



## Effects of nanometric hydrophobic layer on performances of solar photovoltaic collectors

Andrei BUTUZA, Mugur Ciprian BĂLAN\*

*Technical University of Cluj-Napoca; Faculty of Mechanical Engineering; Dept. of Mechanical Engineering; Bd. Muncii 103-105, Cluj-Napoca; Romania*  
E-mails: [Andrei.Butuza@termo.utcluj.ro](mailto:Andrei.Butuza@termo.utcluj.ro); [Mugur.Balan@termo.utcluj.ro](mailto:Mugur.Balan@termo.utcluj.ro)\*

\* Corresponding author, Phone: +40 745 014725 Fax: + 40 264 592 055

### Abstract

The study refers to the experimental investigation of solar photovoltaic collectors' behaviour when the glazed surface is treated with a nanometric layer of hydrophobic solution. The experiment was carried out on two photovoltaic collectors, of which one was considered as reference and the other one was coated with a commercial hydrophobic solution. It was studied the evolution of the following electrical parameters: current, voltage, power, efficiency and daily energy production. The voltage was almost unaffected, but for all the others parameters, important drop were recorded. The preliminary conclusion of the study is that the use of hydrophobic solutions, for the treatment of glazed surfaces of solar collectors is not recommended. This hypothesis needs supplementary investigations and measurements in the context of reduced available information concerning the optical properties of hydrophobic solutions.

### Keywords

Hydrophobe; Nanometric; Photovoltaic; Solar energy; Solar collector; Self-cleaning, Efficiency

## **Introduction**

The study of hydrophobic coating layer effects on solar photovoltaic modules is continuing previous studies concerning the renewable energies, at the Technical University of Cluj-Napoca [1-3].

The principles of solar energy based photovoltaic (PV) effect are presented in [4].

It is already known that soiling, or dust deposition, of the collectors' surfaces can be considered the third cause of efficiency drop in photovoltaic solar plants, after the availability of solar radiation and after the air temperature [5]. In this context the study of all cleaning solutions of solar photovoltaic modules, is of height technical interest.

The use of self-cleaning glazing products based on nanometric layers is recommended for different technical applications [6].

In the frame of this study was found that first references of the use of hydrophobic solutions, are dating from 1972, suggesting that these type of substances is relatively new and modern [7 and 8].

A useful method for evaluation of the self-cleaning glazing products is presented in [9] while in [10] is studied the behaviour of self-cleaning glass in urban atmosphere.

Properties and effects of super hydrophobic surfaces, including silicon wafer specimens, replicates of water-repellent leaves of plants and commercially available metal foils additionally hydrophobized, are presented in [11].

Improvements of self-cleaning properties of photovoltaic modules, by different methods (use of low-cost foil cleaning for PV, use of thin film PV foil, use of plasma surface modification technology in PV cell manufacturing and use of micro and nano super hydrophobic surfaces, are presented in [12].

Based on the literature review, no references were found concerning the effects of hydrophobic solutions, layers or coatings, to the electrical performances of photovoltaic collectors. Under these circumstances, it seems this study could be the first one concerning this subject.

The aim of this study is to present the effects of a nanometric hydrophobic coating layer, on the electrical performances of the solar photovoltaic modules.

