EVALUATION OF THE HOURLY DIRECT SOLAR, DIFFUSE AND GLOBAL RADIATION INCIDENT ON TILTED, HORIZONTAL AND VERTICAL SURFACES OVER TRIPOLI

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الخلاصة :

في هذه الورقة تم تقييم الإشعاع الشمسي الحراري المباشر و المنتشر و الكلي (global) على مدينة طرابلس و مدى تأثير زاوية الميل, تحت ظروف مناخية مناسبة خالية من الغيوم و الظلال و الغبار . الدراسة تتضمن محاكاة ثلاثة سطوح, أفقية و عمودية و مائلة, باعتبار تأثير الإشعاع الشمسي المؤسس على أن السماء صافية. حيث تم الحصول على نتائج باستخدام نموذج رياضي (ASHRAE Model) طُور باستعمال برمجة لغة فورتران90 على أساس عرض مقدم في صورة أنماط و مخططات (graphs and patterns) توضح المتوسط الشهري للإشعاع الشمسي الساعي الساقط على سطح أفقي و عمودي و مائل بدرجة 35^0 , و الإشعاع المباشر الساعي عند زوايا مختلفة وذلك لأربعة أشهر, يناير الذي يمثل فصل الشتاء, أبريل الذي يمثل فصل الربيع, يوليو الذي يمثل فصل الصيف و أكتوبر الذي يمثل فصل الخريف, وقد تم أخذ القيمة المتوسطة لكل شهر. حيث يُلاحَظ من النتائج أنه قد تم الحصول على أعلى إشعاع شمسي مباشر للسطح المائل بزاوية 35^0 عند أفضل الظروف W/m^2 1025 لشهر أكتوبر, و للسطح الأفقي $911W/m^2$ لشهر أبريل, و للسطح العمودي $791W/m^2$ لشهر يناير, أما الإشعاع الشمسي المنتشر فللسطح المائل بزاوية 35^0 ,$224W/m^2$ لشهر يوليو, و للسطح الأفقي كذلك شهر يوليو $118\ W/m^2$, و للسطح العمودي $175W/m^2$ لشهر أبريل, كذلك يقال بالنسبة لإشعاع الشمسي الكلي للسطح المائل بزاوية 35^0 عند أفضل الظروف $1195W/m^2$ لشهر أكتوبر, و للسطح الأفقي $1001W/m^2$ لشهر أبريل, و للسطح العمودي $917W/m^2$ لشهر يناير, عند نفس الظروف. أما زاوية الميل للإشعاع الشمسي المباشر في أفضل الظروف°55 لشهر يناير, و°10 لشهر أبريل, و°0 لشهر يوليو, و°45 لشهر أكتوبر عند نفس الظروف, و كما يلاحظ أيضا من النتائج أن الإشعاع المنتشر له قيمة معينة في بداية النهار و آخره أي في الساعات الأولى و الأخيرة من اليوم, بخلاف الإشعاع المباشر, هذا وبشكل ملحوظ ذو أهمية كبيرة من حيث الحسابات الشمسية. إن النتائج المعروضة في هذه الورقة مفيدة يمكن تطبيقها على أرض الواقع بهدف استخدام ألواح الخلايا الفوتوفولتية للحصول على الطاقة الكهربائية اللازمة لتغذية الأحمال المطلوبة ,كذلك استخدامها في حساب طاقة التبريد للمباني، تمّ الاعتماد على بعض البيانات الخاصة مثل :الارتفاع عن سطح البحرh، و زاويتي خط العرض(ϕ) وخط الطول(L)، و زاوية المنحدر(β), و زاوية قوس السماء للسطح المدروس0^o (γ).

Abstract

This paper has evaluated the direct, diffuse, and global thermal solar irradiance incident on tilted, horizontal and vertical surfaces over Tripoli city, and what is the extent of the influence the slope angle, under suitable climatic conditions on the basis of clear days and dust, dirt, trees and shading that have a negligible effect. Where, the geographical location and climatic conditions play a major role in improving the performance of solar systems. The study includes simulation of three surfaces inclined, horizontal and vertical, considering effect of solar radiation based on the clear sky. Results were obtained using a mathematical model (ASHRAE Mode) developed utilizing the programming language Fortran 90 on the basis of a presentation presented in the form of graphs and patterns showing the monthly average of the hourly direct solar, diffuse and global radiation incident on tilted, horizontal and vertical surfaces and the direct solar radiation on tilted surfaces as function of sloped angle (β) during the daylight hours for four independent months January which represented wintertime, April represented springtime, July represented summertime and October autumn time of the year.

Results show that the higher value of the hourly direct solar radiation for the titled surface 35^o was, 1025 W/m2 for the month of October, horizontal surface, 911W/m2 for April, and a vertical surface, 791 W/m2 for January, and with regard to the hourly diffuse solar radiation for titled surface 35^o , 224 W/m2 for month July, horizontal surface, 118W/m2 for July, and a vertical surface, 175W/m2 for April, also with regard to the hourly global solar radiation for titled surface 35^o , 1195W/m2 for month October, horizontal surface 1001W/m2 for April, and vertical surface 917W/m2 for January at the same conditions. Furthermore, the optimal tilt angle for direct solar radiation in January almost was 55˚, in April the optimal tilt angle was 10˚, in July the optimal tilt angle was 0˚ and in October, the optimal tilt angle is 45˚. It can be noticed from the results that the hourly diffuse solar radiation has a certain value in the first hours of daytime and the last hours, unlike the beam solar radiation; these signs are an evident significance with regard to the Solar Radiation Calculations. However, this study results are useful and satisfactory; they can be applied in reality, with a view to using Photovoltaic Systems to get the necessary electrical energy for the requested load supply. Also, for purpose calculations of the cooling loads and the solar collectors' performance.

1. INTRODUCTION

The earth is receiving quite large amounts of energy in the form of solar radiation almost average $8 \times 10^{16}\ W$. This amount may exceed about 10000 times of the present world needs of the energy. For this reason, study and estimation amount of the hourly total (global) solar radiation is very important, since it quite useful for calculations of cooling load, solar collectors' performance and Photovoltaic systems. The solar radiation incident on earth's surface is not simple procedure; because it depends on a lot of variables and the factors like the sun's rays beyond the earth's atmosphere, the solar energy that diffuses within reason impact solar irradiance with particles atmospheric air, the solar angles changes simultaneously and local etc. Where, can't control amount the solar radiation which reaches to earth's surface. That is why it is, changed continuously as result for several effects the more important which called fundamentals Solar Components.

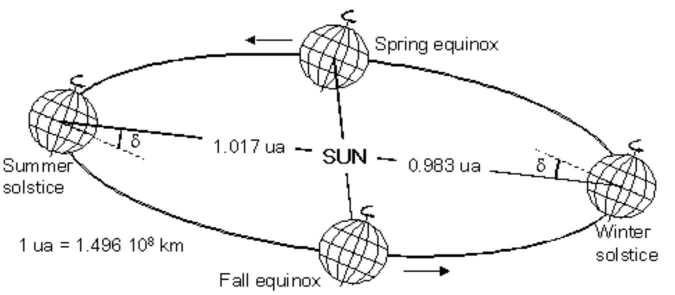


Figure (1) Maximum and minimum value of declination angle[4].

1.1. Basic Solar Components

Solar Constant (G_{SC}), the mean solar constant G_{SC} is the rate of irradiation on the surface normal to the sun's rays beyond the earth's atmosphere and the mean earth-sun distance. Extraterrestrial radiation is given by (1) [5].

$$G_{ext} = G_{SC}\left(1 + 0.33\cos\left\{\frac{360\ N}{365}\right\}\right) \quad (1)$$

Where G_{ext} Extraterrestrial radiation and N is the day of the year and G_{SC} is solar constant, 1367 W/m2.

