GLOBAL SOLAR RADIATION ESTIMATION IN MANSOURA, EGYPT

تقدير شدة الإشعاع الشمسي الكلى فى المنصورة، مصر

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الملخص:

لا تتوفر قياسات الإشعاع الشمسى بسهولة فى أماكن كثيرة فى العالم. قياسات الإشعاع الشمسى فوق سطح أفقى أو مائل متفرقة جداً لمواجهة احتيجات البحث العلمى العلمية والتطبيقات الزراعية والهندسية. تقدير الإشعاع الشمسى اليومى فى الدلتا هو أمر حيوى حيث أنها أكثر الأماكن ازدحاماً وتتركز فيها الأنشطة الزراعية والصناعية حيث لا توجد مراصد شمسية. ولذلك فى هذا البحث، تم قياس الإشعاع الشمسى الكلى اللحظى على سطح أفقى ومائل (30° مواجه للجنوب) وكذلك فى الاتجاه العمودى ومقارنتها بالمودل الرياضى للسماء الصافية والبيانات المأخوذة من موقع وكالة الفضاء الأمريكية (ناسا) [1]. تم عمل برنامج كمبيوتر مبنى على MATrix LABoratory (MATLAB) (MATLAB) لحل المعادلات الحاكمة لمودل السماء الصافية. أظهرت النتائج أن الإشعاع الشمسى المحسوب على سطح أفقى ومائل وفى الاتجاه العمودى قد تطابقت جيداً مع القياسات. كما أظهرت النتئج بصورة بيانية أن البيانات المستنبطة من مودل السماء الصافية وموقع NASA تمثل وسيلة سريعة ومعقولة لحساب الطاقة الشمسية عند عدم توفر القياسات الفعلية.

ABSTRACT

Solar radiation data are not easily available in many places over the world. Measurements of solar radiation in Mansoura either on a horizontal or tilted surfaces are too sparse to meet demand for scientific research and applications in agriculture and engineering. Estimation of daily global solar radiation is essential in Delta zone, since it is one of the most crowded areas and most agriculture and industrial activities are concentrated at this area where no solar observatory exist. Therefore, in this work, the hourly average total solar radiation data on horizontal, tilted (30° facing south) and normal surfaces is measured and compared with that data computed the clear sky model and the data recorded from the National Aeronautics and Space Administration (NASA) website [1]. Based on the MATrix LABoratory (MATLAB), a computer program has been developed to solve the clear sky model governing equations. The obtained results revealed that, the predicted solar radiation on horizontal, tilted, and normal surfaces were validated well with that measured. Results which are given in graphical form show that the data obtained from the clear sky model and that obtained from NASA website can be used as a reasonable and quick method for estimating the solar radiation when actual measurements are not available.

Keywords: Global, Estimation, Solar radiation, Mansoura, Egypt.

NOMENCLATURE

B	Beam solar radiation intensity (W/m^2)
D	Diffuse solar radiation intensity (W/m^2)
$\overline{D}_h$ and $\overline{D}_n$	The daily diffuse solar radiation on a horizontal and normal surfaces respect.
G	Global solar radiation intensity (W/m^2)

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G_{sc}	Solar constant = 1367 W/m^2
K_{td}	Daily average clearness index
m	Air mass ratio
N	The day number starting from January first
R_b, R_d	Tilt factor for beam and diffuse solar radiation intensity, respectively
G_{oh}, G_{on}	The extraterrestrial irradiance on horizontal and normal surfaces, respectively
$\overline{G}_{oh}$ and $\overline{G}_{on}$	The daily extraterrestrial solar radiation on horizontal and normal surfaces, respectively
r_d	The measured ratio, of diffuse irradiance on a horizontal and normal surfaces to the diffuse daily irradiation

Subscripts

C	Tilted surface
h	Horizontal
n	Normal
o	Outside the atmosphere

Greek symbols

α	Sun altitude angle
β	Tilt angle
δ	Solar de clination angle
ϕ	Latitude angle of the place
ω	Solar hour angle
ω_s	Sunset hour angle

INTRODUCTION

Due to increasing costs of fossil fuels, uncertainty of availability, increasing environmental pollution and general awareness amongst common people, the green sources of energy are being encouraged. The green sources of energy include solar, wind, biomass, hydro, tidal, wave and ocean energy. Among these, wind, solar and hydro are the common ones in use. Despite being relatively costly compared to other green sources of energy, solar technology is commonly used for electricity generation in both grid connected and standalone power systems. An accurate knowledge of global solar radiation is essential in designing and studying solar energy conservation devices. However, solar radiation measurements are not easily available due to the cost and techniques involved all over the world El-Sebaii et al [2]. In addition, the growing population and fast depleting reserves of fossil fuels have lead researchers to pursue the development and use of renewable energy resources like solar energy.

Knowledge of global solar radiation is essential in the design and study of solar energy applications such as analysis of thermal load on buildings, solar energy collecting systems, crop growth models, evapotranspiration estimates in the design of irrigation systems and many other important applications Robaa [3]. Knowledge of global solar radiation is also essential in the prediction, study and design of the economic viability of solar systems. Obviously, measured data are the best form of this knowledge. Unfortunately, there are very few meteorological stations that measure the global solar radiation especially in developing countries like Egypt. For such stations where no measured data are available, the common practice is to estimate global solar radiation from other measured meteorological parameters like relative sunshine duration Akpabio and Etuk [4].

Many small communities all over the world depend on solar radiation data in agricultural and solar energy applications. Mansoura, Egypt is one of these places that have abundant solar radiation. Solar energy can solve a part of energy demand problem. However the use of solar energy in Egypt could play a useful role in satisfying energy requirements of most urban areas in appropriate circumstances. The amount of global solar radiation and its temporal distribution are the primary variables for designing solar energy systems. Knowledge of these parameters is required for prediction of the system efficiency of a possible solar energy system at a particular location. However, global solar radiation is measured only at a limited number of sites in the world, while sunshine duration is measured in many stations. Therefore, it has been the most widely available factor for solar radiation estimations by Sen [5]. Then, objective interpolation of solar radiation measurement is often required for the sites where measurements do not exist, using global solar radiation estimations calculated from sunshine duration data.

Solar radiation data and its compound play very important role in designing, sizing and performance of energy and renewable energy systems Mellit [6]. Although solar radiation is considered an important source for cheap and clean energy, the measurements of solar radiation components are only available from 11 of Egypt's stations Robaa [7]. He indicated also that the rarity of meteorological stations that measure solar radiation is a problem not only for Egypt but for many other countries. In order to resolve this problem, many empirical formulae have been deduced in many previous studies to calculate the solar radiation values using sunshine durations.

Although Egypt is a vast country, the numbers of its meteorological stations that measure the solar radiation components are only a few. Therefore, some empirical models have been developed to calculate solar radiation, especially global solar radiation, over different sites in Egypt. Measurements of global solar radiation began in 1969 at both Cairo and Bahtim using an Eppley Pyranometer (Model PSP).

Information of global solar radiation is required in many applications due to its essential role as a driving input to agronomic, ecological, hydrological and soil–vegetation–atmosphere transfer models. In spite of its significance, solar radiation is not widely measured compared to other meteorological variables Thornton and Running, [8] due to the cost and maintenance and calibration requirements of the measuring equipment. Thus, the lack of adequate and effective observations on solar radiation has become a worldwide problem Iziomon and Mayer [9], particularly in remote regions where the harsh conditions hinder the construction of measurement plat form and maintenance of solar radiation instruments. In order to overcome these difficulties, a number of modeling approaches have been developed to estimate surface solar radiation. 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 Bakirci [10]. The earth-atmosphere system receives energy from the sun as a continuous electromagnetic flux at an average rate of 173 trillion kW, or $1353.73 W/m^2$ of cross sectional area as reported by Thekaekara, [11]. The solar energy incident on the Egyptian land has a magnitude of 12–30 MJ/m^2 /day, and the sunshine duration is between 3500 and 4500 h /yea- Tadros, [12]. Many authors at many places have investigated the correlation between sunshine duration and global solar radiation in different empirical methods. Choosing among these models usually takes into account two characteristics: the availability of meteorological and other data required as model input and the model accuracy Badescu, [13].

As the primary energy source for life on our planet, solar radiation drives most of water, energy and carbon cycles in the Earth's system. Solar radiation data are thus required in many research fields such as agriculture, hydrology, and meteorology. Solar radiation data can be measured by pyranometers on the ground. Compared to measurements of other meteorological variables, the measurement of solar radiation is more prone to errors and often encounters more problems such as technical failure, Moradi [14]. Possible sources of errors related to solar radiation measurement can be mainly categorized into two classes: equipment errors, uncertainty and operation related problems Shi et al [15].

Solar radiation data provide information on how much of suns energy strikes a surface at a location on earth during a particular time period. These data are needed for effective research into solar energy utilization. Due to the cost and difficulty in measurement, these data are not readily available [16 and 17]. Therefore, it is needed to develop alternative ways of generating these data. It is very common to design solar energy systems based on the monthly average of global solar radiation and other climatic data. Also, it is rather important to determine the beam and diffuse components of total radiation incident on a horizontal surface El-Sebaii et al [18]. Once these components are determined, they can be transposed over tilted surfaces, and hence, the short as well as the long-term performances of tilted flat plate collectors, photovoltaic modules and other solar devices can be estimated.

