

Application of Solar Radiation Models to Predict the Average Values of Global Solar Radiation in south-east cities of Iran

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ABSTRACT: Two simple models for global horizontal insolation have been compared with the average monthly values of global solar radiation measured by the Iranian Meteorological Organization (IMO) in major cities of the south-east (SE) region of the country. The models have been calibrated to provide good agreement with the experimental data. They are based on algebraic expressions, rather than the look-up tables, which greatly simplifies the use of the model. The models provide results that will agree with reliable experimental data. The paper consists of the application of models found in literature to verify the reliability of the models in Iranian cities. The global solar radiation is compared with the IMO real data of Kerman and SE cities. The obtained results are interesting because of the strict correspondence between the model values and the real data. The models can be used as viable tools for those locations in Iran where no measured data are available. The parameters of the models for remote places are chosen by applying correction factors to climatologically determined constants for nearby monitored places.

Keywords: solar radiation models, global irradiance, measured data, direct, diffuse

NOMENCLATURE

		H	Daily global irradiation at earth's surface, Eq. 1
a	Climatological constant in Eq. 1	H ₀	Extraterrestrial daily irradiation, Eq. 1
a _w	Water vapor absorptance, Eq. 4	H _{DF}	Diffuse daily global irradiation at earth's surface, Eq. 2
B _a	The percentage of diffuse radiation to the ground due to particles, Eq. 5	H _B	Direct daily global irradiation at earth's surface, Eq. 3
b	Climatological constant in Eq. 1	h	Elevation from sea level, Eq. B2
c	Climatological constant in Eq. 2	i	Incident angle, Eq. 6
d	Climatological constant in Eq. 2	I _B	Direct beam irradiance for clear sky, Eq. 4
e	Mean relative error, Eq. C1	I _{DF}	Diffuse irradiance for clear sky,
E ₀	Eccentricity correction factor for the earth's orbit, Eq. A2		

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	Eq. 5
I	Global Irradiance for clear sky, Eq. 6
IMO	Iranian Meteorological Organization
I_o	Solar constant, Eq. 4
K^*	Constant used in Eq. 8
m	Air mass, Eq. 5
MAPE	Mean Average Percentage Error, Eq. C3
n	Hours of measured sunshine, Eq. 1
n^*	Day of year, Eq. A2
N	Potential astronomical sunshine hours, Eq. 1
P	Local absolute pressure, Eq. B1
P_o	Reference pressure at sea level, Eq. B2
r_g	Ground albedo, Eq. 6
r_s	Sky albedo, Eq. 9
RMSE	Root Mean Square Error, Eq. C2
T_A	Transmissivity due to absorption and scattering by particles, Eq. 4
T_{AA}	Transmissivity due to absorption by particles, Eq. 5
T_{AS}	Ratio of T_A to T_{AA} , Eq. 5
T_{as}	Quantity introduced in Eq. B14
T_o	Transmissivity due to ozone, Eq. 5
T_M	Transmissivity of atmospheric gases except water vapor, Eq. 4
T_R	Transmissivity due to Rayleigh Scattering, Eq. 5
T_{UM}	Transmissivity due to oxygen and carbon dioxide, Eq. 5
T_W	Transmissivity of water vapor, Eq. 5
U_W	Precipitable water in a vertical column, Eq. B4
X_o	The amount of ozone times the air mass, Eq. B12
δ	Declination angle, Eq. A4
ϕ	Latitude, Eq. A1
θ	Zenith angle, Eq. 5
τ_A	Turbidity coefficient, Eq. B3
β	Solar altitude angle, Eq. 3
ω_s	Mean sunrise hour angle, Eq. A1

1. LITERATURE SURVEY

The need for insolation models has been recognized for many years to properly design a solar energy system for a location lacking an insolation data base. The early and widely used insolation model was published in 1940 by Moon [1]. This model is still used today in its original or modified forms [2, 3].

In 1978-79 Atwater and Ball [4, 5] published their direct and global insolation models. The direct insolation model was taken from Kastrov as discussed by Kondratyef [6]. The form of the equation for water vapor absorption (a_w) was taken from McDonald [7]. The value of sky albedo, $r_s = 0.0685$, for a molecular atmosphere, as reported by Lacis and Hansen [8] was used in this model. Atwater and Ball used Mie calculations to obtain turbidity coefficient, τ_A , which is much too rigorous for a simple model. Therefore, a value of τ_A that will be described later in the Bird model was used here. The input parameters required for this model are the solar constant, zenith angle, surface pressure, ground albedo, precipitable water vapor, total ozone, and broadband turbidity. The Atwater and Ball model significantly underestimates the diffuse sky irradiance.

