International Journal of Engineering Science Invention (IJESI)
ISSN (Online): 2319-6734, ISSN (Print): 2319-6726
www.ijesi.org ||Volume 10 Issue 6 Series I || June 2021 || PP 10-24

Optimize and Develop of Empirical Correlations Models of Solar Energy on Horizontal and tilted surface over Saudi Arabia

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Abstract: *Solar radiation data are essential in the design of solar energy conversion devices. In this regard, empirical models were selected to optimize the solar radiation on horizontal and inclined surfaces. The measured data in this article were used during 25 years of solar radiation over Jeddah, Saudi Arabia from 1992-2016 to optimization and developing a new empirical correlations on horizontal and inclined surfaces. The maximum solar radiation occurs in summer and spring months, while the minimum solar radiation occurs in winter months. The solar irradiance measurements strongly affected by cloud. Surface estimations of the diffuse segment of sun powered irradiance are especially touchy to overcast cover. Starting from cloudy days in the morning, the dark clouds gradually dissipate throughout the afternoon to the evening, until the dark clouds are completely cleared. The statistical indicators of main base error MBE, root mean square error RMSE, mean percentage error MPE and t-state are done. The values of correlation coefficients (R^2) are higher than 0.98 and the values of the RMSE are found the range 1.95– 4.65. The both (R_b) and (R_t) decrease with increasing tilted angle (β) during the summer months, while during winter months, (R_b) and (R_t) are increase with increasing (β) until an optimum value beyond which the behavior is reversed. The high tilt is required to meet the energy demand in the winter months when the insolation on a horizontal surface is usually low. The results revealed that the (β) varies with the month of the year. The revealed results indicate that the daily (β) variesfrom 58.5° in January to 0.5° in May months, but the values of (β) were negativefor the period from May to August months. Isotropic, Perez, Hay, and Klucher models, so anisotropic models Hay, Klucher, and Perez models are basically in a predictive state, and generally have similar performance, that is, the irradiance incident on the inclined surface. The observation results of the Perez model and the Klucher model describe the irradiance at tilt more accurately than other models. The results of this study are similar to previous studies [65, 66].*

Keywords*: Solar energy; Models; Isotropic Models; Anisotropic Models; Inclined Surface.*

Date of Submission: 02-06-2021 Date of Acceptance: 16-06-2021

I. INTRODUCTION

The solar energy that reaches the outer atmosphere will be absorbed, reflected and transmitted through the atmosphere before reaching the earth's surface. Solar radiation data is the basic input for solar applications, such as photovoltaics, solar thermal systems, and passive solar designs. This information should be reliable and easy to use in the design, optimization and performance evaluation of solar energy technology in any particular place, and radiation is extremely important for the optimal design of solar energy conversion equipment [1-3]. The entire radiation on the amount is termed the global irradiance that is that the total of the incident diffuse radiation and the direct traditional irradiance projected on the amount. If the surface is inclined with relevancy the horizontal plane, the overall irradiance is that the incident diffuse radiation and the direct traditional irradiance projected on the inclined surface and the bottom mirrored irradiance incident on the inclined surface [4].

Solar radiation data is usually measured within a certain range of levels and the overall radiation range. The necessary condition for calculating the radiation incident on the inclined surface is to determine the relative amount of the beam, and therefore the scattered radiation contained in the measured horizontal global radiation. The solar collector is tilted to maximize solar energy collection. Therefore, it is important to determine the best angle to collect the maximum solar energy [5]. The tracking system follows the direction of the sun as the sun sweeps across the sky every day to maximize the radiation incident on the surface of the collector. If a two-axis tracking system is used instead of a hard and fast collector, the radiation incident on the collector will obtain a gain of 40% [6, 7]. The amount of solar energy incident on the solar pan in various time frames can be a complex function of many factors, including the local radiant climate, the orientation and inclination of the exposed collector surface, and the ground reflection characteristics. The performance of a solar cell is greatly affected by its orientation and the angle of inclination from the horizontal. This is usually due to the fact that both orientation and angle will change the radiation reaching the collector surface [8, 9].

In the 21st century, engineers and designers increasingly rely on building energy efficiency simulation codes to design more energy efficient buildings. One of the common features found in new commercial buildings across Europe is therefore buildings with large glass curtain walls. It is very important to accurately model the effects of solar radiation through glass, especially in simulations. The measured solar values are usually used to develop solar models, which describe the mathematical relationship between solar energy and meteorological variables (such as ambient temperature, humidity, and sunshine rate), and in the past few years, many authors have proposed the following models of predict radiation on inclined surfaces [10, 11]. Many of these models are applicable to specific situations. Some require special measurements, while others have limited range. These models use equivalent methods to calculate beams on inclined surfaces and ground reflected radiation. The only difference is in the treatment of scattered radiation. The approximate value usually used to convert the value of the diffuse reflection component to the level of a certain oblique component is that the sky radiation has the least number of isotropic distributions [12-14]. However, the theory also as an experimental result shows that this simplified hypothesis is usually far from reality [15]. Therefore, it looks that sky radiation ought to be thought to be anisotropic, particularly because of the sturdy forward scattering result of aerosols [16-19]. There square measure many empirical models that can't estimate star radiation; use offered geographic, climatically and meteorological parameters, like temperature, sunshine length, latitude, longitude, precipitation, wind speed, and cloudy sky [20-25]. The foremost normally used parameter for estimating total radiation is that the length of sunshine. During this regard, folks have wide compared the changed version of metric linear unit equation with varied correlations to estimate the general radiation level [26-29].

In most solar applications, inclined surfaces with different angles are widely used. Many weather stations around the world measure the solar irradiance at a certain level, but only a few stations can measure the solar component on the slope. There are a variety of models that can estimate the solar radiation on the slope based on the corresponding horizontal data [30-32]. Usually, this requires detailed information about the magnitude of scattering and direct horizontal irradiance. As shown in [33-36], various diffusion fraction models can be used. These models are usually expressed by a polynomial function that relates the diffusion score to the transparency index [37-40].

Many solar energy models have been proposed in the literature using mathematical linear and nonlinear functions, artificial neural networks and symbolic logic [41-44]. A key aspect of modeling solar energy is that the accuracy of the developed model is evaluated using statistical errors (for example, mean absolute percentage error (MAPE), mean deviation error (MBE), and root mean square error (RMSE)). MAPE is an indicator of accuracy. During this period, MAPE expresses the difference between the actual value and the predicted value as an important value. For each fitted or predicted time point, add the calculated MAPE and then divide by the number of fitted points; MBE is an indicator of the typical deviation between the predicted value and the measured data. A positive MBE value means that it is overestimated within the predicted total solar energy range, on the contrary, it is around [45-49]. Instead, RMSE provides information about the short-term performance of the model and can measure changes in the expected value surrounding the measured data. RMSE also shows the efficiency of the developed model in predicting future personal value. A positive RMSE value means that there is a huge deviation between the predicted value and the measured value [50-53]. This work involves the best slope and direction of the surface that receives the most radiation, and we should always be ready to determine the best slope of the collector at any latitude, any surface azimuth, and any day of the year. Therefore, this research aims to develop a strategy to calculate the best angle ($\beta_{opt.}$) for any position within a word. In addition, our goal is to use this method by calculating the best angle in the most Saudi regions (especially Jeddah). We first measure the level of total radiation and scattering levels received per hour [54, 55]. These quantities are then transferred to the machine through a mathematical program. The optimal angle is calculated by checking the following values: in a specific day or a specific time period, the entire radiation on the collector surface may be the maximum [56-59].