Knowledge of the amount of solar radiation falling on a surface of the earth is of prime importance to engineers and scientists involved in the design of solar energy systems. In particular, many design methods for thermal and photovoltaic systems require monthly average daily radiation on a horizontal surface as an input, in order to predict the energy production of the system on a monthly basis. In practice, it is very important to appreciate the order of measurements prior to any modelling study for both solar radiation and sunshine duration or daylight. There is a relative abundance of sunshine duration data and therefore it is a common practice to correlate the solar radiation to sunshine duration measurements. In many countries, diurnal bright sunshine duration is measured at a wide number of places Zekai [19]. El-Metwally [20] shows that error values are also low particularly at clear sky and increase gradually with the increase of cloudiness. This is due to great effects of cloudiness on increasing the error, particularly at overcast conditions. He indicated also that it was important to measure the validation of the existing methods at different sky conditions (Clear sky, partially cloudy and overcast). All methods show that the more the cloudiness, the more the error. Naturally, the error is low at clear sky and high at overcast sky. It appears that solar radiation is strongly attenuated under overcast conditions; this may result from the presence of additional cloud layers above overcast layer which are undetected by surface-based observations DeGaetano et al [21].

The objective of this study is to measure the total solar radiation data on horizontal, tilted surface (30° facing south), normal direction and compare these data with the clear sky model and the data recorded from (NASA) website. A computer program is developed to predict the solar radiation data at this place using the (MATLAB) by solving the clear sky model governing equations. For future studies, a new model could be established, to easily calculate the solar radiation values using cloud amount data from any locality in Egypt which has no measured data of solar radiation components, or there are instrumental and other difficulties encountered when measuring components of solar radiation.

Measurements

The solar radiation data are measured with a solar power meter TES1333 as shown in Fig. 1, with the following specifications:
Display 3-1/2 digits Maximum indication 1999
Range 2000 W/m^2
Resolution 1 W/m^2
Spectral response 400-1100μm
Accuracy typically within ± 10 W/m^2 or ±5%, whichever is greater in sunlight;
Additional temperature induced error ± 0.38 W/m^2 / °C from 25 Celsius

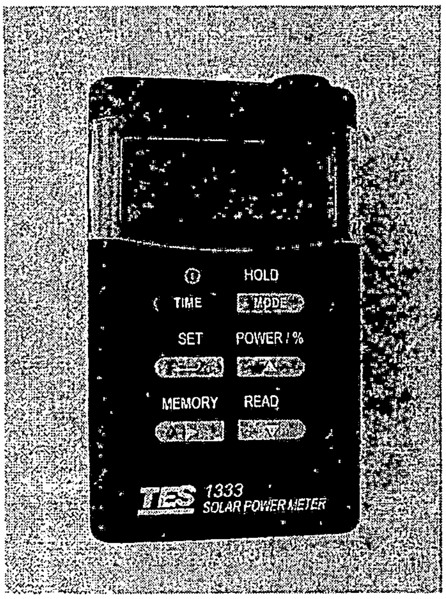


Fig. 1. The solar power meter TES 1333.

Angular accuracy cosine corrected < 5% for angles < 60°
Calibration user recalibration available
Sampling Time Approx. 0.4 second
Manu data memory and read 99 sets
Auto data memory 32000 sets
Battery, battery life 4pcs size AAA, Approx. 100 hours
Operating temperature and humidity 0 °C to 50 °C below 80% RH
Weight Approx, 195 g
Dimension 111(L)x64(W)x34(H) mm

The experimental work is carried out on the roof of the Thermal engineering laboratory, Mechanical power department, Faculty of Engineering, Mansoura University, latitude 31.04083° N and longitude 31.4861° E. The experiments were performed during different days in May and June 2011 and February to June 2012 on sunny days. Measurements are taken with intervals of about 30 minutes at horizontal surface, tilted surface with 30° facing south and normal direction.

MODELING OF SOLAR RADIATION DATA

Solar radiation data is essential for design and sizing solar systems. However, these data are also very useful for decision makers. Neglecting the reflection component, the hourly value of the total solar radiation intensity on tilted surface, G_c can be calculated from Duffie and Beckman [16] as,

$$G_c = R_b B_h + R_d D_h \tag{1}$$

Where, B_h and D_h are the beam and diffuse solar radiation component intensities respectively on a horizontal surface,

and R_b and R_d are the beam and diffuse tilt factors respectively given by,

$$R_b = \frac{\cos(\phi-\beta)\cos(\delta)\cos(\omega)+\sin(\phi-\beta)\sin(\delta)}{\cos(\phi)\cos(\delta)\cos(\omega)+\sin(\phi)\sin(\delta)}$$

and $$R_d = \cos^2\left(\frac{\beta}{2}\right) \tag{2}$$

Where, ϕ is the latitude angle of the place and β is the tilt angle,

ω solar hour angle defined by,

$\omega = 15(t-12)^{\circ}$

(t is the local time, hr),

and δ is the solar declination angle defined by,

$$\delta = 23.5 \sin\left[\frac{360}{365}(N+284)\right] \quad (3)$$

Where, N is the day number starting from January first.

The hourly global solar radiation intensity on a horizontal and normal surfaces are, $G_h = B_h + D_h$ and $G_n = B_n + D_n$ respectively in clear sky model is given by Meinel and Mainel [22] as,

$$G_h = G_{oh}\,(0.7)^{m^{0.678}} \quad (4)$$

$$G_n = G_{on}\,(0.7)^{m^{0.678}} \quad (5)$$

Where, G_{oh} and G_{on} are the extraterrestrial irradiance on horizontal and normal surfaces respectively given by Markvart et. al [23] as,

$$G_{oh} = G_{sc}\left[1+0.033\cos\left(\frac{2\pi N}{365}\right)\right](\cos\phi\cos\delta\cos\omega + \sin\omega\sin\delta) \quad (6)$$

$$G_{on} = G_{sc}\left[1+0.033\cos\left(\frac{2\pi N}{365}\right)\right] \quad (7)$$

G_{sc} is the solar constant = 1367 W/m^2

and, m is the air mass ratio calculated for clear sky condition by Kreith and Kreider [24] as,

$$m = \left[1229 + (614\sin\alpha)^2\right]^{0.5} - 614\sin\alpha \quad (8)$$

Where, α is the sun altitude angle obtained from,

$$\sin\alpha = \cos\phi\cos\delta\cos\omega + \sin\phi\sin\delta \quad (9)$$

The data collected from several stations by Collares-Pereira and Rabl [25], has shown that, the measured ratio, r_d of diffuse irradiance on a horizontal and normal surfaces, D_h and D_n to the diffuse daily irradiation, $\overline{D}_h$ and $\overline{D}n$ can be estimated by,

$$r_d = \frac{D_h}{\overline{D}_h} = \frac{G_{oh}}{\overline{G}_{oh}} \quad (10)$$

$$r_d = \frac{D_n}{\overline{D}_n} = \frac{G_{on}}{\overline{G}_{on}} \quad (11)$$

Where, $\overline{G}_{oh}$ and $\overline{G}_{on}$ are the daily extraterrestrial solar radiation on a horizontal and normal surfaces respectively, Iqbal [26] as,

$$\overline{G}_{oh} = \frac{24}{\pi}G_{sc}\left[1+0.033\cos\left(\frac{2\pi N}{365}\right)\right](\omega_s\sin\phi\sin\delta + \cos\delta\cos\phi\sin\omega_s) \quad (12)$$

$$\overline{G}_{on} = \frac{24}{\pi}G_{sc}\left[1+0.033\cos\left(\frac{2\pi N}{365}\right)\right] \quad (13)$$

Where ω_s is the sunset hour angle obtained from Duffie and Beckman [16] as,

$$\omega_s = \cos^{-1}(-\tan\phi\tan\delta) \quad (14)$$

The daily diffuse solar radiation on a horizontal and normal surfaces, $\overline{D}_h$ and $\overline{D}_n$ can be estimated in terms of the daily average clearness index, k_{td} from Collares - Pereira and Rabl [25] as,

$$\overline{D}_h = F_d\,\overline{G}_h \quad (15)$$

$$\overline{D}_n = F_d\,\overline{G}_n \quad (16)$$

Where,

$$F_d = 0.974 + 0.326\,k_{td} - 3.896\,k_{td}^2 + 2.661\,k_{td}^3$$

$$= 0.942 \quad \text{if} \quad k_{td} \le 0.18$$

$$= 0.79 \quad \text{if} \quad k_{td} \le 0.115$$

$$k_{td} = \frac{\overline{D}_h}{\overline{D}_{oh}} \quad (17)$$

$$k_{td} = \frac{\overline{D}_n}{\overline{D}_{on}} \quad (18)$$

$$\overline{D}_h = F_{Dd} * \overline{G}_h \quad (19)$$

$$\overline{D}_n = F_{Dd} * \overline{G}_n \quad (20)$$

The hourly beam solar irradiance, B_h can be obtained from,

$$B_h = G_h - D_h \quad (21)$$

$$B_n = G_n - D_n \quad (22)$$

Finally, the hourly average total solar radiation intensity on the array tilted surface, G_c at any day of the year can be obtained from equation (1).

The flow chart for MATLAB program in Fig. (2).

