Issue 24, January-June 2014
p. 115-130

Thermal Aspects Related to the Operation of Photovoltaic Collectors with Water Film Cleaning System

Andrei BUTUZA, Mugur C. 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; Mugur.Balan@termo.utcluj.ro;

* Corresponding author: Phone: (+) 40 745 014725 Fax: (+) 40 264 592 055

Abstract

This study presents an explorative experimental investigation of solar photovoltaic collector's behavior, when equipped with a water film based cleaning system. The study was focused mainly on thermal aspects and demonstrated the thermal potential of the water film, to be used in preheating domestic water. The results obtained in temperate continental climate and in autumn conditions, are in good agreement with similar studies. The electric effects of the water film were also investigated. This category of results was affected by limited precision of the data acquisition but the trend of water film electric effects could be still revealed. The general practical conclusion of the study is that water film cleaning system of the solar photovoltaic collectors can be recommended only with reserves, because of reduced and uncertain global performances.

Keywords

Photovoltaic; Soiling; Water Film; Cleaning System; Heat Recovery; Solar Energy; Efficiency.

Introduction

Availability of solar radiation, cells temperature and soiling of collectors surfaces are the main causes for the efficiency drop in active solar photovoltaic (PV) plants [1]. The dust on the transparent glazed surfaces of PV collectors is obstructing the solar radiation [2] and can determine the development of hot spots within the photovoltaic collectors [3, 4].

It was reported that even a low quantity of dust, such as 1 g/m^2, if deposited on the glazed surface of a photovoltaic collector, can lead to an annual 6.5 % loss in the efficiency, which in terms of energy production losses and revenue, is equivalent with about 1 % of the entire photovoltaic system cost of investment [5].

Solar photovoltaic soiling can cause a significant 28 % drop in the collector's short circuit current while the reduction of the open circuit voltage is less significant, representing about 6 %. These values are corresponding to 22 g/m^2 of dust deposition [6].

An experimental study, reported a power drop of 13 % for a photovoltaic collector, after only 18 days of exposure, in Abu Dhabi, United Arab Emirates [7].

For two photovoltaic plants of 1 MW each, one built on compact soil and the other one built on a sandy soil, were reported drops in energy production due to soiling of 1.1 %/year for the compact soil plant and of 6.9 %/year for the sandy soil plant [8].

The efficiency drop of a photovoltaic collector operating under soiling exposure and accumulating a dust quantity of 4 g/m^2 was of 1.5 %, compared with an identical cleaned photovoltaic collector [9].

These studies proved that soling of photovoltaic collectors is a serious operating problem and preventing or eliminating soling is a challenging issue.

One possible solution to the soiling problem is represented by the use of a thin layer of water on the front side of the collectors. Such approach was investigated in [10].

In the frame of this study, it was developed an original water film based cleaning system for photovoltaic collectors that is investigated in this study from thermal behaviour point of view, taking also into account that water is not only cleaning but is also extracting heat that can be used for domestic hot water preheating.

The aim of the paper is to provide information concerning thermal and electrical aspects related to a water film based cleaning system, specially designed for photovoltaic collectors.

Material and Method

The study is based on experiment that consists in comparative analysis of two identical photovoltaic collectors installed on the roof of a new building at the Technical University of Cluj-Napoca. The two collectors are facing south with a fixed tilt angle of 37°, representing the optimum inclination angle for solar energy applications in Cluj-Napoca.

The experiment was realised between 21st of October and 21st of November 2013.

The first collector (PV1) was untouched throughout the experiment and was considered as reference. The second collector (PV2) was equipped with a water film based cleaning system that provided in conditions of enough solar radiation availability, a continuous 1 mm water film flowing on the glazed surface of the collector.

The effects of water film on solar photovoltaic collector, was also studied in [10] using almost similar experimental method. In this study the original character is derived from the different construction of the water based cleaning system, for which a patent was requested.

Images of the glazed surface of reference photovoltaic collector (PV1) and of the water film on the second photovoltaic collector (PV2) are presented in Figures 1 and 2.

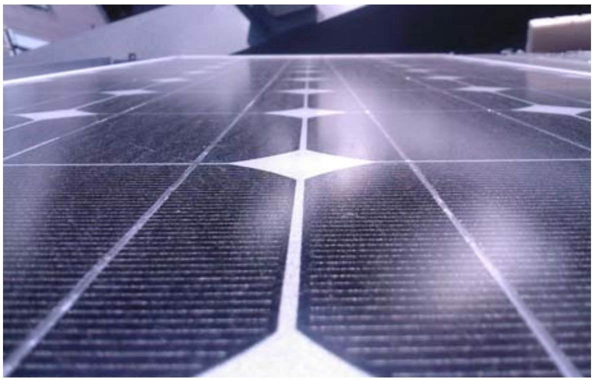

Figure 1. *The glazed surface of PV1*

Figure 2. *The water film on PV2*

The water is sucked from a thermally insulated water tank placed under the photovoltaic collector, by a pump that discharges the water into a distributor manufactured from a perforated pipe. From the distributor the water is forming a uniform layer that flows on the glazed surface. Water is collected by a collector and returned into the tank through a filter.