A model for direct and diffuse solar insolation was developed by Davies and Hay [9]. The equations used in this model were particularly the result of comparing several existing models. The expressions for ozone transmittance, T_o , and water vapor absorption, a_w , were taken from Lacis and Hansen [8]. The transmission due to Rayleigh scattering, T_R , was presented in tabular form, and so the Bird model expression for T_R was used in this model. The value of aerosol transmittance, $K=0.91$ was used for data generated in this model and is representative of aerosol conditions in southern Ontario. Single scattering albedo, $W_o=0.98$, and the percentage of diffuse radiation to the ground due to particles, $B_a=0.85$, were also used in this model.

Another direct and diffuse model has been constructed by Watt [3], based particularly

on the work of Moon [1]. The upper layer broadband turbidity, τ_u , was not well defined by Watt. A value of $\tau_u=0.02$ appears to be an average value for locations in the United States.

Hoyt [10] proposed a model for the calculation of solar global insolation, in which the air mass values, m , were obtained from Bemporad's [11] Tables. The expression for air mass of Kasten [12] may alternatively be used in this model. The values of transmittance of aerosol scattering, T_{AS} , and transmissivity due to Rayleigh scattering, T_R , are calculated from tables furnished by Hoyt [10]. The Table values from which T_{AS} is calculated are limited so that large optical depths can occur from high turbidity or from large zenith angles.

Lacis and Hansen [8] developed an extremely simple model for total downward irradiance. It tends to overestimate the global irradiance by approximately 8%, and it has no provision for calculating direct irradiance.

Page [13] used the Angstrom type formula for the estimation of mean values of global radiation from sunshine records. He derived a linear regression equation from the published observations, linking the ratio of diffuse radiation on a horizontal plane to the total radiation with the atmospheric transmission. He also proposed a method to convert the mean daily radiation on the horizontal plane to mean daily direct radiation on inclined planes based on the use of conversion factors. The Page model can estimate the diffuse radiation incident on vertical and inclined planes.

Bird [14] formulated the direct and diffuse components of solar radiation. The cloudiness effect is accounted for by the ratio of measured to potential astronomical sunshine duration.

A brief description of the Page [13] and Bird [14] models will be presented here, as these two simple models will be compared with the average monthly values of global solar radiation measured by the IMO in major cities of the south-east region of the country.

Further details regarding the models mentioned in this introduction can be found in [15].

Since solar measurements in many Iranian cities are sparse, developing a model for accurate prediction of available solar energy in every location is worthwhile. The objective of this paper is therefore to present methods for estimating solar radiation in Iran. Once these models are validated by comparing the results with the available IMO measurements in major cities, they can be applied to locations where no measured data are available.

2. INTRODUCTION

Nowadays, more than 81% of the total world energy and 95% of Iran's energy consumption are provided by fossil fuels. Continuation of consuming fossil fuels not only increases air, water, and soil pollution, but also results in global warming because of releasing more carbon dioxide in atmosphere. To reduce the pollution caused by using fossil fuels and optimization of oil and gas consumption in industrial and domestic sections, it is inevitable to pay more attention to solar energy which is renewable and environmentally friendly. The solar radiation energy available in Iran is tremendous and the technology to convert this energy into heat or electricity is relatively simple. According to experimental measurements conducted by IMO the average daily solar radiation energy available in Iran in about 18 MJ/m². Considering the total national energy consumption in 2005 being equivalent to 1 billion oil barrels, the solar radiation energy available in an area about 0.12% of the country's land (roughly 2000 square kilometers) would be sufficient to supply the country's total energy consumption [1]. To control and utilize such an enormous source of energy requires one to know and understand the variations and parameters influencing the solar radiation energy available in a place both quantitatively and

