., 2009; Chong et al., 2012).

Collectors absorber name	**Absorber pipe design**	**Thermal efficiency**
Direct flow		48%
Oscillatory flow		60%
Spiral flow		70%

Serpentine flow		48%
Parallel-serpentine flow		70%
Web flow		62%
Modified Serpentine-Parallel		68%
Prototype of V-trough		70%

The collector housing is highly insulated at the back and sides to reduce the heat losses. There are still some collector heat losses due to the temperature difference between the glass cover and the absorber with the ambient air as a result of which the convection losses are caused by the angle of inclination and the spacing between the glass cover and the absorber plate, while the radiation losses are caused by the exchange of heat between the absorber and the environment.

The absorber plate which covers the full aperture area of the collector must perform three functions: i) absorb the maximum possible amount of solar radiation, ii) transfer this heat into the working fluid at a minimum temperature difference, and iii) lose a minimum amount of heat back to the surrounding.

Solar radiation passing through the glazing is absorbed directly onto the absorber plate. Surface coating that has a high absorption capacity for short-wavelength light is applied on the absorber in which paint or plating is used and the resulting black surface will typically absorb over 95% of the incident solar radiation. The second function of the absorber plate is to transfer the absorbed energy to a heat-transfer fluid at a minimum temperature difference and this process is achieved by conducting the absorbed heat into the tubes that contain the heat-transfer fluid which may be either water or water with antifreeze liquid. Transferring the heat absorber onto the absorber surface into the fluid gives rise to heat losses. The liquid collector absorber plates consist of a flat sheet of metal with the tube attached to it spaced at 10 cm apart. The sheet of metal absorbs most of the solar radiation and acts as a carrier to bring the absorbed heat into the fluid. In an efficient system, the absorber sheet is made of a material with a high thermal conductivity. The tubes are not spaced too far apart otherwise a much lower temperature will occur halfway between them (Grigorios, 2009; Khan & Obaidullah, 2007).

Since the temperature of the absorber surface is above the ambient temperature, the surface re-radiates some of the heat it has absorbed to its surroundings. This loss mechanism is a function of the emission of radiation from the surface for low-temperature and long-wavelength radiation. Many coatings that enhance the absorption of sunlight (short wavelength radiation) also enhance the long wavelength radiation loss from the surface. A good coating will produce an absorbent surface that is a good absorber of short wavelength solar radiation but a poor emitter of long wavelength radiant energy.

Normally the absorbed radiation is covered with one or more transparent cover sheets to reduce the convective heat loss. However, convective loss is not completely eliminated because a convective current exists between the absorber and the cover sheet, hence, the transference of heat from the absorber to the cover sheet from which the external convection then produces a net heat loss from the absorber as it cools the cover sheet (Manickavasagan et al., 2005; Vairamani et al., 2011).

2.2.1 Basic design of flat plate collector and SWH system

A flat-plate collector is a non-concentrating collector in which the absorbing surface is essentially planned. A typical flat-plate solar collector basically consists of the following main components:

- A transparent top cover.
- A collector plate
- Insulation set.
- A casing.

The transparent top cover or glazing allows the incident short wavelength solar radiation to be transmitted through it but traps the radiated long wavelength energy from the collector plate using the greenhouse effect. The collector plate or absorber plate as it is sometimes called, absorbs and converts the solar energy falling on it into useful heat as the insulation around the collector plate prevents heat losses. The external casing protects the insulation and collector plate from the environment (Cruz-Peragon et al., 2012). Generally, solar water heating systems may be conveniently grouped according to:

- Passive (gravity, natural convection, thermosyphon) or active (forced circulation, pumped) system,
- Direct and indirect system.
- Pressurized and non-pressurized (open, drain down) system.

In Malaysia the direct, passive or active solar water heater systems are available for domestic purposes. Occasionally booster pumps are incorporated or they are connected to the main water pipe line for a higher pressure supply. For commercial use, the direct and indirect active systems are most commonly installed.

2.2.1(a) Glazing

A transparent cover over the solar collector has the function of allowing the short wavelength solar radiation to pass through it and trapping the long-wavelength reradiation emitted by the collector plate. It also reduces the convective heat losses from the top of the plate (Khoukhi & Maruyama, 2006). An ideal glazing cover over the collector plate should have the following characteristics:

- Maximum transmissivity for solar radiation (0.3 to 3.0 μm).
- Minimum transmissivity for long wave radiation (>3μm).
- Low absorptivity.
- Low thermal conductivity.
- High weather resistance.
- Impact resistant.

2.2.1(b) Reflectivity

The reflectivity of a transparent or translucent material depends on its refractive index and on the angle of incidence formed between the incident radiation and the normal to the surface angle. For a metallic fluoride coating similar to camera lens coatings, the resulting reflectivity is 0.028. The reflectance of this coated surface is only 5.6% as compared to 8.8% reflectivity for the uncoated glass surface. However the process of coating the glass is relatively expensive and it is not viable to apply such coatings for solar water heating applications (Greenspec, 2010).

2.2.1(c) Absorptivity

Glass, air, water and most clear plastics absorb very little energy while having a high transmissivity. Typically, about 10% of normal incidence is reflected and about 5 to

10% is absorbed by the glass. The absorption is due to impurities and the iron content in the glass. Glass with high iron content has a greenish appearance and is relatively poor transmitter, hence, low iron content glass is recommended for solar energy applications (Marion & Wilcox, 1990).

2.2.1(d) Transmittance

Transmittance is a function of wavelength of the incident radiation. Generally, the transmission coefficient of clear glass is about 85-90%. The transmittance of glass rises sharply in the ultraviolet and remains high. The transmittance of glass is also dependent upon the angle of incidence (Nielsen, 2005).

Transmittance of plastic film is more wavelength dependent than glass. Most plastics have high transmittance values even for wavelengths beyond 15 μm. Most flat-plate collectors use glass covers as glass is an excellent material for glazing and is also long lasting, durable and weather resistant as compared to plastic. Its disadvantage is that it is heavy and easily broken. The thickness of glass used varies from 3 to 5 mm, depending upon the distance between the supports (Ong, 1994). Plastic glazings are lighter in weight and are more resistant to shattering as well as cheaper than glass. Plastics, such as polycarbonate, acrylics, polyvinyl flouride, flourinated ethylene propylene and glass fiber reinforced polyester are sometimes used for collector glazing. However, most plastics degrade with age because after a prolonged exposure to the atmosphere, plastics tend to turn yellow and crack as it becomes brittle, thus, toughened glass is still the preferred glazing material. A multi glazing system has a relatively smaller net value of transmittance for solar radiation than a single glazing system, but its insulation effect is much more effective. A double glazing is more effective in windy and cold regions. The optimal gap between the absorber and the glazing should be about 15 mm. In the case of double glazing, the distance between the two glazings should be kept between 15 to 20 mm (Rodríguez-Hidalgo et al., 2011).

2.2.1(e) Collector Plate

This is the nucleus of the solar collector. It consists of a durable flat metal sheet of good thermal conductivity, with closely spaced channels through which water or other heat transfer fluid can be circulated. These channels can become integral passages with the flat sheet or they can be formed from a series of metal tubes aligned parallel to one another and arranged along in close thermal contact with the flat metal sheet. The inlet and outlet manifold pipes or headers are connected to the flow channels of the collector tubes located at the bottom and top of the solar collector plate. Heat is extracted from the collector plate by allowing water or a heat transfer fluid to flow through these channels or tubes (Zondag, 2008).

There are many types of flat plate solar collector design available one of which is the tube and sheet flat plate solar collector in which the tubes can be either metallurgically bonded onto the sheet or they can be mechanically secured by rivets or wire straps. The contact between the collector tubes and the flat sheet is not as good as the contact obtained as in the case where the collector tubes are fitted into the grooved sheet. Collector plates of copper tubes mechanically bonded to aluminium sheet are quite common nowadays. In some cases, in order to improve the thermal contact between the collector tubes and the plate, a liquid metal compound is introduced to fill any void space between them. There are some laminated-sheet types of flat plate collectors which are fabricated by using two flat metal sheets in which grooves are pressed. Here, identical semi-circular grooves are pressed longitudinally onto two steel sheets each about 1.0 mm thick. One or both sheets may be grooved. The sheets are then placed together and pressure-welded along the flats to form the flow channels of the collector plate. Both the inlet and outlet manifolds are also pressed out together with the flow channels. In some designs, two flat sheets with pre-formed ‘dimples’ are spot-welded together to form a dimple plate heat exchanger (Adinberg et al., 2010).

Built-in channels are formed when the tubes and plate are extruded together. Aluminium is used since it can be easily extruded. If water is used as the heat transfer fluid, it can ultimately corrode the tube by pitting, hence, copper tubes can be inserted into the extruded channels and expanded to produce a tight fit.

Apart from the efficiency of bonding, extraction of heat from the collector depends upon the type of material used for the collector tube and also for the plate in which the materials used should have a high thermal conductivity whereby the collector tube should be thin-walled but the plate should be thick. Tube-to-tube (pitch) spacing is also important and normally, tube spacing varies from 100 to 150 mm apart where higher efficiencies will be obtained when the collector tubes are spaced closer to each other. The contact between the collector tubes and the plate should be as thermally efficient as possible so as to reduce the thermal resistance caused by inefficient bonding (Gillies, 2008).

2.2.1(f) Materials of construction

The normal operating temperature of a solar water heater is in the region of between 50 to 80°C. This temperature will depend upon the collector plate design and dry climatic condition under which the heater is operating.

Care has to be exercised when selecting a material not only for the suitability of the solar collector but also for the rest of the solar water heating system in terms of efficiency. Mild steel, galvanized iron, stainless steel, aluminium, copper, and some plastics are the most common materials used for the collector tube and plate. Copper with the highest thermal conductivity represents the best choice of material which is used extensively for both hot and cold water supply systems as it is the most trouble-free material to use as a solar collector material. Aluminium is a potentially excellent material for solar collectors because it is cheaper than copper, light in weight, easily extruded or roll-bonded, and possesses an excellent thermal conductivity (Kumar &

Rosen, 2010). Unfortunately, aluminium is easily and rapidly corroded and pitted when chloride ions are present even in minute quantities, like a few parts per million (ppm). Aluminium can only be used in an indirect solar water heater system, thus, it should never be used in a direct (water) system. Although stainless steel tubes have a high degree of resistance to corrosion, its low thermal conductivity and high cost make it less attractive as a collector material. However, thin stainless sheets have been used for making the sheet-type collector plates. Ordinary mild steel can only be utilized in an indirect solar water heater system because it can be corroded rapidly by water.

2.2.1(g) Selective surface

The top surface of the collector plate exposed to the solar radiation is colored black in order to increase its absorptive capacity towards the incident shortwave radiation. By definition, a blackbody is a perfect absorber of radiation of all wavelengths and directions. A blackbody is also a perfect emitter of thermal radiation. Some materials like a thick layer of carbon black can approximate a blackbody with an absorption coefficient of 99% of all incident thermal radiation. Matt-black paint is usually used for the coating in which the absorption coefficient of matt-black paint is about 0.95 but its emissivity is also high, about 0.95. There are also a host of proprietary paints which can be used on the collector surface (Marion & Wilcox, 1990).

A selective surface is one which absorbs most of the incident radiation falling on it and emits nothing in the long wavelength region of the energy spectrum. Such surfaces are ideal when applied with such absorber coatings, hence selective surfaces are usually based on a layer of semi-conducting oxide and can be applied to enhance and improve the collector plate performance. Using selective surfaces, a high proportion of the incident solar radiation can be absorbed (> 90%) (Ong, 1994). Black nickel or nickel-plated steel and black chrome on nickel-plated steel or copper are available commercially. They give a good humidity resistance and their ratios of absorption to emissivity are high and can be applied on to collector surfaces. It is of utmost importance to keep in mind that whatever surface coating is selected, it must be durable on any surface that has deteriorated through the paint peeling off or by degradation of the underlying metal substrate which will result in a poor collector performance. For black-painted surfaces, strict precautions must be observed, especially, during surface preparation prior to painting. The manufacturers' guidelines for surface preparation must be followed. Selective surfaces are usually applied at the factory.

2.2.1(h) Insulation

Thermal insulation is provided in solar collectors to minimize heat losses from the back and sides of the absorber system. The insulation material should possess the following intrinsic characteristics.

- Chemically stable and not deteriorate, outgas, expand, or contract at temperatures between 30 and 200°C.
- Structurally stable and must not become compact or settled with time.
- Fire resistant and not absorb moisture.
- Lightweight

The most common materials utilized in the solar collectors are fiberglass wool and mineral rock wool as they both have more or less the same value of thermal conductivity. Although rock wool is able to withstand a higher temperature than fiberglass wool, fiberglass wool is more preferable since solar collectors operate at temperatures around 200°C.

Usually a thin aluminium reflective foil is laid between the insulation material and the collector plate to enhance the thermal insulation effect. The optimum thickness of insulation for a 64 kg/m^3 fiberglass wool is 50 mm (Roonprasang et al., 2008).

2.2.1(i) Casing

An external casing is provided to protect the insulation and collector plate from the environmental conditions and also to minimize the heat loss from around the sides and bottom of the plate. Materials, like aluminium, galvanized steel, stainless steel and fiberglass are used for the casing which should provide a good mechanical rigidity so that the glass or other glazing material may be securely fastened onto it.

2.2.1(j) Piping

Pipes are extensively used to connect the solar collectors to the storage tank. Pipe material should be non-corrosive and stable at the operating temperatures of 100°C. Copper is recommended for hot water piping as copper pipes are easy to work with and install and are resistant to corrosion. It is to be strictly observed that PVC pipes soften at around 60°C and should only be used for the cold supply line and never for the hot lines. All hot pipes should be insulated and a protective outer casing provided to protect the insulation. For domestic systems in which pipe sizes are small, less than 25 mm in diameter, closed-cell preformed foam insulation is used. For commercial and industrial systems which involve pipes over 50 mm in diameter, calcium silicate with aluminium casings are used. Pipes should be designed and sized properly for a maximum pressure drop and kept as short as possible. All hot water pipes should have a diameter of at least 12 mm, and most importantly, water should never be allowed to penetrate the insulation (Bourdoukan et al., 2008; Zondag, 2008).

2.2.1(k) Storage tank

The design of storage tanks is quite standard. For pressurized tanks, they have to be manufactured to strict codes and tested to one and a half times their rated operating pressures. Mild steel tanks must be adequately protected against corrosion. Galvanized steel tanks should not be used for temperatures exceeding 65°C, since rapid corrosion can occur above this temperature. Plastic tanks have their service temperature limitations.

Storage tanks should be well insulated to minimize heat losses in which the insulating material should not degrade at the operating temperature (around 80°C) of the storage tank. Fiberglass wool or polyurethane foamed in-situ to provide an effective insulating value of at least 4 W/m^2 K should be considered (Ong, 1994).

2.2.1(l) Active system

If the solar collectors located at a level higher than the storage tank, water would not circulate between the collectors and storage tank by natural convection. In this case, an electric pump would be required to circulate the water wherein the differential temperature controller will manage the operation of the pump. The controller consists of temperature sensors located at the outlet of the last collector in the array and near the bottom of the storage tank. When the temperature at the collector outlet is higher than that at the bottom of the storage tank by a few degrees, the pump is activated. When the temperature of the storage tank is higher than the collector, the pump is stopped.

2.2.1(m) Direct system

A direct system is one in which the domestic hot water supply drawn off should be non-toxic for use in contact with the solar collectors. The materials for construction of the collectors, storage tank and connecting pipes must be appropriately compatible in order to avoid bimetallic corrosion. Another problem common to all direct systems is the possibility of ‘furring’ or even ‘scaling’ of the tubes due to hardness of the cold water supply.

2.2.1(n) Indirect system

In an indirect system, the domestic hot water supply drawn off is isolated from the collector fluid by incorporating a heat exchanger in the storage tank. The heat transfer fluid in the collector may or may not be water-based, and circulation may be by either forced or natural circulation. Such a system is used when a clean, uncontaminated hot water supply is required or where freezing or corrosion is to be avoided in the collector panel. An anti-freeze solution is used as the heat transfer fluid in the primary or collector circuit A sealed expansion tank or an automatic air release valve is installed at the highest point of the primary circuit to prevent an air-lock in the collector circuit.