The principle drawing of the test bench for the photovoltaic collector with water based cleaning system is presented in Figure 3.

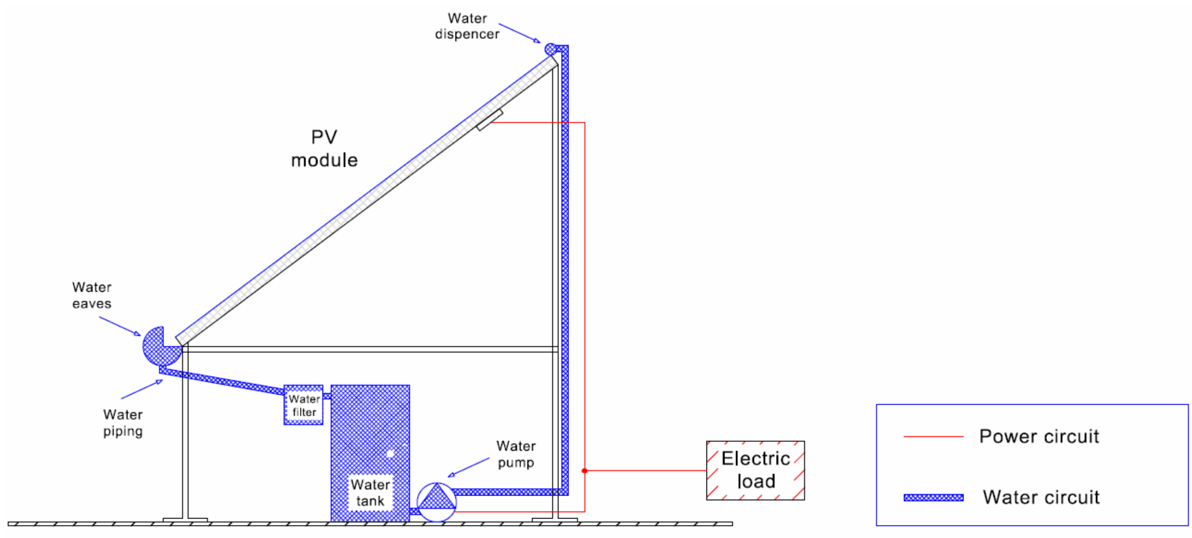

Figure 3. *Schematic diagram of the experimental setup*

A rendering of the experimental setup structure and photovoltaic collectors is illustrated in Figures 4 and 5.

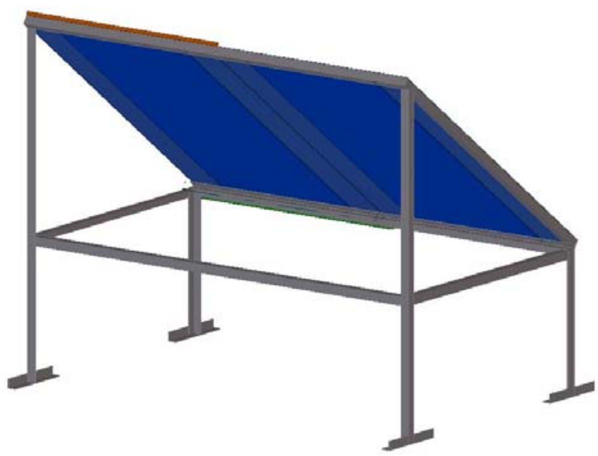

Figure 4. *Rear view of experimental setup*

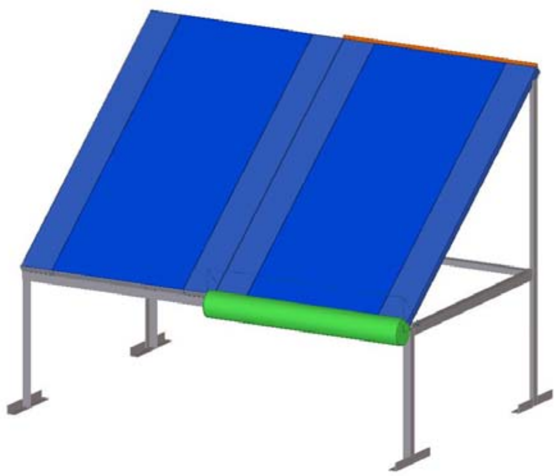

Figure 5. *Front view of experimental setup*

The photovoltaic collectors used in this experimental study are manufactured by the company Suntech and technical characteristics are listed in Table 1 [12].

Table 1. Suntech STP075S-12/Bc PV collector technical data

Parameter	**Value**
Rated Maximun Power (P_{max})	75 W ± 5 %
Current at P_{max} (I_{mp})	4.35 A
Voltage at P_{max} (V_{mp})	17.3 V
Short-Circuit Current (I_{sc})	4.87 A
Open-Circuit Voltage (V_{oc})	21.7 V
Nominal Operating Cell Temp. (NOCT)	50°C
Short-Circuit Current Temperature Coefficient	0.020 %/K
Open-Circuit Voltage Temperature Coefficient	-0.34 %/K
Peak Power Temperature Coefficient	-0.46 %/K
Maximum System Voltage	1000 V
Cell technology	Crystalline Silicon
Dimensions	1195×541×30 mm

The water pump is powered directly from the photovoltaic collector equipped with cleaning system. The pump was chosen with power consumption lower than 10 % of the maximum power of the photovoltaic collector [13].