qualitatively. This kind of information is not only used in design and assessment of solar energy systems, but also is very essential in climatology, meteorology, architecture, air conditioning, etc. The data for solar radiation energy can be obtained in two different ways. The first way which is more reliable is the direct measurement of solar radiation components. The second way relies on empirical-analytical relationships and predicts the solar radiation components as a function of time, latitude, altitude, zenith angle, clear sky conditions, hours of measured sunshine, etc. The latter can be used in locations where experimental data on solar radiation energy is scarce. To obtain a general correlation to estimate the solar radiation components taking into account all the affecting parameters is not an easy task. On the other hand, some of the parameters are less effective and can be eliminated and only the important parameters are taken into account. In this article, the IMO information for global daily solar radiation energy for the period of 9 years, the hours of measured sunshine for the period of 6 years, and the potential astronomical sunshine hours for the period of 22 years have been analyzed for possible omission of erratic data. According to the selected data the Page [13] and Bird [14] models have been modified. These models have been recommended to be used for predicting the incident solar radiation energy in SE Iran.

The aims of the present paper are: (1) calibration of two analytical models using the global solar radiation intensities measured by the IMO in city of Kerman, (2) validation of calibrated models using the global solar radiation intensities measured by IMO in city of Yazd, (3) comparing the predictions of calibrated models for the city of Zahedan with the global solar radiation intensities measured by the IMO for the same city, in order to double check the validity of the calibrated model, (4) using the calibrated models to predict the mean global solar radiation intensities in remote

areas of these provinces where no measured data is available, but the model parameters can be obtained locally, (5) comparing the predictions of the calibrated models with those predicted by other researchers, and (6) access to daily global solar radiation intensities in rural areas for solar energy applications. It is worth mentioning that solar energy is abundant in Iran, and the solar data in the major SE cities are given in Table 1.

Table 1. Annular solar data in the capital cities of Kerman, Yazd, and Sistan provinces
A=Solar energy (MJ/m²), B=Hours of measured sunshine, and C= Hours of cloudiness

	A	B	C
Kerman	7625	3157	1223
Yazd	7787	3270	1110
Zahedan	7645	3241	1139

It is expected that the application of solar energy engineering, especially solar water heaters, becomes widespread in these provinces in the near future. Therefore, reliable solar models to predict the global solar intensities on horizontal surfaces in remote areas of these provinces, in order to supply their energy demands from renewable (solar) sources is of great concern.

3. THE PAGE MODEL

The Page model [13] predicts the mean daily solar energy intensity for cloudy sky on a horizontal surface as follows:

$$H = H_0 \left(a + b \frac{n}{N} \right) \quad (1)$$

The *model* equations for diffuse and direct components are as follows:

$$H_{DF} / H = c + d(H / H_0) \quad (2)$$

c and *d* are climatologically determined constants for estimating the monthly mean daily diffuse radiation on a horizontal plane, their values for some localities may be

found in [13]. The monthly mean values of the daily direct radiation on the horizontal plane may be found from the relation:

$$\sum H_B \sin \beta = H - H_{DF} \quad (3)$$

It can be shown that maximum diffuse radiation occurs when the ratio of hours of measured sunshine to potential astronomical sunshine hours, n/N , is about 40%-50%.

The Page model (Eq. 1) was calibrated using the global solar energy intensities measured by the IMO in the city of Kerman, and the coefficients a and b were obtained as follows:

$$a = 0.3544 \quad b = 0.4281$$

The details regarding the Page model are given in Appendix [A].

4. THE BIRD MODEL

The direct and diffuse components of solar radiation for clear sky on a horizontal surface that have been formulated by Bird [14] are:

$$I_B = 0.9662 I_0 (T_M - a_w) T_A \quad (4)$$

$$I_{DF} = (I_0 \cos \theta) 0.79 T_0 T_W T_{UM} T_{AA}$$

$$[q(1 - T_R) + B_a(1 - T_{AS})] / [1 - m + m^{1.02}] \quad (5)$$

The global solar radiation in clear sky is the sum of diffuse and direct components and is calculated from the following equation:

$$I = I_B(\theta) \cos i + I_{DF}(\theta)(1 + \cos \beta) / 2 + r_g(I_B + I_{DF})(1 - \cos \beta) / 2 \quad (6)$$

The inclusion of the cloudiness effect is accounted for by the ratio of measured to potential astronomical sunshine duration, n/N . Thus, the actual average daily H_B , and diffuse H_{DF} , radiation including cloudiness can be calculated by the following expressions:

$$H_B = I_B \frac{n}{N} \quad (7)$$

$$H_{DF} = I_{DF} \frac{n}{N} + K^* (1 - \frac{n}{N})(I_B + I_{DF}) \quad (8)$$

$$H = (H_B \cos \theta + H_{DF}) / (1 - r_g r_s) \quad (9)$$

This model was calibrated using the global

solar energy intensities measured by the IMO in the city of Kerman and the coefficient q was obtained as follows:

$$q = 0.65$$

The details regarding the Bird model are given in Appendix [B].