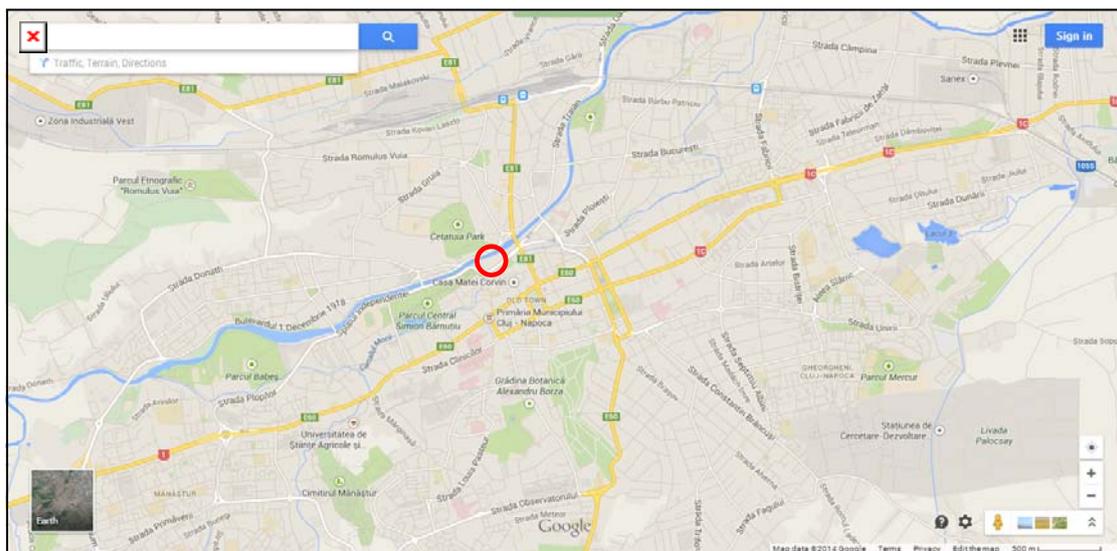
## Material

The study has an exploratory character and was realised with the purpose of testing mainly the trend concerning the effects of a nanometric hydrophobic solution film, applied on the glazed surface of solar photovoltaic modules.

For this study it was developed a simple experiment and the data acquisition system was manufactured using mainly low cost sensors. Mainly qualitative results were expected, but finally also quantitative results were obtained.

The experiment was conducted at the Technical University of Cluj-Napoca, at the geographical coordinates N 46.773003 and E 23.585378, in the autumn period between 21.10.2013-11.16.2013.

The location of the experiment, on the map of Cluj-Napoca, based on Google Maps, is presented in the figure 1.



**Figure 1.** Location of the experiment on the map of Cluj-Napoca.  
Google Maps © 2014 Google

The study is based on the use of 2 identical solar photovoltaic collectors, mounted on the roof of the newest building of the University, facing south, at a tilt angle of  $37^\circ$ , the optimum solar tilt angle for Cluj-Napoca [4].

The first solar photovoltaic collector, considered as reference, is uncoated and is referred as PV1. The second solar photovoltaic collector is treated with a nanometric hydrophobic coating layer, with the "nanoShell for Solar PV" solution, commercial available

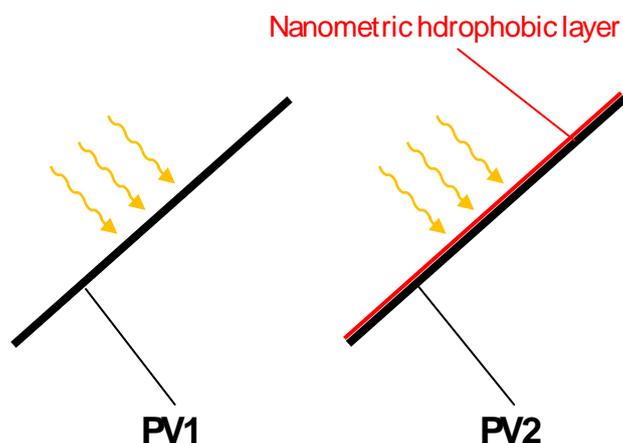
and manufactured by Nano Shell Company and is referred as PV2.

The solar photovoltaic collectors are of STP075S-12/Bc type, manufactured by Suntech. In table 1, are presented the main technical characteristics of the collectors [13].

**Table 1.** Main characteristics of the STP075S-12/Bc photovoltaic collectors

Parameter	Value
Maximum power	75 W $\pm$ 5 %
Maximum current	4,35 A
Maximum voltage	17,3 V
Normal operating temperature (NOCT)	48°C $\pm$ 2°C
Cells technology	Mono crystal Si
Mass	8 kg
Dimensions	1195×541×30 mm

In figure 2 it is presented a schematic drawing of the 2 photovoltaic collectors and of the component layers.



**Figure 2.** Schematic drawing of the 2 photovoltaic collectors and of the component layers

In order to compare the performances of the 2 photovoltaic collectors, it was designed and manufactured an original data acquisition system, based on an Arduino Mega 2560 R3 motherboard [14] and on dedicated sensors to measure the following parameters: global solar radiation in the collector's plane (G), intensity of the current (I) and voltage (U).

In the table 2 are presented the sensors types used for data acquisition.

**Table 2.** Sensors types used for data acquisition

Parameter	Sensor type
Solar radiation	Pyranometer: Davis 6450
Current	Attopilot 90 A
Voltage	Attopilot 90 A

As it is indicated in table 2, a complex sensor was used to measure both current and voltage.

## Method

The research method used in the study is represented by the exploratory experiment based on dedicated designed and manufactured data acquisition system, using an industrial pyranometer and a low cost current and voltage sensor.