2.2.1(o) Pressurized system

In the indirect system, the heat transfer fluid in the primary fluid circuit is completely sealed from the atmosphere. The fluid expands on being heated wherein the system becomes pressurized and provision for expansion is usually provided in the form of a diaphragm expansion vessel. Low temperature is used if the difference in height between the cold water feed tank and the storage tank is not too great and a high-pressure system is used if the cold water feed is pressurized using a pump. Usually, pressurization is referred to the solar collector or primary circuit.

2.3 Review on thermal performance of SWH

The thermal performance of a solar water heater is the most experimentally work related to the flat plate collectors. Different methods have also been developed for modeling and simulating the thermal performance of the solar collector. Many types of conventional flat plate solar collectors with metal absorber plates and glass covers are widely used to transform the solar energy into heat. The performance of evacuated flat plate solar collectors that have a working temperature above 100°C and the performance of evacuated tube integral collector storage SWH have been appropriately measured and modeled (Ammari & Nimir, 2003).

Figure 2.2 shows a schematic drawing of the heat flowing through a collector. It is found that 80% of the sun heat energy is absorbed in the collector plate where the radiant heat is reflected off which resulted as a heat loss in the collector surface which is around 10-35%.

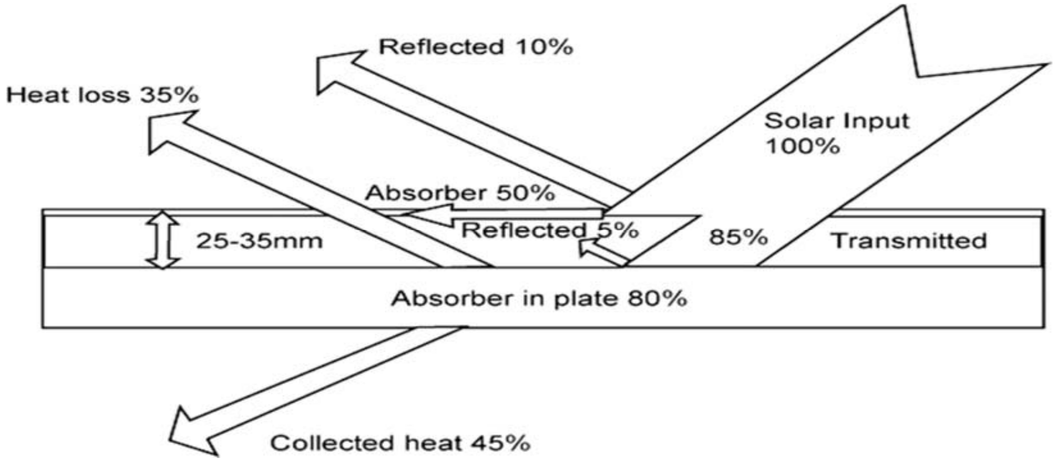


Figure 2.2 Heat flow through a flat plate solar collector (Richman & Pressnail, 2010; Struckmann, 2008; Xiaowu & Ben, 2005).

However, as shown in Figure 2.2, some amount of this radiation is reflected back into the atmosphere. Glazing absorbs the remaining amount of radiant heat which is transferred to the absorber plate as short wave radiation. Therefore, the percentage of the solar radiation, which penetrates the transparent cover of the collector and the percentage of radiation being absorbed, is indicated by the conversion factor. Some of the radiant energy is scattered whereas some is absorbed by the atmosphere. The amount of energy lost depends both on the actual path length through the atmosphere and the condition of the atmosphere in that path. Even with cloud free unpolluted skies, as much as 30% of the incident energy is lost by scattering back into space by air molecules or by absorption in the atmosphere through the naturally occurring gases (Chen et al., 2009; Gao et al., 2007; Gupta & Kaushik, 2010).

There are two general types of instruments for measuring the sun's radiation, namely, i) the solar radiation-pyreheliometer, and ii) the solar radiation-pyranometer. The pyreheliometer also known as solarimeter or actinometer is used for measuring the intensity of direct solar radiation at a normal incidence while the pyranometer is used for measuring the global radiation on a horizontal surface and it also measures diffused radiation alone if the sensor is shaded from the sun with a disc. A fixed shadow band is often used for this purpose.

Most of the solar energy devices work on the greenhouse effect. In order to understand this phenomenon, one needs to refer to the principles of thermal radiation which basically is the radiant energy emitted by a medium by virtue of its temperature. The wavelengths covered by the thermal radiation range approximately between 0.1 to 100µm. Short wave radiation is in the wave length of between 0.1 to 3.0µm. Solar radiation at a source temperature of about 5762 K is in the short wavelength range. Long wave radiation is in the wave length greater than 3.0µm. They originate from sources near ambient temperature (Ho et al., 2010; Huang et al., 2010; Jaisankar et al., 2009).

The sun has an effective surface temperature of about 5762 K and emits most of its energy between the short wave lengths of 0.10 and 3.00µm. A blackbody at a temperature of about 300 K emits radiation at a wave length above 3.00µm. Silica glass transmits 92% of the incident radiation in the wave length range between 0.35 and 2.80µm and is essentially opaque and not in this range. The wave length band of up to 0.35µm contains 4.52% of the total solar emissive power and the wave length band between 0.35 and 2.80µm contains the rest of the solar emissive power. Therefore, 92.79% of the total radiant energy incident on the glass is in the transparent wave length range between 0.35 and 2.80 mm, hence, 85.37% of this solar radiation is transmitted through the glass (Gupta & Kaushik, 2010).

2.3.1 Low temperature flat-plate collector

Low temperature flat-plate solar collectors are employed in the systems which require only small temperature (2 to 10°C) rises. They are normally used for heating up swimming pools. The collectors are usually extruded from ultra-violet resistant synthetic rubber or plastic materials. They generally come in mat forms or in continuous-length rolls. The mat consists of fairly large diameter parallel flow channels which may or may not be separated by narrow strips of webbing that act as the heat-absorbing plate. The mat contains carbon black which increases the absorptive capacity of the plate. Large diameter manifolds at both ends of the mat enable high-flow rates to be circulated at low pressure drops. These collectors are normally designed for use without top glazing or bottom insulation because of the low operating temperatures which are generally below 50°C. In Malaysia, the temperature is not so very high where the daily average temperature is approximately 24-32°C, hence, the category of the heating system is in the low temperature.

The solar energy which is transmitted through the glass heats up any object on which the solar rays may strike. The amount of energy absorbed and the degree of heating up depends upon the coefficient of absorption. The objects in turn reradiate the energy as a heat loss at a low temperature (around 300 K) which is in the form of a long wave length radiation. Since glass is opaque to long length wave radiation, heat is thus trapped within the glass enclosure. However, a small proportion of the radiated energy from the low temperature source is lost through convection and conduction. This phenomenon is known as the greenhouse effect in which it is observed that the inside of a greenhouse is always much warmer than the outside.

2.4 Review on conversion efficiency of solar PV

The conversion efficiency of a solar PV is proportional to the sunlight that the PV cell converts into the electrical energy. This is a very important part of a solar panel because efficiency improvement is vital to making the PV energy competitive with more traditional source of energy (e.g., fossil fuels). Naturally, if one efficient solar panel can provide as much energy as two less-efficient panels, then the cost of that energy will be reduced. For comparison, the earliest PV devices had only converted about 1%-2% of the sunlight energy into electrical energy. Now, the PV devices convert 7 to 17% of the radiant light energy into electrical energy (About, 2012; Frankl, 2010).

Jenny (2003) had discribed the solar photovoltaic energy conversion. It is a one-step conversion process which generates the electrical energy from the light energy. The sun is the source of energy and light is made up of packets of energy which are called photons whose energy depends only on the frequency or colour. When the photons are sufficiently concentrated to excite the electrons, they are then bound into solid materials up to higher energy levels where they are free to move. An extreme example of this photoelectric effect is the celebrated experiment which was explained by Einstein in 1905.

The photovoltaic effect used in the solar cells allows a direct conversion of the light energy from the sun's rays into electricity, hence, it is the method used in the generation and transportation inside a semiconductor material of positive and negative poles of electric charges through the action of light. This material features two regions: one is exhibiting an excess of electrons while another is an electron deficit respectively referred to as n-type doped and p-type doped. When the former is brought into contact with the latter, excess electrons from the n material diffuse into the p material. The initially n-doped region becomes positively charged and the p-doped region becomes negatively charged. For that particular reason, an electric field is thus set up between them which tends to force the electrons back into the n region and holes back into the p region (Report, 2001).

This p-n region is characteristically called the p-n junction. By placing metallic contacts in the n and p regions, these regions act as a diode. When the junction is illuminated with photons having energy equal to or higher than the width of the forbidden band, these photons will then yield their energy to the atoms. Each photon causes an electron to move from the valence band to the conduction band. The p junction holes are able to move around the material, thus, giving rise to an electron-hole pair. If a load be positioned at the cell's terminals, the electrons from the n region will migrate back to the holes in the p region through the outside connection which gives rise to a potential difference as shown in Figure 2.3.

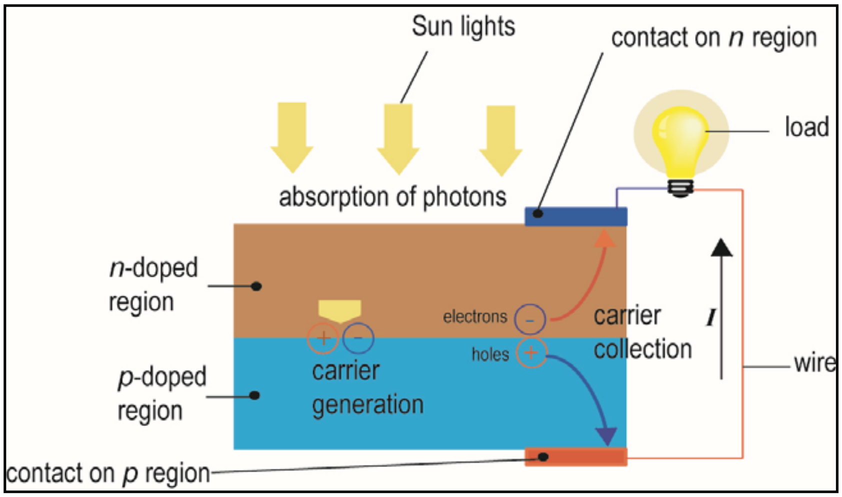


Figure 2.3 Solar PV cell with connecting load (Saricifitci, 2012).

The solar cell is a basic building block of the solar phovoltaics. The solar phovoltaic cell has been considered as a two-terminal device, just like a diode in the dark, which generates a photovoltage when charged by the sun's ray. This solar phovoltaic cell is, normally, a thin slice of semiconductor material of around 100 cm^2 in area the surface of which is treated to reflect the radiant energy as much as possible and appears as dark blue or black. A pattern of metal contacts is imprinted on the surface to make an electrical contact as illustrated in Figure 2.4. When charged by the sun's radiant energy, the basic unit generates a DC photovoltage of 0.5 to 1 volt and in short circuit of a photocurrent of some terms of milliamps per cm^2 (GCEP, 2006; Markvart, 2002).

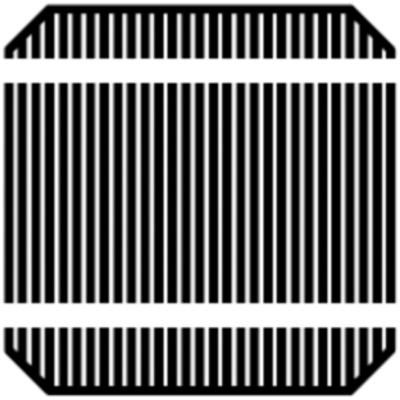


Figure 2.4 Photovoltaic cell surface contact patterns (Power, 2012).

The main objective of the PV solar cell research and development is to reduce the cost of photovoltaic cell and modules to a level that will be competitive with the conventional methods of generating power. Basically, there are two methods of increasing the efficiency of a solar cell: (1) an appropriate choice of the semiconductor materials will enable the energy gaps to match the solar spectrum and facilitate the perfection of their optical, electrical and structural properties. (2) A properly constructed innovative engineering device will mobilize a more effective charge collection as well as a better utilization of the solar spectrum through the single and multijunction approaches (Piebalgs & Potočnik, 2009; Shevaleevskiy, 2008).

At the moment, there is no exact definition of what constitutes a high efficiency device. It is very much a function of a given technology on how it impacts on the overall cost structure. However, in the present scenario, it is possible to arbitrarily classify a select group of materials into different efficiency regimes: (1) ultrahigh-efficiency (>30%) devices are achieved by using a multifunction tandem cell, like GaAs and $GaInP_2$; (2) high-efficiency (>20%) cells are generally fabricated by using high quality, single–crystal silicon materials; (3) high efficiency cells (12%-20%) are typical of a number of polycrystalline and amorphous thin-film semiconductor materials, such as, polycrystalline silicon, amorphous and microcrystalline silicon, copper gallium indium selenide (CiGS), cadmium telluride (CdTe) and moderate efficiency cells (<12%) (Deb, 2000).

The first solar power harnessing system in Malaysia was built in 2003 in a village Kampung Denai in Rompin in the eastern coast of Peninsular Malaysia. In a recent development, the Tenaga Nasional Bhd (TNB), which is Malaysia's primary electrical power provider, launched the development of Malaysia's first solar power plant in Putrajaya. At an approximate cost of RM 60 million (US$ 40 million) per megawatt, the project signifies a major step in harnessing the use of a renewable energy in the country. The project would be expected to enable the operator to understand the system well before embarking on the development of solar power plants on a bigger scale (Shaharin et al., 2011).

2.5 Review on economic viability of SWH

Malaysia is the world's largest exporter of natural rubber, palm oil, tropical hardwoods, and so on. The country is also one of the few fortunate countries in the world where adequate supplies of oil and natural gas are available. The 2010 GNP per capita is about US$8,372.84 and in Malaysia, conventional fuel supplies are readily and cheaply available. Solar energy is therefore considered only as a supplementary fuel source for water heating.

Water heaters are still considered luxurious household items in Malaysia. However, with the rising standard of living, now the trend is towards water heaters after air conditioners have been installed, especially, in the urban communities.

It was thought previously that the middle income group would be the most likely potential user of solar water heaters. However, it was the higher income group that has provided the impetus for the solar water heater market. The demand for solar water heaters would depend upon public acceptability based on economics, aesthetics, reliability and the availability and cost of conventional fuel.

It is difficult to estimate accurately the amount of hot water required daily by an average household. Different people use different amount and at various temperature levels. For a typical house with 3 to 4 occupants, a system with a 136 1 hot water storage capacity can be installed. For larger houses with more than 4 occupants, a 2721m^3 capacity system is recommended (Ong, 1994). Supplementary heating is unnecessary because there are hot sunny days throughout the year. Large storage tanks with electric booster elements are expensive both to install and to operate. Thermosyphon-flow systems are preferred for obvious economic reasons since they do not require circulation pumps and control units.

Based on an average daily consumption of about 30 1 of hot water at 60 °C per person, a 2721m^3 capacity system would be sufficient to cater for about 9 persons. However only about 80% of the water heated and stored in the storage tank can be utilized due to temperature dilution by the incoming cold water feed. Thus the amount of water that can be utilized is only about 2181m^3. This would be sufficient to cater for about 6 to 7 persons. Thus the annual energy required to heat 2181 of water from 27°C to 60°C works out to be equal to 3056 kW h.

The retail installed price of a 2721m^3 capacity solar hot-water heater system is presently in the region of RM 4000.00. On one hand, a comparable 901 electric storage-type heater costs around RM 750.00 installed, while an instantaneous-type gas water heater retails for about RM 500.00. On the other hand, the 2721m^3 solar heater serves all the hot water outlets in a house. Therefore, in order to provide a similar central service, two units of the electric heater and three units of the gas heater would be required. The difference in initial costs between the solar and the conventional electric or gas system is hence around RM 2500.00. The equivalent annual operating energy cost for electric heating is about RM 755.00 and about RM 328.00 for gas heating. Thus, in a 4-year period, the capital cost on the domestic solar hot water system will have paid for itself as against the domestic conventional hot water system.