The main purpose of this research is to optimize and develop empirical correlations to use the available meteorological data to predict the typical monthly daily of global and diffuse radiation at the level of Jeddah, and to calculate the number of days on the tilted surface south of Jeddah All of it radiates Arabia.

II. DATA AND CLIMATE OF THE SELECTED SITE

In this study, the total, direct and diffuse solar radiation incident on the horizontal plane of Jeddah, Saudi Arabia during the period time from 1992 to 2016 (latitude 21^0 42'N & Long. 39^0 11'E) was used. The radiation data for the corresponding period was obtained from Saudi Arabia's Meteorological and Environmental Protection Agency (MEPA). The data set used consists of hourly and daily averages of total solar radiation and scattered solar radiation on the horizontal plane. An Eppley high-precision pyranometer that can respond to 300-3000 nm is used to measure total solar radiation, and another precision pyranometer equipped with a special shading device SBS model is used to measure scattered radiation. The shadow band holder is made of anodized aluminum, weighs about 24 pounds, and uses 300 bands with a diameter of about 2500 to cover the entire radiometer. Because the shadow band blocks a part of the incident scattered radiation from the sky, the measured value is corrected according to the method of Batlles et al. The Eppley Precision Spectral Pyranometer (PSP) records the total solar radiation data at all locations. According to the classification of the World Meteorological Organization [60], the accuracy of these pyranometers is equivalent to the first level. These instruments are calibrated annually against reference instruments that can be traced back to the World Radiation Reference (WRR) maintained by Davos, Switzerland [61, 62].

According to the manufacturer's calibration certificate, the sensitivity is approximately 9 µV/W m^{-2}, in the ambient temperature range of -20 to +49 ^{0}C, the temperature dependence is ±1%, and the linearity is in the range of 2800 W m^{-2} ±0.5%, the cosine is ±1% of the normalized 0-70^{0} zenith angle, and normalized to ±3% of the 70-80^{0} zenith angle. The absolute accuracy of calibration is ±3-4%. Saudi Arabia may be a country in Southwest Asia, encompassing approximately four-fifths of the Middle East peninsula between 16^{0} and 33^{0}N and longitude 34^{0} and 56^{0}E. Saudi Arabia has the world's largest persistent desert, Al-Rub Al-Khali (clearance zone). The desert spring water environment of Al-Ahsa involves most of the eastern region. KSA is very suitable for converting solar energy into capital. The annual average daily solar radiation level reaches 6 kWh/m^2, and the proportion of sunny days is 80-90%. The annual solar radiation level exceeds 2400 kWh/m^2 [63].

Jeddah is an important city Hejaz Vilayet (Hejaz Vilayet), the Kingdom of Hejaz and other ordinary political materials that appear in the history books of Hijaz. Jeddah is in a dry environment under the climate shift arrangement of Koppen's, in the tropical temperature range. Jeddah maintains a warm temperature in winter, and the temperature in summer is incredibly annoying. In addition to the daunting sultry heat, there is concentrated dew. In this study, the average high and low temperatures of Jeddah during this period are obvious in Figure (1), while the average sea temperature of Jeddah, Saudi Arabia is obvious in Figure (2). In this study, the number of daytime/sunlight hours and average humidity in the selected time period are shown in Figures (3 & 4) [63].

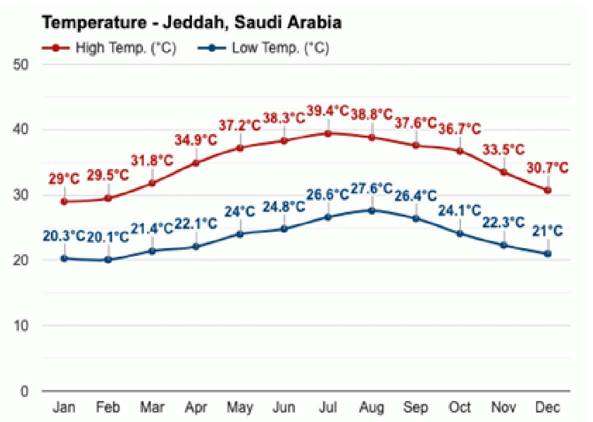

Figure (1): shows the mean high and low temperature in Jeddah

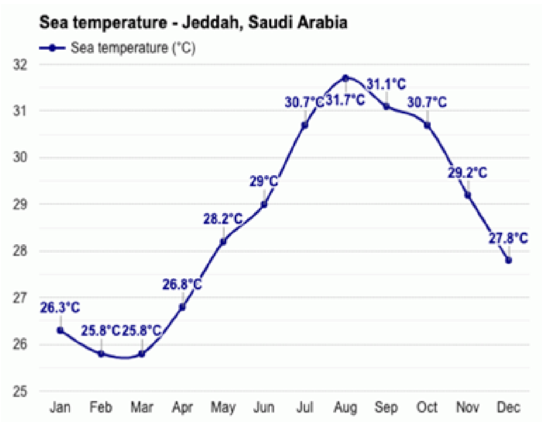

Figure (2): shows the average sea temperature in Jeddah.

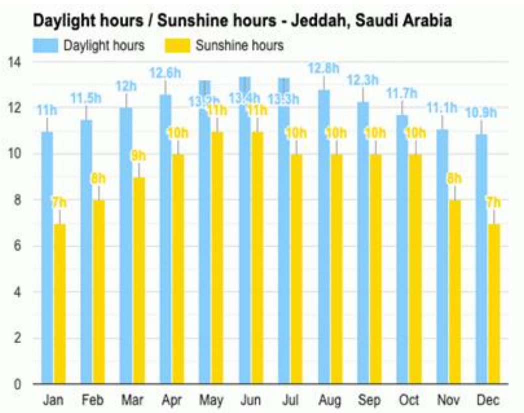

Figure (3): shows the mean daylight/sunshine hours in Jeddah

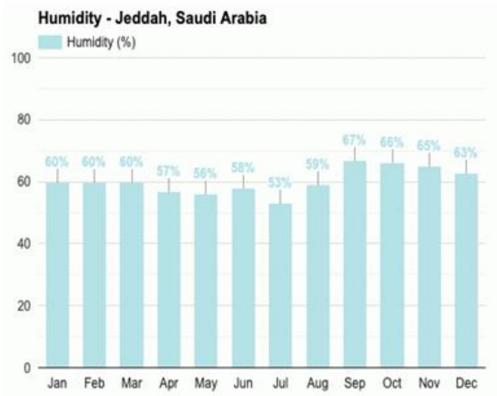

Figure (4): shows the average humidity in Jeddah.

