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A Correlative Measurement of an Hourly Record of Solar Radiation and Climatological Parameters

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Abstract

A correlation of measured data for the solar radiation on a horizontal surface at ambient temperature and humidity was achieved. For all measurements being hourly averaged to fifth order polynomial. The data correlated to a second degree equation with time for an hourly, daily and monthly obtained data. This correlated data compared to best predictive models for the same site of observation. However these measurements appeared to be sensitive to minor and major changes of local weather patterns which is reflected in a deviation to about 4% to the lower margin and 5% to its higher margin.
Keyword: Solar radiation, Correlative model, Predictive model

موديل رياضي لتمثيل الاشعاع الشمسي والمتغيرات المناخية لكل ساعة

الخلاصة

الدراسة هي لتحديد معادلات ترابطية لبياناتِ مقاسة على سطح افقي متمثلة ببيانات الإشعاعِ الشمسيِ، درجة حرارة الظروف الجوية والرطوبة النسبية . حيث ان البيانات المقاسة تمت عند كل ساعة يوميا وتم تمثيلها بمنحنيات من الدرجة الخامسة. كما ان البيانات تم تمثيلها بمعادلات من الدرجة الثانية وكدالة للزمن من خلال حساب المعدل لكل ساعة –يوم –شهر .قورنت البيانات المتمثلة بالمنحنيات التصحيحية لمدينة تكريت مع موديلات رياضيه تجريبيه بعد ان تم ادخال البيانات المقاسة. الموديلات التي تم الحصول عليها وفق البيانات المقاسة لكل–ساعة–يوم –شهر لمده عام كامل بينت ان هناك هذه البيانات لها تغيير ضمن الحد الادنى والاعلى ما بين 4–5% ناتج عن الاختلاف في الظروف الجوية للموقع الذي تمت فيه القياسات. علما ان الدراسة اعطت الإمكانية في تحديد حالة الظروف الجوية الى حد كبير نتيجة للقياسات الدقيقة كونها اعتمدت القياسات لكل ساعة مما يعطي دلاله على الاخذ بنظر الاعتبار كل الاعتبارات للظروف الجوية.
الكلمات الدالة: الإشعاع الشمسي، نموذج تصحيح ، نموذجي تخميني

Nomenclature

I_{Sc} Solar constant (kW /m^2)
Io Hourly extraterrestrial radiation on a horizontal surface (KW /m^2)
$\bar{H}$ Monthly mean daily global radiation on a horizontal surface (KW.h/m^2.day)
$\bar{H}_0$ Monthly mean daily extraterrestrial radiation on a horizontal surface (KW.h/m^2.day)
Ho Daily extraterrestrial radiation on a horizontal surface (KW.h/m^2.day)
$\bar{T}_{max}$ Monthly mean daily maximum ambient temperature (ºC)
$\bar{T}_{min}$ Monthly mean daily minimum ambient temperature (ºC)
E Equation of time
L Latitude angle (º)
RH Relative Humidity
d Day of the month
D Total number of days in the month
CC Coefficient of correlation
N Number of observations

δ Declination angle (º)
ω Hour angle (º)
ωs Sunset hour angle (º)
Φ Longitude angle (º)
τ Atmospheric transmittance coefficient

Introduction

The design of any solar energy system requires solar radiation data at the location of interest.

