THERMAL, ECONOMIC AND ENVIRONMENTAL ANALYSIS OF DOMESTIC SOLAR WATER HEATERS IN MALAYSIA

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ABSTRACT

Solar thermal utilization, especially the application of solar water heater technology, has developed rapidly in recent decades. Solar water heating systems are practical applications to replace the use of electrical water heaters. But the performance of these systems depends on weather and exhibit a nonlinear dependence. This makes it difficult to accurately analyze their performance by simply observing their response to short-term or average weather conditions. The purpose of this project is to show solar potential through contour mapping and do thermal, economic and environmental analysis of evacuated-tube, glazed and unglazed collector solar water heaters. The optimum performance of solar water heaters and their comparison among them is done to select right solar water heater according to the domestic hot water demands along with the calculations of resultant GHG reductions for the period of 20 years. Analysis showed that evacuated-tube, glazed and unglazed solar water heaters achieve solar fraction value of 1.0, 0.92 and 0.82 respectively. Evacuated-tube, glazed and unglazed solar water heaters show life cycle savings of 5200, 4730 and 4150 RM, and greenhouse gas reductions of 113,220, 104,162 and 99633 kg respectively. Optimal thermal performance is obtained by evacuated-tube solar water heater, which results in reduction of household greenhouse gas emissions, reduction of energy consumption and saves money on energy bills as compared to glazed and unglazed collector solar water heaters. Overall, all the types of solar water heaters give satisfactory performance thermally, economically and environmentally. Evacuated-tube collector solar water heater will serve the needs with maximum thermal output with extra liters of water without any auxiliary electric water heater installation and energy use. Glazed and unglazed collector solar water heaters will need extra installations of electric water heater and use of auxiliary energy, which in result increases the cost of equipment and

auxiliary energy for heating purposes as compared to evacuated-tube collector solar water heater.

ABSTRAK

Penggunaan termal suria, terutamanya penggunaan teknologi pemanas air suria,telah berkembang dengan pesat dalam dekad kebelakangan ini. Sistem pemanas air suria merupakan aplikasi yang praktikal untuk menggantikan penggunaan pemanas air elektrik. Tetapi prestasi sistem ini bergantung kepada cuaca dan menunjukkan suatu ketergantungan tidak lelurus. Ini menjadikan ia sukar untuk dianalisis prestasinya dengan tepat melalui pemerhatikan sederhana tindak balas terhadap jangka pendek atau purata keadaan cuaca. Tujuan projek ini adalah untuk menunjukkan potensi suria melalui pemetaan kontur dan melakukan analisis termal, ekonomi dan alam sekitar bagi pengumpul pemanas air suria tiub-dipindahkan, berlapis dan tidak berlapis. Prestasi optimum pemanas air suria dan perbandingan diantara ketiga-tiga jenis pemanas air suria dilakukan bagi memilih pemanas air suria yang tepat mengikut permintaan domestik air panas bersama-sama dengan pengiraanp engurangan GHG bagi tempoh 20 tahun. Analisis menunjukkan bahawa pengumpul pemanas air suria tiub-dipindahkan, berlapis dan tidak berlapis masing-masing mencapai nilai pecahan suria sebanyak 1.0, 0.92 dan 0.82. Pengumpul pemanas air suria tiub-dipindahkan, berlapis dan tidak berlapis masing-masing menunjukkan penjimatan kitaran hayat sebanyak 5200,4730 dan 4150 RM, dan pengurangan gas rumah hijau masing-masing kepada 113220, 104162 dan 99633kg. Prestasi optimum termal diperolehi dari pengumpul pemanas air suria tiub-dipindahkan dimana ia menghasilkan pengurangan pelepasan gas rumah hijau, pengurangan penggunaan tenaga dan menjimatkan wang pada bil tenaga berbanding pengumpul pemanas air suria belapis atau tidak berlapis. Secara keseluruhan, semua jenis pemanas air suria memberikan prestasi haba, ekonomi dan alam sekitar yang memuaskan. Pengumpul pemanas air suria tiub-dipindahkan akan memenuhi keperluan dengan keluaran termal maksimum dengan liter air tambahan tanpa sebarang tambahan pemasangan pemanas air elektrik dan penggunaan tenaga.

Pengumpul pemanas air suria belapis atau tidak berlapis akan memerlukan pemasangan tambahan pemanas air elektrik dan penggunaan tenaga tambahan, menyebabkan peningkatan kos peralatan dan tenaga tambahan untuk tujuan pemanasan berbanding pengumpul pemanas air suria tiub-dipindahkan.

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NOMENCLATURE

A_c	collector area
EC	energy consumption
F_R	modified collector heat removal factor
f	fraction of the monthly total load
GDP	gross domestic product
GHG	greenhouse gases
GIS	geographic information system
H_T	monthly average daily radiation
kg	kilogram
L	monthly total heating load
LPG	liquid petroleum gas
MTOE	metric ton oil equivalent
n	number of days
N	average day of month
NASA	national aeronautics and space administration
NGTP	next generation telemetric pattern
SRCC	solar rating and certification corporations
T_{ref}	empirical reference temperature equal to 100°C
T_a	monthly average ambient temperature
U_L	collector overall loss coefficient
UNFCCC	united nations framework convention on climate change
X	dimensionless group
Y	dimensionless group
Δ	temperature difference
$\overline{\tau\alpha}$	collector’s monthly average transmittance-absorptance

CHAPTER 1: INTRODUCTION

1.1 Background

Economic growth and social progress is building upon energy globally. Due to advanced growth of economy, users' requires more and more energy. At one side where fossil energy is becoming scarce day by day on the other hand it is causing pollution which in fact gives lift to ever-serious contradiction among energy provision, environment protection and economic development (Oh et al., 2010). Currently, fossil fuels are being used increasingly with improved quality of life, industrialization of developing nations, and rise of the world population (Rahman & Lee, 2006). The past research proved that the usage of fossil fuel does not only reduces its reserves, but it also impacts negatively on the environment that gives raise to health risks and the threat of global climate change (IEA, 2009).

Over the last decade, it became apparent that the world's resources of fossil fuels are beginning to come to an end. The estimation of energy resources reported that oil and gas reserves will come to an end roughly 40 to 60 years and coal reserves probably will last for another 200 years. According to International Energy Outlook 2009, World energy consumption will increase from 1.38×10^{23} kWh in 2006 to 1.62×10^{23} kWh in 2015 and 2.0×10^{23} kWh in 2030-a total increase of 44.2% over the projection period 2006-2030 (IEA, 2009).

Along with fossil fuels depletion, the global warming is the hot issue. History has shown a steady increase in the atmospheric GHG concentrations and has now risen close to 400 ppm from the pre-industrial level of below 300ppm as shown in Fig.1. Recent facts and predictions indicate shifts in climate variables. The climate in the mean and variance will be of rainfall and temperature, severe weather events, food and agriculture, manufacturing and prices, water availability, nutrition and health status (Eang, 2009). It is hard to predict indirect risks which are the result of the consequences but could impact worst. To fight with the fossil fuel depletion and global warming, renewable energy resources will play an important role in the world's future. The fossil fuels, renewable resources and nuclear resources are considered as three main categories of energy. Renewable energy sources can be used to reproduce energy, e.g. solar energy, wind energy, biomass energy, geothermal energy, etc. (Panwar, et al. 2011). The domestic energy requirements are covered by renewable energy sources that have potential to provide energy services with zero or almost zero emissions of both air pollutants and greenhouse gases. The most crucial tasks such as improving energy supply reliability and organic fuel economy, solving problems of local energy and water supply, increasing the standard of living and level of employment of the local population, ensuring sustainable development of the remote regions in the desert and mountain zones and implementation of the obligations of the countries with regard to fulfilling the international agreements relating to environmental protection are expected to resolve with the renewable energy development (REN21, 2011).

Malaysia is one of the most developed countries among the Association of Southeast Asian Nations (ASEAN) members, having population over 27.73 million, covering land area of 329,750 km^2 based on the latest census in 2008. The current decade has seen the Malaysian swiftly growing economy and currently Malaysia is emerging strongly from the global financial crisis. Malaysia’s real gross domestic product (GDP) has grown by an average of 5.08% per annum from 1991 to 2010 (Ahmad, et al. 2011). GDP growth of 10.1% in the first quarter of 2010 represents the fastest quarterly growth in 10 years. In future, fuel and the costs required for momentous imports to meet final energy demand in 2020 and rise in GHG emissions are the key future challenges faced by Malaysia, as the economic growth and development affect the increase in energy consumption (Chandran et al., 2010; Tick Hui Oh et al., 2010). Over the past 18 years entirety the primary energy supply has augmented progressively. In 2008, it reached 64

MTOE (Metric ton oil equivalent), which is an additional 200% boost since 1990 relatively which is high amongst developing countries. Other than that rapid industrialization and urbanization has resulted in increase in final energy consumption drastically (Oh et al., 2010). The government's vision of turning Malaysia into a humane industrialized country by the year 2020 will have a great impact on the usage of energy in the country. With the rise at an annual growth rate of 7.2% the final fuel consumption has struck 44.9MTOE from 1990 to 2008. Highest energy consumer is the industrial sector followed by transportation sector with a record of 19.1 MTOE in 2008, which mostly utilize the petroleum products. Fossil fuels are depletable as they are non-renewable energy sources. Energy security is going to be seriously issue because for the next 20 years, the potential energy demand is likely to have 5-7.9% annual growth rate. Being a developing country, Malaysia has no quantitative commitments under the Kyoto Protocol at present (Green Tech Malaysia., 2012). However, together with all other countries Malaysia is already committed under the UNFCCC to formulate, implement, publish and regularly update national, where appropriate, regional programmes containing measures to mitigate climate change and striving to low carbon economy and community through a variety of green policies and energy efficiency (EE) programmes in recent years (Oh et al., 2010). Government of Malaysia has formulated many climatic policies to cut down the greenhouses gases emissions. The target of these polices is to adopt an indicator of a voluntary reduction of GHG up to 40% in terms of emissions intensity of GDP by the year 2020 compared to 2005 levels. Total carbon emission for Malaysia in year 2006 was 187 million tones (6.9 tonnes/person, assuming total population of Malaysia 27 million). On April 2009 the National Green Technology Policy was launched for the development and application of products, equipment and systems to minimize degradation to the environment and has zero or low greenhouse gas (GHG) emissions. Recently Establishment of a Renewable Energy Fund from the

1% Feed in Tariff (FiT) is being administered by a special agency, the Sustainable Energy Development Authority (SEDA), under the Ministry of Energy, Green Technology and Water (KeTTHA) to support development of RE, which provides an annual GHG avoidance of 3.2 million tonnes. GHG emission reduction is dealt via various policy instruments such as CDM, stronger incentives for development of renewable energy and promotion of energy efficiency for productive use of energy (Ong et al., 2011; Poh & Kong, 2002).

Solar thermal energy is the most abundant type of renewable energy and is available in both direct as well as indirect forms. The Sun emits energy at a rate of 3.8×10^{23} kW of which approximately 1.8×10^{14} kW is intercepted by the earth. There is vast scope to utilize available solar energy for thermal applications such as cooking, water heating, crop drying, etc. (Yurismono, 1995). Solar energy has a vast scope for thermal applications such as cooking and water heater to meet the family needs and achieve a sustainable future. The utilization of solar water heater is estimated about 100L per day capacity which can mitigate around 1237 kg of GHG emissions in a year at 50% capacity utilization and in hot and sunny region it is about 1410.5 kg (Aye et al., 2002). In Malaysia, the monthly average daily solar radiation is 4000 - 5000 Whr/m^2 with the monthly average daily sunshine duration ranging from 4 hr to 8 hr (Gastli & Charabib, 2011; Juanico, 2008). Due to the favourable climate conditions in Malaysia, it has a high solar energy potential. The Malaysians are not well aware of the working of Solar water heaters (SWH), that is a big wall in replacing electric water heaters with latest solar heating systems that can meet the needs in inexpensive ways (Kadir & Rafeeu, 2010).

1.2 Solar energy basics

The word solar is derived from Latin that is used for sun, the powerful source to heat, cool, and enlighten our homes and businesses. The energy coming from sun in one hour is equivalent to the energy used in the world in one year. Many technologies transform sunlight into usable energy for different purpose. Solar water heating system, passive solar design for space heating and cooling, and solar photovoltaic for electricity are commonly used technologies for home and business appliances (Kalogirou, 2004). Naturally the sun heat the shallow water of a lake , river ,swimming pool or any other source of water that is exposed in sun, that is the reason why usually shallow water is warmer than deep water. Usually solar water heating system for buildings is composed of two parts, a solar collector and a storage tank (Berbash et al., 1995). The most common collector is called a flat-plate collector that is mounted on the roof. It consists of a thin flat rectangular box with a transparent cover that faces the sun. There are small tubes in the box that carry the fluid, such as antifreeze solution to be heated. An absorber plate is attached with tube, which is painted black to absorb more heat. The heat builds up in collector that heats the fluid in tube to make it hot. The storage tank holds the hot liquid that is produced by this process. It is well insulated and usually large in size. In closed loop systems where two fluids are used, the water gets heated through a heat exchanger from the circulating heating fluid (Ali et al., 2009; Assylkhanov, 2009).

Solar water heating systems are of two types the active and passive where the commonly used are active system. In active system, pumps are used to move liquid between the collector and the storage tank, while through gravity the passive system naturally circulates liquid.

More than 70 million households (most of them in China) as well as in many schools, hospitals, hotels, government, and commercial buildings are using solar hot water collectors. Solar resources to generate process heat in industry and domestic applications are also becoming as a growing trend (Panapakidis, 2009).

1.3 Objectives of the study

Among the developing countries, Malaysia is significantly endorsed to raise sustainable environment and reduce climate change. The Malaysian government is explicating the nation's energy policies since petroleum was obtained. The petroleum was adding to RE (Renewable energy) in its blended energy and supporting EE (Energy Efficiency). The new RE is awaited to feed and act-in tariff mechanism that will be initiated 2011. It will further enhance EE and RE responsiveness. Though on international platforms, Malaysia is extensively participating in propagating the idea of emission reduction and environmental protection that is root source of energy associated activities ratification of Montreal Protocol and Kyoto Protocol (Kadir et al., 2010).

However, Malaysia's energy sources primarily comprising of oil, natural gas, hydropower and coal and recently renewable energy sources such as solar power and biomass are being exploited (Poh & Kong, 2002).

Most of the states in Peninsular Malaysia throughout the year have greater solar radiations incidence that is very potential for solar energy applications (especially solar power plants). That's why there has been increasing interest in application of solar water heater in Malaysia (Chuah & Lee, 1982). Contour maps are also developed in this work to know feasibility of solar hot water projects in different areas of peninsular Malaysia. The payback time for solar water heating now makes solar energy financially viable for the majority of domestic applications. An extra financial incentive is that your property will increase in value by installing a solar energy system and you will be less affected by future energy price rises (Solangi et al., 2011). But still there are confusions and uncertainties in long term usage of the solar water heaters found in public and government. Thus, this study comprises the following objectives.

- To estimate the potential of the solar radiation in Malaysia based on NASA database.

- To calculate and analyse the thermal and economic output of the domestic water heaters
- To find the resulting amount of greenhouse gases (GHG) reductions from the replacement of conventional heating system with solar water heaters.

1.4 Scope of the study

This dissertation deals with the long term assessment of solar water heater in Malaysian climatic conditions dealing with thermal output, economic output and GHG reductions. At first, it is needed to collect the data of solar energy from the Malaysian Meteorological Department and NASA weather database. Three year solar irradiation data from Subang/KL meteorological station was collected which was used for the accuracy of the solar water heating systems analysis (Syafawati et al., 2012).

These are the scopes of the study:

- Solar irradiation data from NASA database is analyzed using ArcGIS9.3 tool producing contour mapping for peninsular Malaysia.
- Based on the finding, from 4.20 kWh/m^2 to 5.45 kWh/m^2 annual average daily solar irradiations are obtained by Malaysia, which indicates that solar energy is paramount for RE.
- Solar thermal output is found out by using f-chart software and solar fraction or total hot water demand contribution is calculated from the total requirement of energy needed to heat the water from the solar water heater.
- Long term economic analysis is done to understand the overall performance of the solar water heaters in domestic applications which will help end users and government to decide whether to go with these system or not.
- Using emission factor of electricity and formula in Malaysia, amount of greenhouse gases will be found out which is being avoided by the use of solar water heater by replacing conventional electric water heaters.

1.5 Outline of the study

This dissertation comprises five chapters. The contents of last four chapters are described briefly here:

CHAPTER 2: This is the literature review chapter and in this chapter the present work, which have been done in this field has been highlighted. The literature review of this study has been divided into four parts namely types of solar water heaters and technologies, review on solar radiations mapping, review on thermal and economic output and review on greenhouse gases reduction.

CHAPTER 3: Methodology chapter contains mainly three parts. In this chapter methodology is described separately for the objectives of the dissertations. Where, firstly the method to use the ArcGIS software is used to develop contour maps on solar radiation in peninsular Malaysia. Secondly, methodology to analyze solar water heaters for 20 years for their thermal and economic outputs through F-Chart software analysis is explained. Thirdly, methodology for greenhouse gases calculations, which are expected to be avoided after the replacement of electric water heaters with each type of solar water heaters, is explained.

CHAPTER 4: This is the result and discussion chapter. In this chapter, the results of the solar radiations mapping, thermal and economic analysis of three types of solar water heaters for 20 years and greenhouse gases reduction are presented. Then obtained results are discussed thoroughly.

CHAPTER 5: Conclusions and suggestions chapter. In this chapter the main outcome of the dissertation has been given very precisely. The main outcomes of the solar radiations maps for peninsular Malaysia, thermal and economic analysis of solar water heaters done through F-Chart and calculations of greenhouse gases have been given comprehensively. The worthy suggestions have been given for the future work.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

Solar energy is the best option to overcome the greenhouse effects on global warming and depletion of fossil fuels. Existing studies reviewed have indicated that the share of solar energy in global energy supply mix could exceed 10% by 2050 (IEA, 2009; REN21, 2009). Solar thermal water heating systems, which have potential to contribute clean renewable energy in wide range of systems are simple and in ingenious source of energy. It is forecasted by experts that by 2010 the number of solar water heaters installed in China will be same to the thermal equivalent of electrical capacity of 40 large nuclear plants (Han et al., 2010). About 1.5 million solar water heaters are used at homes and business in US as reported by Environmental and Energy Study Institute (EESI). Solar water heater systems can work in any climate and it is estimated by EESI that there is sufficient access of sunlight to 40 per cent homes in U.S. Therefore, further 29 million solar water heaters could be installed in U.S. Globally it is understood that solar water heaters have capacity to produce energy more than 140 nukes. In 2005, solar water heaters saved the consumption about 70 million barrels of oil and cut carbon emissions by 29, 000,000 tons. It is not a bad technology, primarily born in America but now used almost everywhere and will celebrate its centennial next year; it is so simple and can be easily built in tool shop (Sinyon, 2012).

In this dissertation, literature review presents an overview on solar radiations, contour mapping and potential for the solar water heating systems in Peninsular Malaysia. And on the basis of these solar radiation data three types of certified commercial solar waters will be analyzed through thermal and economical performances. Lastly, amount of greenhouse gases which is expected to be avoided with the replacement of these solar water heaters with conventional electric heaters will be calculated.

2.2 Literature review on solar collectors and SWHs

A solar thermal collector is a system which is designed to collect heat by absorbing solar radiations**.** The most common types of solar collectors are glazed flat plate, unglazed flat plate collector and evacuated-tube collector. Solar water heating (SWH) or solar hot water (SHW) systems comprise several innovations and many mature renewable energy technologies that have been well established for many years. SWH has been widely used in all over the world (Morrison, 1997; UFC, 2004). This chapter deals with relevant types of solar collectors and solar water heating systems in extensive format.

2.3 Types of solar collectors

Solar thermal technology is subject to continuous development and improvement. Obviously, the performance of a system relies on the performance of each individual component and the optimal arrangement of these components. For the example of the solar collector, the evolution of the technology is demonstrated from 1980 to the present. In practice different kinds of solar collectors for hot domestic water heating worldwide are used. Some of them which are commonly and successfully used for the domestic hot water purpose are presented in following sections (Abdunnabi, 2012).

2.3.1 Glazed flat-plate collectors

Glazed flat-plate collectors are commonly known as liquid-based and air based collectors. The moderate weather is ideal for such collectors and for winter season the required heat for such applications is 30-70°C. Heating of domestic and commercial hot water, buildings, and indoor swimming pools uses liquid based collector. Heating of buildings, ventilation air and crop-drying use the air-based collectors (Kreider & Kreith, 2011).

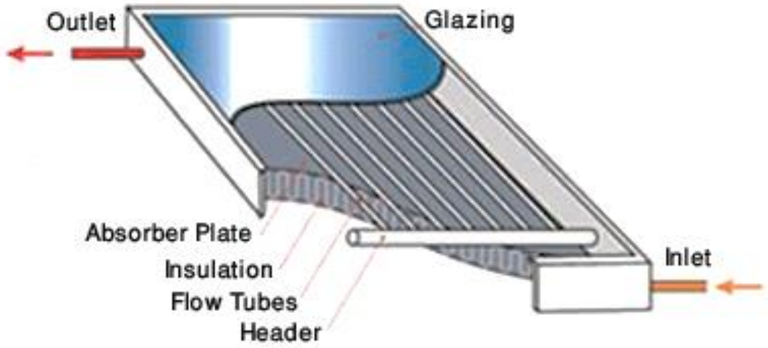


Figure 2.1 Glazed flat plat collector (Ab Kadir et al., 2010).

Sunlight is efficiently transformed into heat by using flat absorber in such kind of collectors. A plate is used between a glazing (glass pane or transparent material) and an insulating panel to minimize heat lost. The glazing is selected to pass maximum sunlight through and reach the absorber.

2.3.2 Unglazed flat-plate solar collectors

Unglazed flat-plate solar collectors are neither insulated nor covered with glass. These collectors are best suited for low temperature and demand temperature is 30°C. Unglazed flat plate collectors are more in number than any other solar collector installed in North America. The market for these collectors is primarily heating outdoor swimming pools along with other markets as seasonal indoor swimming pools, water used in fish farming and preheating water for car wash. For these collectors, there is some other market potential such as summer camps at remote and seasonal locations (Watson, 2011).

Figure 2.2 Unglazed flat-plate collectors (RETScreen, 2011).

Unglazed flat-plate collectors are usually made of black plastic that is absorbent of ultraviolet light. Therefore without glazing a large portion of the sun's energy is absorbed. However, when it is windy and not warm outside, a large portion of the heat absorbed is lost due to no insolation. They transfer heat so well to air (and from air) that they can actually 'capture' heat during the night when it is hot and windy outside.

They are sensible to loose and capture heat form the atmosphere. Therefore, they lose heat at the day time when overheated and capture the heat from air at night time.

2.3.3 Evacuated-tube collectors

Evacuated-tube collectors are mostly used in residential applications that require higher temperatures to heat water. Sunlight changes to heat once it enters through outer glass of tube and strikes the absorber tube. The produced heat is then transferred to liquid that flows into absorber tube. The collector is based on parallel rows of transparent glass. Each tube carries an absorber tube along with selective coating. In these types of solar collectors tubes can be either added or removed. The pattern of the tube allows air to evacuate from the space that is generated between the two tubes. In this way both conductive and convective heat losses are extinguished due to no air to conduct heat nor to circulate and form convective losses (Chong et al., 2012).

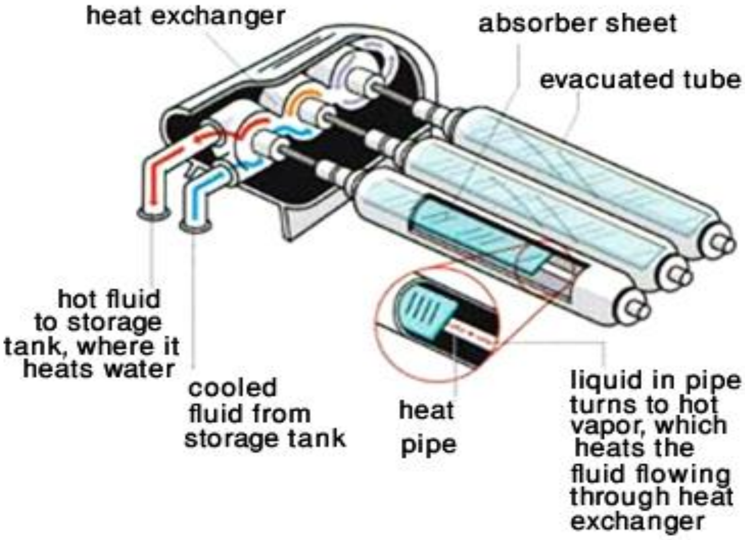


Figure 2.3 Evacuated-tube collector (Solar Tribune, 2012).

There is variety of evacuated-tubes collectors. Few of collectors used a third glass tube inside the absorber tube, where some of them contain configuration of heat transfer fins and fluid tubes. To get additional sunlight the reflectors are used behind evacuated tubes. This way collector work more efficient and offering better performance in both diffuse and beam radiation. Its shape also impact positively, such as circular shape absorbs the sunlight perpendicularly for most of the day (NREL 1996). The drawback of using such tube is that such collectors are expensive comparatively to flat plate (Budihardjo & Morrison, 2009).

2.3.4 Concentrating collectors

Concentrating collectors uses mirror surfaces to gather sunlight on an absorber called receiver. In the presence of direct sunlight these collectors can achieve high temperature. The small absorber has the ability to collect sun’s energy on large scale to achieve high temperature. Two different ways can be adopted by concentrating collectors. The most advantageous is called” focal line” in that sun’s energy is concentrated along a thin line. The second method collects sun’s energy onto a “focal point”. By the use of first method, a heat transferred fluid flows through the receiver and absorbs heat.

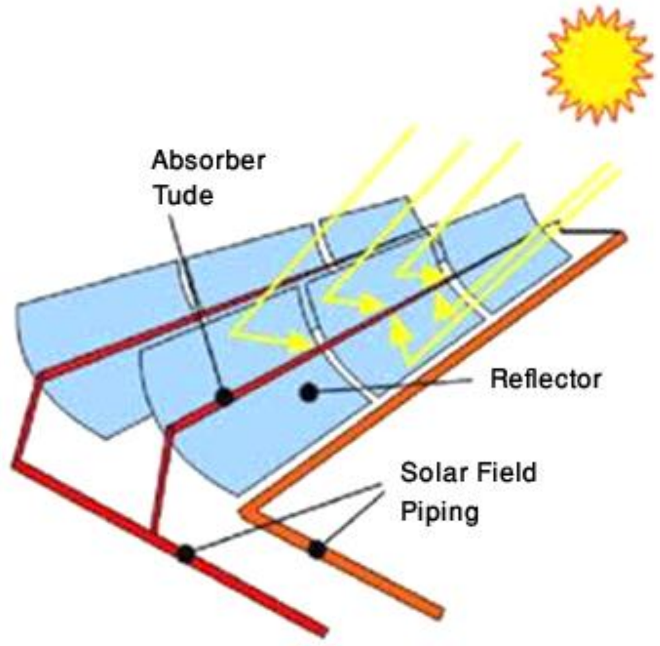


Figure 2.4 Concentrating collector (Ab Kadir et al., 2010).

Concentrating collectors can reach much higher temperatures compared to flat plate collectors. In cloudy weather, however their performance is affected due to the only focus on direct radiation. In order to increase the collector’s performance, the tracking mechanisms are used to keep them focused on the sun. There are single axis trackers moving from east to west, dual axis moving from north to south. There are also passive trackers using Freon on supply the movement. Due to high cost and frequent maintenance of tracking mechanisms, concentrators are mostly used in commercial applications. To fulfill the needs of residential applications the parabolic trough collector with simple tracking mechanisms are used, which are less expensive than dual axis that serves the hot water or space heating purposes as shown in Figure 2.4.