The technical parameters of the pump used in the experiment are listed in Table 2.

Table 2. Phobya DC12-220 water pump technical data

Parameter	**Value**
Rated Voltage	12 V (±10 %)
Starting Voltage	> 8 V
Rated Power	6.5 W (±10 %)
Rated Current	0.62 A
Maximum Flow	400 l/h (±10 %)
Maximum Pump Head	2.2 m (±10 %)

On both photovoltaic collectors were connected two identical resistive loads of SR Pasives R80W-4R7 type [14].

The technical parameters of the resistors are listed in Table 3.

It was designed and manufactured a data acquisition system based on an Arduino Mega 2560 R3 motherboard [15] and on the sensors presented in Table 4.

The complex sensor used for measurements of currents and voltages, proved to be of relative low precision. Some errors were identified. In these situations, the values affected by errors were replaced by the averages of the neighbour values.

Table 3. SR Pasives R80W-4R7 resistor technical data

Parameter	**Value**
Resistance	4.7 Ω
Rated Power	80 W
Tolerance	± 0.5 %
Temperature coefficient	200 ppm/°C

Table 4. Sensors types used for data acquisition

Parameter	**Sensor type**
Solar radiation	Pyranometer: Davis 6450
Collectors temperatures	DS18B20+
Water temperature	DS18B20+
Current	Attopilot 90 A
Voltage	Attopilot 90 A

Even in these conditions the trend of electric behaviour of solar photovoltaic collectors with water film cleaning system was still revealed.

A meteorological station of TFA Primus WS-2800 type [17] was used to measure different ambient parameters such as air temperature.

The collector's temperatures were measured on the backside of each collector, behind the same cell. The water temperature was measured in the storage tank. The global solar radiation was measured in the plane of the collectors. The data from all the sensors was recorded to a computer.

Based on measured instantaneous current and voltage were also calculated instantaneous power and efficiency, using the basic relations of definition [11].

The relative differences between parameters were calculated considered as reference the parameters corresponding to the collector PV1.

Results

The results used for qualitative analysis, providing the trend of water film influences are provided for the whole period of the study, between 21.10.2013 - 21.11.2013.

The results used for quantitative analysis, providing values of different parameters and of differences between the parameters of the two collectors are provided for a two days period: (26-27).10.2013.

The variation of solar radiation for the period of (21.10 - 21.11).2013 is presented in Figure 6 and for the period (26-27).10.2013 is presented in Figure 7.

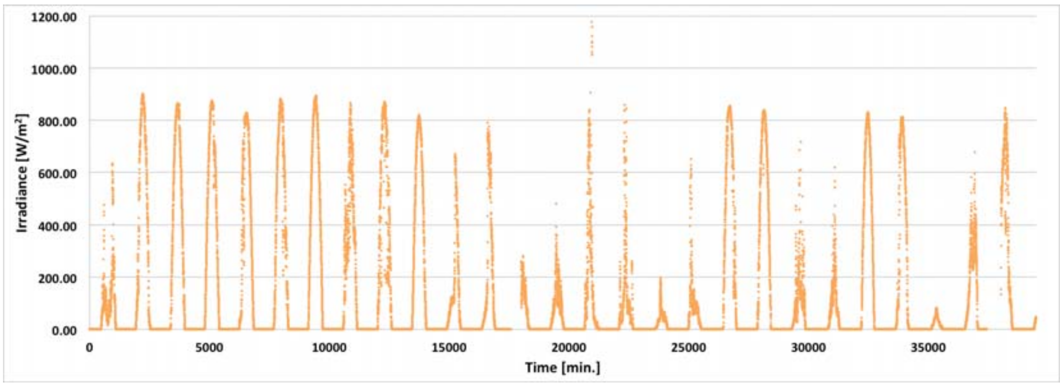

Figure 6. *Global solar radiation 21.10 - 21.11.2013*

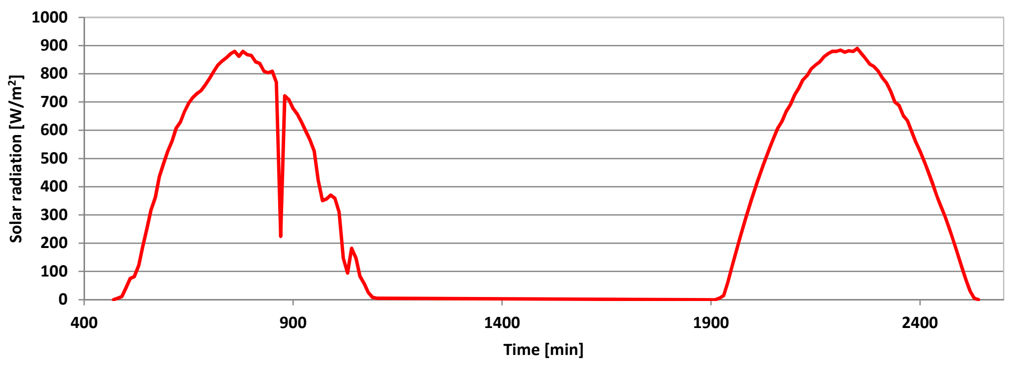

Figure 7. *Global solar radiation 26-27.10.2013*

The outside temperature variation is presented in Figure 8.