The best database would be the long-term measured data at the site of the proposed solar system. However, the limited coverage of radiation measuring networks dictates need for developing solar radiation models. despite the availability of space sensing the best way of knowing the amount of global solar radiation at a site is to install Solar meter at many locations in the given region and look after their day to day maintenance and recording, which is a time consuming. The alternative approach is to correlate the global solar radiation with the meteorological parameters at the place where the data is collected. Technology for measuring global solar radiation is costly (Alam *et al*., 2005)[1]. Although, solar radiation data are available in most meteorological stations, many stations in developing countries suffer a shortage concerning a wide range of these data. Thus, alternatively methods for estimating these data are required is to correlate with the measurement (Al-Dulaimy,and Al-Shahery)[2]. One of the two methods have to be used an empirical models, but an accurate modeling depends on the quality and quantity of the measured data used. There are many empirical formulae have been developed to estimate the solar radiation using different meteorological parameter (Yag, 1994[3]; Gopinathan[4], 1988; Ksakal and Shafiq,[5] 1999). Further studies concern with further metrological parameters precipitation (Rietveld, 1978[6]), latitude (Raja, 1994[7]), relative humidity (Alnaser, 1993[8], Trabea and Shaltout 2000[9]), cloudiness (Kumar and Umanand, 2005[10]), sunshine hours (Akinoglu and Ecevit, 1990[11], Kadir Bakirci [12] 2009; Koussa et al., 2009[13]; Bulut and Buyukalaca, 2007[14]), and air temperature (Fletcher, 2007[15]). Despite of many studies being developed to estimate the solar radiation in Iraq: Iraq has great solar energy potential and this potential is about 2600 hour per year with average daily solar radiation is 501 W/ m^2 (AL-Riahi and AL-Kayssi, 1998 [16]). In spite of these energy abundant the uses of solar energy is very limited. Moreover Several empirical models have been used to calculate solar radiation, utilizing meteorological, geographical and climatological parameters. The new changes in global climatological environment required an assessment of what had been reported, Concerning Iraq Global solar radiation has been measured at the various parts in the Iraq.[2,16,17], and Angstron based model performing an estimate solar energy used. This model has been developed by Page (1964[18]) who presents a linear regression model used in correlating the global solar radiation data with relative sunshine duration. Badescu (1999[19]) studied existing relationships between monthly mean clearness index and the number of bright sunshine hours using the data obtained. Trabea and Shaltout (2000[10]) studied the correlation between the measurements of global solar radiation and the meteorological parameters using solar radiation, mean daily maximum temperature, relative humidity, sea level pressure, vapour pressure, and hours of bright sunshine data. While Sfetsos and Coonick (2000[20]) used artificial intelligence techniques to forecast hourly global solar radiation. Hepbasli and Ulgen (2002[21]) correlated the ratio of monthly average hourly diffuse solar radiation to monthly average hourly global solar radiation with the monthly average hourly clearness index in form of polynomial relationships for the city of Izmir, Turkey. further study, Ulgen and Hepbasli (2002[22]) correlated solar radiation parameters (global and diffuse solar radiation) with respect to ambient temperature in the fifth order. Several investigations (Akpabio *et al*., 2004[23]; Falayi and Rabiu, 2005[24]; Safari and Gasore, 2009[25]) have demonstrated the predictive ability of the Angstrom type model, correlating the global solar radiation to relative sunshine duration in a simple linear regression form. Falayi *et al*. (2008[26]) based their studies on the correlation between global solar radiation and meteorological parameters using monthly average daily global solar radiations, sunshine duration, temperature and relative humidity data. The distribution of total radiation on a horizontal surface over a day was examined by Liu and Jordan[27], also whom shown that the ratio of hourly to daily radiation could be correlated with the local day length and hour angle. The hours were designated by the time for the midpoint of the hour, and the days were considered to be symmetrical about solar noon. The results of Liu and Jordan were confirmed by Collares-Pereira and Rabl[28], using a wider database. A model for hourly solar radiation has also been developed by Al-Sadah *et al*. [29], which were correlated with the local time of day. In this study More than 9050 record of hourly solar radiation on a horizontal surface measured at Tikrit site. The density of records found to be important in correlated model to estimates solar energy in Tikrit. Moreover due to disruption in the social services department from 2003 to 2011 there is no metrological supportive data at this location, a measurement facility found to having taking care only for metrological and climatological data measurement from 2011 onward.

Measurements

The measuring station was located on the roof-top of the Mechanical Department, Faculty of Engineering, University of Tikrit, Iraq (34.66^0 N; $43.46^{\mathbf{0}}$ E), Figure.1 The measurements have been carried out using Portlog (Weather instrument) manufactured by Rainwise Inc, China .

The solar radiation data measured by the zsbauthor, during the period from January to December 2011 were used in this study. The parameters are solar radiation, ambient temperature, dew temperature relative humidity, wind speed , direction of the wind and precipitation. But some days in November and December there is a missing data recording, which is dealt with by using the Kurt Model. The meteorological data were collected for every minute and then averaged for each hour, and each hour of the days average over the whole month giving rise to reasonable statistics of the measurement.

The measurements of solar radiation, ambient temperature and humidity that being measured. however, the measured parameters of one year in an hourly solar radiation Figure.2, with humidity, and ambient temperature for a full yearly record for an hourly shown in Figure 3,4 and 5 respectively. For both of the parameters of ambient temperature and humidity averaged out to fifth order polynomial as given in Figure.6 Furthermore the treatments of the missed data of solar radiation in some days in November and December a Kurt Spokas model[30] being used. The Kurt Spokas model depends on the beam atmospheric transmittance which is a function of humidity using the decision matrix as shown in table.1. which found to be successfully filling up the missed data from recording of solar radiation. The solar radiation effected in early summer and at the Autumn Season by an predictable dust storm with a minor to a major storm accounted to 250 of such storm with its peak value especially in August.

Modeling

In this study a comparison between the existing solar radiations models of calculations with the present correlated experimental measurements. A few important models being used in this study Liu and Jordan[27] , Collarese-Pereira and Rabl[28], Hargreaves and Samani [31] and Annandale et al Model [32]. As far as the empirical calculations concerned in these models depend either on an hourly or a daily distributions. Accordingly the correlations geared to suit these models in terms of hourly or daily required statistics.

1. Hourly Models

Liu and Jordan model being used to estimate the monthly mean hourly global radiation on a horizontal surface ($\bar{I}$) from the monthly mean daily global radiation ($\bar{H}$) on a horizontal surface.

$$\frac{\bar{I}}{\bar{H}} = \frac{\pi}{24}\frac{\cos(w)-\cos(w_S)}{\sin(w_S)-\frac{\pi}{180}w_S\cos(ws)} \qquad (1)$$

Were w is the hour angle in degree for local time in site and w_s is the sunset angle.

Collarese-Pereira and Rabl also is an hourly model and is the same as the Lui and Jordain with additional empirical coefficients.

$$\frac{\bar{I}}{\bar{H}} = (a+b\cos(w_S))\frac{\pi}{24}\frac{\cos(w)-\cos(w_S)}{\sin(w_S)-\frac{\pi}{180}w_S\cos(ws)} \qquad (2)$$

$$a = 0.409 + 0.5016\sin(w_S - 60)$$

$$b = 0.6609 - 0.4767\sin(w_S - 60)$$

For the local site in investigation a period of ten hours daily with 365 days being used to calculate the ratio of monthly mean hourly global radiation to monthly mean daily global radiation using Liu and Jordan model, and Collares-Pereira and Rabl model a computer program was developed in Matlab. The results of these calculations are shown in Figure.8.

