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Abstract: The dependence of photothermal conversion performance on the stability of the radiative regime has been rarely treated in literature and only for systems based on water collectors. The results were not conclusive. The objective here is to estimate whether, and to what extent, the performance of solar air collectors is dependent on weather characteristics other than the level of solar daily irradiation. The method is based on the comparison of the performance of two solar air collectors whose design is almost similar but one has a porous absorber and the other has a U-corrugated absorber. The performance of the collectors has been analyzed experimentally during clear sky days in Bucharest (Romania, South Eastern Europe). The collector based on porous absorber has higher efficiency that the collector based on U-corrugated absorber. This is defined as the reference case. The method used here is to inter-compare the performance of the two solar air collectors in days with different weather characteristics, followed by comparison with the reference case. Dynamic models have been developed and validated against measurements obtained in Bucharest. Simulations have been performed for collectors operation under the climate of Timisoara (Romania). Eight days, covering all four seasons and belonging to different relative sunshine classes and different levels of the radiative regime stability, have been selected. Results show that the performance of the solar air collectors does depend on the stability of the radiative regime. The collector based on porous absorber is more effective or less effective than the collector based on U-corrugated absorber, depending on the radiative regime stability. Other factors such as the level of daily solar irradiation or relative sunshine are of significant importance. The dependence of the collector efficiency on the stability of the radiative regime is more obvious during the morning. The collector based on porous absorber is generally more effective than the collector based on U-corrugated absorber during afternoons. Exceptions are the days with overcast sky.

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CONFLICTS OF INTEREST
(May 8, 2016)

All present authors are disclosing any actual or potential **conflict of interest** including any financial, personal or other relationships with other people or organizations within three years of beginning the submitted work that could inappropriately influence, or be perceived to influence, their work.

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May 8, 2016

Paper: The stability of the radiative regime does influence the performance of solar air heaters

Authors: Viorel Badescu, Qahtan A. Abed and Adrian Ciocanea

Dear Prof. Yogi Goswami:

As attached file you will find the electronic version of the above paper, proposed for publication in Solar Energy. An Electronic Supplemental Material is also attached.

Sincerely,

Prof. Viorel Badescu

Enclosure: text + tables + figures
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Highlights

- The performance of two solar air collectors with similar design but different absorber types is compared
- Two indicators of radiative regime characteristics are used: the daily average relative sunshine and the daily average sunshine stability number.
- The performance of the solar air collectors does depend on the stability of the radiative regime
- The dependence of the collector efficiency on the radiative regime stability is more obvious during the morning

The stability of the radiative regime does influence the performance of solar air heaters

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Abstract

The dependence of photothermal conversion performance on the stability of the radiative regime has been rarely treated in literature and only for systems based on water collectors. The results were not conclusive. The objective here is to estimate whether, and to what extent, the performance of solar air collectors is dependent on weather characteristics other than the level of solar daily irradiation. The method is based on the comparison of the performance of two solar air collectors whose design is almost similar but one has a porous absorber and the other has a U-corrugated absorber. The performance of the collectors has been analyzed experimentally during clear sky days in Bucharest (Romania, South Eastern Europe). The collector based on porous absorber has higher efficiency that the collector based on U-corrugated absorber. This is defined as the reference case. The method used here is to inter-compare the performance of the two solar air collectors in days with different weather characteristics, followed by comparison with the reference case. Dynamic models have been developed and validated against measurements obtained in Bucharest. Simulations have been performed for collectors operation under the climate of Timisoara (Romania). Eight days, covering all four seasons and belonging to different relative sunshine classes and different levels of the radiative regime stability, have been selected. Results show that the performance of the solar air collectors does depend on the stability of the radiative regime. The collector based on porous absorber is more effective or less effective than the collector based on U-corrugated absorber, depending on the radiative regime stability. Other factors such as the level of daily solar irradiation or relative sunshine are of significant importance. The dependence of the collector efficiency on the stability of the radiative regime is more obvious during the morning. The collector based on porous absorber is generally more effective than the collector based on U-corrugated absorber during afternoons. Exceptions are the days with overcast sky.

Keywords: solar air collectors; porous absorber; U-corrugated absorber; solar energy conversion efficiency; stability of radiative regime

1. Introduction

The main radiative characteristic of a place is the amount of incident solar energy. Days with the same value of the solar irradiation may have different time distributions of the solar irradiance (Scharmer and Greif, 2000). By definition, the stability of the radiative regime decreases by increasing the number of moments when the direct solar irradiance vanishes. The stability is another important characteristic of the radiative regime and has been studied from different points of view (Badescu, 2002, 2011; Badescu and Paulescu, 2011a, 2011b; Paulescu et al., 2013; Paulescu and Badescu, 2011).

