Journal of Theoretical and Applied Information Technology
31st July 2012. Vol. 41 No.2

ISSN: **1992-8645** www.jatit.org E-ISSN: **1817-3195**

ESTIMATION THE EFFECTS OF EACH SITE FACTORS, TIME FACTORS, AND OPTICAL FACTORS ON ABSORBED SOLAR RADIATION VALUE THAT INCIDENT ON A FLAT-PLATE SOLAR COLLECTOR

FAWAZ S. ABDULLAH, FIRAS A. ALI
Lecturer, Department of power engineering technology, Technical College /Mosul-Iraq
Assistant Lecturer, Department of power engineering technology, Technical College /Mosul-Iraq
E-mail: fawazsyltan@yahoo.com, firasali59@yahoo.com

ABSTRACT

In this paper, an estimated of absorbed solar radiation was developed to determine the performance of the solar collectors to develop best thermal energy conversion system. The aim of this research is to develop a tool for predicting the performance of a flat-plate solar collector from knowledge the absorbed solar radiation quantity. Also, the factors that affects on absorbed solar radiation value have been considered. These factors represented with collector tilt angle, the season changes that represented with month of year that the global solar radiation on horizontal surface has been measured, the location from the world represented with the latitude, time interval represented with hours of daylight from sunrise to sunset. Another optical factors affect on intensity of absorbed solar radiation has been considered. These factors correlated with absorptivity and transmissivity of the transparent glass cover which represented with (type, thickness, and number of glass covers). The result of each factor was analyzed for different collector tilt angle, latitude of place, and solar hour angle.

Keywords: *Global Solar Radiation, Flat-Plate Solar Collector, Absorbed Solar Radiation.*

1. INTRODUCTION

Global solar radiation is an important parameter necessary for most ecological models and serves as input for different photovoltaic conversion system; hence, it is of economic importance to renewable energy alternative. The solar radiation reaching the earth's surface depends on the climatic condition of the specific site location, and this is essential for accurate prediction and design of a solar energy system [1]. Although, solar radiation data are available in most meteorological stations, many stations in developing countries suffer from a shortage concern of these data. Thus, alternative methods for estimating these data are required [2]. Solar radiation incident on a collector is composed of three components, i.e. the beam, diffuse and reflection from the ground, which have different dependence on the slope of collector, the sum of these three components is called global radiation. Installing a collector properly can enhance its application benefit because the amount of radiation flux incident upon the collector is mainly affected by the azimuth and tilt angles that it is installed. Generally, in the northern hemisphere the best azimuth is due south (facing equator), but the tilt angle varies with factors such as the geographic latitude, climate condition, utilization period of time, etc. Methodologies for the estimation of the hourly global solar radiation in a day on the horizontal have been elaborated and proposed by many researchers, as they are reviewed in [3,4]. The aforementioned methodologies are based either on the analysis of recorded data [5–8] or on modeling techniques based on the analysis of meteorological data, like humidity, ambient temperature, wind speed, etc. in order to predict $I(d,h)$ [9,10] where d is the number of day started from 1_{st} January, h is the hour angle. The amount of solar radiation incident on the absorbing surface at any instant depends on a number of factors such as the season, latitude, absorb surface characteristics (type, amount of thickness, number of layers etc.) and transmissivity of atmosphere as reviewed in [11]. In this work, the effect of location change, time interval, season change and other optical factors such as (types of glass cover, number of glass cover, and thickness of glass cover) on absorbed solar radiation have been estimated.

2. METHODOLOGY

2.1. Observed Hourly Solar Radiation Data on (Horizontal Surface):

The observation data used in present work was given in the form of hourly total irradiation on horizontal surface I which is measured at a specified times and locations as mentioned below. The extraterrestrial hourly global radiation I_o on horizontal surface can be calculated for these locations, [12] as follows:

$$I_o = \frac{12\times3600}{\pi} I_{sc}\times\left[1+0.033\times\cos\left(\frac{360\times d}{365}\right)\right]\times$$
$$(\cos\delta\cos\phi\sin(h_2-h_1)+\frac{\pi(h_2-h_1)}{180}\sin\phi\sin\delta) \text{ .... (1)}$$

Where I_{sc} is the solar constant which is equal to 1367 W/m^2. The hourly clearness ratio K_T can be estimated as the ratio of terrestrial global radiation on horizontal surface to the extraterrestrial radiation on the horizontal surface as follows:

$$K_T = \frac{I}{I_o} \text{ ...... (2)}$$

The hourly diffuse radiation on horizontal surface can be estimated as follows [13]:

For $K_T \le 0.22$

$$\frac{I_d}{I} = 1.0 - 0.09K_T \text{ ..... (3a)}$$

For $0.22 \le K_T \le 0.8$

$$\frac{I_d}{I} = 0.9511 - 0.1604K_T + 4.388K_T^2 - 16.638K_T^3 + 12.336K_T^4$$

.... (3b)

For $K_T \ge 0.8$

$$\frac{I_d}{I} = 0.165 \text{ .... (3c)}$$

Then the hourly beam radiation on horizontal surface can be estimated as follows:

$$I_b = I - I_d \text{ .... (4)}$$

In this paper, the value of monthly average hourly solar radiation that appear in this work has been taken from Iraqi meteorological organization and seismology for a specified month (the tenth day of December) and specified location (Basrah city) for a time interval (7:00 am-5:00 pm) of that day as a sample to estimate the incident total radiation on tilted surface I_T and absorbed solar radiation S for that location, month, and time interval as demand to complete this work.

2.2. Global Radiation Mathematical Models on (Tilted Surface):

As most published meteorological data, which gives the values of hourly global radiation on horizontal surfaces, correlation procedures are required to obtain insolation values on tilted surfaces from horizontal radiation. Total hourly solar radiation on a tilted surface (I_T) is normally estimated by individually considering the direct beam (I_{TB}), diffuse (I_{TD}) and reflected components (I_{TR}) of the radiation on a tilted surface. Thus for a surface tilted at a slope angle from the horizontal, the incident total radiation is given by [14]:

$$I_T = I_{TB} + I_{TD} + I_{TR} \text{ .... (5)}$$

Several models have been proposed by various investigators to calculate global radiation on tilted surfaces from the available data on a horizontal surface. The hourly beam radiation received on an inclined surface can be expressed as [14]

$$I_{TB} = (I - I_d)\times R_b \text{ ...... (6)}$$

Where I and I_d are the hourly global and diffuse radiation on a horizontal surface, and R_b is the ratio of the average hourly beam radiation on a tilted surface to that on a horizontal surface. The hourly ground reflected radiation can be written as [14]:

$$I_{TR} = I\times\rho_d(1-\cos\beta)/2 \text{ ...... (7)}$$

Where β the collector slope is angle (degree), and ρ_d is the ground reflection coefficient (albedo). For surfaces located at the northern hemisphere as mentioned at this paper, the collector must be sloped towards the equator (zero azimuth angles). Then the beam radiation tilt factor R_b was calculated as follows [14].

