UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Mechanical Engineering

SOLAR THERMAL WATER HEATER REQUIREMENTS FOR TYPICAL MALAYSIAN HOUSE

Shamila Sandhu anak Ludan

Master of Mechanical Engineering (Energy Engineering)

2016

SOLAR THERMAL WATER HEATER REQUIREMENTS FOR TYPICAL MALAYSIAN HOUSE

SHAMILA SANDHU ANAK LUDAN

A Master Project Report submitted in fulfillment of the requirements for the degree of Master of Mechanical Engineering (Energy Engineering)

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2016

DECLARATION

I declare that this report entitled "Solar Thermal Water Heater requirements for a typical Malaysian house" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature	:	....
Name	:	Shamila Sandhu anak Ludan
Date	:	....

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Mechanical Engineering (Energy Engineering).

Signature : ....

Supervisor Name : Associate Professor Juhari Ab Razak

Date : ....

DEDICATION

This thesis is dedicated to my beloved father and late mother, my brothers and sister, my beloved family members and all my loved ones. Thank you all for your endless love, sacrifices, prayers, supports and advices.

ABSTRACT

As one of renewable resources of energy, solar energy has great potential to be developed in Malaysia because the country receives 4000 - 5000 W/m^2 daily radiation and monthly average daily sunshine duration ranging from 4 hours to 8 hours. The utilization of solar energy would reduce dependency on the fossil fuel which its price keeps fluctuating and also creates environmental pollution from emission of greenhouse gas (GHG) such as carbon monoxide, CO and nitrogen oxide, NOx. Solar photovoltaic (PV) and Solar Water Heater (SWH) are examples of solar energy applications that could be used in Malaysia. Solar Water Heater uses solar energy to produce hot water needed in households. The objectives of this study are to simulate the transient heating characteristics of solar thermal collector, to determine optimum design parameters of the solar thermal collector system based on year performance under meteorological data of Penang, Malaysia, to develop a TRNSYS simulation model of the flat plate collector system and to investigate the effects of collector area and mass flow rate on outlet temperature and heat transfer rate of solar collector. Simulation using TRNSYS software had been done to investigate the performance of the solar water heater by using typical meteorological year (TMY) data for Penang, Malaysia. Results obtained from simulations shows that 8m^2 solar thermal collector with 70kg/hr mass flow rate is the most optimum parameters for the system. This is considering the cost for the solar thermal water heater system. Larger solar collector area will needs more cost for the system. The highest collector outlet temperature was achieved in January, November and December which is 80°C. The heat transfer rate in solar collector also highest in these months ranging from 22500W to 24000W. Increasing in mass flow rate resulting in decreases of collector outlet temperature. This is due to higher volume of water need to be heated with the same amount of solar energy absorbed by the solar collector. For future research, it is recommended that the study also look into the effect of solar collector tilted angle on the outlet temperature and heat transfer rate, and CFD analysis of the solar collector. Economic analysis of the solar water heater also need to be studied in detail.

ABSTRAK

Sebagai satu sumber tenaga boleh diperbaharui, tenaga solar mempunyai potensi yang besar untuk dibangunkan di Malaysia kerana negara ini menerima 4000 - 5000 W/m² radiasi solar setiap hari dan purata cahaya matahari bulanan adalah 4 jam hingga 8 jam sehari. Penggunaan tenaga solar akan mengurangkan kebergantungan terhadap bahan api fosil yang harganya sentiasa berubah-ubah dan juga menyebabkan pencemaran alam sekitar kerana terbebasnya gas rumah hijau seperti karbon monoksida, CO dan nitrogen oksida, NOx. Fotovoltan solar dan pemanas air solar adalah contoh aplikasi tenaga solar yang boleh digunakan di Malaysia. Pemanas air solar menggunakan tenaga solar untuk menghasilkan air panas yang diperlukan di dalam rumah. Objektif kajian ini adalah untuk mengsimulasi ciri-ciri pemanasan peralihan di dalam pengumpul terma solar, menentukan parameter rekabentuk optimum sistem pengumpul terma solar berasaskan prestasi tahunan di bawah data meteorologi bagi Pulau Pinang, Malaysia, membangunkan model simulasi TRNSYS untuk sistem pengumpul terma solar dan menyiasat kesan luas pengumpul dan kadar aliran jisim terhadap suhu keluar dan kadar pemindahan haba dalam pengumpul solar. Simulasi menggunakan perisian TRNSYS telah dibuat untuk menyiasat prestasi pemanas air solar dengan menggunakan data tahunan meteorologi sama untuk Pulau Pinang, Malaysia. Keputusan yang diperoleh daripada simulasi menunjukkan pengumpul terma solar 8m² dengan kadar aliran jisim 70kg/hr adalah parameter yang paling optimum untuk sistem tersebut. Ini dengan mengambilkira kos untuk sistem pemanas air solar. Lebih besar luas pengumpul solar akan memerlukan lebih banyak kos untuk sistem tersebut. Suhu keluar pengumpul paling tinggi telah dicapai pada Januari, November dan Disember iaitu 80°C. Kadar pemindahan haba juga tinggi dalam bulan-bulan ini bermula daripada 22500W hingga 24000W. Peningkatan dalam kadar aliran jisim menyebabkan penurunan dalam suhu keluar pengumpul. Ini adalah kerana lebih banyak isipadu air yang perlu dipanaskan menggunakan jumlah tenaga solar yang sama yang diserap oleh pengumpul solar. Untuk penyelidikan pada masa hadapan, adalah dicadangkan kajian juga melihat kepada kesan sudut kecondongan pengumpul terma terhadap suhu keluar pengumpul dan kadar pemindahan haba. Analisis CFD pada pengumpul solar dan analisis ekonomi pemanas air solar juga harus dikaji dengan lebih terperinci.