2.4 Types of solar water heating systems

The Solar systems for water heating can either be passive or active. If we look at a system that is passive it will be having no pump; on the other hand active uses a power driven pump for circulation of heat- shift fluid. The volume of the heated water produced by the heater is dependent on the size, kind of system, on the area exposed to the radiations of the sun and the positioning and the slope of collectors. These systems are even considered as direct (“Open loop”) or indirect (“Closed loop”). An indirect system utilizes a heat- shift fluid for instance antifreeze or water to assimilate heat and then an exchanger for the transfer of heat to the water in the home. While the household water passes through the collector in a direct system (Khan & Obaidullah, 2007).

2.4.1 Active systems

Such systems use valves, electronic pumps, and regulators for the circulation of water or the heat-shift fluids via collectors. These are costly but are more efficient when compared to the passive systems. Active systems usually are simpler to retrofit in comparison with passive systems because the storage tanks are not needed to be placed close or above the collectors but simply as they employ power, they will not function in a very electrical power outage. These systems cost vary from RM 6,000 to RM 8,000.

2.4.2 Open-loop active systems

In open-loop active systems household water is circulated by the pump through the collectors. Though this design is low in operation cost and efficient but quickly malfunctions because of corrosion and scale when hard or acidic water is used. These systems are not feasible for the climates where temperatures reach freezing point for long times. Therefore these systems can be installed in mild and rarely freezing temperature considering freeze protection.

Recirculation systems are a specific type of open-loop system that provides freeze protection. Recirculation open loop systems are provided with freeze protection, where the warm water from storage tank is circulated through collectors and piping exposed to freezing temperature. (Lenel & Mudd, 1984). Recirculation systems are only installed at the places where temperature reaches freezing point once or twice a year at most. Activating the freeze protection more frequently wastes electricity and stored heat. Of course, when the power is out, the pump will not work and the system will freeze. To guard against this, a freeze valve can be installed to provide additional protection in the event the pump does not operate. In freezing weather, the valve dribbles warmer water through the collector to prevent freezing (Hossain et al., 2011). There is no heat exchanger, which allows efficient heat transfer directly to the water. The system operates at standard line pressure. It is simple to add capacity to the system if demand changes. The system integrates easily with existing systems (NREL, 1996).

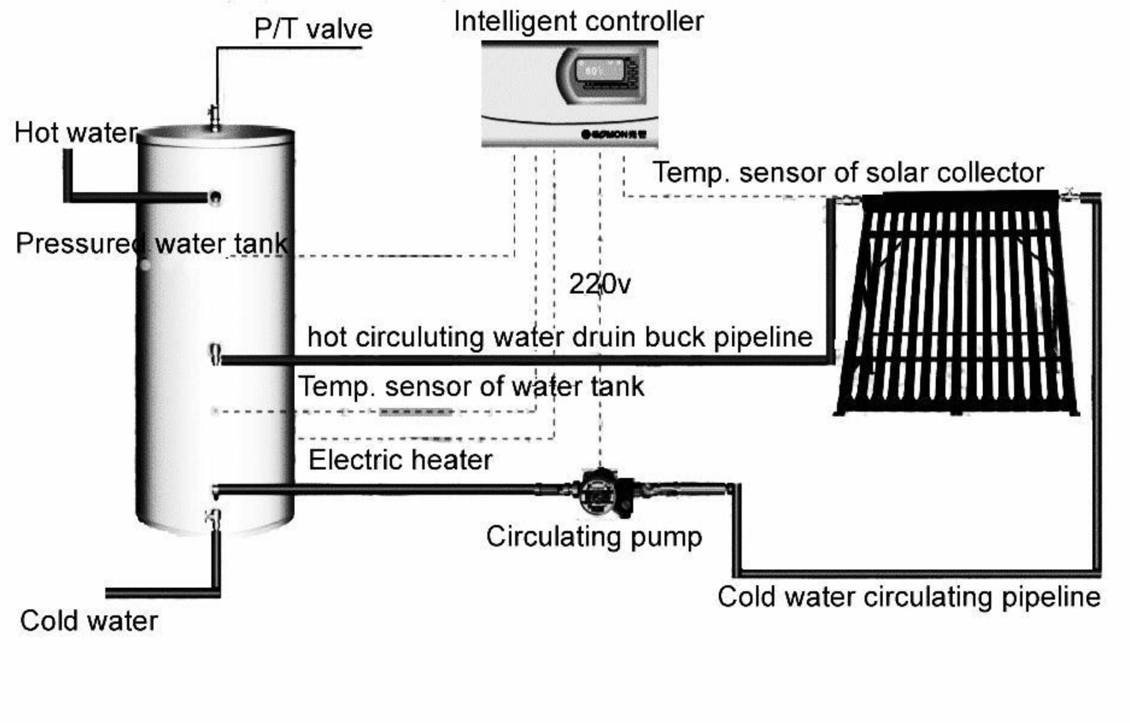


Figure 2.5 Open loop active system (Sharan, 2009).

Active closed loop system and Closed Loop Solar Heating Systems are suitable for single and multiple solar heating application systems, e.g. domestic solar water heating, solar water heating hot tub, solar swimming pool heating or solar space heating systems. The Closed Loop Solar Systems are suitable for areas with questionable water quality and all climate conditions. The Closed Loop Solar Heating Systems are the preferred option for extremely cold areas (Veeraboina & Ratnam, 2012).

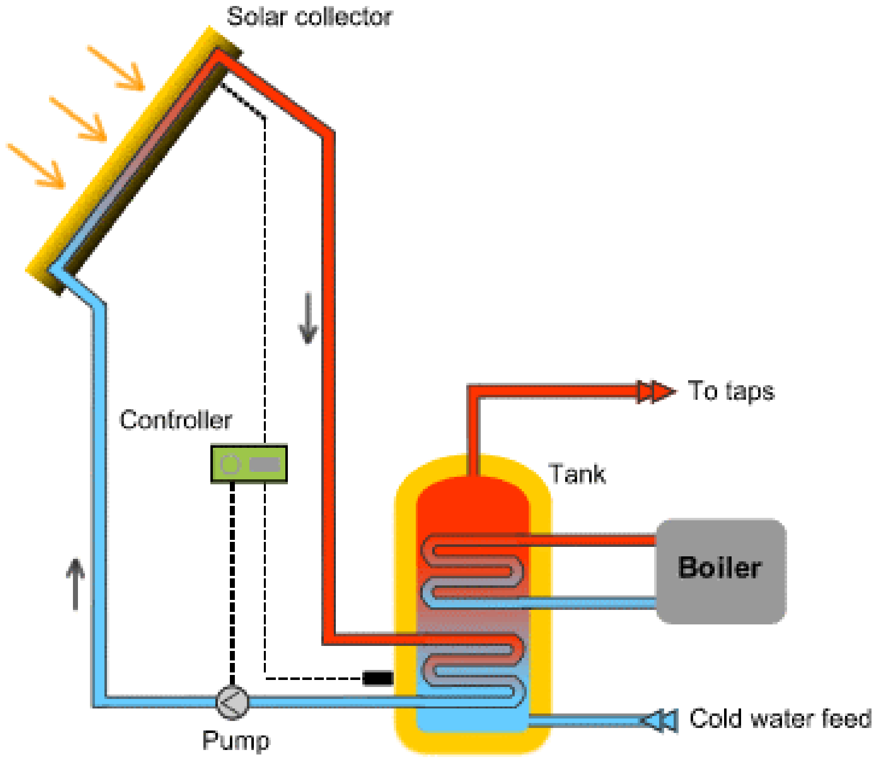


Figure 2.6 Closed loop active system (Assylkhanov, 2009).

2.4.3 Closed-loop active systems

These systems push the heat-shift fluids (typically a mixture of glycol-water) through the collectors. Heat exchangers shift the heat from fluid to the domestic water in the tanks. For prevention of contamination double- walled exchanger (heat) are used. A few codes need double wall when anything else is used as heat- exchanger fluid instead of the domestic water. Such systems with glycol are preffered in regions where the climate is cold which is because they provide protection from freezing. Nonetheless systems with glycol are a little bit expensive to purchase and setup and also the glycol is to be checked every year and ought to be replaced after 3 - 10 years which is dependent on the quality of glycol and the temperatures of the system. Water is used as the heat-shift fluid present in collector for drain-back systems. For the circulation of water a pump is used. Water drains to the storage and heat-exchanger by gravity. Collectors empty when pumps are not working, this affirms the protection of the antifreeze and allows shutting down of the system when it becomes too hot in the tank (UFC, 2004b).

2.5 Solar water heating application markets

Solar heating application markets are distinguished on the basis of the use of this system. Most communal application of solar water heating is swimming pools and hot water systems.

2.5.1 Service hot water

There are many applications of hot water systems. The most usual application is domestic hot water systems (DHWS), commonly traded as typical kits.

Figure 2.7 Solar Domestic Hot Water (Thermosiphon) Systems in Australia.

There are many other places where solar hot water is used such as process hot water for institutional and commercial applications, including apartment buildings and multi-unit houses as shown in Figure 2.7 and in health center, hospitals, schools, office buildings and restaurants etc. Service hot water is also used in small commercial and industrial applications e.g. laundries, car washes and fish farms (Sharan, 2009). Large industrial loads and district heating networks are the other uses of the solar water heating systems on massive scales (Panapakidis, 2009). Such huge systems can be seen installed in northern Europe and other locations.

Figure 2.8 Housing Development, Küngsbacka, Sweden.

2.5.2 Swimming pools

The temperature of the water in pools can be regulated using solar water heating systems, by which energy costs are saved as well extending pool season. The basic working is that these systems match with solar heating systems, while using difference that the swimming by itself acts as place for heat storage. Regarding outdoor swimming pools, an adequate type of solar water heater could substitute as a standard heater; water is pumped directly through the collectors by the filtration system. Applications to pool can vary in range from smaller summer season for outside swimming pools.

The demand for solar heating of pools is high. For instance, in the U.S the mainstream sales of solar collectors are for the unglazed panes for heating process. There are some factors that could assist to find out that a specific project has equitable market and probability for effective implementation. All these factors compromise of a strong demand of heated water to cut down the relative significance of the costs for the project, Expensive energy, unreliable common energy source and an immense environmental interest from stake holders and customers.

2.6 Review on solar radiation contour mapping

To design a solar project, the global solar irradiation on horizontal surface is required as primary information. For solar energy system design the solar irradiation intensity at a given location is indeed important. Solar radiation data plays an important role for the making solar-energy conversion devices. Though, without sufficient information of feasible locations and accurate database of renewable energy applications in the country, investing in renewable energy projects will not be profitable and efficient. This goal can be attained for multiple regions in peninsular Malaysia by producing contour maps through solar radiations.

The fast growing market of solar energy in many countries is contributed by innovations in solar radiation mapping. It is not only solar-panel suppliers and end users but also financiers and developers of power projects on large scale, industry experts and governments are benefited by the developed solar radiation maps. In addition, precise solar maps, with the present worldwide credit crisis and the perilous world and local economy are increasingly important as investors seek profitable assurance. By better information we mean quick decision, saving money and bringing renewable-energy resources into more and quick production. Therefore it is very crucial to find a right location to install solar-energy systems. Developing solar radiation maps like a given region means to create illustrations, to reveal the geographical distribution of solar radiation and to cover that particular region. Solar-energy potentials of specific region are demonstrated by a solar radiation map, and it also helps in best site selection for a solar energy project. Solar radiation data obtained from metrological stations can generate a solar radiation map. However due to insufficiency of metrological stations such a method is not applicable to many parts of the globe. One solution is to create solar radiation maps by using satellite-derived solar radiation data. There are a lot of places in the world, which don’t have sufficient metrological stations either because of high cost or topographic difficulties. These facts make surface measurements are sparse or nonexistent. East Malaysia is one of the regions, which have difficult topography and have only three meteorological stations installed. There are only ten stations working in Peninsular Malaysia, the data from these stations are not sufficient to demonstrate precise solar radiation potential through contour maps, hence for this region it is better to use global NASA database as alternative choice to get precise maps.

Cogliani et al., (2008) produced hourly maps of irradiance and monthly average daily maps of irradiation both global and direct normal using the physical model SOLARMET, developed in ENEA. In these maps, the data necessary for selecting the sites to install solar thermal concentration power plants are present. The deep lack of solar data in Italy, in particular direct solar radiation data, has been overcome.

Ineichen (2000) proposed a model to retrieve the direct irradiance from GOES satellite data by using generalized cloud indices. A root mean square difference (RMSD) of 50% for hourly values was obtained through the comparison between satellite-derived direct irradiance and that obtained from measurements.

Serm (2010) proposed well established model that utilized satellite visible image for deriving the global and irradiance. A global-to-direct irradiance conversion model is used to derive direct normal irradiance. Hourly satellite data was the base for calculation of satellite derived irradiance. The discrepancy of the range of 112-207 W/m^2 were noted when measured with 13data sets from measurements in USA, in terms RMSD between the measurements and the direct normal irradiances derived from GOES-East and GOES-West satellite. (Vignola, 2007) found the RMSD of satellite-derived direct irradiance value was 41% after testing this model against one year high-quality data from Kimberly, Idaho (USA).

Schillings et al., (2004) have formulated a method that helps to derive the high resolution direct normal irradiance from METEOSAT satellite data. For the first time, broadband direct normal irradiance under cloud-free sky condition was calculated based on the said method. Taking into account the attenuation due to clouds index derived is used from the visible channels and infrared of the METEOSAT satellite. Finally obtained is the direct normal irradiance under all sky conditions via the information on DNI_{clear} and cloud attenuation. The validation of this method was performed in the Arabian Peninsula against direct normal irradiance measurements. Half-hourly slots of the visible and infrared channels MTSAT satellite of the year 2000 were used for the validation. It was reported that the values of RMSD between the satellite-derived and measured hourly irradiance at eight sites for all sky conditions were in the range of 26.6–44.6%.

Martins et al., (2007) have introduced satellite-based radiation model named “BRASIL-SR” in their report on the solar and Wind Energy Resource Assessment (SWERA) solar radiation resource maps of Brazil from GOES-East satellite data. Satellite-derived effective cloud cover index (CCI), and the direct normal irradiance were computed from atmospheric and cloud transmittances by calculating the surface global solar radiation by using this model. In this regard, the cloud transmittance was also derived from CCI and the said calculation is derived from hourly satellite data. The RMSD between ground-based measurements and direct solar irradiation values provided by the BRASEL-SR model was 23.9% (Serm, 2010).

Al-Lawati et al., (2003) developed RBF models for estimation of the solar radiation and clearness index for a location given its longitude, latitude altitude and number of sunshine hours, as well as the month of the year. Contour maps were plotted by the generated data using these models for the solar radiation and clearness index over Oman. These parameters can be obtained from these maps in any location in Oman.

The main aim of this work is to show how we can produce a solar radiation contour maps for regions where no, or insufficient meteorological stations are situated. Also, this work will be very helpful for countries with difficult topography or poor economy. In the present work the case of study will be focused on East Malaysia because it has insufficient meteorological stations.

2.7 Literature review on F-Chart method, solar savings fraction and economics

Different design methods have been developed for designing solar energy systems, which ranges from detailed simulation, simple designing methods such as f-chart method to rule of thumb. Many analyses have been done using the f-chart method in designing liquid solar heating systems due to its simplicity and ability to estimate the fraction of total heating load supplied by solar heating system. This method is widely used in designing both active and passive solar heating systems, especially in selecting the sizes and type of solar collectors that provide the hot water and heating loads. For the design of passive and active solar heating systems, F-Chart is one of the analysis methods, which is specially used for selecting the type and size of domestic hot water (DHW) and heating solar water collectors (Okafor, 2012). It was Dr.Sanford Klein who developed F-Chart method as part of his Ph.D thesis with title of "A Design Procedure for Solar Heating Systems", 1976.. The F-Chart is designed by TRANSYS by simulating a huge number of detailed simulations. This method basically contains correlations simulations results (Klein, 1973). In f-Chart method, system performance is expressed in terms of f (Solar Friction), which is the fraction of the heating load supplied by solar energy during each month. The relationship between f and the dimensionless variable X and Y simulates the water heating systems. One year after Ph.D thesis of Klein in the book by Beckman 1977, the first publication entitled as "Solar Heating Design by the F-Chart Method" was published. Two values are necessary for F-Chart to describe a solar collector, which are intercept (FR $\tau\alpha$) and solar collector thermal performance curve slope (FRUL, W/m^{2}C) from standard collector tests (Okafor, 2012). Whillier introduced the parameters FRUL and FR (τα) in 1953. For the development of the φ concept i.e. Utilizability, Hottel and Whillier in 1955, and Liu and Jordan in 1963 also introduced these parameters, where, fraction of total incident radiations on horizontal surface is calculated. (Whillier, 1953) developed the φ concept, which was later use for as location-dependent, monthly-average hourly utilizability by (Hottel, 1955). Liu and Jordan (1963) then generalized the Whillier's φ concept to location-independent monthly average hourly utilizability. For the solar domestic hot water and solar space heating, flat plate collectors have been used. About 70 years before the introduction of utilizability concept by Whillier for flat plate collector system, there the idea of flat plat collectors. Later in his work, tellier built tilted flat plate collector system, which heated amomia for driving a solar water pumping system and was for heating. The Methodology for forecasting the flat plate collector performance which ultimately led to the development of F-Chart Solar Analysis system was first reported in 1942 by Hottel et al. With the advent of computers in the early 80's along with the evolution of various platforms for programming languages, the F-Chart method development was initiated in mainframe computers as a FORTRAN program. The consolidated F-Chart combining all the conceptual phases was released in the 4th Version from the Solar Energy Laboratory at the University of Wisconsin, Madison (Beckman et al. 1982). Later next year the 5th version of F-Chart was written by (Klein & Beckman, 1983) on a microcomputer based BASIC language. In lieu of FORTRAN, the BASIC version also evaluated passive solar systems and solar-heated pool systems, including pool energy losses except for analysis comprising of heat pumps. With the advent of Windows, after a decade in 1993 Klein and Beckman again released F-Chart method version 6.17 which gave identical results to version 5.6 programmed in BASIC running under disk operating system (DOS) used in conjunction to ESL’s eCALC emissions calculator.

2.8.1 Solar saving fraction

In dealing with the solar energy, it is understood that the solar fraction (f) or solar savings is the amount of energy rendered by the solar technology bifurcated by the total energy necessitated. Thus, for no solar energy utilization, the solar savings fraction thus is zero to 1.0 for all energy provided by solar. For each particular system, the solar savings fraction is dependent on several factors mentioning few are: the load, storage size, the collection and the operation and the climate. For instance, a similar solar-thermal water heating system installed in a single family house in Arizona might have f =0.75 (75%) and the same in a much colder and cloudier climate, like Pittsburgh, PA, might only have a solar fraction of f =0.3 (30%) or so. Thus, a greater level of care is required in designing such systems, and in evaluating their economics (Simonsa & Firth, 2011).

Therefore energy conservation measures should be employed for increasing the solar savings fraction before expanding the size of the solar energy collection system. This action helps reducing the need for hot water or space heating. The Simple Solar domestic water heater provided hot water to a 250 square meter family home in Calgary, Alberta. It featured a 300 liter water tank and three evacuated-tube solar collectors mounted on a south facing wall (Tripathi & Tiwari, 2006). The solar collectors were partially shaded during the winter months by a neighboring house. “We are very proud that even with shading our solar domestic water heater achieved 74% solar fraction”, said Jackman. Data collected by Simple Solar Heating is displayed in Table 2.1.

Table 2.1 Domestic water heating analysis, Calgary home (RETScreen, 2011).

Calgary home	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
DHW energy used (MJ)	1,662	1,488	1,700	1,638	1,581	1,311	1,304	1,155	1,129	1,332	1,394	1,327	**17,021**
Solar energy collected (MJ)	690	1,018	1,119	1,437	1,155	939	1,380	1,195	1,742	1,289	761	636	**13,761**
Solar energy utilized (MJ)	690	1,018	1,119	1,437	1,155	939	1,304	1,155	1,129	1,289	761	636	**12,633**
Solar fraction (%)	42%	68%	66%	88%	73%	72%	100%	100%	100%	97%	55%	48%	**74%**
Highest solar energy day (MJ)	58	76	83	89	70	55	62	72	83	78	65	38	
Highest solar tank (°C)	45	70	64	63	60	54	62	71	75	66	56	41	
Highest ambient outside (°C)	15	16	17	10.7	25	29	32	34	33	22	15	14	
Lowest ambient outside (°C)	-14	-22	-23	- 5	3	8	9	8	5	-3	-15	-11	
DHW used (L)	9,194	8,769	9,830	9466	9,105	8100	8,955	9,0778	8,245	9,150	8,490	8,543	**106,928**
Highest daily DHW (L)	512	471	519	493	416	395	420	476	427	513	415	474	
Lowest daily DHW (L)	154	213	204	142	121	165	189	125	6	169	176	136	
Average daily water used (L)	**297**	**313**	**317**	**316**	**294**	**270**	**289**	**293**	**275**	**295**	**283**	**276**	**293**

Solar fraction changes seasonally, because it is typically expressed in terms of percent of total load met and it varies between 0% (no SWH system) and 100% (all energy supplied by the SWH system). The SWH system may not meet the daily hot water demands in winter season, while in summer season the system may save more energy than the required one to satisfy 100% hot water needs. This parameter will change geographically.

These seasonal variations in the solar fraction are also important. There will be considerable variation in the solar fraction for a given location from month to month, depending on the amount and consistency of the solar resource over the course of year. For example, for USA, Arizona and Florida have a relatively constant solar fraction (corresponding to little seasonal variation in annual solar resource), while in Oregon and Washington, the solar fraction varies from less than 40% between October and February to more than 70% between May and September. Factors that contribute to this seasonal variation in solar fraction include cloud cover, precipitation, and ambient temperature. Oregon and Washington have a relatively cloudy winter, which significantly decreases the solar fraction during these months. Additionally, cooler ambient temperatures yield lower inlet water temperatures and require more energy for heating. A system that has a solar fraction of 100% during any time of the year is oversized, and curtailment occurs, showing that the more solar energy is available than the required one to be utilized by the system. The amount of energy curtailed is reduced by a smaller system size.

As far Malaysia is concerned, generally, there are two distinct seasons. Generally, there are two seasons in Malaysia; dry and rainy season. The dry season occurs during the south-west monsoon from May to September of the year, while the northeast monsoon brings the rainy season to the country from mid-November to March. Malaysia is mostly warm throughout the year with temperature ranging from 21 to 32 Celsius in the lowlands. Because of such trend (RAMLI, 2010) of weather there is no significant change in solar fraction in Malaysian weather throughout the year. If good solar system, with good capacity ranges of hot water, not even auxiliary energy is needed at all.

2.8.2 Economic analysis

Economics play a central role in any customer's decision to purchase a solar water heater system. Home owner or a corporation is unlikely to buy a solar energy system if they know that it is beneficial in terms of finance and environment. Noticeably, economic is the focal point for solar based power Generation Company to ensure profitability to their shareholders and themselves. The guidance is provided to illustrate the procedure for carrying out a Life Cycle Cost (LCC) economic analysis towards energy solutions (Eang, 2009). Accounting concept is also presented for financial support in an economic analysis, and rising issue to numerous policy and other decision makers. The “real example format" and links to required resources initiated the aim is to illustrate the types of practical considerations and required resources for inclusive, yet simple comparison of the economic and environmental cost of alternatives (Ammar et al., 2009; NREL, 1996). For helping the number of variables that can control an economic analysis of SDWH, the following list is considered:

a) Performance variables

- Solar energy availability
- outside air temperature and cold water temperature
- Orientation and collector tilt (varies with architectural design, aesthetics)
- Shading collector (which varies with shade from building and/ or site objects)
- Hot water usage; usage timing (varies by family size and habits)
- Hot water release temperature (changes from 50-70 C)
- Type and size of Auxiliary water heater (varies considerably)

- Type and size of solar energy system (varies considerably)

b) Economic variables

- Current and future fuel costs
- Current and future rate of inflation
- “Cost of capital” or distance rate. It is normally the interest rate, the home owner earns to lend (or pays to borrow) money; the term is also referred to as “time value money” by investors.
- Homeowners income tax rate (varies with income)
- Financing timings (interest rate, loan period, etc.)
- Investment time period (duration period that homeowner intends to live in home, credit period, etc. depending on individual investment considerations)
- System replacement and maintenance costs over time

According to the EESI, residential solar water heater systems cost between RM4,500 and RM10,500 as compared to RM450 to RM1350 for electric and gas heaters (Ali et al., 2009). Solar water heaters pay for themselves approximately four to eight years by saving natural gas and electricity. Similar to conventional systems- Solar water heaters last between 15 and 40 years- so after the initial payback period is up and about, zero cost actually means having free hot water for coming years (Gan & Li, 2008). The Americans has offered homeowners tax credit of up to 30 percent (capped at RM 6,000) in 2005. The system must be certified by the Solar Rating and Certification Corporation and swimming pool or hot tub heaters are not covered under credit (Kalogirou, 2009; Ying & Li Hua, 2006).

Life cycle, life cycle savings and cash flows are done under economic calculations in F-Chart. Cost and savings of life cycle are calculated from present cost of energy. The energy is drawn from fuels and its expected inflation rate, market discount rate, owning costs and operating costs and economic analysis supposed period, (Klein & Beckman, 2001). Items such as interest and principle payments on funds, which are borrowed for the payment for the improvement e.g. income tax effects of incremental property taxes, incremental mortgage and interest payments, resale value, tax credits, depreciation etc. are included in the improvements on costs of owning and operating of life cycle. Here , each of the economic parameters and argue the meaning of the economic output is dicussed. The solar energy system is also provided the life cost method that is discussed in (Duffie, 1991). (Cassard et al., 2011) observed the general trend in this analysis is that SWH systems that replace conventional electric systems are more likely to achieve break-even costs than SWH systems replacing conventional natural gas systems. (Ammar et al., 2009) studied the use of the solar water heater will be more economical in the long run, in spite of its higher initial cost. The higher initial cost will be recovered through the longer life time and the free source of energy supply which will reduce the monthly electricity bill. Government of California has authorized the F-chart software for the program to assess the long term performance of built in commercial certified solar water heaters (Sakri & Jayaramaiah, 2013).

2.9 Literature review for reduction of GHG from solar water heaters:

Previous literature reveals great information about global warming and the role of GHG emissions particularly in the media. The year 2003 experienced intense weather changes, naming the heat-wave throughout Europe was a distinct indication of the realness of this problem, commonly referred to as the "greenhouse effect." As utilization of fossil fuels release large amounts of GHG into the atmosphere (Panwar et al., 2011), therefore conducive environmental conditions demands using renewable energy sources for instance Solar Wind, Hydro and Geothermal. In this way, dependence on fossil fuels can be minimized and thereby helps reducing GHG emissions.

The intensity of the problem can be understood as average for every 1kWh of energy produced by a coal power station, 1kg of GHG is produced. In the same way, for an average household, water heating accounts for around 30% of GHG emissions. Total GHG emissions by more than 20% can be reduced by installing a solar water heater that can provide between 50-70% of hot water heating energy needs (Shimoda et al., 2010).

If SWH development mainly look for maximizing natural gas savings then it is practical to consider the relative use of prime fuels in personal water heater. In presence of primary energy an electric water heater is less efficient but it performs much better when use end-user energy. The 94% efficiency is estimated from an electric water heater where gas water heater efficiency is 55-85%.The left y-axis established the fraction of time gas must be at the margin for gas use in electric and water heaters to be equal, estimating an 8,000 BTU/kWh heat rate, and a 7% electricity loss rate and a 5% gas loss rate. The right y-axis is alike, but conveys the equivalence in gas use in terms of the natural gas energy content (Klein & Beckman, 2001).