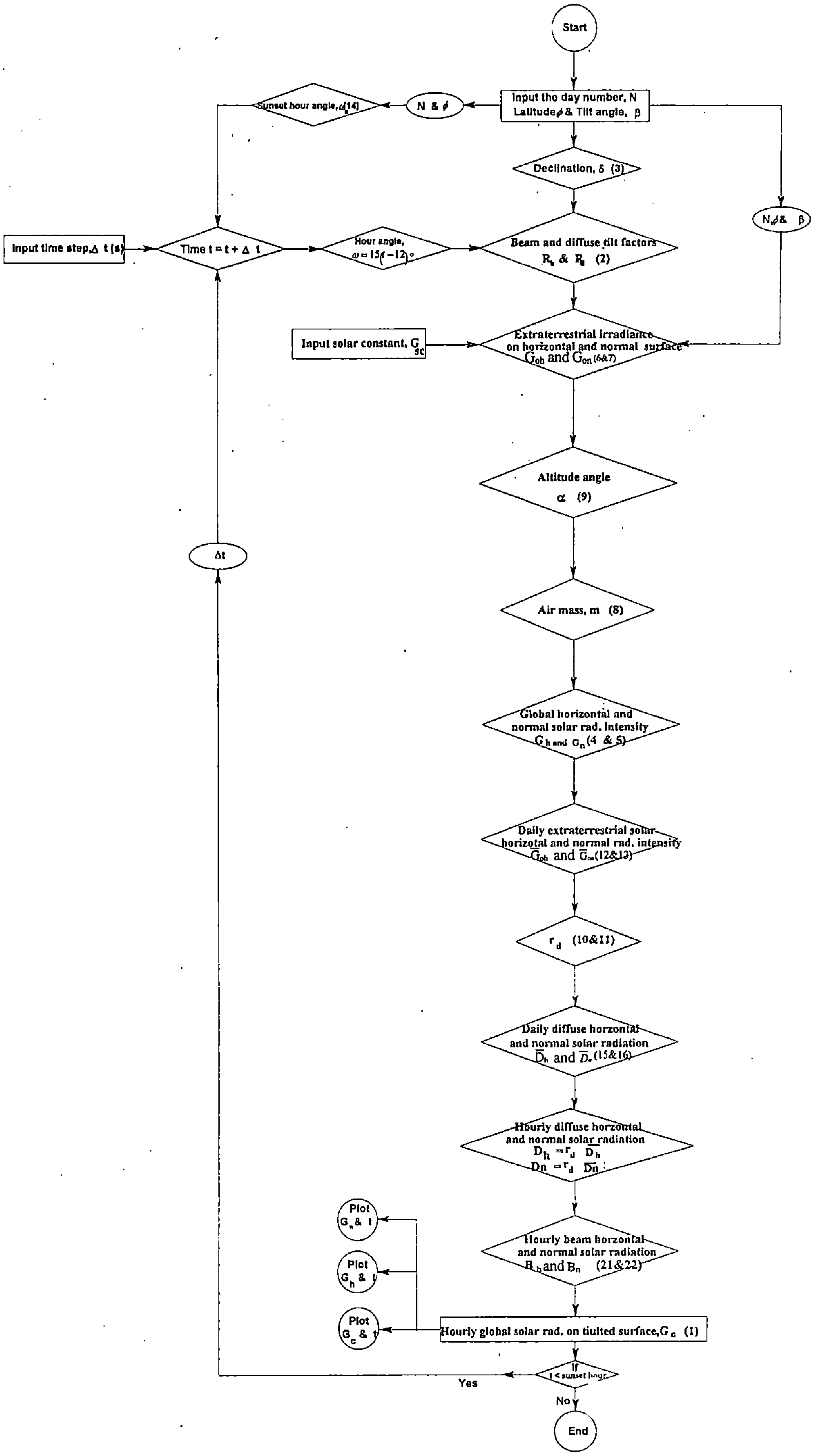


Fig. (2) Flow chart of the computer program.

RESULTS AND DISCUSSION

In the present work, a modeling of clear sky conditions has been carried out. Based on the aforementioned equations a computer program using MATLAB (version 7.0) is developed and employed to solve the above equations. The intensity of global solar radiation on horizontal, normal direction and tilted surface (30° facing south) in Mansoura area, Egypt is obtained as function of time using equations from (1) to (22). Comparison between the experimental measurements and the predicted data from model and that obtained from NASA website is carried out.

Figures from 3 to 20 show the comparison between the predicted data (the black line) and the experimental measurements on horizontal surface and that obtained from NASA website (red line) throughout some on sunny days from the years (2011 and 2012). It is clear that there is a reasonable agreement between the measured and estimated data especially that obtained from NASA website. These figures also show clearly that there is daily trend with super imposed fluctuation hour to hour of the daily values of solar radiation data. Clear sky model demonstrates better fitting than other classes, because radiation data with very cloudy skies are more dispersed than those from clear sky. The reason for these errors could be related to frequent occurrence of fog in the morning, as well as prevailing cloudiness. Therefore, all methods show a good behavior under clear sky conditions.

These data are normalized by comparing each of them by the corresponding clear sky model values. The measured and calculated values of the average global solar radiation intensity on a horizontal surface are illustrated from Figs. from 3 to 20. As can be seen from these figures, agreement between the values obtained from clear sky model. Also, comparison with other sources of estimates was made from NASA website and the measured data are good. In some sunny days in the year (2011), the maximum values of solar radiation intensity as given in Figs. from 3 to 10 (at 12 noon) are 978.4, 1017, 1025, 999.9, 1028, 1003, 1014 and 996.5 W/m^2 respectively. While, in some sunny days in the year (2012), the maximum values of solar radiation intensity as given in Figs. from 11 to 20 (at 12 noon) are 719.5, 750.1, 922, 971, 956.6, 968.9, 898.9, 955.2, 994.1 and 957.3 W/m^2 respectively. All figures show also the solar radiation as calculated from clear sky model and NASA. It is clear that solar radiation increases from zero to a maximum value at noon for a given day.

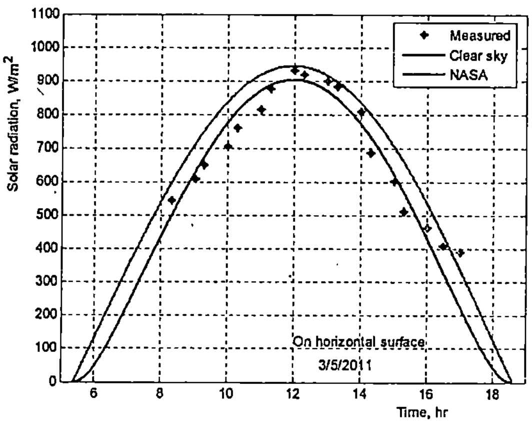


Fig 3. Global solar radiation intensity on a horizontal surface (Latitude=31° N).

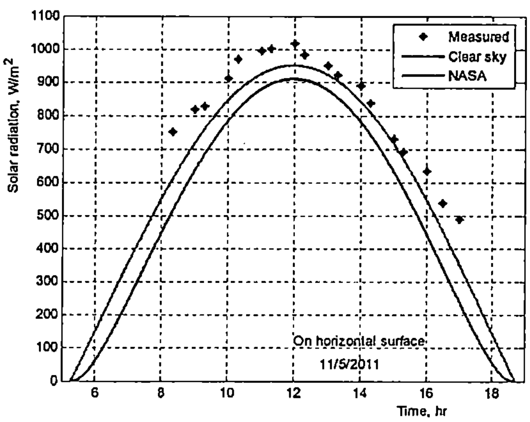


Fig4. Global sola- radiation intensity on a horizontal surface (Latitude=31° N).

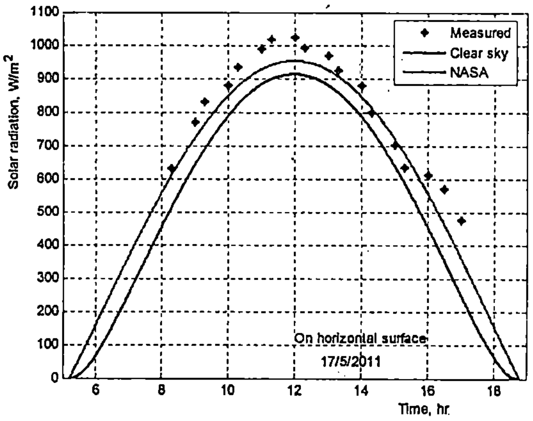


Fig.5. Global solar radiation intensity on a horizontal surface (Latitude=31° N).

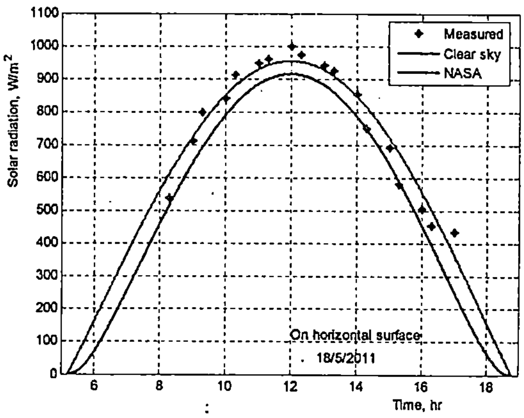


Fig. 6. Global solar radiation intensity on a horizontal surface (Latitude=31° N).

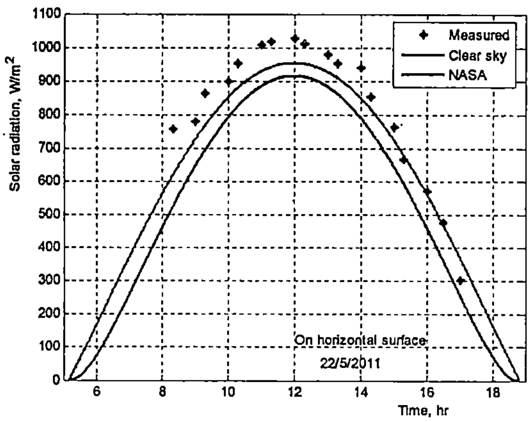


Fig. 7. Global solar radiation intensity on a horizontal surface (Latitude=31° N).

