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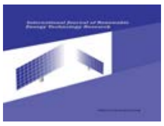

Research article

Correction of the ASHRAE clear-sky model parameters based on solar radiation measurements in the Arabic countries

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Abstract

In Arabic territories, the ASHRAE clear sky model is commonly used as a basic tool for solar radiation estimation. Unfortunately, this model was developed for the atmospheric condition in the USA, which was quite different from weather conditions of the Arabic territories. The purpose of this study was to revise all parameters of the ASHRAE model under the atmospheric conditions of Arabic countries in an attempt to improve the accuracy of the model. The solar-radiation over horizontal surface calculated by the ASHRAE clear-sky model is compared with measurements form (Brack-Libya, Tulkarm-Palestine and Riyadh- Saudi Arabia) cities in order to test the validity of the ASHRAE clear-sky model parameters (A, B and C).The revised model is tested against statistical analysis based on RMSE, MBE and t-stat. the results showed that the revised model can be a good estimator for the prediction of global solar radiation in Arabic countries with an acceptable agreement to the measured data from meteorological record stations. That performance is a more accurate prediction than those throughout the previous studies. This model presented the unique alternative approach for solar radiation prediction in regard to the locations where there is no availability of some input data for other models. Instantaneous, daily, monthly and yearly solar-radiation on various surfaces such as building walls and flat-plate solar collectors can then be conveniently calculated using the adjusted model for different orientations and inclination angles. The model also allows the beam, diffuse and ground-reflected solar-radiation components to be determined separately. **Copyright © IJRETR, all rights reserved.**

Keywords: Clear sky model, ASHRAE model, solar radiation data of Palestine, solar radiation data of Libya, solar radiation data of Saudi Arabia

1. Introduction

Solar energy occupies one of the most important places among the various possible alternative energy sources. In many applications of energy, the solar irradiance incident on a surface at a location of interest is an important input parameter. These include calculation of air-conditioning loads in buildings, design and performance evaluation of passive building-heating systems as well as solar energy collection and conversion systems. Such data are also beneficial in areas of agriculture, water resources, day-lighting and architectural design, and climate change studies.

In order to derive the detailed solar radiation climatology of a region and to estimate the potential of solar energy in any location, extensive radiation measurements of high quality at the location of interest are necessary. An accurate knowledge of solar radiation distribution at a particular geographical location is of vital importance for the development of many solar energy devices and for the process of estimating their performances. Unfortunately, for many developing countries solar radiation measurements are not easily available for not being able to afford the measurement equipment and techniques involved. Therefore, it is rather important to elaborate methods to estimate the solar radiation without the need to meteorological data.

Compared to meteorological parameters such as precipitation, temperature and wind, scarcity of irradiance measurements which are not available except for a limited geographical locations around the world. Even in developed countries, daily measurements of solar radiation are too dispersed location-wise to be used in simulation models. Alternatives such as the use of average values, spatial interpolation, estimates from remote-sensing data, and estimates obtained from models based on climatic variables have been suggested. However, for interpolation to be used , the maximum distance between observing stations and the location of interest should not exceed 30km in order to account for the most spatial variation of global radiation [1].

As for the use of average values, it is not adequate in the analysis of energy systems which usually require hour-by-hour values. Because of the previous needs and the scarce nature of solar radiation measurements, many models with varying degrees of complication, detail and accuracy have been developed. Some of these models are either empirical and therefore are site-dependent or semi-empirical of a more general nature when local parameters are input into them. In this study , the ASHRAE clear-sky model is used to calculate the hourly global solar radiation on a horizontal surface in different locations among the Arabian territories. The basic idea of this study is to compare the theoretical values of the estimation of hourly clear sky solar radiation based on the ASHRAE method with the measurement of data recorded in the meteorological stations along many years. As a result, new constants will be generated from the comparison that fits these constants for widely range of latitudes. Results of the present study can provide a dependable procedure of how to predict the amount of solar radiation on average, hour by hour, during any given month of the year in Arabic territories.

Around the world and for many years of development of solar energy industry many researchers have attempted to develop the ASHRAE clear sky model [2-35], this study conducted to the same issue.

2. Location and climatic information

The Arab world Extends between latitudes 2 degrees in the south, 37.5 degrees in the north and extends between longitude 17 degrees in the west , and 60 degrees in the east. Covering an area of 14.291.469 km^{2}which is equivalent to10.2% of the world including 22 Arab countries, ten of them in Africa by 72.45% of its area and 12 in Asia by 27.55% of its area. Maximum stretch about 6000 km East to West and from North to South about 4000 km. Arab world is located amid the old world continents of Asia, Africa and Europe; its territory is extended throughout Asia and Africa and is separated by the Red Sea; overlooking the Arab world of the Red Sea, the Mediterranean Sea, the Arabian Gulf and the Arabian Sea and overlooks the Atlantic Ocean to the West and the Indian Ocean to the East, as it illustrated in figure 1.More than 80% of the area is the Sahara desert in the African part and Arabian Peninsula in the Asian part. While the climatic of the Arab World can be distinguished by three territories [36]:

1. The desert climate: occupies 80% of the total area, and includes the Arabian Peninsula area and most regions of Iraq and Egypt and Northern Sudan in addition to the Sahara desert which covers most of the area of Egypt, Sudan, Libya, Algeria, Morocco and Mauritania.
2. The Mediterranean climate: the littoral coast prevails and nearby areas of the Mediterranean (the Levant countries, the North of Egypt, Iraq and north Africa countries); and
3. The Tropical climate: prevails Somalia, Eritrea, Djibouti, Yemen, Sudan, Comoros, south western Saudi Arabia and parts of the Sultanate of Oman.

Regarding to this strategic location, the Arabic countries are most favourable for solar energy utilisation. The number of sunshine hours amounts to almost 3300 h./year, but the distribution of the solar radiation is not well known. The importance of this study is stemmed from the fundamental need of knowledge of the global solar radiation data in these countries. AS a result, Europe tended attention to this unpopulated huge desert area with very high solar energy potential, Europe launched the gigantic project "Desertec" to generate the electricity from the Sahara desert and transport to Europe with budget of $ 650 billion.

Figure 1. Map of the Arab World

At the start, the aim of this study was to find out new ASHRAE parameters that are compatible with the measurement data recorded at climatology stations for all capitals of the Arab world. But unfortunately, there is a shortage in solar data for most of those capitals . The data available and only obtained for the cities presented in table 1.

Table 1. Geographic information about the three stations used in the study

Station	Country	Latitude	Longitude	Elevation (m)	Years
Riyadh	Saudi Arabia	24.72	46.72	600	2006
Brack El-Shati	Libya	27.53	14.28	334	2004-2011
Tulkarm	Palestine	32.31	35.03	125	2012-2016

3. Estimation Method

As recommended by ASHRAE (1985) and presented in all text books of solar energy [37,38], hourly global radiation (H), hourly beam radiationin the direction of rays (H_b), and hourly diffuse radiation (H_d) on the horizontal surface on a clear day are calculated using the following equations, respectively:

$$H = H_b + H_d \tag{1}$$

$$H_b = H_{bn} cos\theta_Z \tag{2}$$

$$H_d = CH_{bn} \tag{3}$$

$$H_{bn} = Aexp(-B/cos\theta_Z) \tag{4}$$

Where A is the apparent solar-radiation constant, B is the atmospheric extinction coefficient, and C is the diffuse sky factor and there values are tabulated in table 1 for a widely range of latitudes $0° \leq L \leq 64°$.

Theθ_Z is the zenith angle and the cosine of the zenith angle isgiven by the equation:

$$cos\theta_Z = sinLsin\delta + cosLcos\delta cosh \tag{5}$$

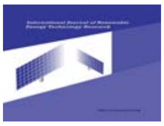
Where δ is the solar declination, L is the latitude of the location, and h is the hour angle. The solar declination (δ) is given as:

$$\delta = 23.45sin\left[\frac{360}{365}(n + 284)\right] \tag{6}$$

where n is the Julian day of the year starting from January 1. The hour angle (h)is an angular measure of time and is equivalent to 15°per hour with morning negative sign morning and positive for afternoon hours. It is measured from noon-based local solar time (ST) from the equation given by:

$$h = 15(ST - 12.0) \tag{7}$$

The local solar time (ST) is calculated from the local standard time (LT) and the equation of time (EOT) is given later by:



$$ST = LT + EOT/60 - 4/60\,(L_S - L_L) \tag{8}$$

where L_S is the standard meridian ($= 45°$) for the local time zone (longitude of the time zone) andL_L is the longitude of the location in degrees west .($0° \leq L_L \leq 360°$). Theequation of time (EOT) is:

$$EOT = 9.87 sin2M - 7.53 cosM - 1.5 sinM \tag{9}$$

where M is given as:

$$M = \frac{360}{365}(n - 81) \tag{10}$$

The advantage of this model is that there is no need for any data from the meteorological station; the only need is for nine parameters, namely: A, B, C, EOT,δ, L, L_S , L_L, and local standard time (LT). The parameters A, B and C that is provided by ASHRAE (1985) for each month are presented in Table 1. The following other parameters are specific to the location of interest. The final parameter; namely , the local standard time (LT) is now the only varying parameter which is input for calculations at any required time of the day.