Several factors are involved in the degree to which SWH systems abate carbon, for instance, SWH system efficiency and total system volume, baseline emission factors for conventional water heating and average insolation rates. The estimates of carbon abatement from typical residential SWH systems in each of six countries are presented in Table 2.2 In this table, figures for carbon savings per 100 liters per system and are presented thereby allowing equal compares among the countries (Kalogirou, 2009).

Table 2.2 Carbon abatement from solar water heating in selected countries (Samuel, M., & Steven, K., 2005).

Country	Data source	Retail Cost per liter (RM)	Number of liters in average system	Average cost of system (RM)	Tons GHG abated/ 100L/yr	Tons GHG abated/system/yr
Barbados	Government	18.0	300	5400	1.07	3.20
Brazil	Vitae Civil is; Energy	12.6	200	2520	0.46	0.92
China	Hua	4.35	180	783	0.45	0.81
China	Hua	2.17	150	978	0.45	0.68
India	MNES	3.50	100	1050	1.50	1.50
Mexico	Quintanilla	19.95	300	5985	0.59	1.77
Mexico	Davila	16.98	265	4500	0.90	2.39
South Africa	SSN	16.89	150	2532	0.96	1.44

The government reports signal that in Barbados each of the systems (estimated roughly around 32,000) saves electricity generation per year around 4,000 kWh of oil-fired, helping about 3.2 tons of GHG per system out of the atmosphere. In the same way, SWH use helps emission abatement per system each year in Brazil (CEUGE & Emissions., 2002).

The data available suggests that in China the average carbon abatement potential per system is approximately 0.75 tons of GHG. Furthermore, domestic SWH use in India’s electric grid reveals significant yearly diminution of approximately 1.5 ton GHG per 100 litre system (Han et al., 2010 ; Azizul Bari et al., 2012). Moreover, SWH systems used in Mexico City metropolitan area helps reducing annually around 1.77 tons of GHG per 300 litre system. In the same way, SWH use helps saving carbon annually around 1.44 tons of GHG per 150 liter system year (Azizul Bari et al., 2010).

2.9.1 GHG abatement policy under CDM

In fact, the change from an electric system to water heating helps reducing household greenhouse gas emissions and energy consumption. That is why, the emerging markets substance significant important possible to subdue obstructions and help advance SWH technology – thereby GHG trading is reasoned an applicable way not only to overcome emissions but also to enable conformity, malleability and cost ratio to users. There are various regulatory GHG trading programs and numerous voluntary activities in procedure. An example is the Kyoto Protocol’s imminent February 2005 that came into force and helped markets growing rapidly (Stevanovi & Pucar 2012). In addition, the Kyoto Protocol’s Clean Development Mechanism (CDM) renders the possibility for carbon trading to help environmental protection and economic development, most importantly in developing nations. In fact participation in the CDM can be arduous and costly, especially for less developed countries based on stringent project review and verification requirements and laborious procedures structured to safeguard environmental objectives. This is because the countries are expected to utilize low volume, small-scale projects. In coping with this, special rules for small-scale project developers are offered by CDM in order to intensify the prospect for increasing involvement (Purohit & Michaelowa, 2008).

From the literature enumerated above, it can be assumed that the countries taken as case studies in this research can potentially make a meaningful contribution to projects involving SWH technology from the sale of Certified Emission Reductions (CERs). Research have found that projects in carbon intensive areas could generate revenue equal to over 10% of a SWH system’s original cost based on undiscounted revenue flows using conservative values of RM15 per ton GHG and a 10-year crediting period (Fayaz et al., 2011)

Moreover, the revenue generated from the emission can help to surmount a multitude of barriers for SWH technology. For instance, increase system affordability to end users and enhance the viability of SWH projects and businesses can be helped by carbon finance. The issues associated with SWH affordability (for example, fee-for service operations) can be helped by investing additional finance where project participants establish emission reduction purchase agreements with creditworthy CER buyers. Others advantages of carbon trading helps overcoming technical issues involved in the development of SWH markets. For this purpose, SWH projects could possibly utilize carbon reduction revenue for market development. Transaction costs associated with CDM participation and enable the attainment of common minimum size requirements can be handled by bundling small-scale projects (Gastli & Charabi, 2011).

In the case of Malaysia, energy division projects especially Energy Efficiency (EE) and Renewable Energy (RE) have been given more interest with regards to the implementation of CDM. The projects initiated are very much linked with the strategies of sustainable growth in the energy sector. Figure. 16, shows the percentage of CDM projects registered with CDM Executive Board (EB). In UNFCCC, 81 projects out of total 2 2172 CDM projects from Malaysia were registered by 30th April 2010. Changing from electric water to solar water heaters can help reduce GHG emissions in Malaysia (Panwar et al., 2011).

CHAPTER 3: METHODOLOGY

3.1 Introduction

The methodology section consist of three parts, the contour mapping of solar radiations for Peninsular Malaysia by using ArcGIS software, economical and thermal analysis of solar water heaters using F-chart software and calculations of greenhouse gases (GHG) reductions in Malaysian climate. In this chapter, methods of contour mapping, thermal, economic analyses and GHG reduction of solar water heaters have been presented individually.

3.1.1 Malaysian general climatic conditions

Malaysia has a geographic coordinates; it lies on latitude 2 30’N and longitude 112 30’E, and it is in the southeast part of Asia. The country has two lands mass, which are separated by South China Sea; one is in Peninsula Malaysia region and other is in Borneo Island; which further consists of two states Sabah and Sarawak. Malaysia has total population of 27 million with geographical area of 329,847 square kilometers (127,355 sq. mi.)

Peninsular Malaysia has equatorial characteristic feature of the climate which is characterized by fairly high but consistent temperatures (ranging from 23 to 31 C/ 73 to 88 F throughout the year). There is high humidity and copious rainfall (average about 250 cm/ 100 annually) in Peninsular Malaysia. The weather in Malaysia is generally considered ‘hot’ and ‘sunny’, as it is located near the equator. It is very rare to have full sunny and bright day with clear sky not even during the time of severe drought. It is, on the other hand, extremely rare to have stretch of a few days with completely no sunshine except during the time of the northeast monsoon seasons.

3.2 Methodology for contour mapping of solar energy

To make a reliable contour map of solar energy, especially for specific location with a difficult topography and insufficient meteorological information like Malaysia, three very important steps have to be followed: data collection, interpolation and extrapolation of the data using a suitable interpolation method to visualize the result and statistical analysis.

3.2.1 Interpolation and extrapolation of data

To build an upright outline map with high resolution, an interpolation is built to improve NASA global solar radiation data. As the solar radiation data has been collected NASA data base for Peninsular Malaysia, to make a good contour map with high resolution, an interpolation or extrapolation is needed to make a contour map. The interpolation and extrapolation are the processes in mathematics which are used to find the value of a function outside their tabulated values. The process in which a value is obtained from a table or a graph located between major points given or between data points plotted, is known as interpolation; where a value is obtained by using ratio process. While the process in which a value is obtained from a chart or a graph that extends beyond the given data. The "trend" of the data is extended beyond the last given point and the estimated value.

It is very important to note which interpolation and/or extrapolation method is suitable and, which leading program has to be used to build upright interpolation and/or extrapolation for specific data. In this study, the Geographic Information system (GIS) has been chosen for contour mapping of wind energy for Peninsular Malaysia. Hardware, software and data are combined by a Geographic Information System (GIS) in order to capture, store, analyze, organize and to show different forms of information with reference of geography. The GIS of present day includes collaboration of different technologies and disciplines like geography, surveying, cartography, satellite energy, remote sensing, photogrammetry, spatial statistics, computer science, topology, geometry, mathematics, information science, library, web technology, etc. Among the GISs, ArcGIS 9.3 has been used for this study. ArcGIS 9.3 is the special type of software that is very useful for data interpolation and/or extrapolation. The built-in toolbox, such as IDW, Kriging, Spline, PointInterp, Natural Neighbor and trend method, for different interpolation and extrapolation techniques, can be used for the surface representation. Each toolbox is used for a particular situation where it depends on the reference data (elevation, temperature distribution, human density, etc) and the type of surface which is produced (Childs, 2011). The spline toolbox has been used as an interpolation and extrapolation method in this work, where a mathematical function is used to estimate various values. It minimizes the overall surface curvature, which gives a smooth surface that passes exactly through the input points.

Table 3.1 Recommended average days for months and values of n by months

Month	**Day number, *n***	**For average day of month**		
		Date	**N**	δ
January	d	17	17	-20.9
February	d + 31	16	47	-13.0
March	d + 59	16	75	-2.4
April	d + 90	15	105	9.4
May	d + 120	15	135	18.8
June	d + 151	11	162	23.1
July	d + 181	17	198	21.2
August	d + 212	16	228	13.5
September	d + 243	15	258	2.2
October	d + 273	15	288	-9.6

November	d + 304	14	318	-18.9
December	d + 334	10	344	-23.0

Table 3.2 Days of special solar interest

Solar Event	**Date**	**Day number, n**
Vernal equinox	March 21	80
Summer solstice	June 21	172
Autumnal equinox	September 23	266
Winter solstice	December 21	355

3.3 Methodology of thermal and economic analysis of SWHs

This section describes the methodology to analyze thermal and economic outputs of evacuated-tube, glazed and unglazed collector solar water heaters obtained through F-Chart software. Thermal output consists of the solar fractions (f), solar energy incident on collector, auxiliary energy and domestic hot water demand. Whereas, economic output determines economic summary, life cycle costs and breakdown of equipment cost. The thermal output data connected with same output for economic analysis, results in combined thermal and economic analysis done through parametric plots. Details are given in the following sections.

3.3.1 Thermal analysis

Using F-chart software, thermal output of the system has been calculated by putting solar collectors' data (evacuated-tube, glazed and unglazed), active domestic hot water system data and monthly weather data from Subang/Kuala Lumpur meteorological station. The input data is shown in Tables 3.3, 3.4 and 3.5 respectively (Klein & Beckman 2001). Evacuated-tube, glazed and unglazed solar water heating systems are taken from RETScreen database, which are Solar Rating and Certification Corporation certified collectors commercially used all over the world.

Table 3.3 Evacuated-tube, glazed and unglazed collector data (F-Chart).

Parameters of collector panels	Units	Evacuated-tube	Glazed	Unglazed
Collector panel area	m^2	2.86	1.87	2.15
FR×UL (Test slope)	W/m^2-°C	1.652	3.230	12.380
FR×TAU×ALPHA (Test intercept)		0.480	0.600	0.740
Collector slop	Degrees	15	15	15
Collector azimuth (South=0)	Degrees	0	0	0
Collector flow rate/area	kg/sec-m^2	0.020	0.015	0.015
Collector fluid specific heat	kJ/kg-°C	4.15	4.15	4.15

Table 3.4 Active domestic hot water system data input window (F-Chart).

Active Domestic Hot water system		
Location	Subang/Kuala Lumpur	
Water volume/collector area	300	Litres/m^2
Fuel	Electricity	
Efficiency of fuel usage	90%	%
Daily hot water usage	150	Liters
Water set temperature	55	°C
Environmental temperature	27	°C

Table 3.5 Weather view/change input data window (F-Chart).

Months	Solar Rad. [kJ/m^2]	Temp. [°C]	Humidity [kh/kg]	Mains [°C]	Reflect.	°C-days
Jan	15270	26.1	0.0173	27	0.30	44
Feb	15290	26.5	0.0170	27	0.30	32
Mar	19100	26.8	0.0182	27.1	0.30	34
Apr	17690	27.0	0.0190	27.3	0.30	29
May	21630	27.2	0.0192	27.4	0.30	28
Jun	17930	27.0	0.0187	28.0	0.30	29
Jul	20310	26.6	0.0183	27.2	0.30	36
Aug	18430	26.6	0.0182	27.0	0.30	36
Sep	15940	26.4	0.0183	27.5	0.30	37

Oct	15700	26.3	0.0184	27.1	0.30	41
Nov	19110	26.1	0.0184	27.6	0.30	42
Dec	20140	26.0	0.0187	27.3	0.30	46

The parameters used in the Tables 3.3, 3.4, 3.5 of F-Chart software are given in the appendix B1, B2 and B3.

3.3.2 Economics analysis

Using F-chart software, economic output of the system has been calculated by putting solar collectors' data (evacuated-tube, glazed and unglazed), active domestic hot water system data, economic data and monthly weather data from Subang/Kuala Lumpur meteorological station in addition with economic data. Same as in thermal analysis section the input data is shown in Tables 3.3, 3.4 and 3.5 respectively (Klein & Beckman, 2001). In the economic input parameters, electricity fuel is taken into effect for the calculations because of the electric water heaters in Malaysia, while the other types of fuels are not calculated by the software. Input parameters for economic analysis are shown in Table 3.6, and the details of parameters are given in the appendix B2. Collectors used in this research are Solar Rating and Certification Corporation certified collectors commercially used all over the world.

Table 3.6 Economics Parameters input table (F-Chart).

Parameters input	**Detailed**	**Units**
Cost per unit area	0	RM/m^2
Area independent cost	6000	RM
Price of electricity	0.2500	RM/kWh
Annual % increase in electricity	1.0	%
Price of natural gas	0.70	RM/100m^3
Annual %increase in natural gas	10.0	%
Price of fuel oil	0.90	RM/liter
Annual % increase in fuel oil	10.0	%

Price of other fuel	6.00	RM/kWh
Annual % increase in other fuel	10.0	%
Period of economic analysis	20	Years
% Down payment	100	%
Annual mortgage interest rate	9.0	%
Term of mortgage	20	Years
% Extra insur. Andmaint. in year 1	0.0	%
Annual % increase in insur. and m	8.0	%
Ture % property tax rate	3.0	%
Commercial system?	No	%
Commercial depreciation Schedule schedule	0	%

3.4 Emissions analysis

The fossil energy savings produced by SWH can be directly translated into GHG emissions reductions. One house of four family members is taken as model for GHG calculations, where washrooms and kitchens require access to hot water. Under conventional heating methods, each bathroom would have its own independent electric water heater to provide hot water for that bathroom and kitchen. It is supposed to replace the electric water heaters with solar water heaters that would provide the bathrooms with hot water while minimizing/eliminating running, maintenance and environmental costs of the auxiliary equipment.

Calculating greenhouse gases (GHG) emissions for energy-related activities is relatively straightforward. Simply multiply the energy consumption amount by the appropriate greenhouse coefficient.

$$GHG = EC\,(kWh) \times GHG Coeff \tag{3.1}$$

Greenhouse gas emissions from electricity vary from country to country because different fuels are used to generate it.

For Malaysia, the GHG emission were calculated using a conservative method where by average efficiency for specific power plants obtained from the Energy Commission were used to calculate the GHG emissions. The main reasons for using these data sources are to reduce the data inconsistency, uncertainty and to obtain realistic baselines results. Moreover, the data is publicly available. The Table 3.7 shows the baseline results based for three regions in Malaysia.

Table 3.7 Baselines results based for three regions in Malaysia (PTM/DANIDA Study, 2006).

Grids system	**Approximate Operation Margin (kg CO_2/kWh)**	**Build Margin (kg CO_2/kWh)**	**Average of Approximate Operation Margin and Build Margin (kg CO_2/kWh)**
Peninsular Malaysia Grid	0.629	0.681	0.655
Peninsular Malaysia Grid (using most recent 20% of existing plants)	0.629	0.781	0.705
Sarawak Sabah Grid	0.985	1.246	1.157
Wast Sabah Grid	0.709	0.744	0.727
East Sabah Grid	-	-	0.800

Hence, average emission factor for Peninsular Malaysia is taken as 0.629kg CO_2/kWh. Taking emission factor of 0.629 kg CO_2/kWh and electric energy savings in kWh for every single house, an average monthly amount of CO_2 equivalent to GHG is found for 20 years.

$$GHG = kWh \times \frac{0.629kg}{kWh} \times 12 \times 20 \tag{3.2}$$

Equation (3.2) is used to calculate the total expected GHG production from the use of electric water heater for the period of 20 years for peninsular Malaysia.

CHATPER 4: RESULTS AND DISCUSSION

4.1 Introduction

The results and discussions section gives the detailed results of the thermal, economic and environmental analysis of the three types of solar water heaters in the climatic conditions of peninsular Malaysia. The assessment section has been divided into small subdivisions like solar radiation maps, thermal and economic analysis and greenhouse gases analysis. On these sub-divisions, point by point discussion has been given.

4.2 Results and discussion for solar radiation maps

As the spline interpolation method is more suitable, therefore this method is used in this study to get highly reliable solar radiation contour maps for the selected zones. Monthly maximum, average and minimum solar insolation data for these contours maps are present in Table 4.1. Annual average monthly mean daily solar insolation map is presented in Figure. 4.1. Where, contour maps for solar irradiation incident on horizontal surface (kW/m^2/day) from January to December are shown in appendix A by using ArcGIS technique version 9.3.

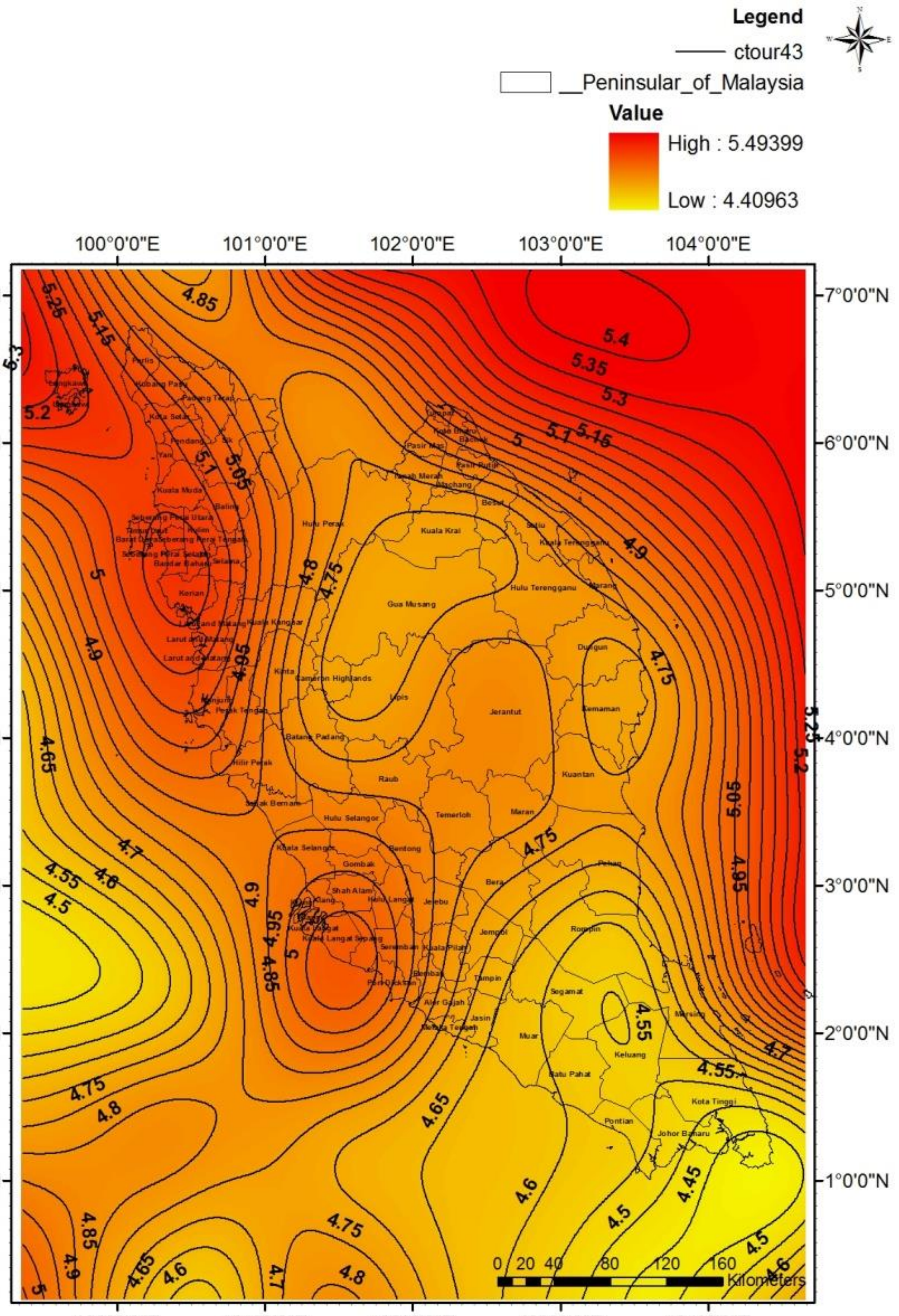


Figure 4.1 Annul average monthly mean daily solar insolation (kWh/m^2/day) incident on horizontal surface through interval (1983-2005) for peninsular of Malaysia cities with contour lines.

Table 4.1 Statistics analysis for all contour maps for monthly mean daily solar insolation (kWh/m^2/day) incident on horizontal surface through interval (1983-2005) for peninsular of Malaysia.

FID	1	2	3	4	5	6
Parameter	Count	minimum	maximum	mean	Sum	Standard deviation
January	736	4.0556	5.8783	4.5520	3350.3	0.4021
February	736	4.9201	6.3321	5.2800	3886.0	0.2824
March	736	4.9095	6.1414	5.3466	3935.1	0.2431
April	736	4.7771	5.8897	5.3660	3949.4	0.2249
May	736	4.4581	5.3760	5.0096	3687.1	0.1710
June	736	4.2945	5.1948	4.8810	3592.4	0.1873
July	736	4.1996	5.1485	4.8317	3556.1	0.1916
August	736	4.2403	5.1954	4.8049	3536.4	0.1846
September	736	4.4202	5.2808	4.8541	3572.6	0.1774
October	736	4.3499	4.9300	4.6456	3419.2	0.1420
November	736	3.7234	4.8394	4.1894	3083.4	0.2313
December	736	3.3214	5.1920	3.9511	2908.0	0.3923
Annual	736	4.4515	5.2081	4.8003	3533.1	0.1472

It has been found through data analysis for Table 4.1 and Appendix A that Malaysia has a large amount from solar energy incident on horizontal surface in April. Maximum amount for solar insolation is observed in January, February, March and April, and minimum amount in November and December. Peninsular Malaysia receives annual average monthly mean daily solar insolation from (4.4515 kWh/m^2/day) to (5.2081 kWh/m^2/day) through the year with annual mean average of (4.8298 kWh/m^2/day). The highest solar insolation is estimated to be in February (6.3321 kWh/m^2/day) while the lowest is found to be (3.3214 kWh/m^2/day) December. Monthly average maximum solar insolation is (5.4498 kWh/m^2/day) and Monthly average minimum solar insolation is (4.3058 kWh/m^2/day). Also, it has been shown from Figure 4.1 for annual average monthly mean daily solar insolation that the northern region has the highest potential for solar energy applications due to its high solar insolation throughout the months of the years. It can be seen easily the names of cities that represent high potential for solar applications in Peninsular of Malaysia.

Now key results of this study can be compared with the previous study to investigate the variation of results along with possible causes of variation. A study by Kamaruzzaman and Yusof (1992) for nine stations in Malaysia reported the minimum value for solar radiation about 3.38 kWh/m^2 /day for the month of December in 1992. In this study there is a little bit difference found to be 3.3214 kWh/m^2/day in December. But there is a slight difference between the average maximum solar radiation (5.57 kWh/m^2/day) in 1992 and current study (6.3321 kWh/m^2/day) and this may be because of the climate change during this interval or the limited years of the previous study. Also, the study by (Azhari et al., 2008) that was carried for only one year showed that on average, Malaysia receives about 4.96 kWh/m^2/day of solar radiation. (Samo et al., 2010) reported depending on meteorological station measurement for 9 stations in 2004 that Malaysia receives 16.6788 MJ/m^2/day or (4.6313 kWh/m^2/day) as annual average.

From the difference between annual average for the year 2004 and annual average for 2008, it can conclude two important things: Firstly, produce solar radiation for one year will be not reliable especially for actual solar potential in our countries, and this confirms that long term from measurement is necessary. Secondly, with taking average value between annual average in 2004 and 2008 the result will be (4.7956 kWh/m^2/day) with respect to the current study (4.8298 kWh/m^2/day) the result show a little bit different and this little bit different may disappear with long term from measurement. Therefore, it confirms that we can use global NASA data base for 22 years to plot a high reliable contour maps for solar insolation to know the actual potential of solar radiation in our countries. These maps show important information about solar energy potential in peninsular Malaysia. Decisions can be made easy by using these contour maps that solar water heaters with different type of collectors can be feasible or not to install for domestic or industrial purposes.

4.3 Thermal and economics outputs.

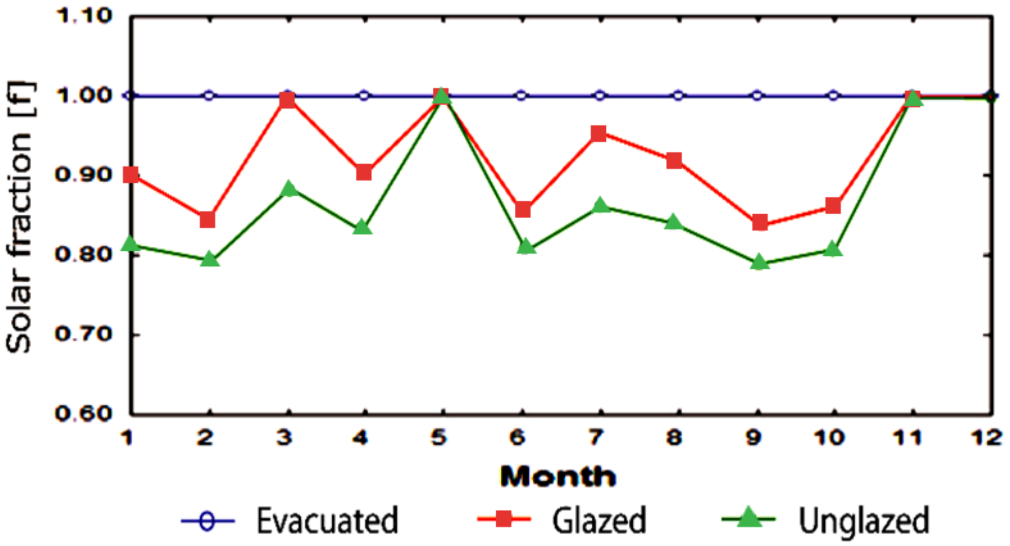


Figure 4.2 Solar fraction versus months.

Solar-run water heaters are the major source of hot water for domestic uses in Malaysia. The Figure 4.2 for evacuated-tube collector solar water heater clearly depicts that almost 100% of the hot water is obtained through solar heaters throughout the year. This shows that solar water heaters with evacuated-tube collectors can fulfill domestic hot water demand of about 150 liters minimum on daily basis. Where, the Figure 4.2 for glazed collector solar water heater illustrates the contribution of solar energy acquired through glazed collector SWH to meet domestic hot water needs. The month-wise breakup shows the fluctuating trend throughout the year in the range of 0.88 to 1. During the January, February, June, September and October the values of solar fractions remains lowest around solar fraction of 0.9 which, means that about 135 liters or 90% of the domestic hot water demand is met by solar energy. Whereas, the left months have highest solar fraction of 0.96 to 1. Taking unglazed collector solar water heater, the Figure 4.2 illustrates the contribution of solar energy acquired through unglazed collector to meet domestic hot water needs. The month-wise breakup shows the fluctuating trend throughout the year in the range of 0.79 to 1. During the May and

November to December the values of solar fractions remains highest as the value of solar fraction 1, which means that about 150 liters of the domestic hot water demand is met by the unglazed solar collector in these three months only. Whereas, the left months have solar fraction fluctuating in between values of 0.79 to 0.88 meaning that 118.5 to 132 liters hot water can be provided.

