CHAPTER TWO

LITERATURE REVIEW

This chapter will introduce the background of solar thermal systems and literature from research work conducted in a different field of parabolic trough concentrators (PTC). However, the focus will be on the work that has been conducted in designing, constructing, developing, and experimental analysis of the PTC under different climatic conditions. Nevertheless, review on some of the operational PTC for either industrial heat applications or for electricity generation will also be included.

Energy demand, global warming issues and greenhouse effect have put the focus on how to make use of alternative source of energy such as solar energy technology (Thomas A., et al., 1992). According to World Energy Council, in 2015 the world energy consumption shows an increased growth in renewable energy consumption. However, most of the energy consumption is still coming from fossil fuels (oil, coal, and gas) as shown in Figure1. Although the usage of renewable sources is still low, but depletion of non-renewable sources encourages the world to shift the energy policy towards renewable energy sources.

In Malaysia, usage of fossil fuels made up around 80 % of Malaysian installed electric generation capacity and almost 92 % of the Malaysian electricity output in the year2012 (Chang et al., 2005). The annual rate of energy consumption is expected to increase at the rate of 4.8 % from year 2000 - 2030 (Mekhilef et al., 2011).

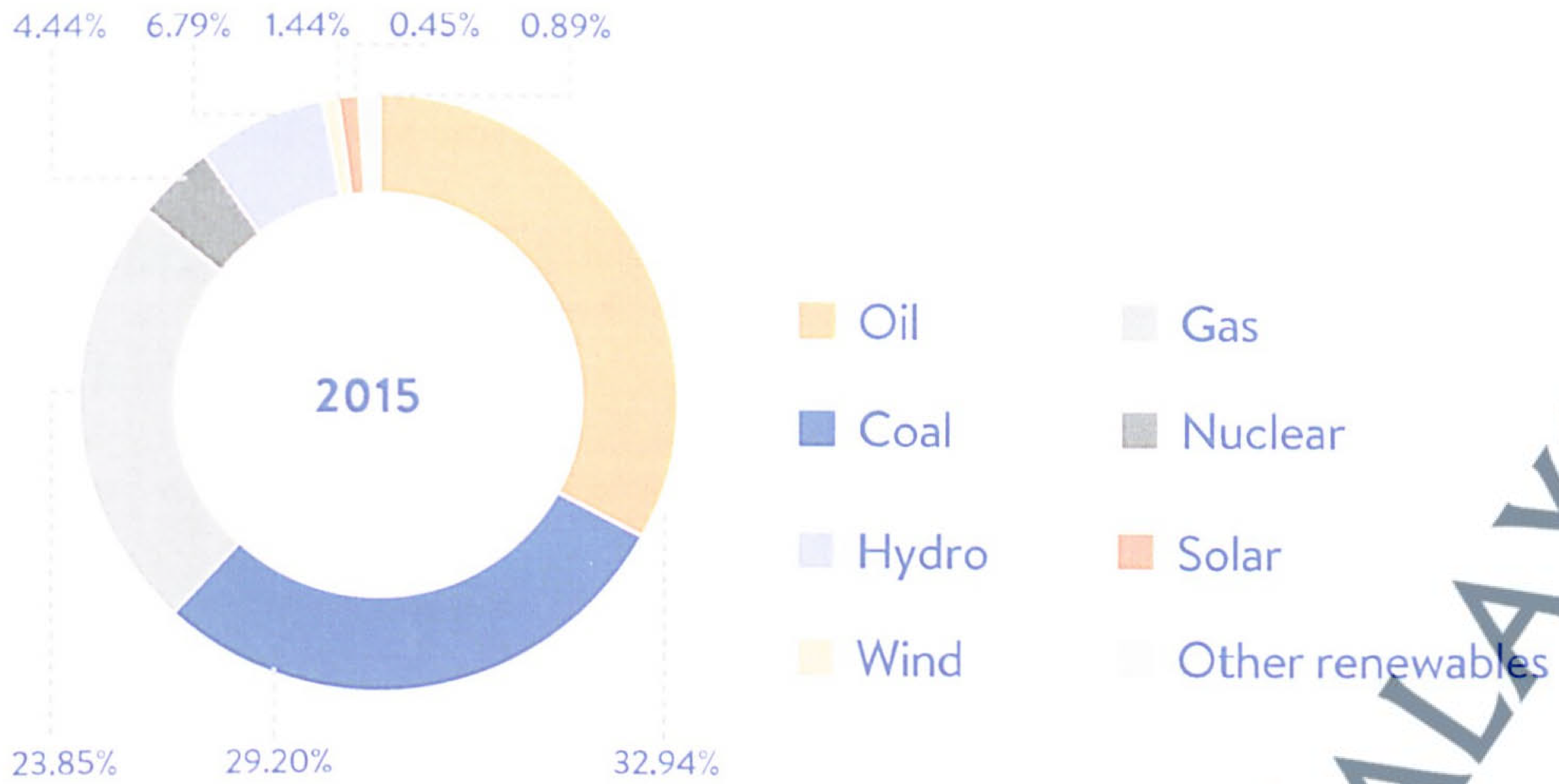


Figure 1: Energy Consumption in 2015 (World Energy Council, 2016)

In the 10th Malaysian Plan, consumption of fossil fuel energy is expected to reduce by aiming to increase 5.5 % the renewable energy power generation by the year 2015 (Kamariah et al., 2011). In this respect, solar energy could be one of the alternative sources of sustainable energy that can replace the usage of fossil fuels.

2.1 The Solar Radiation

2.1.1 The Sun

The Sun is regarded as the largest object in the solar system located at the center with other members revolving around it (Bhargva, 2012). The sun is a sphere of intensely hot gaseous matter with a diameter of 1.39×10^9 km and a distance of 1.5×10^{11} m from the earth. The surface of the Sun is at an effective temperature of about 5762 K which considered as a black body surface and with an estimated central interior region temperature between 8×10^6 K to 40×10^6 K (Sadik et al., 2013). Continuous fusion reactions take place in the sun, which is radiated in the form of electromagnetic waves and then reaches the surface of the earth that can be used for many different applications. The energy produced from the sun is radiated into space by the Stefan-Boltzmann's Law which is given as:

$$E = \varepsilon\sigma T^4 \qquad 2.1$$

where, ε is the emissivity of the surface σ is the Stefan-Boltzmann constant and T is the absolute temperature measured in kelvin (Bhargva, 2012).

