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Temperature base correlation for the estimation of global solar radiation on horizontal surface

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Abstract

In the present study, a correlation have been developed for the extraction of monthly mean daily global distribution of solar radiation from the ratio of monthly mean daily maximum to minimum ambient air temperature. The reason for this approach comes from the fact that, although the air temperature is a worldwide measured meteorological parameter, it rarely used in solar radiation techniques. Numerical calculations have been made using the new model corresponding to five Indian locations (viz. Jodhpur, Ahmedabad, Calcutta, Bombay and Pune) and the results are compared against the models available in literature and with the measured values. Statistical tests of root mean square error (RMSE), mean bias error (MBE) and t-test are also performed to compute the accuracy of present correlation. Based on overall results it was concluded that air temperature successfully substitutes the sunshine duration data in the estimation of the solar energy.

Keywords: Distributions, Broad regions, Ambient air temperature.

1. Introduction

Designing of passive solar buildings and solar systems requires input data of various meteorological parameters, the most important of these is solar radiation [1]. In developing countries, due to lack of meteorological stations equipped for observation of radiation, the numerical methods become a useful alternatives. Most of the correlation models for estimating solar radiation values are based on sunshine hour duration. Since for many locations sunshine duration data are not available, therefore other parameters including ambient air temperature can be used to calculate solar radiation values for such locations with reasonable accuracies. Keeping in mind many investigators [1-9] claimed the accurate estimation of diffuse radiation by taking into account of the various parameters.

Angstrom [2] proposed first theoretical model for estimating global solar radiation based on sunshine duration. Page [3] and Prescot [4] reconsidered this model in order to make it possible to calculate monthly average of the daily global radiation on a horizontal surface from monthly average daily total insolation on an extraterrestrial horizontal surface. Recently, Bakirchi [5] developed a correlation based on bright sunshine hours for Turkey. A new type of approach has been proposed by Bristow and Campbell [6], Allen [7], Chandel et. al. [1] and Paulescu [8] to find a correlation based on ambient day temperature to estimates global radiation.

Since, air temperature is measured at large number of locations therefore, the prime objective of the present study is to analyze the global solar radiation and temperature data of five Indian cities viz. Jodhpur (Latitude 26.30^{0} N, Longitude 73.03^{0} E), Ahmedabad (Latitude 23.07^{0} N, Longitude 72.06^{0} E), Calcutta (Latitude 22.65^0 N, Longitude 88.35^0 E), Bombay (Latitude 19.12^0 N, Longitude 72.85^0 E) and Pune (Latitude 18.53^0 N, Longitude 73.91^0 E) considering first to third order Angström type correlations for India continent to correlate daily global solar radiation with ambient air temperature. Performance of the new constants is checked by comparing present estimated global solar radiation with other available theoretical values along with the measured data for each mentioned station.

2. Data and methodology

The database considered in this study contains daily global solar radiation on a horizontal surface of the periods between 2001and 2005 of five Indian stations, viz. Jodhpur, Ahmedabad, Calcutta, Bombay and Pune were collected from India Meteorology Department (IMD) Pune, a Government of India organization. The latest computing MATLAB software has been used for the entire analysis.

2.1 Mathematical models

The following models for evaluating global solar radiation as a function of ambient air temperature are discussed.

2.1.1 Bristow and Campbell model

Bristow and Campbell [6] suggested the following relationship for daily values of global solar radiation (H) as a function of daily extra-terrestrial solar radiation (H_0) and temperature difference (ΔT) as:

$$H/H_0 = A[1 - \exp(-B\Delta T^C)] \tag{1}$$

where $\Delta T = T_{max} - T_{min}$ and A, B and C are the empirical coefficients. The values of A, B and C in Bristow and Campbell's model were taken to be 0.7, 0.004-0.01 and 2.4, respectively.

2.1.2 Allen model

Allen [7] estimated mean monthly global solar radiation as a function of H_0, mean monthly maximum temperature (T_M), and mean monthly minimum (T_m) as:

$$H/H_0 = K_r\,(T_M - T_m)^{0.5} \tag{2}$$

where K_r is defined as

$$K_r = K_{ra}\,(\frac{P}{P_o})^{0.5} \tag{3}$$

Following Lunde [9], $K_{ra} = 0.17$, and P/P_0 may be defined as:

$$\frac{P}{P_o} = exp\,(-0.0001184\,h) \tag{4}$$

where P and P_0 are the values of local and standard atmospheric pressure respectively and h is the altitude of the place in meters.