When comparing the three graphs, it is clear that evacuated-tube collector solar water heater shows the highest performance to fulfill the complete demand of hot water of 150 liters with the solar fraction of 1. Where glazed collector solar water heater satisfies the demand with solar fraction of 0.92, which means it provides the hot water demand of 92% on average in total. In case of unglazed, it is the lowest in performance in comparison with the evacuated-tube and glazed solar water heaters. It provides the solar fractions of 0.88 on average, which means that it satisfies domestic hot water demands with only 88% of total. For the glazed and unglazed results show that even after use of these two types of solar water heaters there is need to install electric water heaters which in result will increase initial cost and running auxiliary energy cost of the for the system to get the left percentage of hot water demand.

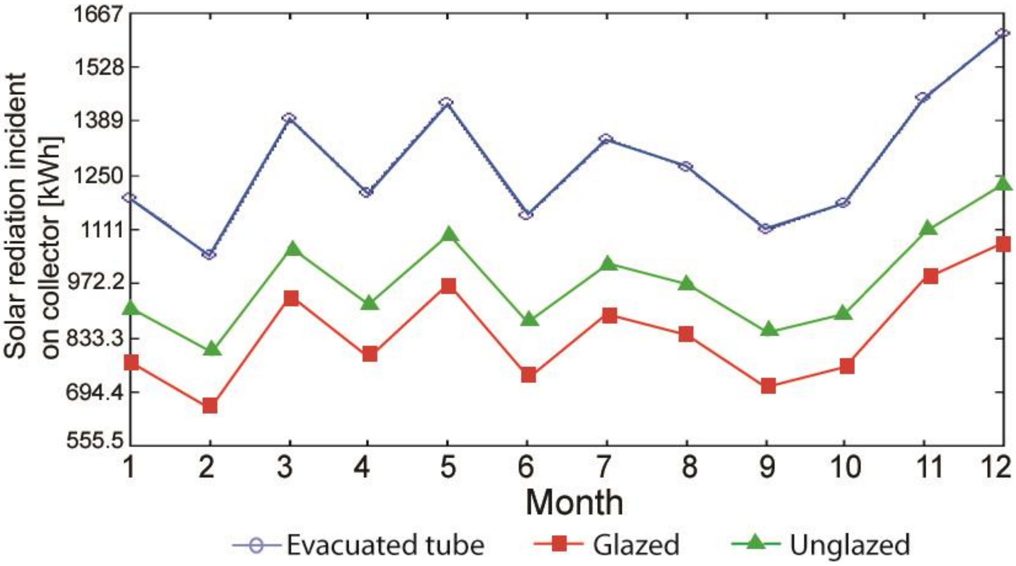


Figure 4.3 Solar energy incident on the solar collector in kWh.

Figure 4.3 shows the average availability of solar energy measured in kilo watt hour (kWh) on monthly basis based on last 3 years data for three different types of collectors. For evacuated-tube collector solar water heater, largely owing to Malaysian weather, the availability of solar energy is quite stable from the 3rd month to 11th month fluctuating within the range of 277.77 kWh, between the interval of 1111 kWh and 1389 kWh. The record indicates substantial improvement in solar energy in the 11th month and later part of the year touching 1611 kWh in 12th month. The lesser supply of solar energy in 2nd month explains the lesser solar fraction in the said month but the evacuated-tube collector solar water heater maintains the demand of hot water through its efficient technology and thus shows the constant solar fraction as shown in Figure 4.2. But for the glazed collector solar water heater, monthly solar energy incident is measured in kWh and presented in Figure. 4.2, it is observed that from March to November solar energy incident remains somewhat stable and fluctuates around 778 to 889 kWh. In the 2nd month, the solar energy is at lowest, whereas, it improves to surpass even 1028 kWh by the 12th month.

In case of glazed collector solar water heater, it is observed that from March to November solar energy incident remains somewhat stable and fluctuates around 889 kWh to 1083 kWh. In the 2nd month, the solar energy is at lowest, whereas, it improves to surpass even 1250 kWh by the 12th month.

It is clear from the Figure 4.3 that evacuated-tube collector solar water heater harnesses highest solar energy, which reaches the value of 1611 kWh. Whereas the lowest performance is for the glazed solar water heater, which harnesses the lowest solar energy of 1027 kWh in the 12th month. Where, the unglazed stands at second by achieving the solar energy of 1250 kWh, which is less than the evacuated-tube collector solar water heater and more than the glazed collector solar water heater.

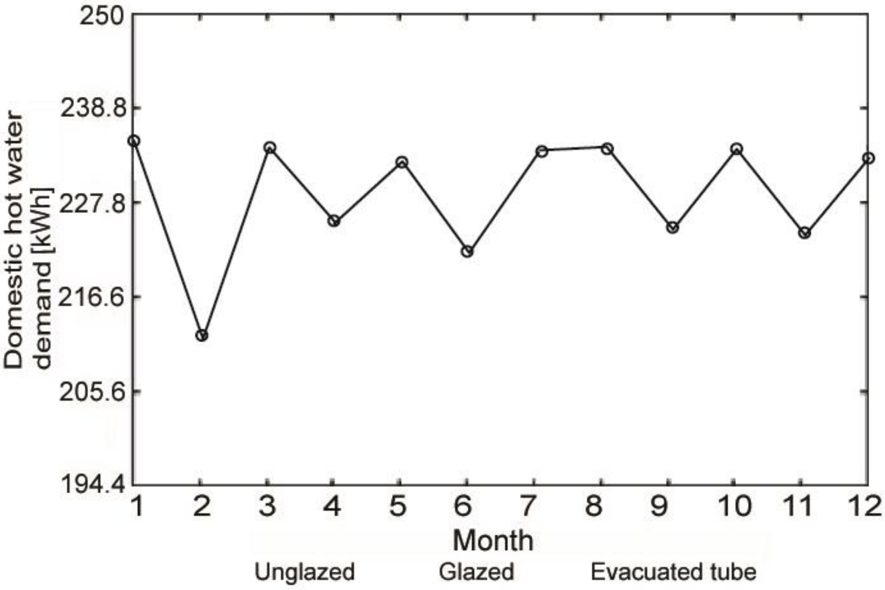


Figure 4.4 Domestic hot water demand versus months.

Figure 4.4 demonstrates the amount of solar energy needed to heat water for domestic needs. Our data covering three years period indicates on average 228 kWh approx. are required for heating throughout the year. In 2nd month of the year, it requires the least amount of solar energy, i.e. 211 kWh. Hence, this result same in the case of all three types of solar water heaters because of the reason that demand depends upon the weather. The above shown demand trend is the target to be achieved by the solar water heaters. Where it shows that maximum demand of hot water at the value of 236 kWh should be satisfied by the suitable solar water heater throughout the year.

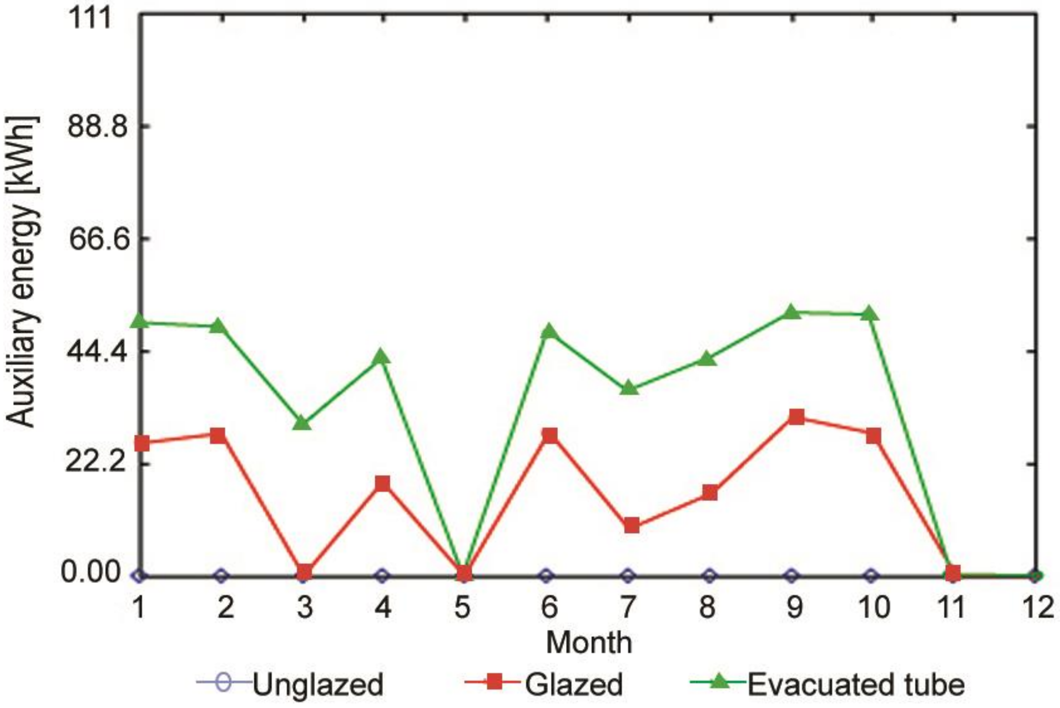
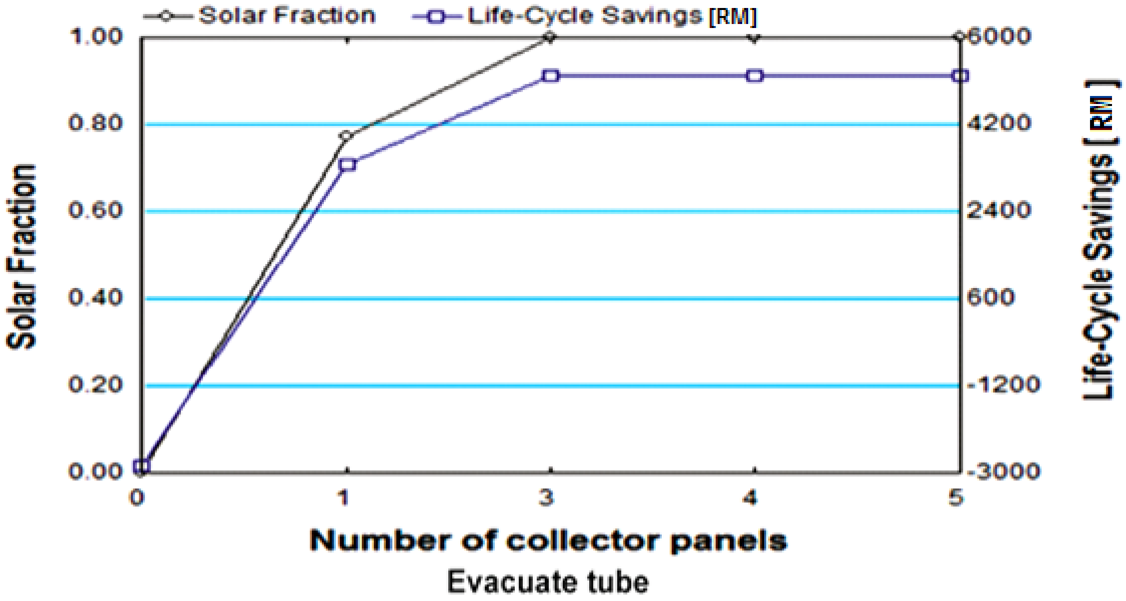
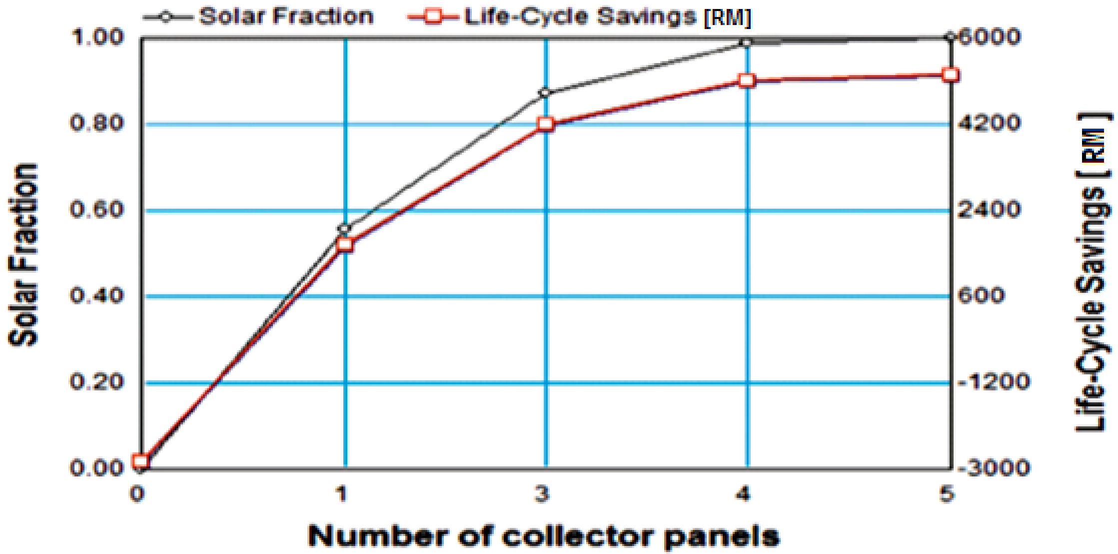


Figure 4.5 Auxiliary energy versus months.

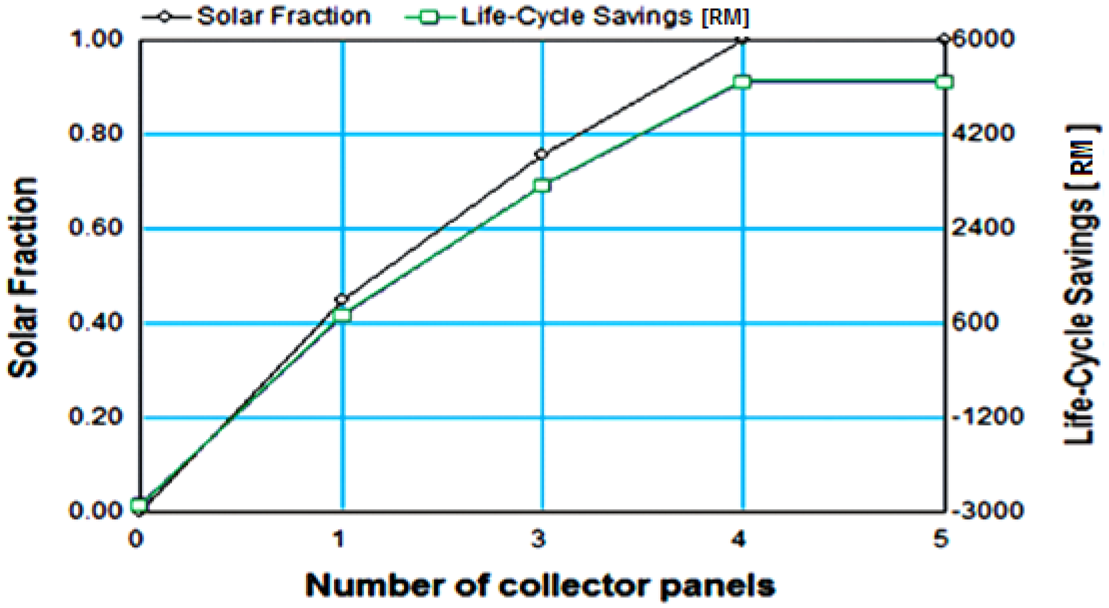
Figure 4.5 clearly depicts that there is no need for the auxiliary energy needed to heat the water through electric water heaters because of the reason that almost of the hot water is obtained by solar water heaters throughout the year. This shows that solar water heaters with evacuated-tube collectors can fulfill 100% domestic hot water demand of about 150 litres minimum on daily basis. Where there is no need to install electric water heaters at all, which in result will save its installation and running cost. In the graph of glazed collector solar water heater, it illustrates the contribution of auxiliary energy added to the domestic water heating demand after using glazed collector water heating system to meet domestic hot water needs fully. The month-wise breakup shows the fluctuating trend throughout the year in the range of 0 to 30.5 kWh. During the January, February, June, September and October the values of auxiliary energy remains highest around 25 kWh. Whereas, the remaining months have lowest dependency on auxiliary energy as the demand is almost satisfied by the glazed collector solar water heating system. Where, the trends for glazed collector solar water heater in graph above show the contribution of auxiliary energy added to the domestic water heating demand after using unglazed collector water heating system to meet domestic hot water needs completely. The month-wise breakup shows the fluctuating trend throughout the year in the range of 0 to 50 kWh. During the January, February, June, September and October the values of auxiliary energy remains highest around 25 kWh. Whereas, the left months have lowest dependency on auxiliary energy as the demand is almost satisfied by the unglazed collector solar water heating system.

From the Figure 4.5, it is clear that evacuated-tube collector solar water heater leaves no room for the use auxiliary energy usage because of the reason that it fulfills the complete demand of hot water demand of 150 litres. Whereas, glazed and unglazed collector solar water heater are not capable of providing full hot water to be used and in result electric water heaters are needed to be installed to fulfill the complete demand. Where, in case of glazed collector solar water heater auxiliary electric heaters are needed to be installed along with the use of 8% auxiliary energy. For the glazed collector solar water heater, electric water consuming auxiliary energy of 12% are needed to install to fulfill the complete demand.





Glazed

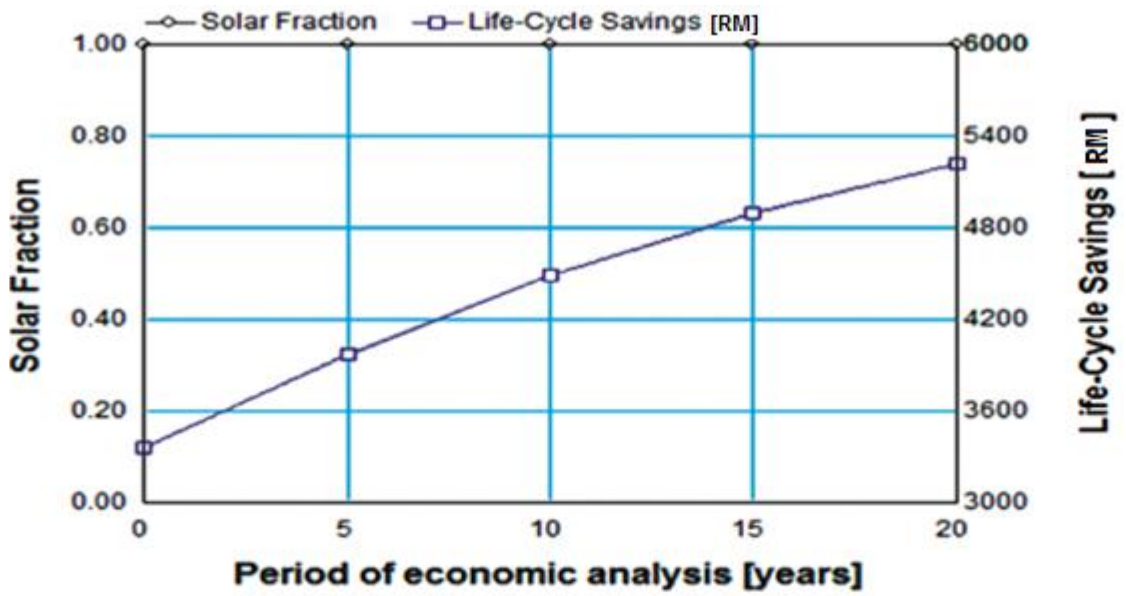


Unglazed

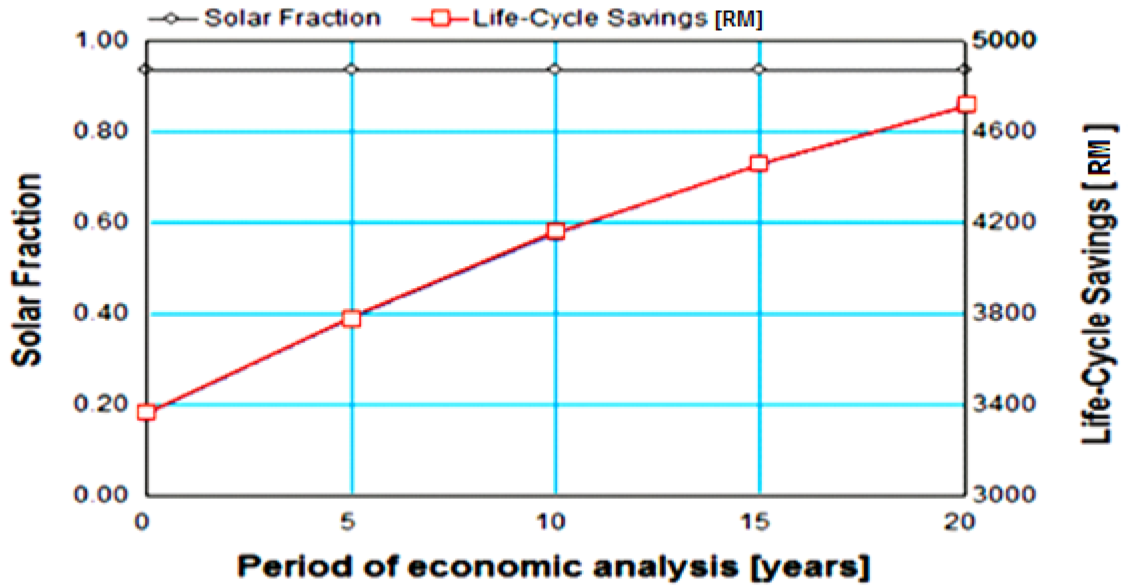
Figure 4.6 Solar fraction versus no. of solar collector panels versus life cycle savings. (Optimal number of collector panels)

This Figure 4.6 simultaneously portrays the relationship of number of collectors installed with solar fraction and with life-cycle savings. According to the results for evacuated-tube collector solar water heater, the optimal number of collectors maximizing both heating and savings over the life of collectors is three. Once the number of collectors exceeds three, the efficiency and savings graph flattens denoting no marginal economic and efficiency-related benefits. Hence, we conclude that with three collector panels the heating and savings can be maximized. The amount of savings can be as high as RM 5200 and solar fraction of 1.0. In the case of glazed collector solar water heater the relationship of collector panels with solar fraction and savings tend to increase but on decreasing rate. The benefits are maximized by installing 4 or 5 collector panels, which in result provides about 100% solar fraction and RM 5,200 savings. The graph further shows that if the no. of collectors is increased then there is no benefit in regard with solar fraction and life cycle savings, which is totally useless. Whereas, reducing number of collectors from 5, will result in decrease in solar fraction and life cycle saving and will create need to purchase and install electric water heater resulting in more investment and running cost in domestic water heating purposes Where, in the graph of unglazed collector solar water heater the relationship of collector panels with solar fraction and savings tend to increase but on decreasing rate. The benefits are maximized by installing 4 collector panels, which in result provide about 100% solar fraction and RM 5,200 savings. The graph further shows that if the number of collectors is increased then there is no benefit in regard with solar fraction and life cycle savings, which is totally useless. Whereas, reducing number of collectors from 4, will result in decrease in solar fraction and life cycle saving and will create need to purchase and install electric water heater resulting in more investment and running cost in domestic water heating purposes.

From the results above, it is clear that evacuated-tube collector solar water heater provides the solar fraction of 1 and the life cycle savings of RM 5,200 with three number of collector panels. It means that three panels give optimal performance to serve hot water demand with maximum savings excluding the need for auxiliary electric water heater. But, for the glazed and unglazed collector solar water heaters the optimum performance is met by 4 to 5 collectors with the same life cycle savings and solar fractions as in the case of evacuated-tube collector solar water heater. Here, in the case of glazed and unglazed collector solar water heater, the drawback is the use of more collector panels, which will result in more area of solar water heater with more initial cost and occupying more space.



Evacuated tube



Glazed

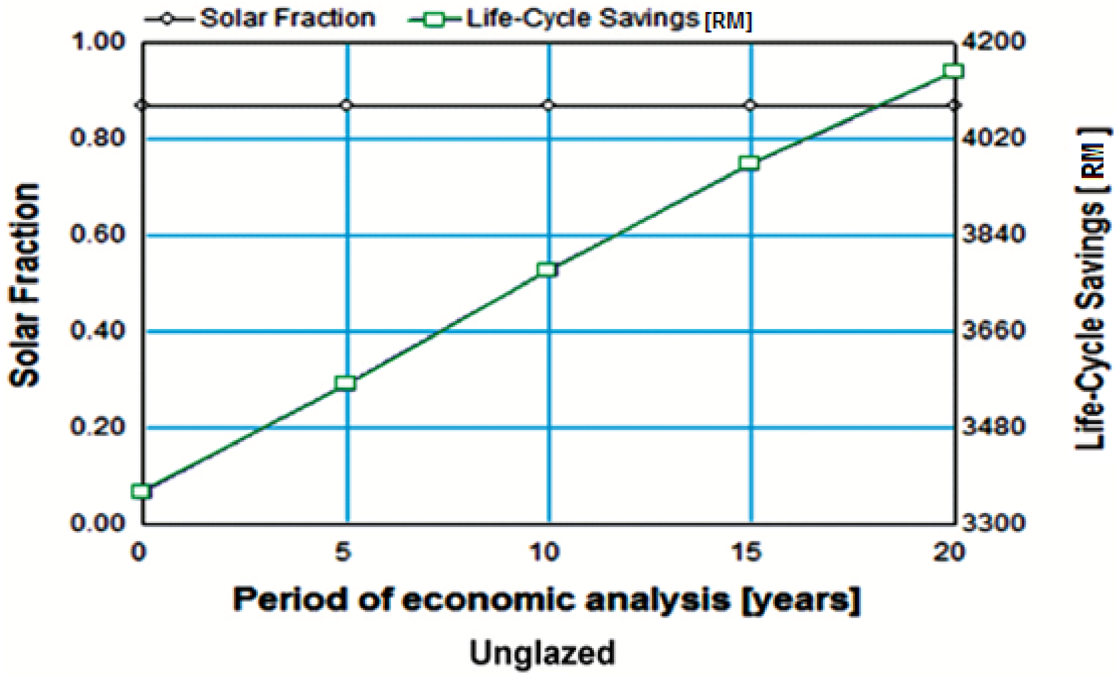
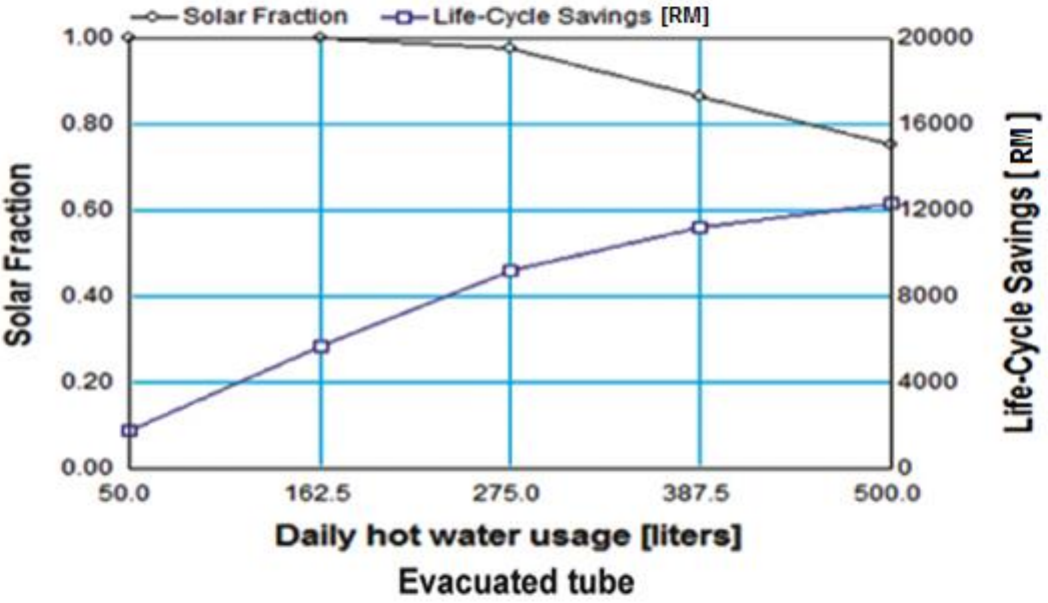
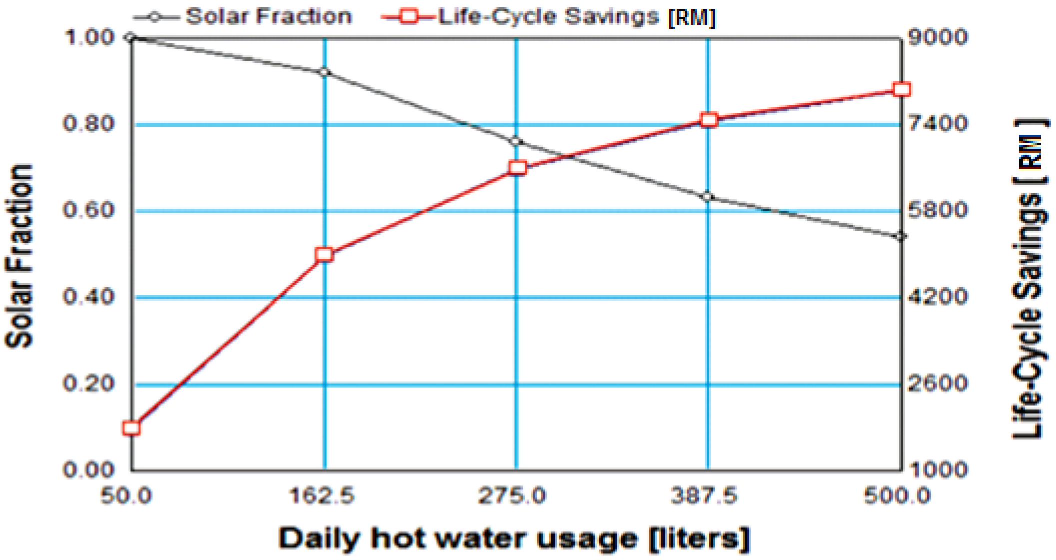


Figure 4.7 Solar fraction and life cycle savings versus period of economic analysis.

