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

Sanda Budea[1 *], *Viorel* Bădescu[2], *Adrian* Ciocănea[1], *Cristiana Verona* Croitoru[3], and *Ilinca* Năstase[3]

[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 analysed. 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 44º24′ N and 26º5′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 season, 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]:

* Corresponding author: sanda.budea@upb.ro

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

The average value of ssn over period Δt equals the relative sunshine during Δt. 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,

$$ssn = \begin{cases} 1 & if \frac{G_t - G_{d,t}}{\sin h} > 120\ W/m^2 \\ 0 & \text{otherwise} \end{cases} \quad (2)$$

where G_t represent the global irradiance and $G_{d,t}$ 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.	II	III.	IV.	V.
Clear sky day	Overcast sky day	Low cloudiness	Medium cloudiness	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)* quantifies the stability of the solar radiative regime [11]:

$$sssn = \begin{cases} 1 & if \begin{cases} ssn_t < ssn_{t-1} & (when\ ssn_1 = 1)\ or \\ ssn_t > ssn_{t-1} & (when\ ssn_1 = 0) \end{cases} \\ 0 & otherwise \end{cases} \quad (3)$$

Depending on the initial value ssn_1, eq. (3) quantifies one of the two different phenomena: sun appearance or sun disappearance on the sky. Note that other ways of defining the stability of the radiative regime may be imagined, such as that used in ref. [7] or simply by comparing two neighbouring *ssn* values. "Measures of the sunshine stability may be based on Fourier transforms and amplitudes of frequency contribution and this approach may be useful for cases where system's time constants correlate with cloudy frequency. The definition by eq. (3) has the advantage that quantifies the stability of a given day, with respect to its initial state. This may be useful for operators of solar systems, especially when the morning is characterized by a clear or moderately cloudy sky "[4].

The average value of the sunshine stability number during the interval Δt is denoted *sssn*, as ranges between 0 (when the instantaneous values of *ssn* are all 0 or 1, respectively, for all time moments *t* during Δt) and 1/2 (when the instantaneous values of *ssn* change at every two consecutive moments during Δt). The radiative regime is fully stable in the first case and fully unstable in the last case.

The daily mean values of the sunshine number (*ssn*) (usually called daily relative sunshine) and 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.

Spring	Day	ssn	sssn
	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	Day	ssn	sssn
	1 oct	0.56132	0.001145
	2 oct	0.65036	0.000442
	3 oct	0.65206	0.000265
	4 oct	0.22203	0.002575
	5 oct	0.51194	0.001975
	6 oct	0.4472	0.005667
	7 oct	0.00102	9.25E-05
	8 oct	0.01807	9.22E-05
	9 oct	0.62262	0.001371
Summer	Day	ssn	sssn
	16 jul	0.00163	6.79E-05
	17 jul	0.16687	0.000407
	18 jul	0.45947	0.00169
	19 jul	0.50237	0.001221
	20 jul	0.44704	0.000543
	21 jul	0.42564	0.001222
	22 jul	0.52551	0.000136
	23 jul	0.50491	0.000205
	24 jul	0.47849	0.001159
	25 jul	0.15905	0.001838

Summer	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

Winter	Day	ssn	sssn
	1 jan	0.53608	0.000348
	2 jan	0.0014	0.000117
	3 jan	0.00577	0.000353
	4 jan	0.01772	0.000117
	5 jan	0.14528	0.00058
	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