Angle of incidence (θ), the angle between the beam radiation on a surface and the normal to that surface.

$$\cos\theta = \sin\delta \sin\emptyset \cos\beta - \sin\delta \cos\emptyset \sin\beta \cos\gamma + \cos\delta \cos\emptyset \cos\beta \cos\omega + \cos\delta \sin\emptyset \sin\beta \cos\gamma \cos\omega + \cos\delta \sin\beta \sin\gamma \sin\omega \quad (2)$$

ϕ is the location latitude angle (in degrees) and δ is the declination angle of the sun (in degrees) given by:

$$\delta = +32.45\ \sin\left(\frac{N-81}{370} \times 360\right) \quad (3)$$

N: The number of day in the year

$$\sin\alpha_s = \cos\delta \cos\emptyset \cos\omega + \sin\delta \sin\emptyset \quad (4)$$

$\boldsymbol{\alpha_s}$ is Solar altitude angle .It between the horizontal and the line to the sun, that is, the complement of the zenith angle.

$$\omega = 15^O(LST - 12) \quad (5)$$

ω is Hour angle The angular displacement of the sun east or west of the local meridian due to rotation of the earth on its axis at 15◦ per hour; morning negative, afternoon positive. As prescribed in Figure 2 [5].

Local solar time (LST) is given by the following relationship

$$LST = LT + {}^{TC}\!/_{60} \quad (6)$$

If daylight savings time, hours (DST) is in effect,

Local Standard Time = Local DST – 1hour {Daylight saving is on}

Local DST= local daylight savings time, hours

Where LT is the local standard time for the studied zone in hours and TC time correction factor in munities is given by eq. (7):

$$TC = 4(L - LSTM) + EOT \quad (7)$$

Where L geographical longitude for the studied zone in degrees and LSTM represented the standard meridian for local time given by the following relationship

$$LSTM = 15(\Delta T_{GMT}) \quad (8)$$

ΔT_{GMT} :The difference between local time of the studied area and Greenwich Mean Time in hours

EOT : Equation of time in munities is calculated by eq. (9):

$$EOT = 9.87\sin 2D - 7.53\cos D - 1.5\sin D \quad (9)$$

D: Constant magnitude and function of number of day in the year can be expressed as eq. (10):

$$D = \frac{360}{365}(N - 81) \quad (10)$$

2. ASHRAE Clear Sky Model

The ASHRAE algorithm offers a simpler method, which is widely utilized by the engineering and architectural communities [6]. The value of the solar constant does not take into account the absorption and scattering of the earth's atmosphere. Several types of radiation calculations are most conveniently done using normalized radiation levels, that is, the ratio of radiation level to the theoretically possible radiation that would be available if there were no atmosphere. For these calculations, which are discussed in next item, we need a method of calculating the Global Solar Radiation on Horizontal, vertical and tilted Surfaces.

At any point in time, the solar radiation incident on a plane inside of the atmosphere is the normal direct solar radiation and the diffuse.

2.1. Radiation on tilted surfaces

The calculation of the radiation over a tilted plane requires determining the sun position together with the slope and orientation of the tilted plane. The plane angles are defined as follows (see Figure 2). β is the slope of the surface, measured from the horizontal plane towards the equator. γ the surface azimuth angle and it measures the orientation of the surface from the local meridian, east positive. θ is the angle of incidence of radiation, that is, the angle between the normal to the surface and the sun earth vector.

Thus, the cosine of the incidence angle θ between the sun beam radiation and a surface tilted an angle β towards the equator, oriented in any direction γ, is given by [5]:

$$\cos\theta_\beta = sin\,\delta\, sin\,\emptyset\, cos\,\beta - sin\,\delta\, cos\,\emptyset\, sin\,\beta\, cos\,\gamma + cos\,\delta\, cos\,\emptyset\, cos\,\beta\, cos\,\omega + cos\,\delta\, sin\,\emptyset\, sin\,\beta\, cos\,\gamma\, cos\,\omega + cos\,\delta\, sin\,\beta\, sin\,\gamma\, sin\,\omega \qquad (11)$$

For vertical surfaces, β = 90◦ and the equation becomes

$$\cos\theta_V = -sin\,\delta\, cos\,\emptyset\;\, cos\,\gamma + cos\,\delta\, sin\,\emptyset\, cos\,\gamma\, cos\,\omega + cos\,\delta\, sin\,\gamma\, sin\,\omega \qquad (12)$$

For horizontal surfaces, the angle of incidence is the zenith angle of the sun, $\theta_H = \theta_Z$. Its value must be between 0◦ and 90◦ when the sun is above the horizon. For this situation, β = 0, and Equation 2 becomes:

$$\cos\theta_H = \sin\delta\sin\emptyset + \cos\delta\;\cos\emptyset\cos\omega \;=\; \sin\alpha_s \qquad (13)$$

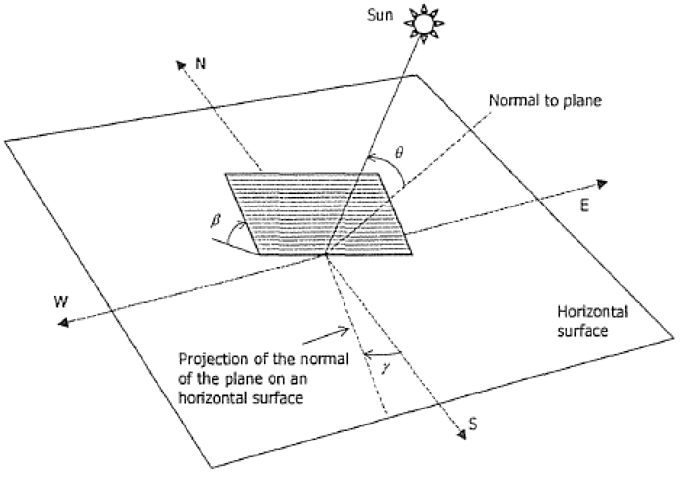


Figure 2. Definition of angles for the incidence of solar radiation on a tilted plane [9].

2.2. Hourly Global Solar Radiation on Horizontal Surfaces (IG_t)

Global solar radiation on horizontal surfaces can be measured with a pyranometer, which is an instrument that measures global solar radiation from all directions. The global solar radiation on horizontal surfaces can be categorized as follows:

- Diffuse solar radiation (IF)
- Direct beam solar radiation (IB)

Solar radiation on a horizontal surface is the sum of the horizontal direct and diffuse radiation.

$$IG_t = IB + IF \tag{14}$$

IG_t= Global Solar Radiation, Btu/(hr-ft^2) or (W/m^2)

IB= Direct beam solar radiation, Btu/(hr-ft^2) or (W/m^2)

IF= rate at which the total diffuse radiation (reflected plus diffuse), Btu/(hr-ft^2) or (W/m^2)

$$IF = Id + \mathrm{Ir} \tag{15}$$

Id = rate at which energy is diffused on to sky (isotropic sky), Btu/(hr-ft^2) or (W/m^2)
Ir = rate at which Energy reflected from ground and surroundings (diffuse reflection), Btu/(hr-ft^2) or (W/m^2)

- **Normal direct irradiation**

$$Ib = \frac{A}{EXP\left(\frac{P_L}{P_O}\frac{B}{\sin\alpha_S}\right)}\ C_N \tag{16}$$

$$\frac{P_L}{P_O} = exp(-0.000184\ H\ ) \tag{17}$$

Ib = normal direct irradiation, Btu/(hr-ft2) or (W/m2)[3]
αs = solar altitude
C_N = clearness number equal 1.0
$\frac{P_L}{P_O}$= ratio between atmosphere pressure at the studied site and the standard atmosphere pressure as function in altitude [8].
H = the altitude of the observer in kilometers

$$A = 1158\left[1 + 0.066\ \cos\left(\frac{360N}{370}\right)\right] \tag{18}$$

$$B = 0.175[1 - 0.2\ \cos(0.93N)] - 0.045[1 - \cos(1.95N)] \tag{19}$$

A = apparent solar irradiation at air mass equal to zero, Btu/(hr-ft2) or (W/m2) [7].