5. RESULTS

The models mentioned in this article were calibrated and validated to estimate the solar radiation distribution in Kerman, Yazd, and Sistan provinces. The calibration was performed using the global solar radiation intensities measured by the IMO in the city of Kerman. The validation was carried out using the global solar radiation intensities measured by the IMO in the city of Yazd. These models can be used in small towns and villages in the three provinces, where a meteorological station does not exist and thus, direct measurement of solar radiation intensity is not possible. The global solar radiation intensities predicted by the Page [13] and Bird [14] models for the cities of Kerman, Yazd, and Zahedan are shown in Figures 1, 2, and 3 respectively. The model predictions are compared with the corresponding measured data. The error analysis was performed for the Page [13] and Bird [14] models when compared with measured data in the cities of Kerman, Yazd, and Zahedan. The results are discussed section 6.

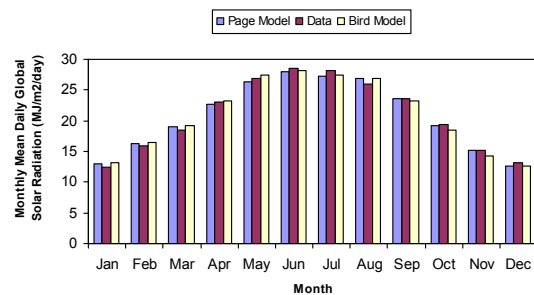


Figure 1. Comparison of the IMO data with predictions of Page [13] and Bird [14] models in city of **Kerman**

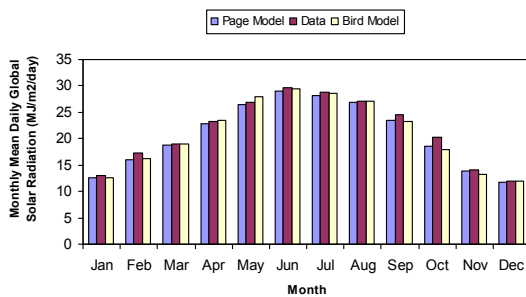


Figure 2. Comparison of the IMO data with predictions of Page [13] and Bird [14] models in city of **Yazd**

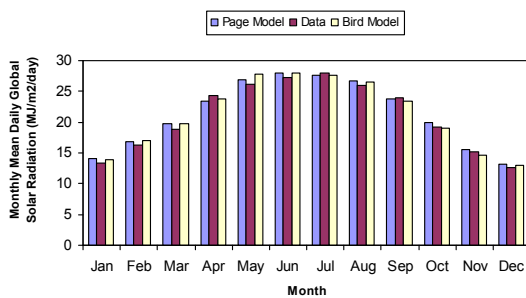


Figure 3. Comparison of the IMO data with predictions of Page [13] and Bird [14] models in city of **Zahedan**

6. COMPARISON AND DISCUSSION

The results predicted by the Bird [13] and Page [14] models for the city of Kerman, as well as the measured data for this city are compared with each other in Table 2. The relative errors for the predicted results are reported in the same table. The biggest error for the Page [13] model happens in December (4.55 percent overestimation), and the smallest error for this model happens in September (0.01 percent underestimation). The biggest error for the Bird [14] model happens in November (6.69

Table 2. Comparison of the IMO global solar radiation intensities ($\text{MJ/m}^2/\text{day}$) with predictions of Page [13] and Bird [14] models in city of **Kerman**

Month	IMO Data	[13]		[14]	
		$\bar{H}$	$e\%$	$\bar{H}$	$e\%$
Jan.	12.52	13.07	-4.41	13.15	-5.06
Feb.	15.83	16.19	-2.28	16.41	-3.64
Mar.	18.39	19.06	-3.67	19.27	-4.84

Apr.	23	22.73	1.20	23.22	-0.93
May	26.83	26.33	1.88	27.43	-2.22
June	28.54	28.05	1.72	28.15	1.34
July	28.11	27.34	2.73	27.45	2.32
Aug	25.90	26.91	-3.89	26.82	-3.56
Sep.	23.58	23.58	-0.01	23.29	1.23
Oct.	19.32	19.16	0.81	18.46	4.44
Nov	15.20	15.12	0.54	14.19	6.69
Dec.	13.19	12.59	4.55	12.55	4.79

percent overestimation), while the smallest error for this model happens in April (0.93 percent underestimation). The Page [13] model predictions, however, have a better agreement with the measured data.

