The stability of the radiative regime in Bucharest during 2017-2018

Sanda Budea1 *, Viorel Bădescu2, Adrian Ciocânea1, Cristiana Verona Croitoru3, and Ilinca Năstase3

1 University Politehnica of Bucharest, Hydraulic Department, 313 Spl. Independentei, 060042, Bucharest, Romania
2 Candida Oancea Institute, 313 Spl. Independentei, 060042, Bucharest, Romania
3 Technical University of Civil Engineering Bucharest, 66 Blvd. Pache Protopopescu, 021414, Bucharest, Romania

Abstract. The paper presents an analysis of the solar irradiation and the stability of the solar radiative regime, available for Bucharest and the southern area of Romania. The study is based on meteorological data measured at 3.6 seconds, on several consecutive days of each season, in the years 2017 and 2018. Data acquisition was performed at Technical University of Civil Engineering Bucharest. The daily mean values for sunshine number and sunshine stability number are computed and analyzed. The analyses carried out in this research are useful for applications of solar energy and conversion to thermal energy in hot air solar collectors to estimate the temperature variation at the collector air outlet as well as for photovoltaic panels to estimate the resulting electrical energy.

1 Introduction. Objectives

Solar energy has multiple applications, so it is necessary to measure and analyse its meteorological and radiometric characteristics (total irradiation at the collector surface) in different areas. Thus, in previous works, meteorological data from the Timisoara city (latitude 45°46′ N, longitude 21°25′E and 85 m altitude above average sea level) were presented and analysed [1-4]. Timisoara is in the West of Romania.

For locations in the south of Romania, there were no meteorological and radiometric data, which is why, with Technical University of Civil Engineering Bucharest's partner logistic support, under a research contract, the authors made such measurements in the city of Bucharest, located at 44°24′ N and 26°5′E, 56-96 m altitude above mean sea level.

The aim of this paper is to present and analyse information about the solar irradiance and the stability of the solar radiative regime, available for Bucharest. The study is based on meteorological data measured at 3.6 seconds, on several consecutive days during all four seasons, in the years 2017 and 2018.

The intensity of the radiative regime may be quantified by the daily solar global irradiation on a horizontal surface, presented in the third paragraph. An indirect measure of the radiative regime intensity is the daily average of the sunshine number - ssn, also called daily relative sunshine, which shows in relative terms how long the sun is visible on the sky, during a given period. Solar irradiation is directly connected with the performance of solar thermal or photovoltaic systems. The stability of the radiative regime is quantified by the daily average value of the sunshine stability number – sssn, which provides information about the number of times when the sun changes from being visible to being covered by clouds.

Several days covering all four seasons have been selected and analysed in this study. The selection objective was to have couples of days with similar values of daily solar irradiation but different levels of the radiative regime stability.

The present paper pursues two major objectives:

i) gives meteorological data for Bucharest and

ii) delivers results for daily average of the sunshine number - ssn and sunshine stability number – sssn. That is important especially because the stability of the radiative regime has not been enough studied in literature. However, some research regarding “clearness index” between 0-1 and irradiance variability, with data from North America and Hawaii, can be found in [5].

The analyses carried out in this research are useful for applications of solar energy and its conversion to thermal energy in hot air solar collectors to estimate the air temperature variation at the collector outlet as well as for photovoltaic panels to estimate the resulting electrical energy. The rapid variation of solar irradiance constitutes a “solar ramp” and creates problems in managing the power grid plant, by instability [6-9].

2 Computation of the indicators of solar radiative regime

The sunshine number is a quantity number, indicating whether the sun shines or not at given time $t$, with two extreme values: 1- for clear sky, 0- for overcast sky. [10]:
The average value of ssn over period $\Delta t$ equals the relative sunshine during $\Delta t$. Series of sunshine number are derived from series of measurements of solar irradiance by using the sunshine criterion [11]: the sun is shining at time $t$ if direct solar irradiance exceeds 120 W/m$^2$. So,

$$
ssn = \begin{cases} 
0 & \text{if sun is covered by clouds at time t} \\
1 & \text{otherwise}
\end{cases}
$$

(1)

The sunshine stability number ($sssn$) quantifies the stability of the solar radiative regime [11]:

$$
sssn = \begin{cases} 
1 & \text{if } \frac{G_{t} - G_{t-h}}{G_{t}} > 120 \text{ W/m}^2 \\
0 & \text{otherwise}
\end{cases}
$$

(2)

where $G_t$ represent the global irradiance and $G_{t-h}$ and diffuse solar irradiance at the moment $t$, and $h$ is sun elevation angle against a horizontal surface [12].