The performance of photovoltaic (PV) systems and solar domestic hot water (SDHW) systems is strongly dependent on the amount of solar energy received. Many studies quantified this dependence (for good reviews see Axaopoulos (2011) and Kalogirou (2014); for recent results see Fiaschi and Bertolli (2012); Buzás and Kicsiny (2014); Kicsiny (2015)).

Several studies have been already published concerning the dependence of PV systems performance on the stability of the radiative regime. These studies are justified by the fast response of the PV systems for changes in the incoming solar irradiance which can exceed 60% in seconds due to passing clouds (Mills et al., 2011). The rapid variation of solar irradiance constitutes the so called “solar ramp” problem which is a big obstacle in managing the power grid (Mills et al., 2011; Tomson, 2010). The grid operator must reduce the power generated by other plants (or to disconnect the PV plant) to avoid grid instability. Therefore, nowcasting of passing clouds and load forecasting on very short time horizon is necessary (Brabec, et al., 2013; Taylor, 2008).

However, the dependence of the performance of the photothermal conversion systems on the stability of the radiative regime has been rarely considered in literature. Few studies are mentioned here. The first study focused on the operation and economic performance of the solar domestic hot water (SDHW) systems (Badescu, and Budea, 2016). The overall conclusion was that the dependence of SDHW systems' performance on the stability of the radiative regime is a complicate function of the specific performance indicator and the intensity of the radiative regime (i.e. daily solar irradiation or relative sunshine). The thermal inertia effects of solar water heaters have been studied in the series of papers (Rodríguez el al., 2011, 2011, 2012) where both experimental and simulation results were compared with the results obtained by applying the collector efficiency normalization curve equation (ENC), which was derived from the collector testing according to EN-12975:2006. The authors concluded that the ENC does not seem to be suitable for the accurate estimation of the collector performance since real working conditions are significantly different from the normalization test operating conditions. Further results concerning the thermal inertia effects of solar water collectors were reported by Soriga and Badescu (2016). The authors showed that the daily variation of thermal inertia depends significantly on the weather conditions.

It is worth noting that when the working fluid is water, the thermal inertia of the fluid represents 30% of the total collector thermal inertia (Rodríguez el al., 2011, 2011, 2012). It is expected that the thermal inertia of air solar collectors is lower and the transient performance of these collectors is more sensitive to variable weather conditions than that of the water heaters. This conjecture is studied in this paper. Two different types of solar collectors are analyzed and their performance is compared experimentally during clear sky days. Accurate mathematical models are developed to describe the dynamic behavior of both collectors. The models are validated against measurements performed in Bucharest (Romania). Simulations are performed under the climate of Timisoara (Romania). Two indicators of the radiative regime characteristics are used: the daily average relative sunshine and the daily average sunshine stability number. Four summer days and four winter days, belonging to different relative sunshine classes and different levels of the radiative regime stability, are selected. The performance of the two air collectors are compared during these days. The results show that the stability of the radiative regime does influence the performance of solar air heaters.

2. Solar air collectors operation in clear sky days. Experimental results

2.1. Experimental setup

Two solar air heat collectors have been considered in this work. Each collector consists of the absorber, glazing, insulation, back and front plenum and a wood collector frame to assemble these components. Both collectors have a single glass cover. Their casings are made of wood. The back and edges of the both collectors are insulated in order to avoid heat dissipation. The thermal insulation is made of polystyrene.

The collectors have the same collection surface area but different absorber types. One collector has a porous absorber while the other collector has a U- corrugated absorber (Fig. 1). The porous absorber is made of soft steel with two layers of a mesh wire. The U-corrugated absorber is made of aluminum. Table 1 shows design details about the design of the two collectors.