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

...... (8)

Where θ is the solar radiation incidence angle (degree), z is the solar zenith angle (degree), and h is the solar hour angle (degree), which can be estimated from the following equation such that [14]:

$$h = 15\times(AST - 12:00) \qquad \text{……. (9)}$$

Where AST is the apparent solar time, which means the sun position before, after, and at local solar noon (when the sun at meridian of the observer). So the hour angle has a negative value before local solar noon, positive value after local solar noon and zero at local solar time (when $AST = 12:00$ pm). The hour angle that used in Eq. (8) may found from the midpoint between any two sequent hours, such that, when the time of calculation of hourly solar radiation was happened between (12:00 pm and 13:00 pm), then the two hours was substituted in Eq. (9) once for first hour to give first hour angle h_1, and another for second hour to give h_2. Then the final hour angle that used in Eq. (8) is the average value of these two values. Also, ϕ is the latitude of place (degree), and δ is the declination angle (degree) which is found equal to [15]:

$$\delta = 23.45\times\sin[360(284+d)/365] \qquad \text{….. (10)}$$

Where d is the Julian day ranging from 1 (at 1 January) to 365 (at 31 December). The sky diffuse radiation can be expressed as [15]:

$$I_{TD} = R_d \times I_d \qquad \text{…… (11)}$$

Where R_d is the ratio of the average monthly average daily diffuse radiation on a tilted surface to that on a horizontal surface. The details of the calculation depend on which diffuse-sky model is used. In this paper, Isotropic diffuse concept on an hourly basis was used, which means the value of R_d was estimated using the following equation as follows [15].

$$R_d = [1+\cos\beta]/2 \qquad \text{…… (12)}$$

Finally the total radiation I_T incident on a south-facing collector tilted at an angle β to the horizontal surface can be calculated as follows [16]:

$$I_T = (I - I_d)\times R_b + \frac{I_d}{2}(1+\cos\beta) + \frac{I}{2}\times\rho_d\times(1-\cos\beta) \qquad \text{…… (13)}$$

2.3. Radiation Transmission Thorough Glazing Cover (Absorbed radiation):

The prediction of collector performance requires information on the solar energy absorbed by the collector absorber plate. The solar energy incident on a tilted surface can be found by modifying Eq. (13) to give the absorbed radiation, S, by multiplying each term with the appropriate transmittance-absorptance product as follows[16]:

$$S = (I - I_d)\times R_b\times(\tau\alpha)_b + \frac{I_d}{2}(1+\cos\beta)\times(\tau\alpha)_d + \frac{I}{2}\times\rho_d\times(1-\cos\beta)\times(\tau\alpha)_g \qquad \text{…… (14)}$$

Where $(\tau\alpha)_b, (\tau\alpha)_d$, and $(\tau\alpha)_g$ are the transmittance-absorptance product for beam, diffuse and ground-reflected radiation components.

The transmission, reflection, and absorption of solar radiation by the various parts of a solar collector are important in determining collector performance. The transmittance, reflectance, and absorptance are functions of the incident solar radiation (I_T), glass thickness (L), refractive index of glass cover (n), extinction coefficient of the material (K), and number of glass cover (N). When a beam of radiation strikes the surface of a transparent plate at angle, θ_1 called the radiation incidence angle. Part of the incidence radiation is transmitted through the glass cover and the reminder is refracted to angle θ_2, which called the radiation refraction angle. Angles θ_1 and θ_2 are not equal when the density of the plane is different from that of the medium through which the radiation travels. The two angles are related by the Snell's law as follows [14]:

$$\frac{n_2}{n_1} = \frac{\sin\theta_1}{\sin\theta_2} \qquad \text{…… (15)}$$

Where n_1 and n_2 are the refraction indices. A typical value of the refraction index is 1.0 for air, 1.526 for glass as used in this present work. Expressions for perpendicular and parallel components of radiation for smooth surfaces were derived by Fresnel law, [14] as follows:

$$r_\perp = \frac{\sin^2(\theta_2 - \theta_1)}{\sin^2(\theta_2 + \theta_1)} \qquad \text{…….. (16a)}$$

$$r_\Pi = \frac{\tan^2(\theta_2 - \theta_1)}{\tan^2(\theta_2 + \theta_1)} \qquad \text{…..... (16b)}$$

Similarly, the transmittance, τ_r (subscript r indicates that only reflection losses are considered) , can be calculated from the above two components as follows [15]:

$$\tau_r = 0.5\left(\frac{1-r_\Pi}{1+r_\Pi} + \frac{1-r_\perp}{1+r_\perp}\right) \qquad \text{….. (17a)}$$

But for a glazing system of N covers of same material, it can be proven that:

$$\tau_r = 0.5\left(\frac{1-r_{\Pi}}{1+(2N-1)r_{\Pi}} + \frac{1-r_{\perp}}{1+(2N-1)r_{\perp}}\right) \quad \ldots\ldots (17b)$$

The transmittance, τ_a, (subscript a indicates that only absorption losses are considered), can be calculated as [15]:

$$\tau_{ab} = \exp\left(-K \times L / \cos(\theta_2)\right) \quad \ldots\ldots (18)$$

Where K is the extinction coefficient (which can vary from 4m^{-1} for low quality glass, to 32m^{-1} for high quality glass), and L is the thickness of the glass cover. Then, the total transmittance for a beam radiation component becomes:

$$\tau_b = \tau_{ab} \times \tau_r \quad \ldots\ldots. (19)$$

The proper transmittance ratio (α/α_n) can then be obtained from the following equation depending on the angle of incident of beam radiation component (θ_1) can be obtained from [17] as follows:

$$(\alpha/\alpha_n)_b = 1 + 2.0345\times10^{-3}\theta_1 - 1.99\times10^{-4}\theta_1^2 + 5.324\times10^{-6}\theta_1^3 - 4.799\times10^{-8}\theta_1^4 \quad \ldots\ldots\ldots (20)$$