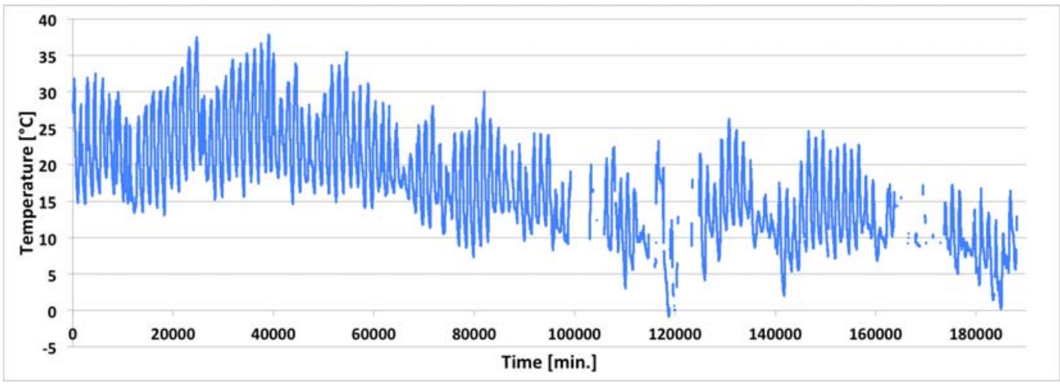

Figure 8. *Outside temperature variation 4.07.2013 - 21.11.2013*

The water temperature variation is presented in Figure 9.

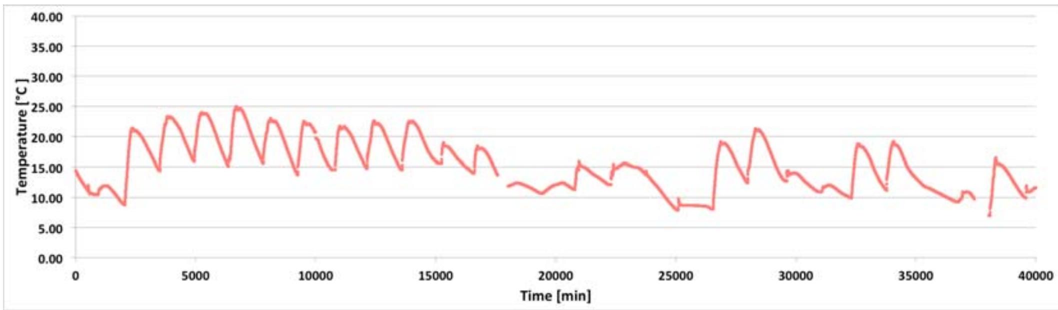

Figure 9. *Water tank temperature variation 21.10 - 21.11.2013 (PV2)*

The comparative variation of outside temperature and of water temperature for a shorter period of time is presented in Figure 10.

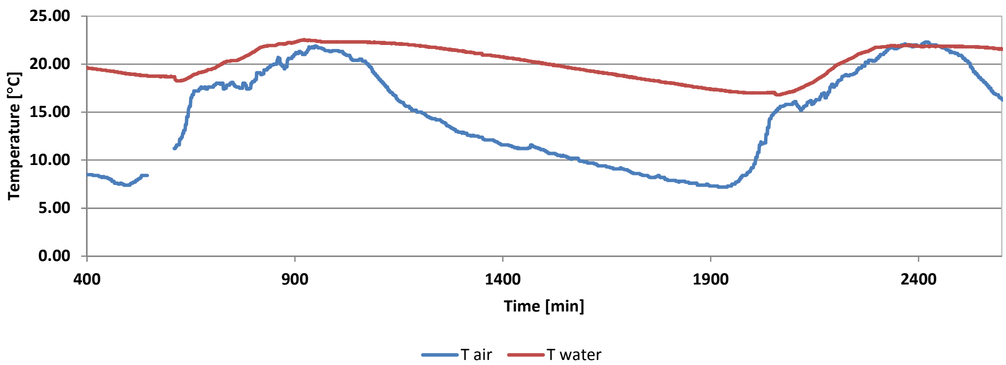

Figure 10. *Comparative outside and water temperatures 26-27.10.2013*

The temperature difference between water and outside is presented in Figure 11.