B = atmospheric extinction coefficient [7].

On a surface of arbitrary orientation, the direct radiation, corrected for clearness, is:

$$IB_\beta = Ib\ max(\cos\theta_\beta, 0) \tag{20}$$

$$IB_H = Ib\ max(\cos\theta_H, 0) \tag{21}$$

$$IB_V = Ib\ max(\cos\theta_V, 0) \tag{22}$$

- **Diffuse radiation**

To evaluate the rate at which diffuse radiation Id strikes a non vertical surface on a clear day, the following approximation can be made, (isotropic sky).

* Device uses to measure the diffuse solar radiation power on surface

$$Id = C\ \ Ib\ \left(\frac{1+\cos\beta}{2}\right) \tag{23}$$

Energy reflected from ground and surroundings is approximated (diffuse reflection)

$$Ir = \ I_{tH}\ \rho_g\ \left(\frac{1-\cos\beta}{2}\right) \tag{24}$$

Ir = rate at which energy is reflected on to wall, Btu/(hr-ft2) or (W/m2)
I_{tH} = rate at which the total radiation (direct plus diffuse) strikes the horizontal surface or ground in front of the wall, Btu/(hr-ft2) or (W/m2)
ρ_g = reflectance of ground or horizontal surface is given 0.2 for dry bare ground or agricultural [8].

Diffuse solar radiation incident on a non vertical surface,

$$IF = Id + \mathrm{Ir} \tag{25}$$

$$IF_\beta = \left[C\ \left(\frac{1+\cos\beta}{2}\right) + \rho_g\ \left(\frac{1-\cos\beta}{2}\right)(\sin\alpha_S + C)\right]\ Ib \tag{26}$$

Where *C* diffuse radiation factor can be calculated in eq. (26) [7].

$$C = 0.0965\left[1 - 0.42\cos\left(\frac{360N}{370}\right)\right] - 0.0075[1 - \cos(1.95N)] \quad (27)$$

For a horizontal surface,

$$IF_H = \left[C \ \left(\frac{1+\cos\beta}{2}\right)\right] Ib \quad (28)$$

For a vertical surface,

If $\cos\theta_V \geq -2$

$$\frac{I_{dV}}{I_{dH}} = 0.55\ 0.437\ cos\,\theta_V + 0.313\ (cos\,\theta_V)^2 \quad (29)$$

Otherwise

If $\cos\theta_V \leq -2$

$$\frac{I_{dV}}{I_{dH}} = 0.45 \quad (30)$$

$$Id_V = C\ \ Ib\ \ \frac{I_{dV}}{I_{dH}} \quad (31)$$

$$IF_V = \left[C\ \ \frac{I_{dV}}{I_{dH}} + \rho_g\ \left(\frac{1-\cos\beta}{2}\right)(\sin\beta + C)\right] Ib \quad (32)$$

- **Global Solar Radiation**

Total solar radiation incident on a non vertical surface,

$$IG_t = IB + Id + Ir \quad (33)$$

$$IG_{t,\beta} = \left[\ max(\cos\theta_V, 0) + C\ \left(\frac{1+\cos\beta}{2}\right) + \rho_g\ \left(\frac{1-\cos\beta}{2}\right)(\sin\alpha_S + C)\right] Ib \quad (34)$$

For a horizontal surface

$$IG_{t,H} = \left[\ max(\cos\theta_H, 0) + C\ \left(\frac{1+\cos\beta}{2}\right)\right] Ib \quad (35)$$

For a vertical surface,

$$IG_{t,V} = \left[max(\cos\theta_V, 0) + C \ \frac{I_{dV}}{I_{dH}} + \rho_g \ \left(\frac{1-\cos\beta}{2}\right)(\sin\alpha_S + C)\right] Ib \qquad (36)$$

3. RESULTS AND DISCUSSION

This paper presents the simulation results obtained from the above mentioned formulae for calculation of the monthly average of the hourly direct solar, diffuse and global radiation incident on tilted, horizontal, and vertical surfaces in Tripoli city as hourly values. They have been calculated the amount of the monthly average of the hourly direct solar, diffuse and global radiation incident on tilted, horizontal, and vertical surfaces through the entire year for four independent months, which represent each of them the four seasons January, April, July and October of the year of Tripoli city, and also they have been calculated the amount of the direct solar radiation on tilted surfaces as function of sloped angle (β) during the daylight hours for every month, by using Fortran90 for carrying out the analysis.

The results depended on some assumptions that were adopted on the basis of clear days and dust, dirt, trees, and shading effects had been negligible. Calculation of the monthly average of the hourly direct solar, diffuse and global radiation incident on tilted, horizontal, and vertical surfaces was according to the geographic coordinates to Tripoli city which is located at Latitude angle (ϕ) 32.9^o ,longitude angle (L) 13.8^o, height above sea level (h) 81m.

There are several commonly occurring cases for which Equation (10) is simplified. For fixed surfaces sloped toward the south or north, that is, with a surface azimuth angle γ of 0◦ or 180◦ (a very common situation for fixed flat-plate collectors).In this present study the studied surfaces are tilted (β) 0^o, 35^o, 90^o from the horizontal and pointed (γ) 0^o south. Also have selected day-time hours started from the sixth in the morning to the seventh in the evening.

Figure (3) depicts the relation between the monthly average of the hourly direct solar radiation (ID) incident on tilted, horizontal, and vertical surfaces in Tripoli city against the local time for several different surfaces tilted, horizontal and vertical sloped toward the south for January month which represents wintertime.

It can be observed that higher values of direct solar radiation are on tilted surface, especially at midday-time. Unlike values the direct solar radiation on horizontal and vertical surfaces. Because of the tilted surface receives the amount of solar radiation due to the effect of solar altitude angle (αs) and solar azimuth angle (γs).

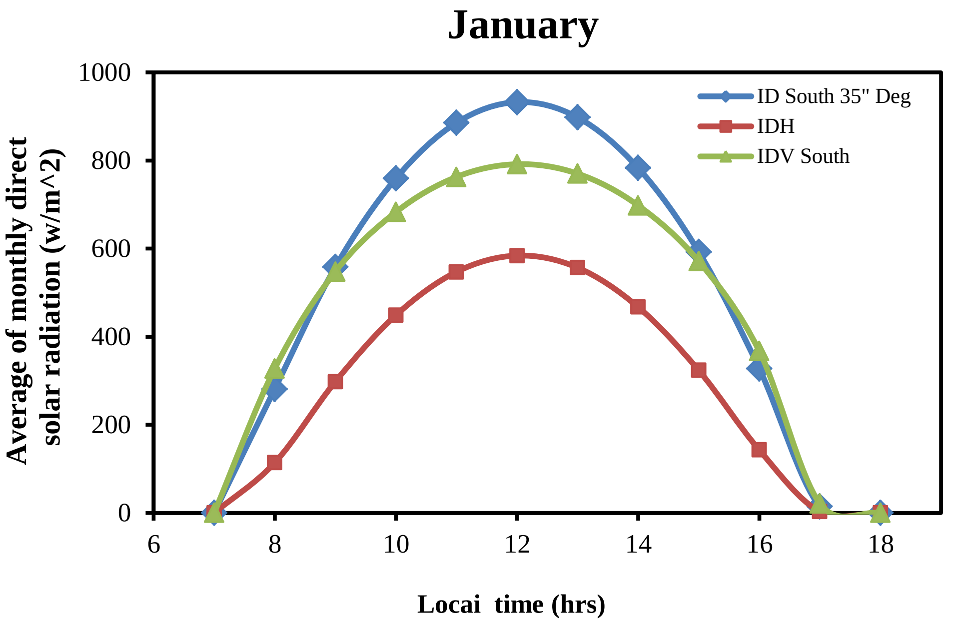


Figure (3) calculation of the monthly average of the hourly direct solar radiation incident on tilted, horizontal and vertical surfaces in Tripoli city

