Potential of Global Solar Radiation in Terengganu, Malaysia

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***Abstract*- Accurate information on the intensity of solar radiation at a given location is essential to the development of solar energy-based projects. This information is used in the design of a project, in cost analysis, and in calculations on the efficiency of a project. As the solar radiation data are not available for most areas in Malaysia, this study is crucial in establishing the solar data for Terengganu, Malaysia. The geographical co-ordinates of the site are 5^0 $10'$ N latitude 103^0 06' E longitude and 5.2 m altitude. The data used in the present study were collected from the Renewable Energy Station, University Malaysia Terengganu from 2004 to 2010. In addition to these data, secondary data were obtained from Malaysian Meteorological Department from 2004 to 2009 at the Terengganu Airport station (5^o $10.0'$ N latitude 103^o 6.0' E longitude) which is nearly 2 km southeast to the study area. From the raw data, the mean, maximum and minimum hourly values were calculated. The highest 24 hours basis daily and monthly mean global solar radiation values were 314.9 W/m^2 and 7556 Wh/m^2/day, respectively. The highest hourly average solar radiation intensity was 1139 W/m^2 during this study period. Yearly average daily solar energy was 18.93 MJ/m^2/day. Besides the global solar radiation, the clearness indexes and air temperature variation are discussed. This study indicates that Terengganu state has a strong solar energy potential.**

Keywords*- *Clearness Index; Daily Mean Solar Radiation; Monthly Mean Daily Solar Radiation; Yyearly Average Daily Solar Energy

I. INTRODUCTION

The accurate information of the solar radiation intensity at a given location is essential to the development of solar energy-based projects and in the long-term performance evaluation of the solar energy conversion systems. This information is used in the design, cost analysis, and efficiency calculations of a project. Furthermore, monthly mean daily data are needed for the estimation of long-term performance of solar systems.

In particular, the clearness index of the area, in addition to other meteorological information such as humidity and temperature for a specific period, is extremely important to assess the feasibility of a solar-driven project. Due to its geographical position in the solar belt, the Terengganu state, Malaysia is blessed with an abundance of solar energy in addition to fossil fuel. The Terengganu state has the opportunity to utilize this bounty of natural energy effectively, promoting a clean environment, and developing renewable energy technologies in the region. The use of photovoltaic devices, on the one hand, is suitable for rural electrification, pumping water from wells, cathodic protection for pipelines, telecommunications, and building facades. Solar thermal devices, on the other hand, can be used for crop drying, and water heating. Given these many possible uses of solar energy, it is important to know the global solar radiation distribution throughout the year for the state.

Further, in solar energy applications, the value of average daily global radiation is the most important parameter. But, values of these parameter measurements are not available at every location. This is due to the factors of cost, maintenance, and calibration requirements of the measuring equipment. In places where no measured values are available, a common application has been to determine this parameter by appropriate correlations, which are empirically, established using the measured data. Several empirical models have been used to calculate solar radiation, utilizing available meteorological, geographical and climatological parameters such as sunshine hours [1-3], air temperature [4], precipitation [5], relative humidity [6], and cloudiness [7].

Malaysia is one of the countries which have abundant solar energy. The annual average daily solar irradiations for Malaysia have a magnitude of 4.21–5.56 kWhm^{-2}, and the sunshine duration is more than 2200 hours per year [8]. Unfortunately, for many developing countries like Malaysia, solar radiation measurements are not easily available due to the high equipment cost and maintenance and calibration requirements of the measuring equipment. An alternative solution to this problem is to estimate solar radiation by using a modeling approach [9-15].