Furthermore, although gas heaters are the most economical, however they are more hazardous to operate with a devastating effect should any leakage occur in the gas piping system. In actual practice, 5 to 10 years are more realistic if the actual usage of hot water is considered. In a solar hot water heater system, the stored energy has no economic value if the hot water collected is not utilized.

Flat plate solar heat collector panels are recommended, as they are more economical to operate than the concentrating-cum-tracking types. Because of the large proportion of diffusion to direct radiation, concentrating units are generally felt to be less efficient than flat plate units. A typical 2721m^3 capacity domestic solar water heater unit would require at least 4.0 m^2 of collector area. Placed side-by-side, the collector panels would cover only a very small area of the building roof. In order to keep the plumbing short, the storage tank would have to be sited fairly close to the panels, leading to the close-coupled system. Aesthetically speaking, the storage tank should be hidden from view (Chen et al., 2009).

Once the collector panels are set up on top of a roof, blending with the roof design or kept out of sight, it should operate reliably with a minimum of maintenance for a number of years. But, because of dirt and dust deposition in a dusty environment, the glass covers would have to be periodically cleaned to ensure high collection efficiency. This periodic cleaning operation could be done by a group of service cleaners for a modest fee. If designed for a longer life (say, 20 years), it would be more attractive for potential users to invest in the system.

For commercial and industrial utilization, forced-circulation solar water heating would have to be adopted in most cases. This is because of the large volume of water storage required. It would be better to locate the storage tanks on the roof if space is available as this would lead to savings in piping cost and better operating efficiency. If a circulation pump is employed, a temperature differential controller would have to be incorporated into the system to activate the pump when sufficient solar radiation is incident upon the collector and to stop it when radiation is low. A typical unit for a large hotel use would be a 15 m^3 storage capacity system with about 400 m^2 of collector area (Ammari & Nimir, 2003). One of the economical considerations in installing solar water heater components is to allocate an available site area for an optimum sun radiation that it can get.

Even though Malaysia has fair climatic conditions for the maturation of solar energy and solar water heaters households use, but because of the lack of public understanding and awareness of the working and potential benefits of solar water heaters, the high initial cost of solar water heater systems as against the ease of installation and relatively reasonable cost to purchase the electric water heaters, many Malaysian families are still using electric water heaters to heat their hot water needs (Ali et al., 2009).

CHAPTER 3: METHODOLOGY

3.1 Introduction

The section comprises mainly four parts: i) design of solar water heater, ii) investigation of thermal performance, iii) efficiency of solar PV and iv) its economic viability. The input data, design configuration, gathered data and MATLAB calculations are presented in this section. In this chapter, the methods based on the abovementioned four parts have been presented separately.

3.2 Modification of a flat plate SHW collector

Design of a SWH collector requires critical technical and economic analyses to optimize the performance. The design method of flat plate collectors can be classified under four groups (Zondag et al., 2003).

A. Sheet and tube collectors.
B. Channel collectors.
C. Free flow collectors.
D. Two-absorber collectors.

This study contains the first method because the design configures well with the copper tube and aluminium sheet. The other three methods also use the flat plate collector but with different configuration. The sheet and tube collector, which is the simplest way to construct a flat plate collector, is to rely entirely on well-known available technology by taking higher thermal efficiency. The thermal performance of such a design can be improved by changing the tube shapes and size or number of pipes. The basic layout of the sheet and tube collector is as shown in Figure 3.1.

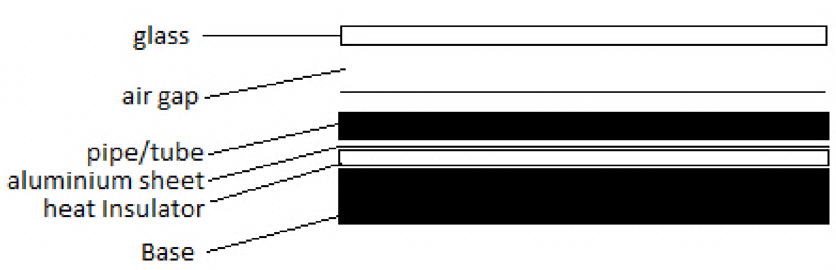


Figure 3.1 Basic design of a flat plate collector (Zondag et al., 2003).

Figure 3.1 shows the primary construction of a flat plate collector. It has a glass plate, air gaps, as well as tubes or pipes, an aluminium sheet and a heat insulator.

The angle and thermal efficiency of the SWH enables it to be a good collector design. Hussain (1996), designed a low cost water heater but efficiency was very low. Dubey (2008), modeling thermal and photovoltaic of a combined system of a solar water heater and the efficiency was 64%. Recently Chong (2012), designed V-trough absorber of a solar water heater and it was the highest efficiency 70%.

This work presents a configuration modified design for a flat plate collector absorber. Previous designs have also been investigated and compared in this work. In a literature review chapter, the previous design has already been fully described on the performance part of this dissertation. The most common types of solar collectors are the flat plate, vacuum tube and concentrator collectors. The flat plate collector is one of the easiest, simplest and low-cost SWH collectors. The design's distinguishing feature is its use in various types of collector copper pipes and its energy capacity is determined through a theoretical analysis. Some of the equations, analyses and technical terms from Hottel-Whillier model are duplicated in this work for convenience of reference (Hottel & Whillier, 1958).

The shapes and arrangement of pipes are very important in a collector, because the pipe should be heated by the sun. Thus, if the design is more effective, then the output temperature will increase. There are two ways to identify the absorber design performance: One is through simulation using software while the other is through experimental design and their thermal efficiency. This work presents a design of a flat plate SWH collector which is a "parallel 2-side serpentine flow" absorber collector. A new pipe arrangement is used throughout the plate collector.

The modified design of a solar water heater collector is presented in Figure 3.2. There is a 3.81cm air gap between each pipe and a 7.62 cm gap between the collector and the body. The system performance has been evaluated based on two different configurations. Figure 3.3 shows part A and B of the collector absorber and it can be readily observed that the two parts are not attached together. The practicality of the design is that faults appearing on one side can be easily fixed. The inside air gap is important as when the sunlight hits the glass plate, the inside air is heated like the inside of a greenhouse. Nevertheless, the water flowing inside the copper pipe takes time to reach the outlet and during this time, the water flowing inside the absorber tubes is heated as a result of which hot water from the collector outlet is obtained.

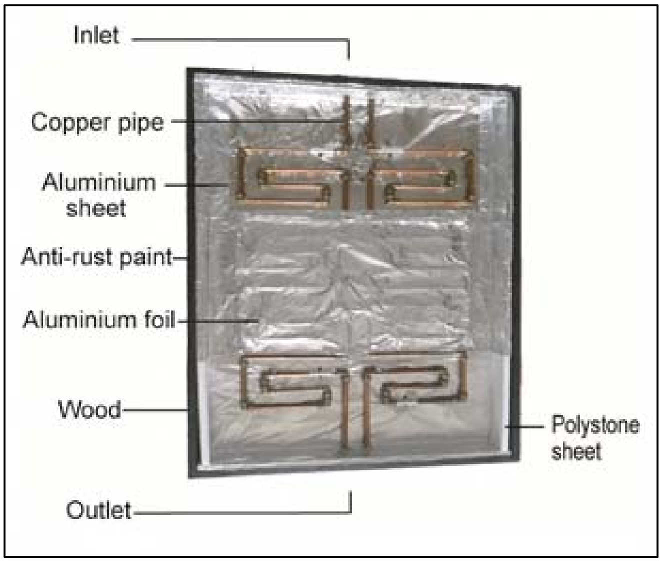


Figure 3.2 The solar water heater collector.

3.2.1 Experiment set-up

The experimental setup followed a stander of an active or open loop system of a flat plate SWH collector. Basically this type of solar water heater system must be connected a pump. This solar heater has two different tanks; one is the cold or normal water supply and the other is hot water storing. The tank includes some controller valves, which can help the over flow water. One flow meter should be connected for measuring the water flows between cold water tank and pump. This experiment includes a solar photovoltaic panel that can supply power to the pump controller circuit. The controller circuit has two sensors. The sensor 1 is connected to the solar water heater collector and the sensor 2 is connected to the hot water tank. The schematic diagram of the experimental setup of a solar water heater is as given Figure 3.3.

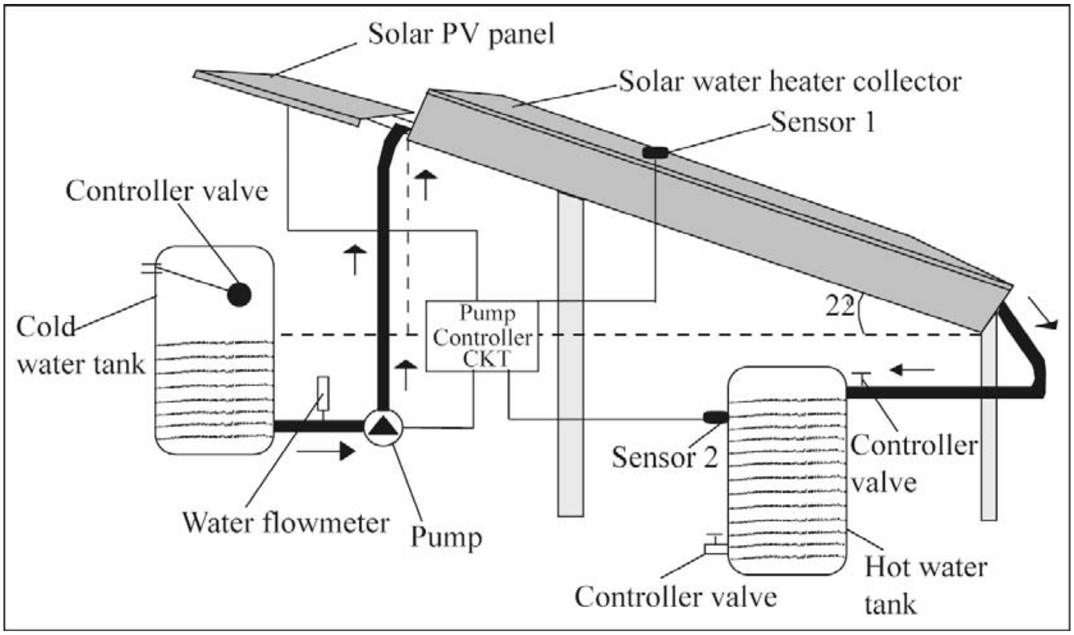


Figure 3.3 Schematic diagram of the experimental setup of a solar water heater.

3.2.1(a) Material description of the collector

Wood box: The collector base is made of wood. This is a solid wood colored with water proof black coating. The base is very important because it can give a long and lasting durability to the collector. The wooden box has the dimension of 127 cm high, 81.28 cm wide and 2.54 cm thick. The box border height is 12.70 cm. This wooden box is capable of hold the copper pipe wattage.

Polystone sheet: In this study, the polystone sheet is used for insulation. This is a common material for use in the heat insulator and is easy to find in the market. The polystone sheet is fixed into the wooden box setup which is 125 cm high, 79.28 cm wide and 1.5 cm thick.

Aluminium plate: The aluminium plate is also available in the market. This thin aluminium plate is covered with the polystone sheet and the aluminium plate cover has a dimension of 125 cm high, 79.28 cm wide and 0.5 mm thick.

Copper pipe: This forms a very important part of the collector. The absorber material is designed to have a hollow-tube copper pipe containing two channels which are parallel to each other in a serpentine form. In this experiment, copper pipes have been used because this is a low cost solar water heater collector as it is easy to cut and to be fixed to each other. In Figure 3.4, it shows that the pipes are connected with 68 pieces of copper elbows which incidentally are a modified design of the collector absorber. Hence, each parameter of the absorber collector pipe is 22.86 mm in diameter, 1mm thick, 170.18 cm long and 24.13 cm wide. The absorber pipe air gap is around 3.81cm. The copper pipe distance from both side lengths of the polystone sheet is around 7.62 cm, while the width of the inlet side to pipe is approximately 12.70 cm and to the outlet side is 10.16 cm. The collector has one inlet and one outlet channel joined together with a solid pipe.

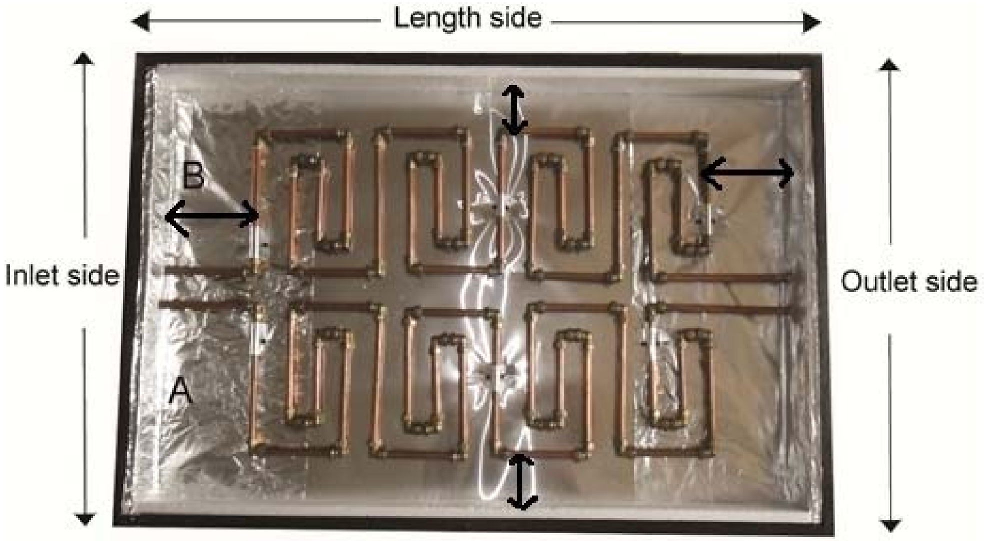


Figure 3.4 Copper pipes inside the wood box.

Aluminium foil: Aluminium foil is used to cover the copper pipes and polystone sheet shoes as shown in Figure 3.5 for this modified design which uses one roll of 7.62cm×454.7cm aluminium foil. This is almost the final stage of an absorber design of the main plate of the collector after which it is painted in black colour on the aluminium foil and the whole box.

Figure 3.5 Copper pipes with aluminium foil of the collector.

Glass plate: This is the final design of a solar water heater absorber painted in black as shown in Figure 3.6 after which a glass plate is used to cover the box. The dimension of the glass plate is 121.92 cm long, 76.96 cm wide and 5 mm thick.

Figure 3.6 Complete design of a collector absorber.

3.2.1(b) Installation of a solar water heater collector

This experimental setup is developed on the roof of the Engineering Tower on the 4th floor of Block L, University of Malaya, Malaysia which is geographically located at latitude 3.11° North and longitude 101.65° East (RETScreen, 2005; SunEarthTools, 2012). A survey of the orientations of domestic solar water heaters in Malaysia should an exhibit a wide range of variations. These collectors are installed on the roof top, the slope being the same as the slope of the roof which is commonly found to be between 30° and 40° (Saiful, 2001), but in this case, at the engineering tower, the collector slope is determined by Cooper's equation (Struckmann, 2008), because the experiment began on 1st June 2012. It is observed that a different month has a different sun angle (Saiful, 2001).

The slope of the collector, *(β)* angle of inclination δ and day of year (n_1) is calculated from the equation:

$$\delta = 23.45\sin[0.9863(284 + n_1)] \tag{3.1}$$

$$\beta = (Q_1 - \delta) \tag{3.2}$$

The slope and inclination angles are calculated from June to July (2012) on the collector as shown in Appendix A. Calculation of the inclination and collector slopes is obtained by using the MATLAB software (R2011b).

Table A1 shows the relevant collector slope angles. When β is positive, it means that the orientation of the surface is towards the equator and when negative, it will be towards the (North) pole (Saiful, 2001). In the complete modified design of the SWH collector and the solar PV, the average slope is setup with a 22° angle on the roof surface. This is the average value of 2 months with the slope of the collector and the solar PV being the same inclination angle. In this system, the SHW collector is designed to concentrate the sunlight onto the absorber in order to effectively convert the solar energy into the thermal energy.