4. Clear sky radiation

A clear sky in this context is exemplified by a continuous smooth recording of radiation intensity with steady values at any time. An indicator of sky conditions which is often used is the "clearness number" K, defined as:

$$K = \frac{H}{ET} \tag{11}$$

where H is the daily global radiation (direct plus diffuse incident on a horizontal surface) and ET is the daily extra terrestrial radiation. Obviously K cannot exceed unity and in practice would not be expected more than 0.8. unfortunately, regional/seasonal values of clearness index, required to use the clear-sky model are not measured.

The 12 sets of coefficients reflect the annual variation of the absolute atmospheric humidity. Because humidity had an influence on particle size of aerosols, the variations of the constants B and C indicate a variation in turbidity as well. The constant A is related to the solar constant. The tabulated values of A are based on work dating back to 1940, which assumes a solar constant of 1332 W/m^2. Recent accurate measurements yield an agreed-upon value of 1367 W/m^2. To account for regional variations of humidity and turbidity, ASHRAE published maps for a parameter called ‘‘clearness number’’ for both summer and winter and for different regions in the USA. This parameter is used to modify the radiation values obtained from the model. The unavailability of these factors for other regions of the world prevented the use of this model for these regions. The purpose of the present study is to develop adjustment factors to the ASHRAE clear-sky model for Arabic countries in the same spirit of these ‘‘clearness numbers’’ [8].

5. Comparison Methods

To evaluate the accuracy of the correlations described above, two statistical tests were enhanced -root mean square error (RMSE) , mean bias error (MBE), and t-statistic [9,10].

5.1. The root mean square error (RMSE)

The root mean square error is defined as:

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}\left(H_{i,calc} - H_{i,meas}\right)^2\right]^{1/2} \tag{12}$$

where $H_{i,calc}$ is i^{th} calculated value, $H_{i,meas}$ is the i^{th} measured value, and N is the total number of observations. The RMSE is always positive when a zero value is ideal. This test provides information on short- terms performance of the correlation by arranging them term by term and in comparison with the actual deviation between the calculated value and the measured value; whenever the value is smaller , the performance of the model is better. However, a few large errors in the sum can produce a significant increase in RMSE.

5.2. The mean bias error (MBE)

The mean bias error is defined as:

$$MBE = \frac{1}{N}\sum_{i=1}^{N}\left(H_{i,calc} - H_{i,meas}\right) \tag{13}$$

This test provides information in regard to the long term performance through which a low MBE is desired. Ideally, a zero value of MBE should be obtained. A positive value gives the average amount of over-estimation in the calculated value and vice versa. A drawback of this test is that an individual observation will can celled over estimation under a separate observation. It is obvious that each test by itself may not be an adequate indicator of a model’s performance. It is possible to have a large RMSE value and at the same time a small MBE (a large scatter about the line of perfect estimation). On the other hand, it is also possible to have a relatively small RMSE and a relatively large MBE (a consistently small over – or under – estimation); however, although these statistical indicators generally provide a reasonable procedure to compare models, they do not objectively indicate whether the estimates of a model are statistically significant, i.e., not significantly different from their measured counterparts. In this study, the *t*-statistic was used as an additional statistical indicator. This statistical indicator allows models to be compared and at the same time indicate whether or not the estimates of a model are statistically significant at a particular confidence level.

5.3. The t-statistic (t-stat)

It was observed that a more reliable and explanatory results are yielded when the *t*-statistic is used in addition to the RMSE and MBE.
The t-statistic is defined as:

$$t - stat = \left[\frac{(N-1)MBE^2}{RMSE^2 - MBE^2}\right]^{1/2} \qquad (14)$$

The smaller the value of *t-stat*, the better is the performance of the model. To determine whether the estimates of a model are statistically significant or not, a critical *t-stat* value obtainable from standard statistical tables has simply to be determined at a particular confidence level, i.e. $t\alpha/2$ at the α level of significance and (*N-1*) degrees of freedom. For the estimates of a model to be judged statistically significant at the 1- α confidence level, the calculated *t-stat* value must be less than the critical *t* value.

6. Methodology

In order to obtain the data of the clear sky for each month in a year, a technique to identify solar radiation data of the clear sky condition was adopted. The recorded data of the clear sky for the whole day over many years has been sorted out. The sorted data were selected out from those days which had a ratio between the duration of bright sunshine hours and the total possible bright sunshine hours greater than 0.85. A clear sky day can be identified by observing the symmetry of the amount of a half day global solar radiation before and after the solar noon during a day. However, for some locations , it was hard to find any clear day during the winter monsoon season. The selected 21st from every month were tabulated in tables 2,3and 4 for Riyadh - Saudi Arabia, Brack - Libya and Tulkarm - Palestine respectively.
Combined equations 1-4 yields:

$$H = A\,exp\left(\frac{-B}{cos\theta_Z}\right)(cos\theta_Z + C) \qquad (15)$$

$$ln(H) = \ln\left[A\,exp\left(\frac{-B}{cos\theta_Z}\right)(cos\theta_Z + C)\right] \qquad (16)$$

$$= \left(\frac{-B}{cos\theta_Z}\right) + ln(A) + ln(cos\theta_Z + C) \qquad (17)$$

Separating the values of A,B and C, yields:

$$A = \frac{H}{exp\left(\frac{-B}{cos\,\theta_Z}\right)(cos\theta_Z + C)} \qquad (18)$$

$$B = [ln(A) + ln(cos\theta_Z + C) - ln(H)]cos\theta_Z \qquad (19)$$

and

$$C = \frac{H}{A\,exp\left(\frac{-B}{cos\,\theta_Z}\right)} - cos\theta_Z \qquad (20)$$

Because the values of the parameters A,B and C are taken constants during a day, the last three equations must satisfy the global solar radiation for any hour in a particular day. Depending on our experience, the shortest way to get out these parameters is to use the maximum value of solar radiation to find out the parameter A, the minimum value of solar radiation to find out the parameter B and the value of C must satisfy any value of the list of solar radiation data. This equation can be solved by using trial and error technique and the process will reach stability after no more than 30 iterations with allowable error not exceed more than 0.0001.In some days the stability of answer can't be achieved because the asymmetrical behaviour of the data. To overcome this problem, this study enhanced only two equations (18 and 19) , and for parameter C a trial and error technique is enhanced -alone on the excel work sheet and directly until the best satisfaction between the calculated and the measured values of the solar radiation is recorded. A FORTRAN computer program is written to solve these equations under the given data in tables (2, 3 and 4) for Riyadh, Brack and Tulkarm, respectively. The obtained results are tabulated in table 5.The revised ASHRAE model of this study was verified for its accuracy of predications. The obtained parameters of A, B and C were then used to predict solar radiation under clear sky days. The results of the prediction were compared with the actual observations in the same period. The accuracy of the revised model was determined for root mean square error(RMSE) and mean bias error (MBE).

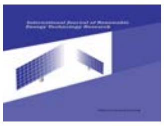
The hourly solar radiation for the three cities are tabulated in tables 2,3 and 4 for Riyadh, Brack and Tulkarm, respectively. It was obtained These data directly from the meteorological stations in a friendly way.