The influence of the hydrophobic layer of the performances of the solar photovoltaic collectors was evaluated by comparison between the values of electrical parameters of performances. Some of these parameters were measured, such as intensity of the current (I) and voltage (U). The values of the other parameters of performance, such as power (P), efficiency ( $\eta$ ) and energy production (E), were calculated based on their fundamental relations of definition presented in [4] and also indicated as follows.

The electric power (P), was calculated with equation (1)

$$P = I \cdot U \text{ [W]} \quad (1)$$

where I [A] is the intensity of the current and U [V] is the voltage.

The efficiency ( $\eta$ ), was calculated with equation (2)

$$\eta = P / (G \cdot S) \text{ [W]} \quad (2)$$

where P [W] is the electric power, G [ $\text{W}/\text{m}^2$ ] is the global solar radiation and  $S=0.646 \text{ m}^2$  is the area of the glazed surface of the collectors.

The energy production (E), was calculated with equation (3)

$$E = P \cdot \tau / 100 \text{ [kWh]} \quad (3)$$

where P [kW] is the electric power and  $\tau$  [h] is the time of operation. In this analysis as operating time were considered only intervals of 24 hours.

The percentage differences between the different parameters were calculated considering as reference the parameters of solar photovoltaic collector without the hydrophobic layer (PV1):

Some isolated measurement errors were identified, one value for current and one value for voltage. In these situations, the measured values situated outside the range of normal variations were replaced with the averaged values of the neighbour's values. The corrected values were presented in the tables of results. The corrected values of current and voltage were also used to calculate different performances parameters such as power, efficiency of energy production. This approach allowed the exclusion from analysis of all values affected

by measurement errors.

### Results

All the results are presented for the period of (26-27).10.2013, based on data recorded and calculated for a time step of 10 minutes. The two considered days were characterised by clear sky almost all the day time. Using these data were drawn the graphics presented in figures 3 - 7.

For the quantitative analysis, was considered in the same two days, the period of 2 hours around 13:00 (local winter time), between 12:00 - 14:00, when solar radiation had the highest values (700-890) W/m<sup>2</sup> in the collectors plane. These data were presented in tables 3 - 7. In these tables the column "time" is indicating the time (in minutes), elapsed from the beginning of 26.10.2013 - at 0:00 hour.

Figure 3 is presenting the variation of solar radiation in the period of (26-27).10.2013.

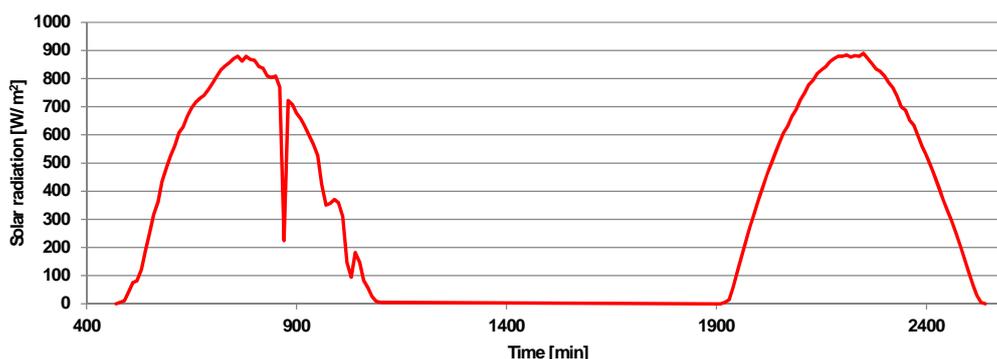


Figure 3. Measured solar radiation in the period of (26-27).10.2013

Table 3 is presenting samples of recorded values of global solar radiation in the plane of the collectors.

Table 3. Recorded values of global solar radiation in period of (26-27).10.2013

26.10.2013			27.10.2013		
Hour	Time [min.]	G [W/m <sup>2</sup> ]	Hour	Time [min.]	G [W/m <sup>2</sup> ]
	720	831.00	12:00	2220	876.00
12:00	730	845.00	12:10	2230	882.00
12:10	740	857.00	12:20	2240	879.00
12:20	750	871.00	12:30	2250	890.00
12:30	760	879.00	12:40	2260	871.00
12:40	770	862.00	12:50	2270	854.00
12:50	780	879.00	13:00	2280	834.00
13:00	790	868.00	13:10	2290	826.00
13:10	800	865.00	13:20	2300	809.00
13:20	810	842.00	13:30	2310	786.00
13:30	820	837.00	13:40	2320	767.00

13:50	830	809.00	13:50	2330	738.00
14:00	840	804.00	14:00	2340	699.00

Figure 4 is presenting current in the period of (26-27).10.2013.

