SAKARYA ÜNİVERSİTESİ
FEN BİLİMLERİ ENSTİTÜSÜ DERGİSİ

Sakarya University Journal of Science
SAUJS

e-ISSN 2147-835X Period Bimonthly Founded 1997 Publisher Sakarya University
http://www.saujs.sakarya.edu.tr/

Title: Site Calibration of a Temperature-based Model for Estimating the Global Solar Radiation

Authors: Ceyda AKSOY TIRMIKÇI

Recieved: 2022-02-22 00:00:00

Accepted: 2022-03-11 00:00:00

Article Type: Research Article

Volume: 26
Issue: 2
Month: April
Year: 2022
Pages: 342-346

How to cite
Ceyda AKSOY TIRMIKÇI; (2022), Site Calibration of a Temperature-based Model for Estimating the Global Solar Radiation . Sakarya University Journal of Science, 26(2), 342-346, DOI: 10.16984/saufenbilder.1077449
Access link
https://dergipark.org.tr/tr/journal/1115/issue/69580/1077449

Sakarya University Journal of Science 26(2), 342-346, 2022

Site Calibration of a Temperature-based Model for Estimating the Global Solar Radiation

Ceyda AKSOY TIRMIKÇI*[1]

Abstract

In this paper, a commonly used global solar radiation (GSR) model is locally calibrated and tested for Kartepe, Kocaeli station. The coefficients of the model are calibrated for monthly and yearly by performing a regression analysis using the measured temperatures. Regression analysis results for both models provide that correlating the clearness index with the second degree of maximum temperature divided by minimum temperature gives the best accuracy for the selected location. Besides, the estimation results for each month indicate that the monthly calibrated coefficients provide very accurate results in terms of statistical errors. Moreover, seasonal calibration and yearly calibration of the model give less accurate predictions. The simple and accurate results by monthly calibrated models using this approach can be used in designing and evaluating solar energy applications in the absence of accurate sunshine data.

Keywords: Maximum temperature, minimum temperature, global solar radiation, regression, calibration

1. INTRODUCTION

Solar energy systems have become one of the best technical and economical solutions to meet increasing energy demand in many parts of the world in a sustainable, secure and clean way [1]. The first step in designing solar energy applications is to assess the availability by accurate solar radiation data. In current literature, there are many solar radiation models to estimate the total solar radiation on a tilted surface accurately [2]. However, solar radiation records are not always available due to high cost, and maintenance requirements [2, 3]. Therefore, there are various solar radiation models estimating solar radiation components from available measured meteorological variables [4-8]. These models are based on empirical correlations between sunshine fractions and commonly measured meteorological parameters including maximum temperature, minimum temperature, mean temperature and relative humidity.

Hargreaves and Samani suggested a very simple model using maximum temperature and minimum temperature to predict clearness index and global solar radiation on horizontal surfaces [8]. Several studies proposed modifications of the very simple model of Hargreaves and Samani. Bristow and Campbell introduced a model correlating clearness index with temperature difference exponentially [9]. Prieto et al. developed a location based model defining clearness index as a function of temperature difference and

* Corresponding author: caksoy@sakarya.edu.tr
[1] Sakarya University, Faculty of Engineering, Department of Electrical and Electronics Engineering
ORCID: https://orcid.org/0000-0003-0354-4022

minimum temperature [10]. Pandey and Katiyar proposed a new model expressing clearness index as a second degree function of the ratio between maximum temperature and minimum temperature [11].

In this paper, a commonly used temperature model proposed by Pandey and Katiyar [11] is selected to estimate global solar radiation, since air temperature measurement is available almost all over the world. The aim of this paper is to calibrate a simple temperature based model correlating clearness index with maximum and minimum temperatures for estimating monthly mean global solar radiation on horizontal surface with high accuracy. For this purpose, a common and simple model is selected from the literature and the coefficients of the model are calibrated by performing a regression analysis using the measured maximum and minimum temperatures of Kartepe, Kocaeli monthly, seasonal and yearly. Meteorological data of the location for each day of 2020 is used to determine the site calibrated coefficients. The modified model is tested in terms of common statistical indicators, Root Mean Square Error (RMSE) and Mean Absolute Percentage Error (MAPE). The results of the paper indicate that monthly specific calibration improves the accuracy of the model greatly, since the clearness index is dependent on the functional relationship between the maximum and minimum temperature variables.

