The Statistical Analysis between Instant Solar Radiation and Instant Temperature in Fayoum Governorate - Egypt

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Abstract: An empirical relation correlating the instant measured solar radiation R_1 (W/m^2) and the instant temperature T(K) was undertaken. A mathematical analysis was performed to give a relation expressing the instant calculated solar radiation R_2 (W/m^2) and the corresponding temperature T (K) by two coefficients a and b. A FORTRAN computer program has been employed to predict these regressing coefficients together with the instant calculated solar radiation R_2. Also, we have manipulated a useful statistical analysis between R_1 and R_2 together by calculating the mean bias error $MBE = (1/n)\sum(R_1\text{-}R_2)$ and the root mean square error $RMSE = (1/n)[\sum(R_1\text{-}R_2)^2]^{(1/2)}$. This study was performed by using measurements extended along four days in different seasons between Jan 17, 2010 and Oct 17, 2010 in Fayoum Governorate-Egypt (Latitude 29.308374 ^{o}N and longitude 30.844105^o E). We predicted the value of the annual daily average of the global solar radiation R_G in Fayoum region (19.7MJ/m^2/day) in comparison with its values in different global locations.

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Keywords: Annual average daily global solar radiation; Statistical analysis; Correlation equation; FORTRAN computing; Fayoum-Egypt.

Nomenclature:

a and b	Regression coefficients
n	Number of the recorded observations
T	Instant temperature (K)
T_{av}	Average of the instant temperature (K)
R	Instant solar radiation (W/m^2)
R_G	Annual daily average of the global solar radiation MJ/m^2/day
R_1	Instant measured solar radiation (W/m^2)
$R_{1(av)} = \sum(R_1)/n$	Average of the instant measured solar radiation (W/m^2)
R_2	Instant calculated solar radiation (W/m^2)
$R_{2(av)} = \sum(R_2)/n$	Average of the instant calculated solar radiation (W/m^2)
$MBE = (1/n)\sum(R_1\text{-}R_2)$	The mean bias error
$RMSE = (1/n)[\sum(R_1\text{-}R_2)^2]^{(1/2)}$	The root mean square error

1. Introduction

Egypt will face shortly two major problems; the resources of fossil energy and fresh water shortages. Both problems could be alleviated by the proper exploitation of the abundance of the inexhaustible solar energy as the country lies in the rich Sun Belt stretched over North Africa. Long-term average values of the instant global and diffuse solar radiation on a horizontal surface are needed in many applications of solar energy designs [1]. The measured values of these parameters are available at a few places. At others no measurements exist, so it is useful to estimate them from theoretical or empirical models that have been developed on the basis of the measured values. In theoretical and practical studies it is a rational idea that the solar radiation coming to Earth depends on some parameters such as the air temperature and sunshine duration [2]. The relation between the instant solar radiation and corresponding instant temperature is our case study. So, the solar energies dependences on temperature will be only taken into the consideration. Several studies which treated the correlation between the solar radiation and the temperature are cited in [3-12]. In our study we have developed a mathematical analysis method to give a more simple correlation model describing the relation between the instant solar radiation and instant temperature using empirical coefficients. We have built a computing program depending on FORTRAN computing language to achieve the calculations [Appendix]. The formulation of the proportionality can be derived from the measurements of the variables through scatter diagrams and most often by the application of statistical regression methods. Like in any other discipline of science, early solar energy models have linear mathematical forms similar to scientific laws, which express linear relationships between two relevant variables. Similarly, in the solar energy literature, the relationship between solar radiation and temperature can be expressed as a linear equation. Such a pioneering relationship was presented by Angstrom [13] which was later adjusted by Prescott [14] to be site dependent in order to evaluate the regression coefficients. Knowledge of the amount of solar radiation falling on a surface of the earth is of prime importance to engineers and scientists involving in the design of solar energy systems, the solar energy conversion models and many applications such as crop growth techniques, irrigation systems and architectural approaches. In particular, many design methods for thermal and photovoltaic systems require the annual average values of the solar radiation on a horizontal surface as an input, in order to predict the energy production of the system in a specific time interval. In this study we have measured the instant solar radiation and instant temperature as hourly data of four days during the different seasons at Fayoum Governorate -Egypt (Latitude 29.308374 ^{o}N and longitude 30.844105^{o} E) in order to evaluate the annual instant averages and hence the estimation of the annual average values of the solar radiation available.

Similar studies have been approached by several investigators around the globe treating the correlation between solar radiation and the temperature or the correlation between the solar radiation and other parameter like sunshine duration such as [15-33]. Also, it was important to be acquainted with the studies which treated the solar radiation in Egypt [34-40].

2. The mathematical analysis

For mathematical analysis of the relation between the instant solar radiation and the corresponding instant temperature, we have used the process of regression analysis which can be denoted by the supposed relation of the type:

$$R = AB^{T} \tag{1}$$

where R is the instant solar radiation (W/m^2), A and B are coefficients and T is the instant temperature (K). In solar energy literature, it has become common practice to refer to regression models as correlation equations based on the well-known least squares method. Correlation is the degree of relationship between variables, which helps to seek determination of how well a linear model describes the relationship [41].