The reflectance of the glass cover for diffuse radiation ρ_d, which used in this paper was found from the following equation:

For ($K.L = 0.0125$, $\rho_d = 0.15$),

($K.L = 0.0370$, $\rho_d = 0.12$), and

($K.L = 0.0524$, $\rho_d = 0.11$) as mentioned in the work [15]. A reasonable approximation of transmittance-absorptance product for beam radiation component for most practical solar collectors is given by the following equation as [17]:

$$(\tau\alpha)_b = 1.01 \times \tau_b \times (\alpha/\alpha_n)_b \times \alpha_n \quad \ldots\ldots (21)$$

For a given collector tilt angle β, the following empirical relations can be used to find the effective angle of incidence of diffuse ($\theta_{e,d}$) and ground-reflectance ($\theta_{e,g}$) radiation can be estimated as follows [18]:

$$\theta_{e,d} = 59.7 - 0.1388\beta + 0.001497\beta^2 \quad \ldots\ldots. (22a)$$

$$\theta_{e,g} = 90.0 - 0.5788\beta + 0.002693\beta^2 \quad \ldots\ldots (22b)$$

The proper transmittance ratios $(\alpha/\alpha_n)_d$, $(\alpha/\alpha_n)_g$ can then be estimated as follows depending on the effective incidence angle (θ_e) as follows:

$$(\alpha/\alpha_n)_d = 1 + 2.0345\times10^{-3}\theta_{e,d} - 1.99\times10^{-4}\theta_{e,d}^2 + 5.324\times10^{-6}\theta_{e,d}^3 - 4.799\times10^{-8}\theta_{e,d}^4 \quad \ldots\ldots\ldots (23a)$$

While,

$$(\alpha/\alpha_n)_g = 1 + 2.0345\times10^{-3}\theta_{e,g} - 1.99\times10^{-4}\theta_{e,g}^2 + 5.324\times10^{-6}\theta_{e,g}^3 - 4.799\times10^{-8}\theta_{e,g}^4 \quad \ldots\ldots (23b)$$

Where $\theta_{e,d}$ and $\theta_{e,g}$ are the effective incidence angle in (degrees) for diffuse radiation and ground reflectance components respectively. α_n is the absorptance at normal incidence angle, which can be found from the properties of the absorber cover. In this work this value was taken equal to (0.91) for three radiation components as mentioned in literature [15]. Now, the total transmittance-absorptance product for diffuse and ground reflectance radiation components can be estimated in same manner that estimated for beam radiation component, after using $\theta_{e,d}$, and $\theta_{e,g}$ as the new incident angles for diffuse and ground-reflectance components from Eq. (15) to (21). Subsequently, Eq. (21) can be used to find $(\tau\alpha)_d$ and $(\tau\alpha)_g$. Finally, each value of transmittance-absorptance product $(\tau\alpha)$ for three incident radiation components are substituting in Eq. (14) to find the net absorbed radiation on collector surface.

3. RESULTS AND DISSCUSSION

Figure (1) shows the transmittance-absorptance product for beam radiation component $(\tau\alpha)_b$ versus collector tilt angle β for different incident angles θ_1, and different $K.L$ product values. As shown, the transmittance-absorptance product value does not affect by collector tilt angle as shown clearly in Equations (15) through (21), but depends on value of incidence angle θ_1, and value of the KL product.

Figure (2) demonstrate the transmittance-absorptance product for diffuse radiation component $(\tau\alpha)_d$ as function of collector tilt angle β for different incident angles θ_1, and different $K.L$ product values. The general behavior show that, as the collector tilt angle increases, causes the transmittance-absorptance product to be increases too until reach to maximum value at certain value of tilt angle approximately between

Journal of Theoretical and Applied Information Technology
31st July 2012. Vol. 41 No.2

ISSN: **1992-8645** www.jatit.org E-ISSN: **1817-3195**

(40°-50°) then decreases to minimum values at (β=90°).

Figure (3) illustrate the transmittance-absorptance product for ground-reflected radiation component $(\tau\alpha)_g$ versus collector tilt angle β at different incident radiation angles θ_1, and different $K.L$ product values. As clear in this figure, as the collector tilt angle increases, causes to the transmittance-absorptance product to be increases until reach to maximum value at collector right angle when(β=90°).

Figure (4) clarify the transmittance-absorptance product for beam radiation component $(\tau\alpha)_b$ as function of incoming radiation incidence angle θ_1 for different collector glass covers numbers N. As the glass cover numbers increased, causes to decreases in transmittance-absorptance product values, also as the incoming solar radiation incident angle increases causes to decrease in this product until reach to minimum value at (θ_1=90°).

Figure (5) and Figure (6) illustrate the transmittance-absorptance product for diffuse and ground-reflectance radiation components versus collector tilt angle β for different collector glass covers numbers N. In two figures, as the number of glass cover increases, cause to reduce in radiation losses and this reduction in losses depends on the optimum collector tilt angle as shown in these figures.

Figure (7) illustrate the extraterrestrial hourly radiation (that estimated outside of atmosphere) versus hours of daylight (7:00am to 5:00pm) for different months represented with January (d=17), February (d=47), and December (d=344). As shown from this figure, there are two variations in solar radiation intensity, firstly, the variation of solar radiation intensity from hour to hour of the daylight, which means when sun moves across the sky from shine time through local solar noon. Secondly, the variation in solar radiation intensity value from month to another or from season to another due to inclination of earth rotation axis during the seasons. As example, for northern hemisphere of earth as mentioned in this work, the earth rotation axis is towards sun during summer months, and trend keep away from sun at winter months. In this figure, it is clear that the solar radiation has maximum value at February (d=47) rather than January (d=17) or December (d=344), due to decreases in solar declination angle (δ) which affects on extraterrestrial radiation intensity as clear in Eq. (1).

Figure (8) shows the extraterrestrial hourly radiation versus hours of daylight (7:00am to 5:00pm) at different latitudes (30°N, 40°N, 50°N) for January month. This figure illustrates the variation in solar radiation intensity value due to variation in position of solar collector. That means as the collector keep away from the equator plane (ϕ=0°), the solar radiation intensity decreases, due to increase in radiation traveled distance and increase in angle of incidence of solar radiation that may incident at high value to horizon at north pole when (ϕ=90°), while decreases as approach to equator plane when the radiation is approximately perpendicular to earth surface when (ϕ=0°).