According to the solar spectrum, the solar radiation received on the earth's surface can be categorized into ultraviolet (UV) radiation, visible light and infrared (IR) radiation. The relative solar energy intensity as a function of wavelength shows that 49 % of the solar radiation emitted is infrared, which is in the range of 750 nm – 1 nm wavelength, and 43 % of the emitted solar radiation is visible light with the wavelength range of 380 - 750 nm, while only 8 % of the radiation is ultraviolet with wavelength less than 380 mm (Dascomb, 2009).

The amount of solar energy radiation striking the earth is usually reduced by the atmosphere with some of the amount reflected back into space and some being absorbed (the UV radiations are absorbed by the ozone layer and IR radiations are absorbed by the water vapors and carbon dioxide). These reduce the intensity of the solar radiation upon reaching the earth's surface. The incident solar radiation could reach the earth in two methods namely:

- **Diffuse solar radiation:** This is the solar radiation scattered by particles in the atmosphere, and reflected by the air molecules, water vapors, clouds, dust, volcanoes etc, eventually hitting the Earth at random.

- **Direct (beam) solar radiation:** Direct normal insolation is the radiation that travels directly through the atmosphere without interference. Atmospheric conditions can reduce direct beam radiation by 10 % on clear, dry days and 100 % during thick, cloudy days.

2.1.2 The Earth

The earth revolves around the sun every 365.25 days with a diameter of about 3.0×10^{6} km in an elliptical orbit called ecliptic plane, and it completes a full rotation about its axis every 24 hours (see Figure 2). Almost 70 % of the earth is covered by water and the remaining 30 % is land. The earth is inclined at an angle of 23.5° that reflects one third of the sunlight that falls on it.

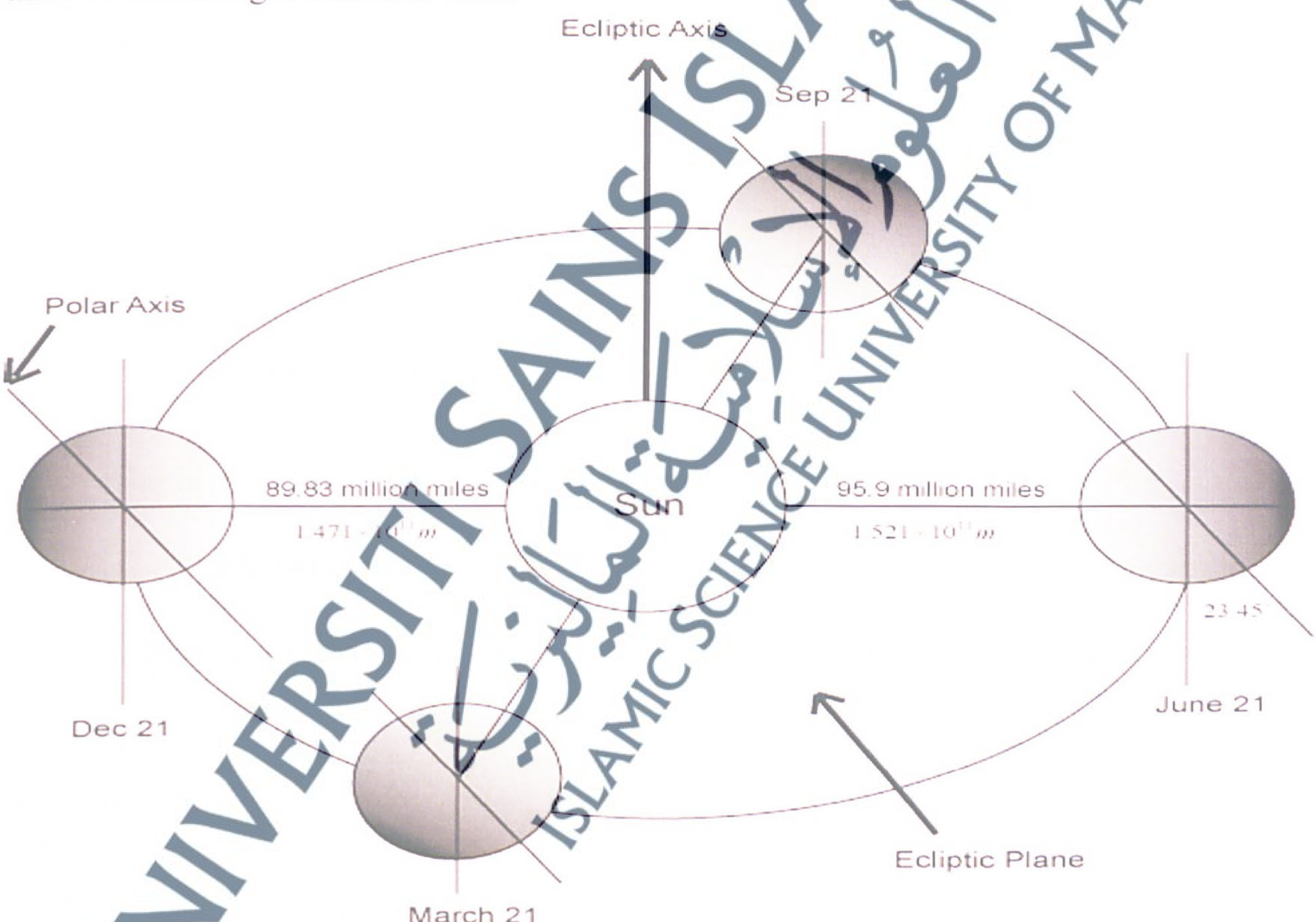


Figure 2: Motion of the Earth about the Sun (Mutlak, 2012)

2.1.3 Earth and Sun Angles

The following are the basic earth and sun angles:

- **Zenith angle (θ):** This is the angle between the sun's ray and perpendicular line to the horizontal plane.