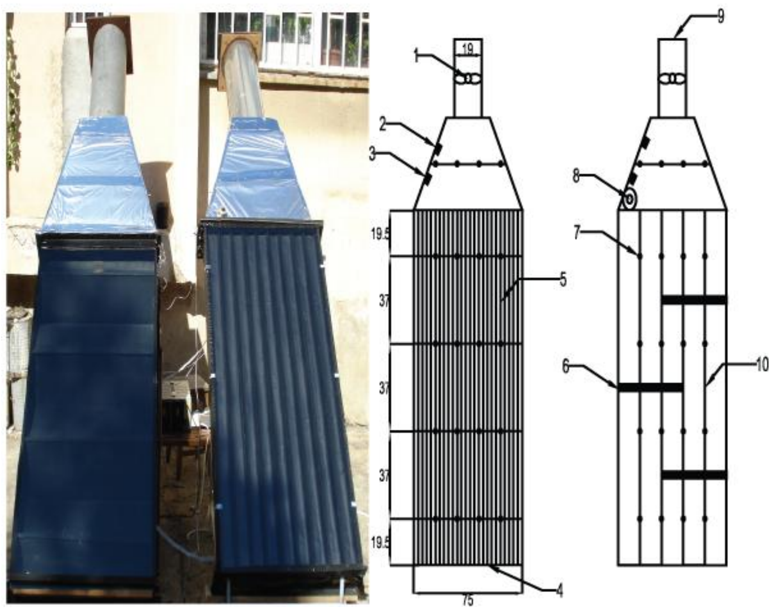

Fig. 1. Solar air collectors considered in this study. Left – the left side collector has a porous absorber while the right side collector has a U-corrugated absorber; Right – schematic view of the two collectors, showing the place of the thermal transducers. 1 – fans; 2 – humidity transducer; 3- Pressure transducer; 4 – air inlet; 5 – porous absorber; 6 – fins; 7- thermal transducer; 8 – pyranometer; 9 – air outlet; 10 – U-corrugated absorber.

Table 1. Design details about the two solar air collectors.

Quantity	Value
Common to both collectors	
Glass cover surface area (m^2)	1.25
Absorber thickness (m)	0.0007
Collector case height (m)	0.085
Number of glass covers	1
Number of absorber layers	1
Surface area of air inlet cross section	0.760 m x 0.085 m
Collector with porous absorber	
Absorber material	Steel mesh
Heat transfer surface area (m^2)	3.15
Collector with U-corrugated absorber	
Absorber material	Aluminium
Heat transfer surface plate area (m^2)	3.4

The collectors have been installed at Polytechnic University of Bucharest (44° 26' North, 26° 6' East). The collectors are oriented South and their slope is 55˚. Details about the experimental setup are shown in Fig. 1. The following parameters have been measured: (1) ambient temperature; (2) atmospheric pressure; (3) atmospheric humidity; (4) wind speed; (5) incident solar irradiance on the tilted collector surface; (6) inlet and outlet air temperatures; (7) volume air flow rate (8) rotating speed of the fans; (9) temperatures in 32 places evenly distributed on the absorber surface.

Details about measuring devices and instruments follow. The ambient temperature and humidity was measured using a HygroFlex humidity temperature transmitter version 4 (IN-E-HyFlex-V4_10), placed behind the collectors case. Atmospheric pressure has been measured with a common barometer. A cup anemometer type was used for measuring wind speed. A Kipp and Zonen CMP3 Pyranometer was used for measuring solar irradiance. Inlet air temperatures were measured by using two thermal transducers mounted in the same position for both collectors. To measure the outlet air temperatures four thermal transducers were fixed at the end section of each collector. The air flow rate was measured with a Hot Wire USB Logging Anemometer DT-8880 (ATP Instrumentation). Thirty-two thermal transducers were distributed evenly on the bottom surface of the absorbers, at identical positions along the direction of air flow for each collector. Measurements were recorded at time intervals of 10 sec. Further details may be found in (Abed et al., 2016).

2.2. Procedure used to process experimental data

Measurements are performed at collector outlet for air outlet temperature, $T_{a,out}$, outlet air pressure, $p_{a,out}$, and air speed, v_a. Then, the volume flow rate of air leaving the collector, $\dot{V}_a$, is given by:

$$\dot{V}_a = v_a \frac{\pi d^2}{4} \quad (1)$$

where d is the diameter of the exit duct from the collector (see Fig. 1). The outlet air mass density is computed by using the ideal gas state equation:

$$\rho_{a,out} = p_{a,out} / (R_{air} T_{a,out}) \quad (2)$$

where $R_{air} (\approx 287\ J/(kgK))$ is the air constant. Also, the air mass flow rate $\dot{m}_a$ is computed by:

$$\dot{m}_a = \rho_a \dot{V}_a \quad (3)$$

The air inlet temperature $T_{a,in}$ is measured. The following relationship is adopted for the dependence of the air specific heat, $C_{p,a}$, on temperature (Kalogirou, 2014):

$$C_{p,a} = 0.0057 + 0.000066\ (T_{a,m} - 27) \quad (4)$$

Here $T_{a,m} \equiv (T_{a,out} - T_{a,in})/2$ is the average air temperature inside the collector, expressed in $°C$. The assumption here is that the inlet air temperature equals the atmospheric temperature. The useful heat flux supplied by the air collector is computed by using the usual equation:

$$Q_u = \dot{m}_a C_{p,a} \left(T_{a,out} - T_{a,in} \right) \quad (5)$$

The efficiency of converting the incident solar energy into useful energy, η_{sol}, is given by:

$$\eta_{sol} = \frac{Q_u}{A_c G_T} \quad (6)$$

where A_c is collector surface area and G_T is the irradiance incident on the tilted collector surface.