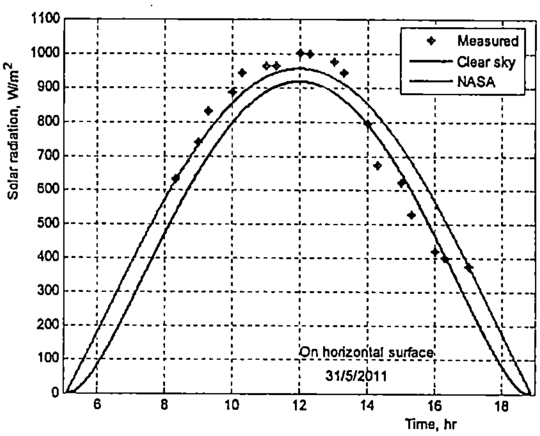


Fig. 8. Global solar radiation intensity on a horizontal surface (Latitude=31° N).

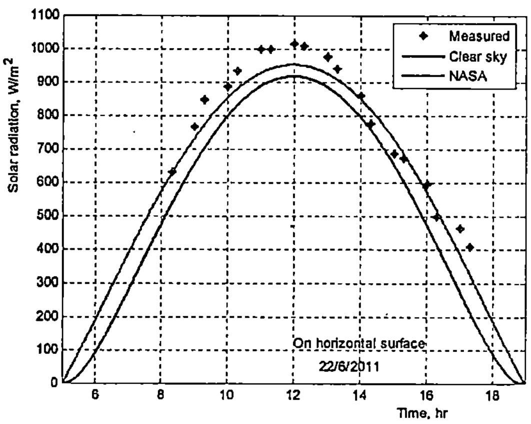


Fig. 9. Global solar radiation intensity on a horizontal surface (Latitude=31° N).

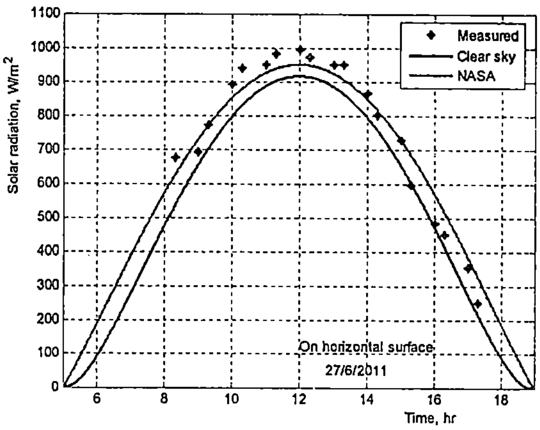


Fig. 10. Global solar radiation intensity on a horizontal surface (Latitude=31° N).

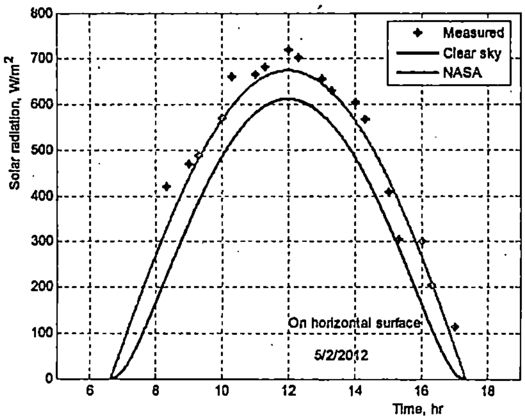


Fig. 11. Global solar radiation intensity on a horizontal surface (Latitude=31° N).

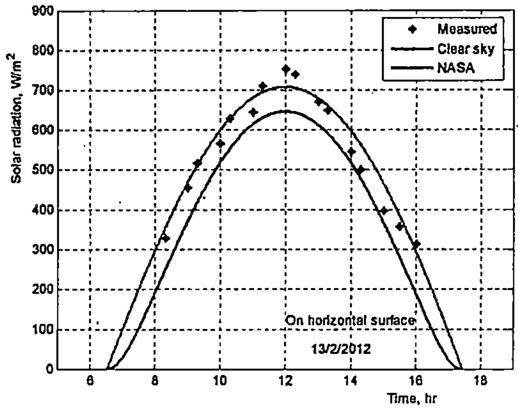


Fig. 12. Global solar radiation intensity on a horizontal surface (Latitude=31° N).

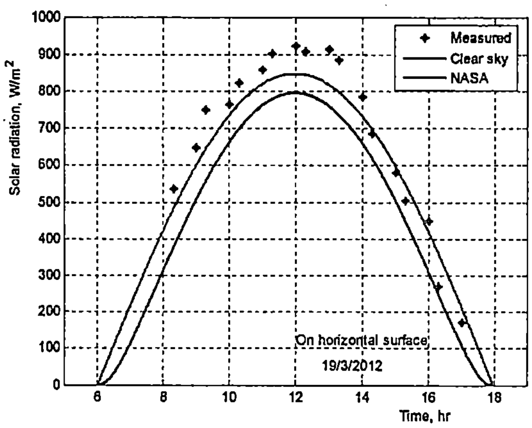


Fig. 13. Global solar radiation intensity on a horizontal surface (Latitude=31° N).

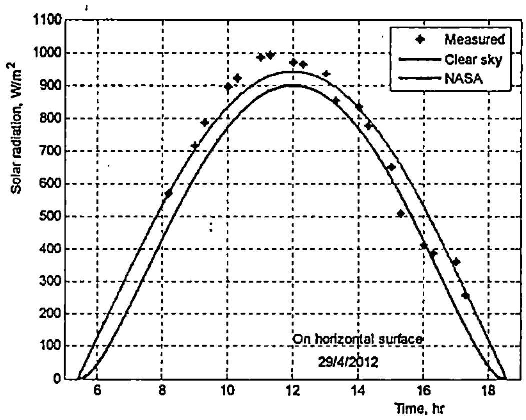


Fig. 14. Global solar radiation intensity on a horizontal surface (Latitude=31° N).

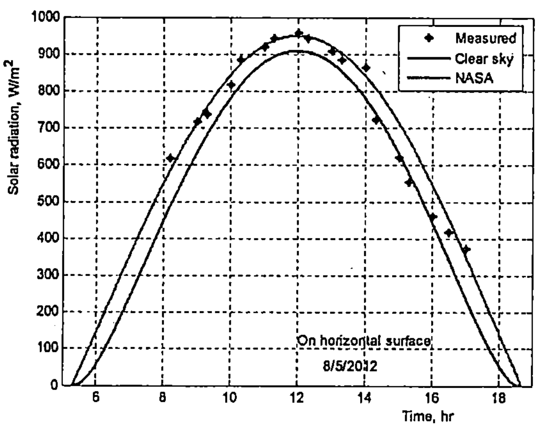


Fig. 15. Global solar radiation intensity on a horizontal surface (Latitude=31° N).

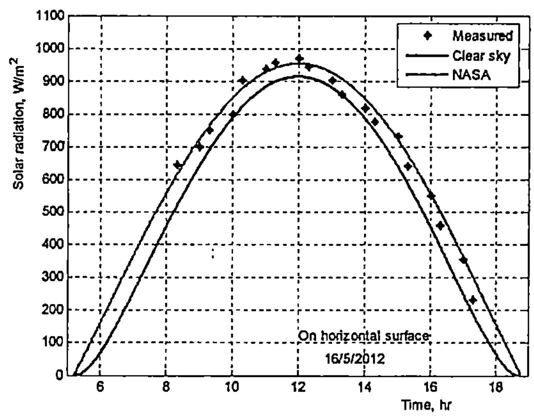


Fig. 16. Global solar radiation intensity on a horizontal surface (Latitude=31° N).

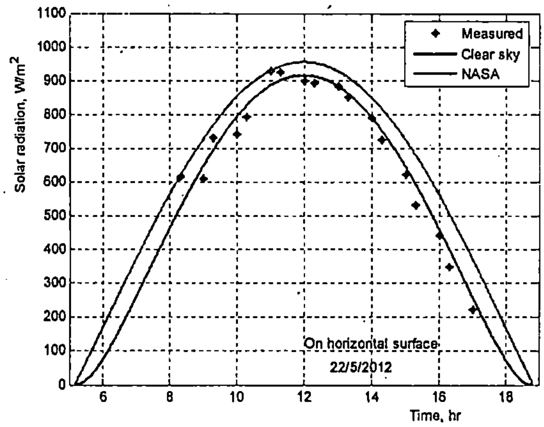


Fig. 17. Global solar radiation intensity on a horizontal surface (Latitude=31° N).

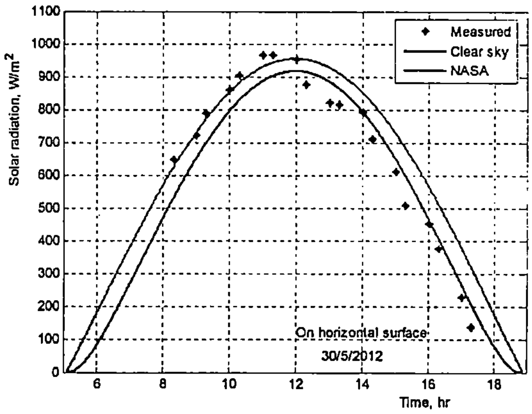


Fig. 18. Global solar radiation intensity on a horizontal surface (Latitude=31° N).