3.2.1(c) Working principle of the whole system of a SWH

The working principle of the solar water heater is based on the rules of the open loop system. From the flowchart (Figure 3.7) of the system, we can see that the water is heated from the sun. This hot water will be stored into the hot water tank. In this experiment will be used a small photovoltaic panel and pump controller circuit. It is very easy to control the system automatically because the logic circuit will control the pump. The temperature will be sensed by the sensor S1 and S2. The sensor logic is that when S1 higher than S2 (S1>S2) the pump will run (on) and S1 less than S2 or equal the pump will stop (off). If the logics are working then from the cold water tank supply the water to the absorber. Then after storing the hot water from the solar collector and the process will be end. Here is the flowchart for working whole system of a solar water heater.

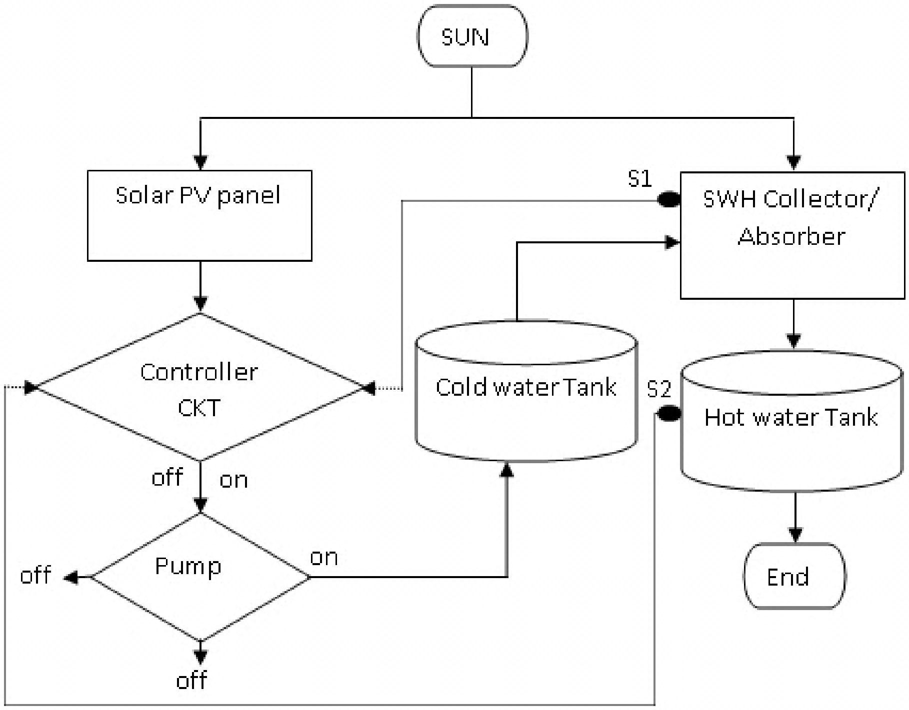


Figure 3.7 Flowchart of the whole system of the solar water heater.

3.2.1(d) Experimental procedure

The connection top view specifications of the overall experimental setup are as given in Figure 3.10. Two water tanks have four holes while the cold water tank have only one hole each and is connected to the main water supply. One tank uses an automatic valve which controls the supply of cold water from outside and is connected to the water pump which pumps the water to the other side which has been connected to the collector inlet. The pump control connection is as described in Figure 3.12. The collector outlet is connected to the hot water storage tank which uses a manual gate valve to control the hot water supply. After all the hardware connections have been completed, the thermocouples (K-type) are then used with the heat sensor, data logger (version 5), Pyranometer and a computer to measure the temperature and solar radiation. As shown in Figures 3.8 and 3.9, a data logger and a Li-Cor pyranometer (LI200) connected to the Universal Transconductance Amplifier with a HOBO data logger. This arrangements for recoding absorber temperature, water temperature, solar radiation, weather temperature, light intensity and humidity as well.

Figure 3.8 Data logger (DT80).

Figure 3.9 Li-Cor pyranometer connected to amplifier and data logger.

There are four connections involved in the making of a good solar powered hot water tank, i.e., two connections for the collector to measure the absorber temperature and two connections for the inlet and outlet water supply temperature. In this experiment we needed solar radiation data from the inlet and the outlet for specific purposes of calculating the thermal performance of the SWH.

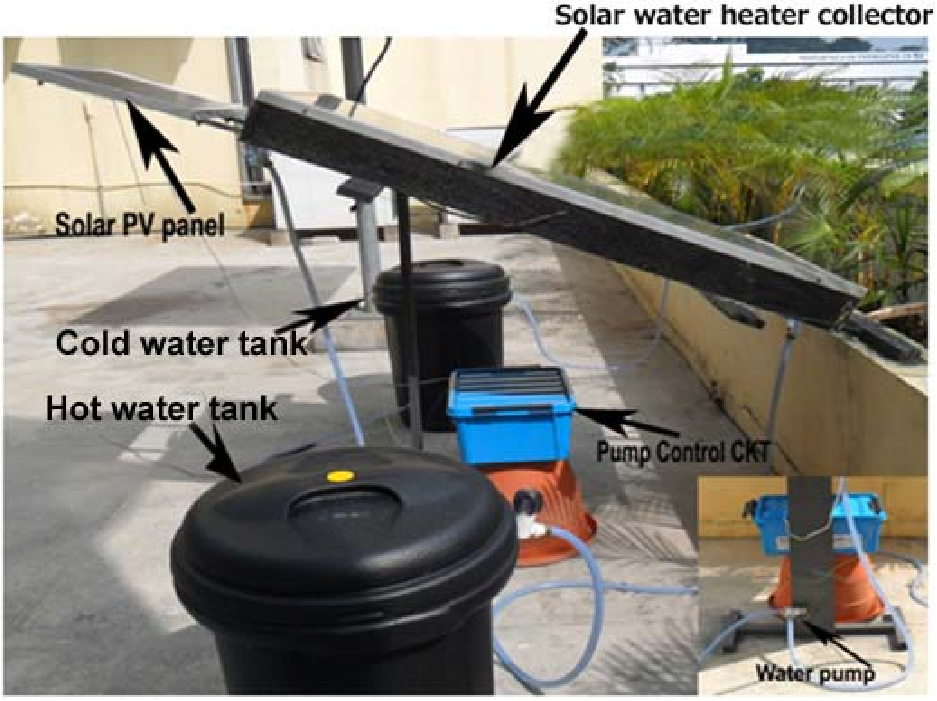


Figure 3.10 Experimental setup of a solar water heater collector.

3.3 Thermal performance of a solar water heater

A solar hot water heater system consists of a solar collector or collectors, an insulated hot water storage tank and an inter-connecting piping system. The performance of the entire system depends upon the thermal performance of the solar collector/s and the system design. The solar collector is the most important piece of equipment in the overall integrated system because the solar collector collects and transforms the incident solar radiation energy into useful thermal heat energy through the three modes of heat transfer i.e. via radiation, conduction, and convection. For high temperature collection, the majority of the systems installed are still largely dependent on the flat plate solar collectors which are used for water and space heating and their performances depend mainly on:

- The absorption-emission properties of the absorption surface of the collector plate.
- The design and materials of construction of the collector plate.
- The type of top cover used.
- The type of insulation provided.
- The prevailing ambient conditions.

A blackened flat plate collector absorbs as much solar radiation as it loses if the plate absorptive and emissive values are equal. The use of special selective surfaces with a high absorptive and a low emissive properties are commonly used so as to reduce the effective radiation heat loss from the plate to the top cover.

A good thermal contact between the collector tubes and the collector sheet will ensure an efficient heat transfer from the collector sheet to the fluid flowing in the tubes, e.g., the integral fluid channels. The use of a high thermal conductivity material and a plate with a large number of tubes will provide a greater heat transfer area by virtue of the fact that all these characteristics will result in a solar collector with a high thermal efficiency.

3.3.1 Hottel-Whillier equation for thermal performance of flat plate collector

The performance of a collector is expressed by its thermal efficiency (η_{th}) that is usually the ratio of the system's useful thermal gain to the solar radiation incident on the collector gap within a period (Jaunzems & Rochas, 2006; Jercan, 2006).

The thermal performance of the collector is affected by many system design parameters and operating conditions. In the following formulae, the system was subjected to various conditions of solar radiation (E), ambient temperatures (T_{a1}) and mass flow rates ($\dot{m}$). The efficiency parameters were based on the Hottel-Whillier equation (Hottel & Whillier, 1958; Jercan, 2006).

$$Q_a = (\alpha \times \tau) \times E = A_0 \times E \tag{3.3}$$

$$q_{opt} = E - Q_a \tag{3.4}$$

$$q_t = k \times (T_m - T_{a1}) \tag{3.5}$$

The usable heat derived from catcher (Q_u) is the heat from the absorption surface and the thermal losses (q_t) from the collector (the relationship is called Hottel-Whillier-Bliss) (Jercan, 2006):

$$Q_u = \alpha \times \tau \times E - k \times (T_m - T_{a1}) \tag{3.6}$$

However, in the above-mentioned equation, the effect of the following parameters are neglected: i) the heat lost though the thermal factor, ii) the collector's specific heat, and iii) the adjustment angle through which the drop in the solar radiation can be manipulated. Considering the mentioned equations, the thermal efficiency is defined as follows (Jercan, 2006):

$$\eta = \frac{Q_u}{E} = \frac{\alpha \times \tau \times E - k \times (T_m - T_{a1})}{E} = \alpha \times \tau \times E - k \times \frac{(T_m - T_{a1})}{E} \tag{3.7}$$

On the other hand, the heat absorbed by Q_t is equal to the $\dot{m}$ multiplied by c and the temperature gradient between the thermal factor temperature at the collector exit and the point of entry (T_e-T_i). Since the heat absorbed by the thermal factor equals the solar collector's usable heat the equation can be rewritten as follows:

$$\dot{m} = \frac{Q_u}{c \times \Delta T} \tag{3.8}$$

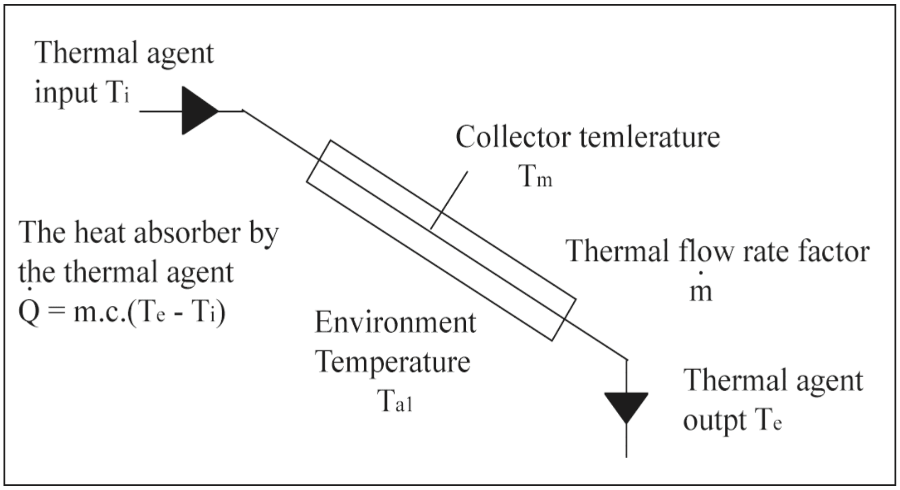


Figure 3.11 Schematic diagram of the various absorber parts.

Small temperature differences between the entry and the exit temperatures of the collector implies a high flow-rate factor in the collector. A low flow-rate factor causes a high difference in temperature between the collector entry and exit points as shown in Figure 3.11.

If the heat absorbed off the absorption surface is not absorbed by the thermal factor, the circulating pump then stops and the temperature of the absorption surface rises to the value of T_{max}, and the solar collector heat losses equal the solar radiation heat absorption. For a specific solar collector, the temperature at null weight flow is determined by:

$$T_{\max} = \frac{E_{\max} \times A_0}{k} \tag{3.9}$$

These variable temperatures not only impose conditions upon the materials used to build the solar catcher, but they also affect the thermal factor selection and overpressure protection for the thermal factor circuit (Jercan, 2006).

3.3.2 Collector plate overall heat loss coefficient

Heat is lost not only from both the top and bottom surfaces of the collector plate but also from the sides. The overall heat loss coefficient consists of a top, a bottom, and a side loss coefficient. Generally, heat losses from the side of the collector casing are small as compared to the top and bottom losses and can be neglected (Ong, 1994).

3.3.2(a) Top heat loss coefficient of the collector

Klein (1973) proposed the following empirical equation for the heat loss coefficient of the collector.

$$U_t = \left[\frac{N_1}{(344/T_p)\left[(T_p - T_a)/(N_1 + f)\right]^{0.31}} + \frac{1}{h_w} \right]^{-1} + \frac{\sigma(T_p + T_a)(T_p^2 + T_a^2)}{[\varepsilon_p + 0.0425N_1(1-\varepsilon_p)]^{-1} + \left[(2N_1 + f - 1)/\varepsilon_g\right] - N_1} \tag{3.10}$$

where, U_t is collector plate bop heat loss coefficient, N_1 is number of glass covers and f is factor in collector top heat loss coefficient.

In this equation, the factor f is determined from

$$f = (1 - 0.04h_w + 5\times10^{-4} h_w{}^2)(1 + 0.058N) \tag{3.11}$$

and the wind heat transfer coefficient from

$$h_w = 5.7 + 3.8v \tag{3.12}$$

3.3.2(b) Bottom heat loss coefficient of the collector

Most of the resistive component against the heat loss from the bottom of the collector plate is mainly from the insulation material itself. Neglecting the convection and radiation resistances from the environment as well as the resistance due to the casing thickness, the bottom heat loss coefficient is thus (Ong, 1994):

$$U_b = \frac{k_{bi}}{x_{bf}} \tag{3.13}$$

where, U_b is collector plate bottom heat loss coefficient, k_{bi} is thermal conductivity of collector back insulation and x_{bf} is collector back insulation thickness.

3.3.2(c) Overall heat loss coefficient

Neglecting side losses, the overall heat loss coefficient for the collector plate is found by adding the top and bottom losses together (Ong, 1994):

$$U_c = U_t + U_b \tag{3.14}$$

where, U_c is collector plate overall heat loss coefficient.

3.4 Conversion efficiency of Solar PV (Photovoltaic)

In this study, the solar PV is used to operate the pump to activate the overall system. A 12-volt battery charged from the solar photovoltaic cells and a small circuit is used to control the rate of flow of the water to the collector. There are four types of solar PV cell available, namely, i) Monocrystalline solar cell, ii) Amorphous solar cell, iii) Multicrystalline solar cell, and iv) Hybrid solar cell. The Multicrystalline solar PV cell is used in this experiment.

3.4.1 Pump controller circuit connected with solar PV panel

A PV solar panel works by means of connecting a pump controller circuit to a PV solar panel. That circuit can easily operate a 12-volt DC pump (REUK, 2012). A solar PV panel is initially installed and connected to the solar charger controller. The solar panel height is 13.5cm and the width is 21.5cm. This panel voltage rating is 17.3 volts and the current is 1.3 amperes. The solar panel is then setup on top of the solar water heater collector with the same angle of 22° as the roof surface and this small size solar PV panel is then connected to a 12-volt DC battery which is specifically used for storing the electric charge from the solar PV with the voltage and current obtained being measured by the digital multimeter (DT9205M). The configured system is then connected to the controller circuit as illustrated in Figure 3.12. This circuit is operating as a digital logic circuit where one IC (LM393) 8 pin and some electronic equipment, like Capacitor (100µF), Resistor, Diode, LED and one MOSFET (STP50N) are soldered to the circuit board. The controller circuit has three connections where one is used to operate the pump, the second is for sensor 1 and the third is for sensor 2. Sensor 1 and sensor 2 use two transistors (LM335Z) which are specifically used for temperature sensing. Sensor 1 is used for the collector absorber and sensor 2 is used for the outlet storage tank both for sensing their individual temperatures.