Figure (9) illustrate beam radiation tilt factor as function of collector tilt angles at different daylight hours (7:00am-12:00pm) for a specified month (January), and at specified location (ϕ=30°N). As shown in this figure, the beam radiation tilt factor has maximum value at time interval between (7:00am-8:00am) and this value was increases as the collector tilt angle increases until reach to maximum value at certain tilt angle value. Due to the large guidance that needed to direct the incident radiation on collector surface. So this time interval value was substituted in Eq. (8) to give maximum value for R_b. Again, for all time intervals, the value of R_b is raised as collector tilt angle increases till reach to maximum value at certain tilt angle values.

Figure (10) shows beam radiation tilt factor as function of collector tilt angles at different latitudes (ϕ=30°N, 40°N, 50°N) for a specified month (January), and at specified time interval (8:00am-9:00am). As clear in this figure, for constant collector tilt angle, the larger value of latitude gives the highest value of R_b due to the larger amount of latitude that substituting in Eq. (8) which make the numerator of this equation has high increments in R_b value.

Figure (11) illustrate beam radiation tilt factor as function of collector tilt angles for months of

January (d =17), February (d =47), and December (d =344) for a specified hour (h =7-8 am), and at specified location (ϕ =30^{o}N). Since at December month the sun has low altitude in the sky, which cause to collector to be tilted away from horizontal to make the solar radiation incident at right angle or near of it. While at February month the day length is increased and sun has an altitude higher than in December and January months, which cause the collector to be arranged at low sloped angle.

Figure (12) demonstrate beam radiation tilt factor versus daylight hours (7:00am-5:00pm) for different collector tilt angles (β =10^o-60^o) at a specified location (ϕ =30^{o}N), and specified month (January). As clear from this figure, firstly: the vales of beam radiation tilt factor decreases for all tilt angles at time intervals (7:00am-12:00pm). That means, when sun rises from horizon till reach to local solar noon, then the guidance of solar radiation requires minimum tilt factor value. Secondly: as the collector tilt angle decreases, then the tilt factor R_b has little effect on incident solar radiation value.

Figure (13) demonstrate different types of solar radiations values versus daylight hours (7:00am-5:00pm) at a specified collector tilt angle (β =10^o), for a location of (ϕ =30^{o}N), day number of (d =344), and (for a single glass cover, $K.L$ =0.0524 per sheet) to estimate the absorbed solar radiation S . As shown from this figure, the value of incident total radiation on tilted surface I_T is higher than total solar radiation on horizontal surface I that measured at this location and time interval. This is true due to the effect of beam radiation tilt factor R_b that make the solar radiation directed towards solar collector.

Figure (14) shows incident and absorbed solar radiations versus daylight hours at different months (December, January, February) for a collector tilt angle (β =10^o), for a location (ϕ =30^{o}N), for a single glass cover, and $K.L$ =0.0524 per sheet.

Finally, Figure (15) demonstrate incident and absorbed solar radiations versus daylight hours at different latitudes (30^{o}N, 40^{o}N, 50^{o}N) for a collector tilt angle equal (β =10^o), for a December month (d =344), for a single glass cover, and $K.L$ =0.0524 per sheet.

4. CONCLUSION

1. The monthly average hourly global radiation on horizontal surface I for specified location and month was taken from Iraqi meteorological organization and seismology. The monthly average hourly extraterrestrial radiation I_o was calculated from Eq. (1) depending upon day number, specified location, and time interval of that day as a purpose to calculate the K_T value as clear in Eq. (2).

2. The beam I_b and diffuse I_d radiation components were computed from global solar radiation I on horizontal surface for a specified position. But this value was taken as a sample for another locations and seasons to complete the necessary prediction for incident solar radiation I_T , and absorbed solar radiation on collector surface S .

3. The incident radiation on tilted surface I_T is consisting of three components (beam I_{TB} , diffuse I_{TD} , and ground-reflectance I_{TR}) as shown in Eq. (13), and it was affected by collector tilt angle β and beam radiation tilt factor.

4. The value of R_b was affected by (latitude of place ϕ , solar hour angle h , declination angle δ , in addition to collector tilt angle β). Again collector tilt angle was appeared in first term of Eq. (5). All above factors are affected on incident radiation I_T and subsequently on absorbed solar radiation S .

5. All of the above factors that affects on absorbed solar radiation in addition of another optical properties such as (type, thickness, and numbers of collector glass cover) which represented with transmittance-absorptance product for beam, diffuse, and ground-reflectance components that appear in Eq. (14).

6. The value of $(\tau\alpha)_b$ depends on radiation incidence angle θ_1 which estimated from numerator of Eq. (8), then substituted in Eq. (15) to estimate the radiation refraction angle θ_2). So it depends on number of collector glass cover N , and $K.L$ product factor that associated with type and thickness of collector glass cover.

7. The values of $(\tau\alpha)_d$ and $(\tau\alpha)_g$ depend on number of collector glass cover N and

$K.L$ product factor in addition to effective incidence angles $\theta_{e,d}$ and $\theta_{e,g}$ (instead of θ_1) which may calculated from Equations (22a,b) depending on collector tilt angle β. These values of $\theta_{e,d}$ and $\theta_{e,g}$ are used as incident angles in Equation (15) to get the radiation refraction angle θ_2 for diffuse and ground-reflectance components.

8. This paper considered with winter months (December, January, and February) only due to important of this season on solar water heating technology that may applied on flat-plate solar collector at any location and at time intervals.

REFERENCES

[1] Burari, F.W. and A.S. Sambo, 2001. *Model for the prediction of global solar radiation for Bauchi using meteorological data*. Nigeria J. Renew. Energ., 91: 30-33.

[2] Al-Salihi, A.M., M.M. Kadum and A.J. Mohammed, 2010. *Estimation of global solar radiation on horizontal surface using meteorological measurement for different cities in Iraq*. Asian J. Sci. Res., 3(4): 240-248.

[3] Davies JA, MacKay DC. *Evaluation of selected models for estimating solar radiation on horizontal surfaces*. Solar Energy 1989;43:153–68.

[4] Gueymard C. *Critical analysis and performance assessment of clear sky solar irradiance models using theoretical and measured data*. Solar Energy 1993;51:121–38.