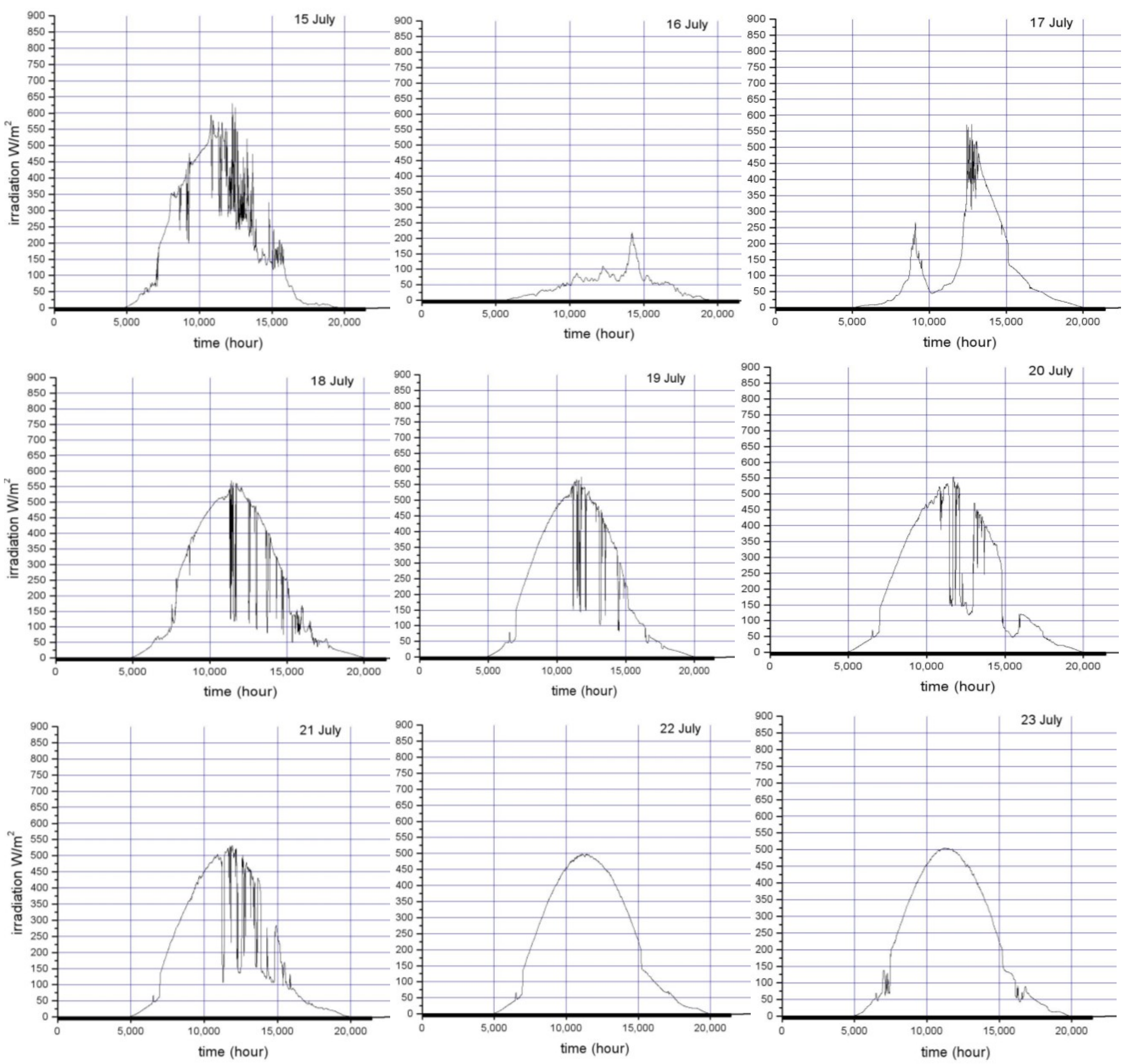

Fig. 1. Solar irradiance in July 2017.