2.1.3. Present model

In order to adapt the temperature dependent ratio of monthly mean global solar radiation to extra-terrestrial radiation, instead of relative sunshine duration, ratio of maximum to the minimum air temperature is used. Hence the global solar radiation for the region of our interest may be estimated by the following relations:

$$H/H_0 = a_1 + b_1 * \left(\frac{\theta}{\theta_o}\right) \tag{5}$$

$$H/H_0 = a_2 + b_2 * \left(\frac{\theta}{\theta_o}\right) + c_1 * (\frac{\theta}{\theta_o})^2 \tag{6}$$

$$H/H_0 = a_3 + b_3 * \left(\frac{\theta}{\theta_0}\right) + c_2 * \left(\frac{\theta}{\theta_0}\right)^2 + d * \left(\frac{\theta}{\theta_0}\right)^3 \quad (7)$$

where θ and θ_0 are the maximum and minimum air temperature respectively and $a_1 - a_3, b_1 - b_3$, $c_1 - c_2$ and d are regression constants. The accuracy of the constants is tested by comparing it with the measured data and with well known statistical tests the root mean square error (RMSE), mean bias error (MBE), t- statistic and the mean percentage error (MPE) for all considered stations. The RMSE (MJ/m^2 day), MBE (MJ/m^2 day), t- statistic and MPE (%) are as follows:

$$RMSE = \left[\left\{\sum\left(\mathrm{H}_{i,c} - \mathrm{H}_{i,m}\right)^2\right\}/ p\right]^{0.5}, \quad (8)$$

$$MBE = \left[\left\{\sum\left(\mathrm{H}_{i,c} - \mathrm{H}_{i,m}\right)\right\}/ p\right], \quad (9)$$

$$t = \left[\frac{(p-1)MBE^2}{RMSE^2 - MBE^2}\right]^{\frac{1}{2}}, \quad (10)$$

$$MPE = \left[\sum\left\{\left(\mathrm{H}_{i,m} - \mathrm{H}_{i,c}\right)/ \mathrm{H}_{i,m} * 100\right\}/ p\right], \quad (11)$$

where $\mathrm{H}_{i,c}$ and $\mathrm{H}_{i,m}$ are the ith calculated and measured values and p is the total number of observations. In general, a low RMSE is desirable. The positive MBE shows overestimation while a negative MBE indicates underestimation.

3. Results and discussion

A least squares regression analysis was used to fit equations (5), (6) and (7) for the pairs of (H/H_0) and $\left(\frac{\theta}{\theta_0}\right)$ values of whole year to obtain the regression constants $a_1 - a_3, b_1 - b_3$, $c_1 - c_2$ and d. This analysis of data points provides the following first, second and third order polynomial correlations.

$$H/H_0 = 0.2889 + 0.1562 * \left(\frac{\theta}{\theta_0}\right) \quad (12)$$

$$H/H_0 = -1.148 + 1.901 * \left(\frac{\theta}{\theta_0}\right) - 0.5109 * \left(\frac{\theta}{\theta_0}\right)^2 \quad (13)$$

$$H/H_0 = -5.159 + 9.126 * \left(\frac{\theta}{\theta_0}\right) - 4.766 * \left(\frac{\theta}{\theta_0}\right)^2 + 0.8201 * \left(\frac{\theta}{\theta_0}\right)^3 \quad (14)$$

We have calculated the global radiation for Jodhpur, Ahmedabad, Calcutta, Bombay and Pune stations using the above equations and compared the results with the theoretical estimates of Bristow and Campbell [6] and Allen [7] as well as with measured data through Figures 1-5. To test the accuracy of the constants, the RMSE, MBE, t-test and MPE values are also calculated for all correlations and their comparison is presented in Table 1. From Figures 1-5 one can see that our third order correlation provides better estimation over first and second order correlations for the estimating global radiation for all the five locations. Comparison shows that Bristow and Campbell's [6] model for Ahmedabad, Calcutta and Pune shows higher values of global radiation due to higher values of temperature deference, however Allen [7] model gives satisfactory results. The new constants with our third order correlation provide more accurate estimates than Bristow and Campbell and Allen models for all locations under consideration. It is observed that the deviation for Bombay and Pune station is higher due to high value of the ratio of maximum to the minimum air temperature. The present new constants provide remarkable agreement between the measured and estimates of the global radiation with maximum and minimum deviations of 12.22 and 0.59% respectively for Jodhpur, Ahmedabad and Pune stations except for winter season. Further in Table 1 the low values of RMSE, MBE, t-test MPE proves that the proposed correlation (eq. (14)) can be used for the estimation of global solar radiation on a horizontal surface at any location of India.