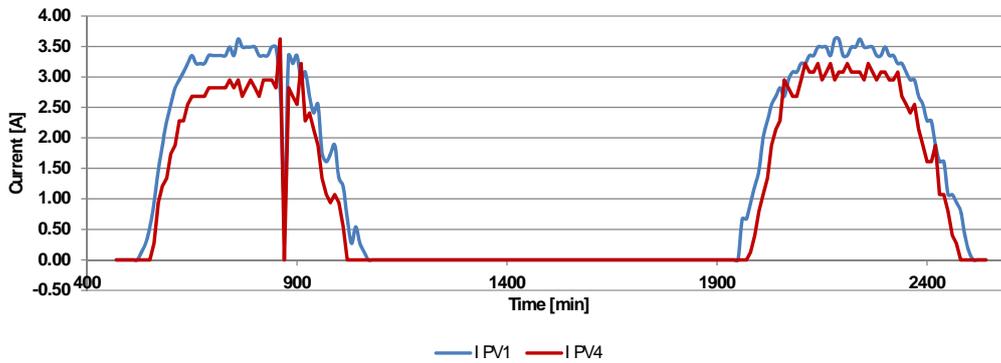


Figure 4. Current in the period of (26-27).10.2013

Table 4 is presenting samples of recorded values of current.

Table 4. Recorded values of current in period of (26-27).10.2013

26.10.2013					27.10.2013				
Hour	Time [min.]	I PV1 [A]	I PV2 [A]	$\Delta I$ [%]	Hour	Time [min.]	I PV1 [A]	I PV2 [A]	$\Delta I$ [%]
12:00	720	3.35	2.82	-15.8%	12:00	2220	3.35	2.95	-11.9%
12:10	730	3.35	2.82	-15.8%	12:10	2230	2.14	1.74	-18.7%
12:20	740	3.49	2.95	-15.5%	12:20	2240	3.49	2.95	-15.5%
12:30	750	3.35	2.82	-15.8%	12:30	2250	3.49	2.95	-15.5%
12:40	760	3.62	2.95	-18.5%	12:40	2260	3.49	3.08	-11.7%
12:50	770	3.49	2.68	-23.2%	12:50	2270	3.08	2.55	-17.2%
13:00	780	3.49	2.82	-19.2%	13:00	2280	2.95	2.55	-13.6%
13:10	790	3.49	2.95	-15.5%	13:10	2290	3.08	2.55	-17.2%
13:20	800	3.49	2.82	-19.2%	13:20	2300	2.82	2.28	-19.1%
13:30	810	3.35	2.68	-20.0%	13:30	2310	2.68	2.01	-25.0%
13:40	820	3.35	2.95	-11.9%	13:40	2320	2.95	2.14	-27.5%
13:50	830	3.35	2.95	-11.9%	13:50	2330	2.95	2.41	-18.3%
14:00	840	3.49	2.95	-15.5%	14:00	2340	3.08	2.41	-21.8%

Figure 5 is presenting the voltage in the period of (26-27).10.2013.