https://doi.org/10.1051/e3sconf/20198504001

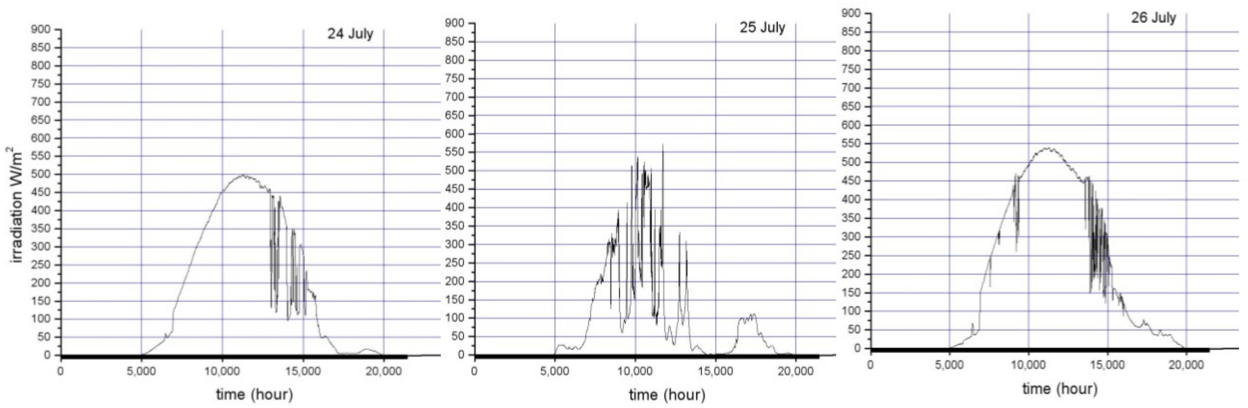

Fig. 1. Solar irradiance in July 2017.