2. METHODOLOGY

In this paper, a polynomial function using Tmax and Tmin variables is selected from the current literature to estimate clearness index for Kartepe, Kocaeli [11]:

$$K_t = a_1 + a_2 \frac{T_{max}}{T_{min}} + a3(\frac{Tmax}{Tmin})^2 \quad (1)$$

The clearness index, K_t, is the global radiation (H) divided by the extra-terrestrial radiation (H_0). The extra-terrestrial solar radiation is defined as follows [12-15]:

$$H_0 = \frac{24x3600}{\pi} xG_0 \quad (2)$$

$$G_0 = G_{sc}x\left(1 + 0.33xcos\frac{360xn_{day}}{365}\right)xk \quad (3)$$

$$k = (cos\varphi xcos\delta xsinw_s + \frac{\pi xw_s}{180} xsin\varphi xsin\delta) \quad (4)$$

where G_{sc}, n_{day}, ϕ, δ and w_s are the solar constant, the number of the day of the year, the latitude, solar declination and the sunrise hour angle for horizontal surface, respectively. G_{sc}, the total solar irradiation at the top of the atmosphere, is 1360.8 ± 0.5 W/m^2 [16].

The coefficients of Equation 1 are locally calibrated by performing regression analysis technique with daily measured maximum and minimum temperature values of August 2020. Then, the model is tested by using the measured solar radiation values of the same period in terms of Root Mean Square Error (RMSE) and Mean Absolute Percentage Error (MAPE). All local parameters are obtained from Meteoblue Weather History.

The RMSE is a commonly used measure determining the standard deviation of the estimation errors. The formula of the RMSE is as follows:

$$RMSE = \sqrt{(EV - MV)^2} \quad (5)$$

The MAPE is also a commonly used measure determining the estimation accuracy of a forecasting model. The formula of MAPE is as follows:

$$MAPE = \left|\frac{EV - MV}{MV}\right| \quad (6)$$

where EV and MV are estimated value and measured value respectively.

3. RESULTS AND DISCUSSION

Calibrated values of a_1, a_2 and a_3 in Equation 1 for each month are given in Table 1. According to the Table 1, clearness index of the selected location is correlated with the second degree of maximum temperature divided by minimum temperature. Table 2 indicates the measured temperature and radiation values at the location in August 2020. Estimated radiation and RMSE values using the presented monthly temperature model are given in Table 3.

Table 1 Site-calibrated monthly coefficients

Month	a_1	a_2	a_3
January	0	0	0.031
February	0	0	0.0546
March	0	0	0.0855
April	0	0	0.0736
May	0	0	0.1358
June	0	0	0.2090
July	0	0	0.2803
August	0	0	0.256
September	0	0	0.2394
October	0	0	0.1761
November	0	0	0.0990
December	0	0	0.0991

Table 2 Monthly minimum and maximum temperatures (°C) and global solar irradiation on horizontal surface at Kartepe (kWh/m2.day) [17]

Month	Maximum Temperature	Minimum Temperature	Shortwave Radiation
January	9.762	2.81	1.532
February	13.51	4.55	2.646
March	15.44	6.65	3.456
April	17.42	6.37	5.257
May	23.54	11.893	5.853
June	27.502	16.697	6.574
July	28.611	19.954	6.499
August	30.356	19.247	6.411
September	28.864	19.131	4.466
October	25.144	14.525	3.210
November	15.967	7.263	2.105
December	14.913	7.514	1.4322

Table 3 Monthly model performance evaluation at Kartepe: global solar irradiation on horizontal surface at Kartepe (kWh/m2.day), RMSE (%) and MAPE(%)