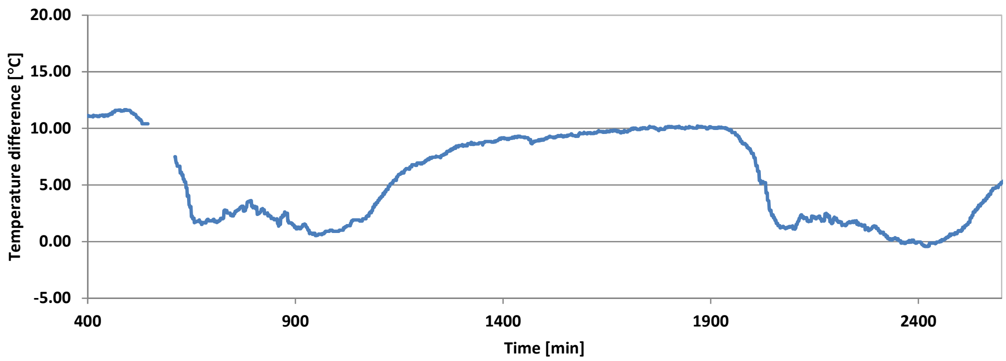

Figure 11. *Temperature difference between water and outside (26-27).10.2013*

The collector's temperatures variation is presented in Figure 12.

Issue 24, January-June 2014
p. 115-130

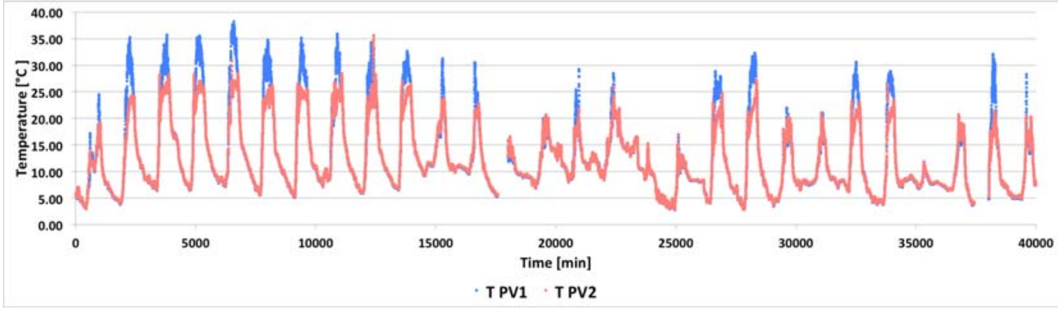

Figure 12. *Collector's temperature variation 21.10 - 21.11.2013*

The comparative collector's temperatures variation for the period 26-27.10.2013 is presented in Figure 13.

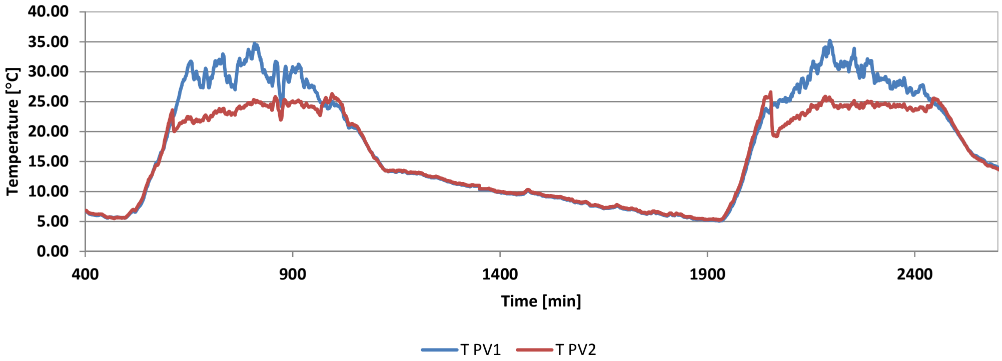

Figure 13. *Collector's temperature variation 26-27.10.2013*

The temperature difference between the collectors is presented in Figure 14.

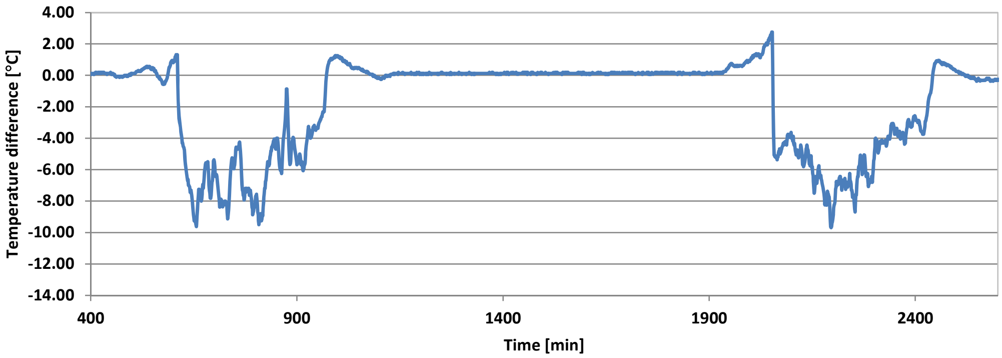

Figure 14. *Temperature difference between the collectors 26-27.10.2013*

The relative difference between currents of the collectors is presented in Figure 15.