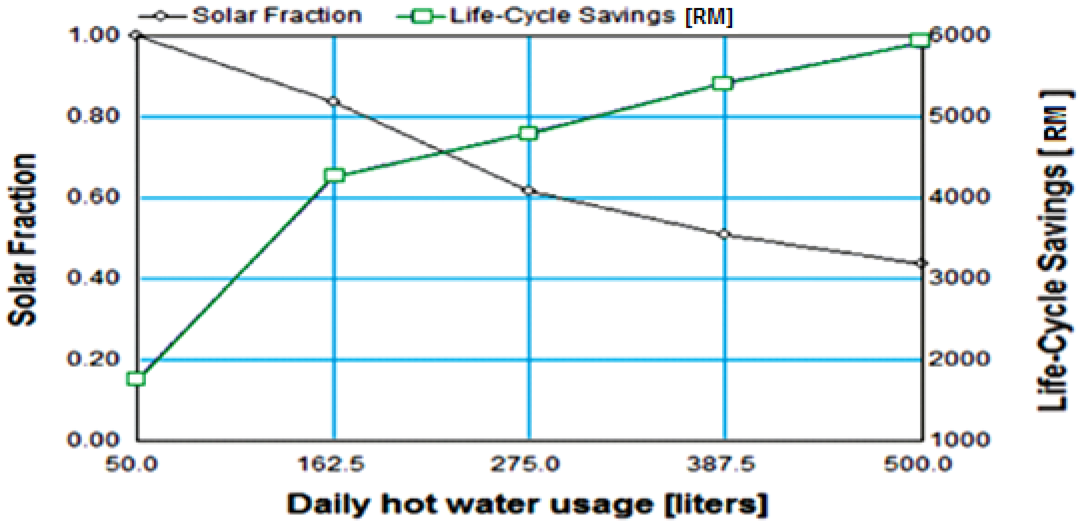
The Figure 4.7 draws the picture of long run economic benefits (in terms of yearly savings) of shifting to solar energy source. As per our analysis, in twenty years span RM 5200 can be saved in the case of evacuated-tube collector solar water heater. While solar fraction is constant as value of 1 along the time period of 20 years, which results in total life time saving of amount RM 5200 as mentioned above. The graph shows the progressive improvement in life cycle savings even after time of 20 years. Hence, it is a significant contribution to overall national as well as personal savings. As considering glazed collector solar water heater, in the long run on average of 0.92 solar fractions, the graph above makes an estimate of yearly savings. Our analysis holds RM 4730 savings are viable in 20 years span of time. These savings nonetheless make almost directly proportional curve with period of economic analysis, indicating lower savings in early years and highest at the end, while it is still improving thereafter. For glazed collector solar water heater, in the long run on average of 0.88 solar fractions, the graph above makes an estimate of yearly savings. Our analysis holds savings of about RM 4150, which are viable in 20 years span of time. These savings nonetheless make directly proportional curve with period of economic analysis, indicating lower savings in early years and highest at the end. Where, it is still improving thereafter with relevant increase in terms of life cycle savings.

From the results, highest life cycle savings are made by evacuated-tube collector solar water heater, which is RM 5200 with the on average overall solar fraction of 1. These savings and solar fraction are more competitive in comparison with glazed and unglazed collector solar water heaters. Where, glazed collector solar water heater saves RM 4730 with solar fraction of 0.92 and unglazed collector solar water heater saves RM 4150 with the solar fraction of 0.88. Both glazed and unglazed collector solar water heaters repeatedly show the need of auxiliary energy usage, which in result increases energy cost and creates pollution to the environment.





Glazed



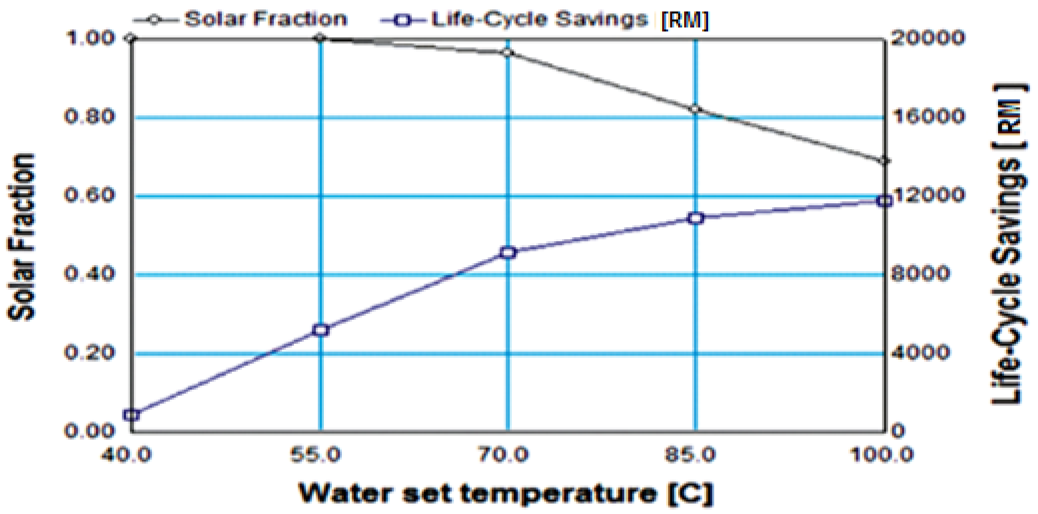
Unglazed

Figure 4.8 Solar fraction, life cycle savings and daily hot water usage.

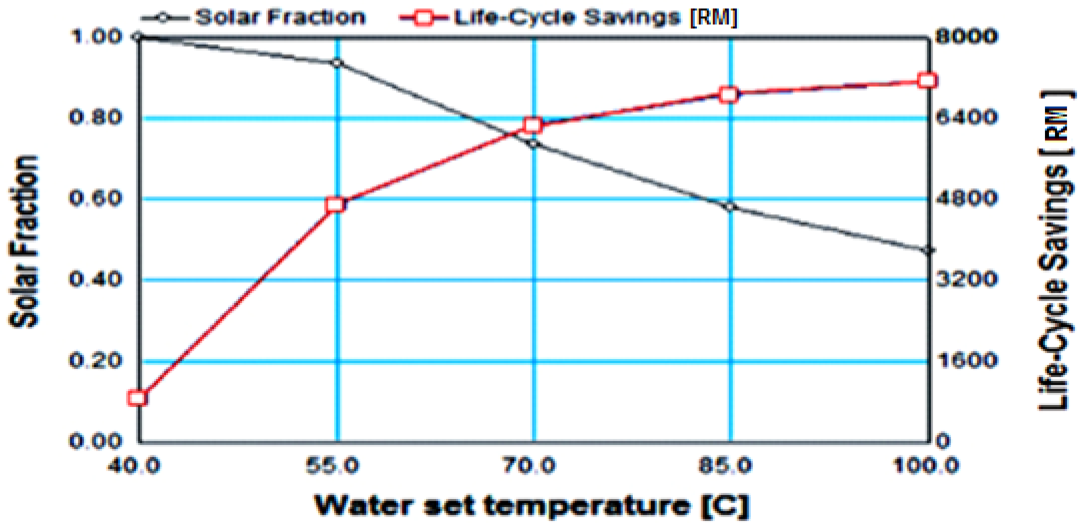
The Figure 4.8 depicts the association of daily hot water consumption (horizontal axis) with solar fraction and projected life-cycle savings (both scaled vertically). The graph for evacuated-tube collector solar water shows that as water consumption increases so does the life-cycle savings, suggesting the effect of economies of scale, according to which higher the consumption, higher the savings. It can, hence, be concluded that large consumers are more to be benefitted from the solar heating system. It is however important to note that the solar fraction falls sharply once the consumption reaches 275 litres a day. This decline in the solar fraction sets in because as demand of hot water increases, it requires more of non-solar more expensive heating sources. With evacuated-tube collector installed, life-cycle savings can go higher than RM 12,000 even with the increase in hot water usage more than 500 liters. Hence, it shows that evacuated-tube solar water heaters are with more capability and flexible to serve the domestic needs.

For the glazed collector solar water heater, like evacuated-tube collector, solar fraction considerably falls when daily consumption of water soars. This suggests that solar option does not meet the entire demand of daily hot water usage even for the amount of 150 litres. For example, solar energy meets just over half of the hot water needs of a consumer having daily water usage of 500 litres with the solar fraction of about 0.52. The same consumer’s savings can touch RM 8000 when the water is used about 500 liters.

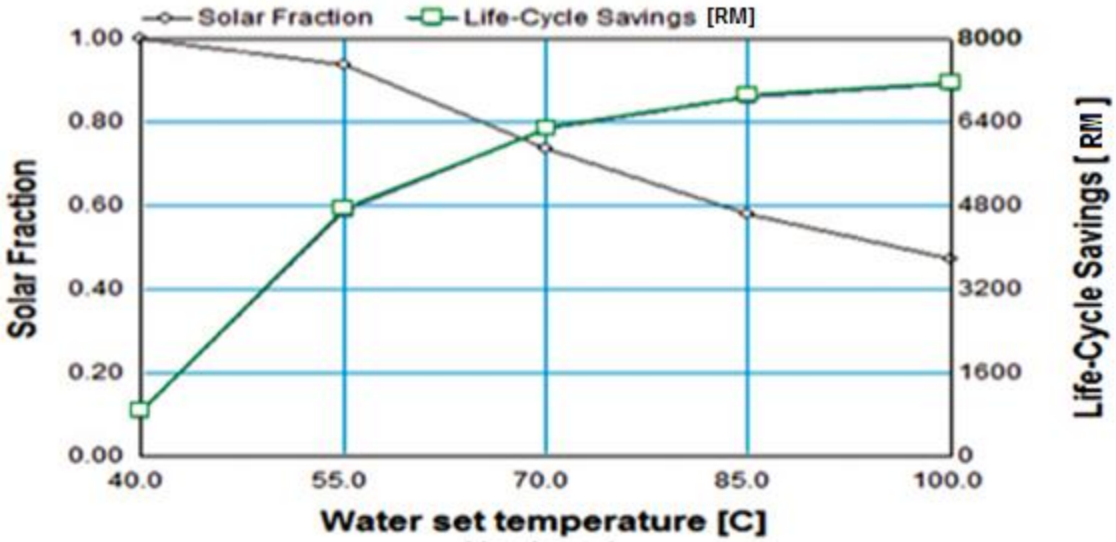
Unglazed solar collectors appear to be less efficient than evacuated-tube and glazed collectors. The graphs showing the solar fraction and daily hot water usage indicates that with these collectors installed, solar energy only meets 40% of the heating system requirements. In other words, users will have to rely on other heating systems such as electric water heaters etc. for their consumption needs. Consequently, the life-cycle savings are much less than those of other collectors. The analysis suggests that, a consumer with 500 litres daily demand of hot water saves only RM 6000, whereas with glazed and evacuated-tube collectors the same consumer can save about RM 8,000 and RM 12,000 respectively.



Evacuated tube



Glazed

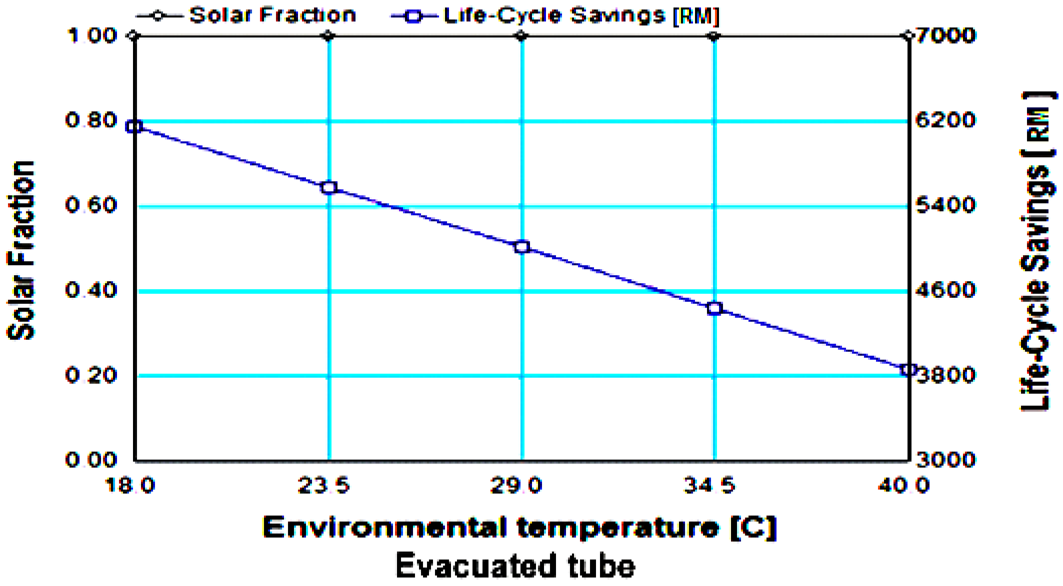


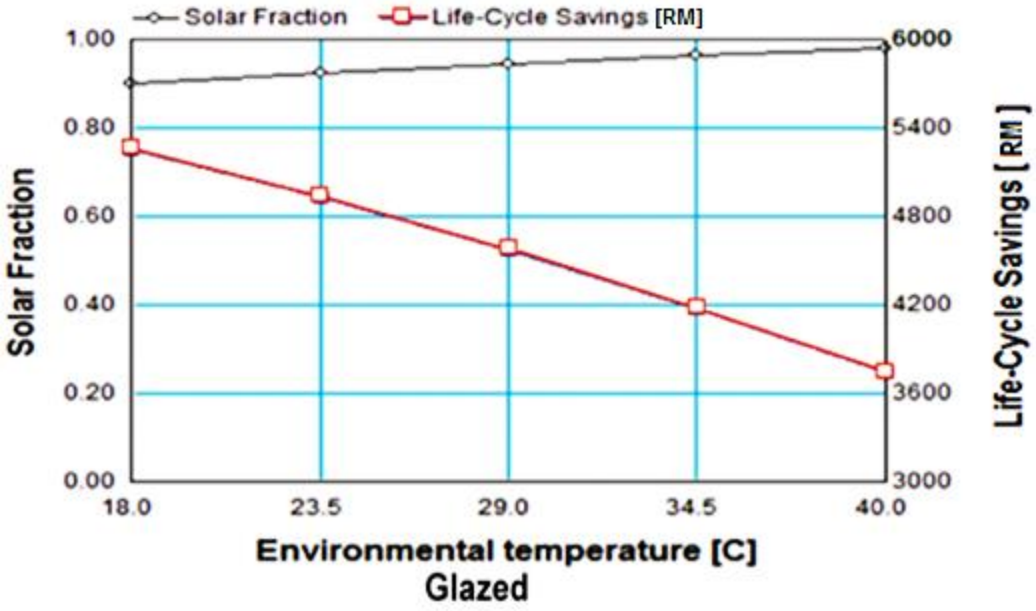
Unglazed

Figure 4.9 Solar fraction, life cycle savings and daily water set temperature.

The Figure 4.9 portrays how solar fraction and life-cycle savings behave with change in water set temperature. For evacuated-tube collector solar water heater, the solar option works well at lower temperatures, sufficing the energy requirements and maximizing the savings at the same time. Below 55°C, there appears no need of additional source of heating technology as the solar system suffices. Life-cycle savings also are affected at higher temperatures, due to significant decline in solar fraction. It shows that higher the water set temperature, lesser will be the solar fraction, while life cycle savings tend to increase to certain level. Glazed collectors are more sensitive to water set temperature. These tend to be abetted by additional heating source, if the required temperature of water is higher. For example given the need of 85°C water set temperature, these collectors can only meet the 60% of the total demand. On the other hand, evacuated-tube collectors are much more efficient to meet 80% of the requirement. Glazed collector solar water heaters show no significant in life cycle savings if the water set temperature is set at higher values. Unglazed collectors can handle the 40°C hot water requirements alone, without any additional heating source, providing 100% solar fraction. Their heating capacity dramatically falls for hotter water need. Specifically, to avail 85°C hot water, one will have to rely on non-solar systems by almost 70%, as solar fraction drops down to mere 30% at this level. As for savings, they also fall as if the need of hotter water increases. It clear shows the increasing trend in life cycle savings until the 70°C and then savings fall down if the water set temperature is set above the 70°C.

From the results it shows that evacuated-tube collector solar water heaters are more stable and flexible in serving hot water at higher temperatures more than 55°C with the solar fraction of 0.70. Where, glazed and unglazed collector solar water heaters are not suitable to serve higher water set temperatures and result in lower performances of 0.43 and 0.30 solar fractions respectively. In terms of life cycle savings, if water set temperature is set at 100°C then RM 12000, RM 7200, RM 3800 are achieved by evacuated-tube, glazed and unglazed collector solar water heaters respectively.





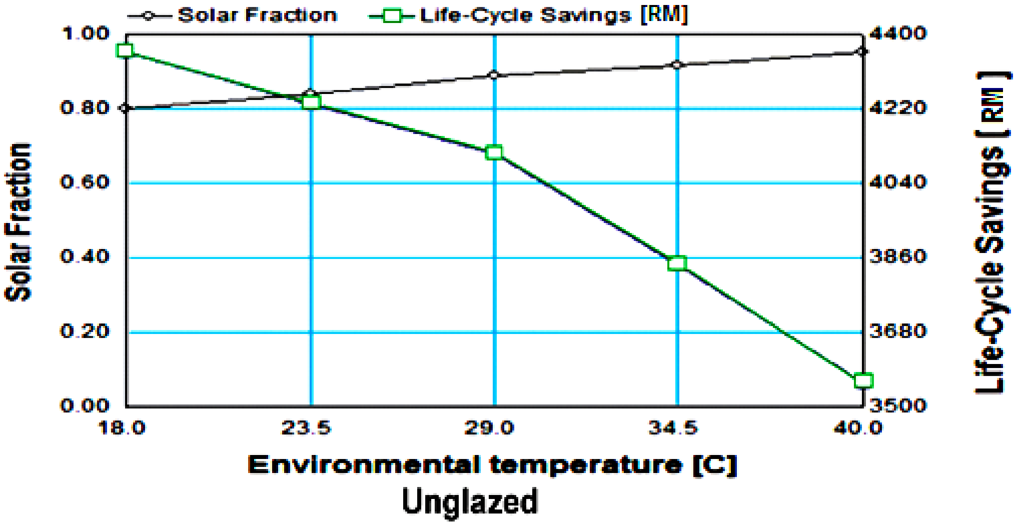


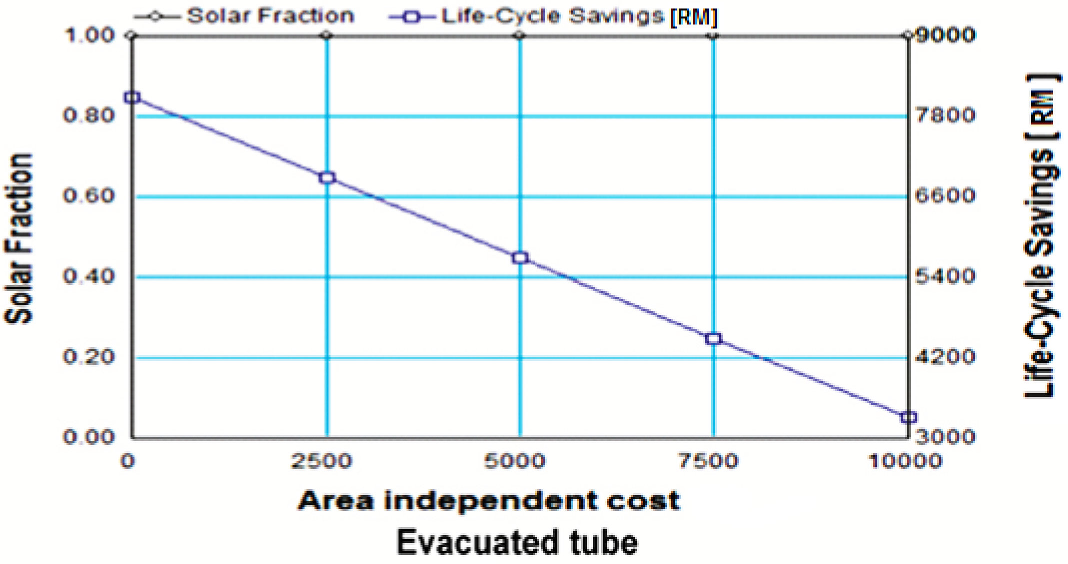
Figure 4.10 Solar fraction, life cycle savings and environmental temperature.

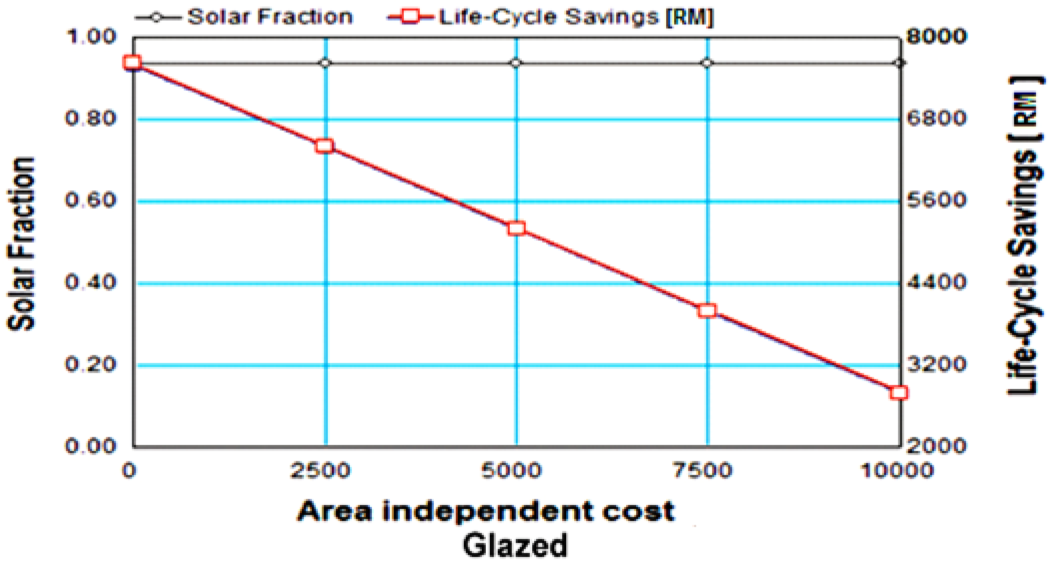
Figure 4.10 shows the impact of environmental temperature on solar fraction and life cycle savings. Evacuated-tube collector solar water heaters are highly efficient as they show good performance even at lower environmental temperatures of 18C. Throughout the temperature scale the solar fraction obtained through these collectors is constant as 1. Where, life cycle savings decline because of the reason that cost of solar water heaters is set at RM6000 and the water set temperature at 55C as input values. Considering these input values, life cycle savings will obviously decrease as the solar water heaters will no longer play major role to heat the water if the environmental temperature goes higher. Evacuated-tube solar water heater results in the highest life cycle savings of RM 6100 at the environmental temperature of 18C and lowest savings of RM 3900 at the temperature of 40C.

Glazed collectors are also good radiation absorbers. These collectors are capable of delivering almost stable heat even at lower environmental temperatures. The graph above suggests these collectors may fulfill 90% of the heating demand even at 18C atmospheric temperatures. The higher environmental temperature adversely affects savings rate, which drops from over RM 5000 to just over RM 3600 at 40C. In this case, the solar fraction of glazed collector solar water heater reduces as the temperature drops more.

Generally, the trend for unglazed collector solar water heater shows the higher the temperature, the better the performance of the solar heating system. Low temperature keeps the water relatively colder, necessitating the heating system to produce more warmth to achieve the desired level of hot water. On the other hand, low atmospheric temperature supplies lower energy to the solar collector to produce more heat. Consequently, solar fraction drops to 0.8 at low temperature of 18C, which may potentially reach even above 0.95 if the temperature suitably rises until 40C. Life cycle savings drop from RM 4360 to RM 3550 at environmental temperature of 18C to 40C respectively.

Evacuated-tube collector solar water heaters has shown the highest efficiency with solar fraction of 1 and highest life cycle savings of RM 6100 as compared to glazed and unglazed collector solar water heaters, which save RM5000 and RM 4300 at 18C with solar fractions of 0.90 and 0.80 respectively.