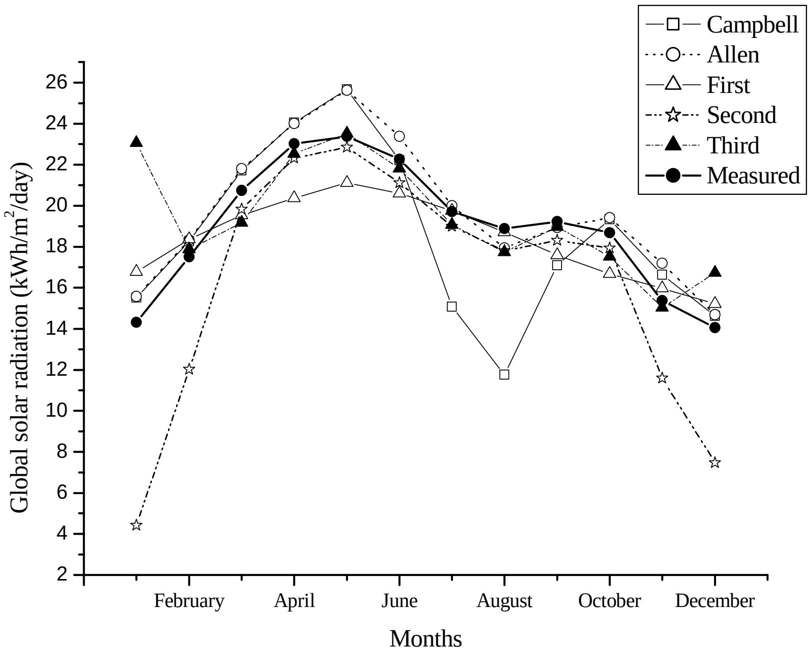

Figure 1. The measured and estimated mean monthly global solar radiation for Jodhpur, India.

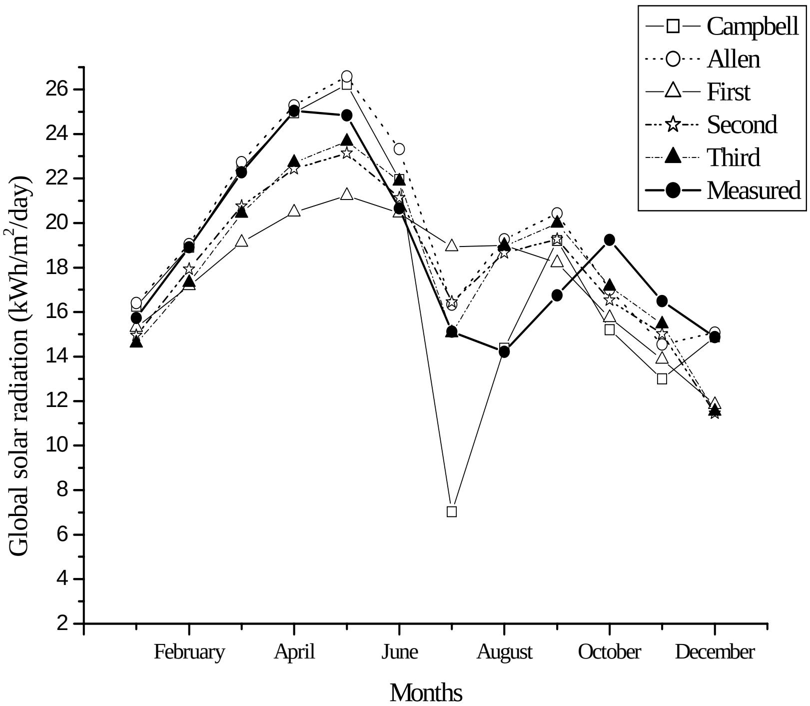

Figure 2. The measured and estimated mean monthly global solar radiation for Ahmedabad, India.