III. THE FUNDAMENTAL OF SOLAR ENERGY

The solar radiation incident outside the earth's atmosphere is called extraterrestrial solar radiation. On average, the extraterrestrial radiation is 1367 W/m2 (solar constant). The extraterrestrial radiation H_{oh} is as follows:

$$H_o = 1367\ (R_{mD}/R_D)^2 \qquad (1)$$

Where R_{mD} is the mean sun–earth distance and R_D is the actual sun–earth distance depending on the day of the year. The earth's axis is tilted approximately 23.5° with respect to the earth's orbit around the sun. As the earth moves around the sun, the axis is fixed if viewed from space. The declination of the sun is the angle between a plane perpendicular to a line between the earth and the sun and the earth's axis. An approximate formula for the declination of the sun is given as follows [64]:

$$\delta = (23.5\pi/180)\ \mathrm{Sin}\ [2\pi\ (284+n)/365] \qquad (2)$$

Where n is the nth day of the year.

3.1. Zenith azimuthal and hour angles

To describe the path of the sun in the sky, one needs to know the angle of the sun relative to a straight line perpendicular to the surface of the earth. This is called the zenith angle (θ) and the position of the sun relative to the north-south axis, which is the azimuth angle (α). The hour angle (ω) is easier to use than the azimuth angle, because the hour angle is measured in the plane of the sun's "apparent" orbit in the sky (Figure 5) [64]. Figure (6) shows the height and azimuth of the solar path in Jeddah from 5:00 am to 7:00 pm on the 21st day of each month. Local time. At the center of the horizontal axis is the zero azimuth of the sun at noon. In summer, the value of (φ_s) will exceed ±90°, and the value of β will be low [65]. Figure (7) shows the irradiance component, I_b; direct I_r reflection and I_d diffusion received from solar altitude β and azimuth (φ_s) by the module with azimuth (φ_c); (modified from reference) [65].

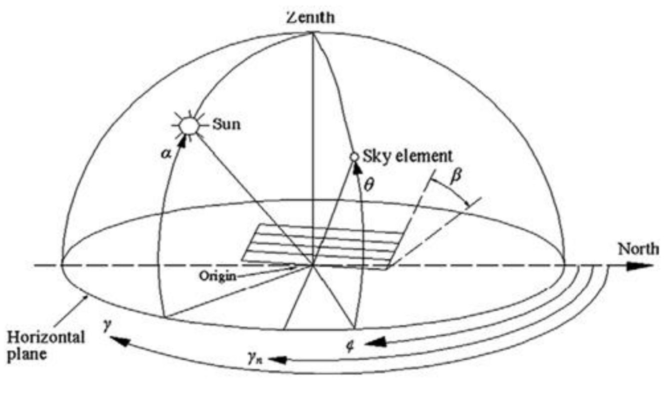

Figure (5): Zenith, azimuthal, and hour angles

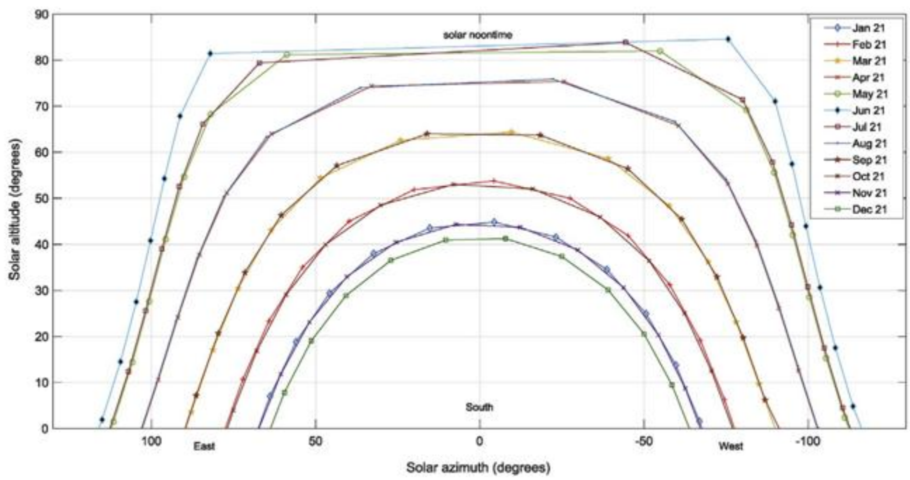

Figure (6): Sun path diagram giving solar altitude and azimuth angles in standard time for Jeddah

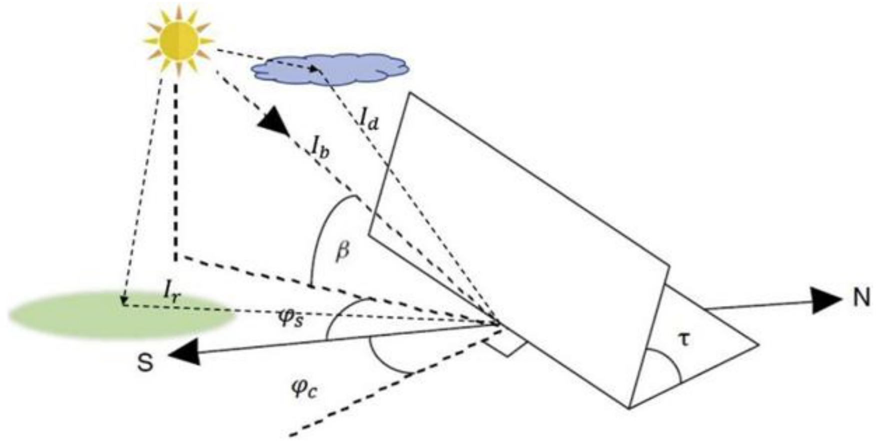

Figure (7): Irradiation components, I_b; direct, I_r, reflected, and I_d, diffuse, received from solar altitude, β, and azimuth, φ_S, by the module with azimuth, φ_C; (modified from Ref. [65].

3.2. The solar time

The local time is the same in the entire time zone, while the solar time is related to the position of the sun relative to the observer and varies depending on the exact longitude of the solar time calculation. To adjust the solar time for longitude, you must subtract (LonglocalLongsm) /15 (in hours) from the local time. (Longlocal) is the longitude of the observer in degrees, and (Longsm) is the longitude of the standard meridian in the time zone of the observer.

3.3. Equation of time (E_{qt})

As indicated by the development of the earth around the sun, sun powered time changes somewhat comparative with the nearby standard time. This time distinction is known as the time condition and can be a significant factor in deciding the situation of the sun for sun based estimations.

IV. METHODOLOGY OF MODELS ON HORIZONTAL SURFACE

These models give the correlation between solar energy on the horizontal plane and certain meteorological variables, for example; sunshine hour's (s), ambient temperature (T), cloud cover (c_w), relative humidity (R_h) and maximum ($T_{max.}$) And ($T_{min.}$) The ambient temperature in Jeddah during 1992-2016 was taken from the Ministry of Defense and Aviation of Saudi Arabia and the General Administration of Meteorology and Environmental Protection (Jeddah). By obtaining the data of the average one day per month, the data is averaged to obtain the monthly average daily value. Then, the average daily value of each month in the past 25 years is averaged. Then, the obtained average values were divided into sub-data sets, one of which was used to calibrate and develop the model from 1992 to 2014, and the other was used to evaluate the model in 2015 and 2016.The correlations to which the measured data were fitted are as follows:

$$H/H_o = a + b\,(s/s_o) \tag{3}$$
$$H/H_o = a + b\,(s/s_o) + c\,(s/s_o)^2 \tag{4}$$
$$H/H_o = a + b\,(s/s_o) + cT \tag{5}$$
$$H/H_o = a + b\,(s/s_o) + c\,R_h \tag{6}$$
$$H/H_o = a + b\,T + c\,R_h \tag{7}$$
$$H/H_o = a + b\,(T_{max.} - T_{min.}) + cc_w \tag{8}$$
$$H/H_o = a + b\,(T_{max.} - T_{min.})^{0.5} + cc_w \tag{9}$$
$$H/H_o = a + b\,(s/s_o) + cc_w \tag{10}$$
$$H/H_o = a + b\,(s/s_o)^c \tag{11}$$

Where a, b and c are empirical constant and s_o is the maximum possible monthly average daily sunshine duration or the day length. Obtain the values of the empirical constant by using the linear and multilinear regression analysis. A computer program is used to determine the empirical constants of equations (3)-(11) with the help of the measured values of H and other meteorological parameters.