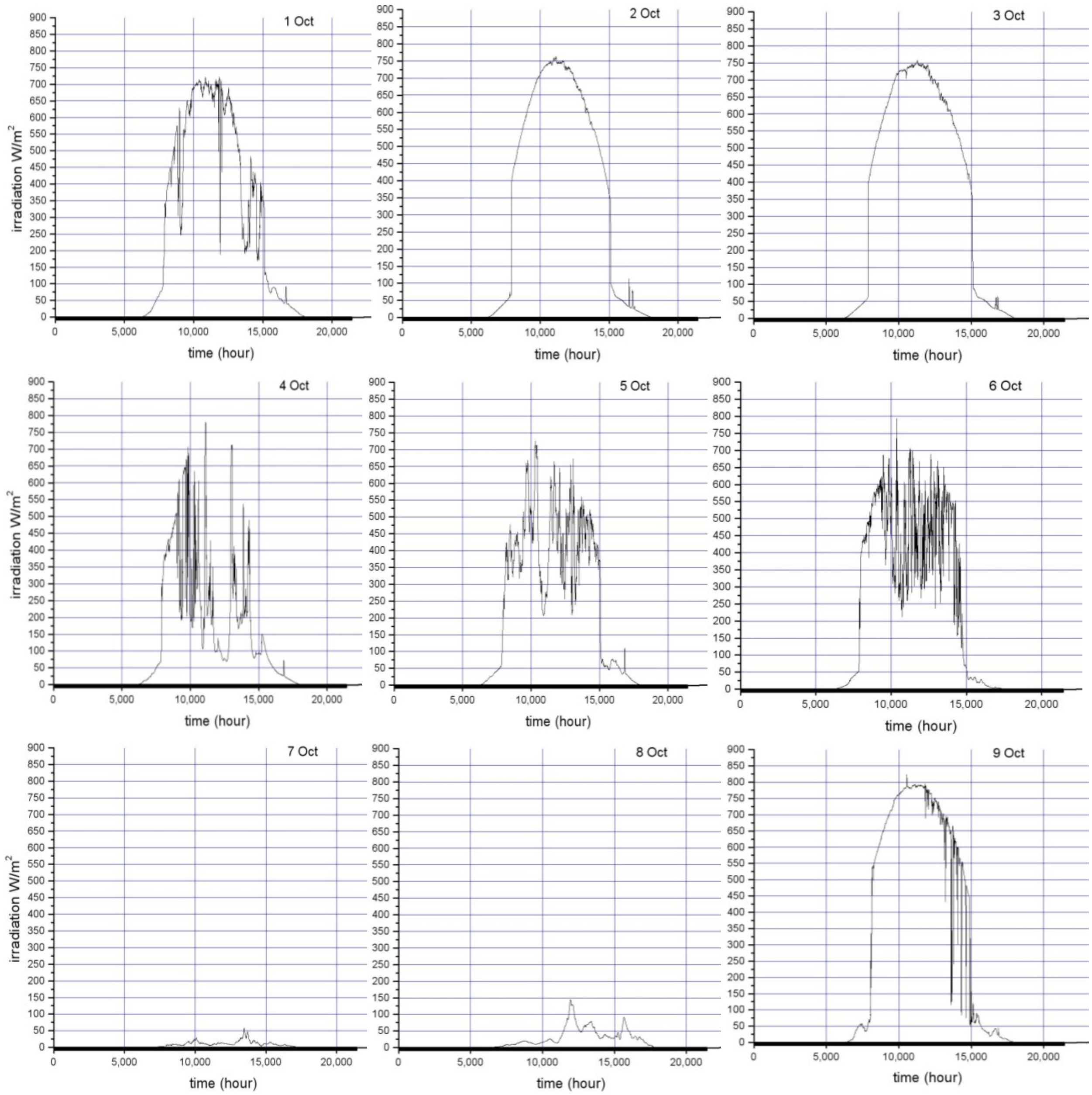

Fig. 2. Solar irradiance in October 2017.

 https://doi.org/10.1051/e3sconf/20198504001

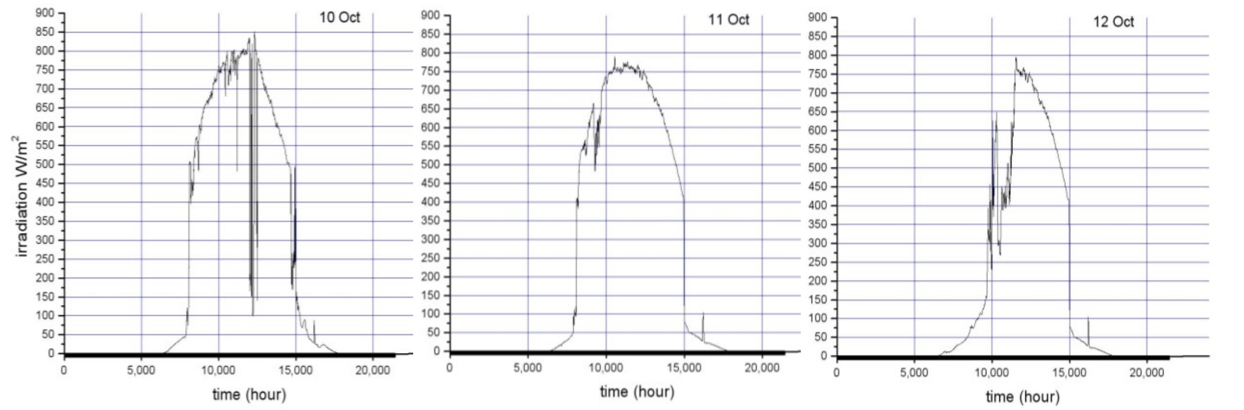

Fig. 2. Solar irradiance in October 2017.