Table 2. Measured global solar radiation on a horizontal surface for 21 every month for Riyadh-Saudi-Arabia

Month Time	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	69	96	151	54	93	0	0	0	0
7	22	65	175	304	305	399	283	321	282	226	30	40
8	205	275	396	525	525	635	526	559	533	332	344	222
9	383	469	586	699	702	831	745	774	745	675	523	391
10	546	641	744	834	825	962	898	919	895	800	661	535
11	662	762	844	904	909	1034	989	1007	980	919	739	631
12	716	822	884	914	897	1048	1019	1036	1000	895	808	663
13	693	808	852	868	827	1011	993	1014	960	902	750	616
14	607	725	752	765	723	918	904	933	850	825	675	509
15	459	573	597	610	591	772	753	793	690	688	544	351
16	260	369	352	384	442	570	549	597	504	500	370	154
17	42	129	131	169	224	336	301	360	270	285	120	38
18	0	0	0	6	33	91	64	113	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0

Table 3. Measured global solar radiation on a horizontal surface for 21st every month for Brack - Libya

Month Time	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	25	90	100	100	27	0	0	0	0
7	10	69	165	245	259	328	297	220	133	65	11	8
8	190	270	402	413	463	533	504	420	346	267	175	183
9	411	457	602	608	617	705	677	595	552	459	371	353
10	502	611	739	762	791	828	793	724	690	617	544	506
11	637	695	822	870	897	895	864	829	797	709	635	582
12	677	750	859	905	940	901	880	869	835	738	664	593
13	646	724	849	868	886	860	853	845	803	725	616	564
14	559	632	770	793	787	758	770	763	718	635	530	500



15	425	492	618	632	630	622	626	623	577	484	402	348
16	242	306	393	427	454	449	470	429	340	285	180	193
17	16	104	191	255	264	286	300	239	186	71	10	2
18	0	0	0	20	75	72	85	49	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0

Table 4. Measured global solar radiation on a horizontal surface for the day 21stof every month for Tulkarm-Palestine

Month Time	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	23	75	90	62	29	0	0	0	0
7	50	158	96	197	245	250	169	179	100	81	19	4
8	208	346	293	291	432	434	370	319	245	257	140	86
9	368	508	490	518	608	599	539	579	410	429	287	240
10	493	629	645	651	751	739	726	693	539	569	412	382
11	566	689	752	817	841	847	782	817	758	657	497	478
12	583	695	818	856	887	903	850	880	745	687	515	519
13	532	644	812	824	876	892	842	866	696	651	500	505
14	438	517	747	751	804	826	771	793	640	554	400	438
15	302	351	577	606	683	708	689	670	531	416	260	321
16	142	162	399	454	522	556	476	498	266	238	100	170
17	15	158	180	266	343	380	267	307	155	68	1	30
18	0	0	0	97	162	198	121	127	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0

7. Results and discussion

From the methodology mentioned above, the revised parameters of the ASHRAE model have been calculated. Evaluation of the errors of the unrevised ASHRAE model and the revised ASHRAE model were compared with the climatic stations recorded data.

7.1. Adjustment of the ASHRAE parameters

The Obtained values of A, B and C are presented graphically in figure 2 and numerically in table 5, together with ASHRAE parameters, for the cities under consideration in the study.

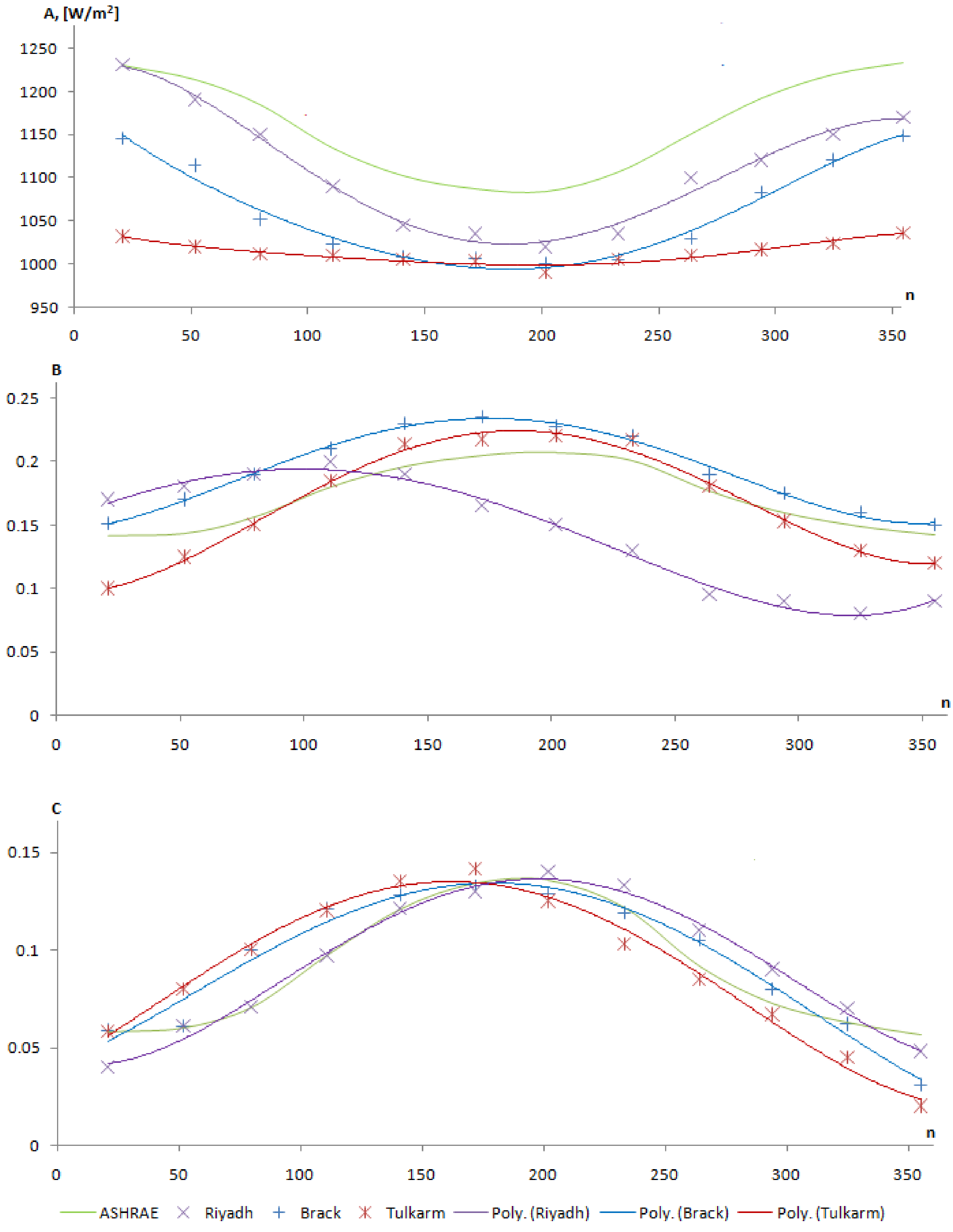


Figure 2. Curve fitting of the revised clear sky model A, B and C and the ASHRAE parameters

Obviously from figure 2, There are a significant difference in the values recommended by ASHRAE and those values obtained in this study especially for the parameter A. However, the behaviour of the revised parameters A, B and C for the three cities are smooth and compatible, except that of Riyadh for the B parameter. The reason may be related to the shortage of data available. The best fitting of the data has been obtained by MS. Excel program and found as:

For Riyadh - Saudi Arabia ($L = 24.72° N$)

$$A = 2\times10^{-10}n^5 - 4\times10^{-7}n^4 - 0.038n^2 + 0.907n + 1224 \qquad R^2 = 0.987 \qquad (21)$$
$$B = 5\times10^{-11}n^4 - 2\times10^{-8}n^3 - 2\times10^{-6}n^2 + 0.153 \qquad R^2 = 0.990 \qquad (22)$$
$$C = 8\times10^{-11}n^4 - 7\times10^{-8}n^3 + 1\times10^{-5}n^2 + 0.044 \qquad R^2 = 0.991 \qquad (23)$$

For Brack - Libya ($L = 27.53°\,N$)

$$A = -4\times10^{-10}n^5 + 2\times10^{-7}n^4 - 5\times10^{-5}n^3 + 0.012n^2 - 2.339n + 1193 \qquad R^2 = 0.980 \qquad (24)$$
$$B = 9\times10^{-11}n^4 - 6\times10^{-8}n^3 + 1\times10^{-5}n^2 + 7\times10^{-5}n + 0.145 \qquad R^2 = 0.992 \qquad (19)$$
$$C = 5\times10^{-11}n^4 - 3\times10^{-8}n^3 + 5\times10^{-6}n^2 + 0.041 \qquad R^2 = 0.973 \qquad (25)$$