Taking the logarithmic operator (ln) on both sides of **Eq. (1),** we get:

$$\ln(R) = \ln(A) + [\ln(B)]T \tag{3}$$

Eq. (3) is linear form of the correlation between the instant solar radiation and instant temperature. So, if we put $\ln(R) = x$, $\ln(A) = \mathrm{a}$ and $\ln(B) = \mathrm{b}$ in **Eq. (3)** , it becomes:

$$x = a + bT \tag{4}$$

Taking the summation operator ($\sum$) of each side of **Eq. (4)** we get:

$$\sum(x) = \sum(a) + \sum(bT) \tag{5}$$

or $$\sum(x) = na + b\sum(T) \tag{6}$$

Multiplying **Eq. (5)** by T we get:

$$\sum(Tx) = \sum(aT) + \sum(bT^2) \tag{7}$$

or $$\sum(Tx) = a\sum(T) + b\sum(T^2) \tag{8}$$

By dividing **Eq. (6)** by n and **Eq. (8)** by $\sum(T)$ we get:

$$\sum(x/n) = a + b\sum(T/n) \tag{9}$$

and $$\sum(Tx)/\sum(T) = a + b\sum(T^2)/\sum(T) \tag{10}$$

Subtracting **Eq. (10)** from **Eq. (9)** we get:

$$\sum(x/n)-\sum(Tx)/\sum(T)=b\sum(T/n)-b\sum(T^2)/\sum(T) \tag{11}$$

or $$b=[\sum(x/n)-\sum(Tx)/\sum(T)]/[\sum(T/n)-\sum(T^2)/\sum(T)] \tag{12}$$

Dividing **Eq. (6)** by $\sum(T)$ and **Eq. (8)** by $\sum(T^2)$ we get:

$$\sum(x)/\sum(T) = na/\sum(T) + b \tag{13}$$

and $$\sum(Tx)/\sum(T^2) = a[\sum(T)/\sum(T^2)] + b \tag{14}$$

Subtracting **Eq. (14)** from **Eq. (13)** we get:

$$\sum(x)/\sum(T)-\sum(Tx)/\sum(T^2)=na/\sum(T)-a[\sum(T)/\sum(T^2)] \tag{15}$$

or $$a=[\sum(x)/\sum(T)-\sum(Tx)/\sum(T^2)]/[n/\sum(T)-[\sum(T)/\sum(T^2)] \tag{16}$$

Therefore; we have: $A = \exp(a)$ and $B = \exp(a)$, by substituting in **Eq. (1)** we get:

$$R = \exp(a+bT) \tag{17}$$

where R is the instant solar radiation which is resulted theoretically by determining the coefficients a and b from the calculation and using the measured corresponding instant temperature T.

To differentiate between the instant measured solar radiation and the instant calculated solar radiation it is suitable to name the first as R_1 and second as R_2 respectively.

3. The statistical analysis

The mean bias error $MBE = (1/n)\sum(R_1\text{-}R_2)$ is given as the arithmetic average of the errors and it provides a measure of the overall trend of a given model. The smaller the *MBE* the better is the model result. The root mean square error $RMSE = (1/n)[\sum(R_1\text{-}R_2)^2]^{(1/2)}$ provides a measure of squared deviations. In statistics, the *RSME* of an estimator is square root of the expected value of square of the error. The error is the amount by which the model estimate differs from the corresponding measurement. The error occurs because of randomness or the model does not account for information that could produce a more accurate estimate.

4. Estimations of the solar radiation and results

The measured data are displaying the instant measured solar radiation R_1 and the instant temperature T with the time, which were undertaken for four different days distributed to represent the days of the different seasons in Fayoum - Egypt. R_1 and T were measured using digital light probe-meter (EXTECH instrument) and digital thermometer respectively during the time between 7:00 and 17:30 for each day. Recording the data was achieved as one observation per half of the hour so the number of the observations is n = 22 per each day (**Table 1**). The figures **1, 2, 3** and **4** represent the relation between R_1 and T for the four days.

Table 1: The measured Data of R_1 and T with the time of four days in Fayoum – Egypt

	Sunday January 17, 2010		Tuesday April 27, 2010		Tuesday July 20, 2010		Sunday October 17, 2010	
Time	T (K)	R_1 (W/m^2)	T (K)	R_1 (W/m^2)	T (K)	R_1 (W/m^2)	T (K)	R_1 (W/m^2)
07:00	285.5	120	296	240	298	220	297.5	180
07:30	286	180	297	320	298.5	300	298	220
08:00	286.5	220	299	340	299	350	298.5	360
08:30	287.5	280	299.5	360	299.5	360	299	450
09:00	288.5	320	300	460	300	440	299.5	540
09:30	290	360	301	490	300.5	490	300	580
10:00	291.5	430	302	540	301	520	300.5	600
10:30	293	450	303.5	580	302	580	301	620
11:00	294.5	480	304	680	303	650	302	660
11:30	295	490	305.5	720	304	720	303.5	680
12:00	295.5	500	305	740	304.5	740	304	700
12:30	296	510	305.5	760	305	780	305	720
13:00	296.5	520	306	780	305.5	800	305.5	720
13:30	297	530	306.5	800	306	810	306	730
14:00	297.5	540	307	820	306.5	820	307	720
14:30	298	530	307.5	830	307	840	306.5	700
15:00	297.5	500	307.5	820	307.5	850	306	680
15:30	297	480	307	760	308	840	305.5	500
16:00	296.5	340	306	660	307.5	800	305	450
16:30	296	240	305.5	580	306	780	304.5	320
17:00	295	200	305	460	306.5	640	304	160
17:30	294	160	304	340	306	550	301	120

A FORTRAN program is employed to achieve the calculating of the two parameters a and b for the 4 days and hence we are able to get the instant calculated solar radiation R_2.

Firstly, we have decided to achieve our estimations simply using the complete data of our first day (Sunday, January 17, 2010) as one totality (without breaking data) and the results are shown in **Tables 2** and **3. Fig. 5** represents variation of R_1 , R_2 with the time.