2.3. Experimental results in clear sky days

Experimental studies were performed simultaneously with both collectors of Fig. 1 during the clear sky days 18, 22, 29, and 30 September 2014 and 1 October 2014. Measurements were processed by using the procedure described in Sec. 2.2.

During all clear sky days, the efficiency of converting the incident solar energy into useful energy η_{sol} was higher for the collector based on porous absorber than for the collector based on the U-corrugated absorber. As example, Fig. 2 shows results obtained during the clear sky day 22 September 2014. During the morning the two collectors have similar efficiency. However, during the afternoon the collector with porous absorber has better performance than the collector with U-corrugated absorber. At daily level, the relative mean bias difference (rMBD) between the efficiencies of the two collectors is 0.0917 (the reference is the efficiency of the collector with U-corrugated absorber).

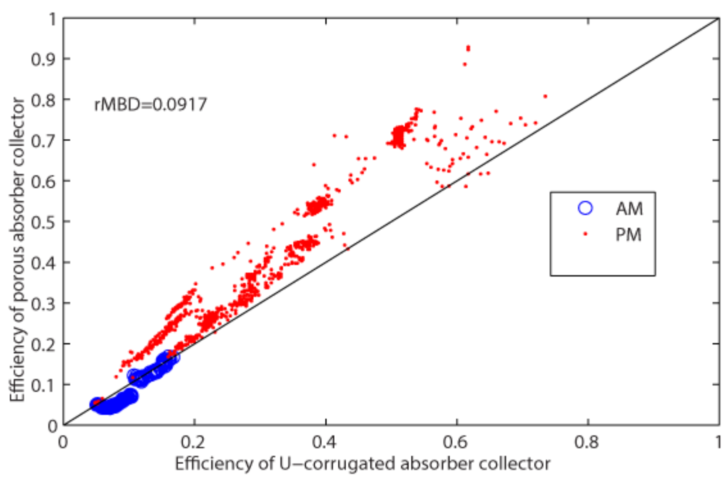

Fig. 2. The efficiency η_{sol} of the collector with porous absorber vs the efficiency η_{sol} of the collector with U-corrugated absorber. Measurements performed during the clear sky day 22 September 2014 have been used. The relative mean bias deviation (rMBD) between the two quantities is also shown (the reference is the efficiency of the collector with U-corrugated absorber).

3. Solar air collector models

Time-dependent models have been developed by Abed et al. (2016) for the operation of the two solar air collectors presented in Sec. 2.1. For convenience the models are shortly presented in Section S1 of the Electronic Supplementary Material (ESM). Section S2 in the ESM shows the relationships used to compute the heat transfer coefficients. The procedure to solve ordinary differential equations is shown in

Section S3 of ESM while accuracy indicators are defined in Section S4 of ESM. The models have been validated against measurements performed in Bucharest. Details are given in Section S5 of ESM.

4. Preparation of meteorological and radiometric input

4.1. Meteorological and radiometric database

Meteorological and radiometric data recorded in the Romanian town of Timisoara (latitude 45°46°N, longitude 21°25°E and 85 m altitude above mean sea level) are used in this work. The climate of Timisoara is temperate continental with an Ivanov index of continentally 130.9% (Badescu, 1999). The multiyear averages of monthly maximum, mean and minimum ambient temperatures range between 2.7 °C, −1.5 °C and −5.2 °C, respectively in winter (January) and 28.2 °C, 21.5 °C and 15.1 °C, respectively in summer (July) (Badescu and Zamfir, 1999).

Air temperature and global and diffuse solar irradiance (G and G_d, respectively) were recorded on horizontal surface at the Solar Radiation Monitoring Station of the West University of Timisoara (SRMS, 2014). Measurements were performed all day long at equidistant time intervals of Δt=15 s. DeltaOHM LP PYRA 02 first class pyranometers which fully comply with ISO 9060 standards and meet the requirements defined by the World Meteorological Organization were employed (WMO, 2014). The sensors were integrated into an acquisition data system based on National Instruments PXI Platform including a PXI-6259 data acquisition board optimized for high accuracy.