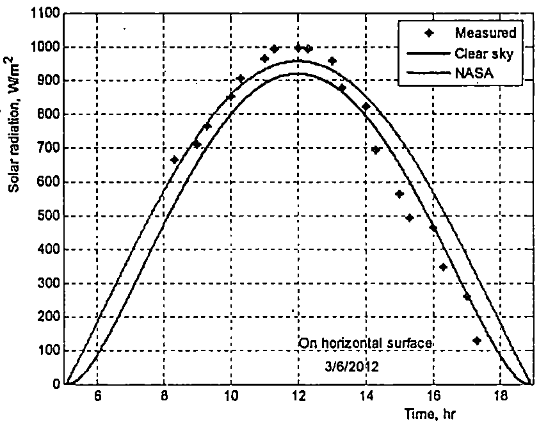


Fig. 19. Global solar radiation intensity on a horizontal surface (Latitude=31° N).

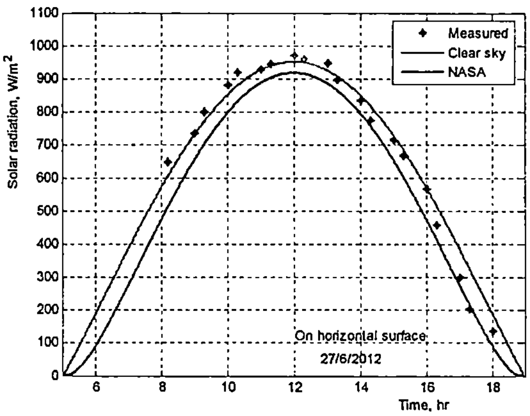


Fig. 20. Global solar radiation intensity on a horizontal surface (Latitude=31° N).

The measured global solar radiation intensity on a normal direction and that obtained from the clear sky models are compared in Figs. from 21 to 38 in the same some sunny days in the years (2011 and 2012). The results show that, in the days of the (2011) the maximum average value of global solar radiation intensity as given in Figs. from 21 to 28 was achieved on the mid day (12 noon) along the whole period of the experiment which are 987.5, 1004, 1016, 996, 1063, 1010, 1017 and 996.8 W/m^2 respectively. While in sunny days in the year (2012) the maximum values of solar radiation intensity as given in Figs. from 29 to 38 (at 12 noon) are 935.8, 946.8, 988, 981.3, 978, 974.1, 964.9, 966.5, 971.7 and 969.6 W/m^2 respectively. It is clear that the deviation between the measured and calculated values as shown in Fig. 23 is smaller than that of others of other figures recoded in 2011. While the deviation between the measured and calculated values as shown in Fig. 38 is smaller than that of others of figures in the year 2012.

Nonetheless, the results of the model evaluation are very good for all the provinces. This is mainly due to highly variable weather conditions in the regions. Moreover, empirical modeling is an essential and economical tool for the estimation of global solar radiation. The accuracy of such models depends on the quality and quantity of the measured data used.

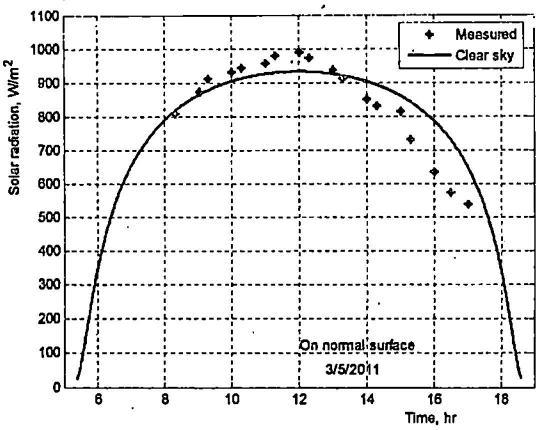


Fig.21. Global solar radiation intensity on a normal direction (Latitude=31° N).

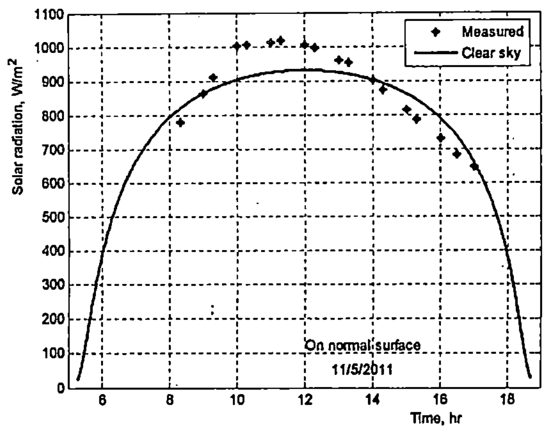


Fig.22. Global solar radiation intensity on a normal direction (Latitude=31° N).

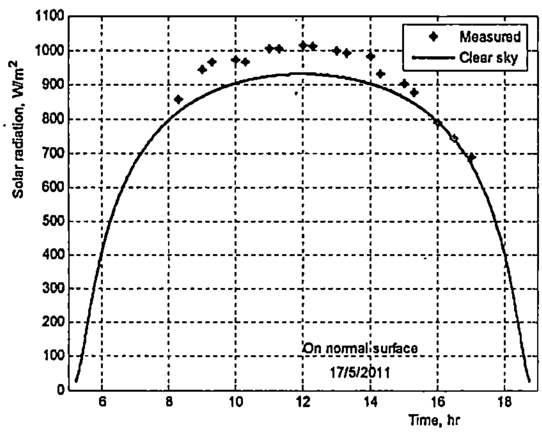


Fig.23. Global solar radiation intensity on a normal direction (Latitude=31° N).

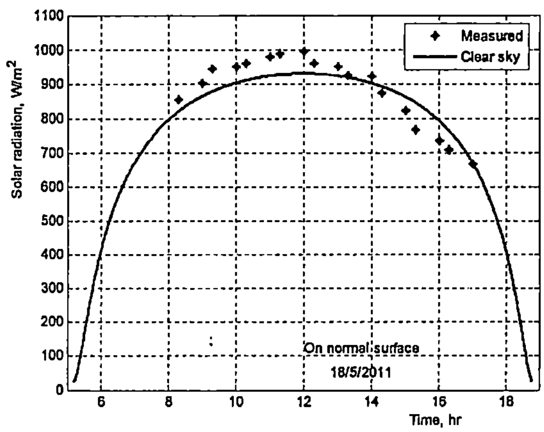


Fig.24. Global solar radiation intensity on a normal direction (Latitude=31° N).

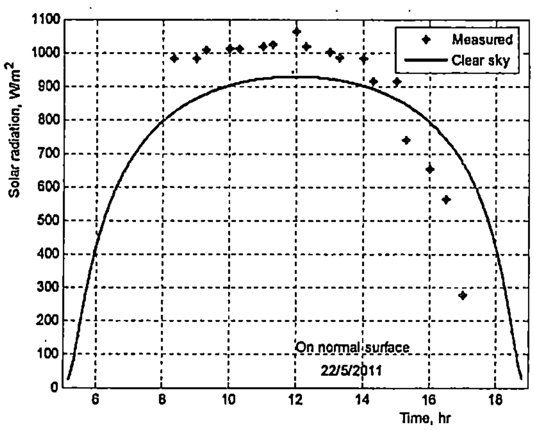


Fig.25. Global solar radiation intensity on a normal direction (Latitude=31° N).

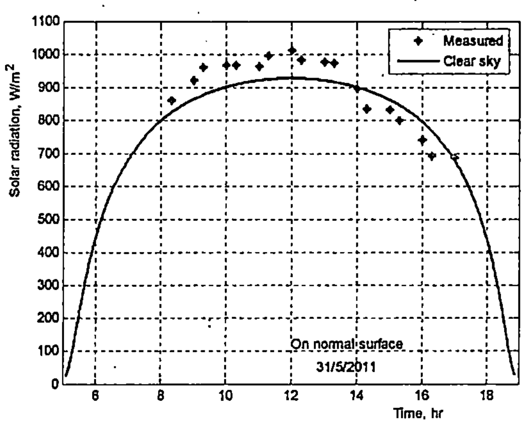


Fig.26. Global solar radiation intensity on a normal direction (Latitude=31° N).

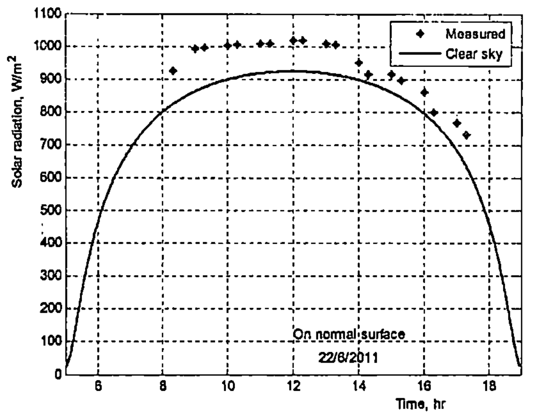


Fig.27. Global solar radiation intensity on a normal direction (Latitude=31° N).

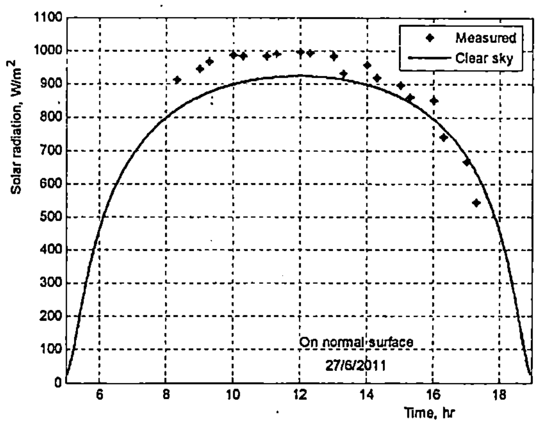


Fig.28. Global solar radiation intensity on a normal direction (Latitude=31° N).