Daily Models

Hargreaves and Samani Model used to estimate the daily total radiation formulated as $G_T = G_0.K_r.\sqrt{T_{max} - T_{min}}$. Having the daily temperature extremes (T_{max} and T_{min}) as well as geographical information. Where G_0 is the extraterrestrial radiation in $\left(MJm^{-2}day^{-1}\right)$ and K_r is an adjustment coefficient ($0.16 - 0.19C^{-0.5}$).The correction factor (K_R) is an empirical constant and is determined by the geographical location with recommended values of 0.16 for sites away from water bodies (interior) and 0.19 for locations near water bodies (coastal) [31].also Annandale et al Model modified Hargreaves and Samani model by introducing correction factor as follow:

$$G_T = G_0 K_r (1 + 2.7 \times 10^{-5} h)\sqrt{T_{max} - T_{min}}$$ ….(3)

Where h is elevation in meter (116m) and *Kr* was locally determined. The results of these calculations comparatively are given in table.2 and the procedure explicitly appeared in appendix.

In comparison with the hourly or daily methods of calculations are a correlated estimate of the ratio of the monthly mean hourly ($\bar{I}$) to monthly mean daily ($\bar{H}$) global radiation on a horizontal surface Al-Sadah et al.[30]. This correlation ($\frac{\bar{I}}{\bar{H}} = At^2 + Bt + C$) are used for this calculation were t is the local time ranging from sunrise to sunset in hours. The correlation constant given in table.2. Then the correlation compared with respect to models of calculation as shown table3. and significantly compared with measured with other as given in Figure.6. The confidence of the correlation have to be compared with the Liu and Jordan model and the Collares-Pereira and Rabl model in terms of coefficient of correlation (r) was calculated using formula defined as

$$r = \frac{N\left(\sum\left(\frac{\bar{I}}{\bar{H}}\right)_{exp}.\left(\frac{\bar{I}}{\bar{H}}\right)_{pre}\right)^2 - \sum\left(\frac{\bar{I}}{\bar{H}}\right)_{exp}.\sum\left(\frac{\bar{I}}{\bar{H}}\right)_{pre}}{\sqrt{N\sum\left(\frac{\bar{I}}{\bar{H}}\right)_{exp}^2 - \left(\sum\left(\frac{\bar{I}}{\bar{H}}\right)_{exp}\right)^2} \times \sqrt{N\sum\left(\frac{\bar{I}}{\bar{H}}\right)_{pre}^2 - \left(\sum\left(\frac{\bar{I}}{\bar{H}}\right)_{pre}\right)^2}}$$ …………. (4)

The coefficient of correlation, *r* can be used to determine the linear relationship between the measured and estimated values. Monthly comparison of the correlation values and others is given in table.3.

Results

A code based on Matlab fitted equations for each month to the data for each hour of the day is used. The regression of the fitted equations ($\frac{\bar{I}}{\bar{H}} = At^2 + Bt + C$). The regression constants A, B and C of this equation for each month are given in table 3. The comparison of the calculated model for ratios of hourly to daily global radiation with Collarese-at el and Lui and Jordain , aslo daily to monthly ratio with Annandale et al and Hargreaves and Samani with this measured correlated data results is given Figure.8 (a—l). The daily measurement shows a tendency of flat out in the overall pictures of the curve at both ends due to the solar detector variable sensitivity to light wavelength that have a tendency toward a shorter wavelength in the morning and longer wavelength near sunset which give an overall differential difference from the of the predicted modeling this is clear seen in Figure (8). By observing the monthly average correlated measured values give a deviation of radiation level for both April and august. In April this clearly noticed that April month is the best month with clear sky and moderate temperature and humidity which reflect the best measurement conditions while that of August with unpredicted dusty storm gives the worst measurement conditions having a lower radiation level with about 4% as in table (3).

Discussion

In the correlated measurement for solar radiation, ambient temperature, and humidity has been hourly recorded, while the sunshine duration affect the solar radiation accordingly in cloudiness and dust storm which appeared in March record for thunder strong weather and in August which affected by an predicted dusty storm or local small scale twister which effect the solar radiation record. However, it appears that the near perfect measurements conditions have been noticed in April month of the year with undisturbed sunshine with a moderate temperature and humidity, moreover the lowest humidity level appears between August and July, where such temperature have the highest ambient temperature and inversely in December and January. For the given reasons above the correlative method for the measured data appeared to be highly affected by the local variations of the weather such as thunder stormily weather or un rest transitions from winter to spring season or that from summer up to the end of starter of autumn with the a dominated high temperature and low humidity with a dusty stormy pattern in comparison to best prediction model for period of time for more than ten year of Al-Dulaimy and Al-Shahery[17] calculation noticeably a variation 5% from month to month over the year of observation. Moreover the mean temperature give a different 4% with earlier predicted model while a different a 5% with an earlier NASA[33] Record of the same site. This hinted to sustain the record for further valuable information which may reflect the state of the global climate changing.

