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Estimation of Solar Radiation on Horizontal Surfaces in Gabès located in the South east of Tunisia

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Abstract: Solar radiation data are important tools for many areas of research and applications in various engineering and scientific fields including for example climatology, agro meteorology, hydrology and solar energy converting system design. The main objective of the present study is to predict the daily solar radiation and the hourly irradiation on a horizontal surface for the city of Gabès located in the south east of Tunisia. The obtained results are used to develop a Matlab program which can be used in the estimation of the solar radiations for all the city of Tunisia.

Key words: solar radiation, solar energy, daily solar radiation, hourly solar irradiation.

1. Introduction

Due to the increase in energy demand and the decrease in energy resources, solar energy is an appealing field of investment. Solar energy research is important for engineers and architects to optimize energy resources. In fact, solar radiation is used directly to produce electricity for photovoltaic setups and to produce heat for solar thermal systems. There are various modeling strategies and particular models for the estimation of the amount of solar radiation reaching at a particular point over the Earth. In practice, meteorological measurements of irradiance are usually registered for the horizontal plane by the pyranometer which measures the direct and diffuse solar radiation and they can also measured by the pyrheliometer which measures only the direct radiation. To determine the feasibility of building a solar energy system, it is necessary to know the amount of solar radiation that is available. Many researchers have presented correlations to estimate solar radiation on horizontal surfaces using the available data on meteorological [1,2], geographical and climatological parameters. These parameters include sunshine hours [3,4], air temperature [5], latitude, longitude and altitude [6]. In this context, we have estimated the hourly direct irradiance, the hourly diffuse irradiance and the hourly global irradiance for each month of the year for the region of Gabès. Also, we have calculated the monthly direct radiance, the monthly diffuse radiance and the monthly global radiance.

2. Site description

A knowledge of the local solar-radiation is essential for the proper design of building energy systems, solar energy systems and a good evaluation of thermal environment. Gabés is located in the Gulf of Gabés, which it also gives its name. It is a gulf on Tunisia's east coast in the Sea. The latitude of Gabés is 33.88˚ N and the longitude is 10.11˚ E. This geographic

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location of Gabès signifies that it is in a position to play an important strategic role in the implementation of solar energy technology in Tunisia, the north of Africa (Figure 1).

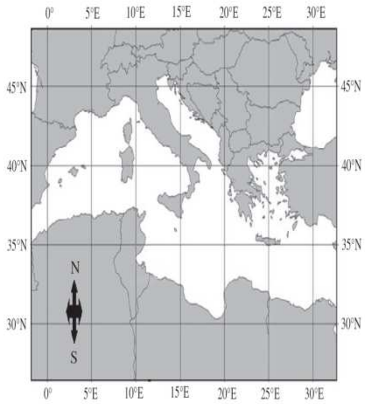


Fig. 1 Map of world with Latitude and Longitude

3. Model

The prediction of hourly beam and diffuse radiation using the models of Liu and Jordan is a good procedure for cases without meteorological stations or recording equipment and data.

3.1 Calculation of the extra-terrestrial daily radiation

The extraterrestrial radiation H_0 for each day of the year and for different latitudes can be estimated from the solar constant, the solar declination and the time of the yea. The extra-terrestrial daily radiation is given by the following formula [7]:

$$H_0 = \frac{24\, G_{sc}}{\pi}\left(1 + 0.033\cos(2\delta\frac{n}{365}\right)(\cos\varphi\cos\delta\sin\omega_s + \omega_s\sin\varphi\sin\delta) \quad (1)$$

Where:

G_{sc}: The solar constant

ω_s: The hour angle

The declination δ is the angle of the sun to its maximum stroke (solar noon) compared to the equatorial plane. Its value, in degrees, is given by Beckman and Duffie as follows [7]:

$$\delta = 23.45\,\frac{\pi}{180}\sin(2\pi\,\frac{284+n}{365}) \quad (2)$$

Where *n* is the *n*th day of the year.

The hour angle of the sun ω is the angular displacement of the sun around the polar axis, in the East to West race against the local meridian. The value of the hour angle is zero at solar noon, negative in the morning and positive in the afternoon positive. However, the hour angle increases of 15° per hour. The hour angle is given by the following formula:

$$\cos\omega_s = -tg\varphi\ tg\delta \quad (3)$$

Where:
φ: The latitude of the site.