For Tulkarm - Palestine ($L = 32.31°\,N$)

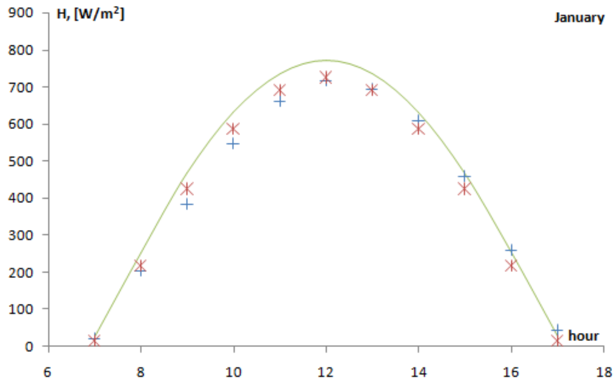
$$A = -2\times10^{-10}n^5 + 1\times10^{-7}n^4 - 4\times10^{-5}n^3 + 0.06n^2 - 0.680n + 1043 \qquad R^2 = 0.928 \qquad (26)$$
$$B = 1\times10^{-10}n^4 - 9\times10^{-8}n^3 + 2\times10^{-5}n^2 + 0.098 \qquad R^2 = 0.992 \qquad (27)$$
$$C = 6\times10^{-11}n^4 - 4\times10^{-8}n^3 + 4\times10^{-6}n^2 + 0.04 \qquad R^2 = 0.979 \qquad (28)$$

Table 5. ASHRAE and revised values of clear sky model parameters A, B and C for several locations

		Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
ASHRAE	A	1230	1214	1185	1135	1103	1088	1085	1107	1151	1192	1220	1233
	B	0.142	0.144	0.156	0.18	0.196	0.205	0.207	0.201	0.177	0.16	0.149	0.142
	C	0.058	0.06	0.071	0.097	0.121	0.134	0.136	0.122	0.092	0.073	0.063	0.057
Riyadh	A	1230	1190	1150	1090	1045	1035	1020	1035	1100	1120	1150	1170
	B	0.171	0.180	0.190	0.200	0.191	0.165	0.150	0.130	0.095	0.090	0.080	0.090
	C	0.04	0.061	0.071	0.097	0.121	0.130	0.14	0.133	0.110	0.090	0.070	0.048
Brack	A	1145	1114	1052	1024	1009	1007	1000	1005	1030	1083	1120	1148
	B	0.151	0.169	0.190	0.209	0.23	0.235	0.228	0.220	0.190	0.175	0.16	0.151
	C	0.059	0.061	0.1	0.121	0.128	0.134	0.129	0.119	0.105	0.08	0.062	0.031
Tulkarm	A	1032	1020	1012	1010	1005	1003	990	1005	1010	1017	1024	1036
	B	0.101	0.125	0.150	0.184	0.213	0.218	0.220	0.217	0.180	0.153	0.130	0.119
	C	0.058	0.080	0.100	0.120	0.135	0.144	0.126	0.101	0.085	0.067	0.045	0.020

7.2. Calculation of global solar radiation incident on a horizontal surface

By using equations 1-4, the hourly global solar radiation is calculated according to the revised parameters of the obtained results which were compared with the previously measured data and with the ordinary ASHRAE models as well. The obtained results presented graphically in figures 4, 5and 6, as well as the measurement data, and the ordinary parameters recommended by ASHRAE for cites: Riyadh, Brack and Tulkarm respectively. It is obvious that the revised parameters model gave acceptable accuracy better than the parameters of the model that are recommended by ASHRAE.