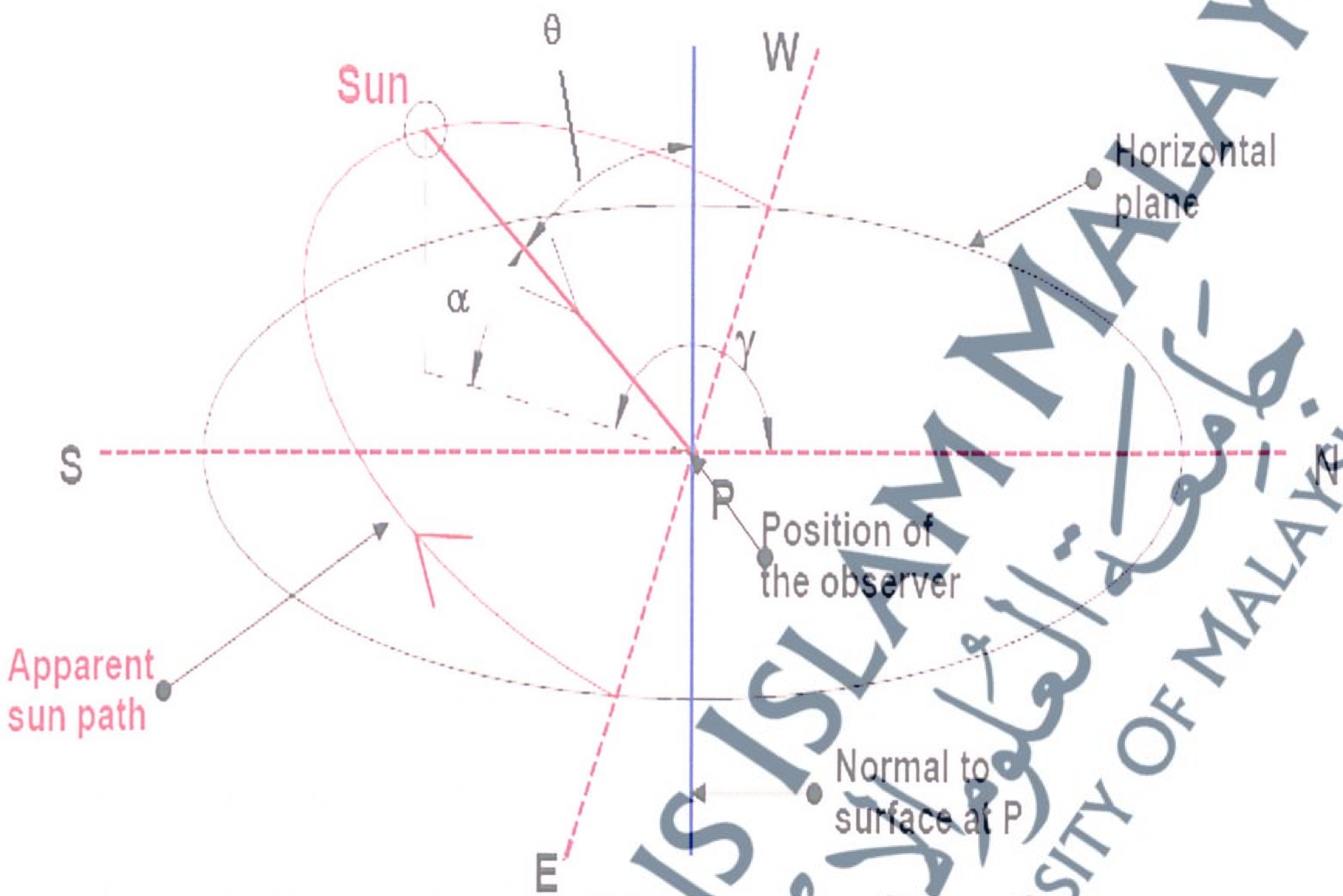


Figure 3: The Earth and the Sun Angles (Bhargva, 2012)

- **Surface azimuth angle (γ):** It is the angle in a horizontal plane, between the line due south and the projection of the normal to the surface of the horizontal plane
- **Altitude angle (α):** It is defined as the angle between sun rays and a horizontal plane.