4.1 Determine beam and diffuse radiation on horizontal surface

Used to calculate the monthly average daily diffuse radiation incident on the horizontal plane, the empirical correlation of the diffuse fraction (H_d/H) and the diffuse transmittance (H_d/H_o) and the first order of the clarity index (K_t), Second-order and third-order correlations and relative sunshine hours (S/S_o) [41]. It is found that the second-order and third-order correlations cannot improve the accuracy of (H_d) estimation. Therefore, the following correlations have been obtained for Jeddah location:

$$H_d/H = 3.956 - 4.652K_t, \quad R^2 = 0.972 \quad (12)$$

$$H_d/H = 5.245 - 6.235(S/S_0), \quad R^2 = 0.945 \quad (13)$$

$$H_d/H_o = 3.154 - 4.354(S/S_0), \quad R^2 = 0{:}928 \quad (14)$$

$$H_d/H_o = 2.358 - 5.125K_t, \quad R^2 = 0.981 \quad (15)$$

In addition, (H_d/H) and (H_d/H_o) are related to the first- and second-order correlations of the combination of (K_t) and (S/S_o). Moreover, it has been found that the second-order correlation between (H_d/H) or (H_d/H_o) and the combination of (K_t) and (S/S_o) cannot improve the estimation accuracy of (H_d). Found the following correlation fit (H_d) measurement data [66]:

$$H_d/H = 4.528 - 6.685K_t + 0.325(S/S_0), \quad R^2 = 0.968 \quad (16)$$

$$H_d/H_0 = 3.225 - 4.425K_t - 0.541(S/S_0), \quad R^2 = 0.971 \quad (17)$$

Calculate (H_d) using the formulas (12) to (17), and compare the obtained result with the measured value of (H_d). The accuracy of the estimated value (H_d) is tested by calculating MBE, RMSE, MPE, R2 and t-test.

4.2. Global solar radiation on tilted surfaces

Many weather stations in the world have measured the total solar radiation on the horizontal plane, but only a few stations can measure the solar component on the inclined plane. There are many models that can be used to estimate solar radiation on inclined surfaces based on radiation on horizontal surfaces, but these models require knowledge of total radiation on horizontal surfaces, direct or diffuse radiation or reflected radiation [66].The monthly average daily total solar radiation on a tilted surface can be written as:

$$H_T = H_bR_b + H_dR_d + H_\rho R_r \quad (18)$$

Where R_b and R_r are the beam and ground reflected radiation conversion factors, given as for both isotropic and anisotropic models and ρ is the ground reflectivity.

The values of R_b and R_r can be obtain from the following equations:

$$R_b = \text{Cos}\ \theta / \text{Cos}\ \theta_z \quad (19)$$

$$R_r = (1 - \text{Cos}\ \beta) / 2 \quad (20)$$

Where θ and θ_z are the incident angels for beam radiation on tilted and horizontal surfaces, respectively. β is the surface tilt angle with respect to the horizontal. The only difference between the isotropic and anisotropic models appears in the diffuse solar radiation conversion factor R_d, and it is given below for each model.

Liu and Jordan's model (isotropic) [67]:

$$R_d = (1 + \text{Cos}\ \beta) / 2 \quad (21)$$

Klucher's model (anisotropic) [68]:

$$R_d = \{[\frac{(1+\text{Cos}\ \beta)}{2}] [1 + F\ \text{Sin}^3(\theta/2)] [1 + F\ \text{Cos}^2\theta\ \text{Cos}^3\theta_z]\} \quad (22)$$

Where $F = 1 - (H_d/H)^2$.

Hay model [69].

$$R_d = (H_b/H_0)\ R_b + (1 - H_b/H_0)\ [\frac{(1+\text{Cos}\ \beta)}{2}] \quad (23)$$

The Perez model (Perez et al., 1986; P8 and Perez et al., 1990; P9) [70, 71] is more computationally intensive, and through empirical applications, it performs isotropic scattering, brightening radiation around the sun and horizon. A more detailed analysis. Derive coefficients. The total irradiance on the inclined surface is given by the following formula:

$$H_T = H_{h,b}\ R_b + H_{h,d}\ [\ (1- F_1) \frac{(1+\text{Cos}\ \beta)}{2} + F_1 \frac{a}{b} + F_2\ \text{Sin}\ \beta\ ] + G_h\rho\ (\frac{1-\text{Cos}\ \beta}{2}) \quad (24)$$

Here, F_1 and F_2 are the perimeter and the horizontal brightness coefficient, respectively, and (a) and (b) are terms that consider the incident angle of the sun on the slope under consideration. The terms (F_1), (F_2), (a) and (b) are calculated using the following formula:

$$F_1 = \max[0, (f_{11} + f_{12}\Delta + \frac{\pi\theta z}{180} f_{13})]\ \&\ F_2 = f_{21} + f_{22}\Delta + \frac{\pi\theta z}{180} f_{23} \quad (25)$$

$$a = \max(0^0, \cos\theta)\ \ \&\ \ b = \max(\cos 85, \cos\theta_z) \quad (26)$$

Based on the statistical analysis of the empirical data of a specific location, the coefficients f_{11}, f_{12}, f_{13}, f_{21}, f_{22} and f_{23} are obtained. The model derived two different sets of coefficients [70, 71]. Temps and Coulson modified Liu and Jordan's isotropic model, and introduced two terms representing scattered solar radiation by assuming clear sky conditions [72].

$$H_{d,b} = ½\ H_d\ (1+ \text{Cos}\ \beta)\ P_1\ P_2 \quad (27)$$

$$P_1 = 1+ \text{Cos}^2\theta\ (\text{Sin}^3\theta_z)\ \&\ P_2 = 1+ \text{Sin}^3\ (\beta/2) \quad (28)$$

Where P_1 is the vicinity of the sun disc and p_2 is the sky radiation from the region near the horizon.

The total solar radiation incident on a tilted surface may be written as:

$$H_t = R_t H \quad (29)$$

Where R_t is the total solar radiation conversion factor defined as:

$$R_t = H_t / H = [1- (H_d /H)] R_b + (H_d / H) R_d + \rho (1- \cos \beta)/2 \quad (30)$$

Numerical calculations were evaluated for calculation of H_t for different tilt angles of a surface facing south using the measured data on horizontal surfaces for the period time (1992-2016).