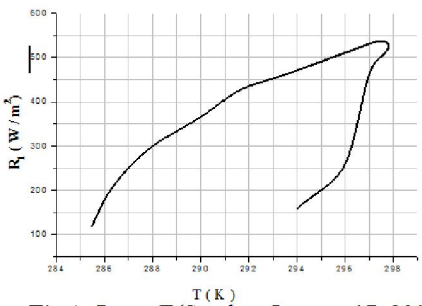

Fig.1: R_1 vs. T (Sunday, January 17, 2010)

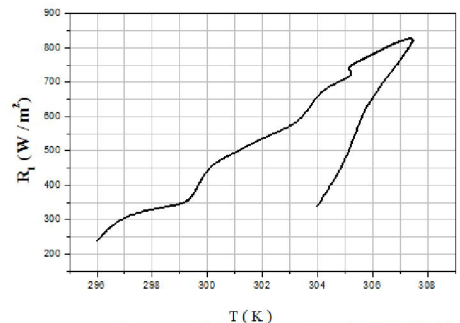

Fig.2: R_1 vs. T (Tuesday, April 27, 2010)

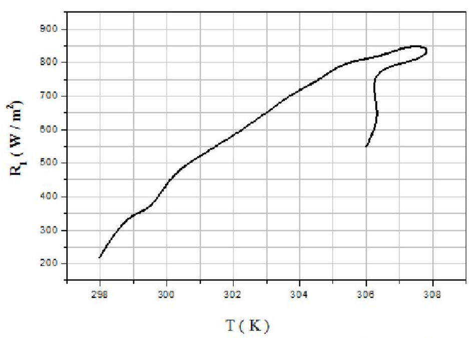

Fig.3: R_1 vs. T (Tuesday, July 20, 2010)

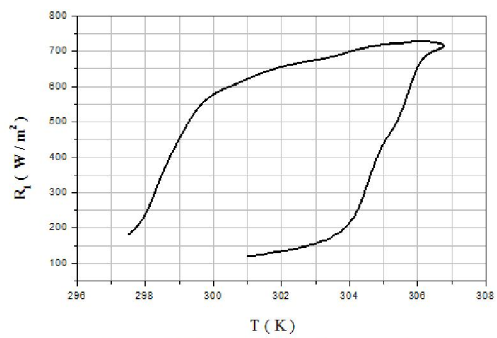

Fig.4: R_1 vs. T (Sunday October 17, 2010)

Table 2: Values of T, R_1 and R_2 (Sunday, January 17, 2010)

Time	T (K)	R_1(W/m^2)	R_2(W/m^2)
07:00	285.5	120	194.6
07:30	286	180	201.9
08:00	286.5	220	209.6
08:30	287.5	280	225.7
09:00	288.5	320	243
09:30	290	360	271.6
10:00	291.5	430	303.5
10:30	293	450	339.2
11:00	294.5	480	379.1
11:30	295	490	393.4
12:00	295.5	500	408.3
12:30	296	510	423.7
13:00	296.5	520	439.7
13:30	297	530	456.2
14:00	297.5	540	473.5
14:30	298	530	491.3
15:00	297.5	500	473.5
15:30	297	480	456.2
16:00	296.5	340	439.7
16:30	296	240	423.7
17:00	295	200	393.4
17:30	294	160	365.3

Table 3: Values of *n, a, b,* T_{av}, $R_{1(av)}$, $R_{2(av)}$, *MBE* and *RMSE* (Sunday, January 17, 2010)

Date	17-1-2010	T_{av}	293.4 K
Time	7:00 to 17:30	$R_{1(av)}$	381 (W/m^2)
n	22	$R_{2(av)}$	364 (W/m^2)
a	-15.88	*MBE*	10399
b	0.074	*RMSE*	0.045

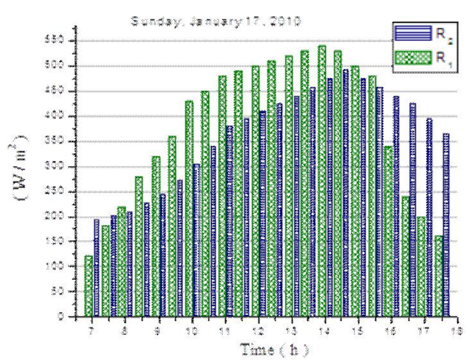

Fig. 5: R_1 and R_2 versus the daily time (Sunday, January 17, 2010, without breaking data)

Also, for more accuracy it was suitable to break the data to two parts, the first part where the temperature increases with the time and the other part where the temperature decreases with the time and hence the parameters *a* and *b* for each part alone were calculated.

So, the data of Sunday, January 17, 2010 will be broken to two parts, the first part starts from 7:00 to 14:30 where the temperature increases from 285.5 K until 298 K and the number of the observation $n=16$ in this part. The second part is starting at the time 15:00 to 17:30 where the temperature decreases from 297.5K until it drops 294K, and the number of the observation $n=6$. This process was very useful to be taken into the consideration for the other days under the study.

Values of T, R_1 and R_2 of the two parts for four days are shown in **Table 4**, where a horizontal line separated between the two parts of the data of each day.