On the other hand, it can be noted that values of the hourly direct solar radiation are lower in the first hours of day-time (zero during sunrise) due to the location difference of the sun towards the earth's surface. i.e., the influence of the angle of the incidence (θ), therefore it can be said that magnitude of the incoming rays from the sun is greater at midday-time about 12 A.M for all the surfaces. The rays which pass through the upper atmosphere layers cross it at a shorter distance in the noontide, and contrarily the distance is longer during sunrise and sunset hours. So the sun's rays are exposing the absorption and dispersion by the atmosphere components. Where can be watched that the direct solar radiation incident on the vertical surface is higher than the direct solar radiation incident on a horizontal surface and these values agree exactly with the reference [3].

Variation of the hourly direct solar radiation incident, ID (the monthly average) on tilted, horizontal, and vertical surfaces against the local time of

Tripoli city for the month of April which represents springtime is shown in Figure (4), where it can be noted that values of the direct solar radiation incident on vertical surface significantly reduced about by 50% from January to April and rose of the horizontal surface about by 50% from January to April. While that values remaining nearly constant on tilted surfaces. The reason is due to reducing Extraterrestrial solar radiation. Furthermore, change the declination angle (δ) from a positive value to a mining value which leads to an increase in the incidence angle (θ). Also, it can be noticed that values of the direct solar radiation incident on two surfaces tilted and horizontal are convergent.

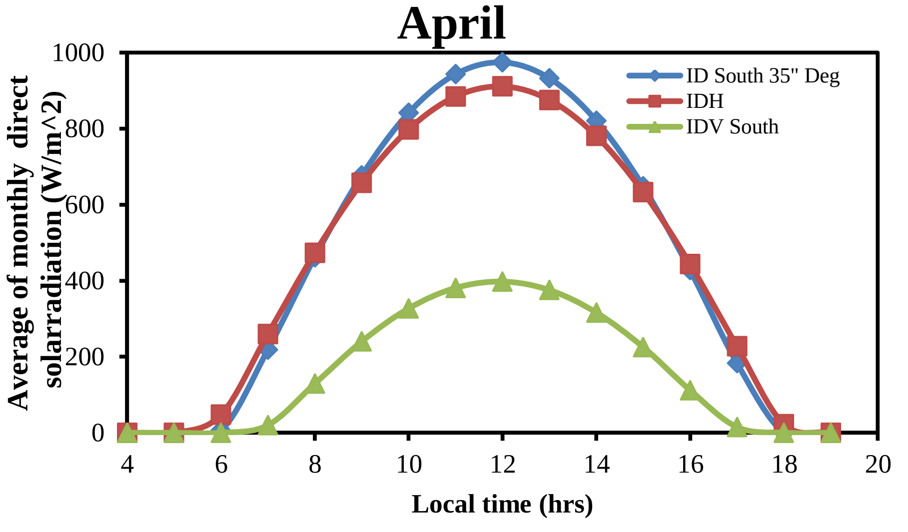


Figure (4) calculation of the monthly average of the hourly direct solar radiation incident on tilted, horizontal and vertical surfaces on April in Tripoli city

In figure (5) presents the variation of the hourly direct solar radiation over Tripoli city on local time starting from the sixth in the morning to the seventh in the evening with several various surfaces tilted, horizontal and vertical pointed (γ) 0o south for month July that represents summertime. Where the hourly direct solar radiation almost linearly increases in the first hours of day-time, especially, tilted and horizontal surfaces are more, until it reaches a maximum at noon time then it decreases gradually.

The hourly direct solar radiation turns at a certain value of noontide, this means that the effect of solar altitude angle (αs), solar azimuth angle (γs), and variation of the declination angle (δ) from 23.45^o to -23.45o results in the decreasing of the incidence angle (θ).

It can be observed that relatively reduction in the solar radiation of the vertical surface, this result in changing the Zenith angle (θz) according to the sequence of day in the year. Where a remarkable change is noticed with regard to the Zenith angle (θz) values in the summer season are about from 65o in the morning to 15o in the noontide. I.e., in July, before 12 noon, the sun moves from the northern half to the southern half of the sky which means that the south vertical surfaces will receive less direct solar radiation, especially in the first hours and the last of the daytime almost is nonexistent. This is comparable almost until for tilted surfaces according to inclined angles. The solar radiation on the inclined and vertical surfaces during this period (the first hours and the last of the daytime) consists of diffuse solar radiation and reflected solar radiation only. This shows the importance of having a good model for these components.

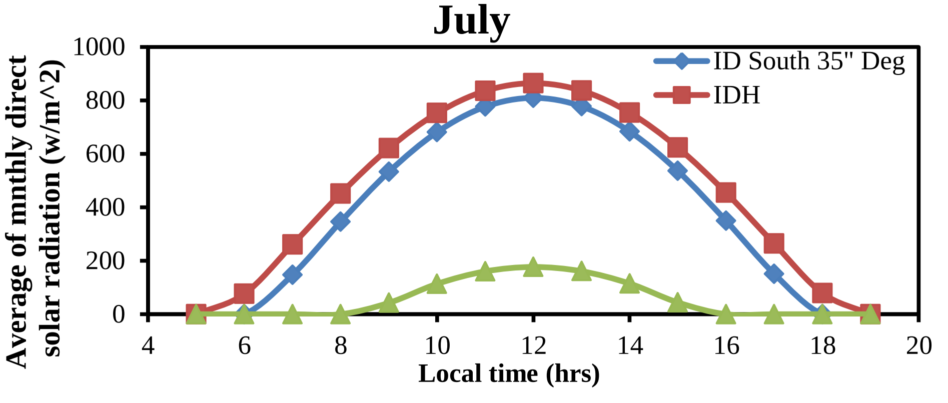


Figure (5) calculation of the monthly average of the hourly direct solar radiation incident on tilted, horizontal and vertical surfaces on July in Tripoli city

Figure (6) illustrates the amount of monthly average of the hourly direct solar radiation incident on tilted, horizontal, and vertical surfaces in Tripoli city for the month of October which represents autumn time. It is evident that the hourly direct solar radiation value of the tilted surface almost is constant relative to all year seasons except summer is less relatively. Moreover, it can be said that the hourly direct solar radiation values of the tilted surfaces for four seasons have recorded higher values and should be taken into account the values during design relative to all solar systems. Also can be noticed that values of the hourly direct solar radiation incident on two surfaces horizontal and vertical are very convergent relatively.

Figure (7) shows the monthly average of the hourly diffuse solar radiation (IF) incident on tilted, horizontal, and vertical surfaces in Tripoli city against the local time for several different surfaces tilted, horizontal and vertical sloped toward the south for January month which represents wintertime. Where, have selected day-time hours started from the seventh in the morning to the fifth in the evening .It can be noticed a reduction in the hourly diffuse solar radiation rate of the horizontal surface, in the same time convergence values of the diffuse solar radiation incident on tilted and vertical surfaces. Further, the values parities of the hourly diffuse solar radiation of the horizontal surface along day-time period. However, an increase and decrease of solar radiation betweenwhiles determine the extent of energy economy and consumption.