3.2 Calculation of Hourly diffuse irradiance

The knowledge levels of diffuse irradiation incident on horizontal surfaces are important in estimating the radiation absorbed by surfaces. The hourly diffuse irradiance is given by the following formula:

$$H_d = r_d\bar{H}_d \quad (4)$$

The ratio of hourly total to daily total diffuse radiation is given by the formula:

$$r_d = \frac{\pi}{24}\frac{\cos\omega - \cos\omega_s}{\sin\omega_s - \omega_s\cos\omega_s} \quad (5)$$

The monthly average daily diffuse radiation is calculated from the monthly average daily global horizontal radiation and it is determined by Erbs et al. [8].
When the sunset hour angle is less than 81.4º, $\bar{H}_d$ is calculated by the following equation:

$$\frac{\bar{H}_d}{\bar{H}} = 1.391 - 3.560\bar{K}_T + 4.189\bar{K}_T^{\,2} - 2.137\bar{K}_T^{\,3} \quad (6)$$

And when the sunset hour angle is much than 81.4º, $\bar{H}_d$ is calculated by the following equation:

$$\frac{\bar{H}_d}{\bar{H}} = 1{,}311 - 3{,}022\,\bar{K}_T + 3{,}427\,\bar{K}_T^{\,2} - 1{,}821\,\bar{K}_T^{\,3} \qquad (7)$$

3.3 Calculation of Hourly Global irradiance

The equation presented here is a simple approach for the calculation of the global hourly irradiance daily distribution based on the formula from Collares-Pereira and Rabl for global irradiance [9]:

$$H = r_t \bar{H} \qquad (8)$$

Where:

$$r_t = \frac{\pi}{24}(a + b\cos\omega)\frac{\cos\omega - \cos\omega_s}{\sin\omega_s - \omega_s\cos\omega_s} \qquad (9)$$

$$a = 0{,}409 + 0{,}5016\sin(\omega_s - \tfrac{\pi}{3}) \qquad (10)$$

$$b = 0{,}6609 + 0{,}4767\sin(\omega_s - \tfrac{\pi}{3}) \qquad (11)$$

3.4 *Calculation of Hourly beam irradiance*

A knowledge of direct irradiance is important in applications where the solar radiation is concentrated, either to raise the temperature of the system, as in solar thermal energy technologies, or to increase the intensity of the electric current in solar cells, as in solar photovoltaic systems. The hourly direct irradiance is given by the formula:

$$H_b = H - H_d \qquad (12)$$

4. Results and discussions

4.1 Direct, diffuse and global radiations

Figures 2, 3 and 4 illustrate the fluctuations of monthly average global, diffuse and direct solar radiation of Gabès throughout the year. It is clear from these results that there is a peak in the global solar radiation in June, July and August (summer season). In this period, both sunshine hour and temperature are high. Figure 3 presents the monthly average daily direct radiation which is the difference between the monthly of average daily solar radiation on a horizontal surface and the monthly average daily diffuse radiation. The maximum value of the monthly average daily direct solar radiation is equal to 5207 Wh/m². Month in July and the minimum value is equal to 1510 Wh/m².Month for the month of January.