There are five classes of relative sunshine, [4, 12,13], see Table 1:

**Table 1. Relative sunshine classes.**

| I. Clear sky day | II Overcast sky day | III Low cloudiness | IV Medium cloudiness | V. High cloudiness |
|------------------|---------------------|-------------------|--------------------|-------------------|
| 1.0              | 0.0                 | 0.8 to 1.0        | 0.4 to 0.7         | 0.0 to 0.3        |

The sunshine stability number ($sssn$) are computed between sun rise and sun set.

### 3 The Database for each season

Solar radiation was recorded with a Star Pyranometer FLA 628S pyranometer, with a resolution of 0.1 W / m$^2$.

Based on meteorological and solar radiation data recorded in Bucharest, we selected several consecutive days for each season. The variation of solar irradiance during July 2017 is shown in Fig. 1 as example.

It can be noticed that in January one can find days with amounts of solar irradiation comparable to the other months of the other seasons, but their frequency is much lower. In July, weather stable days are fewer in number.

### 4 Results for daily average values of ssn and $sssn$

The daily average values of the sunshine number ($ssn$) and the daily average values of the sunshine stability number ($sssn$) are considered next, in Table 2, for the days selected in Section 3.

**Table 2. Indicators of solar radiative regime.**

| | Day | ssn | $sssn$ |
|------------------|-----|------|--------|
| **Spring** | | | |
| 2 april | 0.45975 | 0.004241 |
| 3 april | 0.65406 | 0.000566 |
| 4 april | 0.66731 | 0.000643 |
| 5 april | 0.37295 | 0.002652 |
| 6 april | 0.10237 | 0.001828 |
| 7 april | 0.62220 | 0.000558 |
| 8 april | 0.67202 | 0.00087 |
| 9 april | 0.69966 | 0.000315 |
| 10 april | 0.70312 | 0.000314 |
| **Autumn** | | | |
| 1 oct | 0.56132 | 0.001145 |
| 2 oct | 0.65036 | 0.000442 |
| 3 oct | 0.65206 | 0.000265 |
| 4 oct | 0.22703 | 0.002575 |
| 5 oct | 0.51194 | 0.001975 |
| 6 oct | 0.4472 | 0.000567 |
| 7 oct | 0.00102 | 9.25E-05 |
| 8 oct | 0.01807 | 9.22E-05 |
| 9 oct | 0.62626 | 0.001371 |
| **Summer** | | | |
| 16 jul | 0.00163 | 6.79E-05 |
| 17 jul | 0.16867 | 0.000407 |
| 18 jul | 0.45947 | 0.00169 |
| 19 jul | 0.50237 | 0.001222 |
| 20 jul | 0.44704 | 0.000543 |
| 21 jul | 0.42564 | 0.000122 |
| 22 jul | 0.52551 | 0.000136 |
| 23 jul | 0.50491 | 0.000205 |
| 24 jul | 0.47849 | 0.000159 |
| 25 jul | 0.15905 | 0.000183 |
| Day  | Solar irradiance | Uncertainty |
|------|------------------|-------------|
| 26 Jul | 0.54660          | 0.002129    |
| 27 Jul | 0.06400          | 0.001315    |
| 28 Jul | 0.04326          | 0.000923    |
| 29 Jul | 0.51819          | 0.001944    |
| 30 Jul | 0.57157          | 0.000486    |
| 31 Jul | 0.57331          | 0.000139    |
| 6 Jan  | 0.52043          | 0.001393    |
| 7 Jan  | 0.56218          | 0.000345    |
| 8 Jan  | 0.01461          | 0.00069     |
| 9 Jan  | 0.02116          | 0.00081     |
| 10 Jan | 0.00259          | 0.000118    |
| 11 Jan | 0.00047          | 0.000117    |
| 12 Jan | 0.01344          | 0.000116    |
| 13 Jan | 0.00264          | 0.000115    |
| 14 Jan | 0.38751          | 0.003973    |
| 15 Jan | 0.00258          | 0.000112    |
| 16 Jan | 0.50129          | 0.002462    |
| 17 Jan | 0.43269          | 0.003593    |
| 18 Jan | 0.24949          | 0.002155    |
| 19 Jan | 0.60372          | 0.000668    |

**Fig. 1.** Solar irradiance in July 2017.
Fig. 1. Solar irradiance in July 2017.

Fig. 2. Solar irradiance in October 2017.
Fig. 2. Solar irradiance in October 2017.