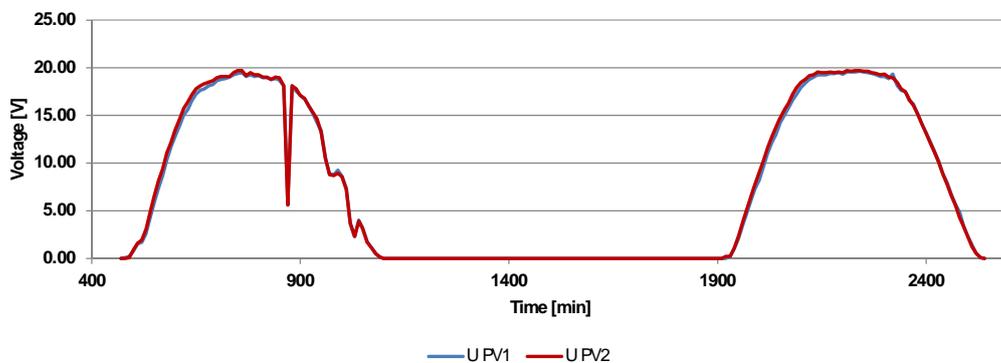


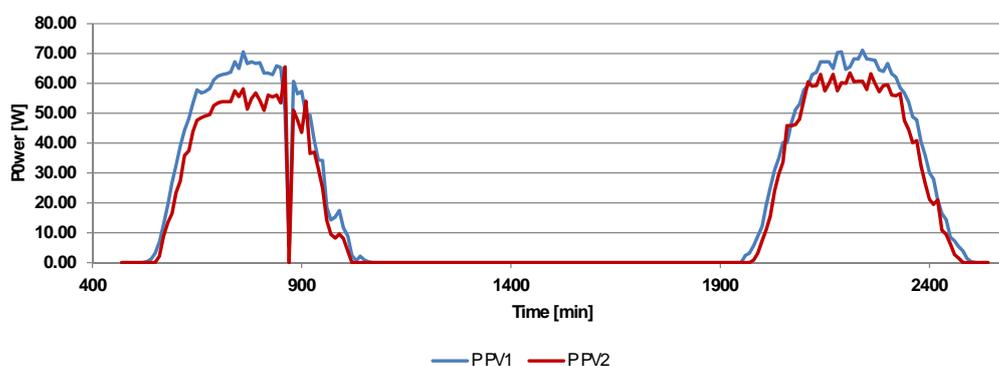
Figure 5. Voltage in the period of (26-27).10.2013

Table 5 is presenting the recorded values of voltage.

**Table 5.** Recorded values of voltage in period of (26-27).10.2013

Hour	Time [min.]	U PV1 [V]	U PV2 [V]	$\Delta U$ [%]	Hour	Time [min.]	U PV1 [V]	U PV2 [V]	$\Delta U$ [%]
12:00	720	18.86	19.09	1.2%	12:00	2220	19.55	19.63	0.4%
12:10	730	19.01	19.09	0.4%	12:10	2230	19.55	19.71	0.8%
12:20	740	19.25	19.48	1.2%	12:20	2240	19.63	19.71	0.4%
12:30	750	19.40	19.71	1.6%	12:30	2250	19.55	19.63	0.4%
12:40	760	19.48	19.71	1.2%	12:40	2260	19.48	19.63	0.8%
12:50	770	19.09	19.17	0.4%	12:50	2270	19.40	19.48	0.4%
13:00	780	19.25	19.48	1.2%	13:00	2280	19.25	19.40	0.8%
13:10	790	19.09	19.25	0.8%	13:10	2290	19.09	19.25	0.8%
13:20	800	19.17	19.25	0.4%	13:20	2300	19.09	19.32	1.2%
13:30	810	18.94	19.01	0.4%	13:30	2310	18.86	19.01	0.8%
13:40	820	18.94	19.01	0.4%	13:40	2320	18.52	18.94	2.2%
13:50	830	18.78	18.78	0.0%	13:50	2330	18.17	18.48	1.7%
14:00	840	18.86	19.01	0.8%	14:00	2340	17.63	17.78	0.9%

Figure 6 is presenting the power in the period of (26-27).10.2013.



**Figure 6.** Power in the period of (26-27).10.2013

Table 6 is presenting samples of calculated values of power.

**Table 6.** Calculated values of power in period of (26-27).10.2013

26.10.2013					27.10.2013				
Hour	Time [min.]	P PV1 [W]	P PV2 [W]	$\Delta P$ [%]	Hour	Time [min.]	P PV1 [W]	P PV2 [W]	$\Delta P$ [%]
12:00	720	63.18	53.83	-14.8%	12:00	2220	68.23	60.46	-11.4%
12:10	730	63.68	53.83	-15.5%	12:10	2230	68.23	60.71	-11.0%
12:20	740	67.18	57.47	-14.5%	12:20	2240	71.06	60.71	-14.6%
12:30	750	64.99	55.58	-14.5%	12:30	2250	68.23	57.91	-15.1%
12:40	760	70.52	58.14	-17.6%	12:40	2260	67.99	63.21	-7.0%
12:50	770	66.62	51.38	-22.9%	12:50	2270	67.71	60.00	-11.4%
13:00	780	67.18	54.93	-18.2%	13:00	2280	64.49	57.23	-11.3%
13:10	790	66.62	56.79	-14.8%	13:10	2290	63.95	59.29	-7.3%
13:20	800	66.90	54.29	-18.8%	13:20	2300	66.62	59.51	-10.7%
13:30	810	63.45	50.95	-19.7%	13:30	2310	63.18	56.08	-11.2%
13:40	820	63.45	56.08	-11.6%	13:40	2320	62.03	55.87	-9.9%
13:50	830	62.91	55.40	-11.9%	13:50	2330	58.51	56.92	-2.7%
14:00	840	65.82	56.08	-14.8%	14:00	2340	56.77	47.65	-16.1%

Figure 7 is presenting the efficiency in the period of (26-27).10.2013.