[5] Kouremenos DA, Antonopoulos KA, Domazakis ES. *Solar radiation correlations for the Athens, Greece, area*. Solar Energy 1985;35:259–69.

[6] Gueymard C. *Prediction and performance assessment of mean hourly solar radiation*. Solar Energy 2000;68: 285–303.

[7] Aguiar R, Collares-Perreira M. *Statistical properties of hourly global radiation*. Solar Energy 1992;48: 157–67.

[8] Gordon JM, Reddy TA. *Time series analysis of hourly global horizontal solar radiation*. Solar Energy 1988; 41:423–9.

[9] Kambezidis HD, Psiloglou BE, Gueymard C. *Measurements and models for total solar irradiance on inclined surface in Athens, Greece*. Solar Energy 1994;53(2):177–85.

[10] Knight KM, Klein SA, Duffie JA. *A methodology for the synthesis of hourly weather data*. Solar Energy 1991;46:109–20.

[11] N. Mohan Kumar, P.V. Hareesh Kumar & R.R. Rao, *An empirical model for estimating hourly solar radiation over the Indian seas during summer monsoon season*. Indian J. of Marine Sci. 2001; 123-131.

[12] Kreith, F., Kreider, J.F., 1978. *Principles of Solar Engineering*. McGraw-Hill, New York.

[13] Erbs, D.G., Klein, S.A., Duffie, J.A., 1982. *Estimation of the Diffuse Radiation Fraction for Hourly, Daily, and Monthly-Average Global Radiation*. Solar Energy, 28, 293-302.

[14] Duffie, J.A., Beckman, W.A., 1991. *Solar Engineering of Thermal Processes*, John Wiley & Sons, New York.

[15] Soteris Kalogirou, 2009. *Solar energy engineering: process and systems*, Academic Press, London.

[16] Liu, B.Y.H., Jordan, R.C., 1960. *The interrelationship and characteristic distribution of direct, diffuse, and total solar radiation*. Solar Energy 4(3), 1-19.

[17] Beckman, W.A., Klein, S.A., Duffie, J.A., 1977. *Solar Heating Design*. John Wiley & Sons, New York.

[18] Brandemuehl, M.J., Beckman, W.A., 1980. *Transmission of diffuse radiation through CPC and flat-plate collector glazing*. Solar Energy 24 (5), 511-513.

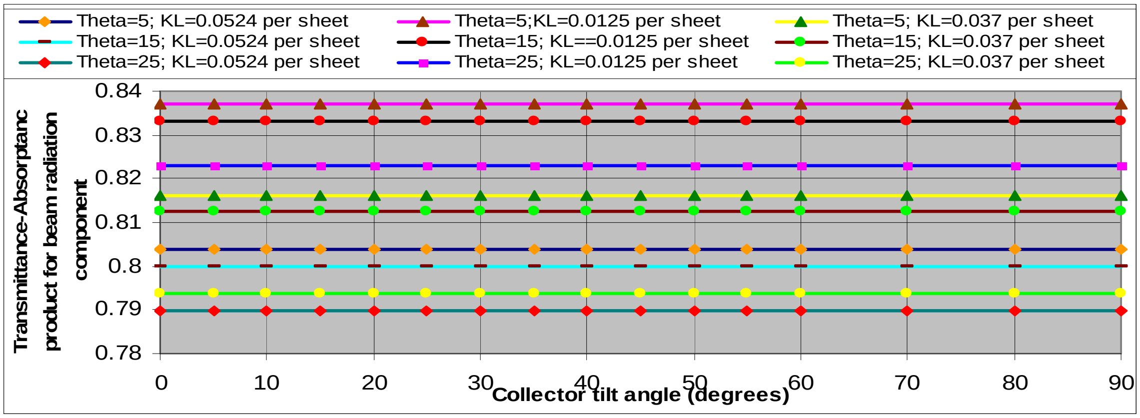


Figure (1)

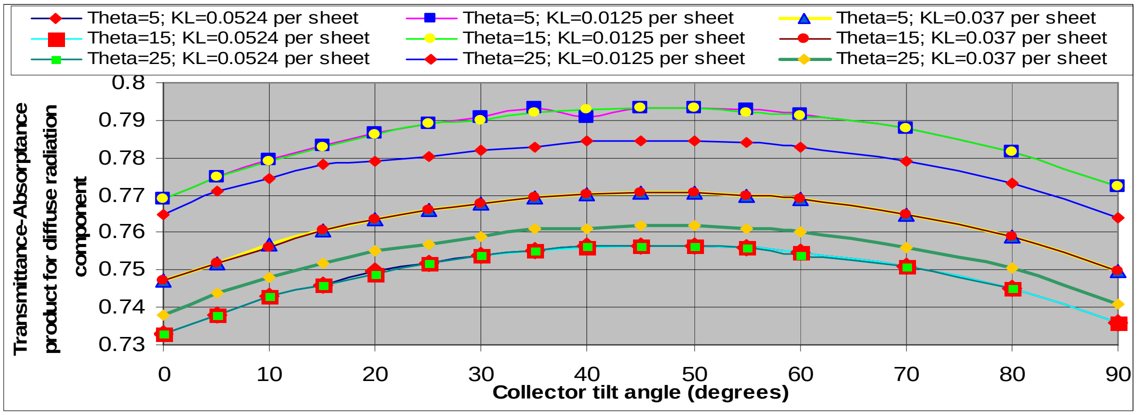


Figure (2)

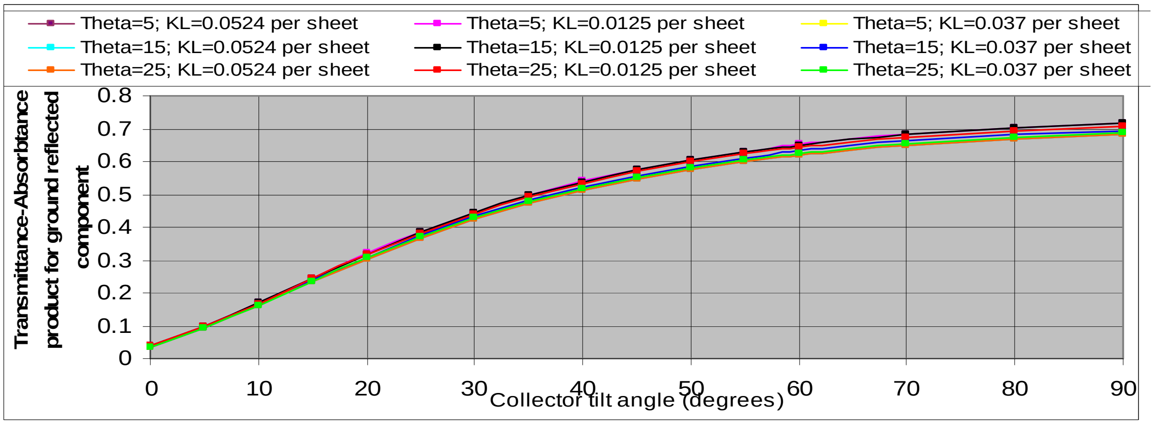


Figure (3)