ACKNOWLEDGEMENTS

First and foremost, I would like to take this opportunity to express my sincere acknowledgement to my supervisor Associate Professor Juhari Ab Razak from the Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka (UTeM) for his essential supervision, support and encouragement towards the completion of this report.

I would also like to express my greatest gratitude especially to Majlis Amanah Rakyat (MARA) for sponsoring my project and my studies throughout these four semesters. Sincerest gratitude also to Mr. Azman bin Ali@Alik, Director of Institut Kemahiran MARA (IKM) Bintulu and top management for giving me opportunity to complete this master project successfully despite of my official duty at work.

My deepest gratitude also goes to my colleagues and my course mates for their assistance and moral support throughout my studies. Their support and cooperation had helped me to complete my project and makes me stronger to face challenges in my studies.

Special thanks to my late mother, beloved father and siblings for their moral support in completing this degree. Lastly, thank you to everyone who had been crucial parts of realization of this project.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

η_{coll} – collector efficiency

$\dot{m}$ – mass flow rate, kg/s

c_p – specific heat capacity kJ/kg.°C

$T_{i_{coll}}$ – inlet temperature of collector, °C

$T_{o_{coll}}$ – outlet temperature of collector, °C

I – intensity of solar radiation W/m^2

CHAPTER 1

INTRODUCTION

1.1 Background

Malaysia is a blessed country located at equatorial region which has a tropical climate that is suitable for solar energy utilization. As one of renewable resources of energy, solar energy has great potential to be developed because daily radiation in Malaysia is 4000 - 5000 W/m^2, and monthly average daily sunshine duration ranging from 4 hours to 8 hours as stated by Ali et al. (2009). The utilization of solar energy would reduce dependency on the fossil fuel which its price keeps fluctuating and also creates environmental pollution from emission of greenhouse gas (GHG) such as carbon monoxide, CO and nitrogen oxide, NO_x. Sukarno et al. (2015) had stated that correct information about solar radiation intensity on allocated location for the solar energy project is very important to ensure the project will succeed. Solar energy is being considered as one of energy resources to fulfil energy needs in Malaysia as well as in the world.

Kamaruzzaman et al. (2012) have highlighted that Malaysia is to face great challenges in developing solar energy project in term of funding and knowledge. Therefore, research programmes should be conducted at educational level to increase knowledge of Malaysian about solar energy and increase the number of experts in this field. It was also stated that the cost of solar energy must be monitored and according to the size of the project. Private organisations could contribute to the development of solar energy project in Malaysia as solar technology has great potential to be established. In order to increase public awareness and interest, tax relief and rebates should be promoted to encourage Malaysian to practice energy saving in daily life.

Hugo and Zmeureanu (2012) had found that not many people interested to invest in the complex solar system because long payback period of initial investment, but the long payback period could be balanced by short energy payback. According to Chaji et al. (2013), solar energy has one main weakness that is frequent changing of gap between time of radiation and consumption. This weakness has become an obstacle to make solar energy as an eternal and worldwide energy source. Therefore, it is important to collect and store solar energy during radiation by using solar thermal collector system.

Wei et al. (2014) had found that for a family consists of three persons in Dezhou city China, the total electricity saving through domestic solar water heater with $1.5m^2$ evacuated tube collectors is 563 kWh. During summer season, the hot water supply exceeds the demand. Meanwhile during winter season, electric water heater also being used together with the domestic solar water heater to fulfil the household needs as more hot water needed by the residents.

According to Rosario (2014) solar energy is a good alternative of energy resources. Even though the price of solar panels are more expensive compared to electric grid, many advance technology could be used to utilize these solar panels. By 2015, its price is predicted to drop 25 cents of a dollar because of silicon availability increases and it is being used as main material to produce solar collector. This means the solar panel and solar collectors could be produced at a lower cost. Solar collector that is placed on good location will results in effective utilization of solar energy. Rosario's (2014) research shows the best locations for solar panels are in countries located on equator and close to equator. The research was looked into three locations namely Pontianak in Indonesia, Tampa in Florida and Fairbanks in Alaska. Among all those three locations, Pontianak in Indonesia has the highest solar radiation. It was 12.42% and 96.9% more energy produced than Tampa, Florida and Fairbanks respectively. This prove that Pontianak, Indonesia is the best location amongst all the three locations due to its location is near the equator. Therefore, Malaysia would be a great location for solar collector and solar panels to generate electricity because Malaysia located exactly on the equator. According to Ranjithkumar et al. (2015), Malaysia has solar radiation of 6.6 kWh/m^2 and 6.0 kWh/m^2 from January to August which is considerably high and good for solar energy harvesting through usage of solar water heater. This is important to prevent our global being polluted continuously as a result of burning fossil fuel for electricity.