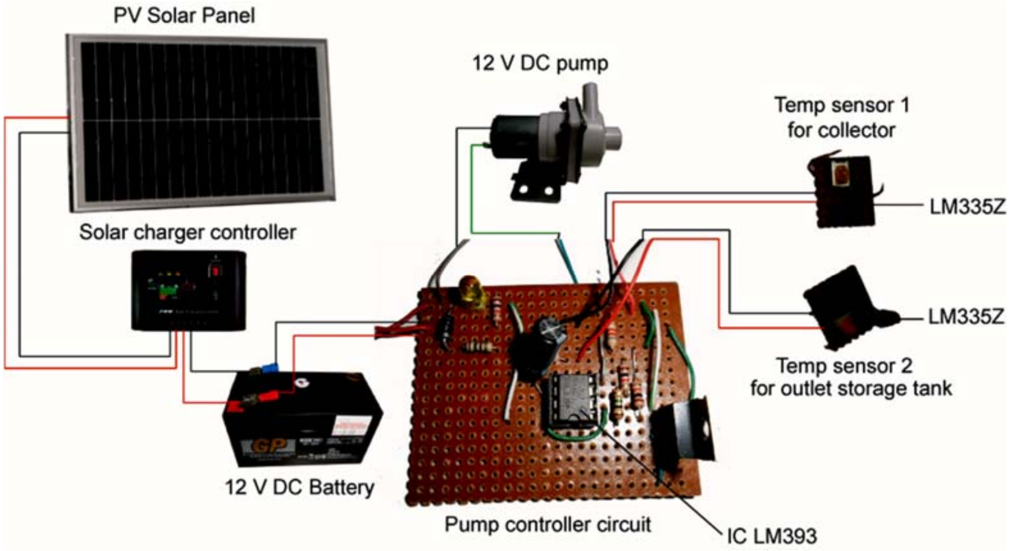


Figure 3.12 Solar PV panel with pump controller circuit.

3.4.2 Equation for conversion efficiency of solar PV

Photovoltaic conversion of solar energy has become a viable technology as a renewable energy source and the efficiency of a PV panel is not a new topic of solar technology as there are a number of ideas and formulas to calculate the maximum efficiency of a photovoltaic panel (Power, 2012).

The efficiency in the photovoltaic cells of solar panels is measured through the ability of a panel to convert sunlight into usable energy for human consumption. The important aspect is to know the efficiency of a panel in order to choose the correct panels for a photovoltaic system similar to the method used by the manufacturers to determine the maximum efficiency of a solar PV panel. The panel efficiency determines the power output of a panel per unit of area. The maximum efficiency of a solar PV cell is given by the following equation (About, 2012):

$$\eta_{\max} = \frac{P_{\max}}{E \times A_C} \tag{3.15}$$

From the equation, the maximum power calculates the output of a PV panel current and voltage. The incident radiation flux can better be described as the amount of sunlight that falls on the earth’s surface in W/m^2. For area calculation, if the data is in feet square (ft^2) it can then be converted into meter square (m^2) by using this formula.

$$A_{m^2} = \frac{A_{ft^2}}{10.76} \tag{3.16}$$

Sometimes the efficiency drop of a solar panel throughout its life cycle is not desirable since the capital cost of the system is quite high. A PV cell can normally last for about 25 years and it takes approximately up to six years for the solar PV module to achieve its optimum solar energy conversion processes. One of the contributing factors in the drop of efficiency of the solar PV panels in Malaysia, as well as in other countries, is the amount of accumulated dust on the panel. The nature of the problem may vary with the geographical location.

3.5 Economic analysis

The economic analysis of a solar water heater is based on a comparison between the solar water heater and the electric water heater and so on. The comparison is made via one standard method, i.e., the Annual-worth method. A high initial cost and a low operating cost are the usual economic definers where the economic problem is in comparing an initial known investment with an estimated future operating cost.

3.5.1 Annual-worth method (Equivalent uniform annual cost)

Annual worth (AW) is the difference between an annual benefit (revenue) and annual cost (Leland & Anthony, 1998). It is a gain if it is a net benefit, and a loss if it is a net loss, i.e.,

$$AW = B_A - C_A \tag{3.17}$$

Where B_A is the annual benefit and C_A is the annual cost. As a decision-making tool, for acceptance of an option, this expression becomes (Ammar et al., 2009):

$$B_A - C_A \geq 0 \tag{3.18}$$

where

$C_1 = C_2 = C_3 = C_N = C_A$

are options for selection if B_A-C_A equals to or exceeds zero.

3.5.1(a) Cost comparison formula for solar and electric water heater

From the literature review, equation (3.19) and equation (3.20) (Ammar et al., 2009) are used for calculating the cost water flow for a solar and an electric water heater. This formula is a part of the social and economic viability, because the main observation area of this studies is to compare the economic advantage between the solar and the electric water heater. Hence, from this formula, it will be able to compare which heater can economically benefit the society.

3.5.1(b) Annual-worth method

Cash flow formula for solar water heater:

$$\mathrm{A.W)_{Solar} = -(I_c + I_{lc})\,(A/P,i,N) - A_{rc} - (C_{afic})\,(A/F,i,N)} \tag{3.19}$$

Cash flow formula for electric water heater:

$$A.W)_{electric} = -(I_c + I_{lc})(A/P, i, N) - (R_c) - (H_{erc})(A/F, i, 0.5N) \tag{3.20}$$

To use the formula of Equation (3.21) & (3.22), any lump-sum payments or benefits must be converted into equivalent uniform periodic ones by using of the capital recovery factors *(A/P, i, N)* and *(A/F, i, N)*.

$$A/P = \frac{i(1+i)^N}{(1+i)^N - 1} \tag{3.21}$$

$$A/F = \frac{i}{(1+i)^N - 1} \tag{3.22}$$

3.5.2 Survey market of SWH & EWH solar thermal collector components

Solar system is generally defined by a high initial cost and low operational costs as compared with the relatively low initial cost and high operating costs of Electric Water Heater systems. Heating water through solar energy also means long-term benefits, such as, free from future fuel shortages and the maintenance of environmental benefits. The cost benefit analysis is performed based on the Annual worth method which deals with two parts, namely, one is the solar water heater cost whereas the other is the electric water heater cost and their comparisons. The cost analysis is presented in a cost flow diagram.

The following Table 3.1 and Table 3.2 are obtained from a survey performed in the Malaysian market. This experiment on the flat plate collector has derived a total cost as listed in Table 3.1. The total cost of constructing a 2-side parallel serpentine flow solar water heater system is RM 1726.6 (U$549.87) (CoinMill, 2012) the full details of which are as shown in the table. Note: as at 24th July 2012 the exchange rate was 1 RM to 0.314 US dollar.

Table 3.1 The breakdown cost of all components for constructing a 2-side parallel serpentine flow solar water heater system.

Component	Description	Retail price (RM)
Solar collector	Wood	116
	Polystone sheet	15
	Aluminium plate	15
	Copper pipe	140
	Copper elbow and T jointer	427
	Aluminium foil	19.90
	Glass plate	55
	Black paint	37
	Putting	22.50
	Screw	10
	Wood jointer glue	12.60
Storage Tank	Plastic storage container	96
	Water pipe get valve	18
	Plastic pipe	40
	Automatic water flow control valve	3.40
	Silicone tap	2
	Silicone glue	18.50
	PVC socket	10
Solar PV panel	Small solar PV panel	360
	PV charge controller device	150
	Electric wire	5
Pump controller circuit	DC pump 12V	20
	DC battery 12V	20
	Circuit board, Electronic equipment	3
	Op amp	1.50
	Two temperature sensors	8
	MOSFET	1.20
Installation Cost		**100**
Salvage Value		**0**
Total Retail Cost		**1726.6**

Table 3.1 above shows the salvage value is zero. The most expensive materials are copper jointer (RM 427, U$ 135.98) and solar PV panel (RM 360, U$ 114.64). Other parts like wood, copper pipe, storage tank and charge controller devices are readily affordable. The solar water heater system normally can last for about 20 to 25 years (Ammar et al., 2009). The installation wrap will be changed every 5 years, and this will

cost 100 Malaysian Ringgit (U$ 31.84). The water proof coating of the sides can be renewed every year. After a maintenance service process, the salvage value of the SWH will be zero.

The reasonable likely lifetime of the electrical water heater is taken as ten years (Ali et al., 2009). The estimated costs of using one electric water heater are as shown in Table 3.3 with the various cost elements. The Alibaba.com is one of the international websites in Malaysia for supplying electric water heater and other electrical appliances.

The running cost of an electric water heater needs to be calculated on the basis of per year cost of electricity in Malaysia. If the system runs 5 hours per day, this will be per hour electricity charge on 5.5kWh and the cost of 1 hour electricity is RM 1.199 (U$ 0.38) (Entrepreneur, 2012), thus the five-hour cost is RM 5.99 (U$ 1.90) and per month cost is RM 32.7 (U$ 10.41) which come to RM 392.4 (U$ 124.96) of electricity cost per year.

Table 3.2 Cost of all components for constructing Electric water heater (Alibaba, 2012).

Component	**Description**	**Retail price (RM)**
Price of Electric water heater	Instant/ Tankless Plastic, Capacity Unlimited Power 5500 (W) Voltage 220 (V) Alpha plus (SH-88)	450
Price of the Heating element	Copper	80
Running Cost		392.4
Installation Cost		**70**
Salvage Value		**0**

Table 3.2 above shows the Electric water heater power of 5500 watts and voltage 220V. This is the latest model (EWH) water heater which is called Alpha plus 88 with its heating pipe made of copper and is also readily available in the market.

CHAPTER 4: RESULT AND DISCUSSION

4.1 Introduction

The result and discussion section gives detailed information on the thermal performance, solar PV efficiency and economic viability of the solar water heater in Malaysia. The assessment section has been divided into a few sub-divisions, like modified design performance, record of daily solar radiation, temperatures the inflow and the outflow of water, record of the voltage and current of the solar panel which are all to be compared between the electrical and the solar water heaters. A detailed discussion has been elaborated on each section of the sub-divisions.

4.2 Modified flat plate SWH collector result

The data collection on ten hours of observations during a two-month periods of the experiment on the flat plate solar water collector are as presented below. The data on the inflow, outflow of water and the main plate temperature are obtained from the data logger while the solar radiation and weather temperatures are recorded by the Pyranometer.

4.2.1 Data collection for a flat plate SWH collector from June to July 2012

It is observed that the average temperature of Kuala Lumpur throughout the year is 32-35°C or 90-95°F with a relative humidity of 95% with two monsoon seasons being observed. One is the North East Monsoon from December to March, and another is the South West Monsoon from October to November. However, a global climatic change has played a vital part resulting in an average rainfall of about 170 millimeters a month of the year. The season is normally wet around October and November, which averages about 250-300 millimeters of rainfall as it seldom rains for days at a time. The driest periods are, as a rule, between May to July with an average rainfall of about 125 millimeters a month. These are the best sunshine months in Kuala Lumpur for collecting temperatures (Destination, 2012). The two-month average temperature recorded data are as shown in Table 4.1.

Table 4.1 June and July 2012-inlet, outlet, main plate and glass inside daily average temperature.

	June				**July**			
Number of day	**Inlet water temperature (°C)**	**Outlet water temperature (°C)**	**Main Plate temperature (°C)**	**Glass inside temperature (°C)**	**Inlet water temperature (°C)**	**Outlet water temperature (°C)**	**Main Plate temperature (°C)**	**Glass inside temperature (°C)**
1	31.03	50.66	78.02	66.32	27.77	45.93	62.36	40.97
2	30.23	49.66	80.36	67.54	27.76	45.89	62.68	40.98
3	32.36	51.12	89.25	70.14	32.56	47.44	62.93	60.99
4	30.51	46.98	70.65	63.89	31.84	47.42	63.32	50.99
5	29.89	49.98	80.56	69.32	31.80	47.23	63.68	51.00
6	31.98	51.65	70.89	56.43	27.75	46.60	63.68	61.01
7	30.77	42.98	65.49	50.63	27.70	46.94	54.96	41.04
8	28.85	42.38	58.94	46.46	27.37	46.78	55.20	51.04
9	32.73	47.11	63.25	49.19	27.36	46.83	55.60	41.06
10	32.01	50.94	87.18	66.49	30.56	46.60	55.69	41.08
11	33.40	47.03	74.66	58.03	30.55	46.64	56.45	41.12
12	33.21	50.47	80.18	71.35	30.56	46.49	57.07	41.10
13	34.71	53.02	89.33	67.03	30.50	46.44	70.97	61.11
14	30.11	44.32	69.23	52.67	26.97	46.28	58.84	51.12
15	33.01	47.24	59.93	48.07	26.94	46.27	63.21	55.11
16	31.95	44.00	55.30	38.00	26.94	46.17	66.59	51.07
17	32.94	46.15	62.96	48.18	26.91	46.06	68.94	61.03
18	32.70	46.15	65.48	50.69	26.44	45.93	55.70	41.27
19	32.00	48.15	61.60	48.57	26.43	45.89	55.14	41.39
20	31.93	46.87	55.03	44.13	32.33	45.79	54.63	41.32
21	30.78	41.49	50.82	40.94	31.90	45.59	54.20	41.51
22	32.22	56.61	66.24	52.29	31.86	45.67	53.79	1.620
23	33.26	54.56	70.00	53.76	31.84	53.65	53.67	40.00
24	33.25	54.25	75.88	58.41	31.80	53.36	68.94	54.82
25	32.49	50.93	63.10	49.59	31.79	50.86	70.97	60.74
26	30.03	55.22	52.51	41.44	31.75	50.52	71.91	61.48
27	31.33	48.02	50.99	47.00	31.72	49.79	72.47	56.56
28	30.72	44.3	64.15	49.83	31.68	49.29	73.72	54.47
29	31.94	44.23	52.97	43.95	31.67	56.08	66.59	50.37
30	30.21	47.25	56.00	42.12	31.62	56.14	74.22	51.36
31					31.62	55.90	64.54	40.37

This flat plate SHW collector has a glass plate and the 4th Column in Table 4.1 shows the temperatures inside the glass. It is found that the average value of the inlet and the outlet water temperature difference is around 16°C in June. However, the temperature difference between the outlet water and the main plate is around 18°C even though, the main plate temperature is approximately double that of the outlet water temperature. The highest water outflow temperature on June 22th was found to be around 56°C for that particular month.

The modified design of the absorber flat plate collector should achieve a temperature of 117°C on the main plate and the temperature at the outflow water is 94°C which is almost a boiling temperature. The inlet water temperature is sometimes increased from 37°C to 40°C because there is some detached air temperature inside the pipe.

Figure 4.1 shows the hourly average inflow, outflow water and the main plate temperature. From 8am to 10am is the period that the low temperature of inlet and outlet water occurs and above 10am, the outflow water temperature begins to increase. It possible to determine the quantity of the flow of water when sensor 1 is activated as it measures the flow of water at 500 milliliters per minute. The Figure 4.1 also shows that sensor 1 activates the water pump at around 10.30am to 4.30pm and this water pump will be running daily for about 4 to 5 hours before coming to a stop. The flow of water depends on sensor 1 and sensor 2 because this is the logic base circuit as and when the temperature increases where the water pump will be automatically activated once the sensor activates the circuit. The flow of water is the same as the water pump speed is running at same speed, hence, the flow of water can be about 30,000 millilitres (30 litres) per hour. If the total pump running period is around 6 hours, the flow of water is then approximately 180 litres (47gallons). The water pump is capable of supplying 7.9 gallons of water per running hour.