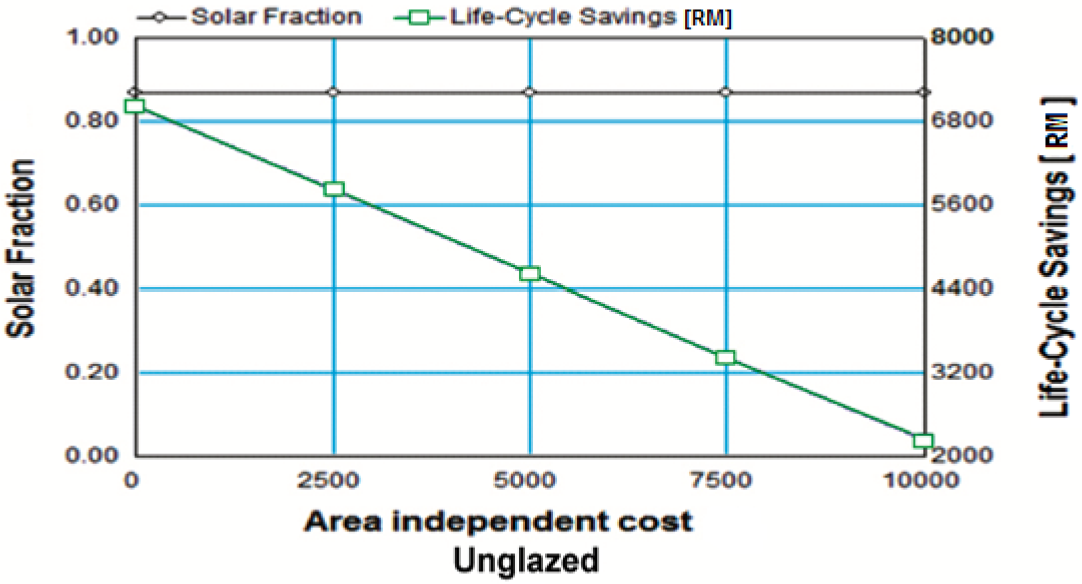


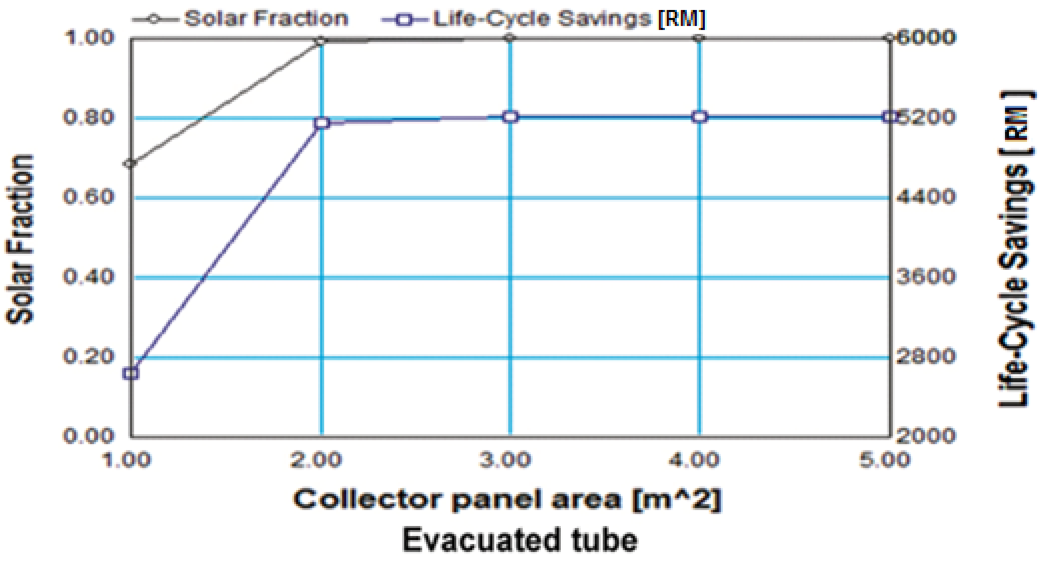
Figure 4.11 Solar fraction and life cycle savings and area independent cost.

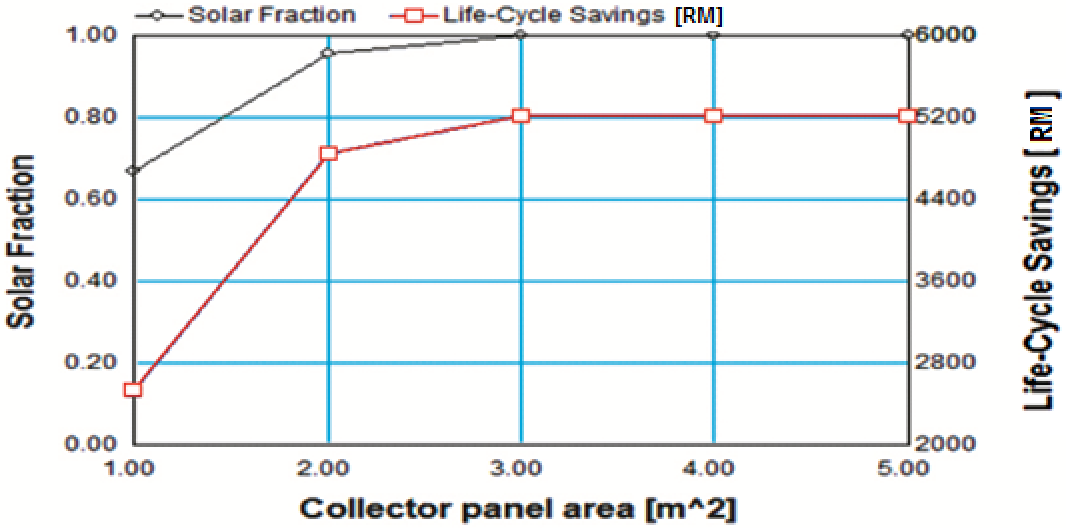
The Figure 4.11 for evacuated-tube collector solar water heater shows the average overall solar fractions as 1. Whereas, the life cycle savings are quite changing with the change in the area independent cost. Savings shown are highest, reaching the value of RM8100 at the system cost of RM0. Life cycle savings are inversely proportional to area independent cost as savings show decreasing trend with increasing area independent cost of the solar water heating system. Life cycle savings of RM 3300 are recorded at the area independent cost of RM 10,000.

Glazed collector solar water heater acquires the average overall solar fractions of 0.93. Since, the life cycle savings are quite changing with the change in the area independent cost. Life cycle savings are recorded as the value of RM7450 at the system cost of RM 0. Life cycle savings at the area independent cost of RM 10,000 are RM 2750.

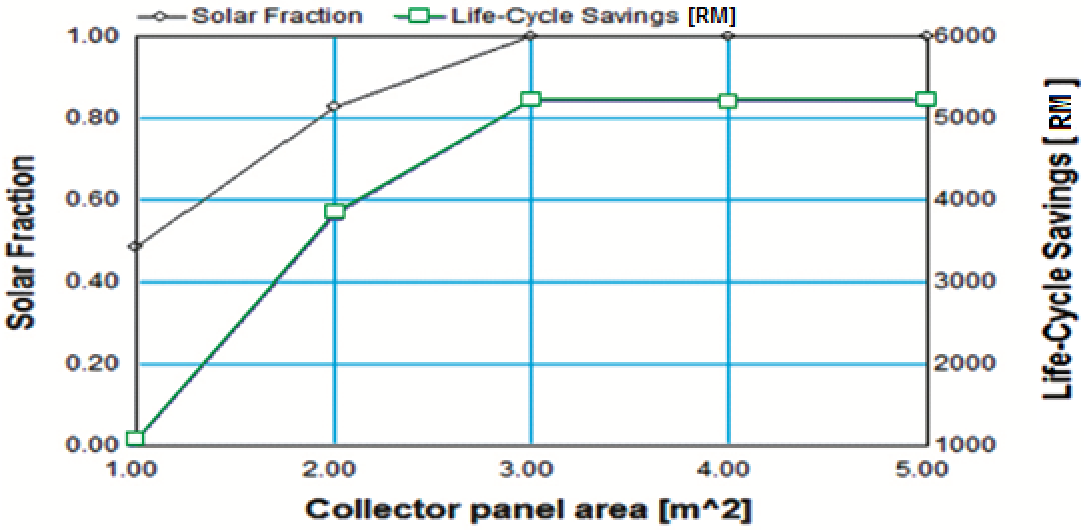
Solar fractions of 0.88 are obtained by unglazed collector solar water heater. But the trend for life cycle savings is not constant and is declining as the area independent is increases. At zero area independent cost life cycle savings are noted as RM 7000, while RM 2200 life cycle savings are achieved at the are independent cost of RM 10,000.

Evacuated-tube collector solar water heater has shown better performance in terms of life cycle savings and thermal performance as compared to glazed and unglazed collector solar water heater as it shows the highest savings of RM 8100 at RM 0. Since, the glazed and unglazed collector solar water heaters save RM 7450 and RM 7000 at RM 0 respectively.





Glazed



Unglazed

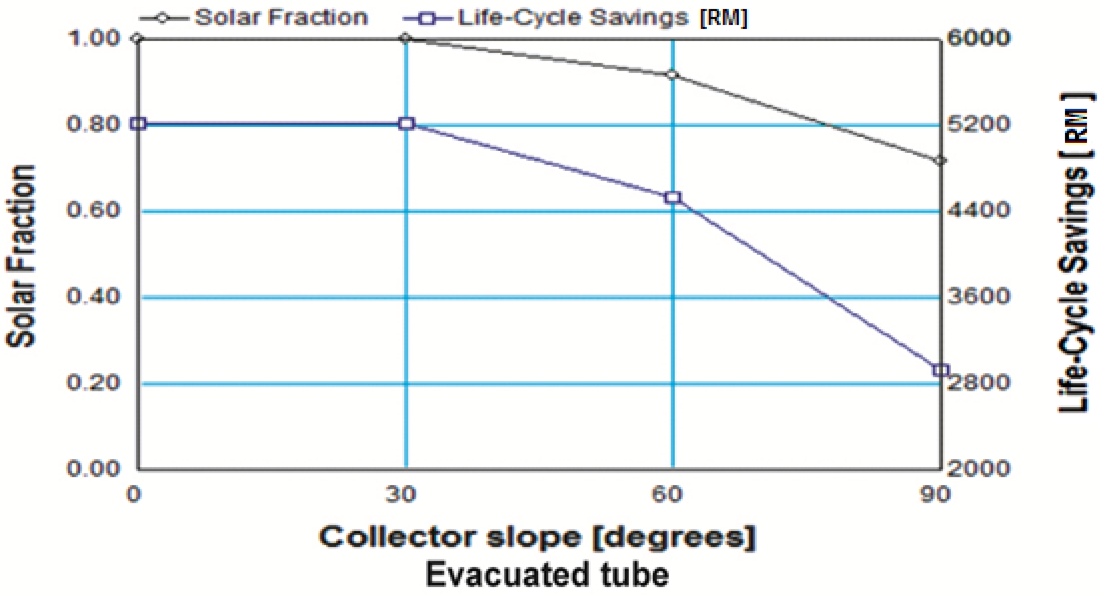
Figure 4.12 Solar fraction and life cycle versus collector panel area.

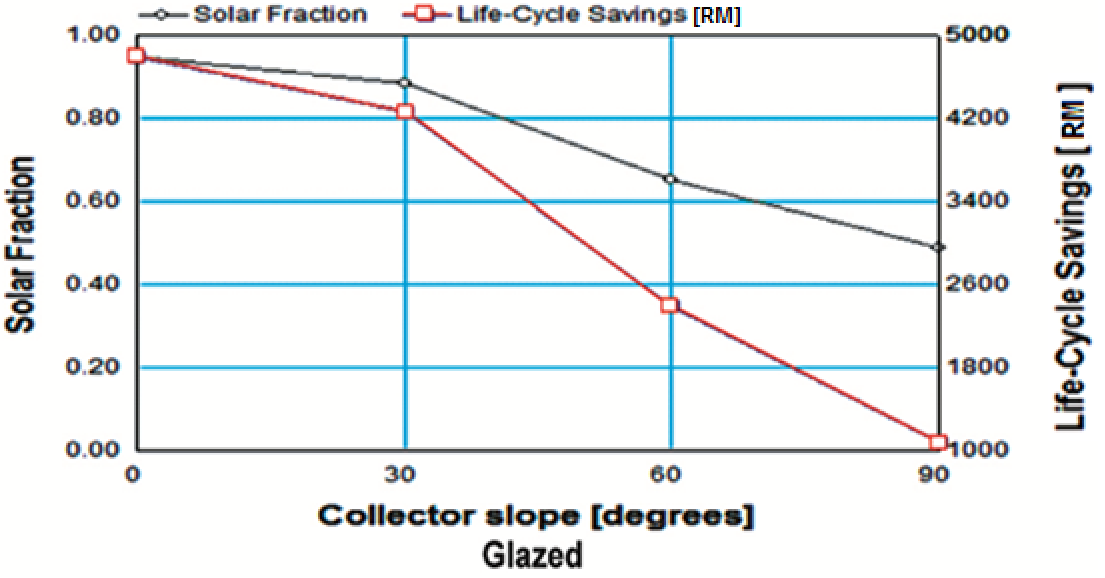
This Figure 4.12 shows the relationship between size/area of collector panel and its heating and saving capacity. The solar fraction and savings are also affected by covered area of collector panel. This analysis shows that for evacuated-tube collector the optimal level of solar fraction is achieved at 2 m^2 collector panel. At 2 m^2, the solar fraction reaches to maximum level (100%) while the savings shoots up to RM 5200. Increasing the collector panel area further results no marginal benefit in terms of solar fraction and savings.

The optimal size of glazed collector, which maximizes both solar fraction and savings, is 3 metre squares. The solar fraction reaches to the max i.e. 100%, while the savings to RM5200. It can be noted, however, that widening the area above 3 m squares results in no more economic or operational benefits.

The unglazed collector requires 3 metre square of area to reach their maximum heating capacity. Solar fraction of 1 is achieved with 3 m square size. However, marginal efficiency becomes zero after 3 metre square, which indicates that installing collector bigger than this size is of no benefit. This is evidenced also by the savings line, which gets flat after this size, resulting the savings just over RM 5200.

From the results, it can be concluded that evacuated-tube collector solar water heater are more efficient and smart in size and working as they occupy less area and with small panel area they can give best performances. But in the case of glazed and unglazed collectors, each of them with small margin in in area compared with each other give the highest performance with the collector area of $3m^2$. Hence, it can be said that evacuated-tube collector are 33% more efficient than the glazed and unglazed collectors in terms of solar fraction and life cycle savings.





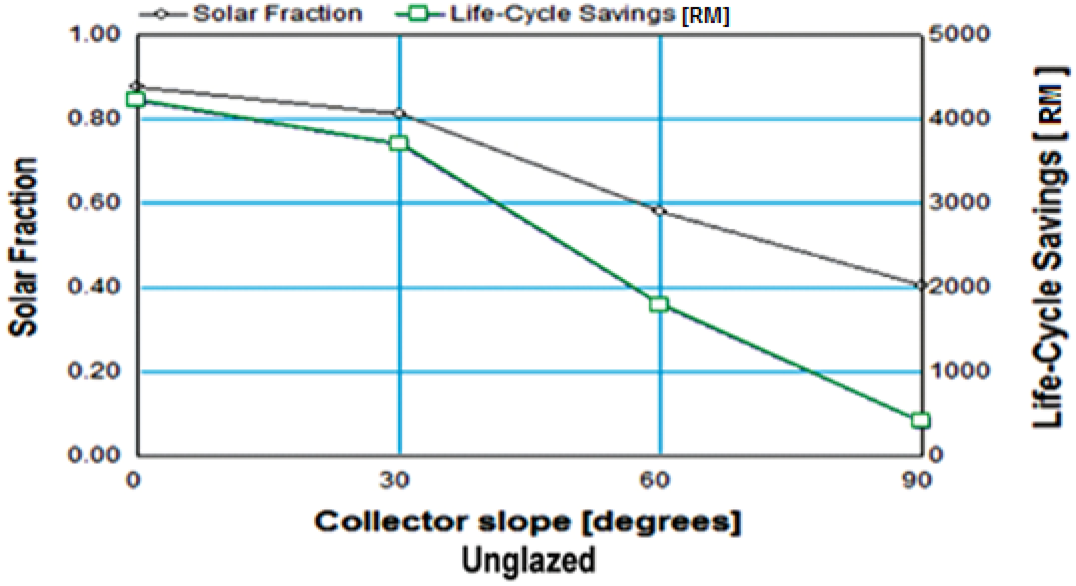


Figure 4.13 Solar fraction and life cycle savings versus collector slope.

It is important to note that collector’s slope has substantial bearings on both maximizing solar fraction and savings. In the case of evacuated-tube collector, the slope / angle at which solar fraction and savings are maximized is from to 30 degrees, where reception of the solar energy reaches to 100% to heat he required amount of hot water, which is 150 litres. Efficiency, thus, acquired yields the annual savings of RM 5200. The efficiency of the collector or the solar radiation incidence decreased effectively beyond the slope of 30degrees. The performance is lowest at the slope of 90 degrees with solar fraction of 0.72 and life cycle savings RM 3000. It shows that the collector's capacity is severely hampered if slope is not properly adjusted.

For glazed collector solar water heaters again, the ideal slope / angle of installation is 0 degrees, at which more than 95% of solar can be easily achieved along with life cycle savings of RM 4800. Efficiency is decreasing in between 0 to 30 degrees but with small variation but it declines rapidly if the slope exceeds 30 degrees. Hence, the lowest performance is found to be at 90 degrees where achieved solar fractions is 0.48 and life cycle savings are about RM 1000 More than RM 4800 can be saved if due care of angling is taken while installing the unit.

Same as evacuated-tube and glazed collectors the efficiency of unglazed solar collectors varies with its angle that it makes towards the sun for optimum reception of solar radiations. Between 0 to 30 degrees, more than 0.8 of solar fraction is achieved along with the life cycle savings of RM 4200. The ideal angle for this collector is 0 degrees at which almost 0.88 of solar fraction is attainable with highest life cycle savings. Both savings and heating efficiency of these collectors are severely affected if their angular position is ignored while installation.

Slope angle is very important for maximum solar collectors' efficiency as shown in the graphs. As shown in Figure 4.13, evacuated-tube collectors are efficient enough to absorb the solar radiations to fulfill the duty of heating 150 litres. Where, in case of glazed and unglazed collectors, they are highly sensitive to slope orientation and can easily be affected. The results show that ideal slope to achieve higher performance for all the types of collectors is between 0 to 10 or 15 degrees where maximum solar fractions and life cycle savings can be achieved as RM 5200, RM 4800 and RM 4200 for evacuated-tube, glazed and unglazed collectors respectively.

4.4 Results for GHG calculations

Since a single home consisting four family member is taken as model to show the expected greenhouses gases reduction from three different types of commercial solar water heaters in Malaysian climatic conditions. It is assumed that electric water heater runs 5hour a day, then energy consumed by electric water heater is 750 kWh.

As three types of solar water heaters are used, therefore the calculations are done separately for the different solar water heaters, the results are obtained as below;

4.4.1 Evacuated-tube solar water heater:

Since, evacuated-tube solar water heater has shown the results in Figure 4.8 that it satisfies the total hot water demand for the one home of 4 members family of about 150liter and above.

Therefore, the calculations are made on solar fraction of 1 or hundred percentage avoidance of electric water heater, where it saves the total energy consumed by electric water heater. The resultant GHG avoided by saved energy by solar water heater is calculated as 113,22 kg based on solar fraction of 1.

4.4.2 Glazed collector solar water heater:

In the case of glazed collector solar water heater shows the achievement of solar fraction of the value 0.92 on average for the 20 years analysis

Therefore, the calculations are made on 92 percent of solar water heater contribution and 8% contribution of electric water heater, which means it saves the 92% energy consumed by electric water heater. The resultant GHG avoided by saved energy by solar water heater is calculated based on solar fraction of 0.92, which calculated as 104,162 kg for single four member family home.

4.4.3 Unglazed collector solar water heater

For the unglazed collector solar water heater, the f-chart analysis shows the average solar fraction obtained through for the 20 years, is 0.88. Therefore, based on solar fraction of 0.88 the calculations will be made as 88 percent of solar water heater contribution and 12% contribution of electric water heater, meaning that it saves the 88% energy consumed by electric water heater. The resultant GHG avoided by saved energy by solar water heater is calculated based on solar fraction of 0.88. Hence the result for single home is 99,633kg of GHG. Figure. 4.14 shows the collective GHG emissions cut down by three types of solar water heaters.

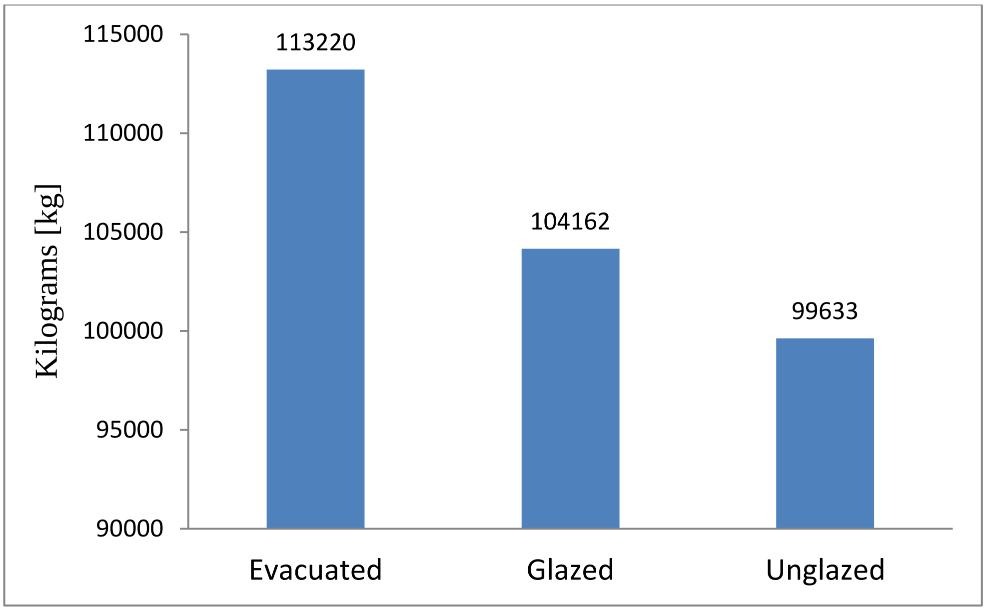


Figure 4.14 GHG emission reductions for evacuated-tube, glazed and unglazed collector solar water heaters.

CHAPTER 5: CONCLUSION

5.1 Introduction

The biggest option for RE is solar energy that is abundant, clean and safe, and its technologies enable rural and surrounding communities to access energy. Its security and climate-change mitigation capability lowers down worldwide carbon emissions. Solar water heating systems are practical applications to replace the use of electrical water heaters. This dissertation contour-mapped Peninsular Malaysia’s hourly and monthly solar irradiation data of NASA satellite database, analyzed thermal and economic output of three types of commercial solar water heaters e.g. evacuated-tube collector, glazed collector and unglazed collector solar water heaters. The expected greenhouses gases abatement through the use of solar water heater on the place of electric water heaters is calculated. This chapter summarizes the dissertation’s main findings, and suggests the use of right solar water heater, which should be thermally and economically viable and environmentally friendly in the climatic conditions of peninsular Malaysia.

5.2 Solar radiations contour maps

NASA database have been improved for the estimation of potential of solar radiation incident on a horizontal surface for peninsular Malaysia. The contour maps that have been produced represent results of 22 years and it is demonstrate without doubt the potential of solar energy in peninsular of Malaysia. These maps can also be used with high confidence for solar energy application and expected to provide a leading guide for future plan related to solar energy applications.

It has been found that Malaysia has a maximum amount for solar radiation in the month of February, March and April and minimum amount in October, November and December. It was found that Peninsular Malaysia receives solar irradiation from 4.4515 kWh/m^2/day to 5.2081 kWh/m^2/day through the year. The highest solar radiation is estimated to be (6.3321 kWh/m^2/day) in February while the lowest is estimated to be 3.3214 kWh/m^2/day in December. The Northern region has the highest potential for solar energy applications due to its high solar radiation throughout the year. Therefore, in this region solar water heating projects can be more feasible and successful as abundant solar energy is available.

5.3 Thermal and economic output of SWH

When comparing the three graphs about solar fraction, it is clear that evacuated-tube collector solar water heater show the highest performance to fulfill the complete demand of hot water of 150 liters with the solar fraction of 1. Where glazed collector solar water heater satisfies the demand with solar fraction of 0.92, which means it provides the hot water demand of 92% on average in total. In case of unglazed, it is the lowest in performance in comparison with the evacuated-tube and glazed solar water heaters. It provides the solar fractions of 0.88 on average, which means that it satisfies domestic hot water demands with only 88% of total. For the glazed and unglazed results show that even after use of these two types of solar water heaters there is need to install electric water heaters which in result will increase initial cost and running auxiliary energy cost of the for the system to get the left % of hot water demand.

The graphs of solar energy show that evacuated-tube collector solar water heater harnesses highest solar energy, which reaches the value of 1611 kWh. Whereas, the lowest performance is for the glazed solar water heater, which harnesses the highest solar energy of 1028 kWh in the 12th month. Where, the unglazed stands at second by achieving the solar energy of 1250 kWh, which is less than the evacuated-tube collector solar, water heater and more than the glazed collector solar water heater.

Results for domestic hot water demand is same in the case of all three types of solar water heaters because of the reason that demand depends upon the weather. The demand trend is the target to be achieved by the solar water heaters. Where it shows that maximum demand of hot water at the value of 236 kWh should be satisfied by the suitable solar water heater throughout the year.

From Figure 4.2, it is clear that evacuated-tube collector solar water heater leaves no room for the use auxiliary energy usage because of the reason that it fulfills the complete demand of hot water demand of 150 liters. Whereas, glazed and unglazed collector solar water heater are not capable of providing full hot water to be used and in result electric water heaters are needed to be installed to fulfill the complete demand. Where, in case of glazed collector solar water heater auxiliary electric heaters are needed to be installed along with the use of 8% auxiliary energy. For the glazed collector solar water heater, electric water consuming auxiliary energy of 12% is needed to install to fulfill the complete demand.

Evacuated-tube collector solar water heater provides the solar fraction of 1 and the life cycle savings of RM5200 with three number of collector panels. It means that three panels give optimal performance to serve hot water demand with maximum savings excluding the need for auxiliary electric water heater. But, for the glazed and unglazed collector solar water heaters the optimum performance is met by 4 to 5 collectors with the same life cycle savings and solar fractions as in the case of evacuated-tube collector solar water heater. Here, in the case of glazed and unglazed collector solar water heater, the drawback is the use of more collector panels, which will result in more area of solar water heater with more initial cost and occupying more space.

Highest life cycle savings are made by evacuated-tube collector solar water heater, which is RM 5200 with the on average overall solar fraction of 1. These savings and solar fraction are more competitive in comparison with glazed and unglazed collector solar water heaters. Where, glazed collector solar water heater saves RM 3500 with solar fraction of 0.92 and unglazed collector solar water heater saves RM 4080 with the solar fraction of 0.88. Both glazed and unglazed collector solar water heaters repeatedly show the need of auxiliary energy usage, which in result increases energy cost and creates pollution to the environment.

The analysis suggests that, a consumer with 500 liters daily demand of hot water saves only RM 6000 for unglazed collector solar water heater, whereas with glazed and evacuated-tube collectors the same consumer can save about RM 8,000 and RM 12,000 for the period 20years respectively. These savings are subjected to no subsidy given by government.

Evacuated-tube collector solar water heaters are more stable and flexible in serving hot water at higher temperatures more than 55C with the solar fraction of 0.70. Where, glazed and unglazed collector solar water heaters are not suitable to serve higher water set temperatures and result in lower performances of 0.43 and 0.30 solar fractions respectively. In terms of life cycle savings, if water set temperature is set at 100C then RM 12000, RM 7200, RM 3800 are achieved by evacuated-tube, glazed and unglazed collector solar water heaters respectively.