H, [W/m²]
January
hour
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100
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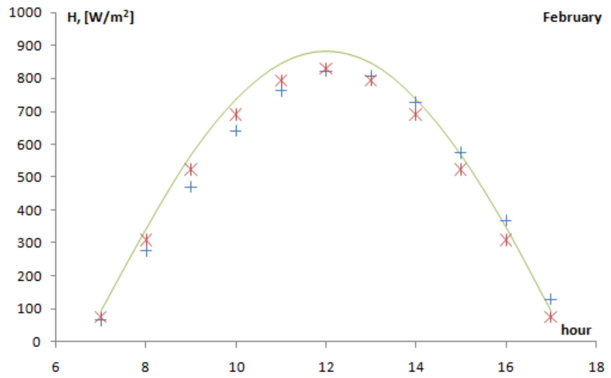
H, [W/m²]
February
hour
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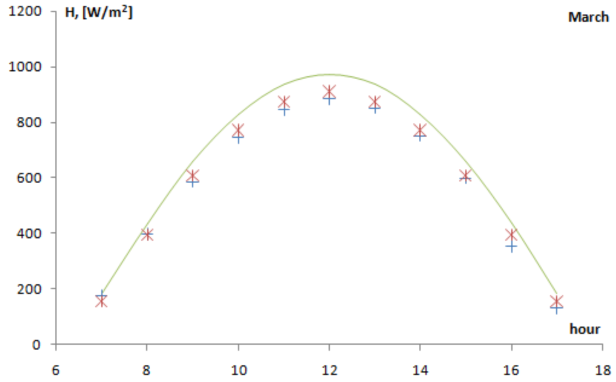
H, [W/m²]
March
hour
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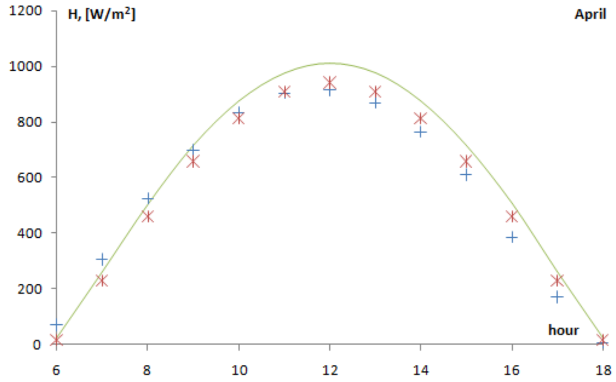
H, [W/m²]
April
hour
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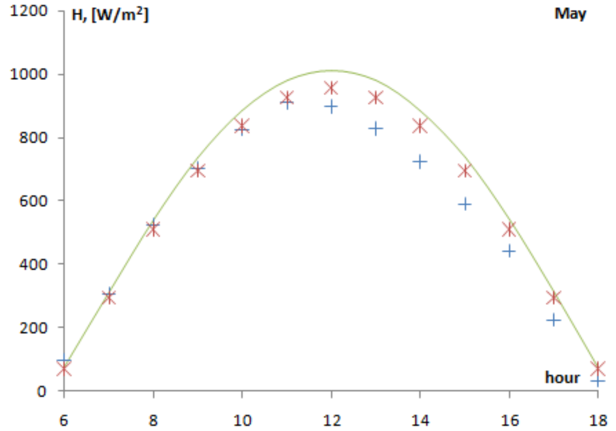
H, [W/m²]
May
hour
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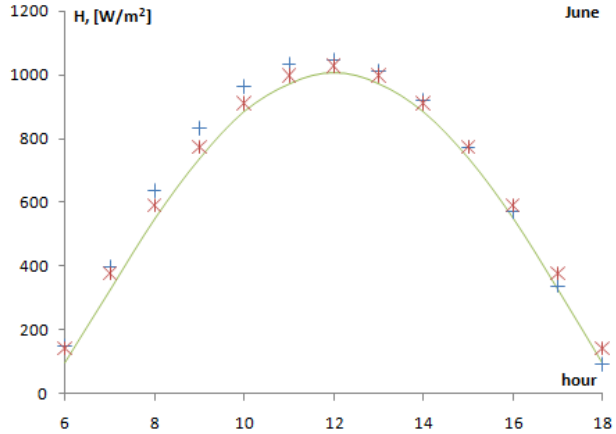
H, [W/m²]
June
hour
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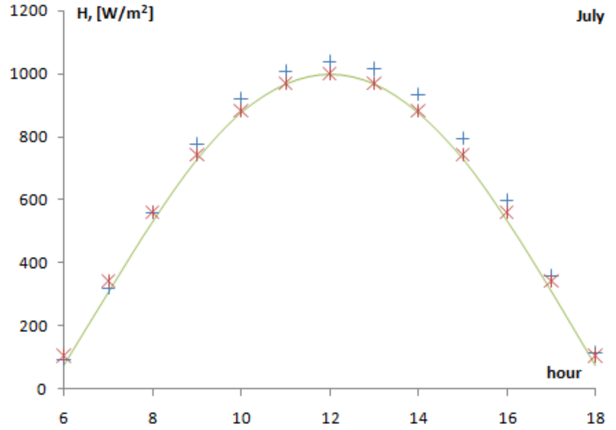
H, [W/m²]
July
hour
0
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600
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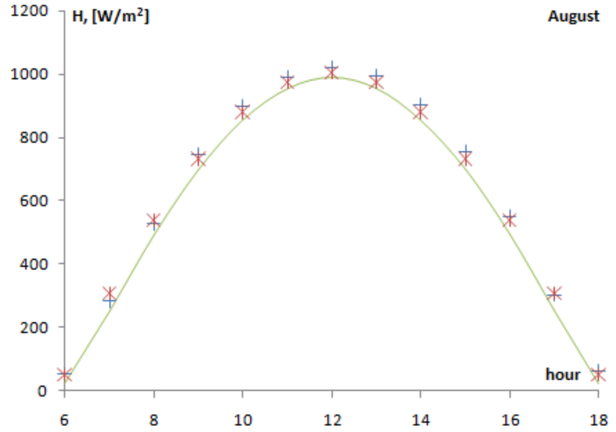
H, [W/m²]
August
hour
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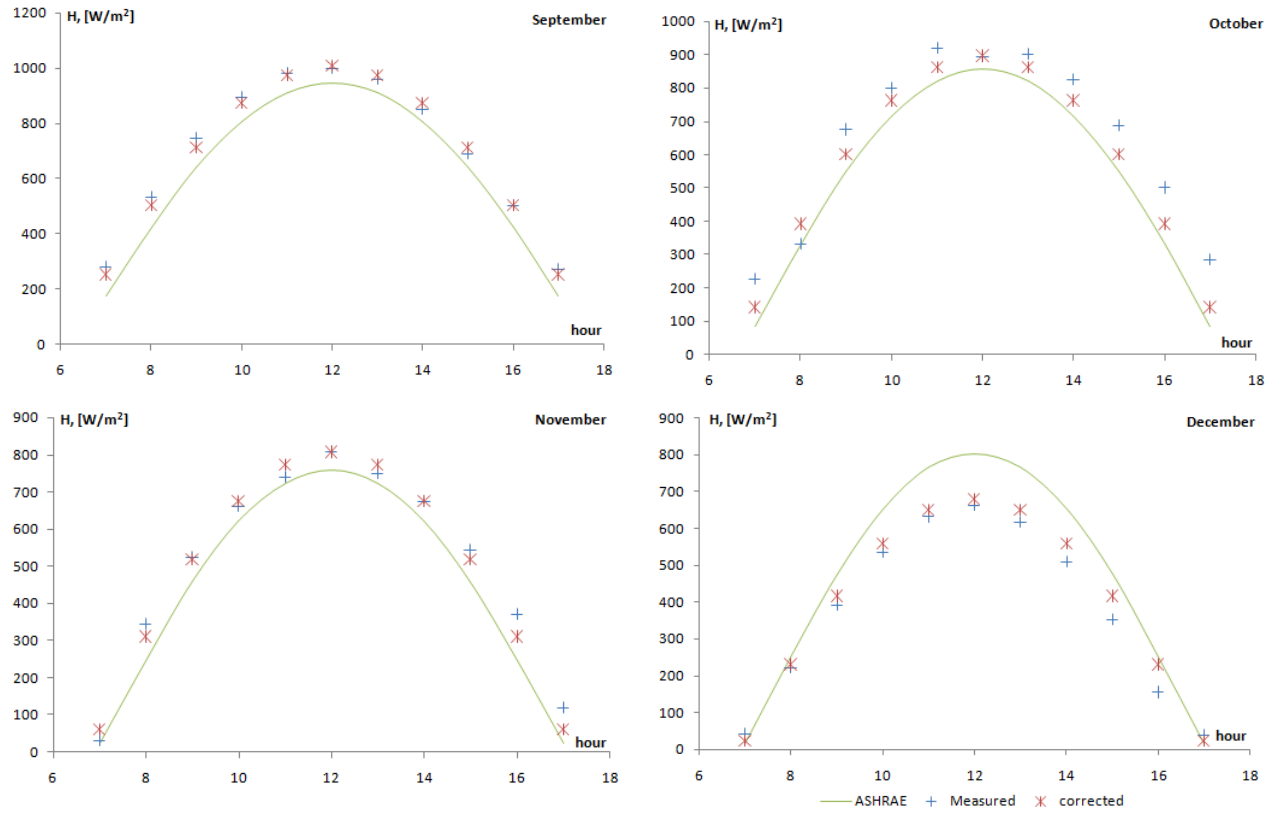
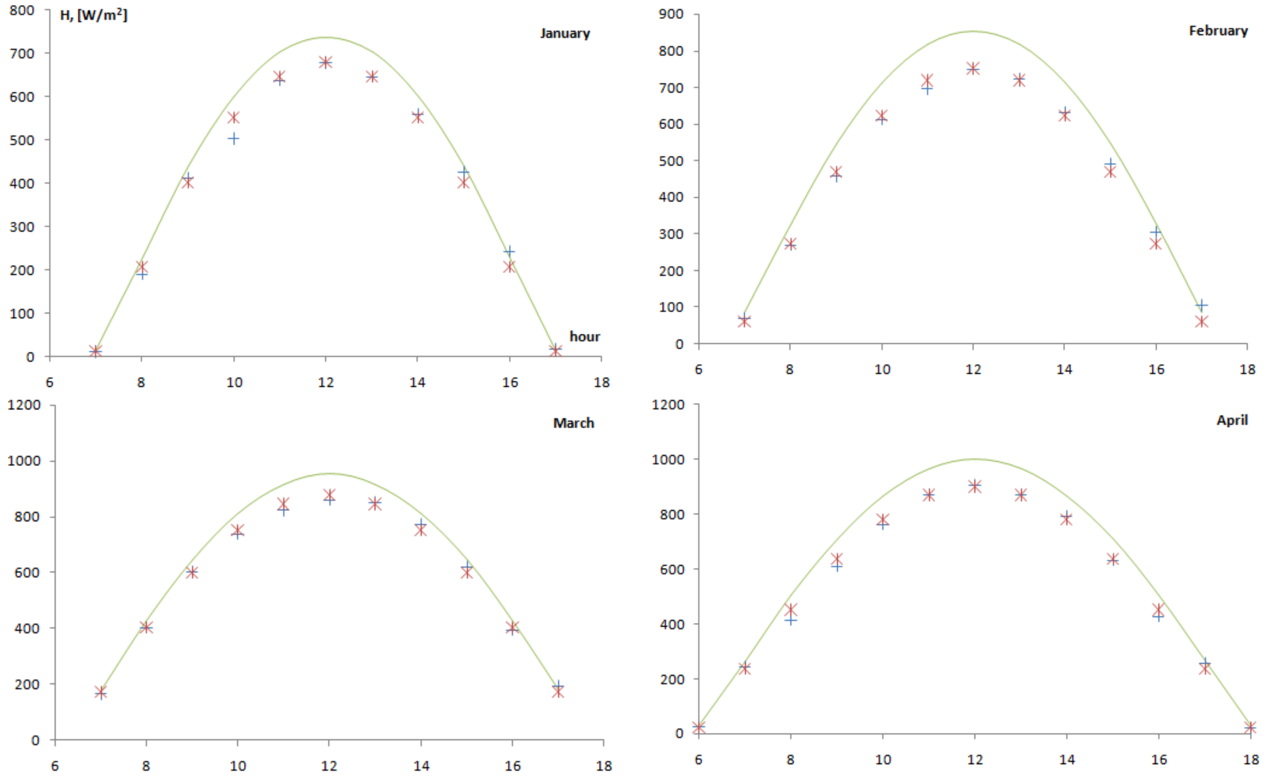


Figure 4. Hour by hour solar radiation for Riyadh - Saudi Arabia measured data and calculated data by ASHRAE constants and by revised constants for 21every month