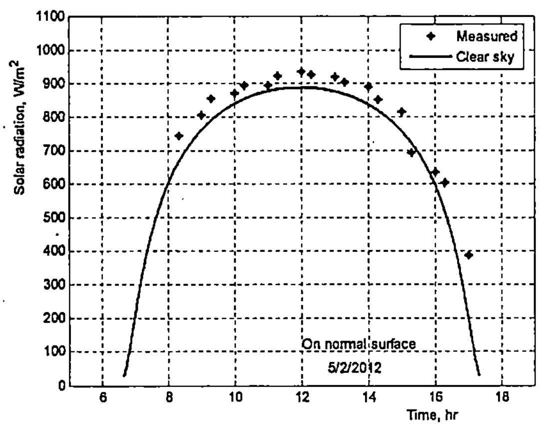


Fig.29. Global solar radiation intensity on a normal direction (Latitude=31° N).

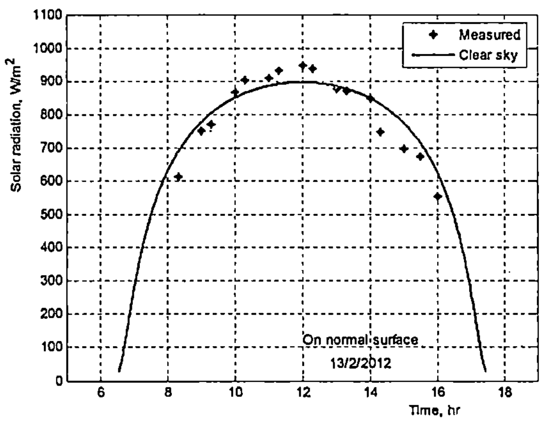


Fig.30. Global solar radiation intensity on a normal direction (Latitude=31° N).

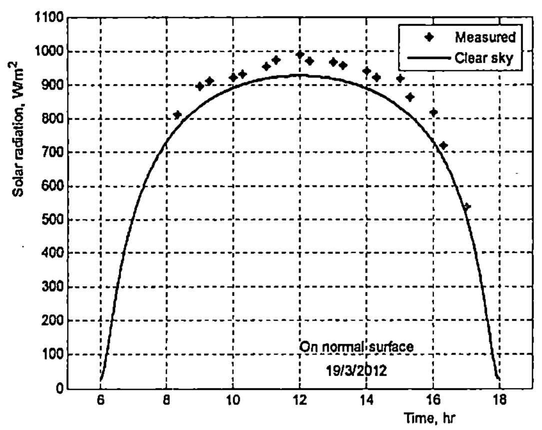


Fig.31. Global solar radiation intensity on a normal direction (Latitude=31° N).

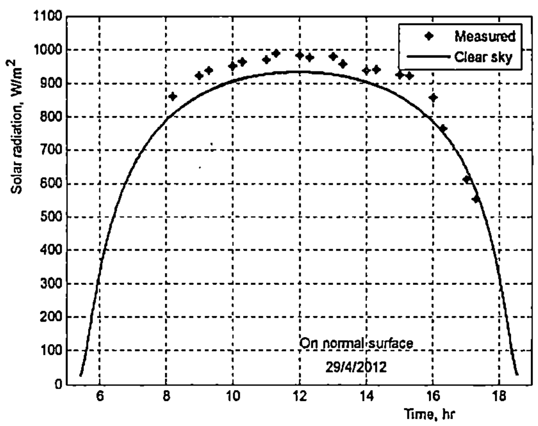


Fig.32. Global solar radiation intensity on a normal direction (Latitude=31° N).

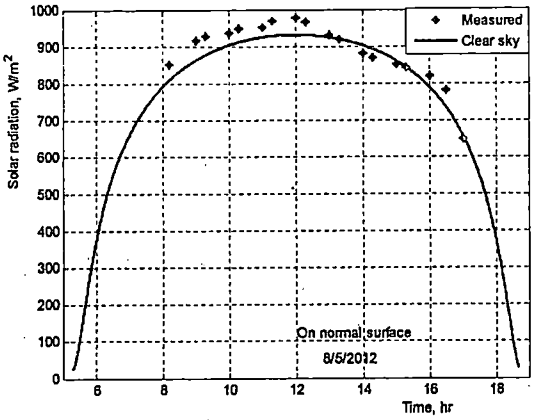


Fig.33. Global solar radiation intensity on a normal direction (Latitude=31° N).

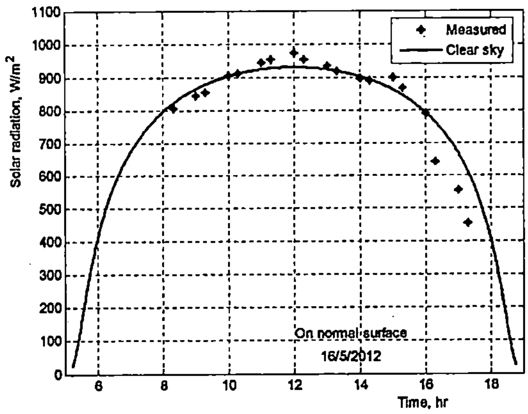


Fig.34. Global solar radiation intensity on a normal direction (Latitude=31° N).

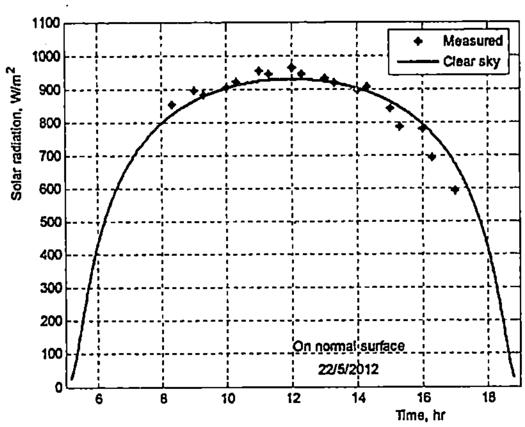


Fig.35. Global solar radiation intensity on a normal direction (Latitude=31° N).

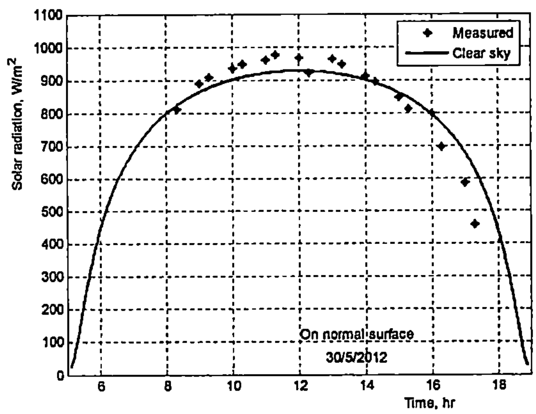


Fig.36. Global solar radiation intensity on a normal direction (Latitude=31° N).

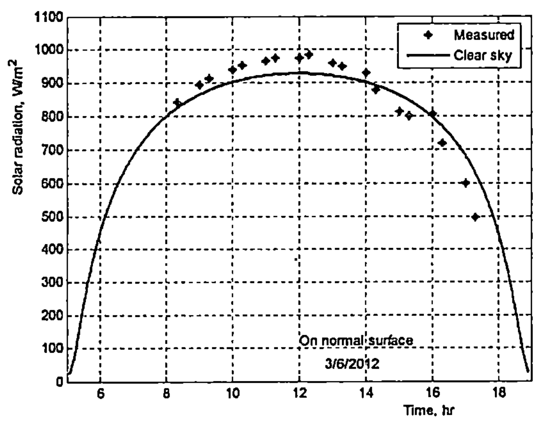


Fig.37. Global solar radiation intensity on a a normal direction (Latitude=31° N).

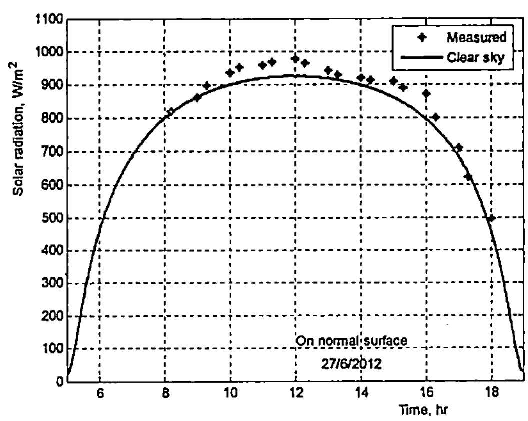


Fig.38. Global solar radiation intensity on a normal direction (Latitude=31° N).

The same trend was noticed along the measured and calculated values of the average global solar radiation intensity on tilted surfac~ (30° facing south) as shown in Figs. from 39 to 56. The records in Figs. from 39 to 46, in the sunny days of the year 2011, the peak values at 12 noon are

967.9, 972.7, 966.6, 945.3, 987.1, 969.7, 963.8 and 925.5 W/m^2 respectively. While in sunny days in the year 2012, the maximum values of solar radiation intensity in Figs. from 47 to 56. (at 12 noon) are 924.5, 901.4, 981, 989.2, 969.6, 944.6, 954.6, 912.7 ,929.5 and 902.6 W/m^2 respectively.