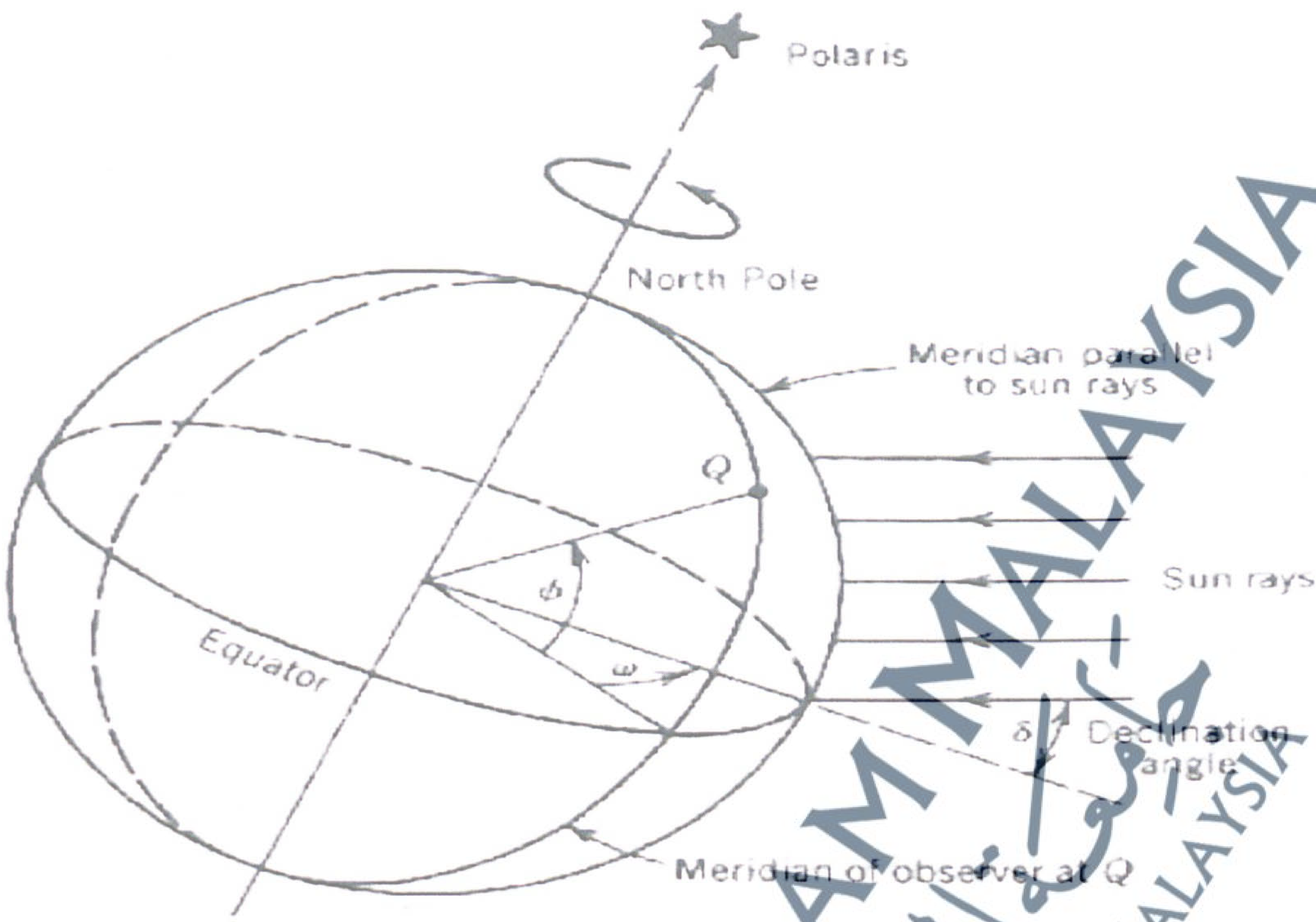
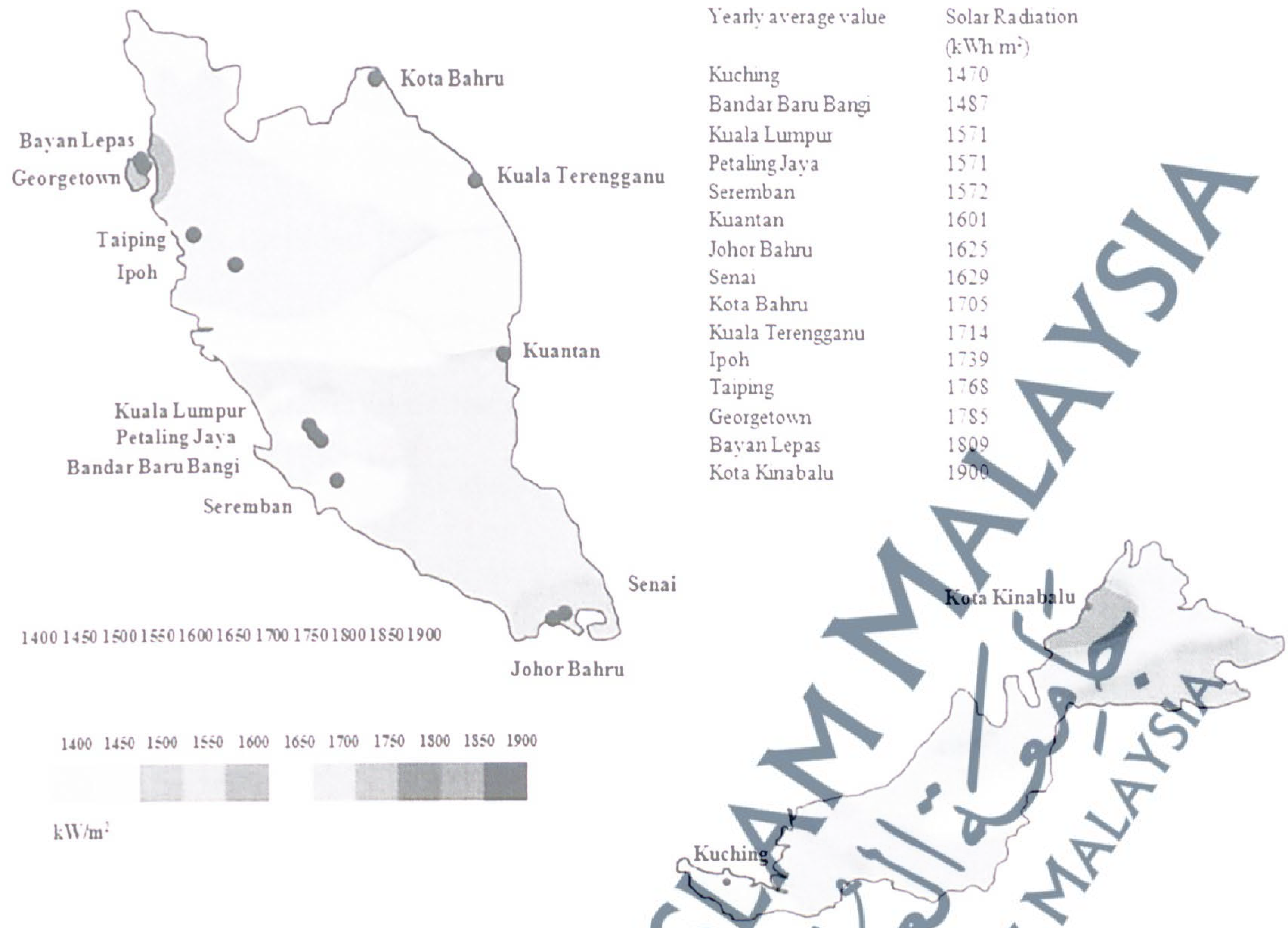


Figure 4: The Earth and the Sun angles (Ahmad, 2012)

- **Latitude angle (ϕ):** This is the angle that joins the given location to the center of the earth with its projection on the equator.
- **Hour angle (ω):** This is the angle through which the earth must be rotated to bring the meridian of the plane directly under the sun.
- **The declination angle (δ):** This is the angle between a line extending from the center of the sun to the center of the earth and the projection of this line upon the earth's equatorial plane.