Month	Estimated radiation	RMSE	MAPE
January	1.5313	7.462×10^{-4}	4.569×10^{-4}
February	2.6472	12×10^{-4}	4.535×10^{-4}
March	3.4556	3.793×10^{-4}	1.157×10^{-4}
April	5.2581	11×10^{-4}	2.092×10^{-4}
May	5.8546	16×10^{-4}	2.733×10^{-4}
June	6.5752	12×10^{-4}	1.825×10^{-4}
July	6.4987	2.973×10^{-4}	4.616×10^{-4}
August	6.4107	3.264×10^{-4}	4.679×10^{-4}
September	4.4653	7.354×10^{-4}	1.567×10^{-4}
October	3.2102	2.102×10^{-4}	6.230×10^{-4}
November	2.105	4.743×10^{-6}	0
December	1.4322	1.786×10^{-4}	0

Table 3 indicates that using the calibrated values for a specific location and a short period provides the highest accuracy. However, the coefficients depend on the functional relationship between maximum and minimum temperature variables and a_3 tends to rise in warmer periods.

Table 4 Seasonal model performance evaluation at Kartepe: global solar irradiation on horizontal surface at Kartepe (kWh/m2.day), RMSE (%) and MAPE(%)

Month	Estimated radiation	RMSE	MAPE
January	2.4599	0.9279	0.3772
February	2.4144	0.2316	0.0959
March	4.0975	0.6415	0.1566
April	7.2338	1.9768	0.2733
May	4.3625	1.4905	0.3417
June	7.7737	1.1997	0.1543
July	5.7290	0.7700	0.1344
August	6.1903	0.2207	0.0357
September	3.3406	1.1254	0.3369
October	3.2651	0.0551	0.0169
November	3.8081	1.7031	0.4472
December	0.7197	0.7125	0.9900

Table 5 Yearly model performance evaluation at Kartepe: global solar irradiation on horizontal surface at Kartepe (kWh/m2.day), RMSE (%) and MAPE(%)

Month	Estimated radiation	RMSE	MAPE
January	2.7060	1.1740	0.7663
February	7.6554	5.0094	1.8932
March	6.3933	2.9373	0.8499
April	11.2867	6.0297	1.1470
May	6.8067	1.2237	0.1629
June	4.9675	1.6066	0.2444
July	3.6609	2.8381	0.4367
August	3.9557	2.4553	0.3830
September	2.9451	1.5209	0.3406
October	2.8786	0.331	0.1032
November	3.3574	1.2524	0.5950
December	2.2819	0.8499	0.5933

Seasonal calibrated values of a_1, a_2 and a_3 in Equation 1 are 0, 0, 0.0498 for winter (December-February), 0, 0, 0.1012 for spring (March-May), 0,0, 0.2471 for summer (June-August) and 0, 0, 0.1791 for autumn (September-November). Calibrated values of a_1, a_2 and a_3 in Equation 1 for a year is obtained as 0, 0, 0.1579 respectively.

These results are coherent with monthly calibration results. Correlating the clearness index with the second degree of maximum temperature divided by minimum temperature gives the best estimations for the selected location.

Estimated radiation and statistical indicators using the presented seasonal and yearly temperature models are given in Table 5 and Table 6. Table 5 and Table 6 prove that the accuracy of the model decreases significantly with coefficients calibrated for a longer period. Since the ability of the model to estimate global solar radiation determines the design parameters of a solar energy application, sensitive calibrations for shorter periods are vital for temperature based models.

4. CONCLUSION

In this paper, a commonly used global solar radiation model is locally calibrated and tested for Kartepe, Kocaeli station. The coefficients are calibrated monthly, seasonal and yearly. Regression analysis results for both models provide that correlating the clearness index with the second degree of maximum temperature divided by minimum temperature gives the best accuracy for the selected location. Monthly calibrated models provide very high accurate results with RMSE and MAPE almost zero. However, the coefficients are highly dependent on the changes in maximum and minimum temperatures. Therefore, values of statistical indicators increase with seasonal and yearly models. In seasonal approach, RMSE is calculated between 0.0551 and 1.9768. MAPE of the estimated values by the same approach varies between 0.0169 and 0.9900. The accuracy decreases with yearly calibrated coefficients with RMSE from 0.331 to 6.0297 and MAPE from 0.1032 to 1.1470 in the same approach. The results prove that calibrating the models for short periods of time improves the accuracy and promises the best results for statistical indicators.