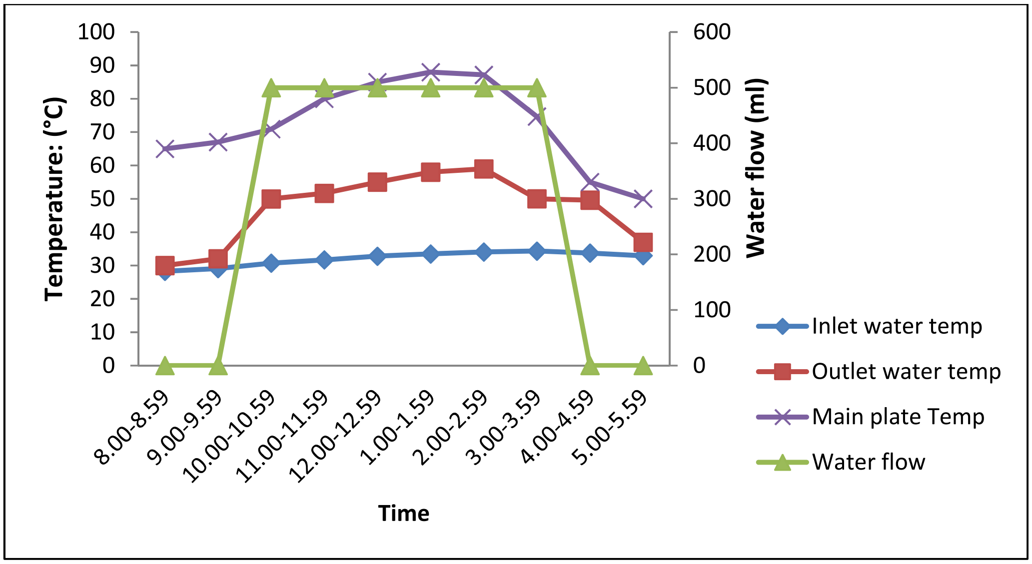


Figure 4.1 June 2012-hourly average for inlet, outlet and main plate temperature.

In the month of July 2012, the weather was not that good because for the first 15 days there were sometimes rainy days and the sky was cloudy. The daily average outlet water temperature was 48.27°C and the inlet water temperature was 28.88°C. In Appendix B, Table B1 shows the maximum daily temperature of the inlet and the outlet water as well as the main plate.

The maximum average outlet water temperature of 68°C was recorded on July 19 and at the end of the month. The maximum main plate temperature of 88°C was very low as compared with the June monthly temperatures.

Figure 4.2 shows the hourly average temperature of the inlet water, the outlet water and the main plate. From 8am to 11am the inlet and outlet water temperature was low while from 11.30am and above, the outlet water temperature had somewhat increased. The flow of water here was measured and found to be 500 millilitres per minute. Figure 4.2 shows when sensor 1 was activated to pump the water at around 11.30am to 4.30pm and this pump was running daily for about 4 to 5 hours while the rest of the time the water pump was stopped. The flow of water per hour was 30,000 millilitres (30 litres). If the total pump running period was around 5 hours, the flow of water could then be approximately 150 litres (39 gallons).

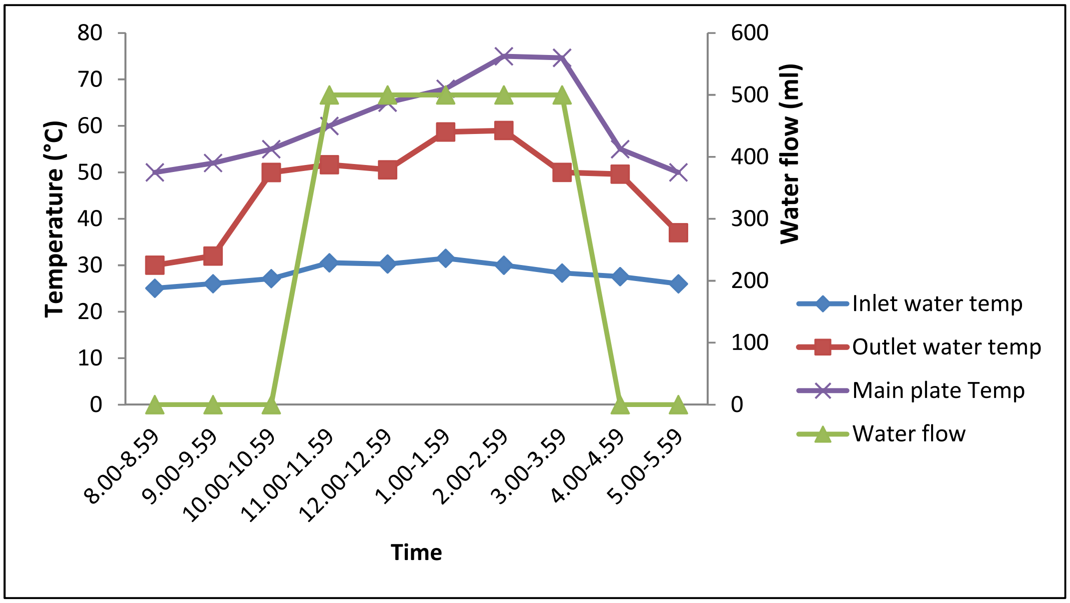


Figure 4.2 July 2012-hourly average for inlet, outlet and main plate temperature.

4.3 Thermal performance of the flat plate SHW collector result

The thermal performance of the collector depends on the inflow water, the outflow water, the daily temperature and the intensity of solar radiation. With the use of some simple formulae, the collected data and some known constants for calculating the flat plate solar water heater collector performance can be obtained. A full construction of the solar water heater and different materials have already been described in the methodology chapter. This experiment used water as the fluid medium and the circulation pipe is made of copper. Hence, from the material transmittance chart the ordinary glass transmittance (τ) is 0.80, and from the absorption surface charts, the short waves radiation (α) is 0.35; global losses factor (k) is 3 W/m^2 and the thermal capacity of water is (c) 4185.5 J/kg/degree Celsius.

4.3.1 Solar Radiation data collection from June to July 2012

In Malaysia, the average solar radiation is 4500 kWh per square meter, thus making it an ideal place for large scale solar power installations. Considering that the country gets an average of 4.5 to 8 hours of sunshine every day, there is a huge potential for a high solar power generation but at present the number of solar PV application in Malaysia is still low.

Solar radiation data are available in several forms as follows.

- Direct, diffuse or global.
- Instantaneous or integrated over a fixed interval of time.
- Based on the orientation of the receiving surface whether horizontal or tilted.
- Average sunshine day on a daily, monthly or yearly basis.

The average global solar radiation data on a horizontal surface are most common and useful in design work. The maximum instantaneous global radiation intensity received normal to the earth's surface is about 1000 W/m^2. However, the daily integrated global radiation varies from location to location and for design purposes, it is reasonable to assume about 4500 W/m^2 for the daily total solar radiation on a horizontal surface.

As has been mentioned above, the average peak instantaneous global radiation received on a horizontal surface is about 1000 W/m^2 and the direct component of this is about 800 W/m^2 during a clear sky and about 400 W/m^2 during an overcast sky condition.

The Malaysian weather is sometimes clear and is sometimes cloudy which explains why the daily base temperature and radiation are sometimes very high sometime very low as shown in Table 4.2 below.

Table 4.2 June and July 2012-Daily average temperature and solar radiation (Solar Radiation and daily temperature data collecting from Pyranometer-LI200).

	June		**July**	
Number of day	**Day temperature (°C)**	**Solar Radiation W/m^2**	**Day temperature (°C)**	**Solar Radiation W/m^2**
1	34.75	93.000	34.77	363.43
2	34.75	257.05	33.77	343.43
3	34.57	386.92	34.54	410.06
4	36.00	259.48	30.97	209.32
5	38.10	370.79	30.97	209.32
6	35.84	254.08	34.21	428.14
7	34.58	93.000	33.51	350.06

8	34.54	330.57	34.25	400.36
9	37.35	624.78	33.60	350.70
10	37.12	436.55	31.50	348.00
11	39.65	538.60	28.31	130.00
12	39.65	538.60	37.72	573.00
13	40.13	609.53	36.47	504.88
14	36.08	311.50	35.44	351.95
15	34.65	270.00	34.05	257.55
16	32.13	200.00	30.22	250.99
17	31.65	218.05	28.45	144.86
18	35.51	378.54	31.14	246.99
19	33.96	326.26	29.23	310.76
20	34.02	257.05	34.22	411.00
21	32.40	236.96	33.23	450.00
22	35.98	422.25	34.05	360.00
23	34.63	386.92	29.66	380.00
24	34.67	417.11	30.22	250.99
25	34.19	332.48	31.14	246.99
26	31.68	259.48	30.97	209.32
27	29.14	219.66	33.77	343.43
28	33.30	370.79	34.21	428.14
29	33.25	283.60	37.72	573.00
30	32.73	254.08	30.22	250.99
31			31.14	246.99

The daily maximum day temperate was recorded as 48°C on June 11 and 12 while an average daily temperature was 40°C on June 13. At the same time the solar radiation on any clear day per month averages approximately 400 W/m^2 but the daily average maximum solar radiation is 900W/m^2 which are as shown in Appendix B, Table B2.

4.3.2 Thermal performance from June to July 2012

For emphasis as mentioned above, the daily maximum day temperate was recorded as 48°C on June 11 and 12 whereas the average daily temperature was 40°C on June 13 while at the same time the solar radiation on a clear day per month averages approximately at 400 W/m^2 but the daily average maximum solar radiation was 900 W/m^2. It is specially noted that this (July 2012) month solar radiation and daily temperature showed a significant change from last month (June 2012).

By using the MATLAB program, equations (3.3) to (3.9) solved the problems. The software application allows the evaluation of the collector efficiency for some different values of the solar radiation. Table 4.3 shows the thermal efficiency and the gradient temperature between the output and the input thermal performance temperature that falls on the solar thermal collector.

Table 4.3 The collector thermal performance and so on for June and July 2012.

	June				**July**			
Number of day	**T_m [°C]**	**q_t [W/m^2]**	**$\dot{m}_s$ [g/sm^2]**	**η_t [%]**	**T_m [°C]**	**q_t [W/m^2]**	**$\dot{m}_s$ [g/sm^2]**	**η_t [%]**
1	40.84	18.26	1.20	8.460	36.85	6.260	4.80	47.42
2	39.94	15.56	4.00	28.93	36.82	9.170	4.40	44.24
3	41.74	21.48	6.00	43.93	40.00	16.38	5.20	51.88
4	38.74	8.230	4.20	30.45	39.63	25.99	2.30	23.40
5	39.93	5.480	6.10	44.52	39.51	25.63	2.40	23.47
6	41.81	17.91	3.90	28.24	37.18	8.910	5.60	55.60
7	36.87	6.880	1.40	10.28	37.32	11.44	4.50	44.73
8	35.61	3.210	5.50	39.96	37.08	8.490	5.20	51.96
9	39.92	7.680	10.3	75.27	37.10	10.50	4.50	44.98
10	41.47	13.05	7.00	51.36	38.58	21.25	4.30	42.75
11	40.21	1.690	9.00	65.67	38.59	30.86	1.20	11.96
12	41.84	6.560	8.90	64.89	38.53	2.430	7.60	76.07
13	43.86	11.18	9.90	72.84	38.47	6.020	6.60	66.35
14	37.21	3.400	5.10	37.59	36.63	3.570	4.60	46.36
15	40.12	16.42	4.20	30.43	36.61	7.680	3.30	33.04
16	37.97	17.53	3.00	21.68	36.55	19.01	3.00	30.19
17	39.54	23.67	3.10	22.90	36.48	24.10	1.50	15.13
18	39.42	11.73	6.10	44.47	36.18	15.14	3.00	30.33
19	40.07	18.34	5.10	37.01	36.16	20.80	3.80	37.85
20	39.40	16.13	3.90	28.89	39.06	14.53	5.20	52.33
21	36.13	11.20	3.70	27.22	38.75	16.56	5.70	57.18
22	44.41	25.27	6.50	47.65	38.76	14.15	4.60	45.59
23	43.91	27.82	5.90	42.92	42.75	39.27	4.40	43.87
24	43.75	27.23	6.40	46.71	42.58	37.08	2.70	27.03
25	41.71	22.54	5.10	37.10	41.32	30.56	2.80	27.64
26	42.62	32.81	3.60	26.51	41.13	30.50	2.30	22.62
27	39.67	31.59	3.00	21.83	40.76	20.97	4.20	42.19
28	37.51	12.61	5.90	43.38	40.49	18.84	5.40	53.87
29	38.08	14.47	4.40	32.40	43.88	18.48	7.30	73.27
30	38.73	17.97	3.90	28.23	43.88	40.98	2.60	26.35
31					43.76	37.87	2.60	26.36

Table 4.3 shows the solar thermal collector efficiency and other related parts of the solar water heater. The solar thermal collector optical losses represent the difference between the solar radiation intensity and the absorbed solar radiation intensity by the absorption surface. The maximum optical losses from the table on June 9 to 13 were 146, 102, 126 and 143W/m^2.

The thermal losses are directly related to the T_m between the absorption surface and the T_{a1}. The average temperature of the absorption surface is determinate with the relationship of the inlet and the outlet water temperatures. ΔT is the difference between the absorption temperature and the average temperature of the environment. The maximum thermal flow rate of this collector was 0.0103kg/m^2, and the maximum temperature of the collector was 159°C. The maximum collector efficiency was 75.27%.

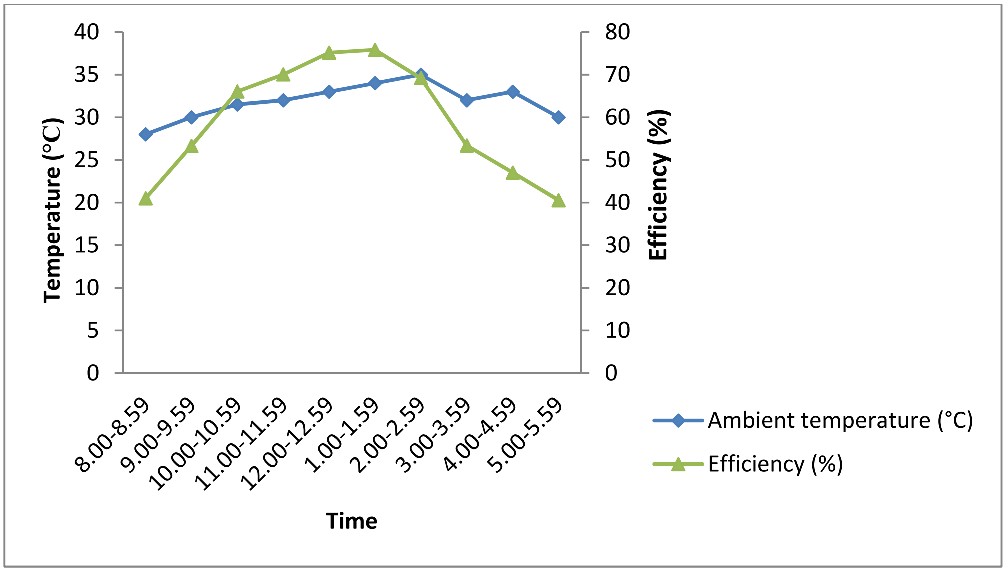


Figure 4.3 Hourly collector efficiency and ambient temperature.

In Figure 4.3, the average ambient temperature of the collector was around 32°C for the whole month of June 2012. The solar thermal collector efficiency at the inlet and the outlet water temperature depends on the solar radiation. Figure 4.3 shows the maximum efficiency was 75% when the solar radiation was 550 W/m^2. It was also observed that the collector high efficiency occurred for 1 hour from 1pm to 2pm.

The daily maximum day temperate of 51°C was recorded on July 12 while the highest average daily temperature was 37°C on June 29. At the same time the average of the clear day solar radiation per month was approximately 333 W/m^2 but the maximum solar radiation daily average was 860 W/m^2. It was found that the thermal efficiency of the flat plate collector had a similar quantity of sunshine radiation in July 2012 and June

2012. Table 4.3 shows the collector efficiency and other related parts of the solar water heater. The maximum thermal flow rate of this collector was 0.0076 kg/m^2, and the maximum temperature of the collector was 146°C. The maximum collector efficiency was 76.06%. For further informative details, refer to Figure 4.4. This is the hour-based graph of the ambient temperature, solar radiation and thermal efficiency.