Conclusions

The measured data of solar radiation, ambient temperature and humidity which is averaged out in a fifth degree polynomial for hourly, daily and monthly of such observation. A correlative model of second degree with respect to time. This correlative model has been compared to Collarese-at el and Lui and Jordain which is already estimated earlier. The observed correlated data to those of the predictive model gives a scatter of 4% in its lowest to about 5% to its highest deviation which appeared to be the observed data sensitive to the local weather patterns and mostly to dusty storm which should be taking care of in future work.

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Appendix

To develop the model, monthly average of daily global radiation for a given month was calculated from the following equation: $\bar{H} = \sum_{j=1}^{ND}\left[\left(\sum_{i=1}^{Nh} H_{i,j}\right)/Nh\right]/ND$ where $\bar{H}$ is the monthly average of daily global radiation, $H_{i,j}$ is the daily global radiation, Nh is the total number of hours in the day, ND is the total number of days in the month , the (i,j) were i is the index representing an hours and j is representing the day,

$$H_0 = I_{sc} E_0 \cos\theta_Z \dots \dots \text{(A1)}$$

where E_0 is the Extraterrestrial radiation measured on the plane of the nth day of the year,

$$E_0 = \left(1 + 0.033 * COS\left(\frac{360n}{365}\right)\right)^{[33]} \text{(A2)},$$

The solar constant I_{sc} is taken as 1367 Wm^{-2} [34], and θ_z = zenith angle of the sun. then the horizontal surface at any time between sunrise and sunset, according to Liu, and Jordan [28] , the cosine of zenith angle can be expressed by:

$$\left.\begin{aligned} \cos\theta_z &= \sin\delta\sin\phi\cos\beta \\ &-\sin\delta\cos\phi\sin\beta\cos\gamma \\ &+\cos\gamma\cos\phi\cos\beta\cos\omega \\ &+\cos\gamma\sin\phi\sin\beta\cos\gamma\cos\omega \\ &+\cos\sin\beta\sin\gamma\sin\omega \end{aligned}\right\} \text{(A3)}$$

Considering $\beta = 0$ and $\gamma = 0$, then Eq.A3 can be rewritten as:

$$\cos\theta_z = \sin\delta\sin\phi + \cos\phi\cos\omega\cos\delta$$

(A4) Combining Eq.(1) and (4) we have:

$$H_0 = I_{sc}E_0(\sin\delta\sin\phi + \cos\phi\cos\omega\cos\delta) \quad \text{(A5}$$

The extraterrestrial daily solar radiation on a horizontal surface can be obtained by integrating eq. (5) over a period from sunrise to sunset using $\omega = \omega_s$ we have:

$$H_0 = \frac{24*3600}{\pi}.I_{sc}E_0.\left(\begin{aligned}\cos\phi\cos\delta\cos\omega_s + \\ \frac{2\pi\omega_s}{360}\sin\phi\sin\delta\end{aligned}\right) \text{(A6)}$$

if we consider $\cos\theta_s = 0$ and $\omega = \omega_s$. then using equation A3. We have $\omega = Cos^{-1}(-\tan\phi\tan\delta)$ were δ is celestial declination in radians given as follow:

$$\delta = 23.45^0 \sin\left(360 * \frac{284 + J.}{365}\right) \quad \text{.(A7)},$$

were J is the Julian day ranging from 1st of January to 31st of December.

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Figure(1) Regional location of Tikrit