Ong et al. (2014) had studied that solar water heater operates using the principle of thermal buoyancy and natural convection. The water in the tubes of collector pipe will be heated and it goes up to the storage tank. Cold water in the storage tank will flow down as its density is higher. This flow of water which is known as natural convection occurs in day time when the collector plate absorb heat from the sun. At night, the flow is in opposite direction and there is heat loss from the collector to the surrounding.

Basically, hot water is needed for baths, washing clothes and some other household needs especially in urban area. Burning of fuel such as kerosene oil, liquid petroleum gas (LPG), coal and usage of electricity are some of the methods to produce hot water. These methods have negative impacts towards the environment and may create environmental pollution. Therefore, usage of solar water heater in a house either in rural or urban area should be able to reduce these adverse impacts because it utilizes solar energy to heat the water (Ayompe et al., 2011).

In solar water heater system, the most crucial part is the solar thermal collector because this is where heat transfer from the sun radiation to the fluid occurs. The sun emits

1353 W/m^2 on the earth surface perpendicular to sun rays provided that there is no atmospheric layer. The earth receives 170 trillion kW solar energy and 23% of this energy is used for evaporation or rainfall cycle in Biosphere, 47% is converted to low temperature heat energy and less than 0.5% used for kinetic energy in wind, waves and plants photosynthesis. The other remaining 30% is reflected back to the space (Ingle et al., 2013). Therefore, full utilization of this solar energy should be made in order to allow the solar collector operates at its best efficiency. As for Kim and Han (2015), the fraction of solar energy transmitted by the sun, absorbed by the land and reflected to atmosphere are as shown in Figure 1.1.

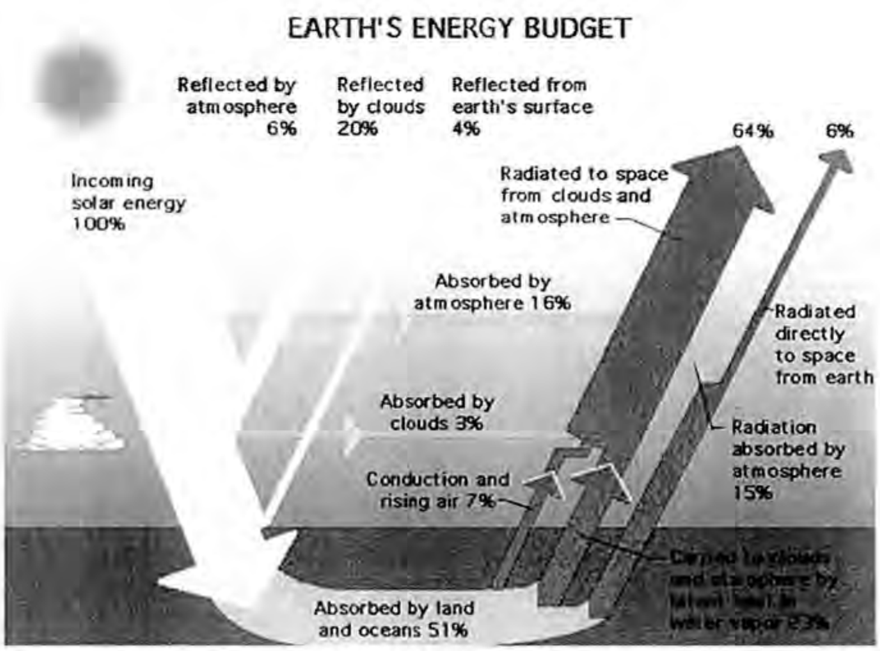


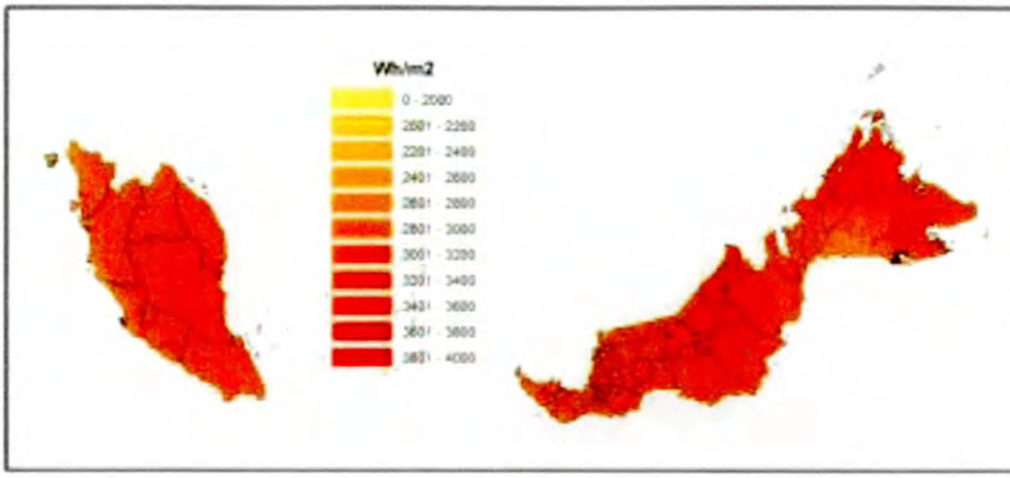
Figure 1.1: Earth Energy Budget (Kim & Han 2015)

Xin and Weiguo (2011) in their research had found that the servicing problem of solar water heater always appear and it could interrupt the solar water heater industry. In order to prevent the servicing problems to occur, a complete solar water heater service industry could be established by incorporating mutually independent service modes and service organisations.