Hence, evacuated-tube collector solar water heaters prove to be highest efficient with solar fraction of 1 and highest life cycle savings of RM 6100 as compared to glazed and unglazed collector solar water heaters, which save RM 5000 and RM 4300 at 18C with solar fractions of 0.90 and 0.80 respectively.

Evacuated-tube collector solar water heater has proved to be first in terms of life cycle savings and thermal performance as compared to glazed and unglazed collector solar water heater as it shows the highest savings of RM 8100 at RM 0. Since, the glazed and unglazed collector solar water heaters save RM 7450 and RM 7000 at RM 0 respectively.

From the results, it can be concluded that evacuated-tube collector solar water heater are more efficient and smart in size and working as they occupy less area and with small panel area they can give best performances. But in the case of glazed and unglazed collectors, each of them with small margin in in area compared with each other give the highest performance with the collector area of 3m2. Hence, it can be said that evacuated-tube collector are 33% more efficient than the glazed and unglazed collectors in terms of solar fraction and life cycle savings.

Slope angle is very important for maximum solar collectors' efficiency. As shown in Figure 4.13 evacuated-tube collectors are efficient enough to absorb the solar radiations to fulfill the duty of heating 150 liters. Where, in case of glazed and unglazed collectors, they are highly sensitive to slope orientation and can easily be affected. The results show that ideal slope to achieve higher performance for all the types of collectors is between 0 to 10 or 15 degrees where maximum solar fractions and life cycle savings can be achieved as RM5200, RM4800 and RM4200 for evacuated-tube, glazed and unglazed collectors respectively.

5.4 GHG abatement

As it is obvious from the results that evacuated-tube collector solar water heater achieves the highest solar fractions of 1, which means that higher the solar fractions, is higher the dependency on auxiliary energy resulting in GHG emissions abatement. Evacuated-tube collector solar water heaters fulfill the duty to cut down emissions of 113,33 kg. Whereas, glazed collector solar water heater achieves 0.92 solar fractions and hence cut the emissions by 104,162 kg. But for unglazed collector solar water heater provides the solar fraction of 0.88, hence helps in reducing the emissions by 99,633 kg of the expected emissions in case when no solar water heaters are installed for domestic water heating purpose and the water is heated through auxiliary energy/electric water heaters.

It can be concluded that NASA database of 22 years radiation data contour mapping showed clearly that highest solar radiations were found in February and lowest in December. The Northern region has the highest potential for solar energy applications due to its high solar radiation throughout the year. With such high potential of solar radiation performance analysis of different types of solar water heaters shows that evacuated-tube collector solar water heater gives optimum performance as compared to glazed and unglazed collector solar water heaters. Thermal output of evacuated-tube collector solar water heater is found to be highest amongst the rest other types of solar water heaters as it harnessed solar fraction of 1 and highest solar energy absorbed is about 1389 kWh. Emissions of cut by evacuated-tube collector, glazed collector and unglazed collector solar water heaters are 113,33, 104,162 and 99,633 kg respectively for the period of 20 years.

5.5 Future work

There are still many gaps and future work in this field of study, which are given below to carry on such projects.

Various other types of solar water heaters brand wise can be analyzed under Malaysian climatic conditions.

1. Various other types of solar water heaters brand wise can be analyzed under Malaysian climatic conditions.
2. As Malaysia has different solar radiations incident on different locations therefore analysis can be done for the different locations as well.
3. Prototype solar water heaters can be analyzed with f-chart by using different nano-fluids.

APENDICES

Appendix A: Monthly solar radiation maps for the all months.

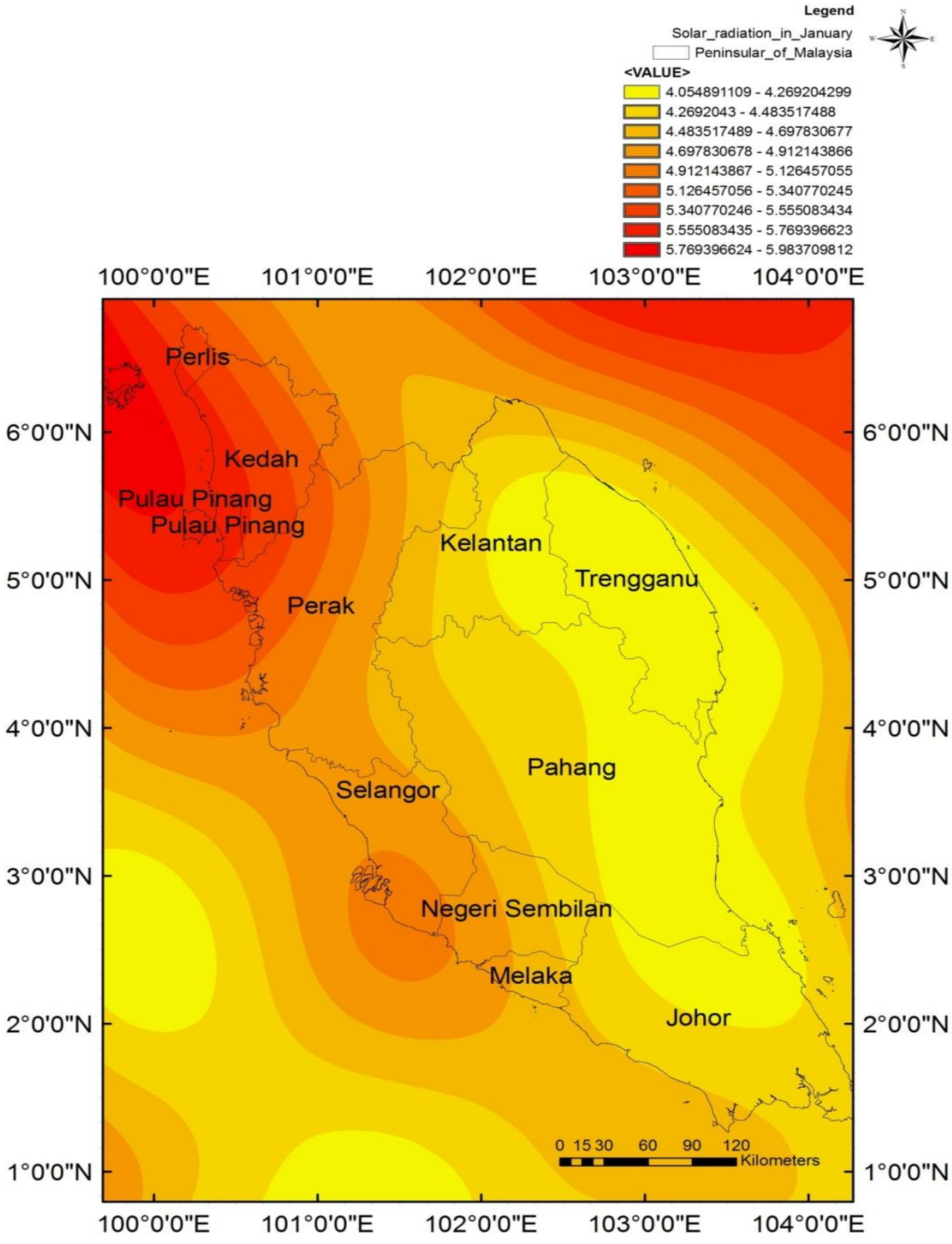


Figure A.1 Solar radiation map for the month of January.

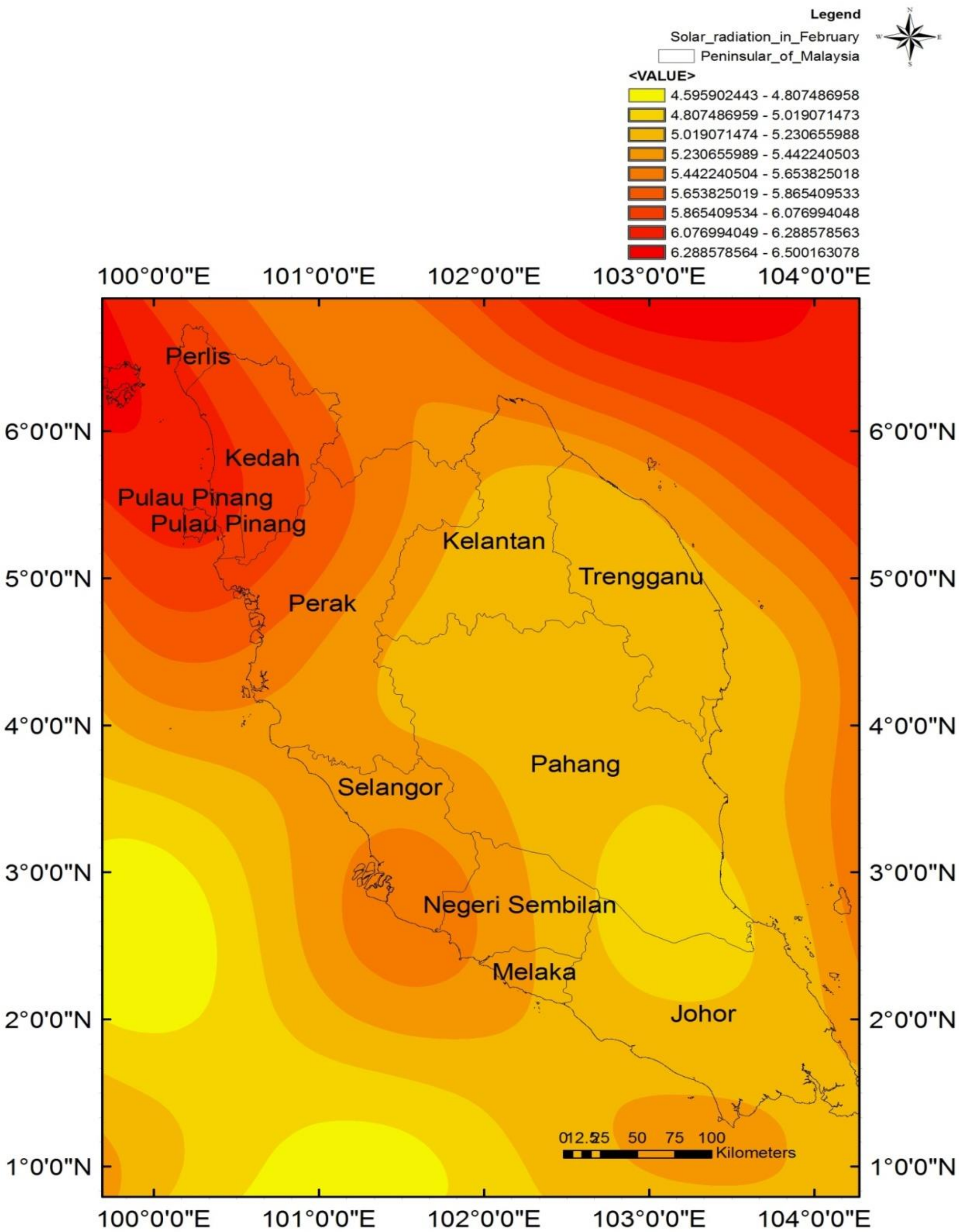


Figure A.2 Solar radiation map for the month of February.

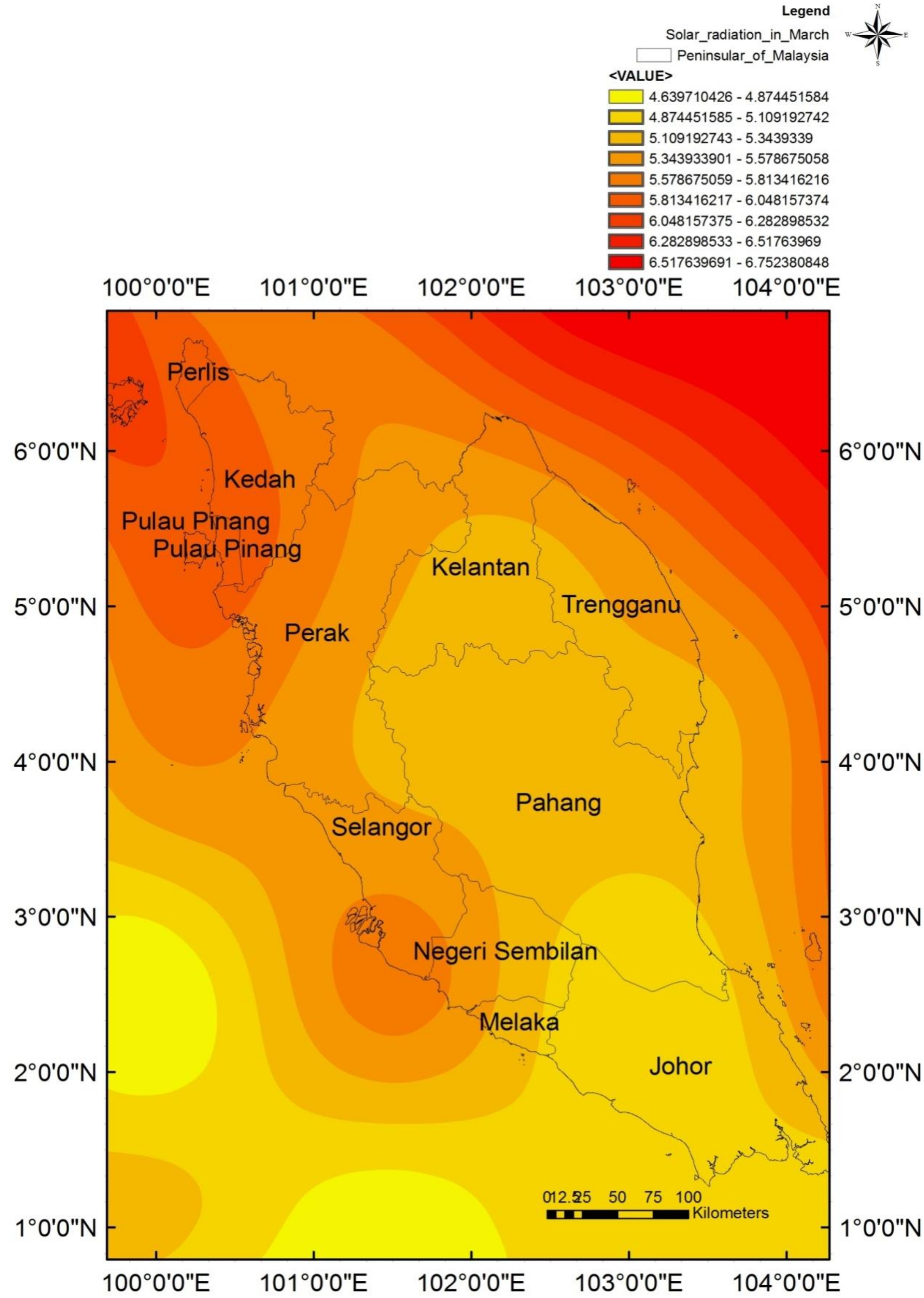


Figure A.3 Solar radiation map for the month of March.

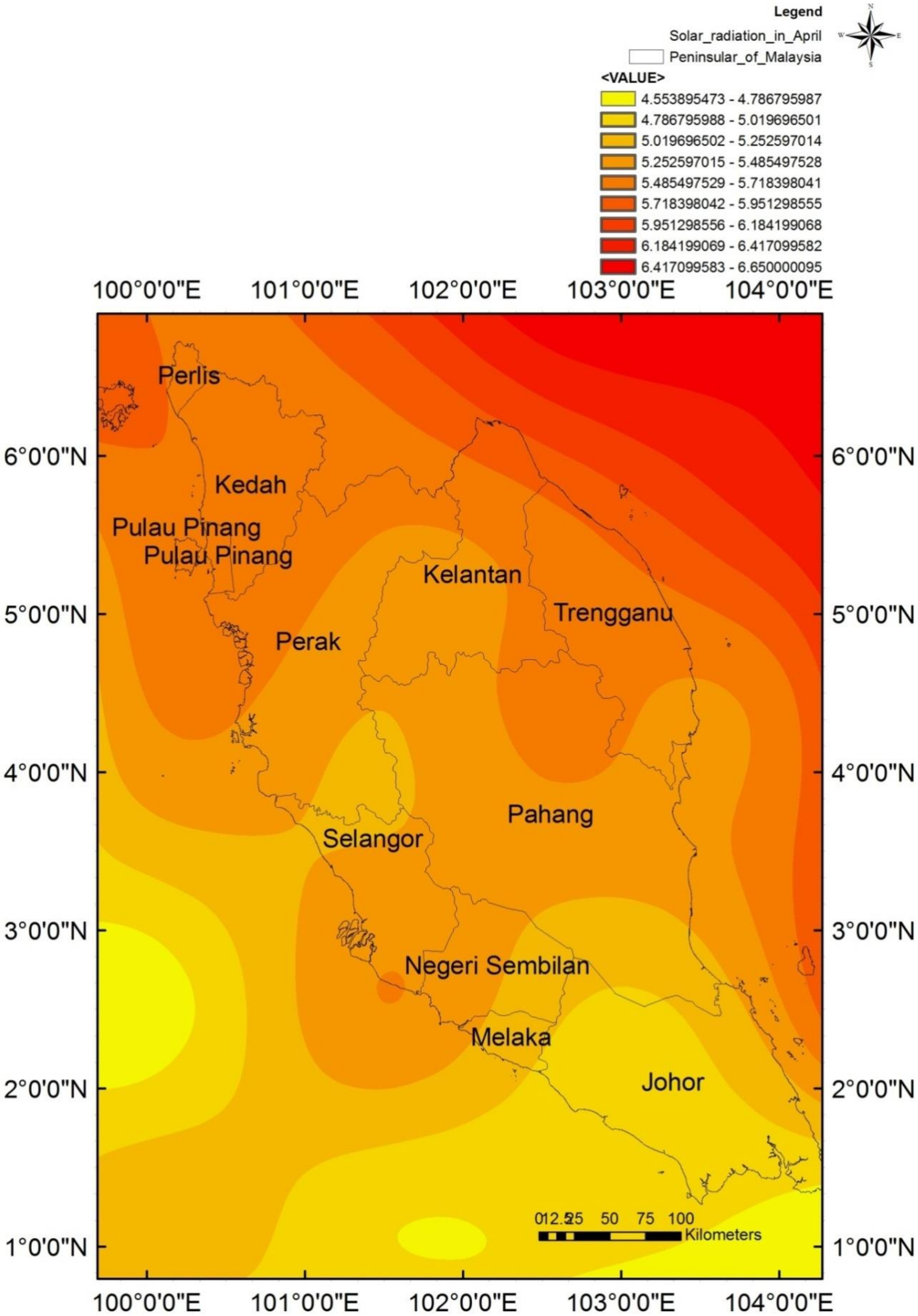


Figure A.4 Solar radiation map for the month of April.

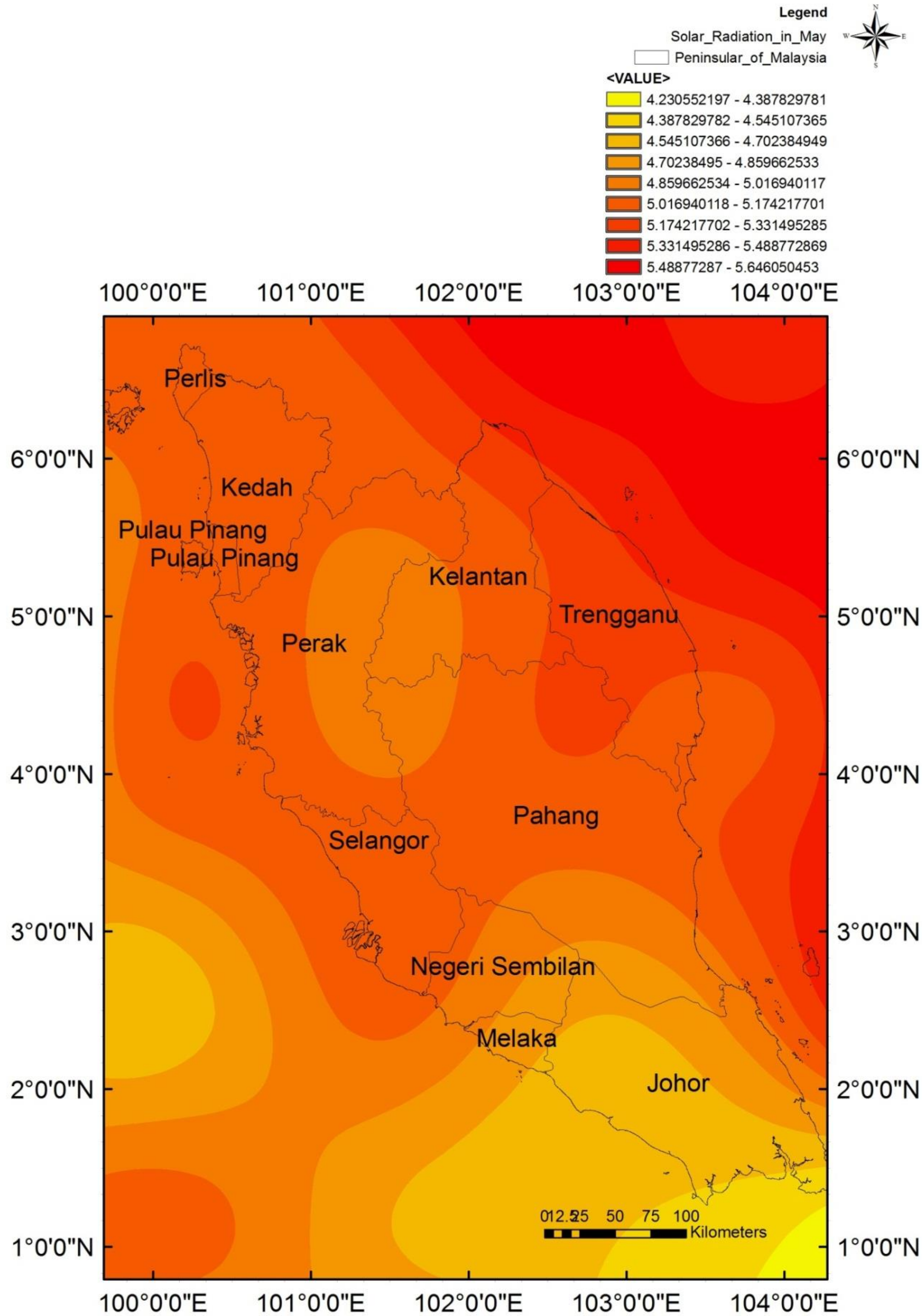


Figure A.5 Solar radiation map for the month of May.

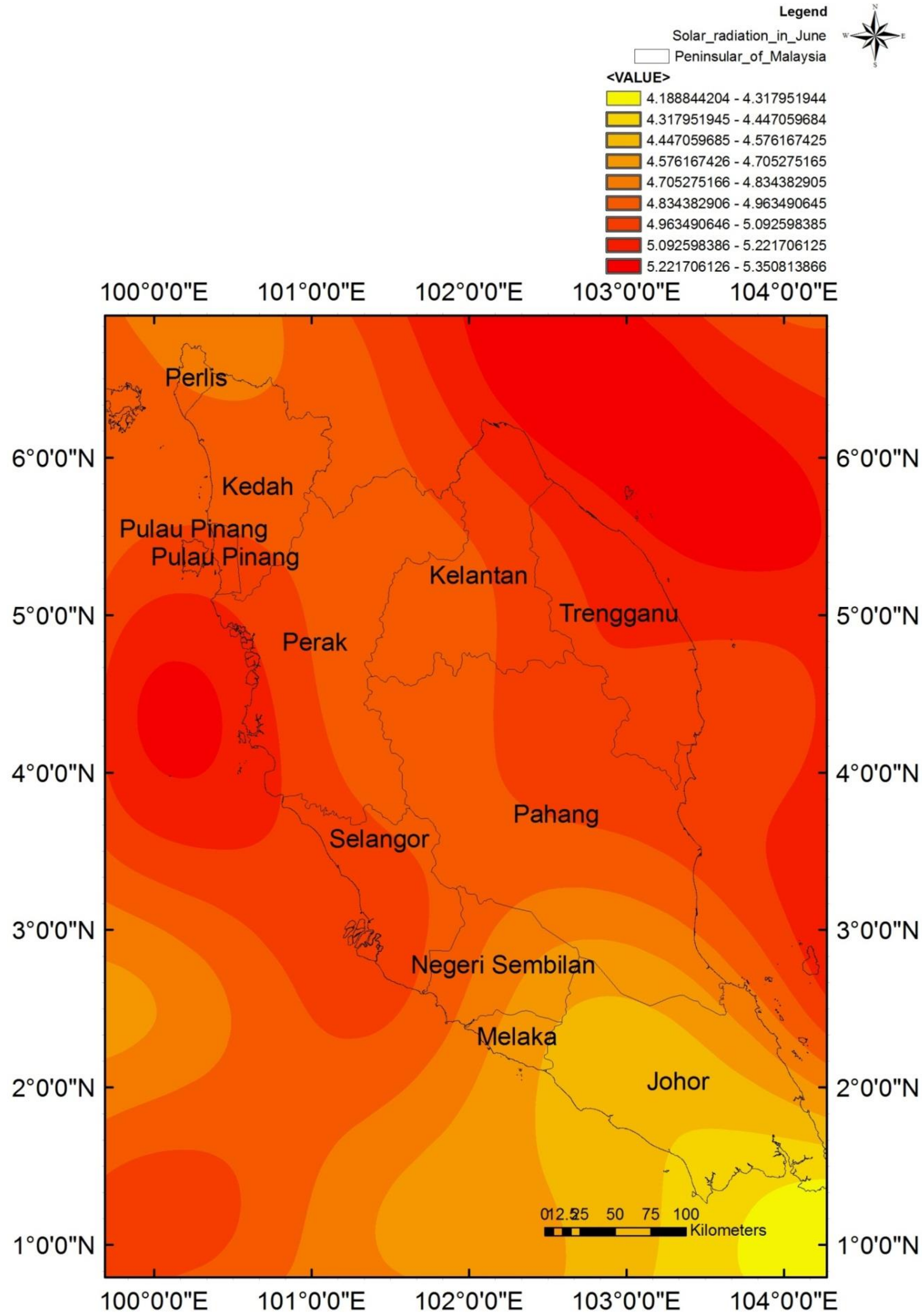


Figure A.6 Solar radiation map for the month of June.