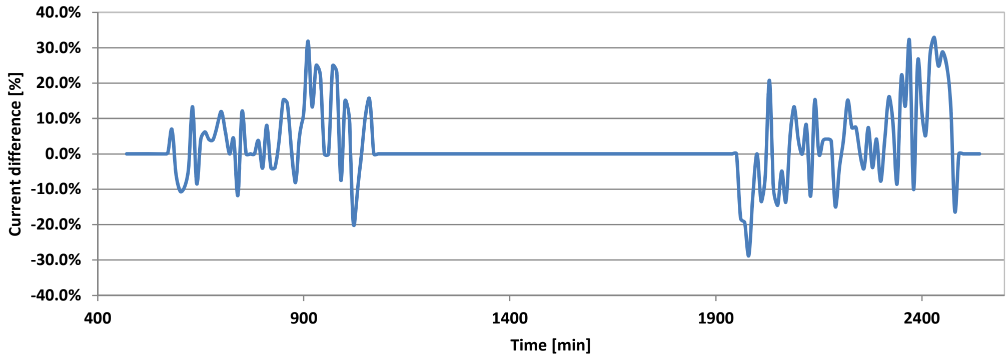

Figure 15. *Relative difference between currents of the collectors 26-27.10.2013*

The relative difference between voltages of the collectors is presented in Figure 16.

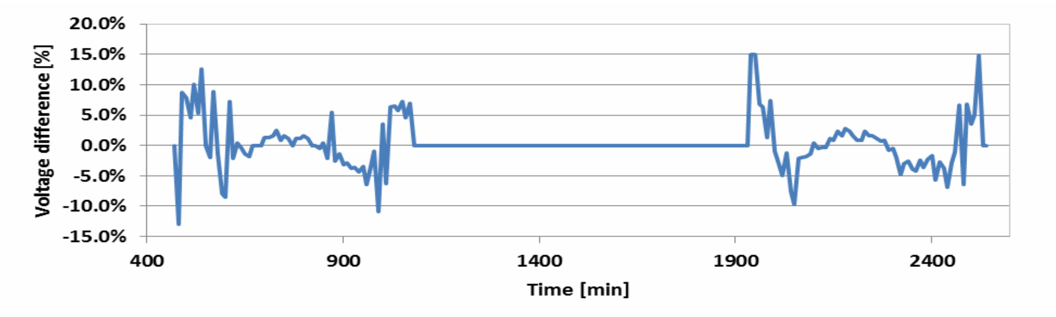

Figure 16. *Relative difference between voltages of the collectors 26-27.10.2013*

The relative difference between powers of the collectors is presented in Figure 17.

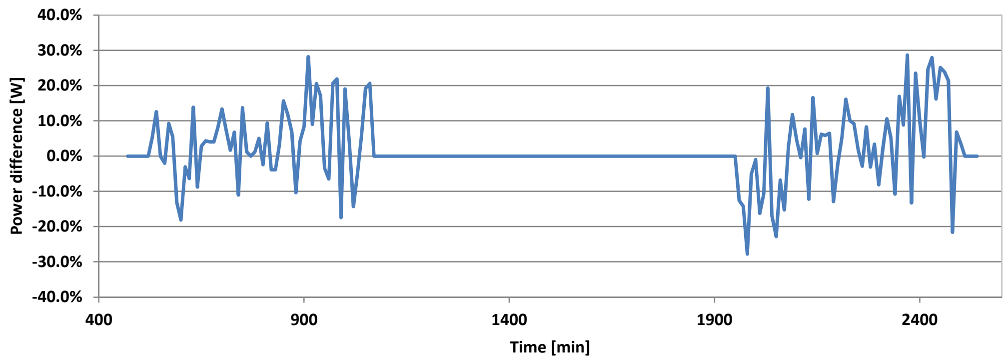

Figure 17. *Relative difference between powers of the collectors 26-27.10.2013*

The relative difference between efficiencies of the collectors is presented in Figure 18.

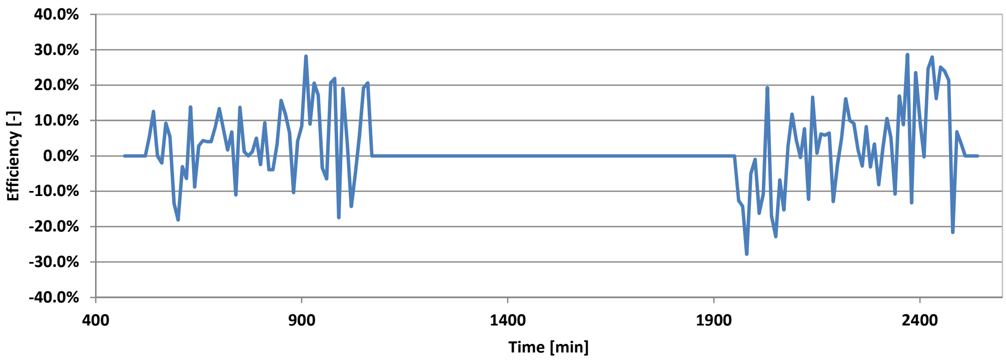

Figure 18. *Relative difference between efficiencies of the collectors 26-27.10.2013*

Comparative backside IR images of PV1 and PV2 are presented in Figures 19 and 20.