Table 3 presents how the predictions of the Page [13] and Bird [14] models for the city of Kerman compare with Daneshyar [20] and Sabziparvar [21] models. The measured data are also included in the table. The mean absolute percentage error for the Daneshyar [20] model turns out to be 10.74% while for the Sabziparvar [21] model is 8.28%. It should be mentioned that the mean absolute percentage error for the predictions of Page [13] and Bird [14] models are 2.31% and 3.42% respectively. This comparison shows that the Page [13] and Bird [14] models modified in this paper predict the global solar radiation more accurately. Comparing the root mean square errors for the above models leads to the same conclusion, because the root mean square error for the modified Page [13] and Bird [14] models as indicated in the last row of Table 3 are 0.54 and 0.68 respectively.

Table 3. Comparison of the global solar radiation intensities ($\text{MJ/m}^2/\text{day}$) obtained in [20] and [21] with predictions of Page [13] and Bird [14] models in city of **Kerman**

Month	IMO Data	[13]	[14]	[20]	[21]
Jan.	12.52	13.07	13.15	10.63	13.03
Feb.	15.83	16.19	16.41	13.90	14.96
Mar.	18.39	19.06	19.27	17.25	16.24
Apr.	23	22.73	23.22	19.64	19.13

May	26.83	26.33	27.43	24.24	23.75
June	28.54	28.05	28.15	26.71	28.51
July	28.11	27.34	27.45	26.25	29.99
Aug.	25.90	26.91	26.82	25.04	28.99
Sep.	23.58	23.58	23.29	21.60	27.71
Oct.	19.32	19.16	18.46	17.12	20.14
Nov.	15.20	15.12	14.19	13.02	15.89
Dec.	13.19	12.59	12.55	10.47	12.55
Mean	20.87	20.84	20.87	18.82	20.91
MAPE		2.31	3.42	10.74	8.28
RMSE		0.54	0.68	2.14	2.27

The root mean square error for the Daneshyar [20] and Sabziparvar [21] models are 2.14 and 2.27 respectively. A similar comparison is made for the city of Yazd in Table 4. The predictions of the Page [13], Bird [14], Daneshyar [20], and Sabziparvar [21] models together with the measured data for the city of Yazd are listed in Table 4. The mean absolute percentage errors for the above models are 2.96%, 3.19%, 13.09%, and 8.63% respectively. The root mean square errors as indicated in the same table are 0.75, 0.88, 2.69, and 2.45 respectively. This comparison leads to concluding that the modified models, especially the Page [13] model offer more accurate results.

Table 5 gives predictions of the modified Page [13] and Bird [14] models, as well as the predictions of Daneshyar model [20] together with the measured data for the city of Zahedan. The mean absolute percentage error and the root mean square error for each model have been calculated and listed in the table. It is evident that the mean absolute percentage errors for the

Table 4. Comparison of the global solar radiation intensities ($\text{MJ}/\text{m}^2/\text{day}$) obtained in [20] and [21] with predictions of Page [13] and Bird [14] models in city of **Yazd**

Month	IMO Data	[13]	[14]	[20]	[21]
Jan.	13.07	12.54	12.67	10.14	12.40
Feb.	17.3	16.05	16.28	13.66	14.61
Mar.	18.96	18.69	19.05	16.75	15.68

Apr.	23.24	22.78	23.48	19.63	18.24
May	26.95	26.52	27.85	23.81	22.80
June	29.73	29.04	29.40	26.22	27.97
July	28.79	28.24	28.60	26.65	28.80
Aug.	27.04	26.93	27.02	26.14	28.24
Sep.	24.56	23.49	23.32	22.29	26.89
Oct.	20.20	18.64	18.01	17.55	19.25
Nov.	14.07	13.88	13.19	12.31	14.57
Dec.	11.91	11.79	11.88	9.88	11.86
Mean	21.32	20.72	20.90	18.75	20.11
MAPE		2.96	3.19	13.09	8.63
RMSE		0.75	0.88	2.69	2.45

above models are 3.17%, 3.1%, and 10.58% respectively. The root mean square errors for these models are 0.65, 0.73, and 2.17 respectively. This table shows that the modified models give closer results to measured data when compared with the Daneshyar model [20].