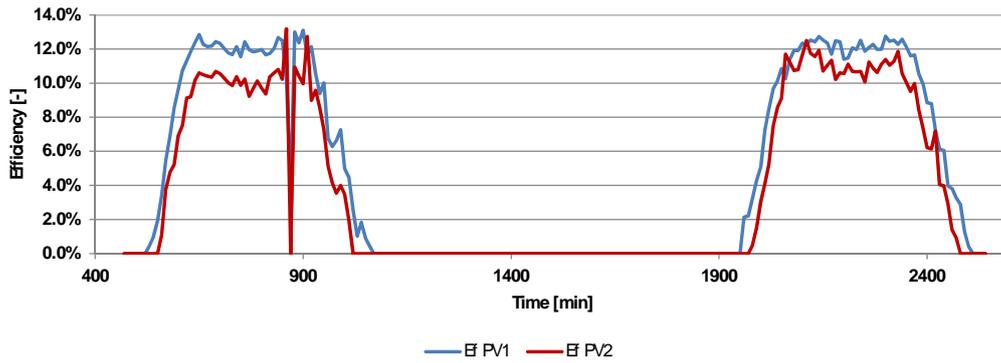


Figure 7. Efficiency in the period of (26-27).10.2013

Table 7 is presenting samples of calculated values of efficiency.

Table 7. Calculated values of efficiency in period of (26-27).10.2013

26.10.2013					27.10.2013				
Hour	Time [min.]	$\eta$ PV1 [%]	$\eta$ PV2 [%]	$\Delta\eta$ [%]	Hour	Time [min.]	$\eta$ PV1 [%]	$\eta$ PV2 [%]	$\Delta\eta$ [%]
12:00	720	11.8%	10.0%	-1.80%	12:00	2220	12.1%	10.7%	-1.40%
12:10	730	11.7%	9.9%	-1.80%	12:10	2230	12.0%	10.7%	-1.30%
12:20	740	12.1%	10.4%	-1.70%	12:20	2240	12.5%	10.7%	-1.80%
12:30	750	11.6%	9.9%	-1.70%	12:30	2250	11.9%	10.1%	-1.80%
12:40	760	12.4%	10.2%	-2.20%	12:40	2260	12.1%	11.2%	-0.90%
12:50	770	12.0%	9.2%	-2.80%	12:50	2270	12.3%	10.9%	-1.40%
13:00	780	11.8%	9.7%	-2.10%	13:00	2280	12.0%	10.6%	-1.40%
13:10	790	11.9%	10.1%	-1.80%	13:10	2290	12.0%	11.1%	-0.90%
13:20	800	12.0%	9.7%	-2.30%	13:20	2300	12.7%	11.4%	-1.30%
13:30	810	11.7%	9.4%	-2.30%	13:30	2310	12.4%	11.0%	-1.40%
13:40	820	11.7%	10.4%	-1.30%	13:40	2320	12.5%	11.3%	-1.20%
13:50	830	12.0%	10.6%	-1.40%	13:50	2330	12.3%	11.9%	-0.40%
14:00	840	12.7%	10.8%	-1.90%	14:00	2340	12.6%	10.6%	-2.00%

Figure 8 is presenting the results of daily energy production in the period between 21.10.2013-11.16.2013.