2.2 Solar Energy Potentials in Malaysia

Malaysia is an equatorial country, has a geographical coordinate of 4.21^o N, 101.27^0 E. Its weather has been characterized by heavy rainfall, light winds, high level of clouds as well as hot and humid throughout the year. For the CST and CSP technology to be economically feasible it requires direct solar irradiation (DNI) of at least 1900-2000 KWh/m^2 per year or daily solar irradiation value of at least 5 $kWh/m^2/day$ (Rosnani et al., 2014). Malaysia receives an average of 6 hours sunshine per day with the annual varying temperature of 26 to 28^0 C (Sabo et. al, 2013). Due to its location near equator lines makes Malaysia as one of the country that receives huge amount of solar irradiation/insolation every year. Figure 5 shows its distribution in Malaysia. Northern Malaysian states and few places in east Malaysia are among the places that receive high amount of solar irradiation throughout the year. The daily solar irradiation in Malaysia is around 4.7 to 5.8 KWh/m^2 with 6.8 KWh/m^2 in August and November respectively while monthly solar irradiation of Malaysia is 133.0 KWh/m^2 and yearly value is around 1596.5 KWh/m^2 to 1643 KWh/m^2 (Rosnani et al., 2014), which make it feasible to implement solar thermal technology. However, on the other hand, Malaysia is also considered as one of the wet climate countries where the annual rainfall is about 2250 mm/year and the cloud cover is normally high throughout the year, even in the dry season (Noor et al., 2014). The rate of humidity in Malaysia varies from 80 % to 90 %. Therefore, it will be quite a challenge to implement solar thermal technology.



Yearly average value	Solar Radiation (kWh m²)
Kuching	1470
Bandar Baru Bangi	1487
Kuala Lumpur	1571
Petaling Jaya	1571
Seremban	1572
Kuantan	1601
Johor Bahru	1625
Senai	1629
Kota Bahru	1705
Kuala Terengganu	1714
Ipoh	1739
Taiping	1768
Georgetown	1785
Bayan Lepas	1809
Kota Kinabalu	1900

Figure 5: Annual Average Solar Radiation in Malaysia (Salsabila et al, 2013).

2.3 Concentrated Solar Thermal Water Heating Systems

Concentrated solar thermal energy involves the collection and conversion of solar energy from the sun at a certain wavelength in the solar spectral region into heat. One of the most prevalent applications of the concentrated solar thermal energy is the hot water production, which requires temperature below 100 ^{0}C for these applications. According to an IEA report for 2006, solar thermal collector capacity in operation worldwide was about 127.8 GWh (182.5 million m^2), mostly for domestic applications, which include domestic water heating (DHW) like kitchen, shower, laundry, sanitation facilities and space heating (Ibrahim et al, 2011).

Many countries currently implemented the water solar heating systems and some promoting this type of technology. Among this country, Israel with more than 90 % of the solar thermal systems retrofitted into existing buildings. Nevertheless, country like Spain current legislation included in the building code requires that all new domestic hot water installations and covered swimming-pool heating should have a solar system to supply a certain amount of the energy demanded. Similarly, Portugal, introduces the requirement of solar thermal installations into their new Portuguese building code (Fernandez-Garcı´a, 2011). In Malaysia, lack of public awareness and understanding of the potential benefits of solar water heating system, high cost of the original water heating system (WHS), inappropriate roofing structures are some of the factors affecting the installation of WHS in Malaysia (Mekhilefet al., 2012)

In CST technology, thermal collector is very important. Generally, there are two types of solar thermal collectors: Concentrating and non-concentrating/stationary collectors. Concentrating solar collectors are usually used the solar tracking collectors and are the type of solar thermal collectors that has the surface area larger than the receiver's or absorbing area. The parabolic reflecting surfaces of this type of concentrators intercept and focus the sun's beam radiation in a smaller receiving area, while non-concentrating collectors refers to the solar thermal collectors that has intercepting area the same as that of the absorbing solar radiation (Kalagirou, 2014). The classification of these solar thermal collectors is given in the table on the following page.

Table 1: Concentrated Solar Thermal Collectors

Tracking system	Type of Collector	Type of Receiver
Stationary	Flat plate collector (FPC)	Flat
	Evacuated tube collector (ETC)	Flat
	Compound parabola collector (CPC)	Tabular
Single-axis tracking	Linear Fresnel reflector (LFR)	Tabular
	Parabolic trough collector (PTC)	Tabular
	Cylindrical trough collector (CTC)	Tabular
Two-axes tracking parabolic	Dish reflector (PDR)	Point
	Heliostat field collector (HFC)	Point

The concentrated solar thermal technology has many advantages and some disadvantages compared to other types of solar energy system. The following are some of the advantages of the concentrated solar thermal (CST) systems:

The concentrated solar thermal technology (CST) is considered to be a clean technology which does not produce any toxic waste or radioactive material, it works noiselessly with less thermal losses, it works with higher efficiency at the higher working temperatures with smaller collecting surface for a given power requirement and has no risk of reaching dangerous stagnation temperatures. Similarly, it has high performance and is considered to be a reliable system with a low maintenance system.

Some of the disadvantages of the CST systems are: It needs innovative absorber design due to its non-uniform cooling, its solar-tracking system increases installation and maintenance costs, it is expensive and has high installation cost, it is not suitable for integration with the present roof system and however it needs a larger space for separate systems (hot water and electricity production) and at the same time it utilizes only beam solar radiation respectively.

2.4 Concentrated Solar Technology

Parabolic trough concentrators (PTC) are the most established and low-cost of the concentrated solar technology for the generation of electricity and steam production. The first practical experience with the PTC's technology reported goes back in 1870 when a Swedish engineer, John Ericsson, design and construct a 3.5 m^2 aperture collector that operates the small engine of 373 W called direct steam generation (DSG) (García et al., 2010). In this type of system, steam is directly produced from the solar collector. Due to this, many parabolic trough solar tracking concentrators were designed, constructed and evaluated for different thermal applications.