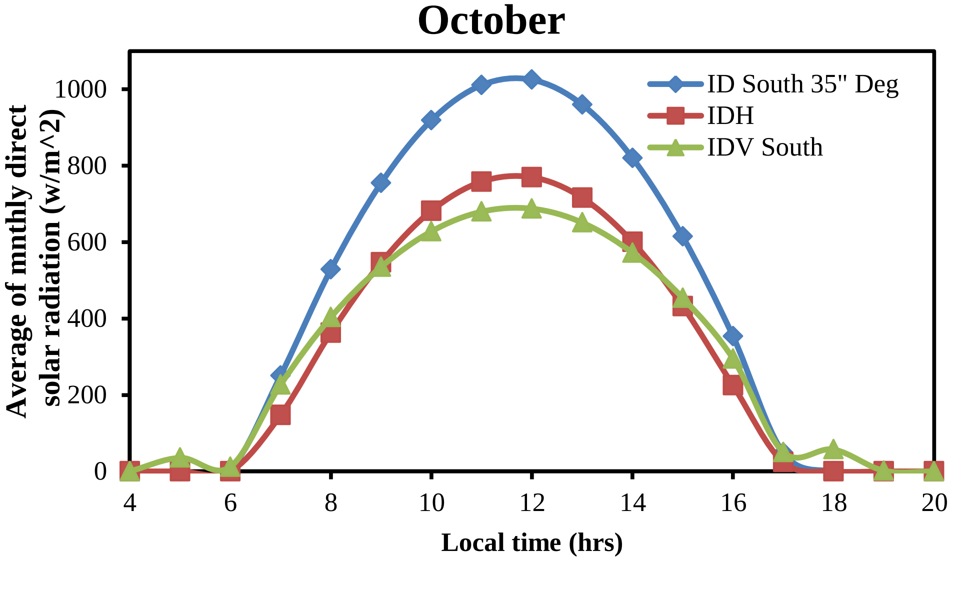


Figure (6) calculation of the monthly average of the hourly direct solar radiation incident on tilted, horizontal and vertical surfaces on October in Tripoli city

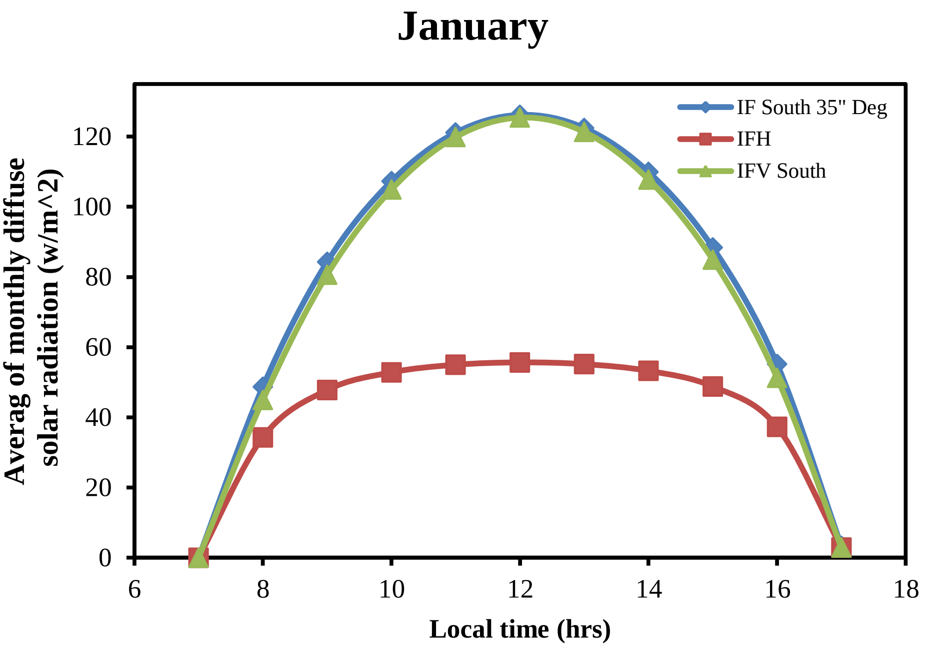


Figure (7) calculation of the monthly average of the hourly diffuse solar radiation incident on tilted, horizontal and vertical surfaces on January in Tripoli city

Calculation of the monthly average of the hourly diffuse solar radiation incident on tilted, horizontal, and vertical surfaces in Tripoli city versus the local time for several various surfaces tilted, horizontal, and vertical pointed (γ) 0^o south for month April which represents springtime is shown in Figure (8). It can be seen evidently that the hourly diffuse solar radiation incident on tilted, vertical, and horizontal surfaces are increasing according to the series of days in the year then decreasing after midyear, furthermore, the values parities of the hourly diffuse solar radiation of the horizontal surface along daylight hours. This indicates that the diffuse solar radiation has a certain value, unlike the beam solar radiation can't have value during the daytime because of the effect of directions and variation of the solar angles, that is, the position of the sun relative to that plane can be described in terms of several angles.

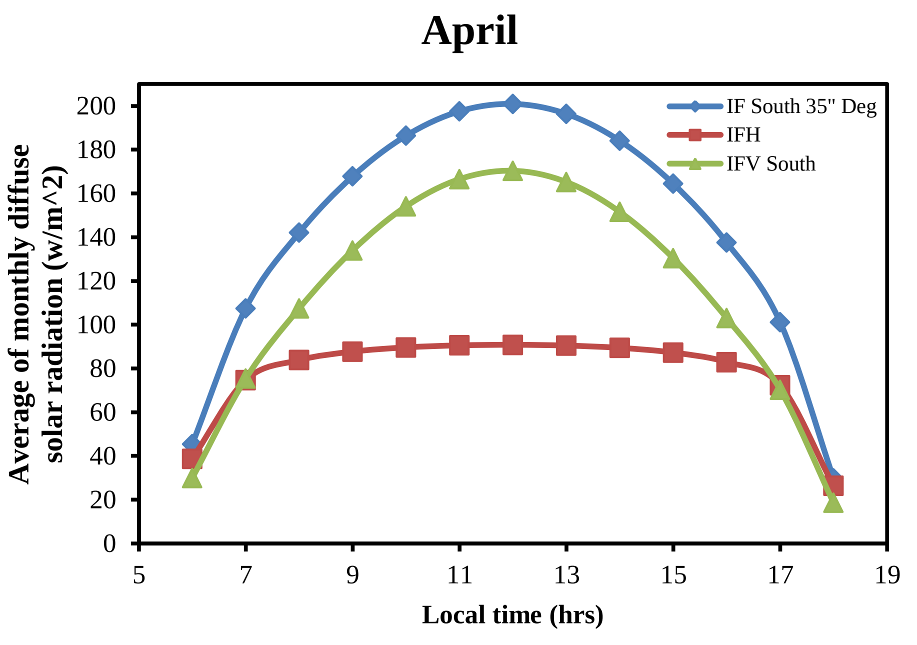


Figure (8) calculation of the monthly average of the hourly diffuse solar radiation incident on tilted, horizontal and vertical surfaces on April in Tripoli city

Figure (9) presents the relation between of the monthly average of the hourly diffuse solar radiation in Tripoli city against the local time for several various surfaces tilted, horizontal, and vertical sloped toward the south (γ) 0o for July month that represents summertime.. Here it is observed that the maximum value of the diffuse solar radiation at midday. I.e. the solar radiation increases until it reaches a maximum at noon time then it decreases. Where it can be said that the tilted surfaces play a significant role in receiving the bundle of the rays with high values when compared with its Successors of the horizontal and vertical surfaces in receiving the rays. It is also noted that the amount or values of the diffuse solar radiation during sunrise and sunset hours are bigger relative to sunrise and sunset hours of the direct solar radiation, that is, for all seasons. Therefore should be taken into considering account diffuse radiation, to get peak value which gives the global solar radiation.