Table 5. Comparison of the global solar radiation intensities ($\text{MJ}/\text{m}^2/\text{day}$) obtained in [20] with predictions of Page [13] and Bird [14] models in city of **Zahedan**

Month	IMO Data	[13]	[14]	[20]
January	13.38	14.05	13.89	10.71
February	16.33	16.91	16.99	13.90
March	18.93	19.70	19.79	16.78
April	24.27	23.46	23.85	20.14
May	26.15	26.81	27.81	24.16
June	27.18	28.20	27.97	26.12
July	27.97	27.65	27.64	26.08
August	25.93	26.77	26.53	25.16
September	23.99	23.75	23.35	22.06
October	19.20	19.86	19.01	17.58
November	15.12	15.60	14.55	13.36
December	12.68	13.25	13.05	10.84
Mean	20.93	21.32	21.20	18.91
MAPE		3.17	3.10	10.58
RMSE		0.65	0.73	2.17

The predictions of the Page [13], Bird [14], and Bahadorinejad [22] models for the city of Kerman, together with the measured data for this city are listed in Table 6. This comparison has been carried out with

respect to the Iranian months rather than Christian months. The mean absolute percentage errors as well as the root mean square error for each model have been calculated and reported in the table. The mean absolute percentage errors for these models are 2.44%, 3.53%, and 4.63% respectively. The RSME for the above models are 0.55, 0.71, and 0.92 respectively. This comparison indicates that the modified Page [13] model offers closer results to the measured data. The definitions for the relative error (e), root mean square error (RMSE), and mean absolute percentage error (MAPE) are given in Appendix [C].

Table 6. Comparison of the global solar radiation intensities ($\text{MJ/m}^2/\text{day}$) obtained in [22] with predictions of Page [13] and Bird [14] models in city of **Kerman**

[22]	[14]	[13]	IMO Data	Month
21.20	21.87	21.54	21.54	Farvardin
24.81	26.08	25.17	25.50	Ordibehar
27.17	28.17	27.70	28.14	Khordad
28.29	27.75	27.62	28.66	Tir
27.27	27.32	27.29	26.48	Mordad
24.00	24.33	24.57	24.36	Shahrivar
19.47	19.83	20.41	20.58	Mehr
15.06	15.33	16.24	16.38	Aban
12.12	12.73	13.03	13.80	Azar
11.21	12.69	12.68	11.94	Day
13.92	15.22	15.10	14.65	Bahman
16.62	18.25	17.97	17.57	Esfand
20.10	20.80	20.78	20.80	Mean
4.63	3.53	2.44	MAPE	
0.92	0.71	0.55	RMSE	

The scatter plots of measured data for the city of Kerman versus the predictions of modified Page [13] and Bird [14] models are shown in Figure 4 and Figure 5 respectively.

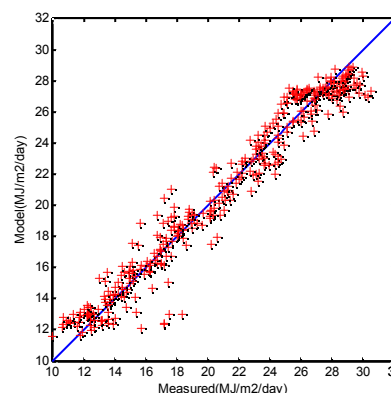


Figure 4. Scatter plot of IMO and Page [13] predictions for 365 days in Kerman

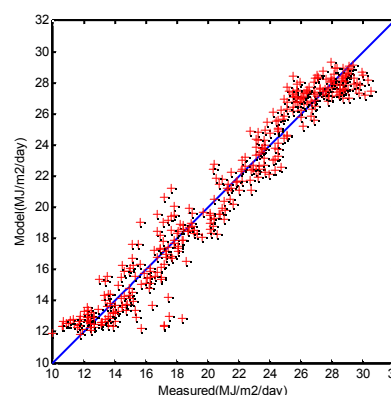


Figure 5. Scatter plot of IMO and Bird [14] predictions for 365 days in Kerman

7. CONCLUSIONS

The Page model [13] was modified to fit the global solar radiation intensities measured in Kerman. The coefficients a and b in the model equation turned out to be $0.41026 \cos \varphi$ and 0.4281 respectively, where φ is the latitude. The modified model is valid for all parts of Kerman, Yazd, and Sistan provinces, provided the latitude of the site under consideration is at hand. In the city of Kerman, for which $\varphi = 30.25^\circ$, the value of a would be 0.3544 .