Also, values of *n, a, b,* T_{av} , $R_{1(av)}$, $R_{2(av)}$ *MBE* and *RMSE* of the two parts of the four days are shown in **Table 5**. The quantities R_1 and R_2 versus the time for the two parts of each day from the four days are shown in **Figs 6, 7, 8** and **9.**

Table 4: Values of T , R_1 and R_2 of the two parts for each day

Time	Sunday , January 17, 2010			Tuesday , April 27, 2010			Tuesday, July 20, 2010			Sunday , October 17, 2010		
	T (K)	R_1 (W/m^2)	R_2 (W/m^2)	T (K	R_1 (W/m^2)	R_2 (W/m^2)	T (K)	R_1 (W/m^2)	R_2 (W/m^2)	T (K)	R_1 (W/m^2)	R_2 (W/m^2)
07:00	285.6	120	196.2	296	240	271.3	298	220	316.6	297.5	180	326.6
07:30	286	180	205.5	297	320	300.9	298.5	300	335.7	298	220	345.1
08:00	286.5	220	215.3	299	340	370.4	299	350	355.9	298.5	360	364.7
08:30	287.5	280	236.3	299.5	360	390.2	299.5	360	377.4	299	450	385.5
09:00	288.5	320	259.3	300	460	411	300	440	400.3	299.5	540	407.4
09:30	290	360	298.2	301	490	456	300.5	490	424.4	300	580	430.5
10:00	291.5	430	342.8	302	540	505.9	301	520	450.1	300.5	600	455
10:30	293	450	394.2	303.5	580	591.2	302	580	506	301	620	480.8
11:00	294.5	480	453.2	304	680	622.7	303	650	569	302	660	537
11:30	295	490	474.8	305.5	720	727.7	304	720	639.7	303.5	680	633.9
12:00	295.5	500	497.4	305	740	690.9	304.5	740	678.4	304	700	669.9
12:30	296	510	521.1	305.5	760	727.7	305	780	719.3	305	720	748.2
13:00	296.5	520	545.9	306	780	766.5	305.5	800	762.8	305.5	720	790.7
13:30	297	530	571.8	306.5	800	807.4	306	810	808.8	306	730	835.7
14:00	297.5	540	599.1	307	820	850.4	306.5	820	857.7	307	720	933.4
14:30	298	530	627.6	307.5	830	895.8	307	840	909.4	306.5	700	675.8
15:00	297.5	500	493.4	307.5	820	895.8	307.5	850	964.3	306	680	566.6
15:30	297	480	414.5	307	760	817.2	308	840	1022.7	305.5	500	475
16:00	296.5	340	348.2	306	660	619.22	307.5	800	782.4	305	450	398.2
16:30	296	240	292.5	305.5	580	539	306	780	640.4	304.5	320	333.9
17:00	295	200	206.4	305	460	469.2	306.5	640	684.6	304	160	279.9
17:30	294	160	145.7	304	340	355.5	306	550	640.4	301	120	97.2

Table 5: The values of a, b, T_{av}, $R_{1(av)}$, $R_{2(av)}$, *MBE* and *RMSE*

Day	Part of the day	*n*	*a*	*b*	T_{av} (K)	$R_{1(av)}$ (W/m^2)	$R_{2(av)}$ (W/m^2)	*MBE*	*RMSE*
17-1-2010	7:00 to 14:30	16	- 21.279	0.093	292.40	403.75	402.41	2714	0.062
	15:00 to 17:30	6	- 97.488	0.349	296	320	316.8	1234	0.166
	Average		- 59.383	0.221	294.2	361.875	359.605		
27-4-2010	7:00 to 15:00	17	- 25.146	0.104	303	604.7	604.8	1532	0.058
	15:30 to 17:30	5	- 78.462	0.277	305.5	560	560	1388	0.200
	Average		- 51.804	0.191	304.25	582.35	582.4		
20-7-2010	7:00 to 15:30	18	- 29.184	0.117	303.1	617.2	616.6	5650	0.055
	16:00 to 17:30	4	- 34.386	0.134	306.5	692.5	686.9	7490	0.250
	Average		- 31.785	0.125	304.8	654.85	651.75		
17-10-2010	7:00 to 14:00	15	- 27.098	0.111	301.8	565.3	556.3	10487	0.066
	14:30 to 17:30	7	- 101.546	0.353	304.6	418.6	403.8	4549	0.142
	Average		- 64.322	0.322	303.2	491.95	480.05		
The total Average			- 51.824	0.192	301.6	522.8	518.5		

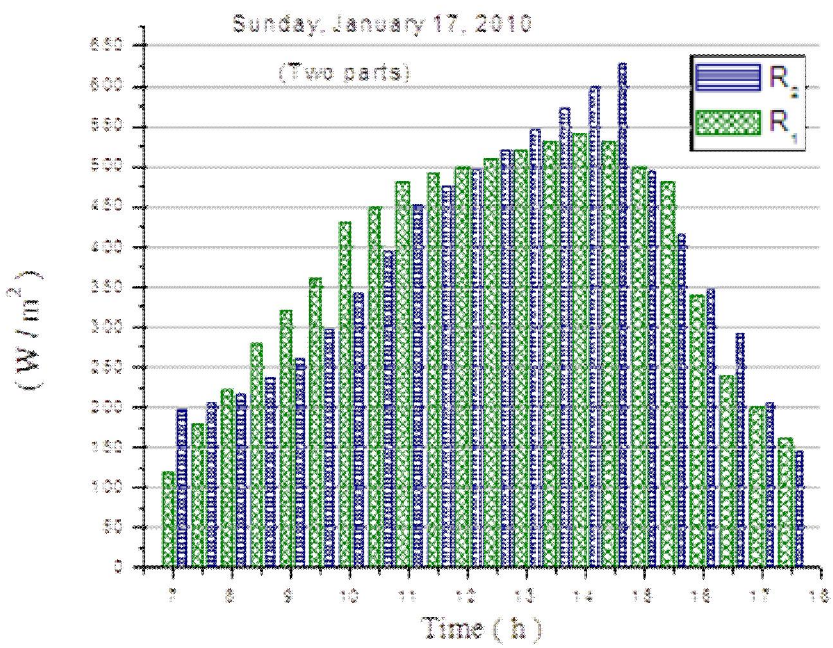

Fig.6: R_1 and R_2 versus the daily time (Sunday, January 17, 2010, two parts)