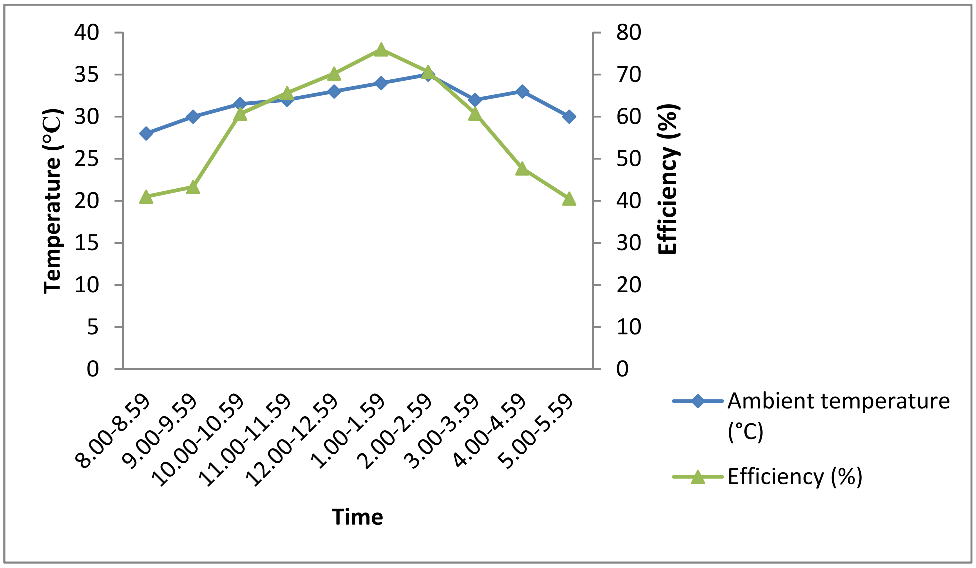


Figure 4.4 Hourly collector efficiency and ambient temperature.

The average daily ambient temperature of the collector for the whole month of July 2012 was around 30°C. The collector efficiency at the inlet and the outlet water temperatures depended on the intensity of the solar radiation. Figure 4.4 shows the hourly maximum efficiency of 76% where the solar radiation was 525 W/m^2. It was also observed that the daily solar sunshine collector efficiency was high from 10.30am to 11.30am and from 1pm to 2pm around a total of 2 hours.

4.3.3 Heat loss coefficient of the collector result

This experiment had investigated the amount of heat losses that had occurred at the top and the bottom of the collector. The heat loss formula required the relevant data, such as, the mean ambient temperature of the plate, the wind speed, the back insulation thickness and the back insulation thermal conductivity of the solar heat collector.

During a two-month period, two different materials were used to calculate the heat losses. Table 4.4 shows the daily average heat losses for the months from June to July 2012 with the following information:

i) From the thermal conductivity chart; the polystone sheet thermal conductivity was 0.043 W/mK.

ii) Wind speed data collected from the RETScreen software; for June and July 2012, Kuala Lumpur wind speed was 1.2 and 1.3 m/s respectively.

iii) Back insulation thickness from methodology chapter; the polystone sheet is 1.5 cm (0.015 m) thick.

iv) Materials emissivity chart;

a) the glass emissivity is 0.92;

b) plate (Aluminium plate) emissivity is 0.68 and Stefan-Boltzmann constant (5.669×10^{-8}).

v) The collector has used a single glass plate; number of glass plate is one.

By using the MATLAB software, equations (3.10) to (3.14) were able to solve the relevant problems to the total heat losses of the average daily top and bottom of the polystone sheet.

Table 4.4 Heat losses of the collector made of wooden and polystone sheet on June and July 2012.

	June			**July**		
Number of day	**Top heat loss W/m^{2}K**	**Bottom heat loss W/m^{2}K**	**Total heat loss W/m^{2}K**	**Top heat loss W/m^{2}K**	**Bottom heat loss W/m^{2}K**	**Total heat loss W/m^{2}K**
1	5.26	3.00	8.26	5.51	3.00	8.51
2	5.26	3.00	8.26	5.51	3.00	8.51
3	5.27	3.00	8.27	5.51	3.00	8.51
4	5.25	3.00	8.25	5.51	3.00	8.51
5	5.26	3.00	8.26	5.51	3.00	8.51
6	5.25	3.00	8.25	5.51	3.00	8.51
7	5.25	3.00	8.25	5.51	3.00	8.51
8	5.25	3.00	8.25	5.51	3.00	8.51
9	5.25	3.00	8.25	5.51	3.00	8.51
10	5.26	3.00	8.26	5.51	3.00	8.51
11	5.25	3.00	8.25	5.51	3.00	8.51
12	5.26	3.00	8.26	5.51	3.00	8.51
13	5.27	3.00	8.27	5.51	3.00	8.51

14	5.25	3.00	8.25	5.51	3.00	8.51
15	5.25	3.00	8.25	5.51	3.00	8.51
16	5.24	3.00	8.24	5.51	3.00	8.51
17	5.25	3.00	8.25	5.51	3.00	8.51
18	5.25	3.00	8.25	5.51	3.00	8.51
19	5.25	3.00	8.25	5.51	3.00	8.51
20	5.25	3.00	8.25	5.51	3.00	8.51
21	5.24	3.00	8.24	5.51	3.00	8.51
22	5.25	3.00	8.25	5.51	3.00	8.51
23	5.25	3.00	8.25	5.51	3.00	8.51
24	5.26	3.00	8.26	5.52	3.00	8.52
25	5.25	3.00	8.25	5.52	3.00	8.52
26	5.25	3.00	8.25	5.52	3.00	8.52
27	5.24	3.00	8.24	5.52	3.00	8.52
28	5.25	3.00	8.25	5.52	3.00	8.52
29	5.24	3.00	8.24	5.51	3.00	8.51
30	5.25	3.00	8.25	5.52	3.00	8.52
31				5.52	3.00	8.52

Reference on Table 4.4, shows that from June to July 2012, the bottom heat losses for the polystone sheet were the same, i.e., 3W/m^{2}K, but the top heat losses were a little bit more, i.e., around 5W/m^{2}K. The bottom heat losses depended on the ‘emissivity’ of the materials which was why the resultant value was the same while the top heat losses were mainly based on the mean ambient temperatures of the collector. It is observed that the total daily heat losses were around 8W/m^{2}K from June to July of 2012.

4.3.4 Efficiency comparison of the SWH collector

Figure 4.5 shows the efficiency improvement on the modified design of the flat plate solar water heater collectors as compared to the previous design of the solar water heater. The modified design can achieve 75% efficiency. However, the direct, oscillatory, serpentine and web flow design of the SWH has a very low efficiency. On the other hand, the modified design of the spiral, parallel-serpentine and prototype V-trough flow, the SWH thermal efficiency is close to 5%. It is clear from Figure 4.5 that the modified design of the SWH can further increase its thermal efficiency.

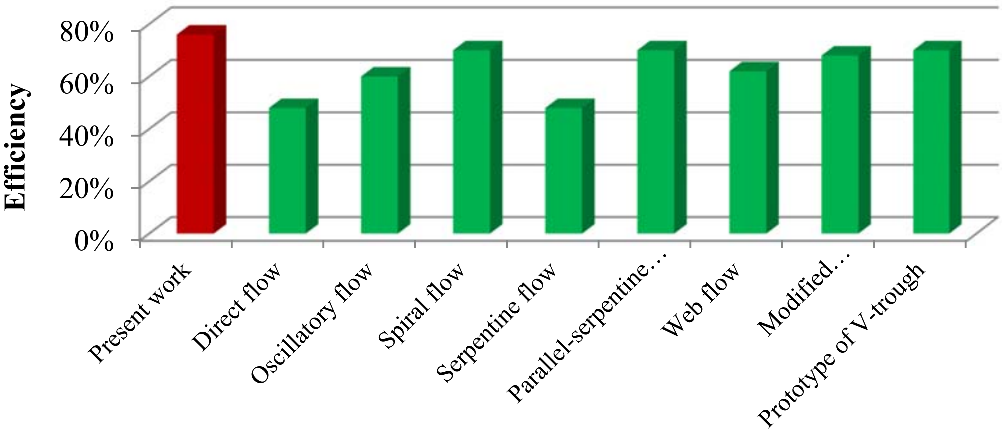


Figure 4.5 Comparison of efficiency between the modified solar thermal collectors and the previous SHW solar thermal collectors.

4.4 Solar PV panel and controller circuit performance result

In this experiment, the solar PV was found to be a very vital part of the solar water heater. The water pump is provided with an automatic on-off switch. The voltage which is stored in the (12V) battery, comes from the solar panel.

When the temperature of sensor 1 (solar panel) is higher than the temperature of sensor 2 (water tank), the water pump is automatically activated and when the temperature of the water tank is higher than or the same as that of the solar panel, the pump is then automatically turned off.

The most sensitive parts are sensor 1 and sensor 2 where the temperature sensing device will accurately measure the temperatures between -40 to 150°C. The voltage between the ground and the positive terminals of the LM335Z increases at 10mV per degree Celsius. Since absolute zero is at -273°C, the voltage measured at 0°C is 2.73V. For example, at a room temperature of 20°C, the voltage will be 273 + 20 = 293 which is equal to 2.93 Volts.

As every sensor is slightly different, the circuit includes a couple of 10kΩ variable resistors which can be used to set the voltage output of the two sensors so that they can give exactly the same reading when they are at the same temperature. In this experiment, an adjustment is made on sensor 1 so that a temperature of 60°C is equal to

3.33 volts and similarly on sensor 2 so that a temperature of 40°C is equal to 3.13 volts. In this way the two sensors will measure the temperature automatically without needing any further adjustment. Note that if the sensor is in contact with the water, this incident will damage the sensor.

4.4.1 Solar PV panel data collection

The digital multimeter has been used to measure the solar PV panel voltage and current from June to July 2012 by employing Ohm's law to calculate the power. The actual data in Table 4.5 shows the PV power and panel area in meter square.

Table 4.5 Solar PV power and panel area from June to July 2012.

June			July	
Number of day	**Solar PV power (W)**	**Panel area (m^2)**	**Solar PV power (W)**	**Panel area (m^2)**
1	22	0.18	22	0.18
2	24	0.18	22	0.18
3	25	0.18	24	0.18
4	22	0.18	25	0.18
5	23	0.18	23	0.18
6	20	0.18	23	0.18
7	21	0.18	25	0.18
8	23	0.18	22	0.18
9	24	0.18	24	0.18
10	25	0.18	25	0.18
11	23	0.18	23	0.18
12	21	0.18	21	0.18
13	22	0.18	22	0.18
14	23	0.18	22	0.18
15	23	0.18	21	0.18
16	23	0.18	23	0.18
17	24	0.18	24	0.18
18	21	0.18	21	0.18
19	25	0.18	25	0.18
20	22	0.18	22	0.18
21	23	0.18	23	0.18
22	24	0.18	24	0.18
23	20	0.18	20	0.18
24	21	0.18	21	0.18
25	22	0.18	22	0.18
26	24	0.18	24	0.18
27	25	0.18	25	0.18
28	23	0.18	23	0.18
29	22	0.18	22	0.18
30	21	0.18	23	0.18
31			25	0.18

4.4.2 Solar PV panel conversion efficiency

The measurement on the conversion efficiency needs a maximum power from the solar PV panel with a maximum solar radiation on the area of the solar panel collector. This was performed, as shown in Table 4.6, for a period of two months with a maximum power from the solar radiation on an area of 0.18m^2. The solar PV conversion efficiency was calculated the equations (3.15) and (3.16) using MATLAB software.

Table 4.6 Solar PV conversion efficiency from June to July 2012.

Number of day	**June**	**July**
	Efficiency (%)	**Efficiency (%)**
1	11.59	11.60
2	12.64	11.60
3	13.17	12.65
4	11.59	13.18
5	12.12	12.13
6	10.53	12.13
7	11.06	13.18
8	12.12	11.60
9	12.64	12.65
10	13.17	13.18
11	12.12	12.13
12	11.06	11.07
13	11.59	11.60
14	12.12	11.60
15	12.12	11.07
16	12.12	12.13
17	12.64	12.65
18	11.06	11.07
19	13.17	13.18
20	11.59	11.60
21	12.12	12.13
22	12.64	12.65
23	10.53	10.54
24	11.06	11.07
25	11.59	11.60
26	12.64	12.65
27	13.17	13.18
28	12.12	12.13
29	11.59	11.60
30	11.06	12.13
31		13.18

The maximum voltage depends on a clear sunlight. In Malaysia, the weather changes quickly but from noon to afternoon, the intensity of sun-light are reasonably good. The solar panel voltage sometimes displayed high voltages of up to 19.8 Volt. From the solar panel, the average efficiency was found to be between 11.96% and 12.09% on June and July 2012.

4.5 Economic analysis of SWH

From equations (3.19), (3.21), (3.22), it is possible to forecast from the assumed years to draw a cash flow for a solar water heater and to calculate the total cost for a period of fifteen years. Data from Table 3.1 are required to calculate the life time and interest rates for the cash flow. This analysis used some assumption values to arrive at some pragmatic amount.

A Cash Flow diagram for solar water heater as flows,

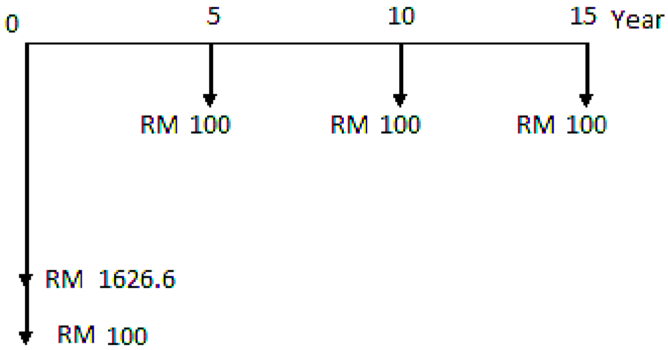


Figure 4.6 Solar water heater cash flow diagram.

Figure 4.6 illustrates the cash flow diagram of a solar water heater from year 0 to year 15 with values and arrows showing the year and cost per 5-year period of RM 100 (U$ 31.84). Zero is the initial year, thus, RM 1626.6 (U$ 518.02) is the initial cost plus RM 100 (U$ 31.84) as the installation cost. Whereas the annual running cost is zero. After 5 years, RM 100 (U$ 31.84) extra is added for the aluminium foil and some additional replacement of component parts.

Cost of running a solar water heater:

For the first 5 years:

A. $W)_{Solar}$ = RM - 464.91 (U$ 148.06)

For the second 5 years:

It is assumed that the second 5 years (total 10 years), will again incur RM 100 (U$ 31.84) for additional replacement of component parts.

$A.W)_{Solar}$ = RM –265.19 (U$ 84.45)

For the third 5 years:

And for the assumed third 5 years (total 15 years), an amount of RM 100 (U$ 31.48) will be incurred for additional replacement of component parts.

$A.W)_{Solar}$ = RM – 210.29 (U$ 66.97)

From equations (3.20), (3.21), (3.22) and assumed years, we can then draw the cash flow for an electric water heater to calculate the total cost for a ten-year period. This calculation needs data from Table 3.2, on the life time and interest rate of the cost as this analysis is using some assumed values.

Cash flow diagram for an electric water heater as flows,

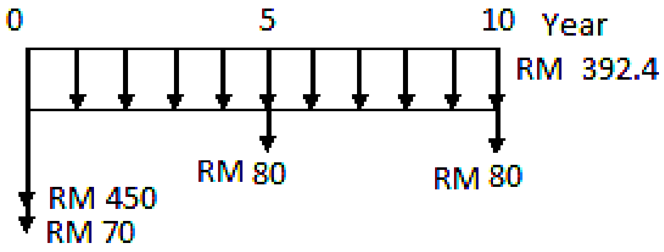


Figure 4.7 Electric water heart cash flow diagram.

The above diagram illustrates the probable cash flow of an electric water heater. 0 to 10 values and arrows represent the year and cost of a 5-year period at RM 80 (U$ 25.47) while zero is the initial year, thus, RM 450 (U$ 144.31) is the initial cost plus RM 70 (U$ 22.29) as the installation cost and an annual running cost of RM 392.4 (U$ 124.96). After 5 years, an extra RM 80 (U$ 25.47) is added for changing the heating element and some additional replacement of component parts.