Global solar radiation has been measured at the few areas in the Malaysian cities [16-23]. Few models have been tested, and few studies based on these models have been performed to estimate solar energy potential. The solar radiation estimates for Peninsula Malaysia were published by Chuah and Lee [17]) for three major towns, namely Kuala Lumpur, Penang and Kota Bharu, who used the Angstrom type regression equation to clear day radiation at the locations. Monthly average solar radiation on the horizontal surface in Kuching, Kota Kinabalu, Kota Bharu, Senai, Bayan Lepas, Kuala Lumpur, Petaling Jaya and Bandar Baru Bangi were studied by Kamaruzzaman and Othman [18], who used the simplified Angstrom model. Azami et al. [24] used Box-Jenkins method to predict the global solar radiation at Bangi. Two statistical methods were used to forecast the monthly average daily solar radiation based on the meteorological factors such as sunshine hours, relative humidity, total rainfall and wind speed in Lapangan Terbang Sultan Abdul Aziz Shah Subang. Ayu et al. [23] used satellite images to predict the solar energy as an alternative method. Although solar radiation data have been reported for few regions in Malaysia, reliable and yearlong global radiation data are still needed for Terengganu state. This study therefore addresses this need.

II. EXPERIMENTAL SETUP, DATA AND PROCEDURE

In this study global solar radiation data were measured to get a better view of the solar energy potential in Terengganu state. The global solar radiation and air temperature data collected from the Renewable Energy Station, Universiti Malaysia Terengganu (UMT) from 2004 to 2010 were considered in this research work. Yearly data were separately used for calculation and analysis. The geographical co-ordinates of the study site are 4° 13.6′ N latitude 103°26.1' E longitude and 5.2 m altitude. The data were measured at one (ten) minute(s) intervals and averaged. The row and hourly averaged data were stored on computer. In addition to the Renewable Energy Station data, secondary data were obtained from Malaysian Meteorological Department from 2004 to 2009 for the Terengganu Sultan Mahmud Airport station (5° 10.0' N latitude 103° 6.0' E longitude) which is nearly 2 km southeast to the study area (Figure 1). The surface air temperature and the global solar radiation measurement instruments were set at 6 m above the ground level. The meteorological data were collected every ten minutes using a computer. A LI-COR, LI-200SZ pyranometer was used to measure the global solar radiation. Its calibration accuracy is ±2%, its linearity is 1 %, and its sensitivity is 80 μA per 1000 W/m^2. The sensors were regularly checked and calibrated against reference sensors maintained at the station and suppliers to ensure the quality of the data collected. There were missing and invalid measurements in the data. The missing and invalid measurements, accounting for less than 0.50% of the whole database of each data, were replaced with the values of preceding or subsequent hours of the day by interpolation. The integrated hourly time-series data from multiple months (2004-2010), excluding incomplete data were combined for validation. Data were manually validated to remove outlier events due to failure of instruments, etc. and statistically analyzed. From the raw data stored, the mean, maximum and minimum hourly values were calculated. From the hourly data set, daily and monthly statistics were made for the solar radiation and temperature data.

Fig. 1 Geographic location of the research area - Kuala Terengganu (Google map)

The monthly average daily clearness index was calculated by taking the ratio of measured global solar insolation to the calculated extraterrestrial horizontal insolation [7]. The values of the monthly average daily extraterrestrial radiation (H_o) were calculated for days giving average of each month [15, 25].

H_o was calculated from the following equation [15, 25].

$$H_o = \frac{24 * I_{sc}}{\pi}\left[1 + 0.033\cos\left(\frac{360n}{365}\right)\right] x \left[\cos\varphi\cos\delta\sin w_s + \left(\frac{2\pi . w_s}{360}\right)\sin\varphi\sin\delta\right] \tag{1}$$

where I_{sc} is the solar constant (=1367 W m^{-2}), φ is the latitude of the site, δ is the sun declination and w_s is the mean sunrise hour angle for the given month. δ and w_s can be computed by the following equations [15, 25]:

$$\delta = 23.45 \sin[360(n + 284)/365] \tag{2}$$

where n is the day number of the year starting from 1st of January.

$$w_s = \cos^{-1}(-\tan(\varphi)\tan(\delta)) \tag{3}$$

III. RESULTS AND DISCUSSIONS

Generally, from the data it is clear that the daily average and maximum global radiations as well as temperatures are higher from February to September and lower from October to January. Figure 2 describes the daily average and daily maximum global solar radiation for the whole year 2004. The graphs show that the daily maximum global radiation of 1139 W/m^2 was recorded on April 5, 2004, while the highest 24 hours basis daily average solar radiation of 314.9 W/m^2 was recorded in April. Daily mean solar radiation values were high during the periods of February to May and July to October. Average daily energy input for the whole year was 18.93 MJ/m^2/day, which agrees with the global solar map [26]. Figure 2 also shows downward excursions in northeast monsoon, especially in November, December and January. These excursions might be due to rain and higher air mass.