V. STATISTICAL TOOLS

Popular statistical tools are used to evaluate the data in this study. The following are the statistical tools described below: mean deviation error (MBE), root mean square error (RMSE), mean percentage error (MPE), correlation coefficient (R) and t statistic (t-state) [73].

$$\text{MBE} = \frac{1}{n}\sum_{i=1}^{n}(X_i - Y_i) \quad (31)$$

$$\text{RMSE} = \{\frac{1}{n}\sum_{i=1}^{n}(X_i - Y_i)*2\}^{1/2} \quad (32)$$

$$\text{MPE\%} = \frac{1}{n}\sum_{i=1}^{n}\{\frac{X_i - Y_i}{X_i}\} * 100 \quad (33)$$

$$R^2 = \frac{n\,(\sum X_i Y_i - (\sum(X_i)\,(\sum Y_i)}{\{[n\sum X_i^2 - (\sum X_i)^2]\,[n\sum Y_i^2 - (\sum Y_i)^2]\} * 1/2} \quad (34)$$

$$\text{T-state} = \{(n-1)\,(\text{MBE})^2/(\text{RMSE})^2 - (\text{MBE})^2\}^{1/2} \quad (35)$$

Where: X_i & Y_i are the measured and the estimated values, respectively and n is the number of data points (observations).

VI. RESULTS AND DISCUSSION

Figure (8) shows the average monthly solar radiation, beam and scattered solar radiation (W/m^2) of the total solar radiation, beam and scattered solar radiation on the horizontal plane during the period from 1992 to 2016 of this research work. It can be seen from this figure that the largest solar radiation occurs in summer and spring, while the smallest solar radiation occurs in winter. For summer figures, in winter months, the beam component is dominant over the scattered component. The beam radiation accounts for almost 62% to 71% of the global solar radiation, while the scattered solar radiation accounts for almost 22% of the global solar radiation. It ranges from 34%. Total radiation. Likewise, it is clear that solar irradiance measurements are strongly influenced by clouds. Surface measurements of the diffuse component of solar irradiance are particularly sensitive to cloud cover. Dark clouds are divided into; first are cloudless days, followed by cloudy morning and an afternoon. In many cloudy days, the daytime conditions start to change from cloudy in the morning, and gradually dissipate throughout the afternoon, until the clouds are completely cleared in the evening. These results are in full agreement with other work given in [6].

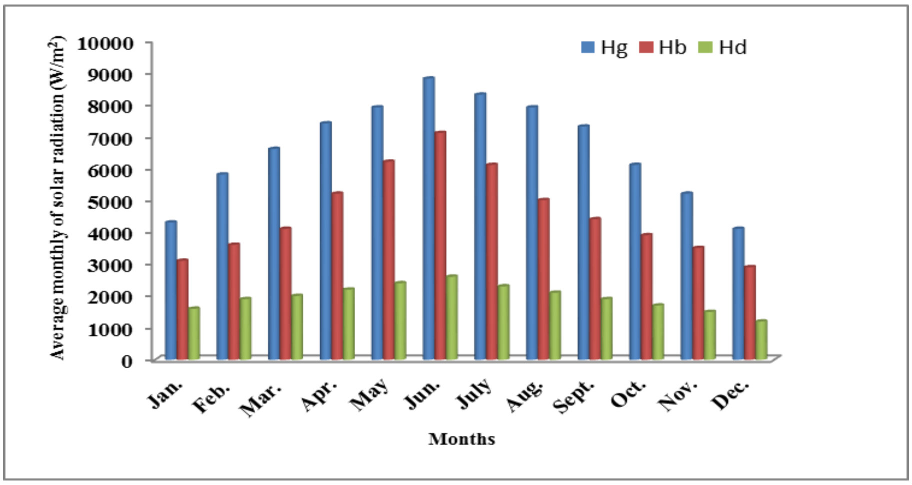

Figure (8): Average monthly of total irradiation (H_g), beam (H_b) and diffuse (H_d) irradiation (W/m^2) on a horizontal surface during the period time from 1992 to 2016 in selected site.

Experimental models for anticipated of all out sun oriented radiation on even surface as equations from (3) to (11) are proposed for Jeddah, Saudi Arabia utilizing the meteorological information during the time frame time from1992 to 2016. The examination of the deliberate and determined estimations of (H), the relapse conditions between (H/H_o) and meteorological factors alongside the estimations of the measurable pointers; (MBE), (RMSE), MPE, R2 and the t-Test statics are summed up in Table (1). Plainly, the estimations of connection coefficients (R^2) are higher than 0.98 and the estimations of the RMSE are discovered the reach 1.95–4.65, this demonstrating genuinely great understanding among estimated and determined estimations of all out solar radiation (H). The negative values of the MPE show that, equations (4, 5, 6, and 11) slightly overestimate the values of the total solar radiation (H), but, equations (3, 7, 8, 9 and 10) slightly underestimate of the global solar radiation (H). In all cases, the supreme estimations of the MPE never arrive at 1.6%, showing generally excellent arrangement between the month to month normal of every day complete sunlight based radiation and the other meteorological boundaries. Additionally from table (1), it is seen that, the estimations of (t-Test) changes in model to another model as indicated by models from conditions (3-11). Hence the model which gives the littlest estimations of the t-Test, at that point it is considered as the best model for assessing the absolute sun oriented radiation at chose site with a worthy mistake. This implies that the models of conditions (4) and (5) are acceptable gauge for the all-out sun oriented radiation in chose area during the time frame time in the current work.

Table (1), Empirical models describe the relation between (H/H_o), (W/m^2) and metrological variable at Jeddah, Saudi Arabia during the period time from 1992 to 2016.

Model No.	Regression coefficients a	b	c	MBE	RMSE	MPE%	R^2	T-state
Equation (3)	0.495	0.345	-	2.65	2.89	4.25	0.958	3.25
Equation (4)	0.511	0.425	0.491	4.56	2.25	-3.89	0.975	3.12
Equation (5)	0.125	0.639	0.621	-1.89	1.95	-1.55	0.968	2.96
Equation (6)	0.124	0.725	0.462	-4.52	2.32	-3.24	0.957	3.32
Equation (7)	0.414	-0.512	0.731	-3.27	3.24	4.32	0.969	4.23
Equation (8)	0.612	0.389	0.425	-4.35	4.65	2.95	0.987	5.36
Equation (9)	-0.298	0.548	-0.515	5.24	3.21	3.25	0.962	5.94
Equation (10)	-0.345	0.485	0.417	4.26	3.95	5.23	0.949	4.85
Equation (11)	0.532	0.297	0.625	-3.75	3.26	-3.48	0.967	4.32

Table (2), shows statistical indicators of measured ($H_{d,m}$) and calculated ($H_{d,c}$) values of the diffuse solar radiation along with the values of mean base error (MBE), root mean square error (RMSE), mean percentage error (MPE), and t-Test statics. It is clear that the low values of the (RMSE) for all models indicate fairly good agreement between measured and calculated values of diffuse solar radiation (H_d). The negative values of (MPE) indicate that the proposed correlations slightly overestimate (H_d). For all models, the absolute values of the (MPE) never reach 1.65%, indicating very good agreement between measured and calculated values of the diffuse solar fraction (H_d/H) or the diffuse solar transmittance (H_d/H_o) and clearness index K_t, relative number of sunshine hours (S/S_o) and the combination of them. The latter results are confirmed for each month. Also from table (2), the t-Test of the model in equation (15) is given the smallest value, and then it is considered as the best model for estimating the diffuse solar radiation at selected site with an acceptable error. These results are in good agreement with pervious work performed for other studies [54].