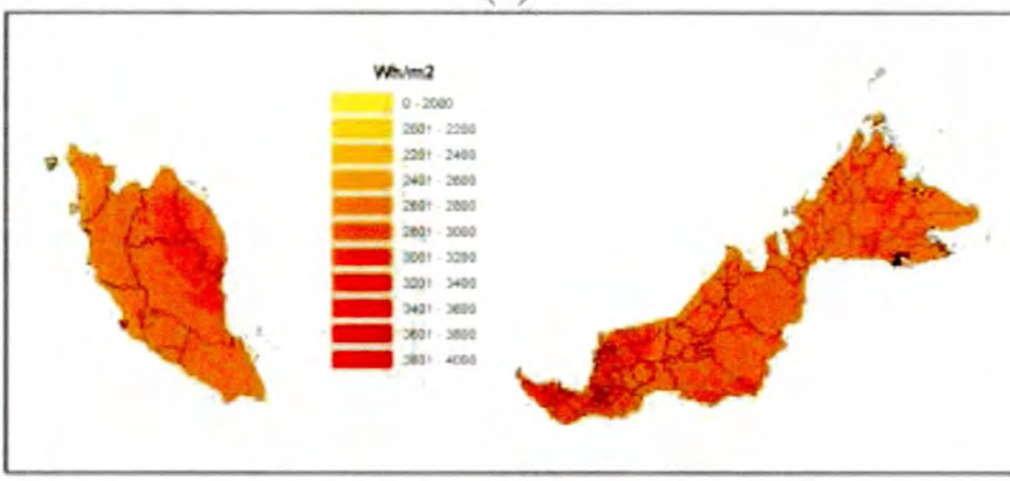
As solar water heater is very much depends upon the solar radiation received from the sun, the system must be designed carefully to maximize the solar energy and save cost. High cost is needed to design and test the hardware of the system in order to identify its efficiency. Simulation is one technology to identify the performance of the system without spending too much budget on hardware of the system. Therefore, it is useful to run simulation of solar water heater system as it could save the cost needs to fabricate and install the solar water heater system.

This project is to simulate a solar water heater system to be installed on typical Malaysian house in order to promote usage of solar energy instead of using electricity for hot water needs. As can be seen in Figure 1.2(a-f), states located in North Malaysia receives more solar radiation compared to states located in the South. Those states in North of Peninsular Malaysia still receives lots of radiation from the sun compared to other states although December is the month of raining season in Malaysia. Therefore, this project is proposed to be installed in Penang, Malaysia. Penang is located on the North of West Malaysia with latitude of 5°25'N, longitude 100°15'E and elevation of 4m. It is expected that the efficiency of the SWH will be increased because the solar radiation is higher. Figure 1.2(a-f) shows monthly average daily diffuse solar radiation for Malaysia from January until December.

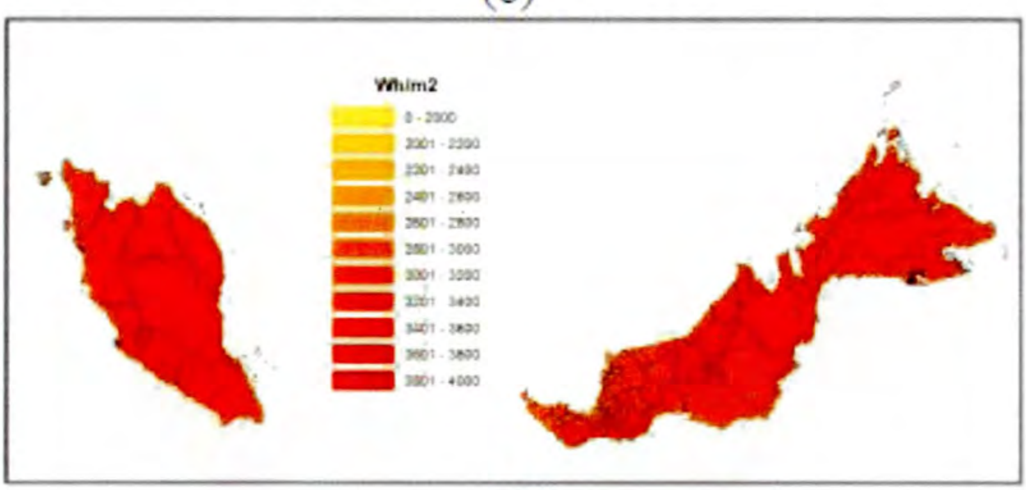
As shown in Figure 1.3, the main elements are solar collector and storage tank. Figure 1.3 also shows solar water heater couples with heating element that will heated hot water tank together with the solar heating system and its tank. When there is not enough sunshine to meet hot water requirements, the electric heater will turn on and heat up the water in the backup tank. However, for this research, there will be no backup hot water tank as Malaysia is a hot climate country.