Cost of running an electric water heater:

For the first 5 years:

A.W$)_{\text{Electric}}$ = RM –540.4 (U$ 172.10)

For the second 5 years;

It is assumed that the second 5-year period (total 10 years) again incurs RM 80 (U$ 25.18) for additional replacement of component parts.

A.W$)_{\text{Electric}}$ = RM – 475.36 (U$ 151.38)

The negative values in both cases are the cost value for the solar water heater and the electric water heater. The Annual worth for the solar water heater is RM 464.91 less than RM 540 for the electric water heater for the first 5 years. Hence, it is abundantly clear that for the first 5 years, the solar water heater will be used free of cost. After a period of ten years, the Annual worth for the solar heater is RM 256.19 and for the electric heater is RM 475.36, which cost much lesser with more benefits to use the solar water heater. If comparison of costs is made after a period of 15 years, the cost of solar water heater is RM 210.29 less than the electric heater which is RM 457.28. Generally, if the annul electricity cost for an electric water heater is RM 392.4 and after a five-year period, the cost of electricity for an electric water heater will be (RM 1962) while the use of the solar water heater will then be free of charge. The above result shows also that, it is advantageous for a family to use the solar water heater for at least 5 years in the long run, as compared to the electric water heater.

CHAPTER 5: CONCLUSION AND SUGGESTION

5.1 Introduction

Different techniques and methods have been applied to improve the thermal efficiency of the flat plate solar water heater collectors for the past. The purpose of this study was to enquire on the theory behind the solar water heater collector cost analysis so as to enhance the development of the potential available techniques to credibly improve its overall performance with the main focus being on the experiment of the flat plate collectors which are commonly used in Malaysia.

An experimental setup was created to examine on how the system could be upgraded in terms of work and heat transfer intensification technique. Then could be economically applied in a real situational system and if it would be viable for practical applications in the long run.

Weather conditions in Malaysia play a very important part in the experiment because all forms of performances and efficiencies entirely depends on sun-light and its radiation energy. The researcher with fervent hope that Malaysia can be much better in technology development as a developing country as compared to other countries. This study has been specifically devoted to introduce a modified design of the solar water heater collector which can be less costly as well as suitable for the local climatic conditions.

This dissertation has been performed to elaborate and highlight the significant experiments and tests conducted the flat plate solar water heater collector and its thermal efficiency. The solar radiation and water temperature for a clearer overall comprehension on, specifically on the solar photovoltaic panel. The conversion efficiency from the solar PV panel power and its equally economic viability and its satisfactory field performance as well as the reliable flexibility of use.

This study has proven that the experimental work performed can be possibly improving the thermal efficiency of the solar water heat collector. Especially; in Malaysia where sunshine is plentifully available in most part of the country for harnessing of renewable solar energy.

5.2 Design of Flat plate collector

The research has been conducted, especially, to enhance the heat transfer process in an active flat plate solar water heater collector using a modified design that can be easily and pragmatically applied in a typical flat plate collector by changing the appropriate shape of its absorption piping system. The collector box area, length of pipe, glass plate, polystone sheet and aluminium plate materials were derived as was provocatively described in Chapter 3, and most importantly, the distribution parameters were scientifically identified by the following methodological approach:

- By increasing the solar energy incident on per unit area of the collector absorber plate whereby the thermal efficiency can be considerably increased.
- By increasing the pipe bends, the fluid outlet temperature has been increased but there are still some small problems in the collector where the fluid inlet temperature rapidly decreases the thermal efficiency.
- The thermal efficiency has been found to decrease rapidly when the ambient temperature increases. Since these parameters cannot change during the day, there is a need to have the maximum thermal efficiency and other parameters related to the solar collector. The operating conditions which should change during the day to be integrated in the modified design of the solar collector based on the daily average temperature.

5.3 Thermal performance of solar water heater

It needs to stress further that the thermal performance of the entire system depends solely on the solar radiant energy collector efficiency as proven by the results obtained that show the daily and hourly through the long term thermal performance tests. The thermal behavior of the system is determined by the measured distribution of both the collector and the water temperatures under different conditions of sunlight. The outcome of the results and some comparisons made with the conventional system are described as in the following:

- The solar water heater with a maximum ratio of 0.5 at the inlet and outlet water temperatures to improve the thermal efficiency of the whole system.
- It is observed that from Table 4.2 on the daily average solar radiation for the months of June and July was 600 W/m^2, where the day temperature was 35 °C.
- The maximum solar radiation for two hours from noon to afternoon was 1013 W/m^2, where the day temperature was 40 °C.
- The Hottel-Whillier-Bliss equation has some critical observation parts, such as, the Optical factor (A_0) was 0.28 solar radiation (E) which is equal to the heat derived from the absorber surface (Qa). The two-month average optical loss was 76 W/m^2 which is equal to the solar radiation (E) minus the average temperature of the environment (Ta_1). The average maximum temperature (T_{max}) for two months was 134 °C.
- The modified absorber water heater collector thermal efficiency was 75% which was 27% greater than the Direct flow, 15% greater than the Oscillatory flow, 5% greater than the Spiral flow, 27% greater than the Serpentine flow, 7% greater than the Parallel-serpentine flow, 13% greater than the Web flow, 7% greater than the Serpentine-Parallel and 5% greater than the Prototype of V-trough water heater collectors (Chapter 2).

- Measurement on the total collector heat losses for two-month average was 8.50 W/m^{2}K (-13.05 W/m^{2}C), which was a very low heat loss.
- The results of the tests and comparisons with the eight designs, it was proven that the new solar water heater collector had achieved its goal and this experiment had also proven that it was not only very economical but it was also very convenient for domestic uses.

5.4 Conversion efficiency of solar PV

The industrial solar panel PV efficiency is 14% which is the standard. In this experiment, the small size solar panel was used to recharge the battery. A simple equation was used to calculate the solar PV efficiency.

- From the Table 4.6 we can find the two-month maximum solar PV efficiency. The average PV efficiency is 11.75% which is 2.5% less than the industrial solar panel efficiency.
- It is also observed that on a clear day, the solar PV efficiency can achieve 13.17%.
- In this experiment, the solar PV was used for the automatic pump control without any external electricity supply to run the whole system.

5.5 Economic viability

The economic viability was determined through a cost analysis for the whole system according to the Malaysian market response as compared to other systems in which the cost of the solar radiation collector was found to be relatively cheap. The initial investment was not so burdensome while its usage for the balance of its useful life would be free of charge as was proven through the cost analysis as fully described in Chapter 4 which showed that the total cost of a solar hot water heater was much cheaper when compared with that of an electric water heater, hence, some important salient points worthy of consideration are as summarized below:

- The total cost of Prototype of a V-trough solar water heater collector is RM 1489.40 (U$ 480.45) (Chong, Chay, & Chin, 2012) without a solar PV panel which control is the pump by using an external supply of electricity. But the (parallel two-sided serpentine flow) solar water heater collector with a solar PV panel runs the pump costs RM 1726.6 (US 543.56) and is more suitable for use without the need for an external supply of electricity.
- The results of calculations on cost analysis show that the SWHS is more economical and become more attractive than the EHW in the long run, thus, it is advantageous for the family to use the solar water heater after a usage period of at least 5 years.
- Subsequently, more families should be encouraged to install the SWHS in order to enjoy the long term economic benefits as well as the clean environment-friendly ecosystem.

5.6 Suggestions for future work

Because of the availability of free energy source from sun, there are various means and methods of technology to store the solar generated energy so obtained. The technology of renewable energy has improved day by day. Especially in this research field there are numerous brilliant ideas and the relevant knowledge that can be made to improve previous works. However, in this study there is only one idea to change for the better and to discover the best feasible method of inventing the solar water heat collector that can be the cheapest but producing the most efficient performance. With this idea in mind, it is fervently hoped that there are a number of problems that can be resolved to obtain the highest thermal efficiency as far as pragmatically possible. For the solar water heater collector in Malaysia, the following works can be concluded in the foreseeable future:

- The absorber pipe design should be changeable and interchangeable so as to enhance and facilitate future possible challenging work in a new design.
- In this study, the fluid used is water and the system can still be active without the use of a heat exchanger, hence, it is most likely feasible to use nanoparticle in the water that can increase the temperatures when connected to the heat exchanger.
- The new feature in the solar water heat exchanger is the automatic activation to run the water pump. It is possible to obtain electricity from the solar PV panel but the pump controller circuit should be suitably modified, i.e., a change in the system and configuration of the temperature sensor transistors (LM335Z) should be on the drawing board because the transistors cannot be in contact with the water as this will deactivate the whole system.
- The glass plate used in the collector should be 5mm thick because it has been tested that a glass thickness below 5mm will be easily broken and will also not last very long.
- It is also possible to use a solar tracker to detect the maximum solar radiation and temperature to maximize the resultant effect on the collector.

If the recommended options are revealed above can be successfully implemented, it will be much easier to obtain higher temperatures with the higher resulting efficiencies. This solar water heater collector can be possible to install on the roof or suitable places. In view of encouraging results of the study for future solar energy utilization could be used to provide the basic needs which are not commensurate to the requirements of main electrical supply.

APENDICES

Appendix A: Two months (June and July, 2012) observation of slope and inclination angle of solar water heater.

Table A1 Slope and inclination angle of solar collector.

Month	Day	Day of year (n_1)	Inclination angle (δ) degrees
June	1	152	22.03
June	2	153	22.17
June	3	154	22.30
June	4	155	22.42
June	5	156	22.53
June	6	157	22.64
June	7	158	22.74
June	8	159	22.84
June	9	160	22.93
June	10	161	23.01
June	11	162	23.08
June	12	163	23.15
June	13	164	23.21
June	14	165	23.26
June	15	166	23.31
June	16	167	23.35
June	17	168	23.38
June	18	169	23.41
June	19	170	23.43
June	20	171	23.44
June	21	172	23.44
June	22	173	23.44
June	23	174	23.43
June	24	175	23.42
June	25	176	23.40
June	26	177	23.37
June	27	178	23.33
June	28	179	23.29
June	29	180	23.24
June	30	181	23.18
July	1	**182**	**23.12**
July	2	183	23.04
July	3	184	22.97
July	4	185	22.88
July	5	186	22.79
July	6	187	22.69
July	7	188	22.59
July	8	189	22.48
July	9	190	22.36
July	10	191	22.23
July	11	192	22.10
July	12	193	21.96
July	13	194	21.82
July	14	195	21.67

July	15	196	21.51
July	16	197	21.35
July	17	198	21.18
July	18	199	21.00
July	19	200	20.82
July	20	201	20.63
July	21	202	20.44
July	22	203	20.24
July	23	204	20.03
July	24	205	19.82
July	25	206	19.60
July	26	207	19.37
July	27	208	19.14
July	28	209	18.91
July	29	210	18.67
July	30	211	18.42
July	31	212	18.17

Appendix B: Two months (June and July, 2012) observation of maximum temperatures from the solar radiation.

Table B1 Daily maximum temperature for the inlet water flow, outlet water flow, main plate and inside glass in June and July 2012.

	June				**July**			
Number of day	**Inlet water temperature (°C)**	**Outlet water temperature (°C)**	**Main Plate temperature (°C)**	**Glass inside temperature (°C)**	**Inlet water temperature (°C)**	**Outlet water temperature (°C)**	**Main Plate temperature (°C)**	**Glass inside temperature (°C)**
1	35.72	68.74	85.49	74.27	28.02	45.98	60.32	48.19
2	39.66	89.94	70.26	62.17	32.65	41.90	61.32	48.11
3	34.84	82.27	98.93	62.17	34.84	51.85	72.65	48.03
4	35.72	69.01	85.49	53.89	35.72	51.90	71.07	47.75
5	39.01	59.71	70.26	58.56	34.01	54.21	71.23	47.77
6	39.66	82.27	98.93	74.27	30.23	54.03	73.45	47.69
7	37.31	69.01	85.49	62.17	29.89	53.82	74.10	47.81
8	34.84	59.71	70.26	53.89	31.65	54.13	70.93	47.75
9	35.72	68.74	77.52	58.56	30.65	65.44	75.28	47.78
10	39.01	89.94	117.31	84.79	33.26	51.81	68.21	47.72
11	38.59	76.06	99.99	71.14	32.01	51.90	60.10	48.72
12	39.01	87.46	104.79	74.50	34.45	51.92	67.33	50.87
13	52.00	83.26	109.03	81.18	31.54	51.93	67.23	53.27
14	37.43	66.66	71.47	54.15	30.44	50.38	64.31	52.89
15	39.00	63.90	77.42	58.90	30.60	50.21	62.33	52.52
16	33.27	50.00	57.00	45.58	30.30	51.90	61.02	52.15
17	37.16	56.90	74.13	53.85	30.60	51.85	60.12	51.90
18	39.04	70.87	91.12	64.84	31.02	51.90	67.85	51.60
19	36.15	63.32	85.57	65.10	29.55	68.34	68.95	65.77
20	37.50	64.95	83.53	63.15	30.25	67.55	68.95	65.70
21	34.87	41.52	77.79	59.99	34.87	67.45	68.74	65.67
22	40.94	79.35	97.60	77.05	35.23	67.56	69.10	65.64
23	40.00	94.83	107.59	79.75	33.21	67.47	86.06	65.68
24	41.00	89.49	99.95	77.26	32.21	67.69	86.74	65.70
25	37.34	70.61	103.53	76.82	35.54	67.77	86.84	65.63
26	37.74	77.86	94.93	72.55	34.56	67.85	87.22	65.70
27	35.23	60.56	78.00	60.00	35.23	67.94	87.60	65.82
28	40.12	68.85	94.62	72.02	34.58	68.42	87.42	65.91
29	36.86	89.94	93.83	70.79	36.86	68.95	88.19	65.93
30	34.54	60.35	72.00	60.00	34.54	68.45	87.95	66.02
31					35.69	68.95	88.26	66.23

Table B2 June and July 2012-Daily maximum day temperature and solar radiation.

	June		July	
Number of day	**Day temperature (°C)**	**Solar Radiation w/m2**	**Day temperature (°C)**	**Solar Radiation w/m2**
1	39.29	1012.4	42.77	933.00
2	38.56	682.70	38.03	890.00
3	37.25	628.42	40.89	907.77
4	38.95	846.71	34.86	909.57
5	45.94	1013.0	40.56	890.60
6	42.29	1012.7	43.52	994.11
7	37.64	519.25	38.08	1012.11
8	38.08	568.39	37.60	860.00
9	41.50	1013.0	37.00	905.00
10	41.61	984.04	36.50	750.00
11	48.37	977.02	33.15	513.15
12	48.37	977.02	51.24	860.75
13	47.84	963.90	42.14	995.36
14	42.47	809.17	40.89	862.58
15	37.04	650.00	40.22	814.66
16	35.31	590.00	37.02	600.00
17	41.12	698.09	33.46	835.72
18	43.19	891.87	35.58	751.80
19	38.56	796.05	39.03	1011.2
20	40.37	785.06	45.94	924.53
21	38.42	782.32	33.15	513.15
22	46.22	897.98	36.50	750.00
23	40.80	971.52	33.46	835.72
24	44.28	857.08	38.03	890.00
25	41.76	894.62	33.46	835.72
26	38.53	882.41	40.22	814.66
27	36.22	756.38	40.89	907.77
28	42.98	882.11	38.08	1012.11
29	38.17	883.94	37.00	905.00
30	37.81	808.56	42.77	933.00
31			38.03	890.00

Appendix C: Relevant publications

Journal Articles

1. **Hossain, M. S.**, Saidur, R., Fayaz, H., Rahim, N. A., Islam, M. R., Ahamed, J. U., et al. (2011). Review on solar water heater collector and thermal energy performance of circulating pipe. Renewable and Sustainable Energy Reviews, 15(8), 3801-3812.

Conference Papers

1. **M. S. Hossain**, N.A.Rahim, K.H.Solangi, R. Saidur, H.Fayaz, N. A. Madlool. Global Solar Energy Use and Social Viability in Malaysia: Clean Energy and Technology (CET), 2011 IEEE First Conference on Digital Object Identifier: 10.1109/CET.2011.6041461. Publication Year: 2011, Page(s): 187 – 192.

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