Also, it was notice that, the peak of the global solar radiation intensity was achieved by med-day (between times 12-14) as shown in most figures. The above results are predicted under clear sky and normal climatic conditions.

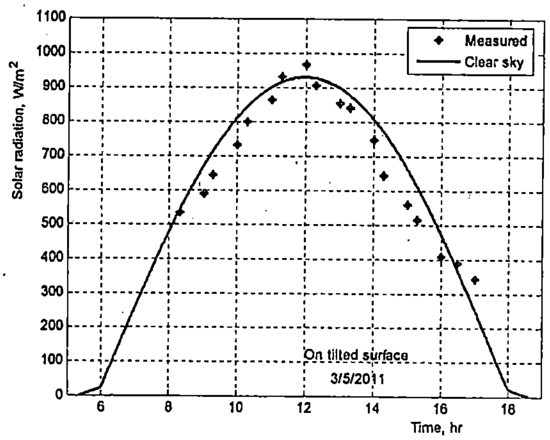


Fig. 39. Global solar radiation intensity on a tilted surface (β =30°, Latitude=31° N).

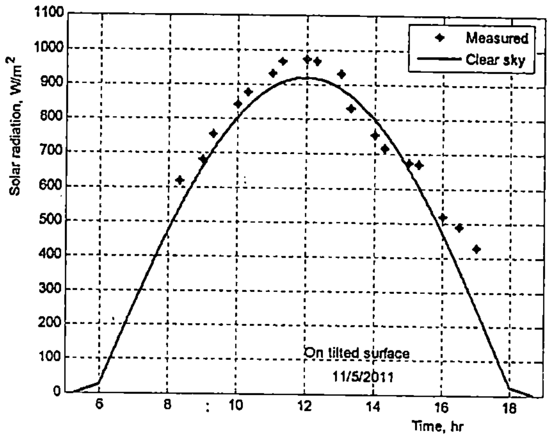
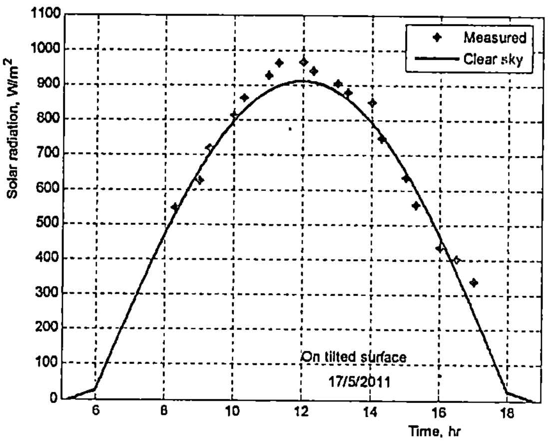


Fig. 40. Global solar radiation intensity on a tilted surface (β =30°, Latitude=31° N).



. Fig.41.Global solar radiation intensity on a tilted surface (β =30°, Latitude=31° N).

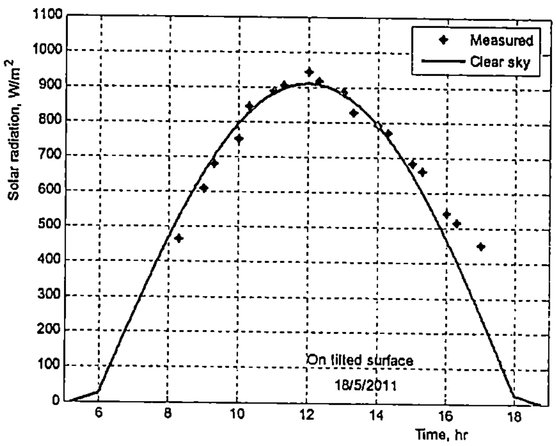


Fig 42. Global solar radiation intensity on a tilted surface (β =30°, Latitude=31° N).

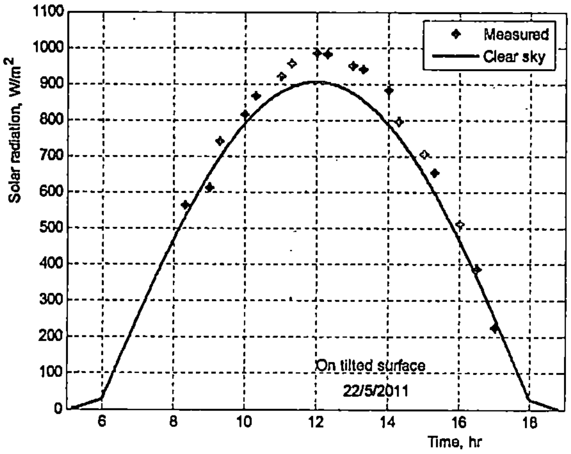


Fig. 43. Global solar radiation intensity on a tilted surface (β =30°, Latitude=31° N).

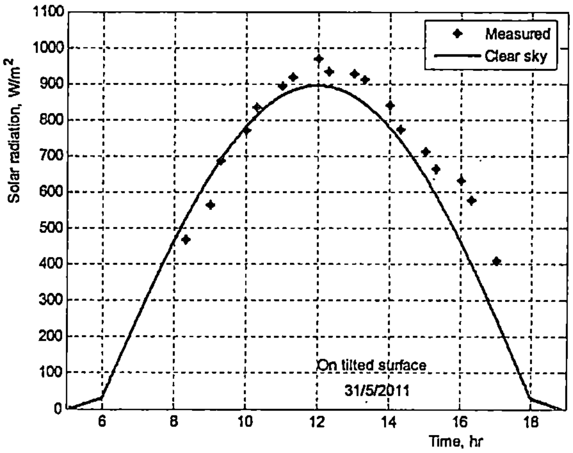


Fig. 44. Global solar radiation intensity on a tilted surface (β =30°, Latitude=31° N).

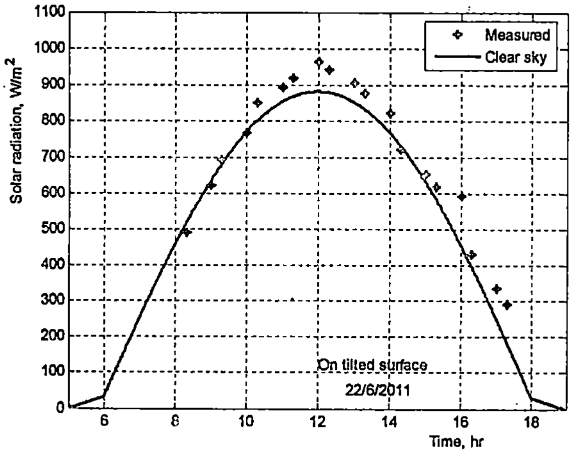
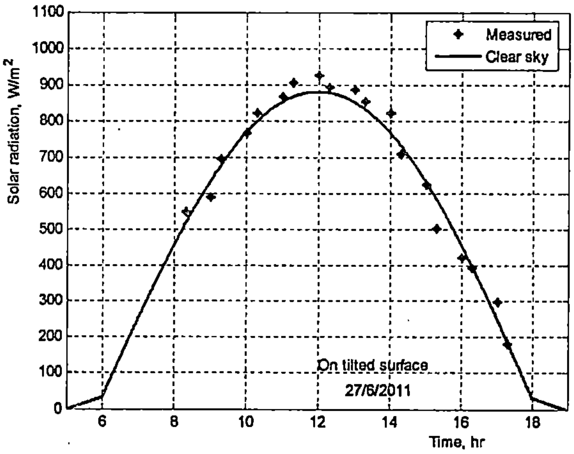


Fig. 45. Global solar radiation intensity on a tilted surface (β =30°, Latitude=31° N).



. Fig. 46. Global solar radiation intensity on a tilted surface (β =30°, Latitude=31° N).

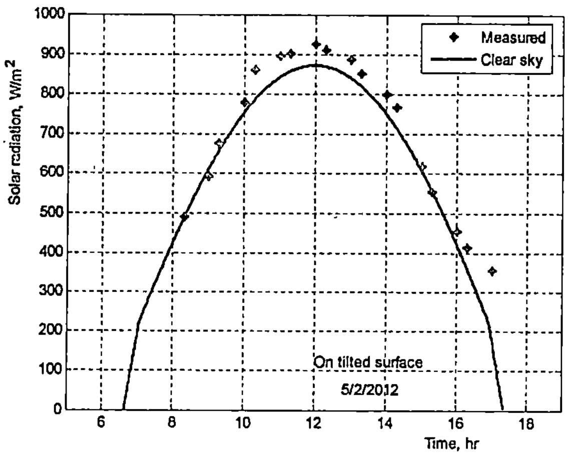


Fig. 47. Global solar radiation intensity on a tilted surface (β =30°, Latitude=31° N).

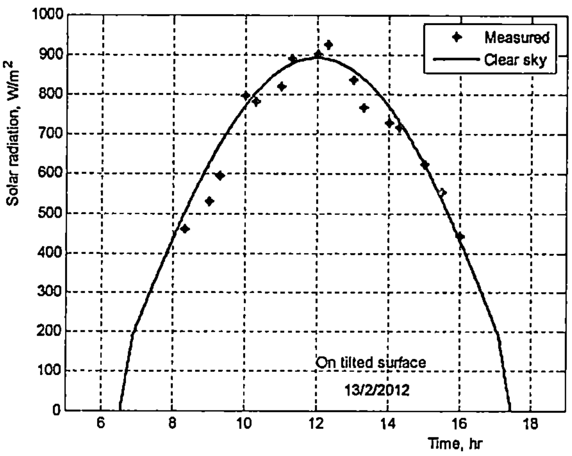


Fig. 48. Global solar radiation intensity on a tilted surface (β =30°, Latitude=31° N).