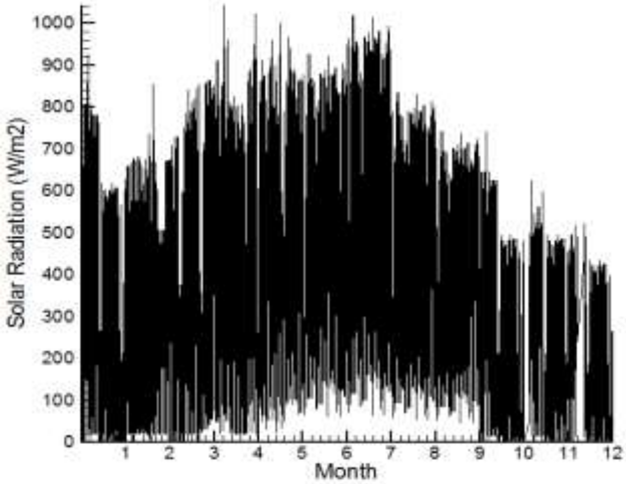

Fig 2. One Year Hourly Solar Radiation With Missing Data

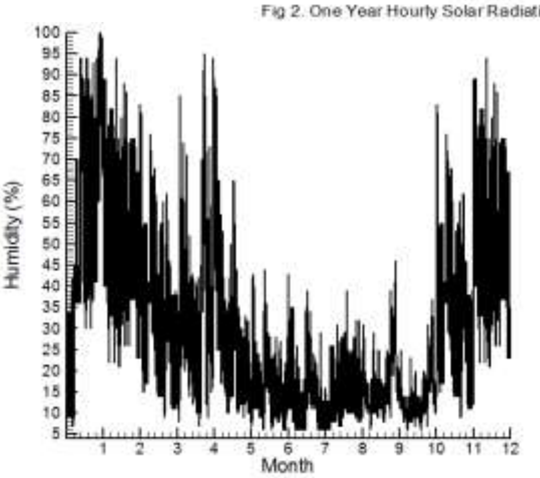

Fig. 3 Complete Hourly Humidity Distribution

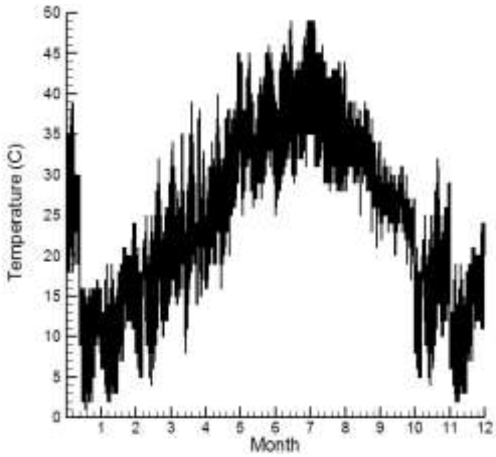

Fig. 4. Complete Hourly Ambient Temperature Distribution

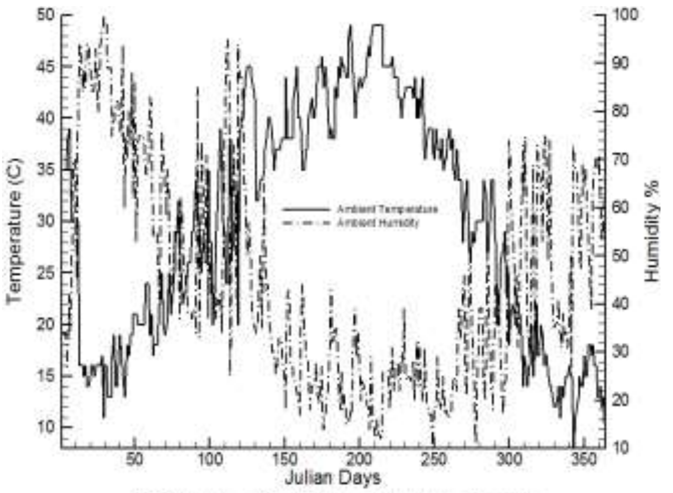

Fig.5 One Year Hourly Data of Relative Humidity And Ambient Temperature

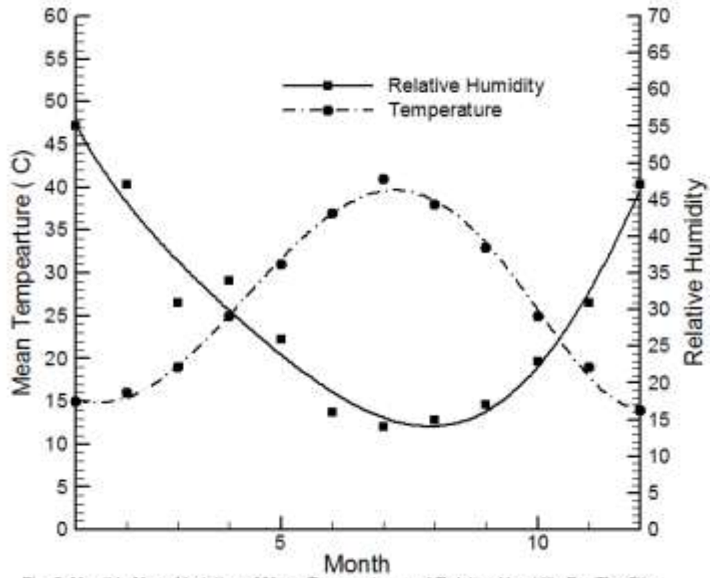

Fig. 6. Monthly Mean Variation of Mean Temperature and Relative Humidity For The Site

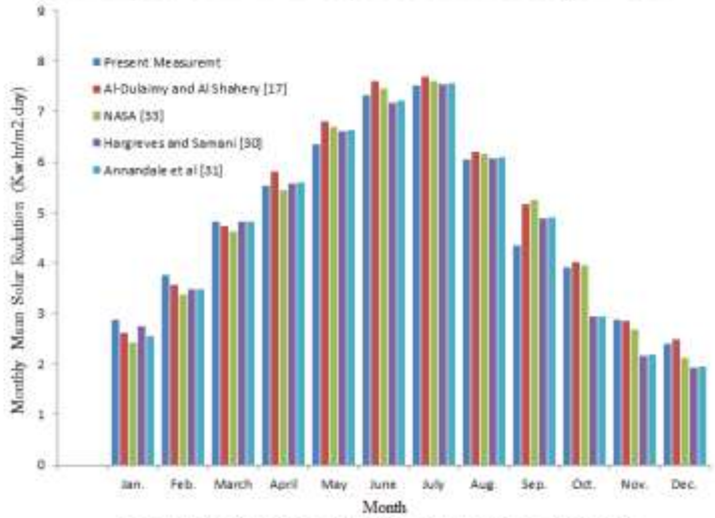

Fig.7. Plot Monthly Global solar Radiation from meaured vs. Other Models

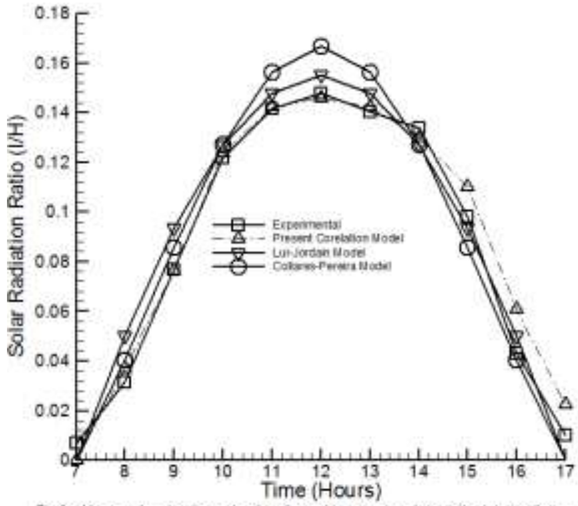

Fig.8a Measured and estimated ratios of monthly mean hourly to daily global radiation for the month of january in Tikrit Site.