In 2007, Valan reported development of fiberglass trough parabola concentrator (Valan et al, 2007). The parabolic trough concentrators consist of aperture area of 1 m^2 and 90^o rim angle using lay hand technique for hot water application. The thermal performance of the fiberglass reinforced parabolic trough collector reported in this study was determined according to the ASHRAE standard 93 method of testing. Copper tube of 12.8 mm diameter was used as a receiver coated with resistance black paint and enclosed by a glass envelope with the water as a heat transfer fluid. Results from the experiments shows that the standard deviation of the parabolic trough surface error to be 0.0066 rad, which clearly indicates that the parabolic trough surface was accurately constructed.

Moreover, the developed fiberglass reinforced parabolic trough can be used for low-cost production as well as the batch production for all collectors' size.

In 2012, Tadahamum Ahmed Yassen conducted an experimental and theoretical study of a parabolic trough collector to determine the thermal efficiency during winter and summer climatic conditions of Takrit, Iraq. The study was carried out by conducting theoretical calculation of the solar radiation of Takfir University and then programmed the theoretical result into the FOTRAN 90 programmed. Parameter of the solar collector were used in order to determine the thermal efficiency of the collector theoretically. On the other hand, experimental study was performed using the same size and dimension of the PTC during winter and summer and comparison was made between the experimental and theoretical study of the PTC. Result shows that the theoretically determined thermal efficiency of the concentrator is greater than the actual thermal efficiency by 7 % to 15 % during summer and the thermal efficiency during winter is greater than that of summer by 2 % to 5 %, respectively.

Design, test and mathematical modeling of two PTC prototypes of aperture area 1.85 m^2 and 5.78 m^2 with 180^o rim angle was developed by Marco in 2012. Two different composite fiberglass materials with extruded polystyrene (Univpm.01 and Univpm.02) were used for both prototypes and the mathematical model was developed in order to predict the thermal losses and optical efficiency of any parabolic trough concentrator (PTC). This was validated through experimental results where comparisons were made between them. Both prototypes were tested using oil and water as a heat transfer fluid and tested under working temperature ranging from 10 – 150 ^{o}C.

In the same year, Kawira et al., reported the study on the potential of solar thermal concentrators for the steam production from three parabolic trough solar concentrators. The collector dimensions are: aperture width 1.2 m, collector length 508 m, and aperture area of 6.95 m^2 with copper tube as the receiver which carried water as the heat transfer fluid. The concentration ratio of the collectors is 128. Testing was carried out for each of the concentrator and the maximum temperature of the steam obtained was 248.3 ^{0}C while the average temperature of the steam produced was 150 ^{0}C. Result obtained indicates that, the concentrator can be used in providing electricity to the rural areas, which are far away from the electricity transmission grid.

On the other hand, Santohkumar Singh et al., (2012) designed and fabricated a parabolic trough solar water heater for hot water production. The trough concentrator was fabricated with 1.20 m × 1.20 m aluminum sheet reflector of 0.635 m thickness, which was covered by a cloth and pasted by rectangular mirror of 1.20 m × 0.05 m strips. The performance evaluation of the fabricated cylindrical collector was carried out with two different absorbing tubes in order to compare the thermal efficiencies between the two. Result from the experimental evaluation indicates that the thermal efficiency of the aluminum tube absorber is less than that of the copper tube with a percentage of 18.23 % aluminum tube and 20.25 % of a copper tube. It was observed from the efficiencies of the parabolic trough concentrator obtained that, this type of technology can be used to generate hot water that would be hot enough for the conversion of solar power thermal systems specifically when enclosed copper tube was used as the absorbing tube. However, similar study was conducted by Forristal in 2013, on the designing and manufacturing the PTC that uses a mirror as a reflecting surface to reflect and concentrate solar radiation onto the receiver tube at the focal line of the parabolic cylinder. The incoming solar radiation will be absorbed by the receiver and then transformed into thermal energy. This method of solar collection has the advantage of high efficiency and low cost, and can be used either for thermal energy collection, for generating electricity or for both.

Sadik, et. al. (2013) conducted experiments for the performance evaluation of PTC under climatic condition of the Dundaye area of the Usmanu Danfodio University, energy research Centre Sokoto, Nigeria. The experimental performance evaluation was carried out with a constructed PTC of an aperture area of 2.85 m^2, focal distance 1.82 and collector's lengths of 1.82 m using locally available materials. Copper pipe of 28.5 mm diameter was used as a receiver, which was painted with a black paint in order to increase the thermal conductivity of the receivers. Result obtained from this experimental study indicates the maximum outlet temperature of 110 ^{0}C attained which can be consider as fairly acceptable, even though, that some problems were encountered during the experiment with the tracking inaccuracy due to the manual tracking of the PTC. Similarly, design and testing of solar parabolic trough concentrating collector were reported by (Eltahir Ahmed Muhammad, 2013). In this type of study, a small type of PTC was fabricated with the aim to carry out an experimental study by testing the parabolic trough collector under Darfur climatic condition, Sudan. The PTC was fabricated locally with an aperture width of 1 m stainless steel reflectors and a galvanized steel pipe of 3.8 cm diameter and water as a working heat transfer fluid. The results from the experimental study indicate that the collector's orientation North-South will prevent solar radiation end loss and can increase the thermal performance of the collector.

However, the average collector's efficiency of the experimental testing was found to be 37 % and hence, using stainless steel pipes enclosed by evacuating glass envelope round the absorbing tube can increase the thermal performance of the parabolic trough solar collector.

An educational single tracking PTC was designed and developed by (Odeh& Abu-Mulaweh, 2013) for moderate heat purposes and for instruction and demonstration purposes. The solar collector was designed and developed as a self- powered solar tracking collector that can operate remotely and independently under moderate radiation levels with a minimum technical supervision. The average thermal efficiency of the solar collector determined from this type of study was 60 % using 0.0005 m × 2 m × 1 m stainless steel sheet reflecting surface and 2 cm copper tube receiver. However, the development of small scale concentrating PTC for drying purpose was reported by (Aamir et al., 2013). In this study, a concentrating PTC was developed using steel sheet reflector of aperture area of 2.9 m^2 and a steel pipe receiver of 0.05 m diameter connected to steel drying box with the aim to determine the performance of the PTC for drying fruits and consequently to study the thermal efficiency of the concentrating collector. The experimental results during the performance evaluation using two air mass flow rate indicates that the average temperature of the month and the mass air flow rate affected the thermal efficiency of the concentrating solar collector, and in addition the solar collector's efficiency of drying increases with increased in mass flow rate.