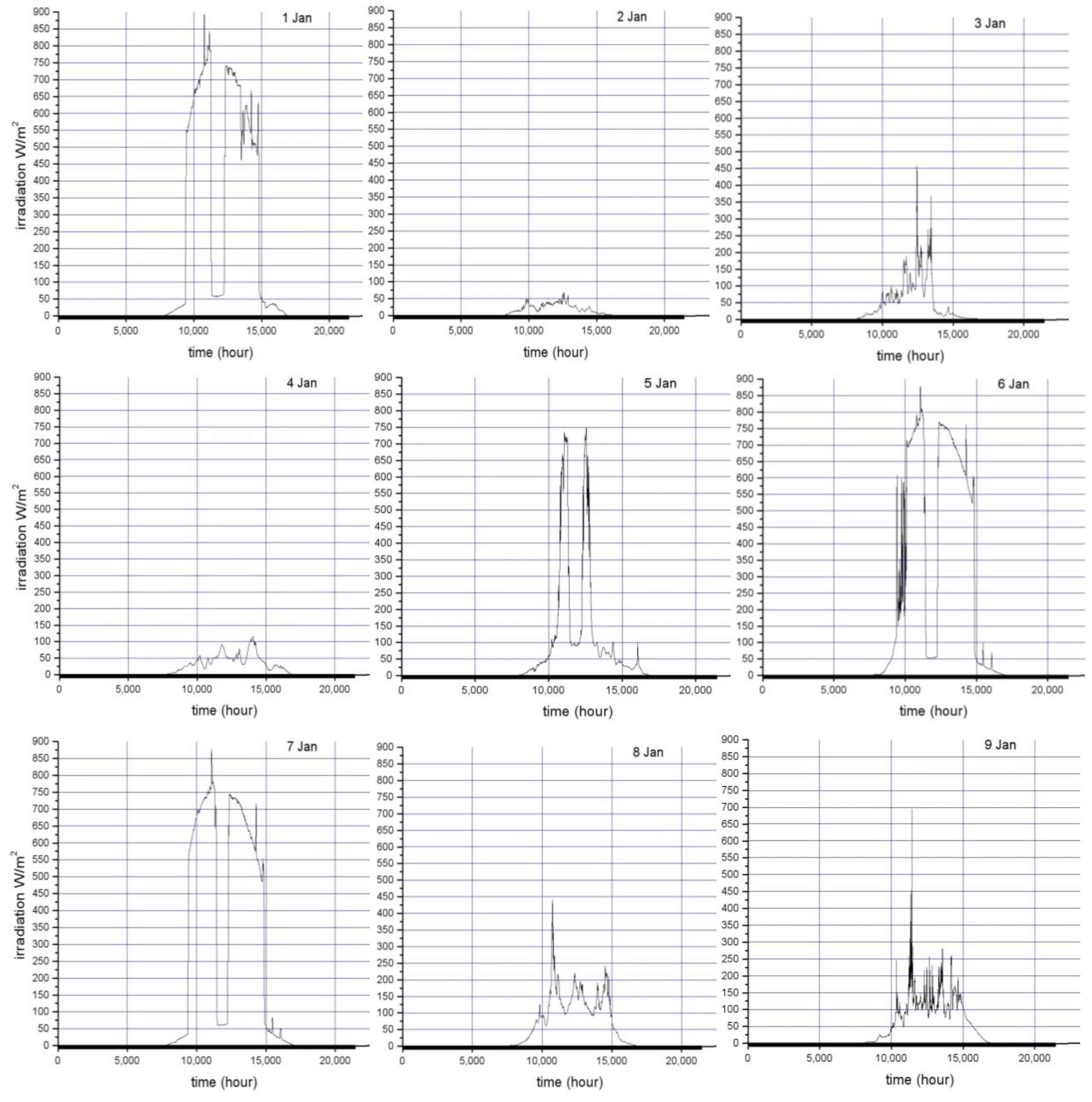

Fig. 3. Solar irradiance in January 2018.