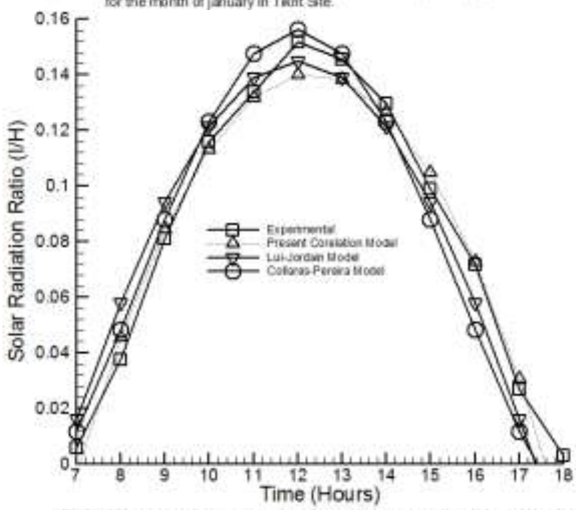

Fig.8b Measured and estimated ratios of monthly mean hourly to daily global radiation for the month of February in Tikrit Site.

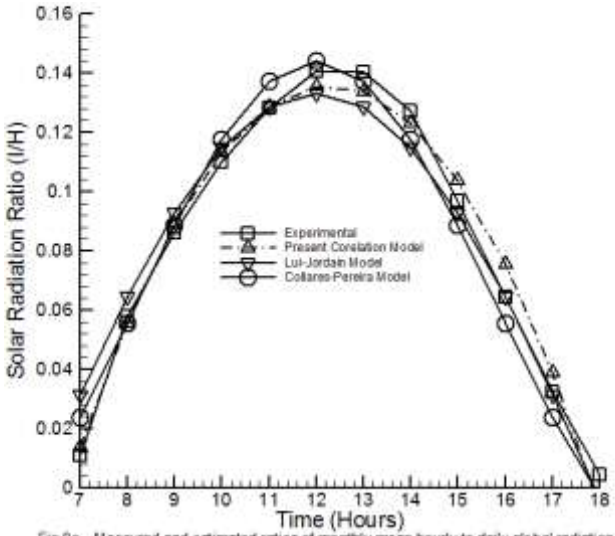

Fig.8c Measured and estimated ratios of monthly mean hourly to daily global radiation for the month of March in Tikrit Site.

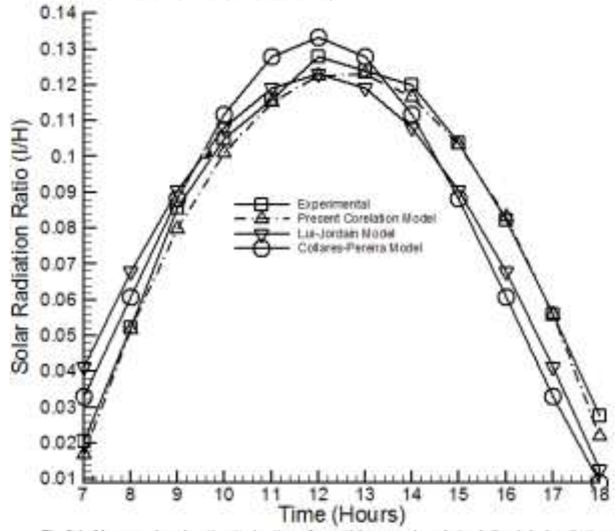

Fig.8d Measured and estimated ratios of monthly mean hourly to daily global radiation for the month of April in Tikrit Site.

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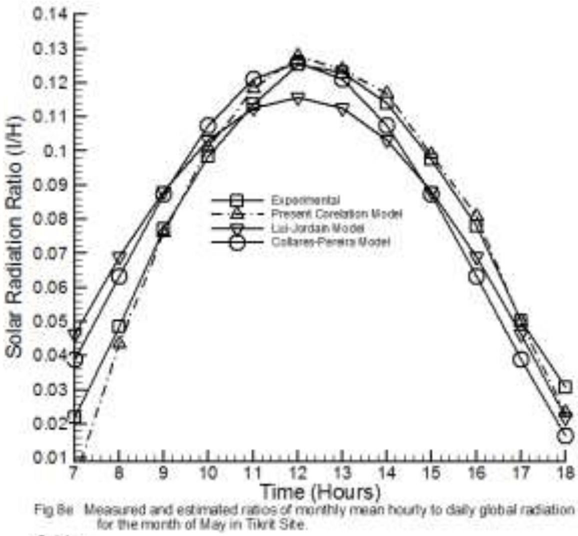

Fig 8e Measured and estimated ratios of monthly mean hourly to daily global radiation for the month of May in Tikrit Site.