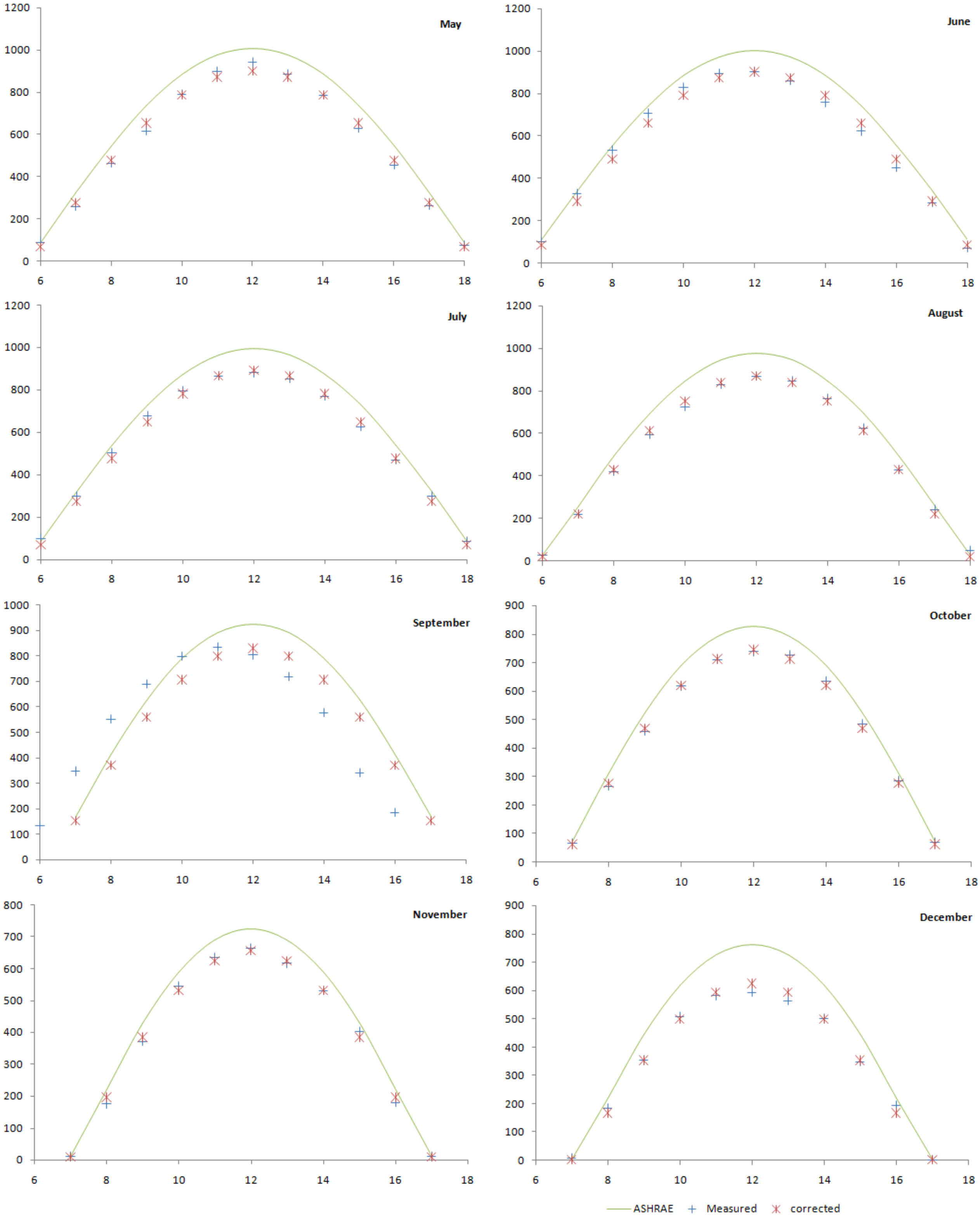
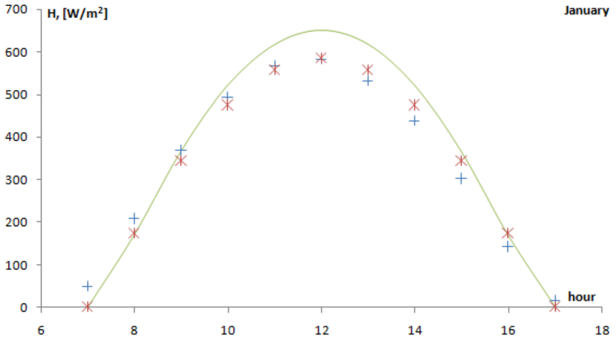


Figure 4. Hour by hour solar radiation for Brack El-Shati - Libya measured data and calculated data by ASHRAE constants and by revised constants for 21every month


January
H, [W/m²]
700
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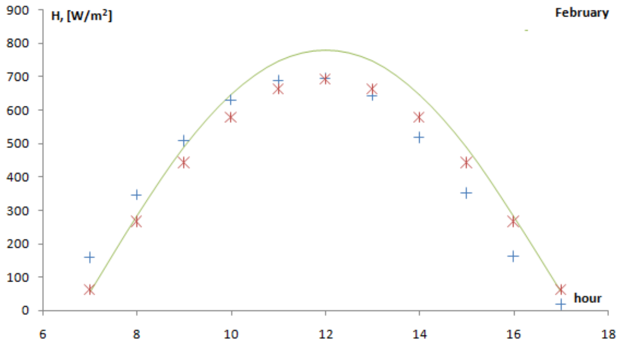
hour


February
H, [W/m²]
900
800
700
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500
400
300
200
100
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6
8
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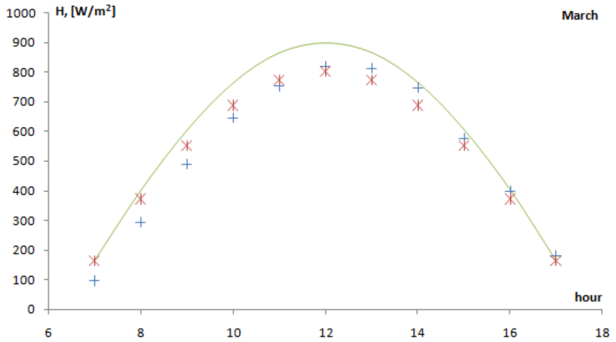
12
14
16
18
hour


March
H, [W/m²]
1000
900
800
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600
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400
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100
0
6
8
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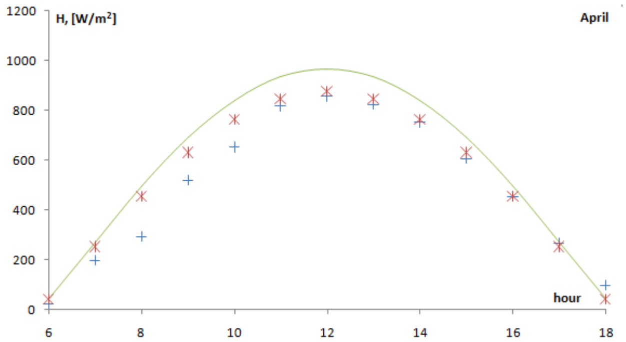
12
14
16
18
hour


April
H, [W/m²]
1200
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400
200
0
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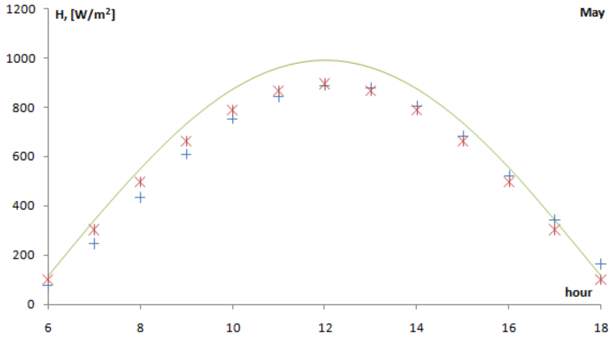
16
18
hour


May
H, [W/m²]
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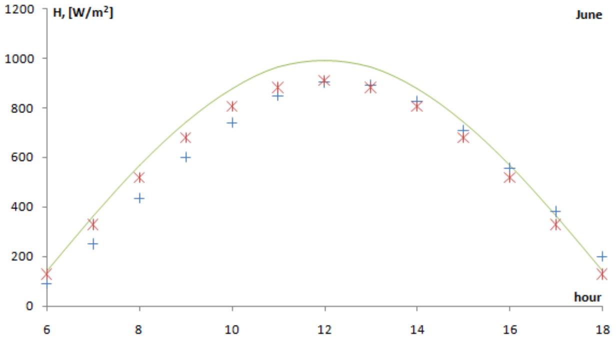
June
H, [W/m²]
1200
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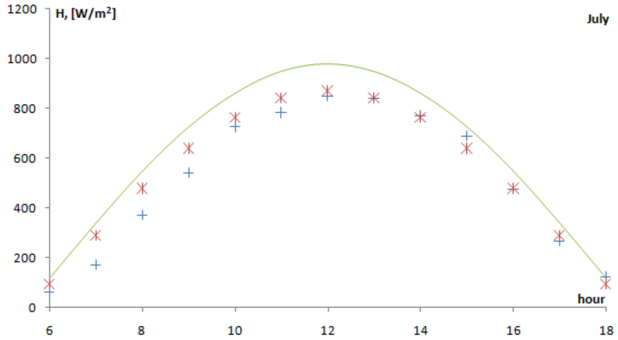
hour