https://doi.org/10.1051/e3sconf/20198504001

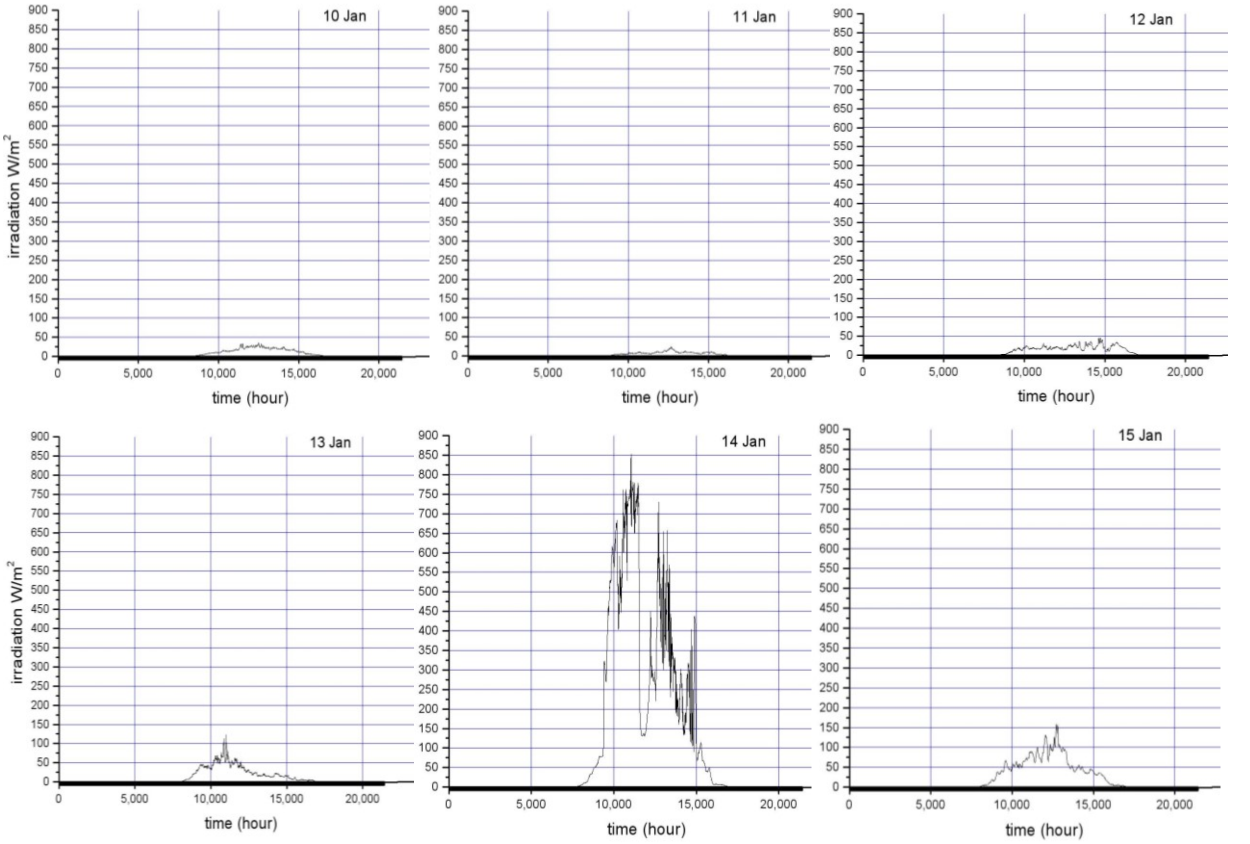

Fig. 3. Solar irradiance in January 2018.