Table (2), Statistical indicator of measured ($H_{d,m}$) and calculated ($H_{d,c}$) values (W/m^2) with the metrological variable at Jeddah, Saudi Arabia during the period time (1992-2016).

Model No.	$G_{d,m}$	$G_{d,c}$	MBE	RMSE	MPE%	t-Test
Equation (12)	1299	1311	2.35	3.89	2.58	2.68
Equation (13)	1368	1481	-1.65	2.78	-2.89	3.12
Equation (14)	1412	1425	2.45	1.99	1.98	2.97
Equation (15)	1356	1366	-1.45	1.61	1.64	1.69
Equation (16)	1352	1372	2.38	2.19	-2.47	3.24
Equation (17)	1315	1329	2.65	2.46	2.65	2.57

The linear regression analysis was used to comparison between; measured and calculated values of the total solar radiation, measured and calculated values of beam solar radiation and measured and calculated values of diffuse solar radiation in the selected site during the period time from 1992 to 2016 are show in figures 9. From this figure indicated that good agreement between measured and calculated values of solar radiation.

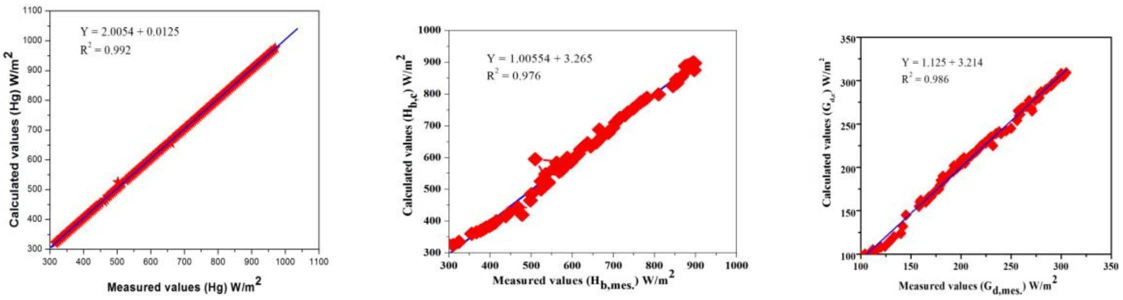

Figure (9): Differences between measured and calculated values of global solar radiation (H_g), beam solar radiation (H_b) and diffuse solar radiation (H_d).

The relationship between the beam conversion factor and the surface inclined angels from 0^o to 90^o with increments of 0.5^0 in Jeddah is depicts in figure (10). From this figure, indicate that the one hundred and eighty curves can be obtained, but for clarity and simplicity, only ten curves at increments of ten degrees of tilted anglesare clear. At a slope point 0°, the shaft transformation factor is equivalent to solidarity for the entire days of the year on the grounds that the surface is flat. As the slope point steadily increments from 0° to 90°, the pillar transformation factor gets more noteworthy than the solidarity for the times of winter and pre-winter, while, it worth turns out to be not exactly the solidarity for the times of spring and summer. This might be ascribed to the moderately little estimations of the sun rise points in winter and generally huge estimations of the sun rise points in summer. Substituting from the equations (21), (23) and (29) in the equation (20), the monthly average total solar radiation is calculated for asouth-facing flat surface at each 0.5° of incline angles as varying from 0° to 90°. In addition, it is seen that both (R_b) and (R_t) decrease with increasing (β) during the summer months. However during winter months, (R_b) and (R_t) are found to increase with increasing (β) until an optimum value beyond which the behavior is reversed. Also, a high tilt is required to meet the energy demand in the winter months when the insolation on a horizontal surface is usually low. Figure (11), shows the monthly variation of ideal incline angle for a south-facing flat surface in Jeddah. The results revealed that the (β) varies with the month of the year. The (β) decrease from January to May months, remains at zero from Jun to July months, and then increase from August to December months.

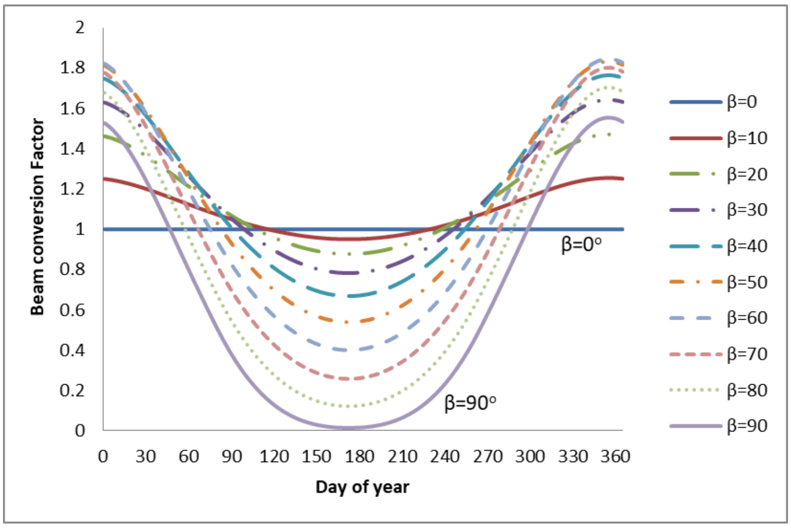

Figure (10): The relationship between the beam conversion factor and the surface inclined angels from 0^o to 90^o in Jeddah.

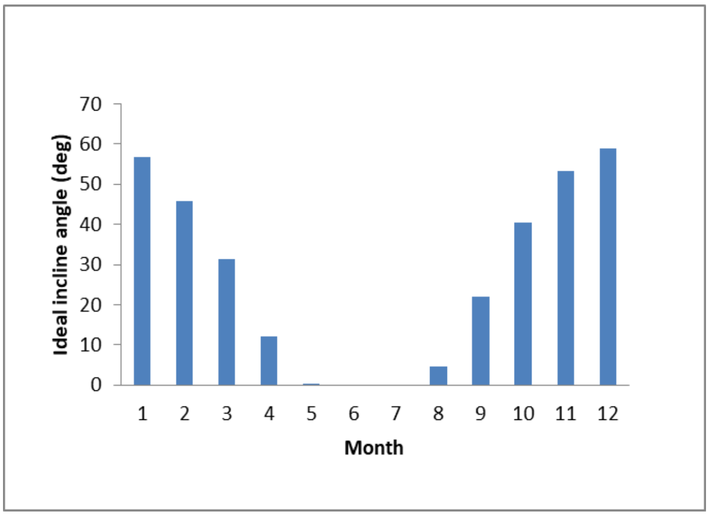

Figure (11): Monthly variation of ideal incline angle for a south-facing flat surface in Jeddah

The daily (β) for a south-facing flat surface in Jeddah is shown in Figure (12). From this figure we noticed that, the values of (β) were found by searching for the values for which the total solar radiation on the inclined plane is at maximum for a particular day. The revealed results indicate that the daily (β) varies from 58.5° in January to 0.5° in May months, but the values of (β) were negative for the period from May to August months. However, a zero value is suggested for such days, since a negative tilt to the north has no significance. From August to December months the (β) varied from 0.17° to 57.5°. These results are the same results with other studies such as [45].