Wh/m2
0 - 2000
2001 - 2200
2201 - 2400
2401 - 2600
2601 - 2800
2801 - 3000
3001 - 3200
3201 - 3400
3401 - 3600
3601 - 3800
3801 - 4000

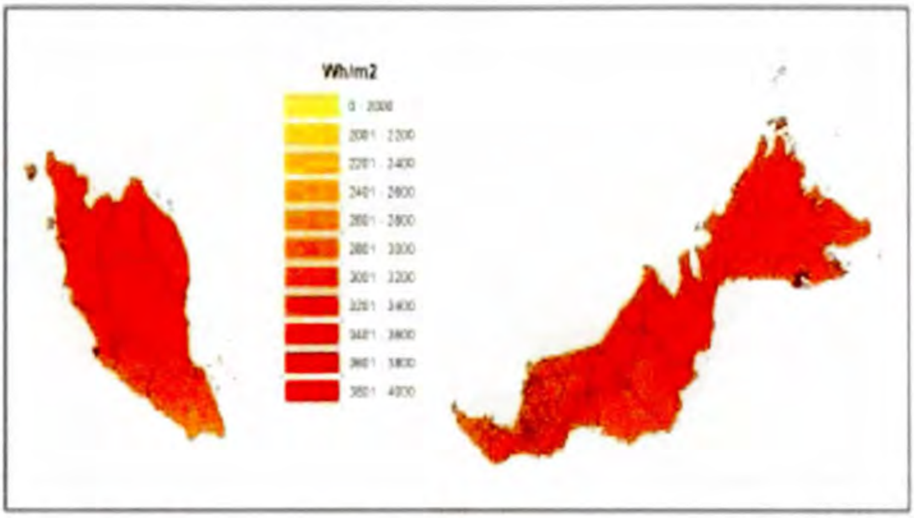
(a)


Wh/m2
0 - 2000
2001 - 2200
2201 - 2400
2401 - 2600
2601 - 2800
2801 - 3000
3001 - 3200
3201 - 3400
3401 - 3600
3601 - 3800
3801 - 4000

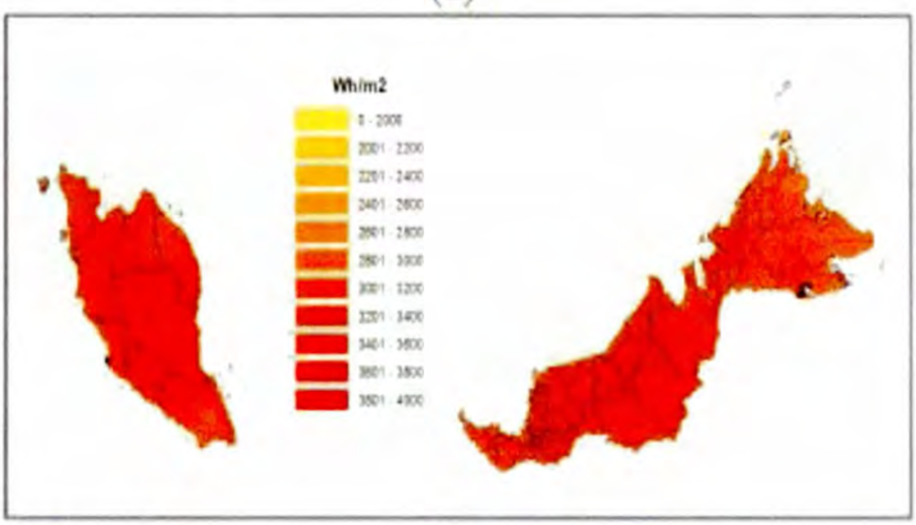
(b)


Wh/m2
0 - 2000
2001 - 2200
2201 - 2400
2401 - 2600
2601 - 2800
2801 - 3000
3001 - 3200
3201 - 3400
3401 - 3600
3601 - 3800
3801 - 4000

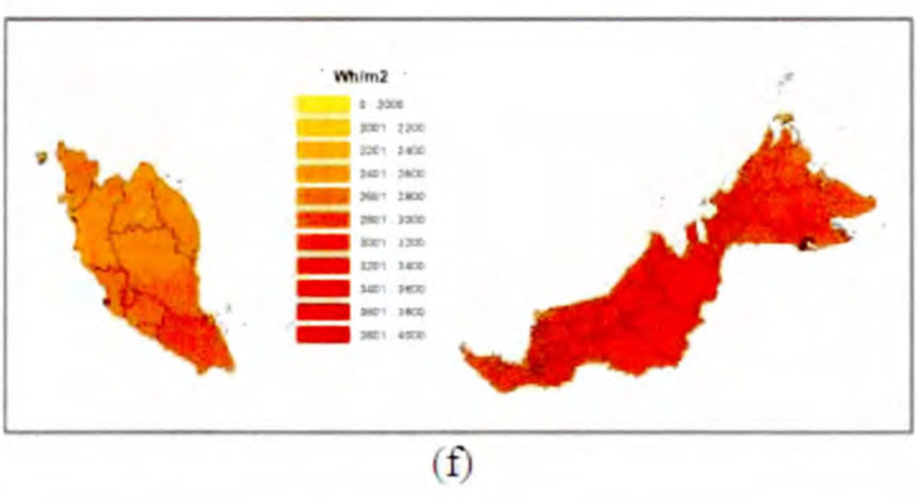
(c)