The Bird [14] model was modified to fit the global solar radiation intensities measured in Kerman. The coefficient q turned out to be 0.65. The modified model is valid for all parts of Kerman, Yazd, and Sistan provinces, provided the right geographical

parameters (such as h , θ , ...) for the selected site are included in the model equations.

The modified Page [13] and Bird [14] models, when calibrated, were in good agreement with the global solar radiation intensities measured in Yazd and Zahedan. The modified models can therefore be applied in remote regions of the three provinces where no measured data are available. To verify the validity of the modified models, their predictions were compared with the measured data in the capital cities of three provinces.

REFERENCES

- [1] Moon, P., "Proposed Standard Solar-Radiation Curves for Engineering Use.", J. Franklin Institute . Vol. 230: pp. 583-617; 1940.
- [2] Mahaptra, A. K., "An Evaluation of a Spectro-radiometer for the Visible-Ultraviolet and Near-Ultraviolet." Ph.D. dissertation; University of Missouri; Columbia, Mo; 1973; 121 pp. (University Microfilms 74-9964)
- [3] Watt, D., "On the Nature and Distribution of Solar Radiation.", HCP/T2552-01. U.S. Department of Energy; 1978.
- [4] Atwater, M. A., Ball, J. T., "A Numerical Solar Radiation Model Based on Standard Meteorological Observation.", Solar Energy, Vol. 21: pp. 163-170; 1978.
- [5] Atwater, M. A., Ball, J. T., Solar Energy, Vol. 23: p. 725; 1979.
- [6] Kondratyev, K. Ya., "Radiation in the Atmosphere", New York: Academic press; 1969.
- [7] McDonald, J.E., "Direct Absorption of Solar Radiation by Atmospheric Water Vapor.", J. Metrology, Vol.17, pp. 319-328, 1960.
- [8] Lacis, A.L.; Hansen, J.E., "A Parameterization for Absorption of Solar Radiation in the Earth's Atmosphere", J. Atmospheric Science, Vol. 31: pp. 118-133, 1974.
- [9] Davies, J.A., Hay, J. E., "Calculation of the Solar Radiation Incident on a Horizontal Surface" Proceedings, First Canadian Solar Radiation Data Workshop, April 17-19, 1978. Canadian Atmospheric Environment Service; 1979.
- [10] Hoyt, D. V., "A Model for the Calculation of Solar Global Insolation." Solar Energy, Vol. 21: pp. 27-35, 1978.
- [11] Bemporad, A., Zur "Theorie der Extinktion des Lichtes in der Erdatmosphäre" Mitteilungen der Grossherzoglichen Sternwarte Zu Heidelberg; No. 4; 1904.
- [12] Kasten, F., "A New Table and Approximation Formula for the Relative Optical Air Mass." Thechnical Report 136, Hanover, New Hampshire: U. S. Army Material Command, Cold Region Research and Engineering Laboratory; 1964.
- [13] Page, J.K., "The Estimation of Monthly Mean Values of Daily Total Short -Wave Radiation on Vertical and Inclined Surfaces from Sunshine Records for Latitude 40°N-40°S", Solar Energy, Vol. 10, p.119, 1964.
- [14] Bird, R.E., and Hulstrom, R.E., "A Simplified Clear Sky Model for Direct and Diffuse Insolation on Horizontal Surface, U. S. Solar Energy Research Institute (SERI), Technical Report TR-642-761, Golden, Colorado, 1981.
- [15] Bird, R. E., and Hulstrom, R.E., "Direct Insolation Models." SERI/TR-335-344. Golden, Co: Solar Energy Research Institute; 1980.
- [16] Barbaro, S., Coppolino, S., Leone, C., and Sinagra, E., "An Atmospheric Model for Computing Direct and Diffuse Solar Radiation, Solar Energy, Vol. 22, pp. 225-228, 1979.
- [17] Drickinson W. C., and Cheremisnoff, P. N., "Solar Energy Technology Handbook", Part A: Engineering Fundamental, Sec. 4.2, Selection of Typical Atmospheric Condition, The International Solar Energy Society, 1980.
- [18] Pisimanis, D., and Notaridou, V.,

"Estimating Direct , Diffuse and Global Solar Radiation on an Arbitrary Inclined Plane in Greece", Solar Energy, Vol. 39, pp. 159-172, 1987.