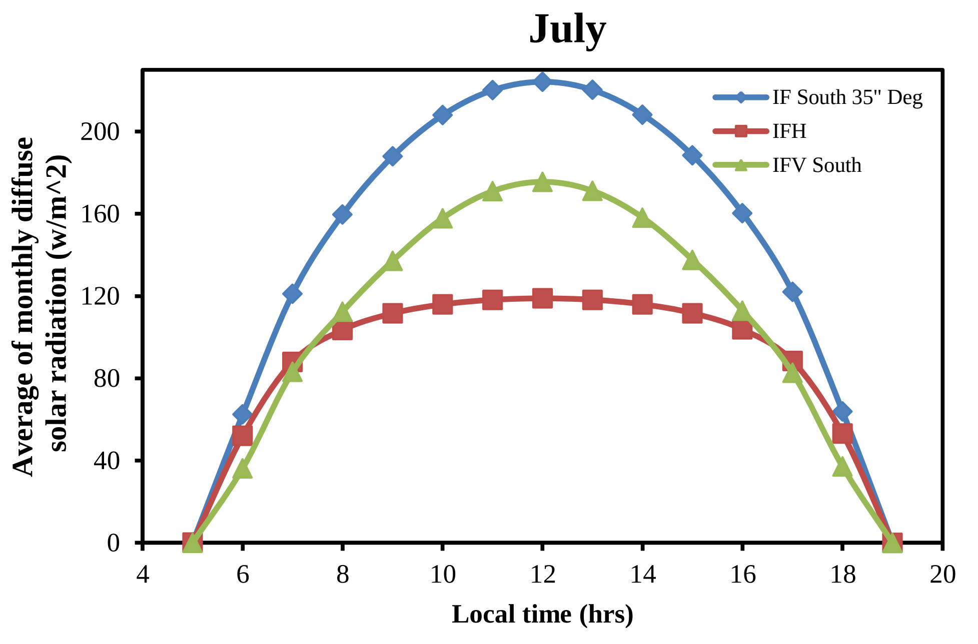


Figure (9) calculation of the monthly average of the hourly diffuse solar radiation incident on tilted, horizontal and vertical surfaces on July in Tripoli city

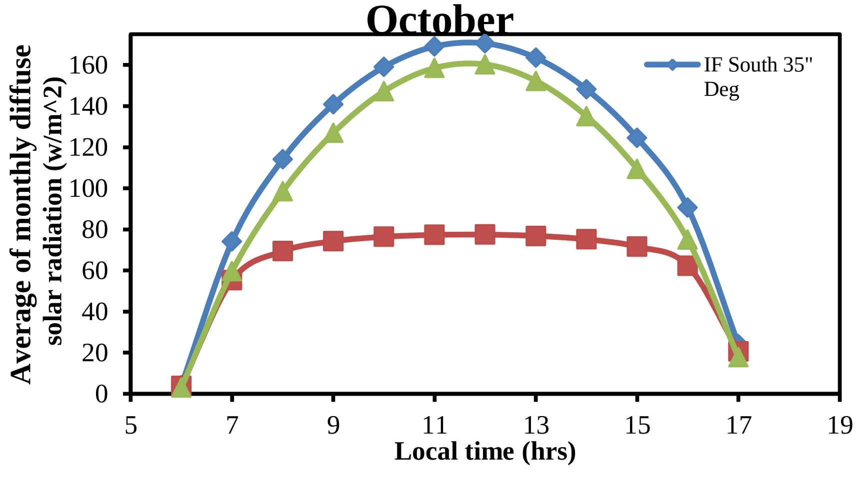


Figure (10) calculation of the monthly average of the hourly diffuse solar radiation incident on tilted, horizontal and vertical surfaces on October in Tripoli city

Figure (10) shows the monthly average of the hourly diffuse solar radiation (IF) incident on tilted, horizontal, and vertical surfaces in Tripoli city against the local time for several different surfaces tilted, horizontal and vertical sloped toward the south (γ) 0o for month October which represents autumn time. Where one can see decreasing radiation intensity, these results confirm the strengths and weaknesses of our yearly calculation very clearly.

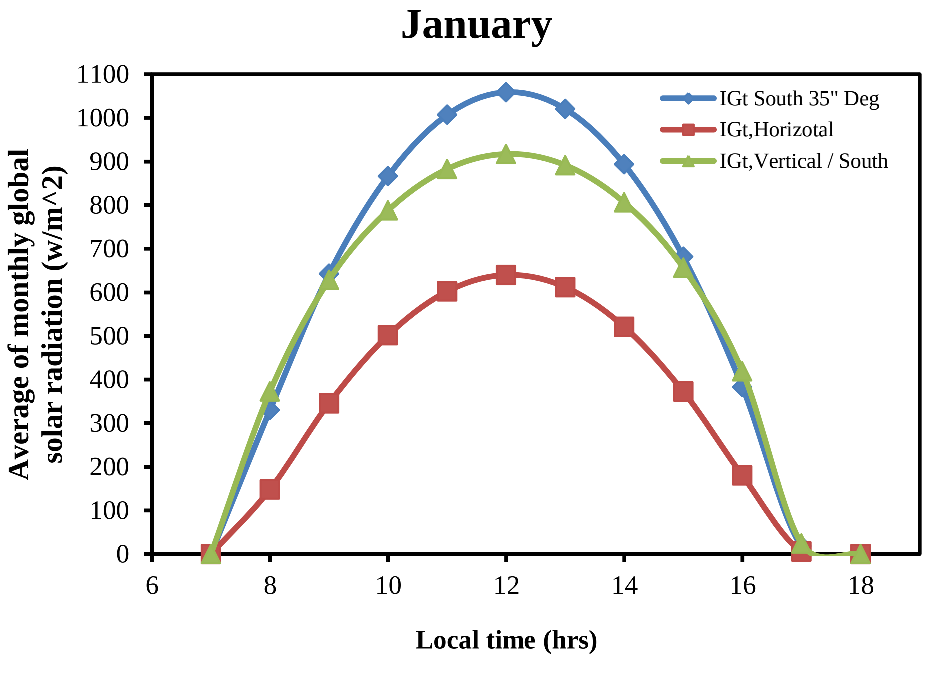


Figure (11) calculation of the monthly average of the hourly global solar radiation incident on tilted, horizontal and vertical surfaces on January in Tripoli city

Global solar radiation incident on tilted, horizontal and vertical surfaces consists of ground reflected, diffuse, and direct radiation .certainly; here we know that global solar radiation received by an inclined, horizontal and vertical surfaces is summation for these rays. Figures (11), (12), (13) and (14), respectively ,present the monthly average of the hourly global solar radiation incident on tilted, horizontal and vertical surfaces in Tripoli city for month January, April, July and October that represent the four reasons, viz, the whole year. Global solar radiation was calculated, maximum values for month January for a cloudless sky were over 1058 W/m^2, 639 W/m^2 and 917

W/m^2 for tilted, horizontal and vertical surfaces, respectively, month April were over 1175W/m^2, 1000 W/m^2 and 568W/m^2 for tilted, horizontal and vertical surfaces, respectively, month July were over 1033W/m^2, 982W/m^2 and 352 W/m^2 for tilted, horizontal and vertical surfaces, respectively, and month October were over 1195 W/m^2, 847 W/m^2 and 847 W/m^2 for tilted, horizontal and vertical surfaces, respectively. These values completely agree with the results shown in reference [3] for two surfaces horizontal and vertical sloped towards south (γ) 0^o.