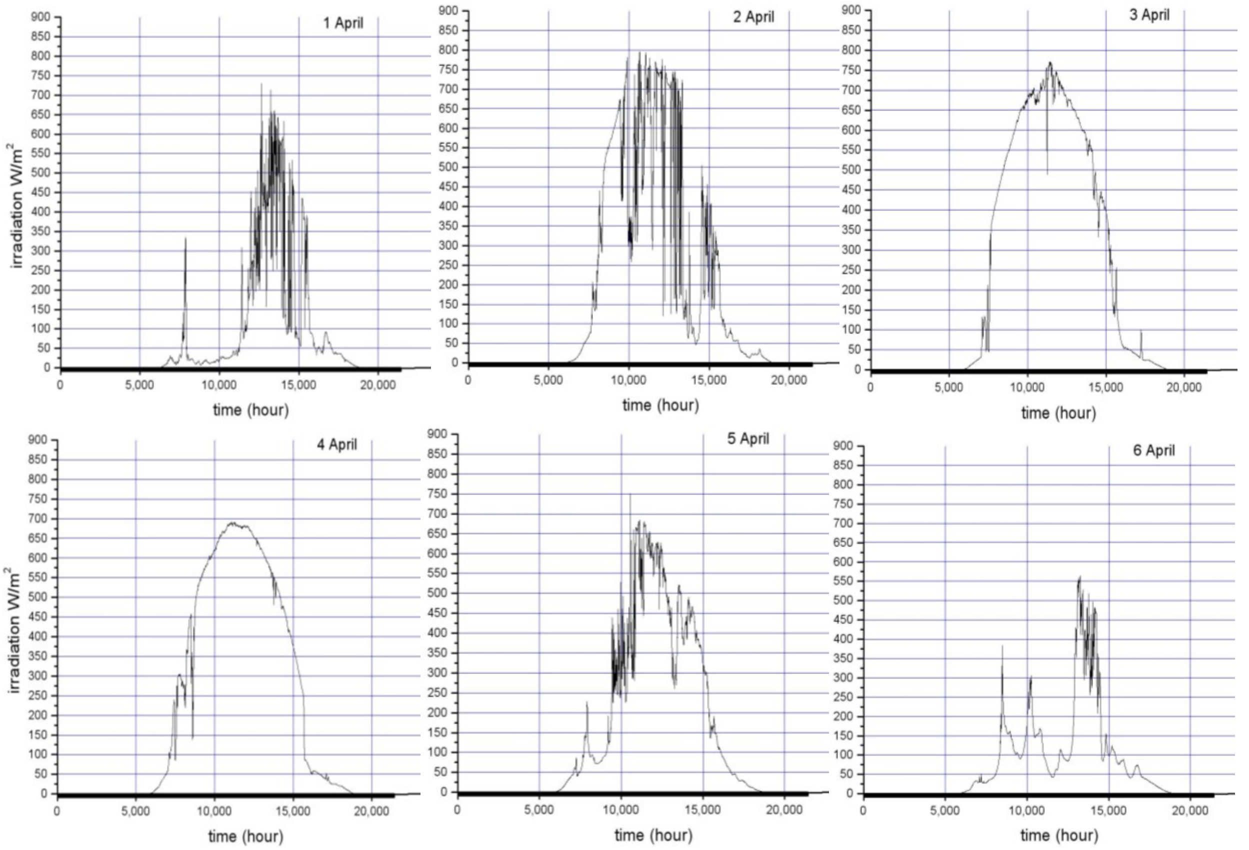

Fig. 4. Solar irradience in April 2018.