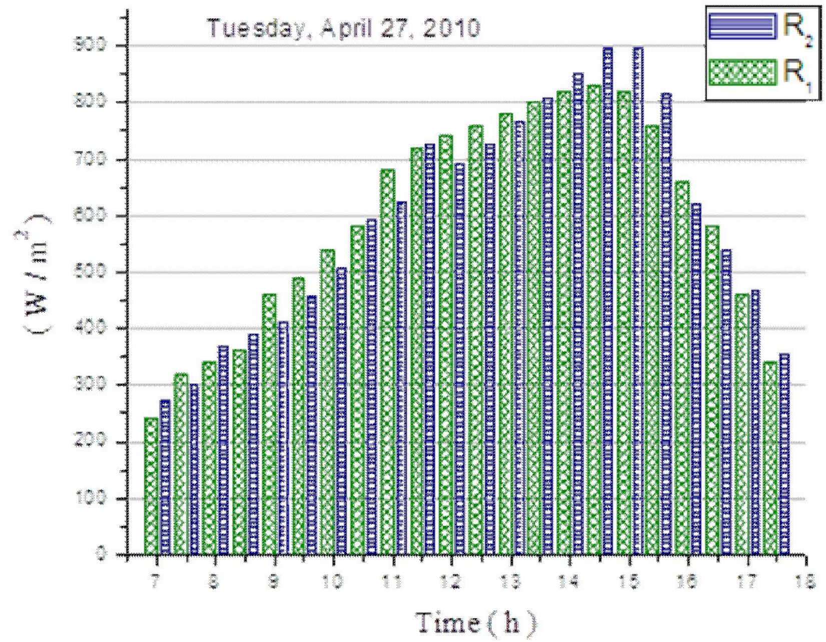

Fig.7: R_1 and R_2 versus the daily time (Tuesday, April 27, 2010, two parts)

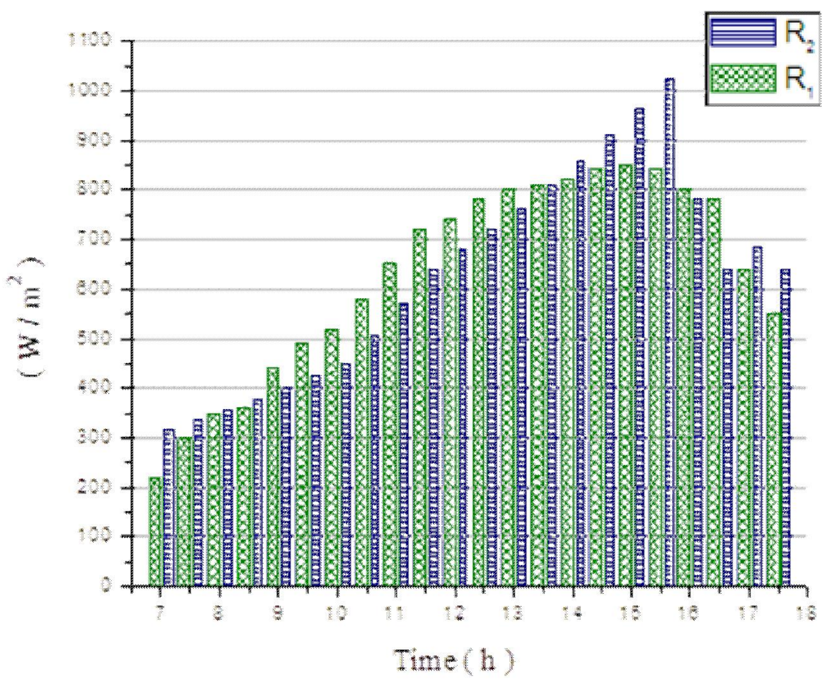

Fig.8: R_1 and R_2 versus the daily time (Tuesday, July 20, 2010, two parts)

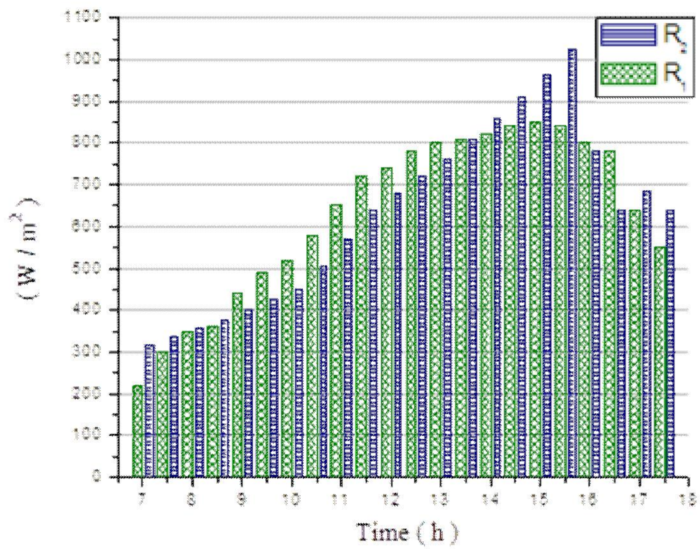

Fig.9: R_1 and R_2 versus the daily time (Sunday, October 17, 2010, two parts)