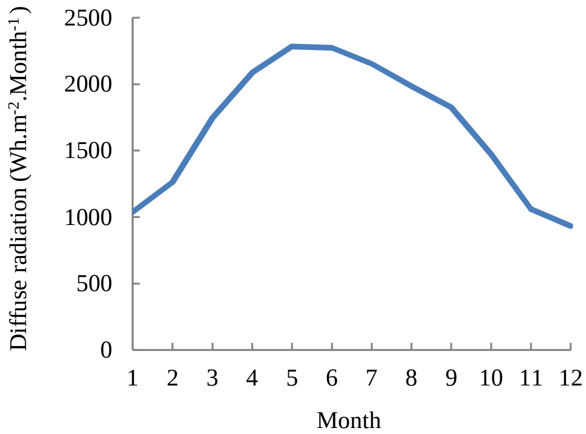


Fig. 2 Monthly of average daily diffuse radiation

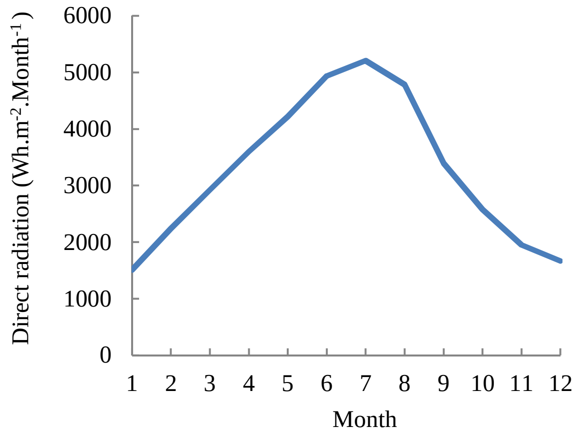


Fig. 3 Monthly of average daily direct radiation

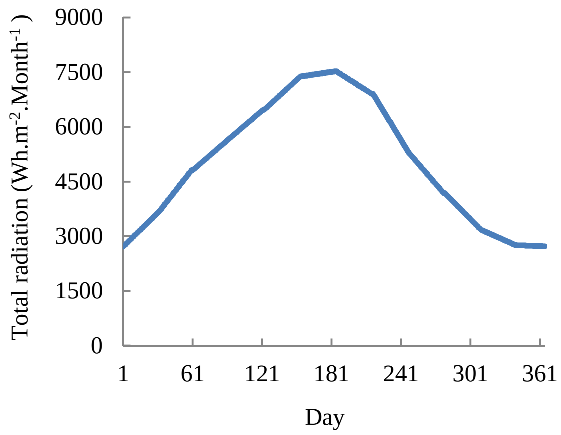
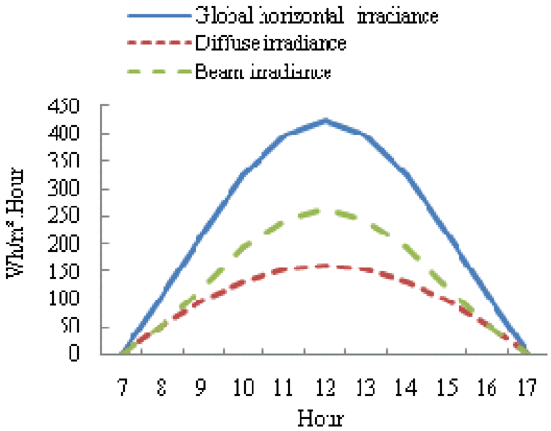


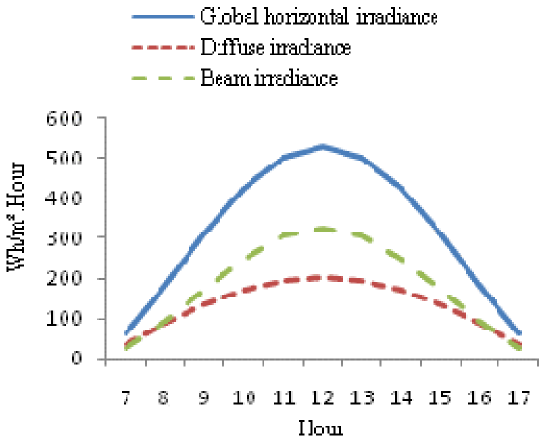
Fig. 4 Monthly of average daily solar radiation on a horizontal surface

4.2 *Hourly direct, diffuse and global irradiations*

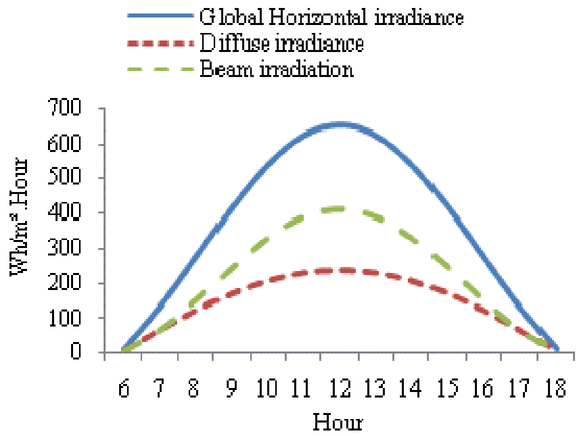
Figure 5 illustrates the variation of the hourly global irradiance H, the hourly diffuse irradiance H_d and the hourly direct or beam irradiance H_b for each month of the year in Gabes city. According to these results, it has been observed that the distribution of the hourly irradiances during a day vary with a sinusoidal form. In addition, the maximum sunlight of the global, diffuse and direct irradiances is at the midday for each day.