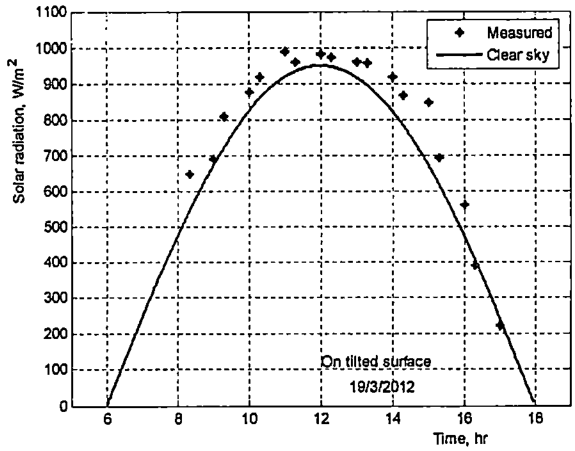


Fig. 49. Global solar radiation intensity on a tilted surface (β =30°, Latitude=31° N).

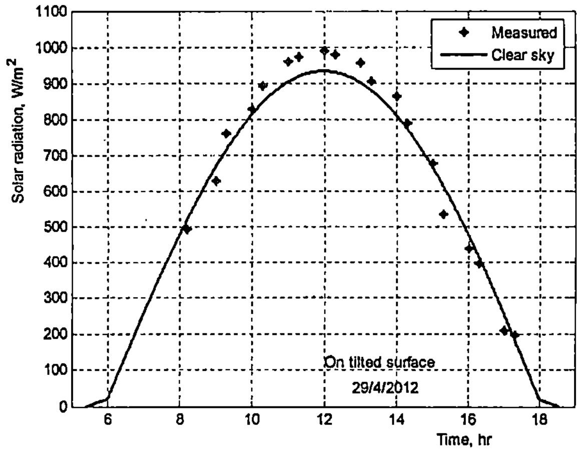


Fig. 50. Global solar radiation intensity on a tilted surface (β =30°, Latitude=31° N).

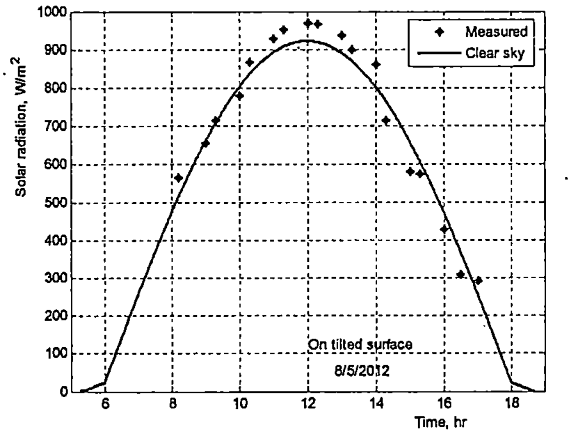
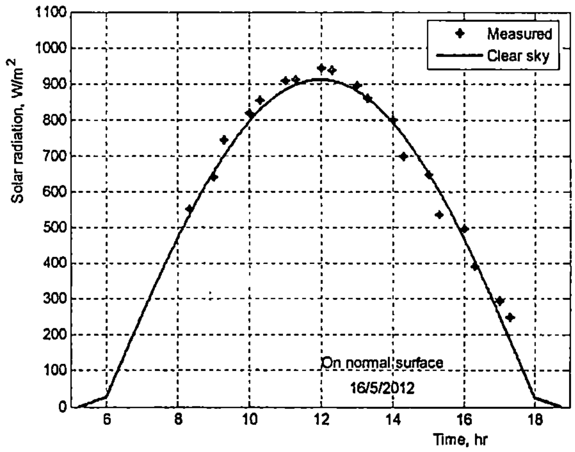


Fig. 51. Global solar radiation intensity on a tilted surface (β =30°, Latitude=31° N).



. Fig. 52. Global solar radiation intensity on a tilted surface (β =30°, Latitude=31° N).

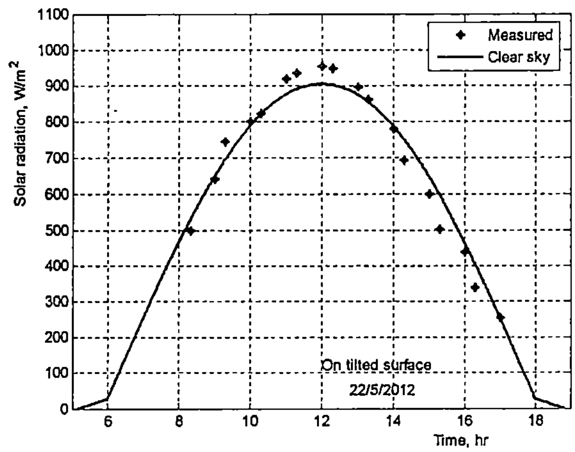


Fig. 53. Global solar radiation intensity on a tilted surface (β =30°, Latitude=31° N).

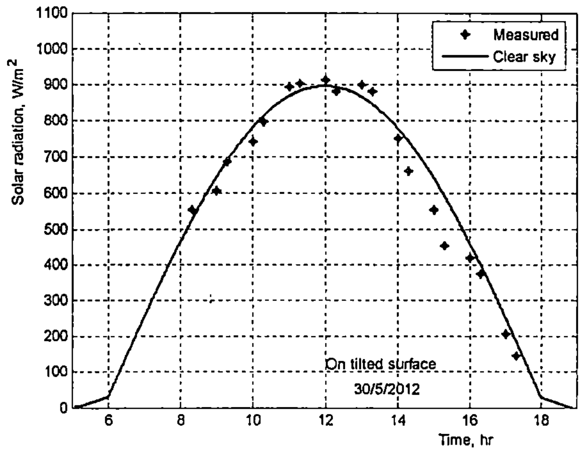


Fig. 54. Global solar radiation intensity on a tilted surface (β =30°, Latitude=31° N).

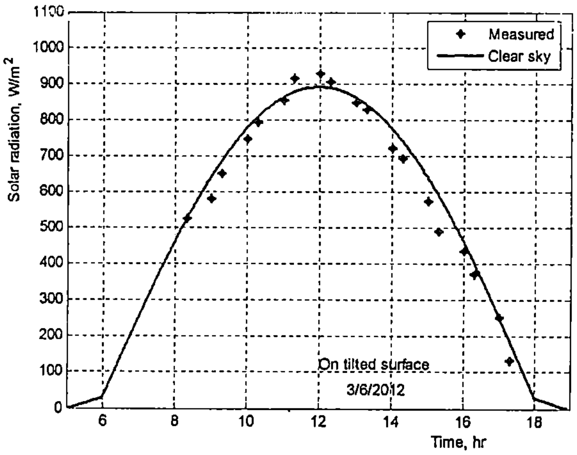


Fig. 55. Global solar radiation intensity on a tilted surface (β =30°, Latitude=31° N).

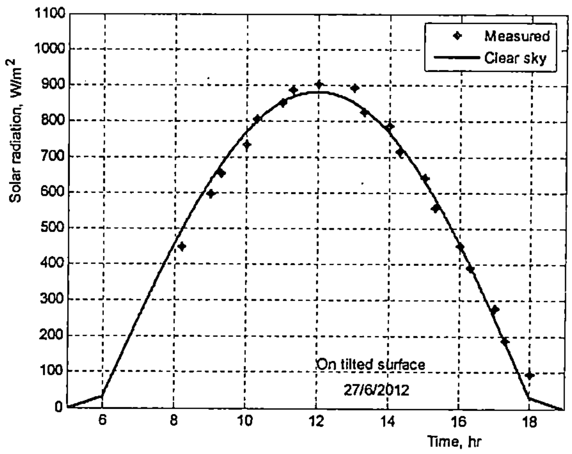


Fig. 56. Global solar radiation intensity on a tilted surface (β =30°, Latitude=31° N).

The agreement between measured and calculated annual average of daily global solar radiation is good. Therefore, the performances of thermal and electrical solar energy devices can be estimated; consequently, the economic return on investment may be predicted before installing such systems. Economic empowerment of restive youths and women through renewable energy technologies can be achieved through encouragement of personal investments, formation of farmer co-operative society's provision of loans, credit facilities and establishment of manpower development centers.

CONCLUSIONS

Mansoura is an Egyptian city located at 31.04083° N (latitude) and 31.4861° E (longitude) and it is one of the most solar energy abundant cities all days of the year. Therefore, solar energy devices can work with high performance. In the present work measurements were performed during different days in May and June 2011 and February to June 2012 on sunny days. The solar radiation data are measured with a solar power meter TES1333 on horizontal normal, tilted surfaces (30° facing south) and normal direction. A computer program is also developed to predict the solar radiation data at this place using the MATLAB by solving the clear sky model governing equations. The model is adapted to simulate the hourly solar radiation data at any day of the year. It was found that the model using clear sky as inputs, gives good accurate results. Comparing results, which are given in graphical form, show that the data obtained from the clear sky model on horizontal, normal and tilted surfaces (30° facing south) and from NASA, give reasonable results and can be used as a good and quick method for estimating the solar radiation when actual measurements are not available in this place. For future studies, a new model could be established, to easily calculate the solar radiation values using cloud amount data from any locality in Egypt which has no measured data of solar radiation components, or there are instrumental and other difficulties encountered when measuring components of solar radiation.

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