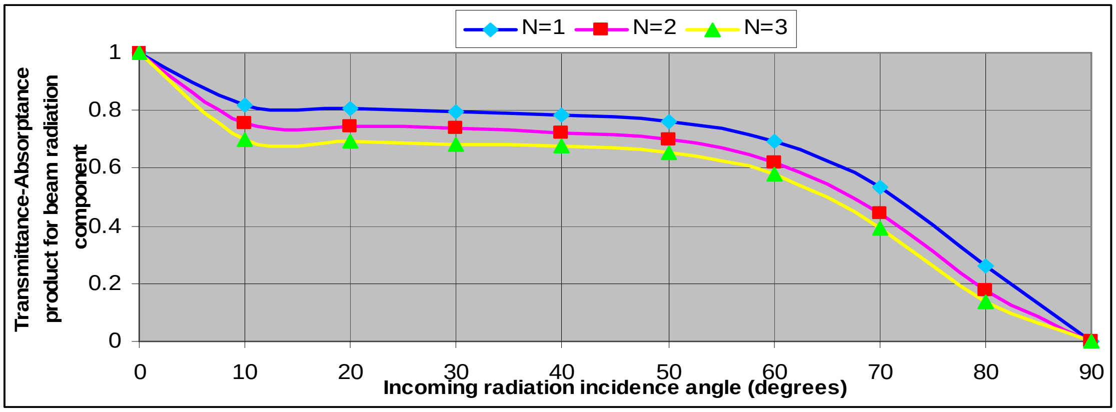


Figure (4)

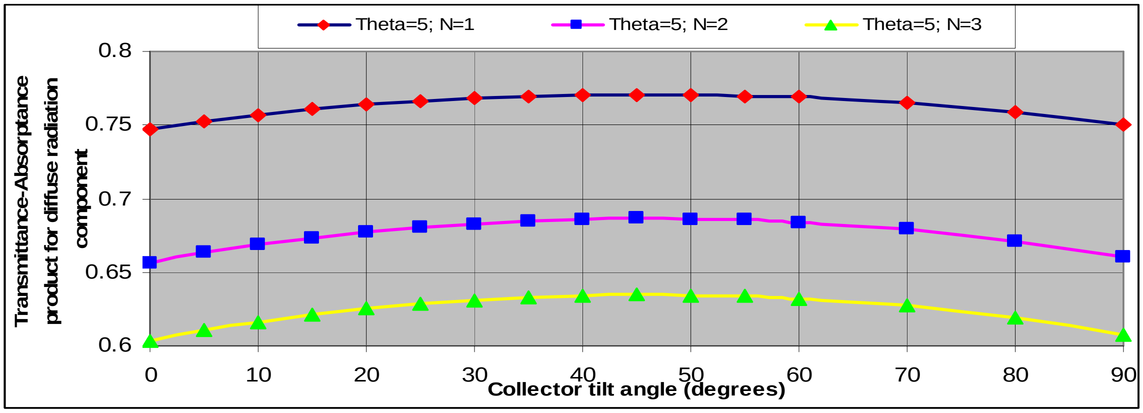
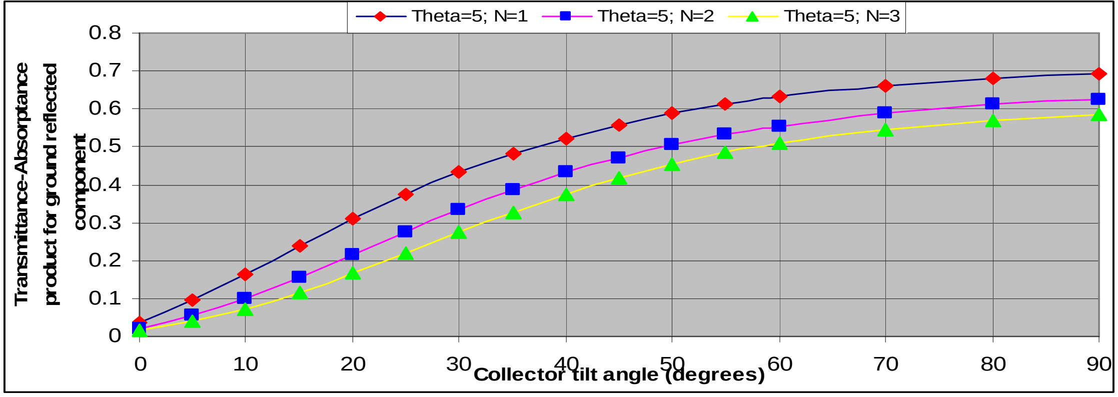


Figure (5)

Figure (6)



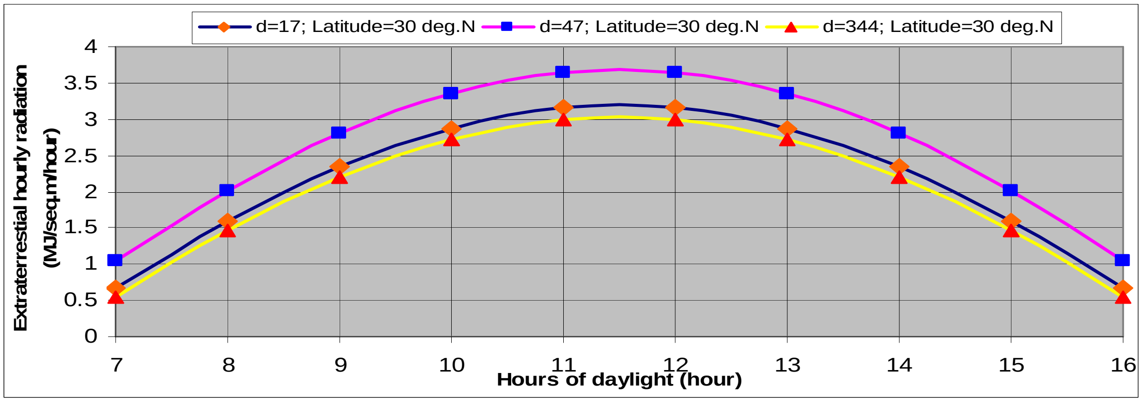


Figure (7)