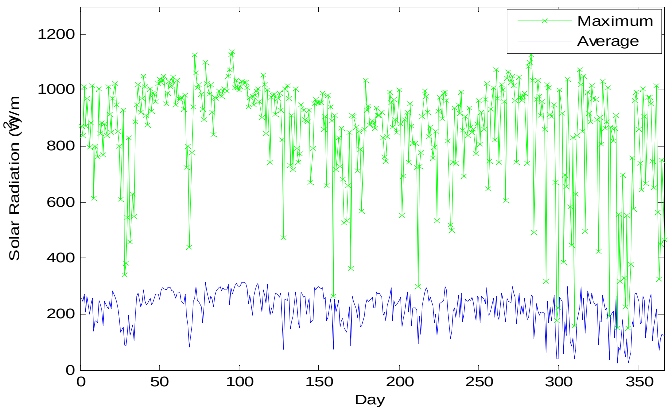

Fig. 2 Daily average (24 hours) and daily peak of global solar radiations throughout the year at the research site

Daily averages for each month and peak daily global solar radiations for a complete year based on measured data at RES are shown in Figure 3. The month of April had the highest monthly average daily radiation of 6566 Wh/m^2/day and the highest daily peak in solar radiation of 7556 Wh/m^2/day. December had the lowest monthly average daily solar radiation of 3715 Wh/m^2/day.

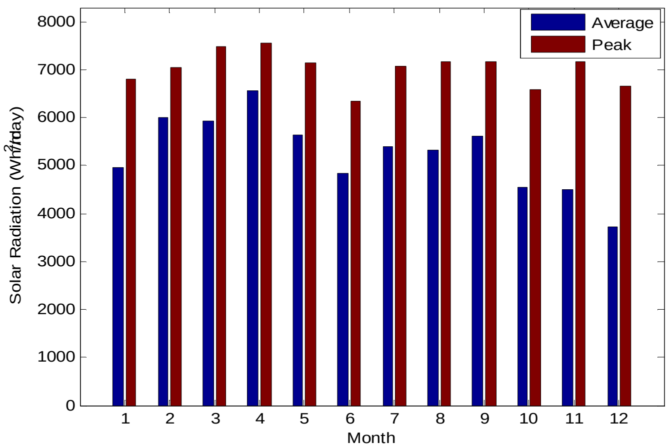

Fig. 3 Monthly average and monthly peak daily total solar radiation at the research site

The monthly mean daily values of global solar radiation of other cities (Kuching, Kota Kinabalu and Kota Baru since these cities identified as high solar energy potential areas) of Malaysia {18] are compared with Kuala Terengganu monthly mean daily values of global solar radiation (Table I). It is clear that the monthly average global radiation over the course of the year is higher for Kuala Terengganu, though in few months Kota Kinabalu city has higher monthly mean daily global solar radiation values.

TABLE I. MONTHLY MEAN DAILY VALUES OF GLOBAL SOLAR RADIATION FOR KUALA TERENGGANU, KUCHING, KOTA KINABALU AND KOTA BARU [18]

Months	**Global radiation (MJ/m²/day)**			
	Kuala Terengganu	**Kuching**	**Kota Kinabalu**	**Kota Bharu**
January	17.91	12.02	17.71	16.26
February	21.60	13.35	19.36	17.72
March	21.40	15.39	20.97	19.72
April	23.64	13.07	21.64	19.74
May	20.34	13.42	20.16	18.23
June	17.42	16.28	19.11	17.10
July	19.43	16.57	19.41	17.17
August	19.15	15.14	19.44	17.42
September	20.20	15.79	18.20	18.12
October	16.40	15.23	19.21	17.09
November	16.24	14.92	18.08	13.28
December	13.38	12.56	18.00	12.15
Annual Average	18.92	14.48	19.27	17.00