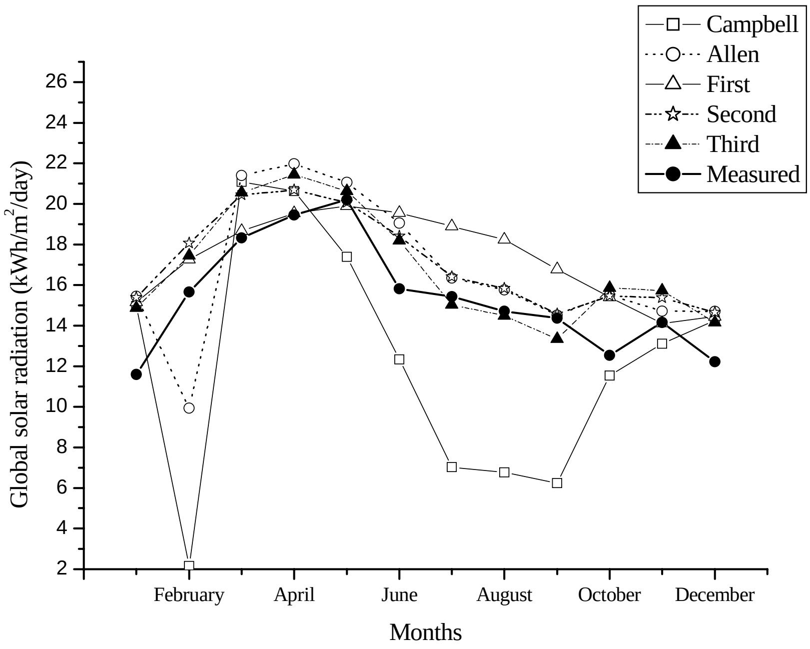

Figure 3. The measured and estimated mean monthly global solar radiation for Calcutta, India.

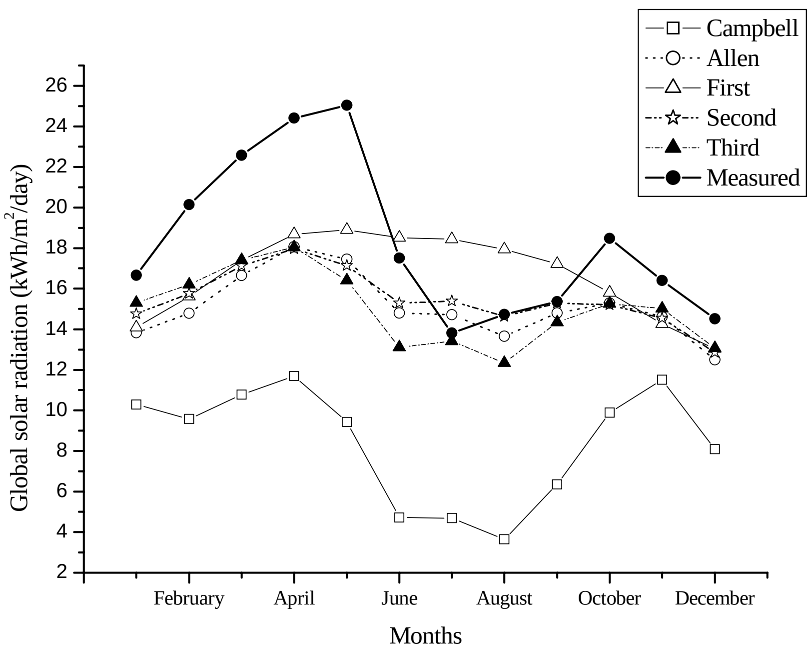

Figure 4. The measured and estimated mean monthly global solar radiation for Bombay, India.

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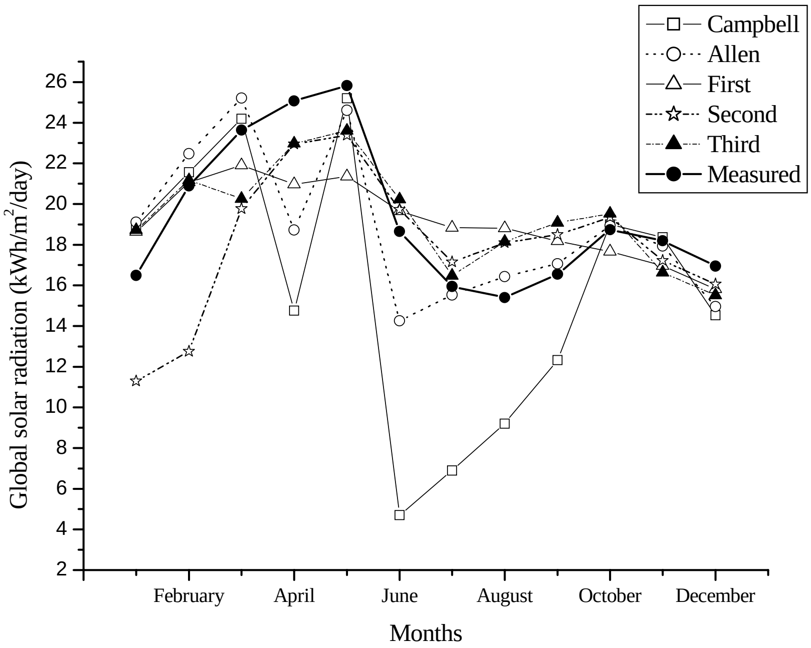