The most common and recent application of the PTC for power generation is the nine-commercial solar energy generating systems (SEGS) that has aperture of a black silvered mirror area of 2.32×10^6 m^2 and a receiver of 70 mm diameter steel tube which have been developed, installed and in operation in Mojave Desert Area of southern California that has a total installed capacity of 354 MWe (Kalagirou, 2014). However, the power generating system consists of two subsystems that use two heat exchangers with oil as thermal heat transfer fluid. The function of the two subsystems is to obtain superheated steam and to convert the thermal energy into electricity while rejecting the waste heat.

Chiat et al., (2014) conducted the study on the improvement of solar concentrator for hot water generation. Two axes solar tracking system was used for this method, which proved the reception of higher energy gain and improved collector efficiency. The aim of the project is to improve the design of the parabolic trough collector in terms of its thermal efficiency, thermal heat losses and tracking system. The results obtained from the experimental study conducted under Baghdad climatic conditions (33.3° N, 44.4° E) during selective days of the month of October shows the average maximum thermal efficiency of the fabricated (0.8× 1.8 m) multi - piece glass mirror PTSC to be 50 %, which regarded as fairly acceptable assessment result of PTSC fabricated locally. However, it was reported from the experimental test that the evacuated receivers are suitable for obtaining high temperature of about 130-140 °C and hence, the fabricated PTSC is suitable for space heating and hot water loads, because of the higher temperature of storage that reaches 135 °C.

Asfar et al., (2014) reported the performance assessment of the parabolic trough solar concentrator designed and constructed with an aperture area of 10.02 m^2 using 304 AB stainless steel sheet reflectors and a 25/32 mm inner/outer diameter copper tube receiver. The aim of the project is to generate a steam directly from the constructed parabolic trough concentrator tested under the Jordanian climatic condition with the normal irradiance on the surface of the collector measured to be $G_n = 1032\ W/m^2$. Result from the experimental assessment conducted indicates the maximum temperature of 123 ^oC of the steam generated at a pressure of 2 bars with 22 % maximum efficiency obtained.

Kasaeian et al., (2014) conducted a feasibility study of the parabolic trough collector with the aim to investigate the performance enhancement of the smooth 90^0 rim angle trough collector that has been designed and manufactured with an aperture area of 1.4 m^2 steel mirror reflector. The optical and thermal performance of this type of solar collector were determined with the use of a black painted vacuumed steel tube, copper bare tube with black chrome coating, glass enveloped non-evacuated copper tube with black chrome coating, and a vacuumed copper tube with black chrome coating respectively. However, carbon nanotube/oil based nanofluids were used as working fluid during the experimental testing of the trough collector, which was followed the conditions of ASHRAE Standard 93 (2010). Results from the experiment indicate that the copper absorber tube coated with black chrome has the highest optical and thermal conductivity when compared with other absorbing. Moreover, the convection heat losses from the absorbing tubes during the experimental testing resulted to the enclosed absorbing tube to averagely have higher efficiency than bare absorbing tube with 11 %. Furthermore, experimental investigation shows that the potential of using nanofluids, as high capable and quite simple mean to increase the performance of high flux solar collectors.

Macedo et al., (2014) presented the design, construction and evaluation of a prototype PTC for demonstrative purposes. The prototype was designed by considering the parabolic aperture of 0.5 m wide and 0.95 m long using computer aided design device. The result obtained during the evaluation of the thermal performance of the prototype was a maximum of 47.3 ^{o}C outlet temperature for 783 W/m^2 direct solar irradiation at rate flow of 0.200 L/min. Furthermore, the thermal efficiency and the useful energy obtained from this study was not the one expected, this is due to the optical properties of the coated pipe absorber but the collector's thermal efficiency was related to the room temperature, cloudiness and atmospheric conditions. However, the concept of combining a parabolic dish concentrator with the thermo-electric (TE) module to produce electricity and thermal energy from the sun was explored with a simple prototype and some preliminary experimental measurement (Lertsatitthanakorn et al., 2014). It was found in this study that the solar parabolic concentrator couple with a thermo-electric (TE) generator could produce a maximum power output of 1.38 W at 0.42 m^2/min of the air flow under maximum heat flux.

Gianluca et al., (2015) reported the design, manufacture and testing of a prototype PTC for industrial process applications. The main features of this prototype are its cost-effectiveness, low weight, high mechanical resistance, and easy to manufacture. Testing results indicate that the equation of the thermal efficiency is comparable with other similar thermal collectors for industrial heat process applications ranging from 70 to 250 ^{o}C. The PTC was presented with 90^{o} rim angle and a lower concentration ratio of 9.25 build in fiberglass and extruded polystyrene with the cross-sectional aluminum pipe receiver contained within a low-iron glass envelope. Recently, the experimental study of the performance of PTC for hot water generation was carryout by (Mayur et al., 2015). The PTC was designed and fabricated using aluminum sheet reflector of aperture area of 1.82 m^2 and aluminum tube as a receiver surrounded by a glass and metal pipe in order to minimize the thermal heat loss. However, the experiment from this study indicates the maximum outlet temperature of 65 °C with a collector thermal efficiency of 32 %. The maximum value of temperature was obtained at noon and hence the manually tracking parabolic trough solar collector can be a better option for hot water generation during the winter season for rural and remote areas.

2.5 Parabolic Trough Solar Concentrators in Malaysia

Solar thermal organic Rankin circle was studied by Chang et al., (2005) is among the PTC design developed in Malaysia. The objective of the research project is to study the feasibility of an organic Rankin circle (ORC) as a renewable thermal energy source for the generation of less than 10 MW for small and medium scale commercial purposes. However, there are two cycles in the power generating systems of the organic Rankin cycle (ORC) namely the solar thermal cycle that circulates heat transfer fluid in the circle and subsequently converts the solar thermal energy from the sun via a heat exchanger into the organic compound in the Rankin cycle (ORC); and the power cycle which is the organic Rankin cycle that generates electricity. Furthermore, the two organic materials R123 and isobutene used as a thermal fluid were examined for power generation and it was found that the R123 gives higher thermal efficiency, more suitable for high temperature applications and less thermal efficiency when superheating than the isobutene.