- [19] Bird, R. E., and Hulstrom, "Review Evaluation and Improvement of Direct Irradiance Model", Journal of Solar Energy Engineering, Vol. 103, p. 183, 1981.
- [20] Daneshyar, M., "Solar Radiation Statistics for Iran", Solar Energy, Vol. 21, pp.345-9, 1978.
- [21] Sabziparvar, A. A., "A Simple Formula for Estimating Global Solar Radiation in Central Arid Deserts of Iran", Renewable Energy, In Press, Corrected Proof, 2007.
- [22] Bahadori, M. N., and Mirhosseini, S. A., "Solar Radiation Data for Various Cities in Iran (in Persian), Presented at the Third Conference on Optimization of Fuel Consumption in Building, pp. 603-619, 2004.

APPENDIX [A]

$$H_0 = \frac{24I_0E_0}{\pi}(\cos\varphi\cos\delta\sin\omega_s + \frac{\pi\omega_s}{180}\sin\varphi\sin\delta) \quad (A1)$$

$$E_0 = (1 + 0.033\cos\frac{360n^*}{365}) \quad (A2)$$

$$\omega_s = \cos^{-1}(-\tan\varphi\tan\delta) \quad (A3)$$

$$\delta = 23.45\sin(360\frac{284+n^*}{365}) \quad (A4)$$

$$N = \frac{2\omega_s}{15} \quad (A5)$$

APPENDIX [B]

$$T_M = 1.041 - 0.15[m(9.368 \times 10^{-4}P + 0.051)]^{\frac{1}{2}} \quad (B1)$$

$$\frac{P}{P_0} = \exp(\frac{h}{1000(-0.174 - 0.0000017h)}) \quad (B2)$$

$$T_A = \exp[-\tau_A^{0.873}(1 + \tau_A - \tau_A^{0.7088})m^{0.9108}] \quad (B3)$$

$$a_w = 2.4959mU_w[(1.0 + 79.03mU_w)^{0.6824} + 6.385mU_w]^{-1} \quad (B4)$$

$$T_w = 1 - a_w \quad (B5)$$

$$m = 1/[\cos\theta + 0.15(93.885 - \theta)^{-1.253}] \quad (B6)$$

$$\tau_A = 0.2758\tau_{A(0.38)} + 0.35\tau_{A(0.50)} \quad (B7)$$

$$T_{UM} = \exp(-0.127m^{0.26}) \quad (B8)$$

$$T_{AA} = 1 - 0.1(1 - T_A)(1 - m + m^{1.06}) \quad (B9)$$

$$T_R = \exp(-0.093m^{0.84}) \quad (B10)$$

$$T_{AS} = T_A / T_{AA} \quad (B11)$$

$$T_0 = 1 - 0.161X_0(1 + 139.48X_0)^{-0.3035} - \frac{0.00271X_0}{1.0 + 0.0044X_0 + 0.0003X_0^2} \quad (B12)$$

$$r_s = 0.0685 + (1 - B_a)(1 - T_{as}) \quad (B13)$$

$$T_{as} = 10^{-0.045[(P/P_0)m]^{0.7}} \quad (B14)$$

$$r_g = 0.2 \quad (B15)$$

$$B_a = 0.84 \quad (B16)$$

$$K^* = 0.32 \quad (B17)$$

$$\tau_{A(0.38\mu m)} = 0.35 \quad (B18)$$

$$\tau_{A(0.50\mu m)} = 0.27 \quad (B19)$$

$$X_0 = 0.3cm \quad (B20)$$

APPEDIX [C]

$$e = \frac{H_{i,m} - H_{i,c}}{H_{i,m}} \times 100 \quad (C1)$$

$$RMSE = [\frac{1}{n} \sum_{i=1}^n (H_{i,m} - H_{i,c})^2]^{1/2} \quad (C2)$$

$$MAPE = \frac{100}{n} \sum_{i=1}^n \left| \frac{H_{i,m} - H_{i,c}}{H_{i,m}} \right| \quad (C3)$$