The values of the coefficients *a, b* in the first part of 17 January 2010 in Fayoum-Egypt are: -21.2785 and 0.093 and in the second part they are: -97.488 and 0.3485 respectively, the difference in their values is due to the difference in the correlation between the instant solar radiation and instant temperature in the morning from the afternoon. Also, we note that their values in the first part of 27 May 2007 in Lucknow-India [3] are: -25.5403 and 0.0919 and in the second part they are: -175.7627 and 0.5711 respectively, the difference is due to the difference in the correlation in the morning from the afternoon. In addition we can note that there is a change in their values according to the change in the place, if we compare between Fayoum-Egypt region and Lucknow-India region.

Table 6 shows the predicted values of the annual average of R_1 and R_2 by using the total average values of R_1 and R_2 (**Table 5)** and the average of the solar duration time.

Table 6: The annual instant, annual hourly, annual daily, annual monthly and annual yearly averages of R_1 and R_2

	R_1	R_2
Annual instant average	522.8 (W/m^2)	518.5 (W/m^2)
Annual hourly average	1.882 MJ/m^2/h	1.867 MJ/m^2/h
Annual daily average	19.76 MJ/m^2/day	19.6 MJ/m^2/day
Annual monthly average	592.8 MJ/m^2/month	588 MJ/m^2/month
Annual yearly average	7.212 GJ/m^2/year	7.154 GJ/m^2/year

To estimate the annual daily average of the global solar radiation R_G we multiply the total average of instant solar radiation (**Table 5**) by the average of the solar duration time being 10.5 hours hence R_G = 19.7 MJ/m^2/day.

The annual daily average of global solar radiation in Cairo, Matruh and Aswan are respectively 18.6, 19.4 and 21.8 MJ/m^2/day respectively [36], in Uyo-Niger region is 14.32 MJ/m^2/day [25]. **Table 7** shows a comparison between the annual daily averages of the global solar radiation in some places.

Table 7: The annual daily averages of the global solar radiation R_G (MJ/m^2/day) in different global locations.

Location	R_G (MJ/m^2/day)	Reference
Fayoum - Egypt	19.70	Present
Abu Dhabi - UAE	18.48	[4]
Uyo-Niger	14.32	[25]
Gangcha-China	18.00	[33]
Lasa- China	20.67	[33]
Cairo- Egypt	18.60	[36]
Matruh- Egypt	19.40	[36]
Aswan- Egypt	21.80	[36]

5. Discussion

The Figures **1, 2, 3** and **4** represent the variation of instant measured solar radiation R_1 with instant measured temperature T during the days under study, and has been observed that some of the instant temperatures couple with two different values of the instant measured solar radiation R_1 and that was due to the temperature falls in the period of the daytime to acquire some of the same values before the fall, so the process of finding a correlation between instant measured solar radiation R_1 and instant measured temperature T is not available without taking into account the variability of time.

It is noted that when we perform the calculations on the complete data without breaking we have found a more accountable difference between the average of the instant calculated solar radiation $R_{2(\mathrm{av})}$ and the average of the instant measured solar radiation $R_{1(\mathrm{av})}$. And when it has been applied on the day 17 January 2010 , value of $R_{2(\mathrm{av})}$ was 364 (W/m^2), while the value of $R_{1(\mathrm{av})}$ was 381 (W/m^2) with the average of percentage of the solar radiation error $R_{r(\mathrm{av})}$ was 17 (W/m^2) and the percentage of $R_{r(\mathrm{av})}$ is 4.5% (Table 6). We found when we split data of the daytime into two parts where the first part is that in which the temperature increases with time and in the second part the temperature decreases with time. For the day 17 January 2010, the temperature increases with time in the time period from 7:00 to 14: 30 and therefore this period represents the first part, while we find that the temperature begins to decrease from the time 15:00 to 17:30 so this period represents the second part.

We have done the accounts by using FORTRAN where the values of the instant measured solar radiation R_1 and instant measured temperature T are required to determine a and b for both parts of the day of 17 January 2010, we could calculate the average of the instant calculated solar radiation $R_{2(\mathrm{av})}$ .We noted that $R_{2(\mathrm{av})}$ in the first part is 402.41 (W/m^2), while $R_{1(\mathrm{av})}$ is 403.75 (W/m^2), $R_{r(\mathrm{av})}$ is 1.34 (W/m^2).

6. Conclusions

(1) The correlation between the instant solar radiation and instant temperature is reliable in predicting the instant solar radiation in terms of the instant temperature.

(2) FORTRAN computing language is a very powerful in the estimation of the solar radiation models.

(3) Breaking the data into two parts according the increasing or the decreasing in the temperature gives more accurate values of the correlation coefficients a and b and therefore more closer values of R_2 to values of R_1 .

(4) Getting the annual instant average value is useful in predicting of the annual global average value in any interval of the time.

(5) We have calculated the annual daily average of the global solar radiation in Fayoum Governorate and it is 19.7 MJ/m^2/day, which is very important in the study of solar projects and solar conversion energy systems in Fayoum region.

(6) The annual yearly average value of the solar radiation in Fayoum is almost 7.2 GJ/m^2/year. This shows how Fayoum region is considered one of the best places in Egypt for the solar energy production projects.