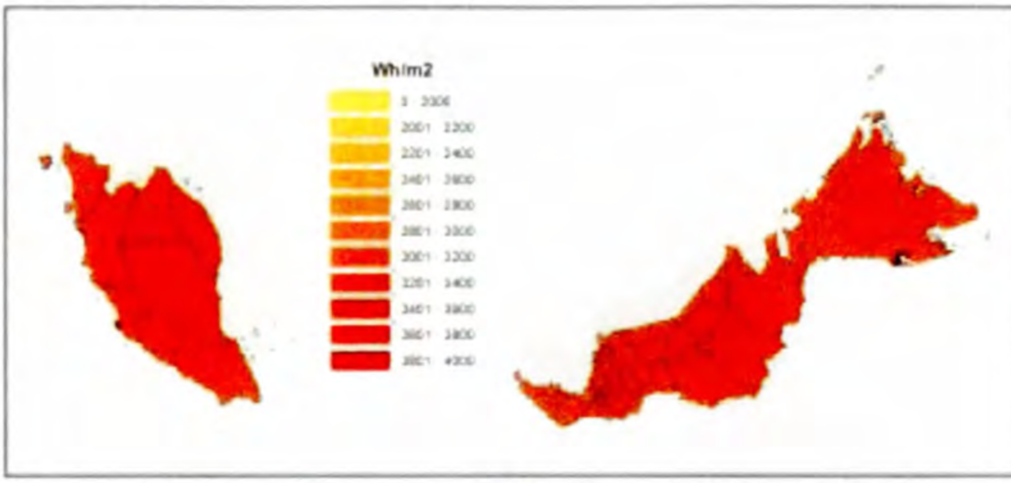
(d)



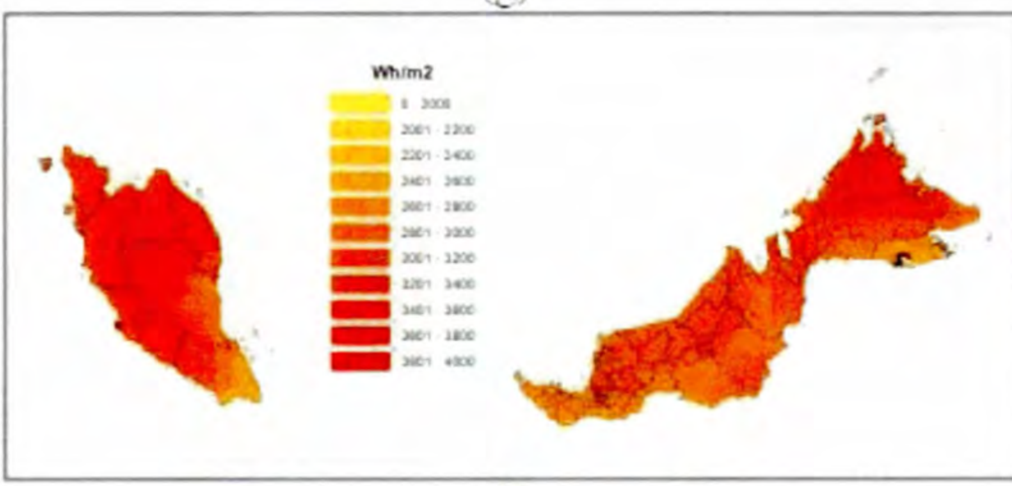
(e)



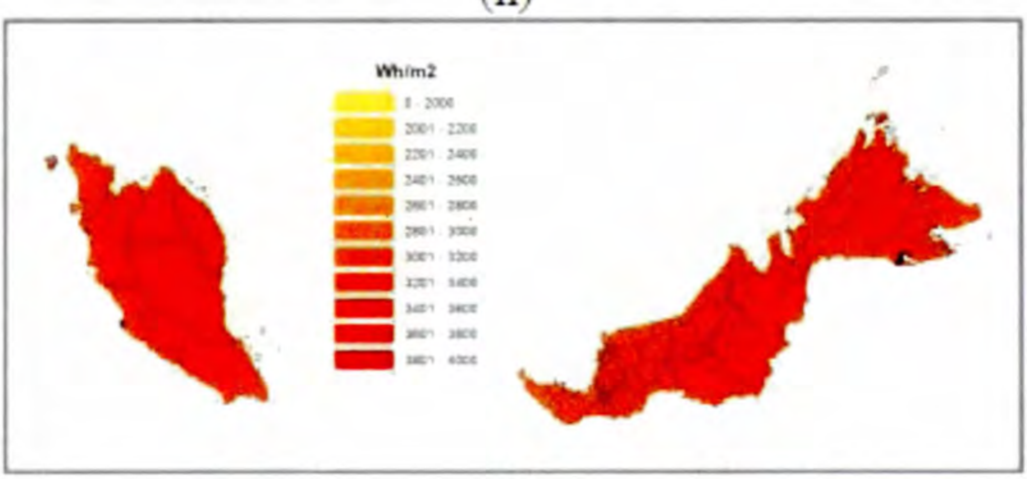
(f)