Figure 5. The measured and estimated mean monthly global solar radiation for Pune, India.

Table 1. The RMSE, MBE, t-test and MPE values for the different models.

Stations		**Campbell [6]**	**Allen [7]**	**1st Order**	**2nd Order**	**3rd Order**
	RMSE	2.71	1.15	1.62	3.99	1.33
Jodhpur	**MBE**	0.43	0.8	-0.54	-2.71	0.11
	t-test	0.16	0.96	0.35	0.92	0.08
	MPE	2.08	-4.39	1.68	17.08	-0.88
	RMSE	5.98	2.76	2.46	2.06	1.86
Ahmedabad	**MBE**	-3.07	1.33	1.96	1.74	1.27
	t-test	0.59	0.54	1.31	1.57	0.93
	MPE	19.62	-9.43	-14.11	-12.41	-9.08
	RMSE	6.13	2.55	2.44	3.35	1.67
Calcutta	**MBE**	-3.56	-0.59	-0.21	-1.34	-0.07
	t-test	0.71	0.23	0.08	0.43	0.04
	MPE	24.51	1.8	-3.16	6.91	-2.36
	RMSE	2.94	2.23	3.08	2.28	2.32
Bombay	**MBE**	-0.81	0.99	-1.06	-0.54	-0.45
	t-test	0.28	0.49	0.37	0.24	0.19
	MPE	5.35	-5.95	3.89	1.91	1.63
	RMSE	10.34	4.05	3.81	3.88	3.55
Pune	**MBE**	-9.91	-3.2	-1.65	-2.81	-2.83
	t-test	3.35	1.28	0.47	1.05	1.32
	MPE	54.23	15.66	6.12	13.18	14.36

4. Conclusions

On the basis of the obtained results for five locations in India, it is concluded that third order correlations provides much accuracy over first and second order for the estimation of monthly average daily global radiation as a function of ambient air temperature incident on a horizontal surface. The results also indicate that the proposed model has good potential for use in estimating values of monthly average global solar radiation on horizontal surface for the locations where measurements of the sunshine duration are not available. Present correlation can also be tested for other in house or out locations on the availability of measured data.

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References

[1] Chandel S.S., Aggarwal R.K., Pandey A.N. A new approach to estimate global solar radiation on horizontal surfaces from temperature data. SESI Journal 2002, 12(2), 109-114.
[2] Angstrom A. Solar and terrestrial radiation. Q. J. Roy. Met. Soc. 1924, 50, 121-126.
[3] Page J.K. The estimation of monthly mean values of daily total short wave radiation on vertical and inclined surfaces from sun shine records for latitudes 400 N-400 S. Proc. U.N. conf. on new sources of energy, vol. 4(598),1961, P. 378-390.
[4] Prescott J.A. Evaporation from water surface in relation to solar radiation. Trans. Roy. Soc. Austr. 1940, 64, 114.
[5] Bakirchi Kadir. Correlations for estimation of daily global solar radiation with hours of bright sunshine in Turkey. Energy 2009, 34, 485-501.
[6] Bristow K.L., Campbell G.S. On the relationship between incoming solar radiation and daily maximum and minimum temperature. Agricultural and forest Meteorology 1984, 31, 159-166.
[7] Allen R.G. A self calibrating method for estimating solar radiation from air temperature. J. Hydrologic Engineering, ASCE 1997, 2, 56-57.
[8] Paulescu M., Fara L., Tulcan-Paulescu E. Models for obtaining daily global solar irradiation from air temperature data. Atmospheric Research 2006, 79, 227-240.
[9] Lunde P.J. Solar thermal engineering space heating and hot water systems. 1979, pp. 69.

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