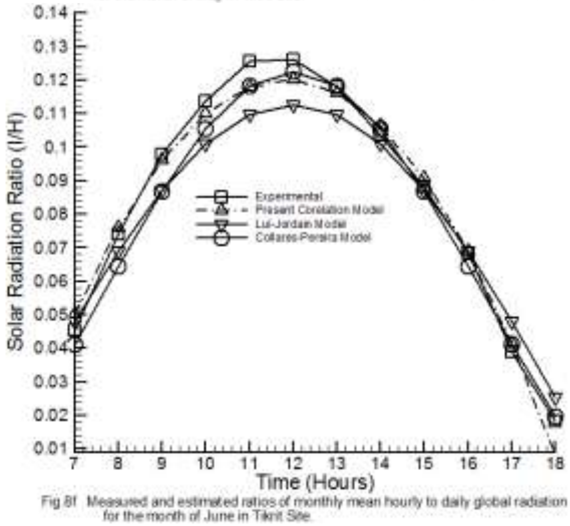

Fig 8f Measured and estimated ratios of monthly mean hourly to daily global radiation for the month of June in Tikrit Site.

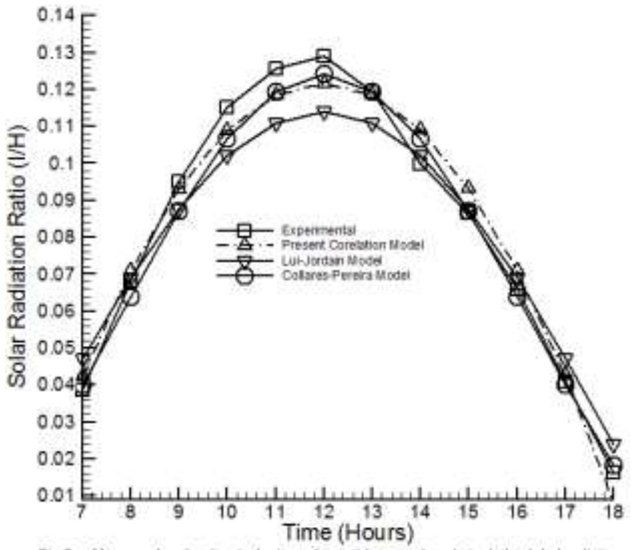

Fig.8g Measured and estimated ratios of monthly mean hourly to daily global radiation for the month of July in Tikrit Site.

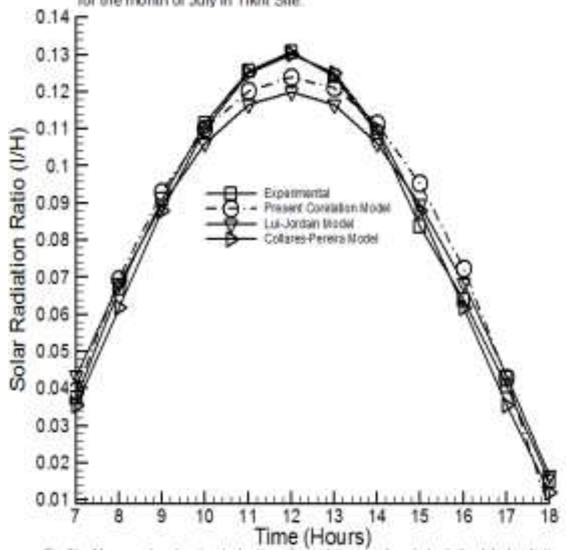

Fig.8h Measured and estimated ratios of monthly mean hourly to daily global radiation for the month of August in Tikrit Site.

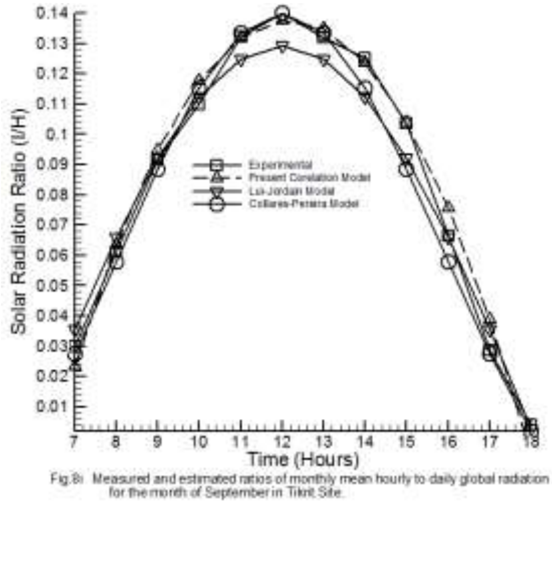

Fig.8i Measured and estimated ratios of monthly mean hourly to daily global radiation for the month of September in Tikrit Site.

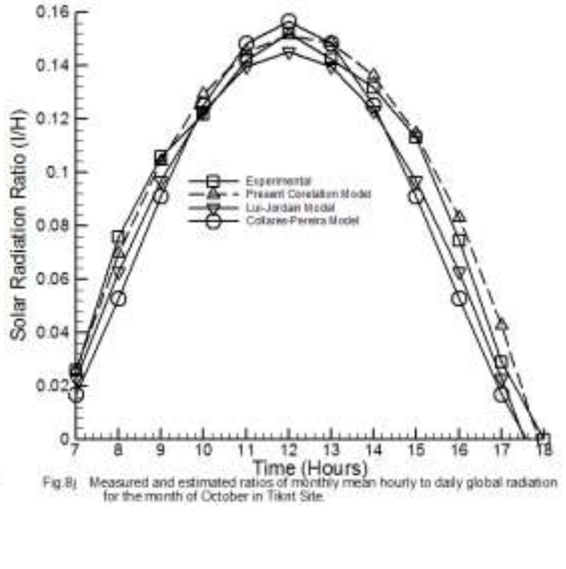

Fig.8j Measured and estimated ratios of monthly mean hourly to daily global radiation for the month of October in Tikrit Site.