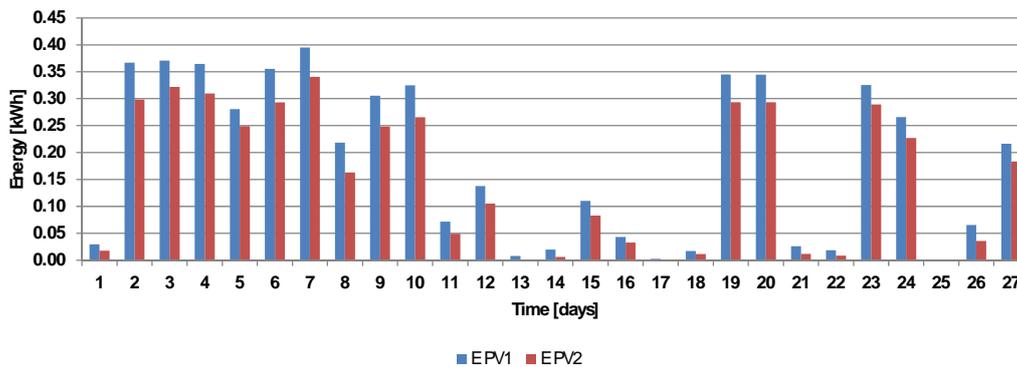


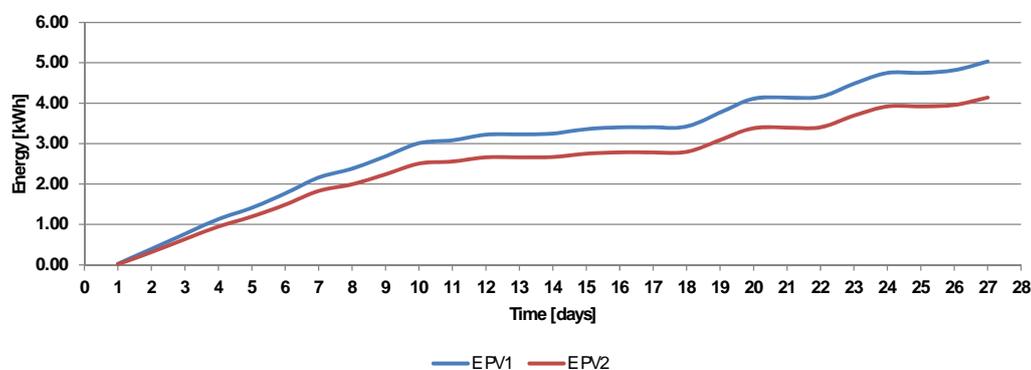
Figure 8. Daily energy production in the period between 21.10.2013-11.16.2013

Table 8 is presenting samples of calculated values of daily energy production.

**Table 8.** Calculated values of daily energy production in period of 21.10.2013-11.16.2013

Day no.	E PV1 [kWh]	E PV2 [kWh]	$\Delta E$ [%]
2	0.37	0.30	-18.6%
3	0.37	0.32	-13.2%
4	0.36	0.31	-15.1%
5	0.28	0.25	-11.3%
6	0.36	0.29	-17.6%
7	0.40	0.34	-13.8%
8	0.22	0.16	-25.3%
9	0.31	0.25	-18.8%
...			
Total	5.03	4.14	-17.7%

Figure 9 is presenting the results of cumulated daily energy production in the period between (22-31).10.2013.

**Figure 9.** Cumulated daily energy production in the period between (22-31).10.2013

## Discussion

The obtained results are capable to reveal the influence of the nanometric hydrophobic layer on the performances of the solar photovoltaic collectors.

The results concerning cumulated energy production are covering the whole period of the study (22-31).10.2013 and the other results are obtained from the data recorded in two consecutive sunny days of late autumn (26-27).10.2013, in the two hours of maximum solar radiation (700 - 890) W/m<sup>2</sup>. The time step for the recorded data considered in analysis was of 10 minutes.

The presented results were obtained both from direct measurements and calculation, following the described methodology.

The main effects of the hydrophobic coating are the followings:

÷ The hydrophobic solution determined a current drop of (11.7 - 27.5) %, representing a

performance shift down.

- ÷ The hydrophobic solution determined a negligible voltage increase of (0.0 - 1.7) %, suggesting that voltage is not affected by the coating layer.
- ÷ The hydrophobic solution determined a power drop of (2.7 - 22.9) %, determined by the current decrease and representing a performance shift down.
- ÷ The hydrophobic solution determined an efficiency drop of (0.4 - 2.8) %, determined by the power decrease and representing a performance shift down.
- ÷ The hydrophobic solution determined a daily energy production drop up to 25.3 %, explained by the power decrease and representing a performance shift down.
- ÷ The hydrophobic solution determined a cumulated energy production drop of 17.7 % in the considered 27 days of study.
- ÷ The surprising and dramatic drop of PV performances parameters could be explained by studying the properties of hydrophobic solutions, with very poor dissemination in the scientific literature and limited at data concerning the self-cleaning effect.

In the recent review [6], are presented the values of transmittance for 5 self-cleaning glazing products in visible spectrum, and for a single product also in the solar radiation spectrum. The properties of the substance used in this study are not presented. The reported values of transmittance in visible spectrum are situated in the range of (65-77) % [6] with an average value of 71%. The single reported value of transmittance in solar radiation spectrum is of 55% [6], for the product "Renew with Viridian Thermotech Clear", manufactured by Viridian Australia, having the transmittance in the visible spectrum of 70%, just near the average of this parameter.

Such low values of transmittance both in visible and in solar radiation spectrum explain the dramatic drop of PV performances.

Because of the important reduction of the global transmittance and of optical efficiency, the hydrophobic solutions will negatively affect also the solar thermal collectors.