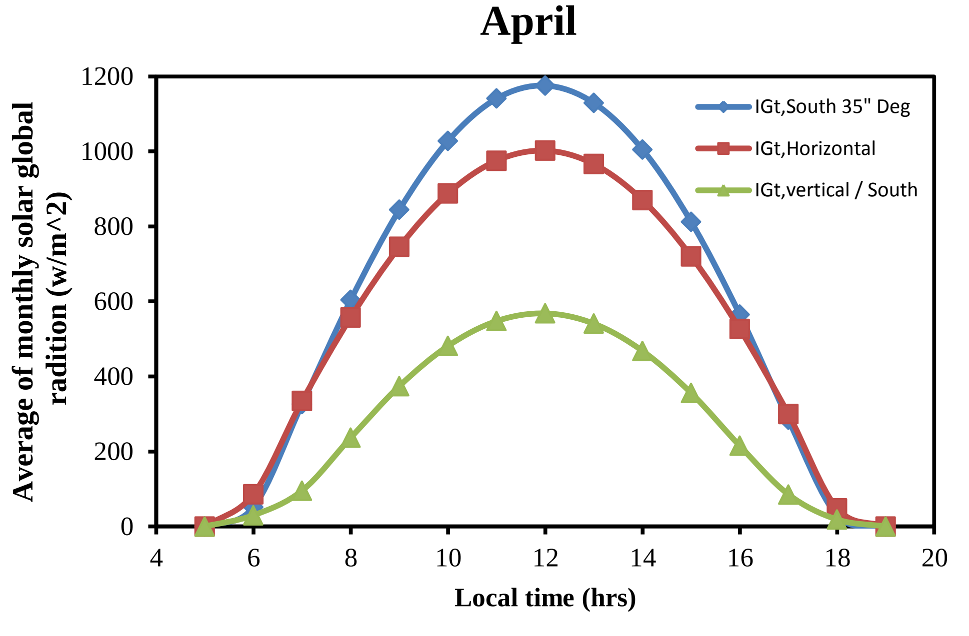


Figure (12) calculation of the monthly average of the hourly global solar radiation incident on tilted, horizontal and vertical surfaces on April in Tripoli city

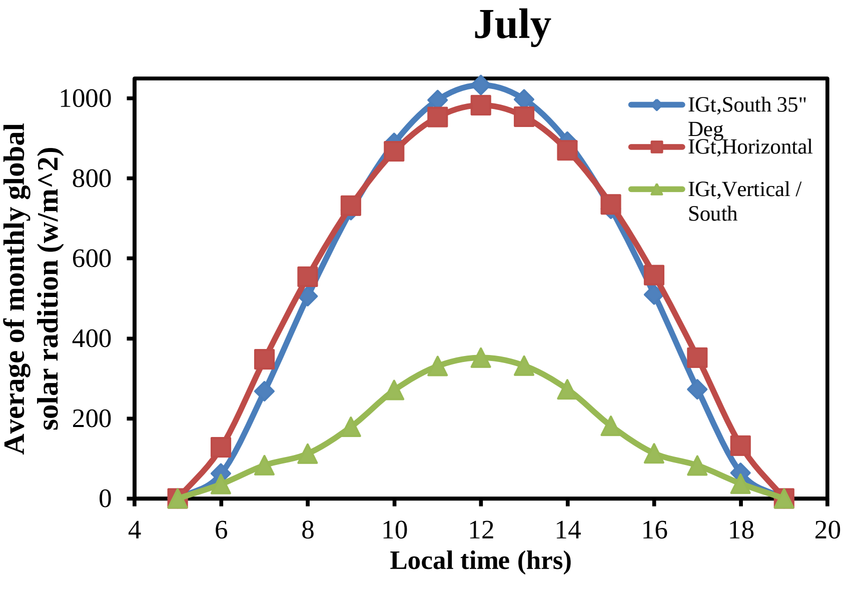


Figure (13) calculation of the monthly average of the hourly global solar radiation incident on tilted, horizontal and vertical surfaces on July in Tripoli city

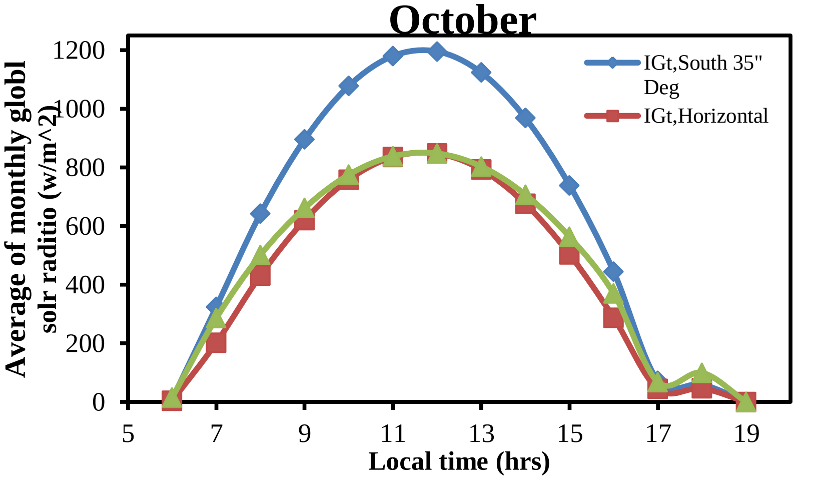
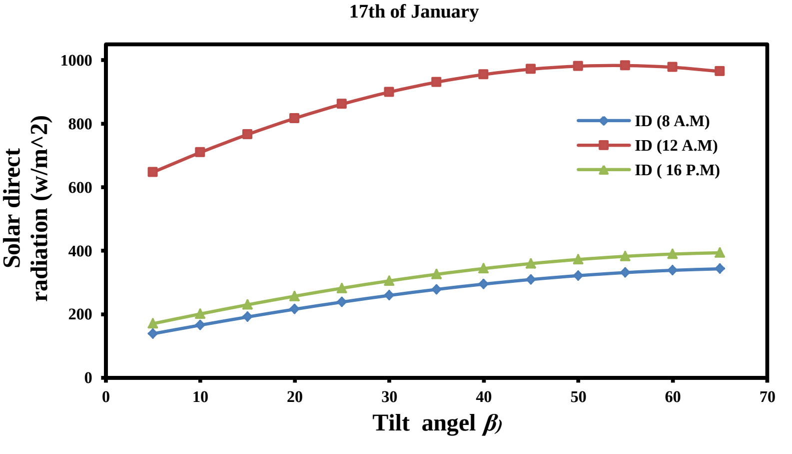


Figure (14) calculation of the monthly average of the hourly global solar radiation incident on tilted, horizontal and vertical surfaces on October in Tripoli city

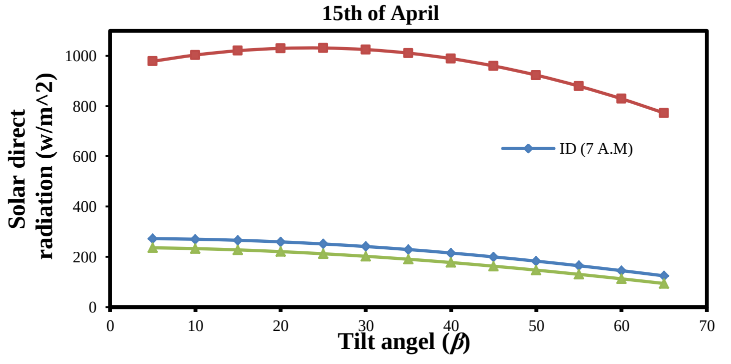
The value of ground reflected radiation increases with the increase of the inclination angle (β). For this reason, the lowest value of ground reflected radiation is 0˚ angle and the highest 90˚ angle for the whole year. The value of diffuse radiation always decreases with the increase of inclination angle (β) owing to the value of scattered and reflected radiation on tilted surface decreases. That is why; the highest value of diffuse radiation is 0˚ angle and the lowest 90˚ inclination angle, for all months of the year. In this present study, the value of beam radiation relies upon various inclination angles and the highest value of beam radiation is found on the optimal tilt surface. Figure 21 shows the variation of beam radiation for various inclination angles (β).