Fauzia et al. (2012) presented the simulated design and analysis of a solar thermal PTC using several meteorological data in different parts of Malaysia using the software writing in MATLAB environment. The study was carried out by changing three parameters: Aperture Area, Receiver diameter and working fluid in order to optimize the simulated design. However, three different types of working fluids were investigated for this study, and the results obtained from the simulation study shows that the receiver's diameter of 0.03 m and concentration ratio of 10 are the optimum parameters to achieving the highest efficiency of this model. More so, the study shows that equilibrium between the thermal losses increment due to the increases in the aperture must be achieved.

In 2014, Alhassan et al reported the simulation analysis of thermal losses of PTC in Malaysia using computational fluid dynamics. The study investigates the thermal loses (Radiation and Convection) of the PTC by simulation with aim to investigates the wind speeds velocity and mass flow rate of the heat transfer fluid (HTF) on the thermal losses of the parabolic trough solar collector. The receiver of the parabolic trough collector (PTC) was modeled with the CDF Code ANSYS commercial heat transfer Software. It was revealed from the numerical analysis of the study that the effect of both the radiation and convection heat losses are not affected by the changes in wind speed, and in addition 64 % of the convection heat loss was contributed to the total heat loss of the glass envelope. Radiation contributes 36 % of the total heat loss for wind speed velocity of 2 m/s.

2.6 Parabolic Trough Receiver

There are many techniques currently under study on how to prevent receiver's heat losses and misalignment. The primary function of the receiver is to absorb and transfer the concentrated heat to the fluid flowing through it. The parabolic trough solar concentrator

(PTC) receiver is in the form of a tube placed linearly along the focal line of the trough collector and is usually covered with an envelope such as a glass tube in order to minimize the thermal heat losses, thereby increasing the thermal performance of the collector. Therefore, the reflected solar radiation onto the receiver will deviate from the focal point or get loose if the receiver is either misaligned or not properly covered. On the other hand, the outer surface of the receiver should be coated with a high temperature resistance paint that has high solar energy absorption and a low energy emittance before enclosing it into a glass tube to increase its efficiency (Kalagirou et al., 1994). The parabolic trough connector's optical performance can be reduced significantly if at any point along the length of the trough, the center of the receiver deviates from the focal length of parabolic trough concentrator which is regarded as misalignment of the receiver. Factors like poor structural design, poor installation, and sag from the weight of the heat transfer fluid and the tube itself, or change in the structure over time due to wind loading can also contribute to the misalignment of parabolic trough receivers (Kathleen et. al., 2012).

2.7 Tracking System

Solar tracking system is an essential component in the solar concentrator, because without tracking system, the solar collectors will collect little energy for a very short period of time. Therefore, collectors must be provided with tracking mechanism that can track the solar radiation from morning to evening (East-west or both east- west and north-south) so as to maximize the energy efficiency. The tracking mechanism must be able to follow the direction of the sun at a certain degree of accuracy. The tracking mechanism for the solar thermal collectors can be mechanical, electrical/electronic or manually operated tracking system. Many tracking systems for parabolic trough solar collectors (PTC) were developed. Among them, is the tracking mechanism presented by (Kalagirou, 1996) which uses three light dependent resistors (LDR), each of the (LDR) will detect each of the following: the focusing of the solar collector, the cloud cover, and to detect or senses whether it is a day or night respectively. However, the resultant signals were controlled by an electronic control system, which operates at low speed 12V DC motor that rotates the concentrator trough a speed reduction gearbox. The intensity of the solar irradiation on the surface of the collector determines the accuracy of the tracking system and in addition the tracking mechanism in this study can be used for parabolic trough collectors of high and low concentration ratios.

Khan et al. 2010 reported the design and construction of a prototype automatic solar tracking system for automatic positioning of the solar panel at a maximum intensity. The sensors used for the solar tracker in this type of study were light dependent resistors with the other component such as stepper motor and a microcontroller. However, the microcontroller based design methodology was adopted for an automatic solar tracking which has the precise control mechanism that provides three ways of controlling the system.

From the literature, it was found that many parabolic trough solar concentrators (PTC) have been reportedly designed, developed, evaluated/experimentally analyzed for research purpose, industrial applications, generation of electricity or any other applications. Some of the reported PTC's are even in operation. However, the follow the direction of the sun at a certain degree of accuracy. The tracking mechanism for the solar thermal collectors can be mechanical, electrical/electronic or manually operated tracking system. Many tracking systems for parabolic trough solar collectors (PTC) were developed. Among them, is the tracking mechanism presented by (Kalagirou, 1996) which uses three light dependent resistors (LDR), each of the (LDR) will detect each of the following: the focusing of the solar collector, the cloud cover, and to detect or senses whether it is a day or night respectively. However, the resultant signals were controlled by an electronic control system, which operates at low speed 12V DC motor that rotates the concentrator trough a speed reduction gearbox. The intensity of the solar irradiation on the surface of the collector determines the accuracy of the tracking system and in addition the tracking mechanism in this study can be used for parabolic trough collectors of high and low concentration ratios.

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From the literature, it was found that many parabolic trough solar concentrators (PTC) have been reportedly designed, developed, evaluated/experimentally analyzed for research purpose, industrial applications, generation of electricity or any other applications. Some of the reported PTC's are even in operation. However, the performance of those reported concentrators for research purpose were mostly evaluated under normal environmental weather where there is uninterrupted degree of solar irradiation. Therefore, the foregoing research work will focus on how to develop and evaluate the performance of PTC's under a tropical environment like Malaysia where the availability of solar irradiation is varying throughout the day. Similarly, the result from the research work will suggest ways on how to implement the installation of parabolic trough solar concentrators (PTC's) for power generation in Malaysian environment.