## **Conclusions**

The effects of nanometric layer of hydrophobic solution on the glazed surfaces of PV collectors can be summarised as were observed in this study.

The current drop with (11.7 - 27.5) % is representing an important shift down of electric performance. The voltage increase is negligible with (0.0 - 1.7) %, suggesting that the hydrophobic layer does not affect the voltage. The power drop with (2.7 - 22.9) % is mainly due to the current drop. The efficiency drop of (0.4 - 2.8) % in absolute values is also representing a significant deterioration of collectors performance capability. The daily energy production drop is up to 25.3 %, and produced after 27 days a cumulated energy production drop with 17.7%.

Following this preliminary study, it results as a practical conclusion that ***the use of hydrophobic solutions, for the treatment of glazed surfaces of solar collectors is not recommended, mainly because of the associated transmittance reduction***. This conclusion applies both for solar thermal and solar photovoltaic collectors. In order to confirm or infirm this conclusion, it is needed to continue with detailed investigation.

### **Acknowledgements**

This paper was supported by the project "*Improvement of the doctoral studies quality in engineering science for development of the knowledge based society-QDOC*" contract no. POSDRU/107/1.5/S/78534, project co-funded by the European Social Fund through the Sectorial Operational Program Human Resources 2007-2013.

### **References**

1. Bălan, M.C., Damian, M., Jäntschi, L. *Preliminary results on design and implementation of a solar radiation monitoring system*, Sensors, 2008, 8, p. 963-978.
2. Bălan, M.C., Jäntschi, L., Bolboacă, S.D., Damian, M. - *Thermal solar collectors behaviour in Romania*, Polish journal of environmental studies, ISSN 1230-1485, 2010, 19(1), p. 231-241.
3. Bălan, M.C., Todoran, T.P., Bolboacă, S. D., Jäntschi, L. *Assessments about soil temperature variation under censored data and importance for geothermal energy applications. Illustration with Romanian data*, Journal of renewable and sustainable

- energy, 2013, 5, p. 1-13.
4. Duffie J.A., Beckman W.A., *Solar engineering of thermal processes*, 2<sup>nd</sup> ed. Wiley-interscience, 1991.
  5. Caron J.R., Littmann B., *Direct monitoring of energy lost due to soiling on first solar modules in California*, IEEE Journal of photovoltaics, 2013, 3(1), p. 336-340.
  6. Midtdal K., Jelle B.P., *Self-cleaning glazing products: A state-of-the-art review & future research pathways*, Solar energy materials and solar cells, 109, 2013, p. 126-141.
  7. Noll W., Büchner W., Lücking H.J., Sucker C., *Beiträge zur Grenzflächenchemie der Polyorganosiloxane - VI. Hydrophil-hydrophob-antagonismus in perfluoralkyl-carbonamid-substituierten siloxanen*, Kolloid-Zeitschrift & Zeitschrift für Polymere, 1972, 250 (8), p. 836-847.
  8. Ropte D., Gu J.U., *Trennung von Vitamin A-alkohol und Calciferol auf hydrophob imprägnierten Dünnschichtplatten. [Separation of vitamin A alcohol and calciferol on thin layer plates hydrophobically prepared]*, Pharmazie, 1972, 27 (8), p. 544-545.
  9. J.Keranen, *Self-cleaning glass-nano-structured self-cleaning coated glasses: modelling and laboratory tests for fundamental knowledge on thin film coatings, EC normalisation and customer benefits 36M publish able activity report, NMP3-CT-2003-505952*, Self-Cleaning glass consortium, 2007.
  10. Chabas A., Lombardo T., Cachier H., Pertuisot M.H., Oikonomou K., Falcone R., Verita M., Geotti-Bianchini F., *Behavior of self-cleaning glass in urban atmosphere*, Building and environment, 2008, 43, p. 2124-2131.
  11. Furstner R., Barthlott W., Neinhuis C., Walzel P., *Wetting and self-cleaning properties of artificial superhydrophobic surfaces*, Langmuir, 2005, 21, p.956-961.
  12. Jasim K.K., Shareef H., Sarhan M., *Improvement of the performance of self-cleaning solar panel*, Indian journal of applied research, 2013, 3, p. 202-206.
  13. \*\*\*, *High efficiency, high quality PV module*,  
<http://www.energymatters.com.au/images/suntech/STP085S-12Bb.pdf>
  14. \*\*\*, *Arduino Mega 2560*, <http://arduino.cc/en/Main/arduinoBoardMega2560>