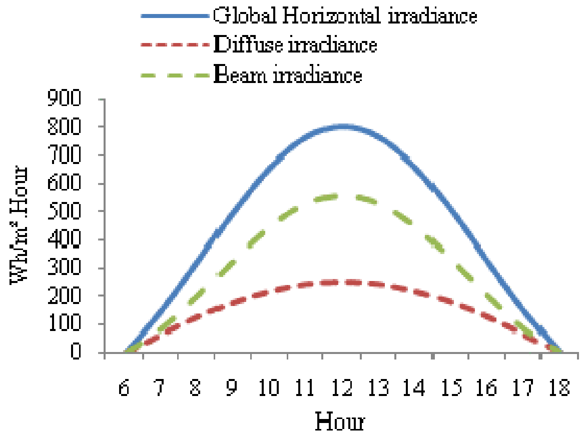
(a) Average day of January



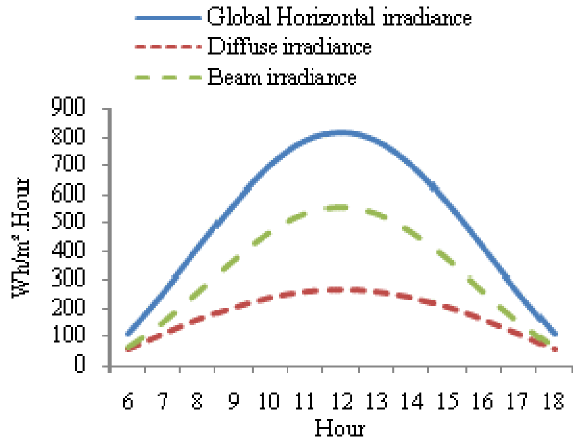
(b) Average day of February



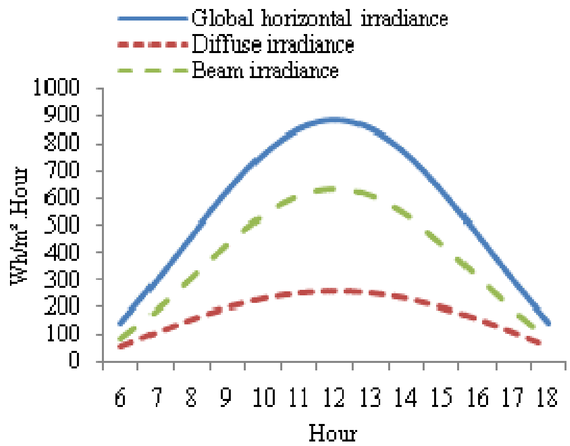
(c) Average day of March



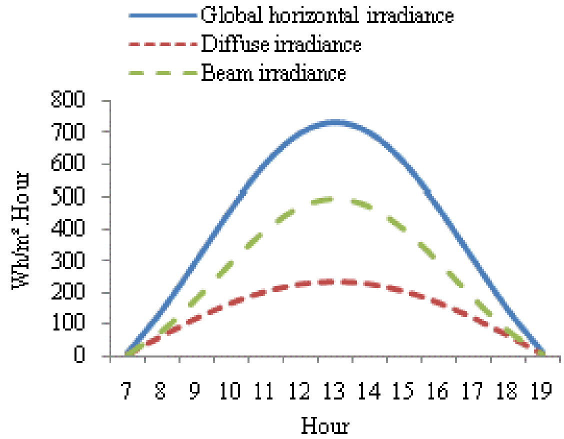
(d) Average day of April



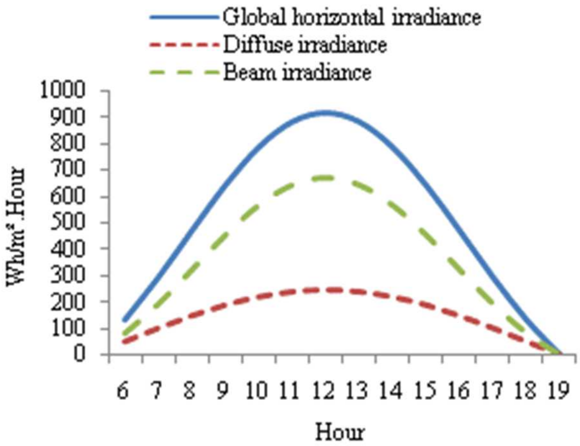
(e) Average day of May



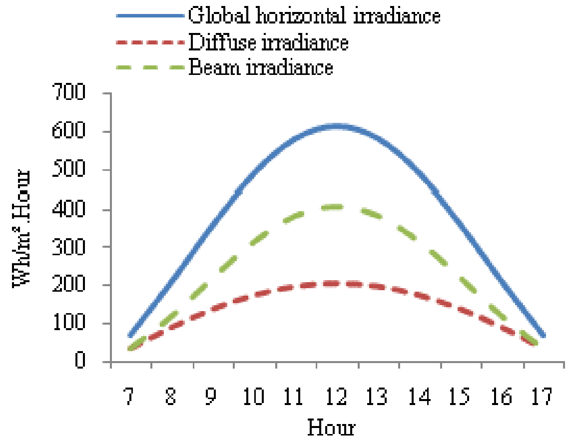
(f) Average day of June



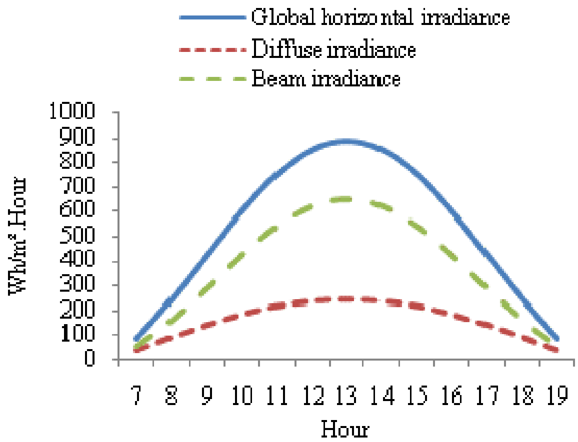
(i) Average day of September



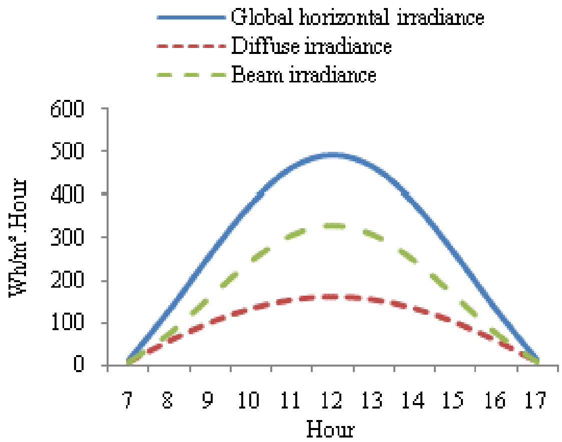
(g) Average day of July



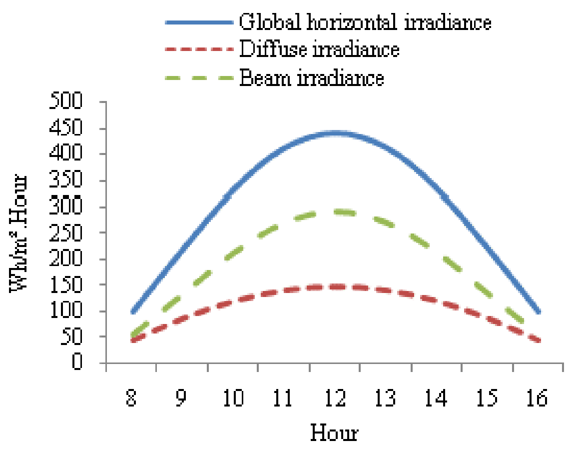
(j) Average day of October



(h) Average day of August



(k) Average day of November



(l) Average day of December

Fig. 5 Hourly components of solar radiation

5. Conclusion

Investments on solar energy systems in any place require information of the availability of solar energy for its optimum use. The correlations proposed for Gabès in this study can be used in another city. From this study, it is clear that Gabès city is endowed with sufficient solar radiation throughout the year. Therefore, solar energy systems can be one of the best options of energy supply in this city if it can be used in a cost effective manner. The radiation received by the earth varies according to time of year. It is then partially reflected and absorbed by the atmosphere. The solar radiation incident on the surface of the earth is based on many aspects such as climatology, hydrology, biology, and architecture. In perspectives, we propose to develop this work to determine the estimations of the solar radiations for the city of Tunisia.

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