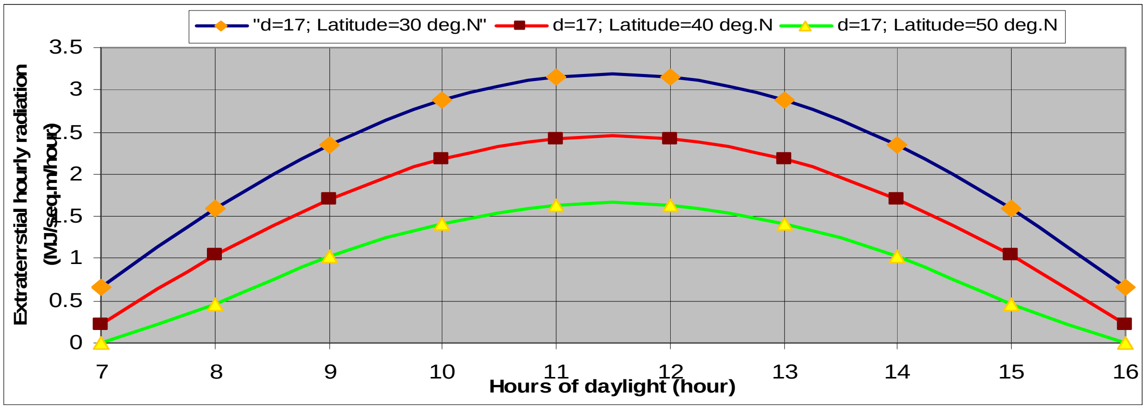


Figure (8)

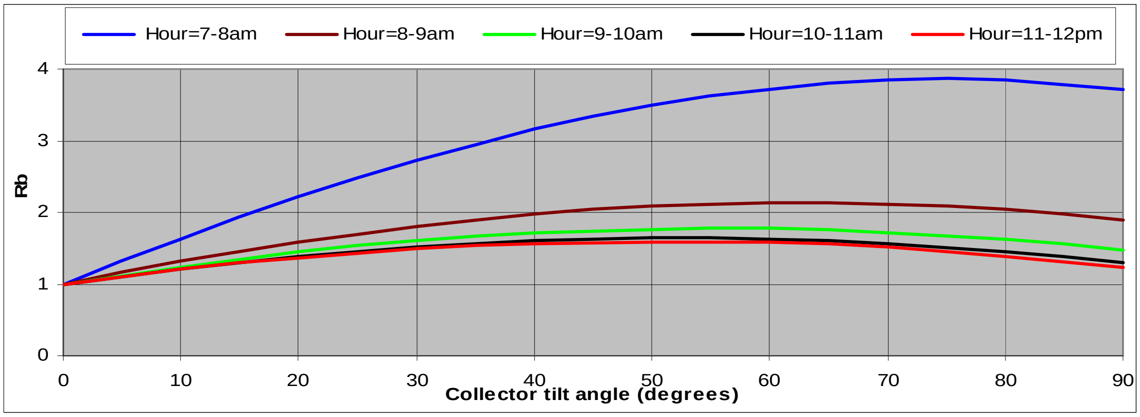


Figure (9)

Journal of Theoretical and Applied Information Technology
31st July 2012. Vol. 41 No.2

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

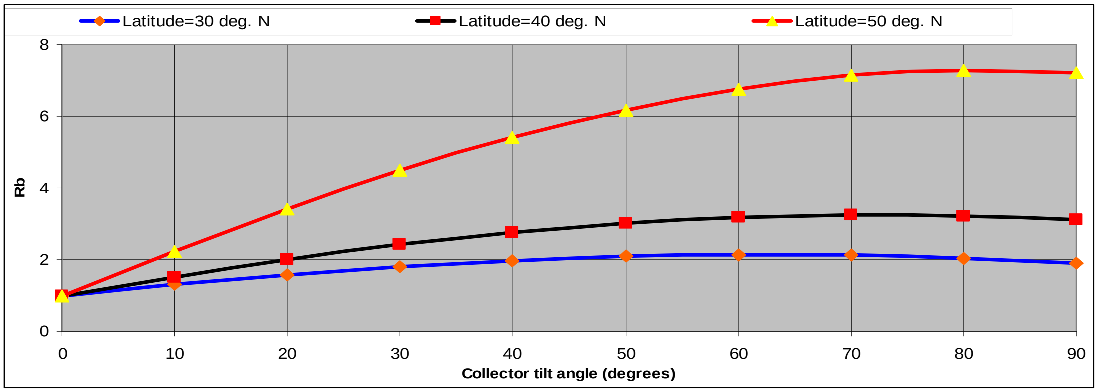


Figure (10)

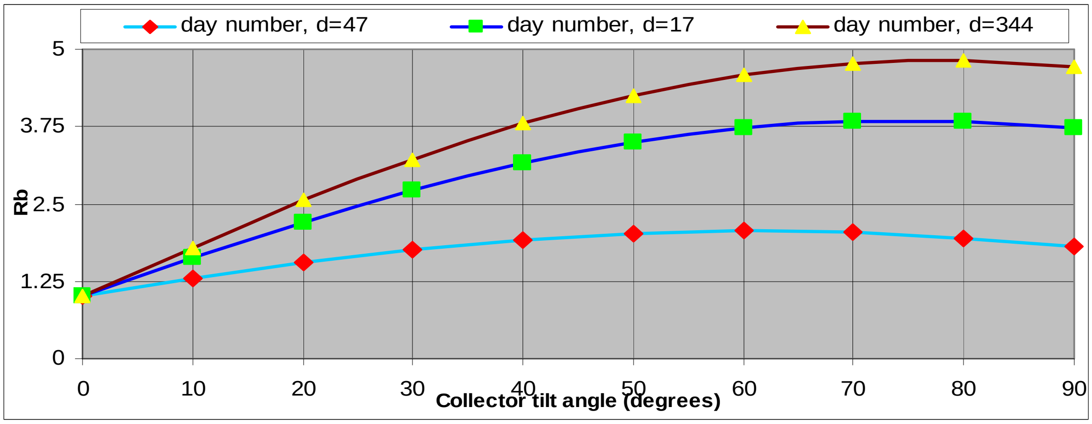


Figure (11)