One can notice that optimal tilt angle refers to such an angle for which the value of solar radiation on that surface becomes the highest. In January, almost the optimal tilt angle is 55˚. In April, the optimal tilt angle is 10˚.In July, the optimal tilt angle is 0˚. In October, the optimal tilt angle is 45˚.

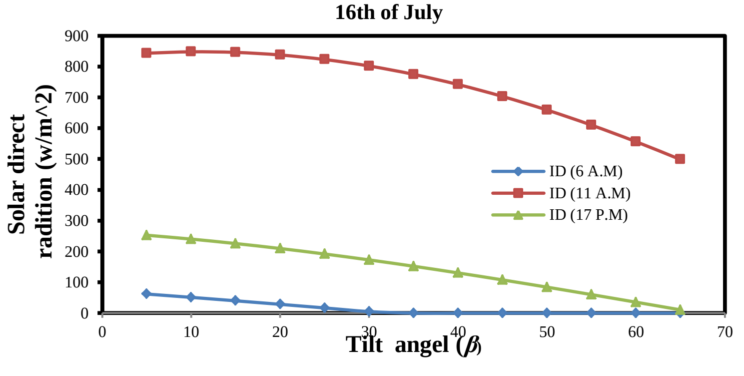
The optimal tilt angle mainly depends on Sun’s declination and latitude. In this study, when the sun’s declination increases from December solstice to June solstice, then the value of optimal tilt angle decreases. This is evident in Figure 15 for the month of January, the optimal tilt angle is 55˚, in April; the optimal tilt angle is 10˚ then for month July, is 0˚. After the June solstice the declination decreases and the value of the optimal tilt angle increases. Where is increasing from 0˚ in July to 45˚ for month October.



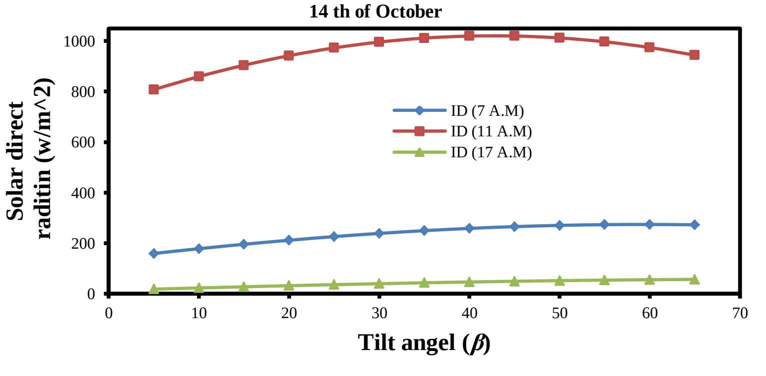
(a)



(b)



(c)



(d)

Figure (15) Variation of beam solar radiation for various inclination angles for month January (a), April (b), July (c) and October (d).

4. CONCLUSIONS

In this present study, the simulation results have been obtained by a developed computational model using Fortran90, which gives the prediction of hourly terrestrial solar radiation incident on tilted, horizontal, and vertical surfaces: direct beam, diffuse and global. Where, the same parameters were modeled for inclined, horizontal, and vertical surfaces. Thus, an important tool for building and solar thermal systems design, simulations, and performance assessments has been developed. The predicted hourly solar radiation incident was compared for tilted, horizontal, and vertical surfaces with each other locally in Tripoli city.

The effect of tilt angle and orientation on the incident solar radiation fluxes are presented along with optimum surface tilt angles and directions for maximum solar radiation collection in the area. This information is useful when a simple solar collector is to be installed without a tracking system. In general, surfaces tilted toward the East and the West have similar trends and the trend is almost the same for other tilt angles. Here, for the surface tilted towards the South, in the period April and October, the effect of tilt angle on the received global solar radiation is positive. However, the tilt angle has a more significant effect in April and October and relatively less in January and July. The results of this study were summarized more below:

1- In general, the research work reported in this paper will help in increasing the level of knowledge relating to solar radiation on horizontal and tilted vertical surfaces and estimate the solar energy potential for practical and efficient utilization in Tripoli city.
2- The effect of the solar radiation incident on tilted is the largest with regard to the solar radiation incident on horizontal and vertical surfaces, therefore advised to utilize tilted surfaces.
3- The total solar radiation increases for two surfaces horizontal and inclined whenever moved us with time from winter, spring, summer then autumn season. Unlike that the total solar radiation decreases for vertical surface as result of decreasing or increasing of solar angles.
4- The highest value of total solar radiation is recorded for inclined surface in October.
5- Diffuse solar radiation plays vital role in increasing energy during day-times especially in the morning the first hours and in the evening the last

hours of daytime, also is available relative to another directions North, South, West and East. Unlike the direct solar radiation.

6- For horizontal surfaces, compared with April, the direct solar radiation during month January, July and October are lower. The maximum direct radiation is reached at a tilt angle of 0o is 911 W/m2 for month April.
7- The results presented in this paper are quite useful for quick estimation of solar radiation for calculations of cooling load and solar collectors' performance.

References

[1] كاميليا يوسف محمد, د .محمد صلاح السبكي-جمهورية مصر العربية، الطاقة الكهرو شمسية"، وزارة الكهرباء والطاقة المتجددة،(2016),ص(39-50).

[2] رسول رمضان عتاب،" حساب وتحليل كمية الإشعاع الشمسي الكلي الساقط على السطح الأفقي لمدينة الناصرية"مجلة عموم ذي قار المجلد)2 (العدد (1),(2010).

[3] نبيل شهيد," ،" حساب وتحليل كمية الإشعاع الشمسي الساعي بمساعدة الحاسوب" مجلة الطاقة و الحياة-العدد (الثالث و العشرون) الصيف (يونيو) 2006 المعهد العالي للمهن الشاملة-مسلاته.

[4] Lucien Wald. Solar radiation energy (fundamentals). https://www.researchgate. net/ pub- lication / 266214117. December 2020.

[5] Duffie,J.A., Becman,W.A.''solar engineering f thermal processes'', John Wiley and Sons, new York,(1980).

[6] Balenzategui, J.L.'' SRADLIB: AC Library for Solar Radiation Modeling'', Informes Técnicos Ciemat,118 pp. 18 figs. 24refs.904 October, 1999.

[7] Joudi,K.,A.,''Some Aspect Of Solar Irradiance Calculation'', Proceeding of the3rd Arb Inerntional Solar Enrgy Conference, edited by N.,I.,AL-Hamdani,S.A.Naman,S.M. Aliwi.Saman, and A.A. Akrawi, Solar Enrgy Research Center,Baghdad,(Feb.1988).

[8] Lunde,P.J.,'' Solar Thermal Engineering-Space Heating And Hot Water System'',John Wiley and Sons, new York,(1980).

[9] M. Ayman Abdullah And O. Ali Abualkh Air, Comparison between Different Methods for Estimation of Global Radiation over Jeddah, JK A U: Mel.. En v. . A rid Land A gric. Sci ., Vol. 5, pp . 105· 117 (14 14 A.H. / 1414 A.D .)

[10] ASHRAE Handbook, 1985 Fundamentals; American Society of Heating Refrigerating and Air-Conditioning Engineers, Inc.: Atlanta, GA, USA, 2011.

[11] Machler, M.A.; Iqbal, M.'' A modification of the ASHRAE clear sky irradiation model''. Ashrae Trans. 1967, 91, 106–115.

[12] Seyed Abbas Mousavi Maleki , H. Hizam and Chandima Gomes,''Estimation of Hourly, Daily and Monthly Global Solar Radiation on Inclined Surfaces: Models Re-Visited''Energies 2017, 10, 134; doi:10.3390/en10010134.