July
H, [W/m²]
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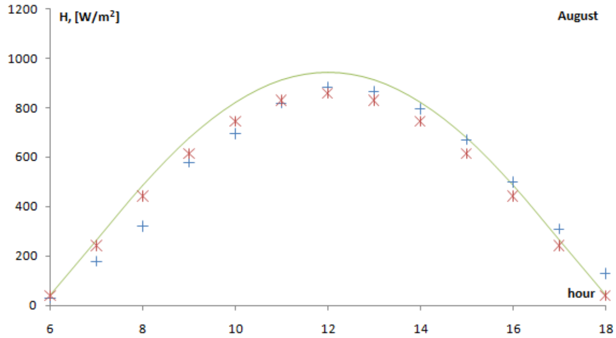
hour


August
H, [W/m²]
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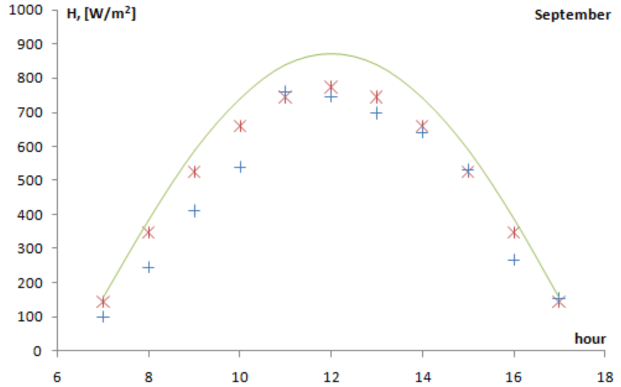
September
H, [W/m²]
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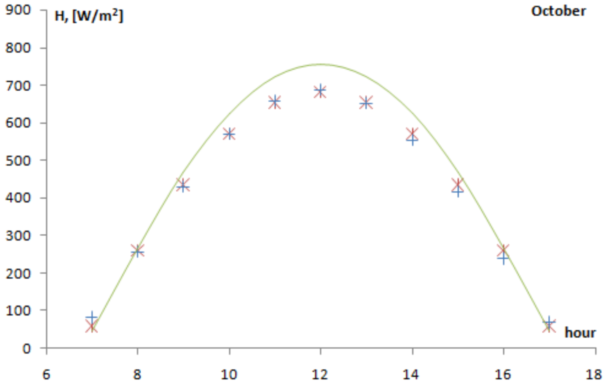
hour


October
H, [W/m²]
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hour

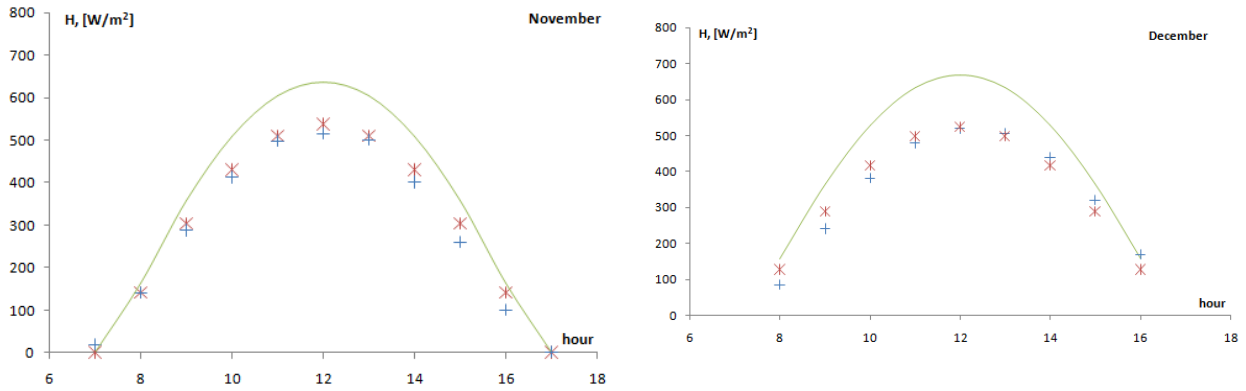

Figure 5. Hour by hour solar radiation for Tulkarm - Palestine measured data and calculated data by ASHRAE constants and by revised constants for 21every month

The calculated hourly global solar radiation incident on a horizontal surface is experienced to MBE, RMSE and t-stat error's test in order to verify the validity of the revised parameters model also to compare this model with other models offered by others. The values of calculated *MBE*, *RMSE* and *t-stat* based on the measurement data for both ASHRAE recommended parameters (unrevised - Un) and the revised parameters obtained in this study (revised - Ri) are shown in Table 4.

Table 4. Values of calculated *RMSE*, *MBE* and *t-stat* in [W/m^2]

Error test month	Riyadh- Saudi Arabia						Brack- Libya						Tulkarm- Palestine					
	RMSE		MBE		t-stat		RMSE		MBE		t-stat		RMSE		MBE		t-stat	
	Un	Re	Un	Re	Un	Re	Un	Re	Un	Re	Un	Re	Un	Re	Un	Re	Un	Re
Jan.	50	27	36.9	-0.44	3.36	0.050	47	21	35.1	-0.9	3.48	0.136	53	29	27.7	-0.94	1.93	0.101
Feb.	60	40	40.1	-2.92	2.82	0.228	78	20	65.8	-7.0	4.92	1.157	89	66	46.1	-0.42	1.90	0.020
Mar.	73	23	68.8	17.3	8.83	3.360	56	14	45.6	0.05	4.47	0.010	98	46	62.3	7.18	4.21	0.497
Apr.	78	48	51.9	4.06	3.09	0.290	75	17	63.0	5.16	5.44	1.102	115	68	90.1	38.0	4.35	2.325
May.	94	67	75.3	47.7	4.61	3.477	81	21	69.4	0.98	5.64	0.158	87	39	70.7	6.19	4.75	0.558
Jun.	55	34	-47.6	-12.0	5.73	1.295	78	30	65.3	-0.73	5.23	0.083	91	53	68.5	12.0	3.95	0.804
Jul.	44	34	-41.9	-25.4	9.24	3.745	74	20	60.0	-4.03	4.79	0.712	121	59	107	31.7	6.42	2.184
Aug.	42	17	-40.9	-9.74	16.36	2.370	80	14	63.9	-1.89	4.62	0.457	82	59	45.7	-6.9	2.32	0.409
Sep.	81	21	-77.4	-7.21	10.28	1.126	73	18	66.2	1.57	6.68	0.266	124	67	110	47.4	6.29	3.148
Oct.	121	77	-108	-57.9	6.34	3.532	57	10	50.73	-3.68	5.83	1.252	50	12	36.4	2.06	3.24	0.534
Nov.	70	32	-60.9	-8.09	5.35	0.810	47	12	41.68	-0.16	5.83	0.042	84	23	70.3	15.4	4.81	2.806
Dec.	108	37	88.3	25.1	4.47	2.834	105	16	87.21	1.75	4.66	0.343	102	30	78.0	0.91	3.73	0.096

(Un- means unrevised ASHRAE and Re- means revised ASHRAE parameters)

From the result of Table 4, it is seen that, the revised ASHRAE parameters show acceptable results in the terms of *MBE*, *RMSE* and *t-stat* for all locations.

8. Conclusion

The analysis of data revealed that the revised ASHRAE clear sky parameter model is better in estimating the incident solar radiation as no data are required to start the process. New values have been given for A, B and C on a specific location; these values exhibit a good impression at the error tests compared with the ASHRAE recommended parameters; moreover, these values are better than other suggested models by many published scientific studies [3,6,22,39-42]. As a result this study recommends using these revised parameters instead of that ASHRAE suggested parameters in all regions of the Arabic world. The parameters A, B and C have also been presented in polynomial expressions form to enable a convenient utilization.