Figure 4 shows the maximum, minimum and average air temperature for one complete year for Kuala Terengganu. The graph shows that during the northeast monsoon the air temperature was lower than 30.0^{o}C when the solar radiation was lower than 5000 Wh/m^2/day. The highest daily maximum and monthly average temperatures were 34.5^{o}C and 29.4^{o}C on 31 August and April, respectively. The minimum daily average temperature recorded was 22.8^{o}C on February 22.

Figure 5 shows the maximum, minimum and average air temperature for Kuala Terengganu in 2004.

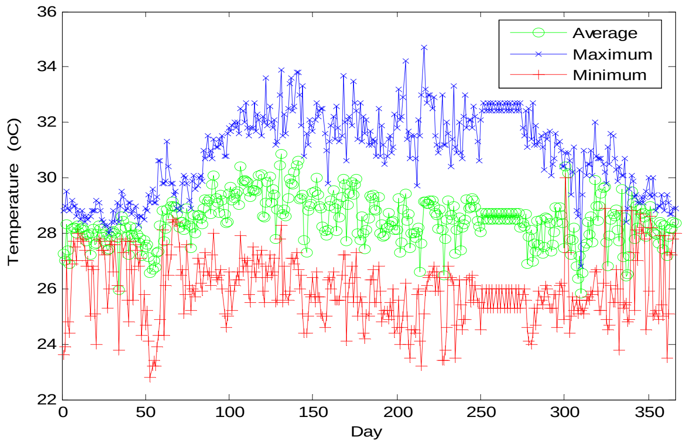

Fig. 4 Daily average, minimum and maximum temperatures throughout the year at Kuala Terengganu site

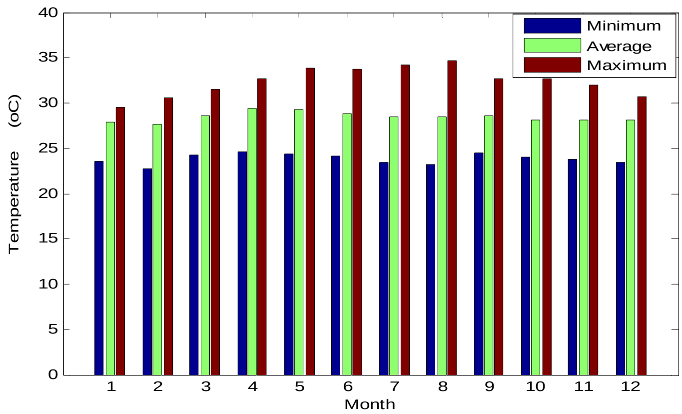

Fig. 5 Monthly average daily mean, minimum and maximum temperatures at the research site

Figure 6 shows the daily variations of the clearness index for Kuala Terengganu throughout the year. The clearness index varies between 0.06 and 0.76 during one complete year. During the northeast monsoon, the clearness indexes are very low; for other periods almost clear sky condition exists.

The monthly average clearness index is shown in Figure 7 and it varies between 0.42 and 0.64. The average clearness index value is approximately 0.53. During the northeast monsoon, when both the clearness index and temperature are low, global solar radiation is likely to be low. Due to the low clearness index the solar radiation energy reduces dramatically.