It is a fact that measurements of solar radiation and its components are not always available due to the high cost and maintenance requirements. Temperature based models are the best alternatives in the absence of sunshine data to estimate solar radiation and its components. However, the accuracy of these models depend on the functional relationships between temperature parameters. This paper proposes that monthly calibrated temperature coefficients of clearness index equations can be employed in the design and evaluation stages for any solar energy application.

Funding

The author has no received any financial support for the research, authorship or publication of this study.

The Declaration of Conflict of Interest/ Common Interest

No conflict of interest or common interest has been declared by the author.

Authors' Contribution

The author contributed 100%.

The Declaration of Ethics Committee Approval

This study does not require ethics committee permission or any special permission.

The Declaration of Research and Publication Ethics

The author of the paper declare that she complies with the scientific, ethical and quotation rules of SAUJS in all processes of the paper and that they do not make any falsification on the data collected. In addition, she declares that Sakarya University Journal of Science and its editorial board have no responsibility for any ethical violations that may be encountered, and that this study has not been evaluated in any academic publication environment other than Sakarya University Journal of Science."

REFERENCES

[1] IEA (2021), Renewables 2021, IEA, Paris https://www.iea.org/reports/renewables-2021.

[2] C. Aksoy Tırmıkçı and C. Yavuz, “Determining optimum tilt angles of solar surfaces in Sakarya, Turkey,” Theor Appl Climatol, vol.133, pp.15–22, 2018.

[3] A.A. El-Sebaii, F.S. Al-Hazmi, A.A. Al-Ghamdi and S.J. Yaghmour, “Global, direct and diffuse solar radiation on horizontal and tilted surfaces in Jeddah, Saudi Arabia,” Applied Energy, vol. 87, no.2, pp.568-576, 2010.

[4] S. Janjai, P. Pankaew and J. Laksanaboonsong, “A model for calculating hourly global solar radiation from satellite data in the tropics,” Applied Energy, vol. 86, no. 9, pp. 1450-1457, 2009.

[5] Z. Jin, W. Yezheng and Y. Gang, “General formula for estimation of monthly average daily global solar radiation in China,” Energy Conversion and Management, vol. 46, no. 2, pp. 257-268, 2005.

[6] M. Li, X. Tang, W. Wu and H. Liu, “General models for estimating daily global solar radiation for different solar radiation zones in mainland China,” Energy Conversion and Management, vol. 70, pp. 139-148, 2013.

[7] E. Gasser, et al., “New Temperature-based Models for Predicting Global Solar Radiation,” Applied Energy, vol. 179, pp. 437-450, 2016.

[8] G.H. Hargreaves and Z.A. Samani, “Estimating potential evapotranspiration,” Journal of Irrigation and Drainage Engineering, vol.108 (IR3), pp. 223-230, 1982.

[9] K.L. Bristow and G.S. Campbell, “On the relationship between incoming solar radiation and daily maximum and minimum temperature,” Agric For Meteorol; vol. 31, no. 2, pp.159–66, 1984.

[10] J.I. Prieto, J.C. Martínez-García, D. García, “Correlation between global solar irradiation and air temperature in Asturias, Spain,” Sol Energy; vol. 83, no.7, pp.1076–85, 2009.

[11] C.K. Panday and A.K. Katiyar, “Temperature base correlation for the estimation of global solar radiation on horizontal surface,” Int J Energy and Environment, vol. 1, no. 4, pp. 737–4, 2010.

[12] J.A. Duffie and W.A. Beckman, “Solar engineering of thermal processes,” 3rd ed. New York: John Wiley & Son, 2006.

[13] P.I. Cooper, “The absorption of solar radiation in solar stills,” Solar Energy, vol. 12, no. 3, pp. 333–46, 1969.

[15] M. Iqbal, “An introduction to solar radiation,” New York, USA: Academic Press, 1983.

[16] G. Kopp, J.L. Lean JL, “A new, lower value of total solar irradiance: evidence and climate significance,” Geophys Res Lett, vol. 38:L01706, 2011.

[17] Meteoblue Weather History Download Kartepe, available at https://www.meteoblue.com, accessed on 15.01.2022