References

[1] Supit I., Kappel R., A simple method to estimate global radiation. Solar Energy 1998;63(3):147– 60.

[2] Engerer N. A., Mills F. P., Validating Nine Clear Sky Radiation Models in Australia, reprint submitted to Solar Energy June 9, 2015.

[3] Badescu V., Verification of some very simple clear and cloudy sky models to evaluate global solar irradiance, Solar Energy, Vol. 61, pp. 251–264, October 1997.

[4] Mikulović J., Đurišić Ž., Zeid S. M., A Model for Estimating the Solar Insolation Under Real Weather Conditions, Infoteh - Jahorina Vol. 14,pp.249-254, March 2015.

[5] Gadiwala, M. S., Usman A., Akhtar M., Jamil K., Empirical Models for the Estimation of Global Solar Radiation with Sunshine Hours on Horizontal Surface in Various Cities of Pakistan, Pakistan Journal of Meteorology Vol. 9, Issue 18: Jan 2013, 43.

[6] Togrul T., Togrul H., Evin D., Estimation of global solar radiation under clear sky radiation in Turkey. Renew. Energy 21: 2000, 271–287.

[7] Al-Mohamad, A., Global, direct and diffuse solar radiation in Syria. Applied Energy 79: 2004, 191–200.

[8] Al-Sanea, S. A., Zedan, M. F., Al-Ajlan, S. A., Adjustment factors for the ASHRAE clear-sky model based on solar-radiation measurements in Riyadh. Applied Energy 79: 2004, 215–237.

[9] Abdullah Yildiz, Investigation of applicability of ASHRAE clear-sky model to Izmir, Turkey, J. of Thermal Science and Technology, Turkey, , 31,2, 2011, 25-32.

[10] Khan M., Ahmad M., Estimation of global solar radiation using clear sky radiation in Yemen, Journal of Engineering Science and Technology Review 5 (2), 2012, 12-19.

[11] K. BAKIRCI, Estimation of Solar Radiation by Using ASHRAE Clear-Sky Model in Erzurum, Turkey, Energy Sources, Taylor & Francis Group, LLC. Part A, 31: 2009, 208–216.

[12] Annear R. L., Wells S. A., A comparison of five models for estimating clear-sky solar radiation, Water Resour. Res., 43, 2007, W10415.

[13] Machler M., Iqbal M., A modification of the ASHRAE clear-sky irradiation model. ASHRAE Trans.;91(Part 1):1985, 106–115.

[14] Bird R.E., Hulström R.L., A simplified clear-sky model for the direct and diffuse insolation on horizontal surfaces. US-SERI Technical report, Golden, Colorado, 1981, TR-642-761.

[15] Dumortier S., Kuhlemann D., Olseth R., Piernavieja J., Reise G., Wald C., Heinnemann D., Rethinking satellite based solar irradiance modelling – The SOLIS clear sky module, Remote Sens. Environ., 91, 2004, 160–174.

[16] Oumbe A., Blanc P., Gschwind B., Lefevre M., Qu Z., Schroedter-Homscheidt, M., Wald, L., Solar irradiance in clear atmosphere: study of parameterisations of change with altitude, Adv. Sci. Res., 6, 2009, 199–203.

[17] Ineichen, P., Comparison of eight clear sky broadband models against 16 independent data banks, Sol. Energy, 80, 2006, 468–478.

[18] Joeijoo P., Sorapipatana C., An assessment of solar radiation estimation of ASHRAE clear sky model in the northern part of Thailand, Proceedings of the 2nd Regional Conference on Energy Technology towards a Clean Environment, 2003, pp. 449-454.

[19] Threlkeld J.L., Jordan R.C., Direct solar radiation available on clear days, ASHRAE Trans, 64,1958, pp. 45-48.

[20] Wessapan T., Somsuk N., Applicability of the ASHRAE Clear Sky Model in Bangkok Metropolitan Area, Thammasat Int. J. Sc. Tech., Vol.13 Special Edition, 2008.

[21] Bird R. E., Hulstrom R. L., A simplified clear sky model for direct and diffuse isolation on horizontal surface, SERI/TR-642-761, Solar Energy Research Institute, Golden, USA, 1981.

[22] Sabziparvar A. A., A simple formula for estimating global solar radiation in central arid deserts of Iran. Renewable Energy 2008;33:1002–1010.

[23] Christian A., Gueymard P., Didier T.,Revising ASHRAE climatic data for design and standards - Part 2: Clear-sky solar radiation model, ASHRAE Transactions · January 2013.

[24] Gueymard C.A., Clear-sky irradiance predictions for solar resource mapping and large-scale applications: Improved validation methodology and detailed performance analysis of 18 broadband radiative models. Solar Energy, 86, 2012, 2145-2169.

[25] Lingamgunta C., Veziroglu T. N., A universal relationship for estimating daily clear sky insolation, *Energy Conversion and Management* 45, 2004, 2313–2333.

[26] Gueymard C., Critical analysis and performance assessment of clear-sky solar irradiance models using Theoretical and Measured Data. Solar Energy 51(2):1993, 121-138.

[27] Younes S., Muneer T., Clear-sky Classification Procedures and Models using a World-wide Data-base. Applied Energy 84 (6), Jun. 2007, 623–645.

[28] Rigollier C., Bauer O., Wald L., On the Clear Sky Model of the ESRA - European Solar Radiation Atlas - With Respect to the Heliostat Method. Solar Energy 68 (1), 2000, 33–48.

[29] Louche A., Simonnot G., Iqbal M., Mermier M., Experimental Verification of Some Clear-Sky Insolation Models. Solar Energy 41 (3), Jan. 1988, 273–279.

[30] Ianetz A., Lyubansky V., Setter I., Kriheli B., Evseev E. G., Kudish A. I., Inter-comparison of Different Models for Estimating Clear Sky Solar Global Radiation for the Negev Region of Israel. Energy Conversion and Management 48 (1), Jan. 2007, 259–268.

[31] Westren B. E., The estimation of solar radiation in New Zeland, solar energy vol. 45 No 4, 1990, 121-129.

[32] Matthew J., Clifford W., Joshua S., Global Horizontal Irradiance Clear Sky Models: Implementation and Analysis, Sandia National Laboratories Albuquerque, California, Printed March 2012.

[33] Salazar G. A., Hernández A. L., Saravia L. R., Practical models to estimate horizontal irradiance in clear sky conditions: Preliminary results, Renewable Energy, vol. 35, 2010, pp. 2452-2460.

[34] Powell G. L., The ASHRAE Clear Sky Model - An Evaluation, ASHRAE Journal-American Society of Heating Refrigerating and Air-Conditioning Engineers,vol. 24,1982,pp. 32-34.

[35] Katiyar A. K, Kumar A., Akhilesh C. K. Pandey D. B., A comparative study of monthly mean daily clear sky radiation over India,The International Journal of Energy and Environment, vol. 1, no. 1, 2010, pp. 177–182.

[36] http://www.wikipedia.org

[37] Duffie J. A. and Beckman W. A., Solar Engineering of Thermal Processes, 3ed., John Wiley & Sons, Inc., 2006.

[38] Nassar Y. F., Solar energy engineering active applications, Sebha University, Libya, 2006. "Arabic language".

[39] Lef`evre M., Oumbe A., Blanc P., Espinar B., Gschwind B., Qu Z., Wald L., Schroedter-Homscheidt M., Hoyer-Klick C., Arola A., Benedetti A., Kaiser J. W., Morcrette J.J., McClear: a new model estimating down welling solar radiation at ground level in clear-sky conditions, Atmospheric Measurement Techniques, 6,2013, pp. 2403–2418, www.atmos-meas-tech.net/6/2403/2013/

[40] Pansak A., Chumnong S., An Assessment of the ASHRAE Clear Sky Model for Irradiance Prediction in Thailand Nuntiya, Asian Journal on Energy and Environment, 08(02), 2007, pp. 523-532.

[41] Dehghan A. A., Faghih A. R., Empirical models for estimating global solar radiation: A review and case study Fariba Besharat, Renewable and Sustainable Energy Reviews ScienceDirect, 21, 2013,pp. 798–821.

[42] Michael S. , Emagbetere O., Emmanuel A., Evaluation of various global solar radiation models for Nigeria, International Journal of Green Energy, vol. 13, no. 5, 2016, pp. 505–512.