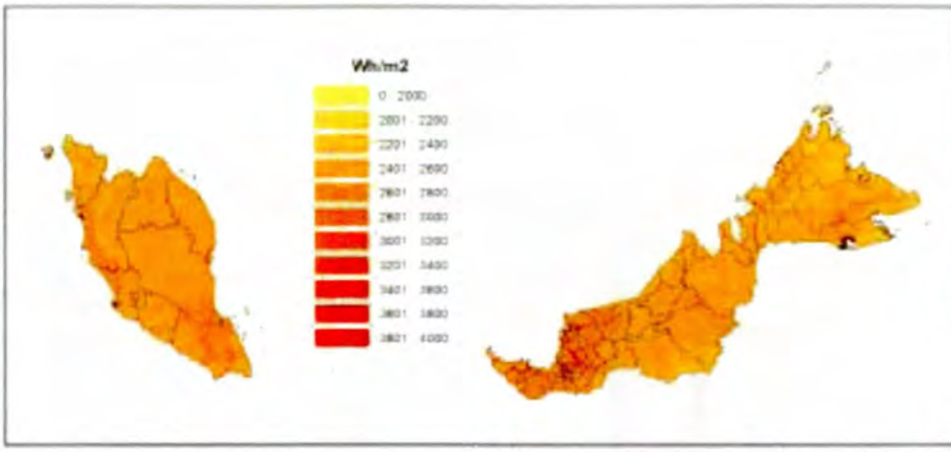
(g)



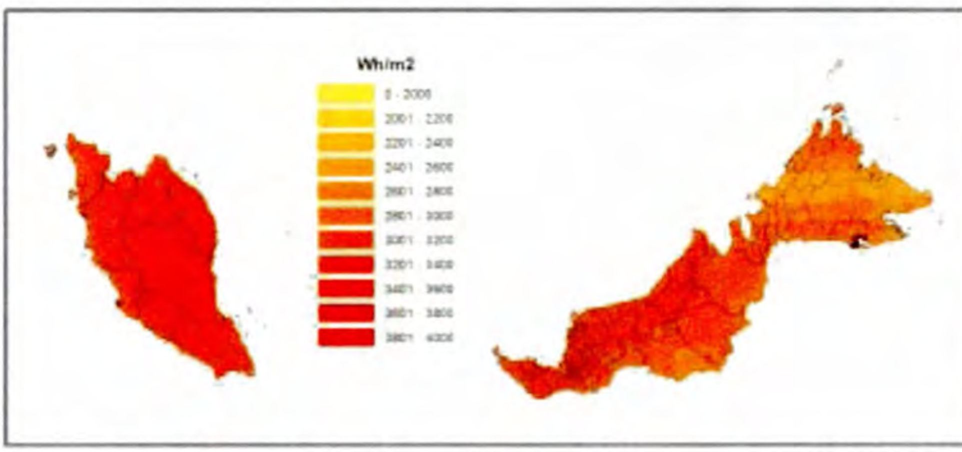
(h)



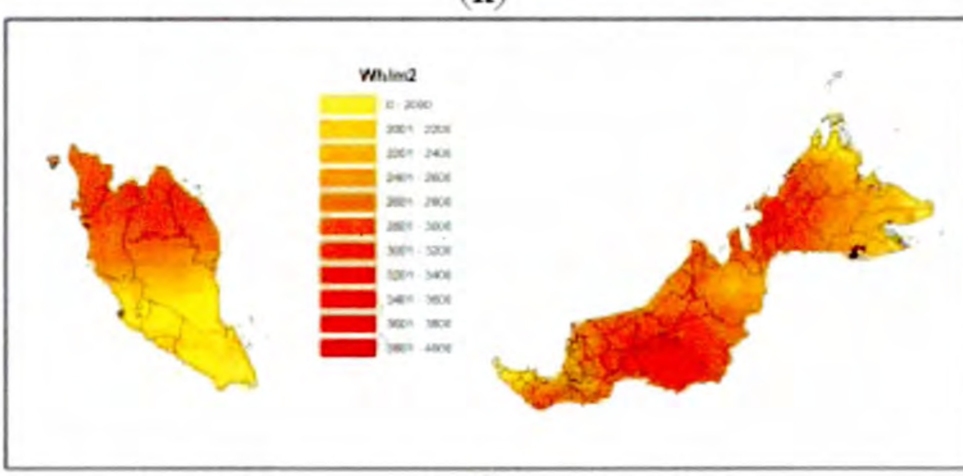
(i)



(j)



(k)



(l)

Figure 1.2(a-f): Monthly average daily diffuse solar radiation for Malaysia from January to December. (Azhari et al. n.d)