References

1. Zekai S. Solar energy in progress and future research trends. Progress in Energy and Combustion Science 2004; 30: 367- 416.
2. Zekai S. Solar Energy Fundamentals and Modeling Techniques. London: Springer-Verlag; 2008 .
3. Usha B, Kalpana S. Estimation of instant solar radiation by using of instant temperature. Acta Montanistica Slovaca- Rocnik 2009; 14: 189 -96.
4. Islam MD, Kubo I, Ohadi M, Alili AA. Measurement of solar energy radiation in Abu Dhabi, UAE. Applied Energy 2009; 86: 511–5.
5. Huashan L, Xianbiao B, Zhen L, Liang Z, Weibin M. Calculating the diffuse solar radiation in regions without solar radiation measurements. Energy 2012; 44:611-5.
6. Tao P, Shaohong W, Erfu D, Yujie L. Estimating the daily global solar radiation spatial distribution from diurnal temperature ranges over the Tibetan Plateau in China. Applied Energy 2013; 107: 384-93.
7. Iranna K, Bapat VN. General formula for the estimation of global solar radiation on earth's surface

around the globe. Renewable Energy 2012; 41: 394 - 400.
8. Prieto JI, Martinez-Garcia JC, Garcia D. Correlation between global solar irradiation and air temperature in Asturias – Spain. Solar Energy 2009, 83: 1076 - 85.
9. Kurt S, Frank F. Estimating hourly incoming solar radiation from limited meteorological data. Weed Science 2006; 54: 182-89.
10. Miroslav T, Zdenek Z, Josef E, Martin D. Global solar radiation in Central European lowlands estimated by various empirical formulae. Agricultural and Forest Meteorology 2005; 131: 54 -76.
11. Punnaiah V, Yesuratnam G, Syam SL. Estimation of annual solar radiation from measured temperatures by using temperature-based (TB) approach in different cities in India. Sustainable Cities and Society 2011; 1: 187 - 94.
12. Xiaoying L, Xurong M, Yuzhong L, Qingsuo W, Jens RJ, Yanqing Z, et al. Evaluation of temperature-based global solar radiation models in China. Agricultural and Forest Meteorology 2009; 149: 1433-46.
13. Angstrom A. Solar terrestrial radiation. Q J R Meteorol Soc 1924; 50: 121-26.
14. Prescott JA. Evaporation from water surface in relation to solar radiation. Trans R Soc Austr 1940; 40:114 -8.
15. Muzathik AM, Ibrahim MZ, Samo KB, Wan Nik WB. Estimation of global solar irradiation on horizontal and inclined surfaces based on the horizontal measurements. Energy 2011; 36: 812-8.
16. Augustine C, Nnabuchi MN. Relationship between global solar radiation and sunshine hours for Calabar-Port Harcourt and Enugu- Nigeria. International Journal of Physical Sciences 2009; 4: 182-8.
17. Ekpe JE, Nnabuchi MN. Solar radiation in Onitsha: A correlation with average temperature. Scholarly Journals of Biotechnology 2012; 1: 101-7.
18. Fariba B, Ali AD, Ahmad RF. Empirical models for estimating global solar radiation: A review and case study. Renewable and Sustainable Energy Reviews 2013; 21: 798 - 821.
19. Guillermo PP, Liliana N, Carlos AV, Maria AS. Estimating daily solar radiation in the Argentine Pampas. Agricultural and Forest Meteorology 2004; 123: 41-53.
20. Hakan OM, Can E, Mehmet HS. Evaluation of global solar radiation models for Konya-Turkey. Energy Conversion and Management 2006; 47: 3149–73.
21. Harry S, Ross SB and Hollands KGT.) Relationship between sunshine duration and solar radiation. Solar Energy 2013; 92: 160-71.
22. Inci TT, Hasan T, Dugyu E. Estimation of monthly global solar radiation from sunshine duration measurement in Elazigg. Renewable Energy 2000; 19: 587–95.
23. Inci TT. Estimation of solar radiation from Angstrom's coefficients by using geographical and meteorological data in Bishkek, Kyrgyzstan, Thermal Science and Technology 2009, 29: 99-108.
24. Isaac R, Bahram B, Kourosh Q, Mehrdad A. Calibration of Angstrom's equation for estimating solar radiation using meta-heuristic harmony search algorithm (Case study: Mashhad-East of Iran). Energy Procedia 2012; 18: 644 - 51.
25. Ituen, Eno E, Esen, Nsikan U, Nwokolo, Samuel C, et al. Prediction of global solar radiation using relative humidity, maximum temperature and sunshine hours in Uyo, in the Niger Delta Region, Nigeria. Advances in Applied Science Research 2012; 3:1923-37.
26. Almorox J, Hontoria C. Global solar radiation estimation using sunshine duration in Spain. Energy Conversion and Management 2004; 45: 1529–35.
27. Kovacs F, Bohm J, Vadászi M. Changes in solar radiation energy and its relation to monthly average temperature. Acta Montanistica Slovaca Rocnik 2002; 7: 164 -6.
28. Iziomon MG, Mayer H. Performance of solar radiation models - a case study. Agricultural and Forest Meteorology 2001; 110 : 1–11.
29. Okundamiya MS, Nzeako AN. Empirical model for estimating global solar radiation on horizontal surfaces for selected cities in the six geopolitical zones in Nigeria. Engineering and Technology 2010; 2: 805-12.
30. Tahas SV, Ristoiu D, Cosm C. Trends of the global solar radiation and air temperature in Cluj-Napoca, Romania (1984–2008). Rom. Journ. Phys. 2011; 56: 784 -789.
31. Theo CC Equations for estimating global solar radiation in data sparse regions. Renewable Energy 2008; 33: 827–31.
32. Xiaoying L, Xurong M, Yuzhong L, John RP, Qingsuo W, Yanqing Z. Choice of the Angstrom–Prescott coefficients: Are time-dependent ones better than fixed ones in modeling global solar irradiance?. Energy Conversion and Management 2010; 51: 2565–74
33. Xiaoying L, Yinlong X, Xiuli Z, Wenying Z, John RP and Wenli L. Assessing models for parameters of the Angstrom–Prescott formula in China. Applied Energy 2012; 96: 327-38.
34. Trabeaa AA, Mosalam SMA. Correlation of global solar radiation with meteorological parameters over Egypt, Renewable Energy 2000; 21: 297–308.
35. Ibrahim A, El-Sebaii AA, Ramadan MRI, El-Broullesy SM. Estimation of solar irradiance on inclined surfaces facing south in Tanta, Egypt. International Journal of Renewable Energy Research 1 (2011) 18-25.
36. Omran MA. Analysis of solar radiation over Egypt. Theor. Appl. Climatol 2000; 67: 225–40.
37. Mosalam SMA, Hassan H, Fathy AM. Study of the solar radiation over Menia. Renewable Energy 2001; 23: 621–39.
38. Mossad E. Simple new methods to estimate global solar radiation based on meteorological data in Egypt. Atmospheric Research 2004; 69: 217–39.
39. Mossad E. Sunshine and global solar radiation estimation at different sites in Egypt. Atmospheric and Solar-Terrestrial Physics 2005; 67: 1331–42.
40. Robaa SM. A Study of Solar Radiation Climate at Cairo Urban Area, Egypt and its Environs. Int. J. Climatol. 2006; 26: 1913–28.
41. Muneer T. Solar Radiation and Daylight Models. Oxford: Elsevier; 2004.