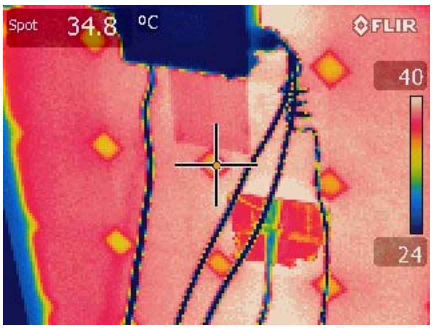

Figure 19. *IR image of the PV1backside*

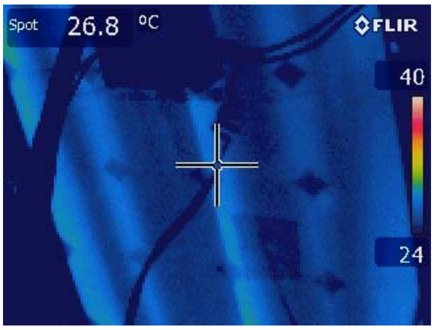

Figure 20. *IR image of the PV2backside*

A combined visible and IR image of the collector PV1 (left) and PV2 (right), is presented in Figure 21.

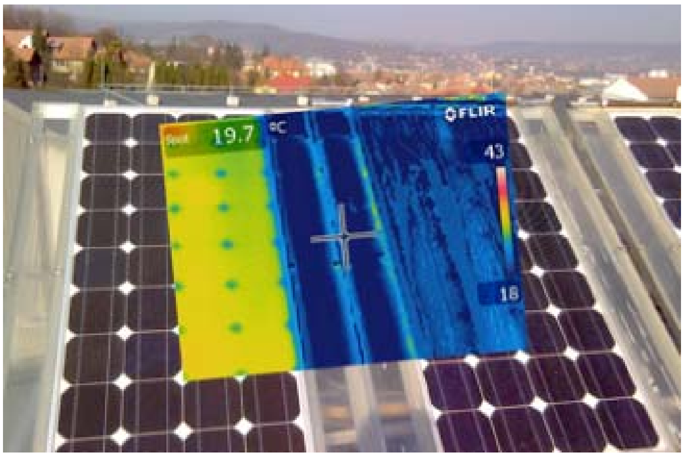

Figure 21. *Combined visible and IR image of the collector PV1 (left) and PV2 (right)*

Discussion

The obtained results are in natural agreement with the exploratory character of the experiment. The relative low precision, mainly of the current and voltage sensors affected the global precision of the experiment. Even in these conditions the trend of water film influences on the electrical parameters of the solar photovoltaic collector was revealed. From thermal point of view, the temperatures measurement precision was enough accurate to provide data comparable with other studies of solar photovoltaic collectors operating with water film on the glazing surface. The results obtained in this study, for the reference PV collector (PV1) and for the second PV collector equipped with the water film cleaning system (PV2), were compared with the results provided in [10] and it was observed a good agreement even if climate and seasons were different.

The values of global solar radiation, in the plane of the photovoltaic collectors, presented in Figures 6 and 7, are indicating that even in the late autumn period of the study, a reasonable number of days were characterised by good solar radiation, mainly in the first part of the experiment, enough to allow such a study.

The outside temperature variation, presented in Figure 8, have a decreasing trend from maximal values over (30…35)°C in the first part of the interval (when the meteorological station was operating as single functional component of the acquisition system), to maximal values of (20…25)°C in the middle part of the interval (the first part of the experiment) and to maximal values of (15…18)°C in the last part of the study. The interval of temperature variation in the period of the study was characteristic for late autumn.

The water temperature in the water tank, presented in Figure 9, is indicating that water have not only a cleaning effect, but also a thermal one. The water film is capable to extract a significant part of the P2V collector evacuated heat. The water temperature is depending both by solar radiation and outside temperature.

The comparative temperatures variation of water and air, presented in Figure 10 is indicating that on one side the water presents higher temperatures and a lower temperature variation interval than air. Under the effect of solar radiation, water temperature is increasing and in the absence of solar radiation is decreasing. Daily, the water temperature becomes almost similar with the air temperature, when air temperature has maximal values. This observation leads to the conclusion that in summer water temperature will be higher, increasing the thermal potential of the water for preheating domestic water. The temperature difference between water and air, presented in Figure 11, is situated in the range (0…10)°C. If heat recovery from the water is desired, the tank insulation should be carefully studied.

The shape of PV collector's temperatures variation, presented in Figures 12 and 13, is similar with the one presented in [10], but differences are lower because this study was realised in temperate climate in late autumn, and [10] was realised in arid climate in summer.

The maximum temperature difference between the two collectors, presented in figure 14 is of about 10°C, while in [10] is of about 20°C. This observation leads to the conclusion that in summer, the temperature differences is expected to be higher, increasing the thermal potential of the water, by reaching temperatures of (35…40)°C.

The effects of the water film on the electric parameters of the photovoltaic collectors are presented in Figures 15-18. Due to measurements imperfections, were recorded fluctuations in measuring the current and the voltage. It can be observed that measurement precision is lower and fluctuations are greater only in the periods with low solar radiation. Measurement precision increase substantially and fluctuations decrease dramatically in the periods with height solar radiation, indicating that the data acquisition system is operating more precise and stable in clear sky conditions with height values of solar radiation. Thus the general trend of the effects on the electric parameters was revealed, but this was exactly the objective of the explorative experiment. For the periods with height values of solar radiation, correct quantitative analyses can be realised.