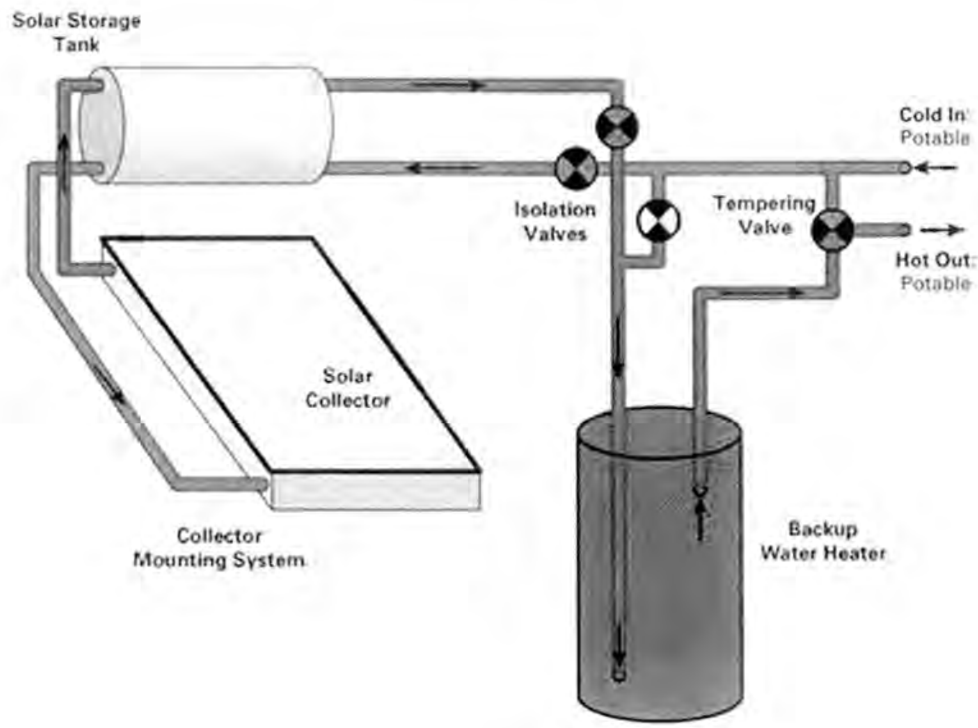


Figure 1.3: Solar water heater of thermosyphon with heating element taken from

http://www.reuk.co.uk/Thermosyphon-Solar-Water-Heating.htm/

Two main components in solar thermal energy system are solar collectors and thermal storage tank as shown in Figure 1.4. The storage tank require high thermal storage density with small volume, low construction cost and excellent heat transfer in order to absorb and release heat at desired rate as stated by Kim and Han (2015). Pump is used to increase the pressure of the water when there is less convection occurs during lower solar radiation received. The pump will starts to run when more water flow needed to the solar collector. A solar water heater that does not use a pump will mainly rely on the solar radiation energy in order for natural convection to occur in the system.

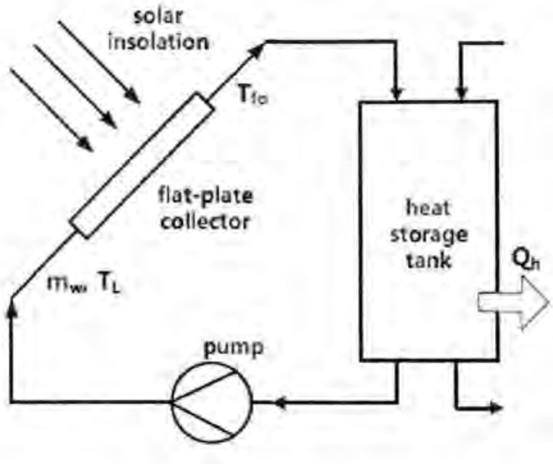


Figure 1.4: Schematic diagram of solar collector and thermal storage system (Kim & Han 2015)

As shown in Figure 1.5, the hot water load pattern was highest at 0800 hours and 1700 hours. The hot water usage in the houses starts at 0500 hours and ends at 2300 hours. These findings was found in research conducted by Abunnabi and Loveday (2012) using weather data for Tripoli Airport, Libya. Such hot water load pattern is almost similar to Malaysia as most Malaysians use hot water for bath before they starts their daily activities such as working and schooling. Other hot water needs is for consumption and washing clothes.

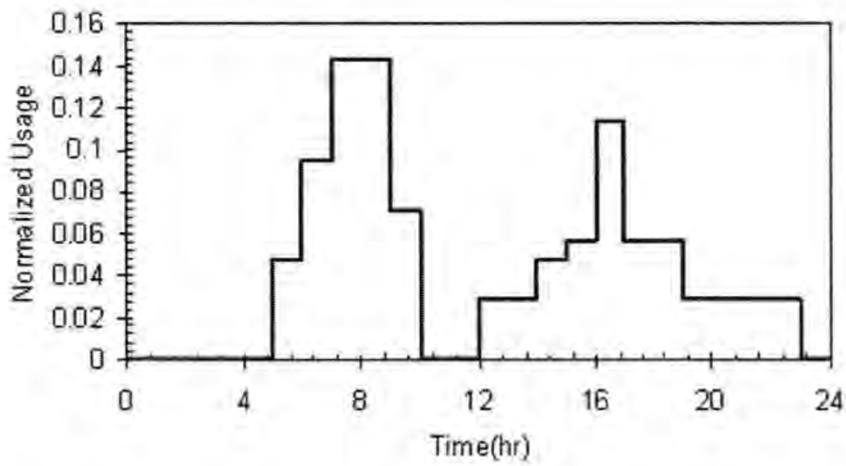


Figure 1.5: Hot water load pattern. (Abdunnabi & Loveday 2012)