Appendix

```
      !FORTRAN Program for Solar Radiation estimations!
      DIMENSION T(50),R1(50),X1(50),T2(50),X1T(50),a(50),b(50),X2(50)
      DIMENSION ST(50),SR1(50),SX1(50),ST2(50),SX1T(50),R2(50),SR2(50)
      DIMENSION MBE(50),RMSE(50), SMBE(50),SRMSE(50)
      INTEGER  n
      REAL a, b
1      READ(*,*) n
      DO 2 i=1,n,1
2      READ(*,*) T(i)
      DO 3 i=1,n,1
3      READ(*,*) R1(i)
      DO 4 i=1,n,1
4      X1(i)=log(R1(i))
      DO 5 i=1,n,1
5      T2(i)=T(i)*T(i)
      DO 6 i=1,n,1
6      X1T(i)=X1(i)*T(i)
      ST(1)=0
      SX1(1)=0
      ST2(1)=0
      SX1T(1)=0
      DO 7 i=2,n+1,1
7      ST(i)=ST(i-1)+T(i-1)
      DO 8  i=2,n+1,1
8      SX1(i)=SX1(i-1)+X1(i-1)
      DO 9  i=2,n+1,1
9      ST2(i)=ST2(i-1)+T2(i-1)
      DO 10  i=2,n+1,1
10     SX1T(i)=SX1T(i-1)+X1T(i-1)
      b(1)=(SX1(n+1)/n-SX1T(n+1)/ST(n+1))/(ST(n+1)/n-ST2(n+1)/ST(n+1))
      s1=SX1(n+1)/ST(n+1)-SX1T(n+1)/ST2(n+1)
      s2=n/ST(n+1)-ST(n+1)/ST2(n+1)
      Tav=ST(n+1)/n
      a(1)=s1/s2
      DO 11 i=1,n,1
11     a(i)=a(1)*T(i)/T(i)
      DO 12 i=1,n,1
12     b(i)=b(1)*T(i)/T(i)
      DO 13 i=1,n,1
13     X2(i)=a(i)+b(i)*T(i)
      DO 14 i=1,n,1
14     R2(i)=exp(a(i)+ b(i)*T(i))
      DO 15 i=1,n,1
15     MBE(i)= R1(i)-R2(i)
      DO 16 i=1,n,1
16     RMSE(i)=(R1(i)-R2(i))**2
      SR1(1)=0
      SR2(1)=0
      SMBE(1)=0
      SRMSE(1)=0
      DO 17 i=2,n+1,1
17     SR1(i)= SR1(i-1)+ R1(i-1)
      DO 18 i=2,n+1,1
18     SR2(i)= SR2(i-1)+ R2(i-1)
      DO 19 i=2,n+1,1
19     SMBE(i)=SMBE (i-1)+MBE(i-1)
      DO 20 i=2,n+1,1
20     SRMSE (i)= SRMSE (i-1)+RMSE(i-1)
      R1AV=SR1(n+1)/n
      R2AV=SR2(n+1)/n
      MBEAV= SRMSE(1+n)/n
      RMSEAV=((SRMSE(1+n))**(1/2))/n
      DO 21 i=1,n,1
21     WRITE(*,*)"T",T(i),"R1",R1(i),"R2",R2(i)
      WRITE(*,*)"n=" , n , "a=" , a(1) , "b=" , b(1)
      DO 22 i=1,n,1
22     WRITE(*,*)"MBE",MBE(i),"RMSE",RMSE(i)
      WRITE(*,*)"Tav",Tav,"R1AV",R1AV,"R2AV",R2AV
      WRITE(*,*)"MBEAV",MBEAV,"RMSEAV",RMSEAV
      GOTO 1
      END
```

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