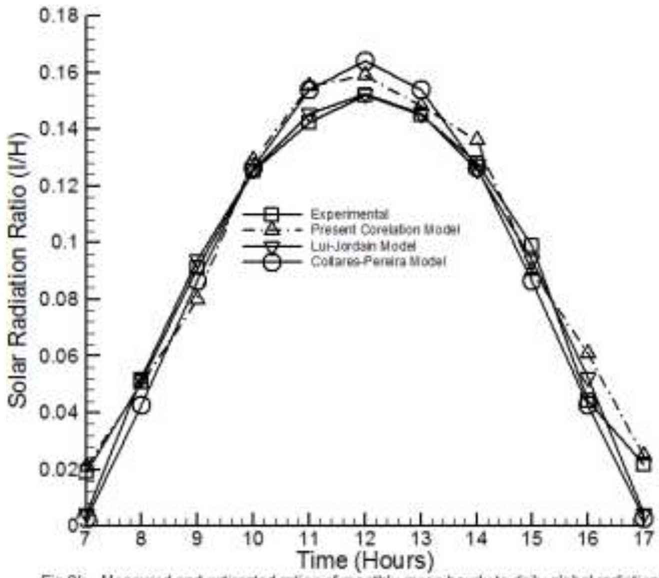

Fig.8k Measured and estimated ratios of monthly mean hourly to daily global radiation for the month of November in Tikrit Site.

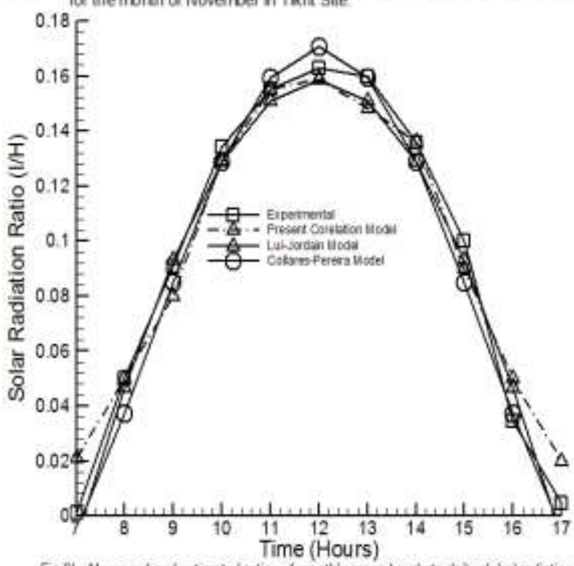

Fig.8l Measured and estimated ratios of monthly mean hourly to daily global radiation for the month of Decmber in Tikrit Site.

Table (1). Atmospheric transmittance coefficient using humidity range

RH	RH <40	40<RH<45	45<RH<55	RH<55<65	65<RH<75	75<RH<80	RH>40
τ	0.69	0.67	0.57	0.47	0.41	0.3	0.2

Table (2). Fitting Constants and Mean solar radiation for Tikrit Weather 2011

	Present model constant			Mean Solar radiation kw. h/m^2 .day				
Month	A	B	C	Present measured	Fayadh 2010 [17]	NASA 2002 [33]	H- S [30]	Annandale et al [31]
January	-0.00625	0.130	-0.710	2.88	2.61	2.42	2.75	2.56
February	-0.00505	0.1246	-0.628	3.76	3.57	3.38	3.47	3.48
March	-0.00437	0.1074	-0.524	4.82	4.73	4.62	4.81	4.82
April	-0.00385	0.0981	-0.495	5.54	5.81	5.45	5.57	5.60
May	-0.00345	0.0867	-0.421	6.35	6.80	6.69	6.62	6.64
June	-0.00297	0.0704	-0.297	7.32	7.60	7.46	7.18	7.21
July	-0.00317	0.0761	-0.335	7.52	7.69	7.60	7.54	7.56
August	-0.00331	0.0798	-0.357	6.05	6.15	6.16	6.08	6.10
September	-0.00406	0.0989	-0.471	4.34	5.16	5.24	4.89	4.91
October	-0.00501	0.1000	-0.510	3.91	4.01	3.96	2.93	2.95
November	-0.00582	0.1203	-0.610	2.87	2.85	2.68	2.16	2.18
December	-0.00651	0.1301	-0.721	2.40	2.49	2.13	1.93	1.94

Table (3). Coefficient of Correlation for Tikrit site Weather

Month	Present	Lui and Jordan model	Collares-pereira and Rabl model
January	0.98789	0.9929	0.9958
February	0.9708	0.9942	0.997
March	0.9874	0.9716	0.9806
April	0.9392	0.9881	0.9896
May	0.9831	0.9824	0.9815
June	0.9842	0.9902	0.9905
July	0.99629	0.9858	0.9911
August	0.9182	0.9922	0.9925
September	0.9707	0.9761	0.9738
October	0.9749	0.9293	0.9182
November	0.96819	0.9483	0.9384
December	0.98489	0.9712	0.9659