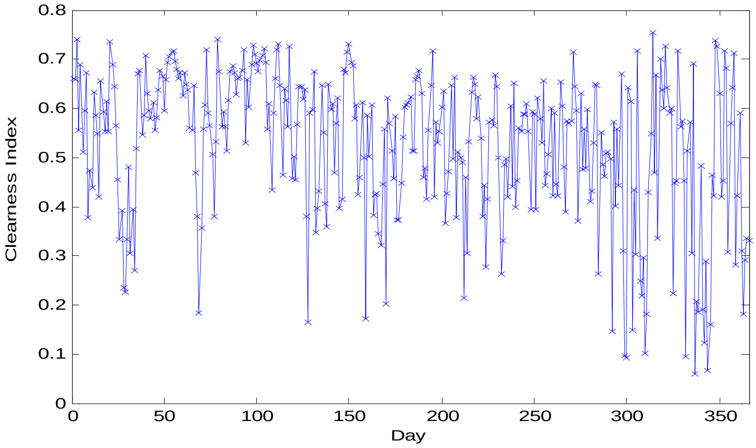

Fig. 6 Daily average clearness index variation throughout the year at the research site

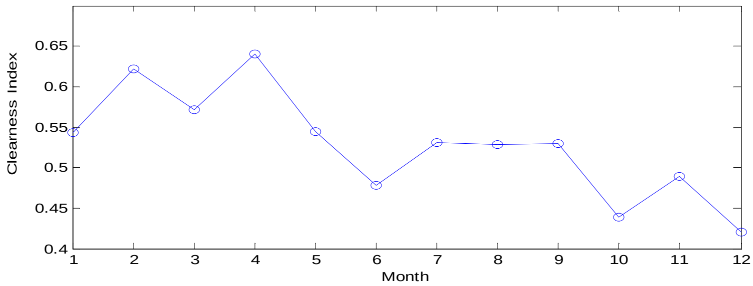

Fig. 7 Monthly average clearness index at the research site

The monthly mean clearness indexes of other cities (Kuching, Kota Kinabalu and Kota Bharu since these cities identified as high solar energy potential areas) of Malaysia [18] are compared with Kuala Terengganu monthly mean clearness index, as shown in Table II. It is clear that the monthly average clearness index over the course of the year is higher for Kuala Terengganu, though in few months Kota Kinabalu city has higher monthly mean clearness index values.

TABLE II MONTHLY AND ANNUALLY AVERAGE CLEARNESS INDEX OF KUALA TERENGGANU, KUCHING, KOTA KINABALU AND KOTA BARU [18]

Months	**Clearness Index**			
	Kuala Terengganu	**Kuching**	**Kota Kinabalu**	**Kota Baru**
January	0.54	0.35	0.55	0.51
February	0.62	0.38	0.57	0.52
March	0.57	0.41	0.56	0.53
April	0.64	0.36	0.59	0.54
May	0.54	0.37	0.53	0.48
June	0.48	0.48	0.53	0.48
July	0.53	0.45	0.51	0.45
August	0.53	0.41	0.51	0.46
September	0.53	0.43	0.50	0.50
October	0.44	0.41	0.53	0.47
November	0.49	0.41	0.53	0.39
December	0.42	0.36	0.54	0.37
Annual Average	0.53	0.40	0.54	0.47

IV. CONCLUSIONS

In this study global solar radiation and air temperature data were measured to get a better view of the solar energy potential in Kuala Terengganu. Daily average solar radiation data show that average values are lower in the northeast monsoon from November to January and are higher in the other periods. The maximum global radiation of 1139 W/m^2 was recorded in April, and the highest 24 hours basis daily average solar radiation of 314.9 W/m^2 was recorded also in April. Average daily energy input for the whole year was 18.93 MJ/m^2/day. The highest daily maximum and monthly average temperatures were 34.5^{o}C and 29.4^{o}C in August and April, respectively. The minimum daily average temperature was recorded 22.8^{o}C iin February. In northeast monsoon the air temperature is lower than 30.0^{o}C. The clearness index varies between 0.06 and 0.76 during one complete year. In northeast monsoon, the clearness indexes are very low, but in other periods almost clear sky condition exists. The monthly average clearness index varies between 0.42 and 0.64. The average clearness index value is approximately 0.53. In northeast monsoon, clearness index, temperature and solar radiations are low. This paper is based on data collected in the first phase of the project and near future another paper will be published with hourly and daily solar radiation prediction models.

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