The influence of water film, on the current, presented in Figure 15, is indicating that due to temperature reduction the water film is slightly increasing the current.

The water film has very reduced effect on the voltage, as presented in Figure 16, because voltage is not sensitive with the collector temperature variation, produced by the water.

The influence of water film, on the power, presented in Figure 17, is indicating a low and fluctuating increasing effect of the water film on the power.

The influence of water film, on the efficiency, presented in Figure 18, is indicating a low and fluctuating increasing effect of the water film on the power.

The general trend of the water film on the electric performances of PV collector was revealed to be determined by the cooling effect of the water. This effect slightly increase the current and don't affect the voltage, leading to low increase of power and efficiency.

In order to confirm the benefic effect of the water film on the electric parameters, more precise measurements should be performed.

The infrared images of the two collectors, presented in Figures 19 and 20, confirm the collector temperature decrease, on the back side of the collector, as effect of the water film.

The combined visible and infrared image of the front PV collectors side reveal the thermal effect of the water film, that is strongly reducing the PV2 collector temperature.

A comparative experimental study of two solar photovoltaic collectors, one of reference and one equipped with a water film based cleaning system, was realised in the period of 21.10-21.11.2013 at the Technical University of Cluj-Napoca.

The thermal effects were clearly revealed and the obtained thermal results are in good agreement with similar studies provided in literature [10].

The electric effects were observed only as general trend, because of limited measurement precision of current and voltage. These results are in natural agreement with the explorative character of this study.

In order to confirm the electric benefits of the water film on the glazing side of the solar photovoltaic collectors more precise investigations should be realised.

Conclusion

The general practical conclusion of the study is that implementation of water film cleaning system on the solar photovoltaic collectors can be recommended with reserves, because of reduced and uncertain global performances.

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. 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.
2. El-Shobokshy M.S., Mujahid A., Zakzouk A.K.M., *Effects of Dust on the Performance of Concentrator Photovoltaic Cells*, IEE Proceedings I: Solid State & Electron Devices, 1985, 132(1 pt 1), p. 5-8.
3. Dorobanțu L., Popescu M.O., Popescu Cl., Crăciunescu A., *The Effect of Surface Impurities on Photovoltaic Panels*, International Conference on Renewable Energies & Power Quality (ICREPQ'11), Las Palmas de Gran Canaria (Spain), 13th to 15th April, 2011.
4. Lorenzo E., Moretón R., Luque I. (online), *Dust Effects on PV Array Performance: in-Field Observations with Non-Uniform Patterns*, Progress in Photovoltaics: Research and Applications, 2013, doi: 10.1002/pip.2348.
5. Kaldellis J.K., Kokala A., *Quantifying the Decrease of the Photovoltaic Panels' Energy Yield due to Phenomena of Natural Air Pollution Disposal*, Energy, 2010, 35, p. 4862-4869.
6. Jiang H., Lu L., Sun K., *Experimental Investigation of the Impact of Airborne Dust Deposition on the Performance of Solar Photovoltaic (PV) Modules*, Atmospheric Environment, 2011, 45, p. 4299-4304.
7. Al Hanai T., Hashim R.B., El Chaar L., Lamont L.A., *Environmental Effects on a Grid Connected 900 W Photovoltaic Thin-Film Amorphous Silicon SSystem*, Renewable Energy, 2011, 36, p. 2615-2622.
8. Massi Pavan A., Mellit A., De Pieri D., *The effect of soiling on energy production for large-scale photovoltaic plants*, Solar Energy, 2011, 85, p. 1128-1136.
9. Kaldellis J.K., Fragos P., *Ash Deposition Impact on the Energy Performance of Photovoltaic Generators*, Journal of Cleaner Production, 2011, 19, p. 311-317.
10. Krauter S., *Increased Electrical Yield Via Water Flow Over the Front of Photovoltaic Panels*, Solar Energy Materials & Solar Cells, 2004, 82, p. 131-137.
11. Duffie J.A., Beckman W.A., *Solar Engineering of Thermal Processes*, 2nd ed. Wiley-Interscience, 1991.

12. ***, *High Efficiency, High Quality PV Modul.* Available at: http://www.energymatters.com.au/images/suntech/STP085S-12Bb.pdf (accessed 07/10/2013)
13. ***, *Comparative test of PHOBYA DC12-220, DC12-260 and DC12-400 Pumps*. Available at: http://www.xtremehardware.com/eng-reviews/comparative-test-of-phobya-dc12-220-dc12-260-and-dc12-400-pumps-201107105434/ (accessed 07/10/2013)
14. ***, Power (Ribbon) Wire Wound Resistors. Available at: http://www.tme.eu/en/Document/0ff7219a5068579357589fcbf949779b/QH_QL.pdf (accessed 07/10/2013)
15. ***, *Arduino Mega 2560*. Available at: http://arduino.cc/en/Main/arduinoBoardMega2560 (accessed 07/10/2013)
16. ***, WS-2800 Wireless Professional Weather Centre. Available at: http://www.meteo.no/file/andre/engelsk-bruksanvisning-35.1099.pdf (accessed 07/10/2013)