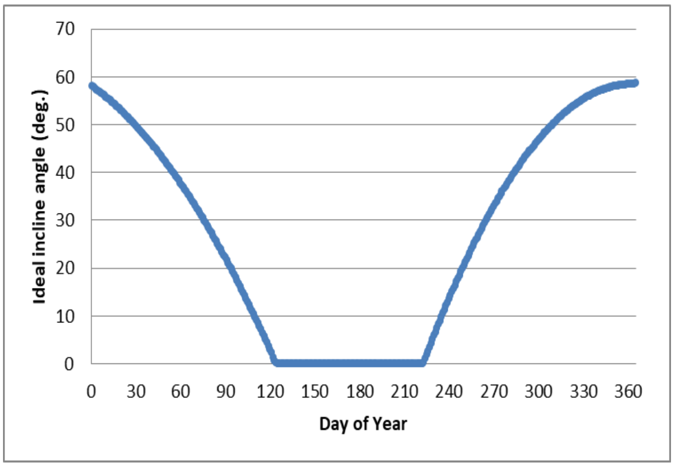

Figure (12): Daily values of the ideal incline angle for a south-facing surface in Jeddah

The values of MBE in the selected site during the period time from 1992 to 2016 at different slope at different models; the isotropic model, Hay, Klucher's, Perez and Tamps and Coulson's are anisotropic models in the present work are show from the figures (13-18). For each model, the measured values of diffuse solar radiation and horizontal values of global solar radiation were used to calculate the solar radiation on surface tilted at 15^0, 30^0, 45^0, 60^0, 75^0, and 90^0 above the horizon. The results were compared with the solar irradiances monitored and presented in terms of usual statistics: the mean base error (MBE) and the root mean square error (RMSE). For these figures, we noticed that the variations of MBE are given maximum values in winter and autumn months, while minimum values of MBE are occur in summer and spring months for all tilted angles 15^0, 30^0, 45^0, 60^0, 75^0 and 90^0. Also the figures clear that, the most values of MBE are negative, this due to the most models are substantially underestimate irradiances incident an inclined surface, with exception models are overestimate the irradiance incident an inclined surface. For tilted 15^0 the values of MBE for the Temp and Coulson model is over estimate during the years of months, while for tilted 30^0 which give the same result in 15^0 tilted with exception January, October and November months. Therefore at tilted 45^0, 60^0, 75^0, and 90^0 the most models given underestimate values of MBE, with exception the summer month for Tamps and Coulson model, Klucher's and Perez's models.

Thus, the estimations of MBE results show that the isotropic, Perez's, Hay's and Klucher's models are significantly under predicts the irradiance episode on a slanted surface, and the Tamps and Coulson model extensively over predicts irradiance occurrence on a slanted surface on a general premise.

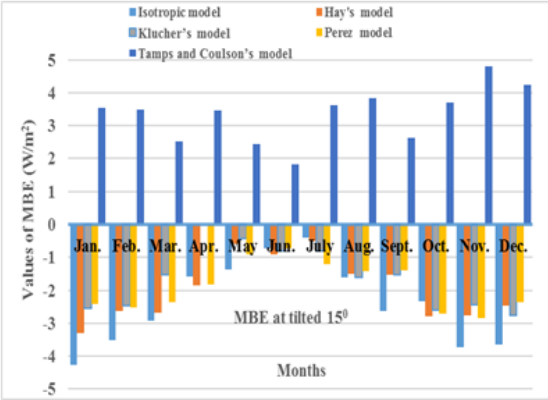

Figure (13): The values of MBE at tilted 15⁰ (W/m²)

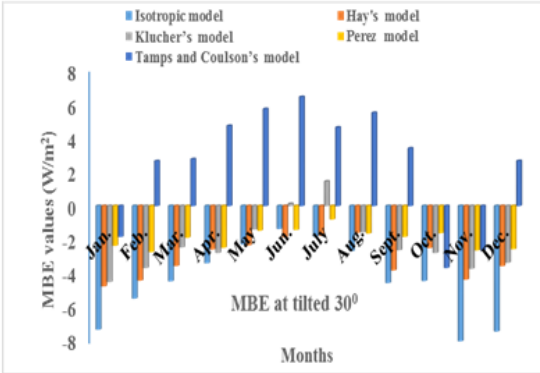

Figure (14): The values of MBE at tilted 30⁰ (W/m²)

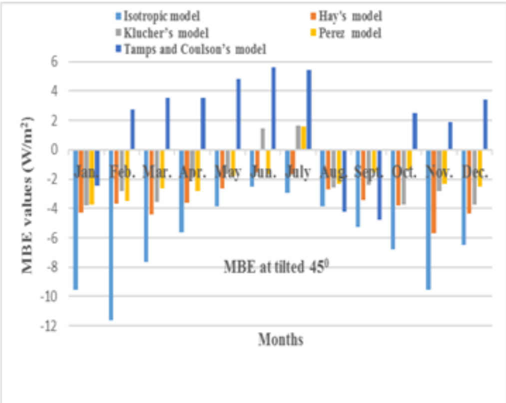

Figure (15): The values of MBE at tilted 45⁰ (W/m²)

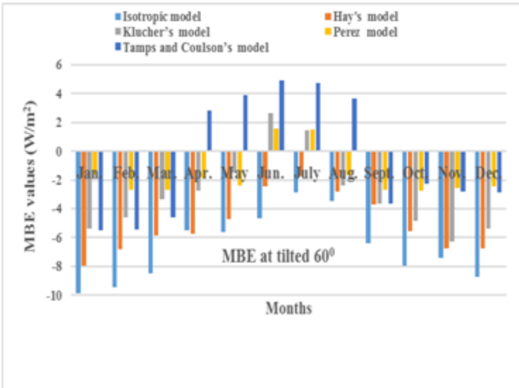

Figure (16): The values of MBE at tilted 60⁰ (W/m²)

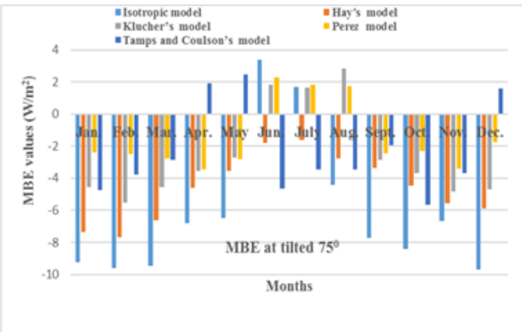

Figure (17): The values of MBE at tilted 75⁰ (W/m²)

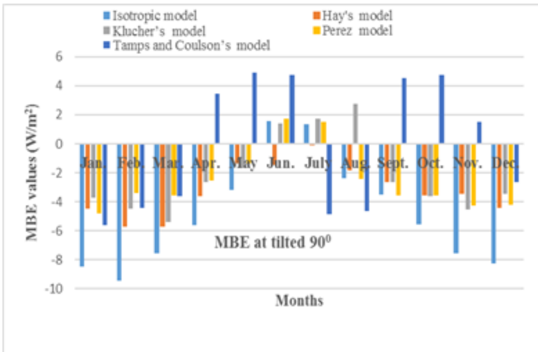

Figure (18): The values of MBE at tilted 90⁰ (W/m²)

The values of RMSE at different tilted angles for south facing surfaces at different models in the present research are shown in figures (19-24). From this figures, we conclude that, the RMSEs values for all different models increases as the slop of the collector increase, The RMSE results indicate that the anisotropic models (Hay, Klucher and Perez) show similar performance on an overall basis, but isotropic model and Tamps and Coulson exhibit much larger error. In general we confirm that, the observation of the Perez's and Klucher models describe the irradiance on inclined plane more accurately than anther models. These results in the present research are good agreement with other work in this field [65, 66].