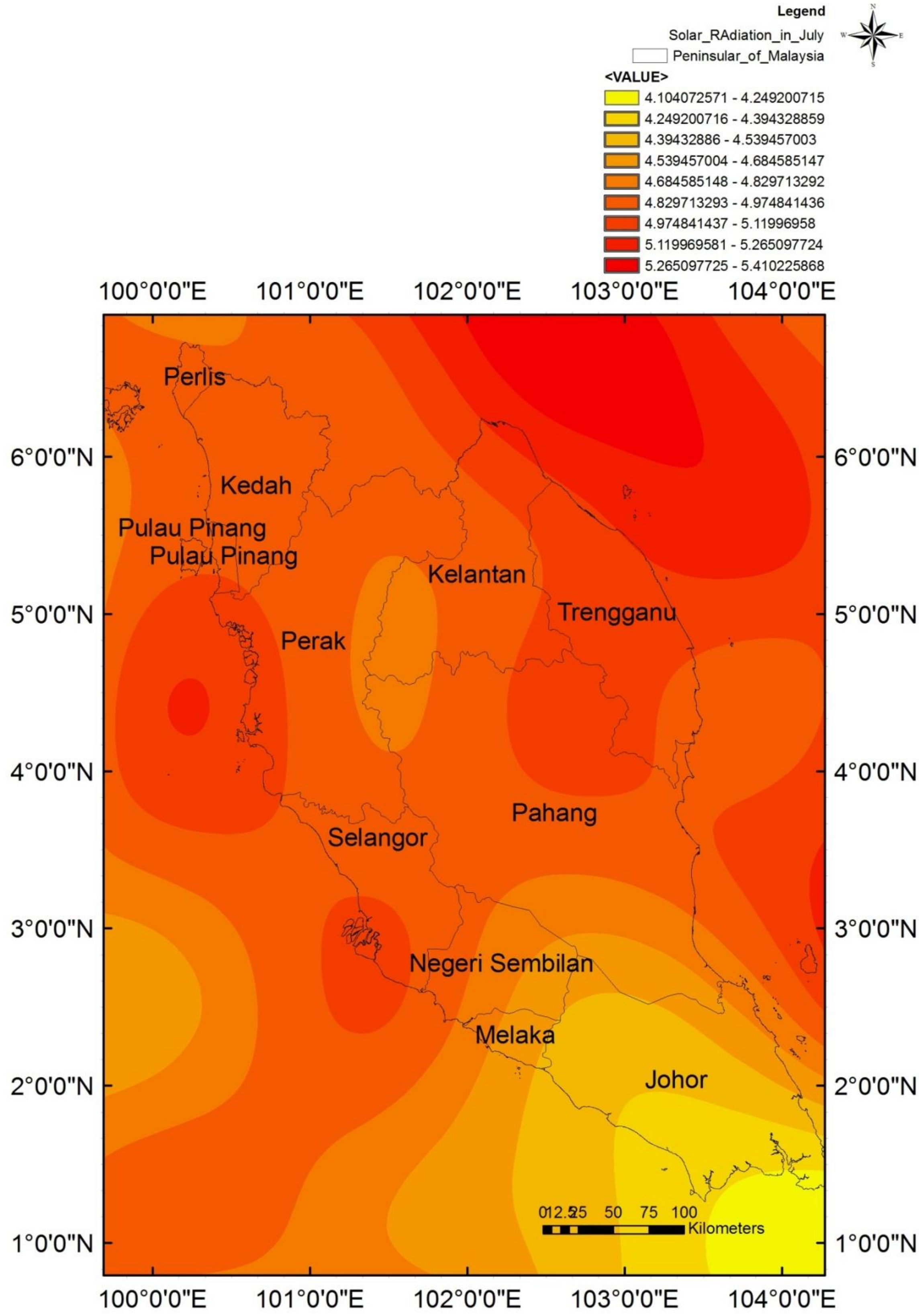


Figure A.7 Solar radiation map for the month of July.

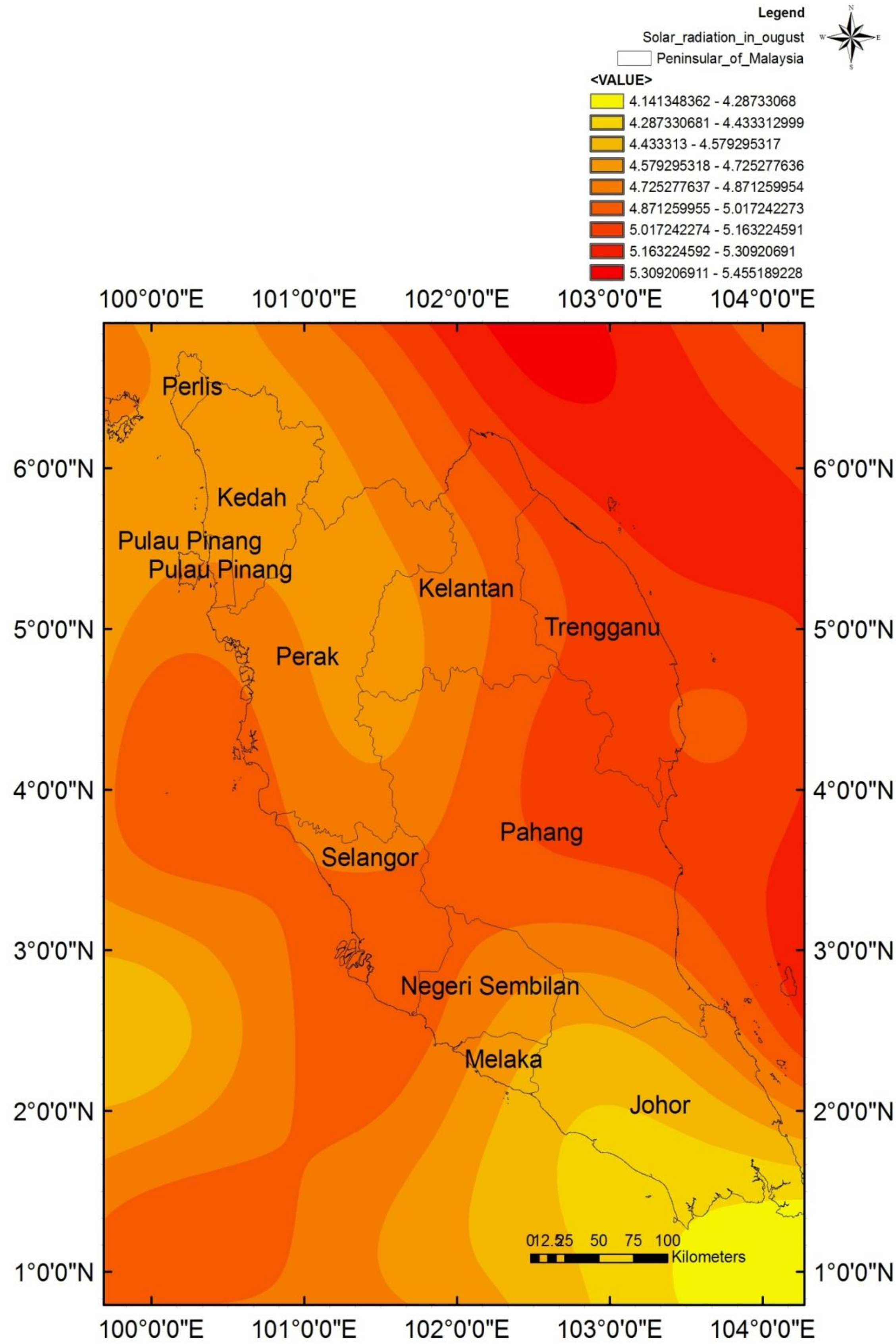


Figure A.8 Solar radiation map for the month of August.

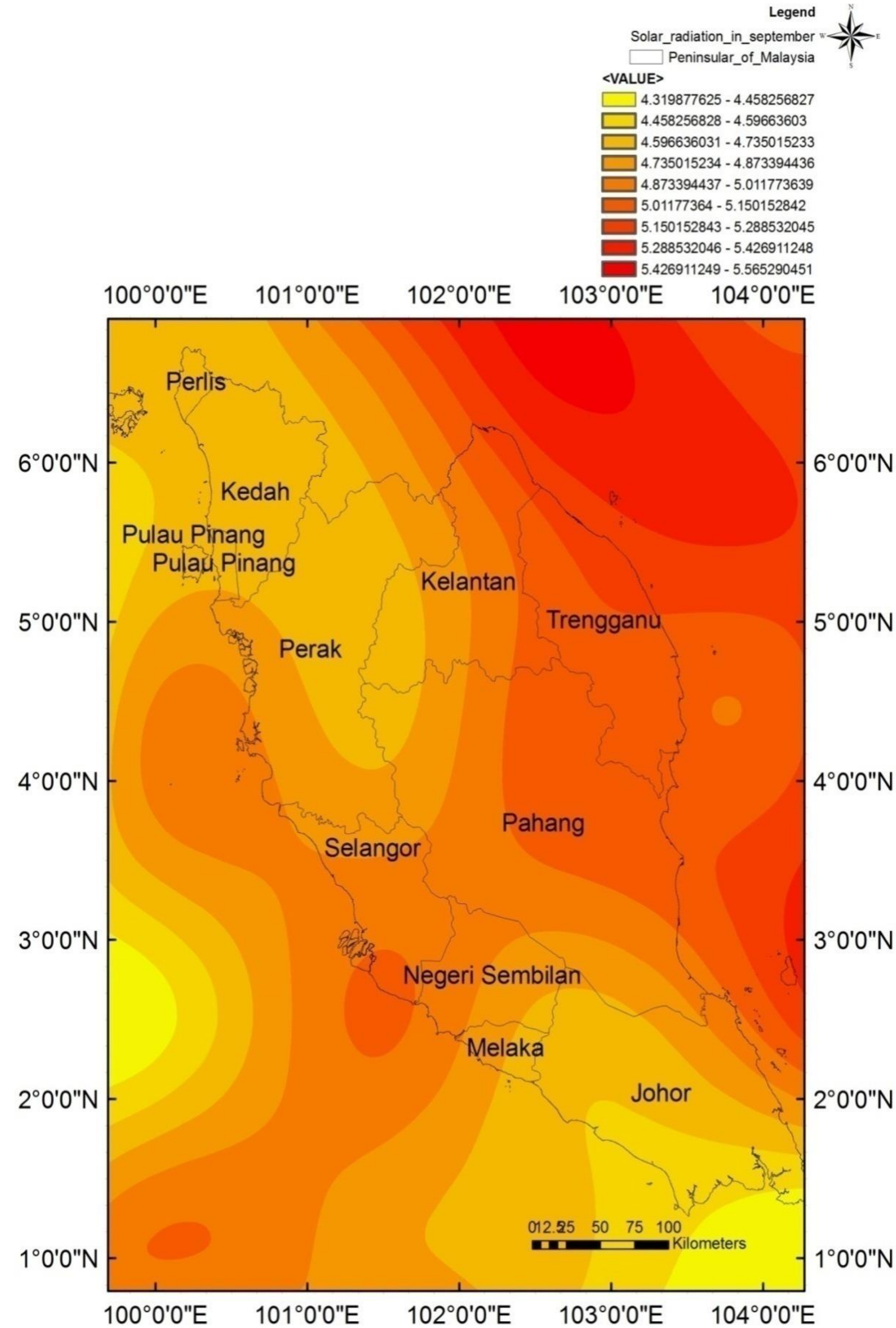


Figure A.9 Solar radiation map for the month of September.

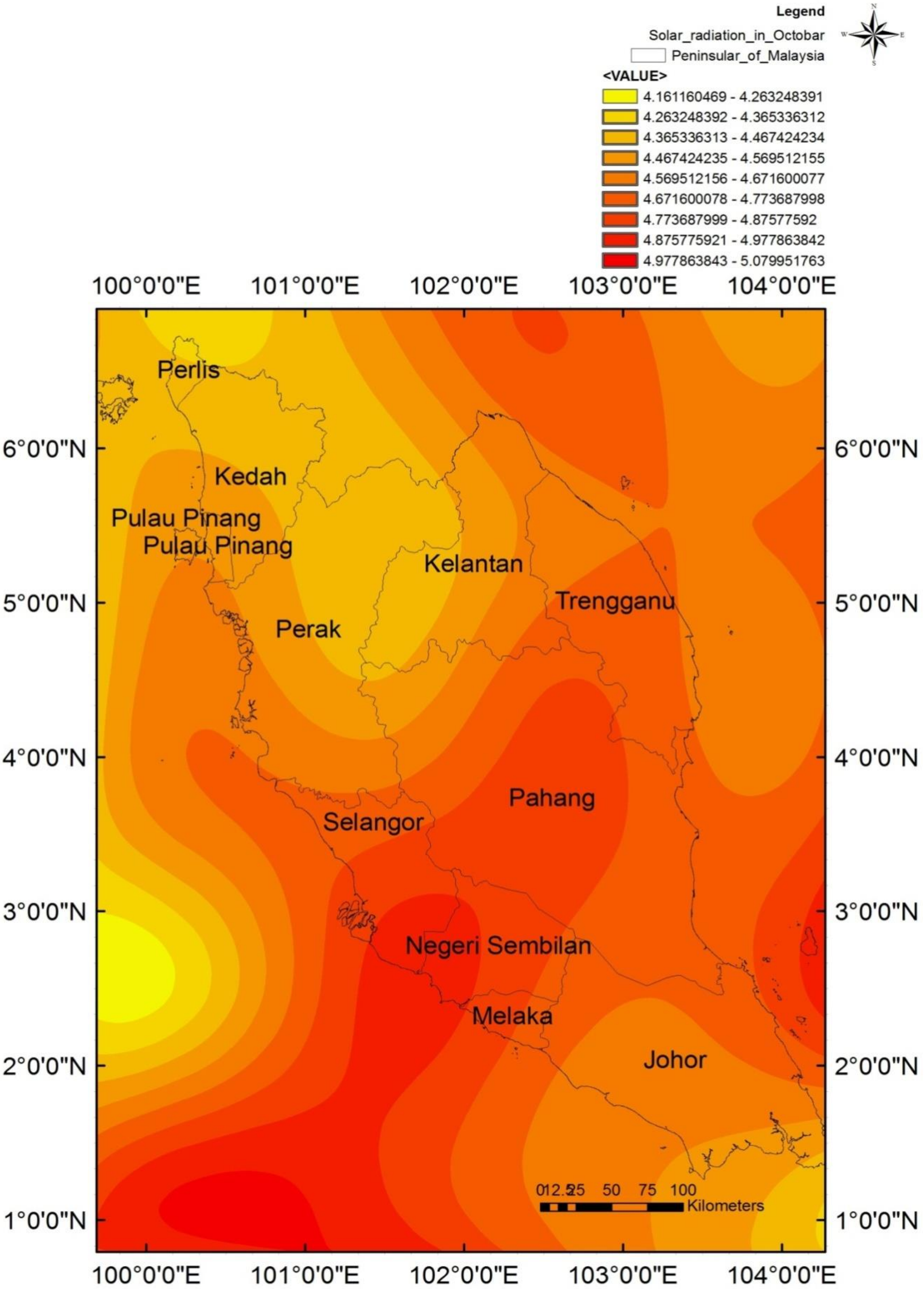


Figure A.10 Solar radiation map for the month of October.

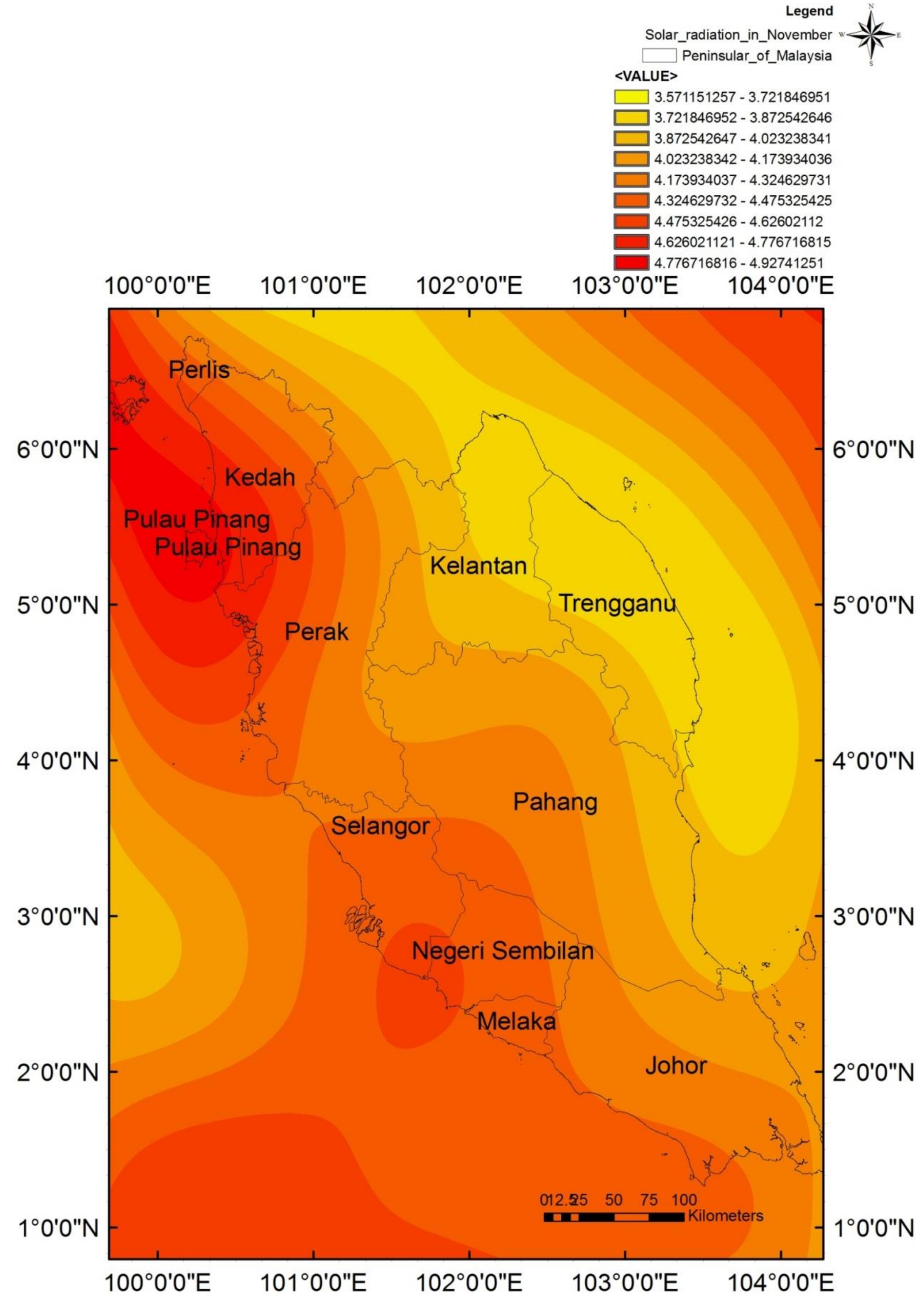


Figure A.11Solar radiation map for the month of November.

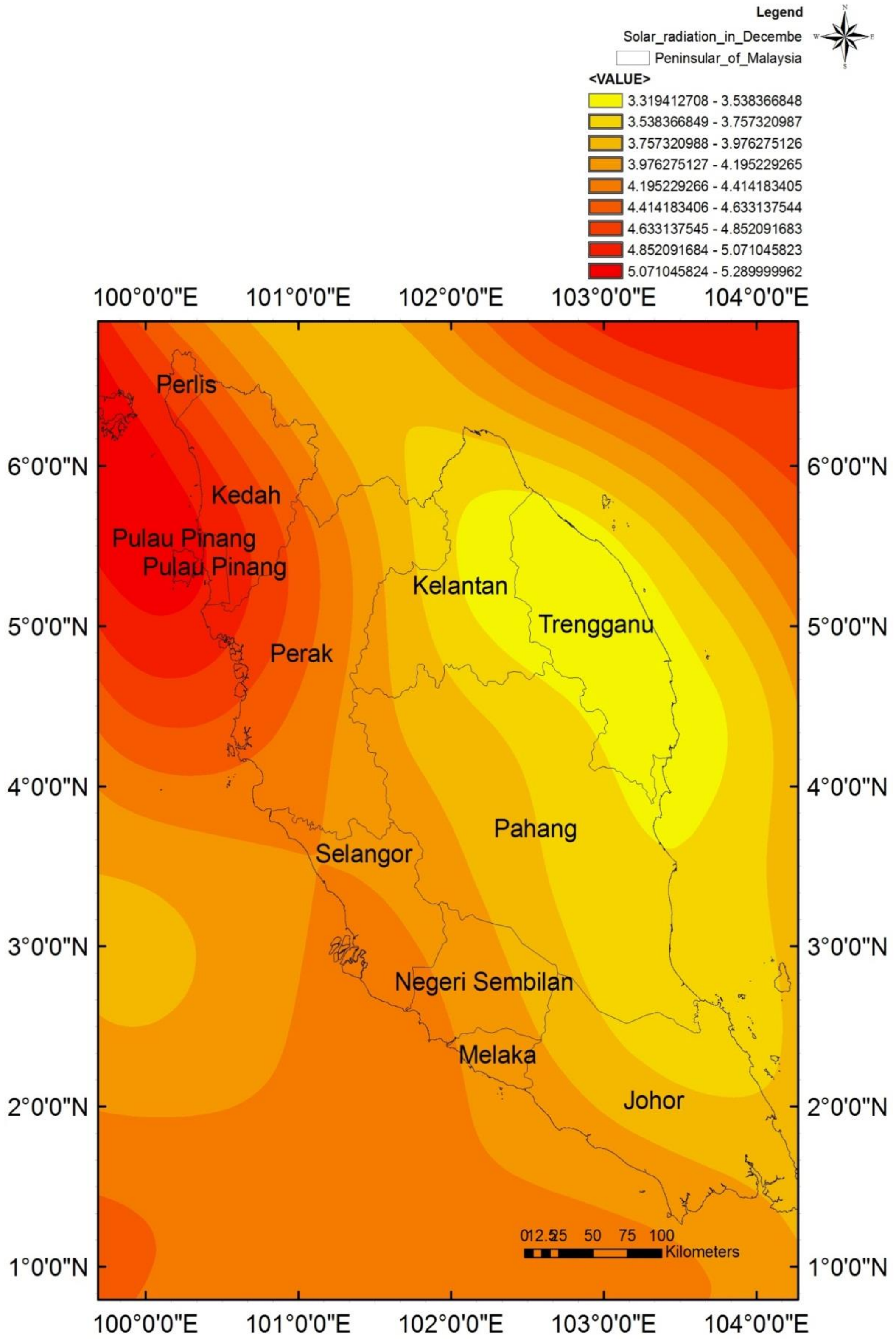


Figure A.12 Solar radiation map for the month of December.

Appendix B: Description of the parameters.

Table B 1: Collector data parameters.

S.No	Parameter	Description
1	Number of collector panels	This parameter is set to the number of collectors used in solar water heater.
2	Collector panel area	It is the area of collector as its net aperture or gross area, which was also used for determining FR×TAU×ALPHA and FR×UL. The same should be used for this parameter.
3	FR×UL (Test Slope)	FR is the collector heat removal factor and UL is the collector overall heat loss.
4	FR×TAU×ALPHA (Test Intercept)	This is the product of the collector heat removal factor, FR, and the transmittance-absorptance product, TAU×ALPHA, at normal incidence.
5	Collector slope	This is the angle between the plane of the collector aperture and the horizontal.
6	Collector azimuth (South=0)	It is the angle between the projection into the horizontal plane of the normal to the collector aperture and the local meridian with the zero point directly facing the equator, west positive, and east negative.
7	Collector flow rate/area	It is the total mass flow rate of collector fluid through the collector array divided by the total collector array area.
8	Collector fluid specific heat	This is the specific heat of the fluid flowing through the collectors. Properties can be found in the ASHRAE handbook of Fundamentals [1985].

Table B 2: Economics Data.

Data was collected through different sources in Malaysia. Data standards are maintained to get the results accurate and covering different situation with not great variations. A description of each parameter follows the parameter listing.

S. No.	Parameters	Description
1	Economic analysis detail	It cycles through "Brief", "Detailed", and "Cash Flow".
2	Cost per unit area	It indicates the cost per square foot of the solar collection system as well as such items as the storage costs that increase with collector increasing area.
3	Area independent cost	It indicates the cost of fixed equipment such as pumps, piping, controllers, storage part, and other costs that are collector area independent.
4	Price of electricity	It indicates average purchase price per kilowatt-hour

		that is paid in first year.
5	Annual % increase in electricity	This indicates anticipated average yearly inflation rate of electricity during the economic analysis period.
6	Price of natural gas	This indicates the average purchase price per 100 cubic feet (approximately per therm) paid in the first year.
7	Annual % increase in nat. gas	It indicates anticipated average yearly inflation rate of gas during economic analysis period.
8	Price of fuel oil	It indicates average purchase price per gallon or per liter paid during first year.
9	Annual % increase in fuel oil	It indicates anticipated average yearly inflation rate of oil during the period of the economic analysis. It is assumed that the average rate occurs each year of the analysis.
10	Price of other fuel	This indicates the average purchase price per million BTU or per gigajoule paid during first year.
11	Annual % increase in other fuel	It indicates the anticipated average yearly inflation rate of heating fuel, such as wood during the economic analysis period.
12	Period of economic analysis	It indicates the number of years over which the life cycle cost analysis is completed.
13	Percent down payment	It indicates the percentage of the incremental cost of the solar system that is rewarded at installation time.
14	Annual mortgage interest rate	It indicates charged rate by the lender on funds borrowed, in percent.
15	Term of the mortgage	It indicates the number of years over which the funds borrowed must be refund.
16	% Extra insur. andmaint. in year 1	It indicates first year's maintenance, extra insurance and other non-fuel operating expenses attributable to the system, expressed as a percent of the initial investment.
17	Annual % increase in insur. andmaint.	It indicates the average expected inflation rate of these expenses (previous parameter) over economic analysis period.
18	True % property tax rate	It indicates the ratio of the increment in real estate taxes due to the solar system to the cost of the solar system (not the assessed tax value of the solar system), expressed as a percent.
19	Commercial system?	Toggles between "Yes" and "No", if this parameter is set to "Yes", then the depreciationx schedule in the next parameter is used in calculating taxes and fuel is assumed to be deductible as a business expense. For solar systems on private homes, this parameter should be set to "No".

Table B 3: Solar Water Heating System Data.

Data was collected from the RETScreen data base. Data standards are maintained to get the results accurate and covering different situation with not great variations. The parameters for the active domestic hot water system are described below. A description of each parameter follows the parameter listing.

1	Location	It is the location where the system is located.
2	Water storage volume / collector area	It is the volume of water of one collector only, if multiplied by the number of all collector panels, gives the stored water used for thermal storage.
3	Fuel	It is the back-up fuel e.g. Oil, Gas, Electricity, Other.
4	Efficiency of fuel usage	It indicates the average furnace efficiency of the back-up (conventional) fuel.
5	Daily hot water usage	It indicates the average amount of hot water required per day at the set temperature.
6	Water set temperature	It is the required temperature of water set by end user.
7	Environment temperature	It indicates the surrounding temperature of the domestic water storage tank.

Appendix C: Relevant publications

Journal Articles

1. H. Fayaz, R. Saidur, N.A. Rahim, H. Niaz, K.H. Solangi, M.S. Hossain, A. Wadi, Policies to control greenhouse gases in Malaysia: A review, submitted to Renewable and Sustainable Energy Reviews, Under review. Submitted on; 21dec 2011.
2. 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.
3. Solangi, K. H., Islam, M. R., Saidur, R., Rahim, N. A., & Fayaz, H. (2011). A review on global solar energy policy. Renewable and Sustainable Energy Reviews, 15(4), 2149-2163.

Conference Papers

1. H. Fayaz,; Rahim, N.A.; Saidur, R.; Solangi, K.H.; Niaz, H.; Hossain, M.S.; Solar energy policy: Malaysia vs developed countries. Clean Energy and Technology (CET), 2011 IEEE First Conference on. Digital Object Identifier: 10.1109/CET.2011.6041512 Publication Year: 2011, Page(s): 374 – 378
2. Hossain, M.S.; Rahim, N.A.; Solangi, K.H.; Saidur, R.; H. Fayaz ; Madlool, N.A.;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
3. Solangi, K.H.; Lwin, T.N.W.; Rahim, N.A.; Hossain, M.S.; Saidur, R.; H. Fayaz, ; Development of solar energy and present policies in Malaysia. Clean Energy and Technology (CET), 2011 IEEE First Conference on Digital Object Identifier: 10.1109/CET.2011.6041447. Publication Year: 2011, Page(s): 115 - 120
4. K.H Solangi, R, Saidur, N.A. Rahim, M.R. Islam and H. Fayaz. Current solar energy policy and potential in Malaysia. 3rd International Conference on Science and Technology Application in industry and education, ICSTIE 2010 UiTM Pulau Pinang Malaysia, 16-17 December, 2010, Paper No. 31.

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