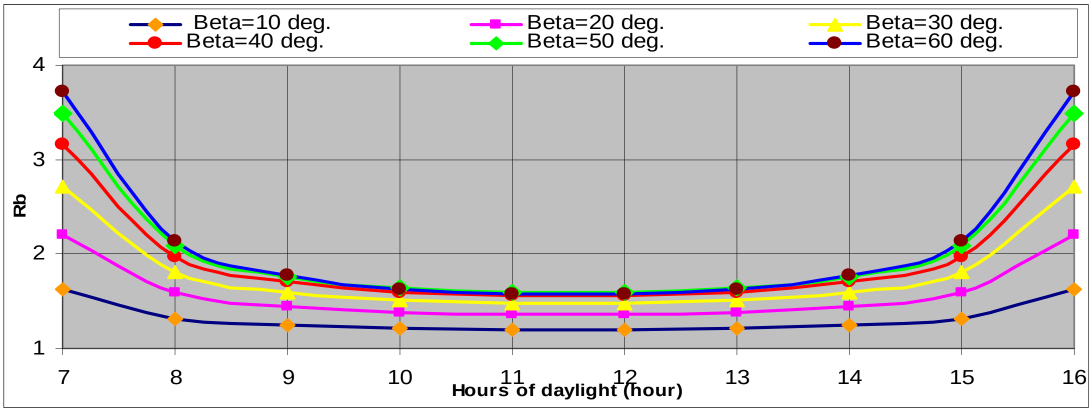


Figure (12)

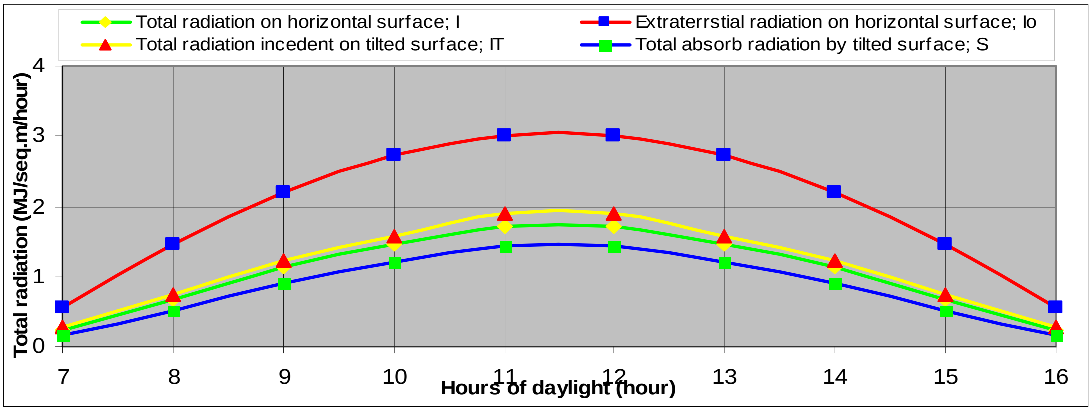


Figure (13)

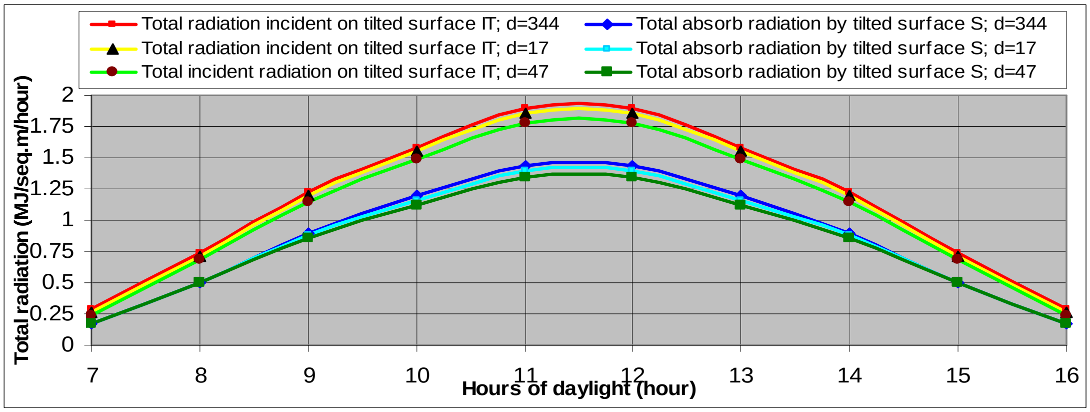


Figure (14)

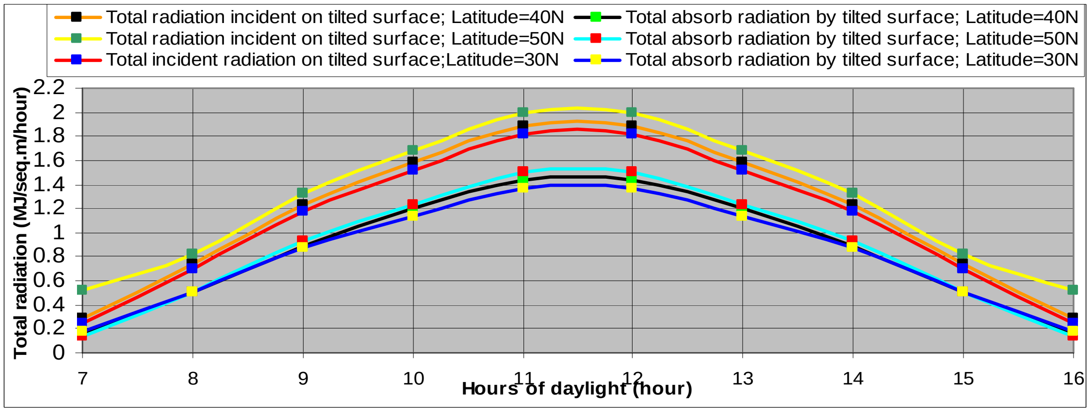


Figure (15)