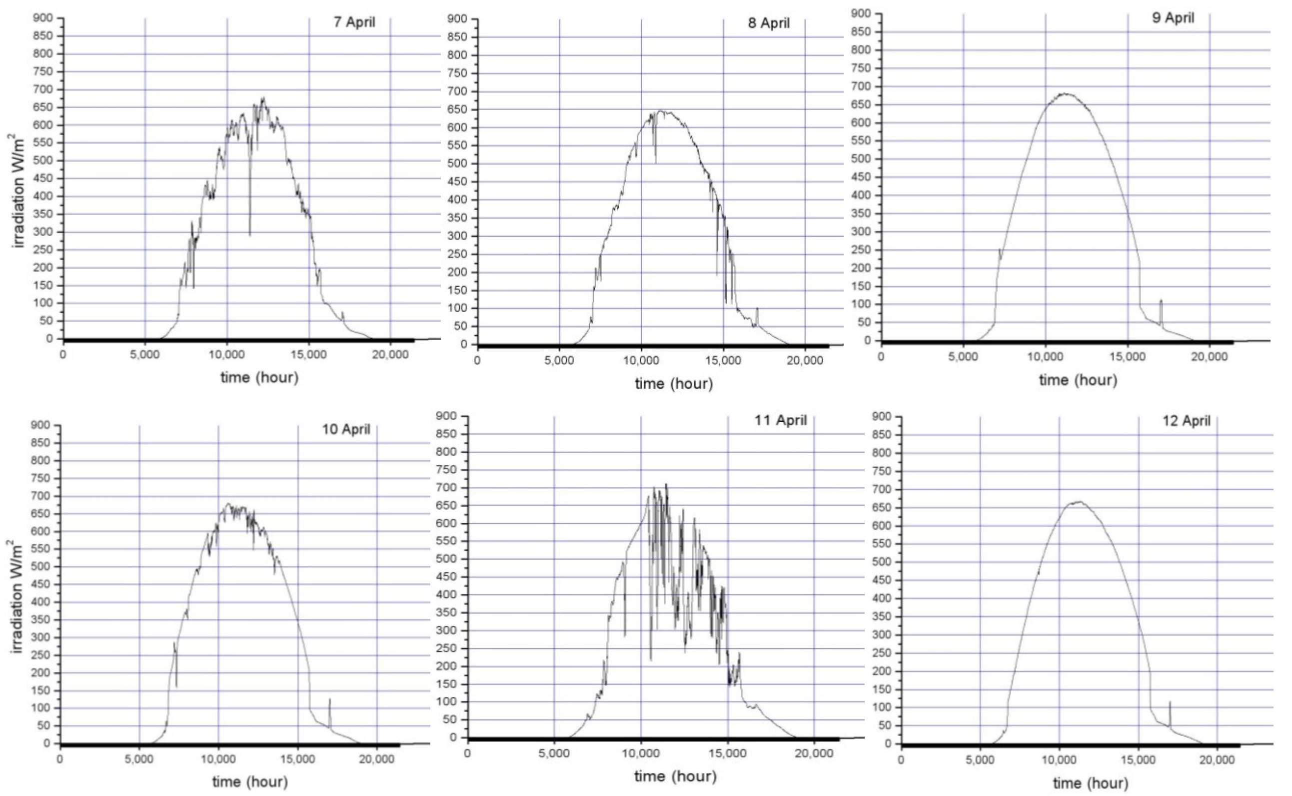

Fig. 4. Solar irradiance in April 2018.

Fig.5. Indicators of solar radiative regime.

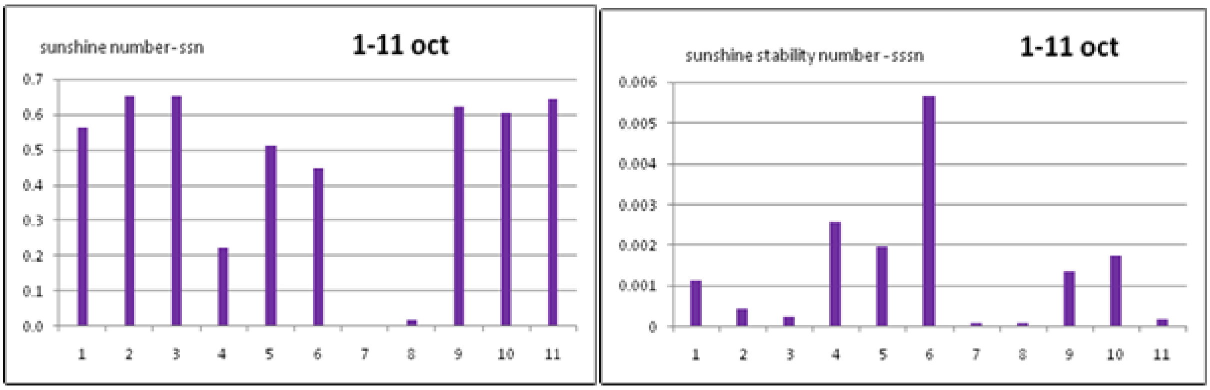

Fig.5. Indicators of solar radiative regime.

The values resulting from the computation of the two indicators, *ssn* si *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.

Regarding sunshine stability number, in October maximum values of 0.0055, are found but for a short period, while January and July are the most stable months.

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 **1(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.