Fig. 3. Solar irradiance in January 2018.
Fig. 3. Solar irradiance in January 2018.

Fig. 4. Solar irradiance in April 2018.
Fig. 4. Solar irradiance in April 2018.

Fig. 5. Indicators of solar radiative regime.
The values resulting from the computation of the two indicators, $ssn$ and $sssn$, on different days from all four season during 2017-2018 years, are presented in Table 2 and Fig. 2. It is noted that April has the most days with sunshine number $ssn$ close to 0.7, while in January the lowest values were found.

5 Conclusions

Present paper considered meteorological and radiometric recent data for Bucharest, during 2017-2018, measured with a frequency of 3.6 s. Solar irradiance is illustrated on consecutive days, covering all four season. As expected, the most unstable days are in January.

Also, in present paper the authors analysed two indicators of solar radiative regime: daily average of sunshine number $ssn$ and sunshine stability number $sssn$. It can see from the values and graphs that dominant is medium cloudiness class for sunshine number $ssn$, with values between (0.4÷0.7). Regarding $sssn$, the best sunshine stability is achieved in July. The worst stability is achieved in April and October.

This research is supported by UEFISCDI PN-III-P2-2.1-PED-2016-1154, contract 83PED/2017.

References

1. V. Badescu, Correlations to estimate monthly mean daily solar global irradiation: application to Romania, Energy 24 (1999), 883-893.
2. V. Badescu, E. Zamfir, Degree-days, degree-hours and ambient temperature bin data from monthly-average Temperatures (Romania), Energy Conv. Manag. 40 (1999), 885-900.
3. SRMT. Solar Radiation Monitoring Station of the West University of Timisoara, Romania. http://solar.physics.uvt.ro/srms (accessed 10.06.18).
4. V. Badescu, S. Budea, How significant is the stability of the radiative regime when the best operation of solar DHW systems is evaluated? Renewable Energy 88 (2016), 346-358.
5. Perez, R., David, M., Hoff, T.E., Jamaly, M., Kivalov, S., Kleissl, J., Lauret, P., Perez, M., Spatial and temporal variability of solar energy. Foundations and in Renewable Energy 11(1) (2016), 1-44.
6. A. Mills, M. Ahlstrom, M. Brower, A. Ellis, R. George, T. Ho, B. Kroposki, C. Lenox, N. Miller, M. Milligan, J. Stein, Y-H Wan, Understanding variability and uncertainty of photovoltaics for integration with the electric power system, IEEE Power Energy Mag. 9 (2011), 33-41.
7. T. Tomson, Fast dynamic processes of solar radiation, Sol. Energy 84 (2010), 318-323.
8. M. Brabec, V. Badescu, M. Paulescu, Nowcasting sunshine number using logistic modelling, Meteorol. Atmos. Phys. 120 (2013), 61-71.
9. J.W. Taylor, An evaluation of methods for very short-term load forecasting, using minute-by-minute British data, Int. J. Forecast. 24 (2008), 645-658.
10. V. Badescu, A new kind of cloudy sky model to compute instantaneous values of diffuse and global solar irradiance, Theor. Appl. Climatol. 72 (2002), 127-136.
11. Guide to Meteorological Instruments and Methods of Observation, World Meteorological Organization, 2008. WMO-No.8, http://www.wmo.int/ (accessed 10.06.18)
12. M. Paulescu, V. Badescu, New approach to measure the stability of the solar, radiative regime, Theor. Appl. Climatol. 103 (2011), 459-470.
13. I. Soriga, V. Badescu, Thermal inertia of flat-plate solar collectors in different radiative regimes, Energy Conversion and Management, 111 (2016), 27-37.