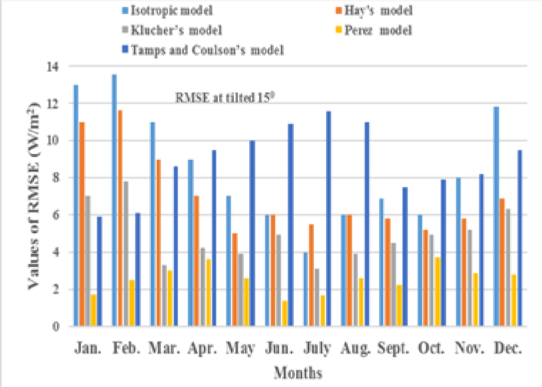

Figure (19): The values of RMSE at tilted 15^0 (W/m^2)

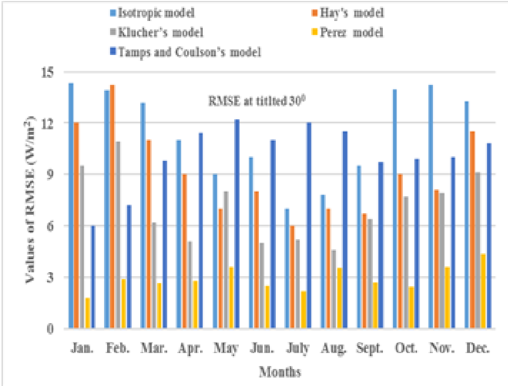

Figure (20): The values of RMSE at tilted 30^0 (W/m^2)

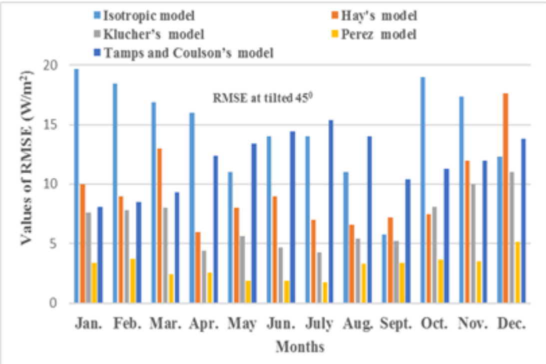

Figure (21): The values of RMSE at tilted 45^0 (W/m^2)

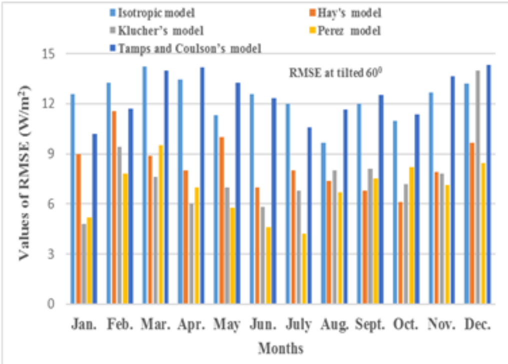

Figure (22): The values of RMSE at tilted 60^0 (W/m^2)

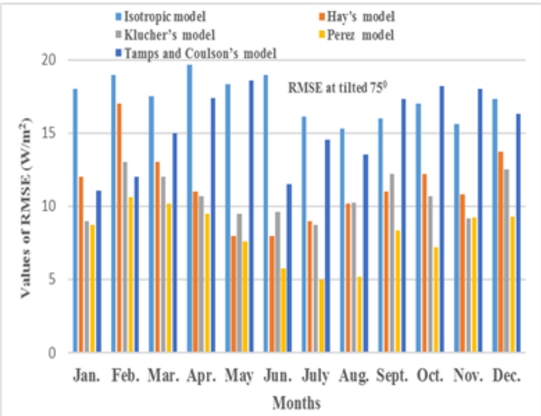

Figure (23): The values of RMSE at tilted 75^0 (W/m^2)

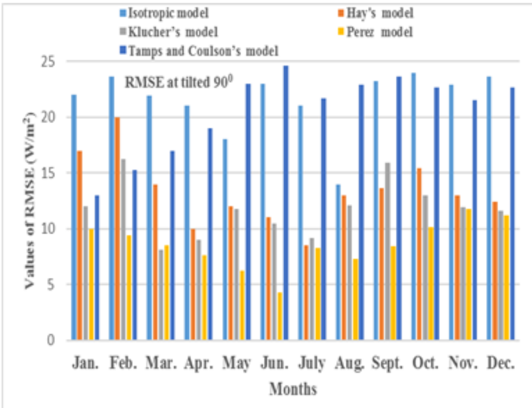

Figure (24): The values of RMSE at tilted 90^0 (W/m^2)

VII. CONCLUSION

The main purpose of this study was calculation of horizontal diffuse and inclined total average monthly solar radiation in Jeddah, Saudi Arabia. The measured data were used to develop new empirical correlations that can be used for calculation of diffuse solar radiation incidet on horizontal surfaces. The average monthly of total solar radiation, beams and diffuses solar radiation (W/m^2) on a horizontal surface during the period time from 1992 to 2016 are done. The beam component is more dominant than diffuse component in winter months, the beam radiation represents nearly vary from 62% to 71% of global solar radiation, while diffuse solar radiation represents nearly vary from 22% to 34% of total radiation. The values of correlation coefficients (R^2) are higher than 0.98 and the values of the RMSE are found the range 1.95– 4.65, this indicating fairly good agreement between measured and calculated values of total solar radiation (H). The absolute values of the MPE never reach 1.6%, indicating very good agreement between the monthly average of daily total solar radiation and the other meteorological parameters. The values of the (RMSE) for all models indicate fairly good agreement between measured and calculated values of diffuse solar radiation (H_d). For all models, the outright estimations of the (MPE) never arrive at 1.65%, demonstrating generally excellent arrangement among estimated and determined estimations of the diffuse sunlight based division (H_d/H).

The both (R_b) and (R_t) decrease with increasing (β) during the summer months. However during winter months, (R_b) and (R_t) are found to increase with increasing (β) until an optimum value beyond which the behavior is reversed. Also, a high tilt is required to meet the energy demand in the winter months when the insolation on a horizontal surface is usually low. The results revealed that the (β) varies with the month of the year. The (β) decrease from January to May months, remains at zero from Jun to July months, and then increase from August to December months. The revealed results indicate that the daily (β) varies from 58.5° in January to 0.5° in May months, but the values of (β) were negative for the period from May to August months.

The estimations of MBE results show that the isotropic, Perez's, Hay's and Klucher's models are generously under predicts the irradiance occurrence on a slanted surface, and the Tamps and Coulson model extensively over predicts irradiance episode on a slanted surface on a general premise. The RMSE results demonstrate that the anisotropic models (Hay, Klucher and Perez) show comparable execution on a general premise, however isotropic model and Tamps and Coulson display a lot bigger blunder. Overall we affirm that, the perception of the Perez's and Klucher models depict the irradiance on slanted plane more precisely than anther models.

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