4.2. Characterization of the daily radiative regime

Two instantaneous indicators of the radiative regime are used in this work. They are the sunshine number ξ and the sunshine stability number ζ, respectively. The sunshine number ξ_t is defined as a time-dependent random Boolean variable, as follows (Badescu, 2002):

$$\xi_t = \begin{cases} 0 & if\ the\ sun\ is\ covered\ by\ clouds\ at\ time\ t \\ 1 & otherwise \end{cases} \tag{7}$$

The sunshine stability number ξ_t quantifies the stability of the solar radiative regime (Paulescu and Badescu, 2011):

$$\zeta_t = \begin{cases} 1 & if \begin{cases} \xi_t < \xi_{t-1} & (when\ \xi_t = 1) \quad or \\ \xi_t > \xi_{t-1} & (when\ \xi_t = 0) \end{cases} \\ 0 & otherwise \end{cases} \tag{8}$$

Time series of ξ_t are derived in this work from series of measured solar irradiance by using the sunshine criterion [25] – the sun is shining at time *t* if direct irradiance exceeds 120W/m^2, i.e.:

$$\xi_t = \begin{cases} 1 & if\ (G_t - G_{d,t})/\sin e > 120\ W/m^2 \\ 0 & otherwise \end{cases} \tag{9}$$

where G_t and $G_{d,t}$ denote the global and diffuse solar irradiance at moment *t*, and *e* is the sun elevation angle.

At daily level, the intensity of the radiative regime may be quantified by the daily solar global irradiation on a horizontal surface, H_{day}. An indirect measure of the radiative regime intensity is the daily average of the sunshine number, $\bar{\xi}_{day}$, which is also called daily relative sunshine (denoted σ_{day}). The stability of the radiative regime is quantified by the daily average value of the sunshine stability number, $\bar{\zeta}_{day}$. It takes values between 0 (fully stable radiative regime), when ξ_t takes just a single value (0 or 1) during the whole day and ½ (fully unstable radiative regime) when the values ξ_t change between every two consecutive moments in the time series.

4.3. *Selection of days with different radiative regimes*

Several classes of daily relative sunshine σ_{day} have been considered in [16]. They correspond to overcast sky days (σ_{day} =0), medium cloudiness days (σ_{day} =0.4-0.7), nearly clear sky days (σ_{day} =0.8-1) and clear sky days (σ_{day} =1). A set of twenty-nine days covering all four seasons in the year 2009 has been selected and analyzed in [16]. Those days were classified according to the daily average values of the sunshine number and sunshine stability number. For space reason, only eight days have been selected for this study (Table 2). They cover all four seasons and most sunshine classes, from σ_{day} =0 (for short, "overcast sky day") to σ_{day} = 0.8-1 (for short, "nearly clear sky day") while from the point of view of the stability they refer to both more stable and less stable radiative regimes.

Table 2

Selected days during year 2009 at Timisoara. The daily average values of the sunshine number ($\bar{\xi}_{day}$), the daily average values of the sunshine stability number ($\bar{\zeta}_{day}$) and the daily solar global irradiation on horizontal surface H_{day} are shown.

Relative sunshine class $\bar{\xi}_{day}$	Radiative regime stability	Spring	Summer	Autumn	Winter
0.8 to 1.0	more stable	April, 10 $\bar{\xi}_{day} = 0.950$; $\bar{\zeta}_{day} = 0.00034$ $H_{day} = 5203\,Wh/m^2$	July, 15 $\bar{\xi}_{day} = 0.966$; $\bar{\zeta}_{day} = 0.00029$ $H_{day} = 6973\ Wh/m^2$		
0.4 to 0.7	less stable		July, 12 $\bar{\xi}_{day} = 0.642$; $\bar{\zeta}_{day} = 0.01471$ $H_{day} = 6101\ Wh/m^2$	October, 17 $\bar{\xi}_{day} = 0.424$; $\bar{\zeta}_{day} = 0.02389$ $H_{day} = 2522\ Wh/m^2$	January, 19 $\bar{\xi}_{day} = 0.509$; $\bar{\zeta}_{day} = 0.0207$ $H_{day} = 1432\ Wh/m^2$
0.0 to 0.3	more stable			October, 29 $\bar{\xi}_{day} = 0.109$; $\bar{\zeta}_{day} = 0.001374$ $H_{day} = 1423\ Wh/m^2$	
0.0	Fully stable	May, 28 $H_{day} = 1352\ Wh/m^2$			January, 28 $H_{day} = 301\ Wh/m^2$

5. Solar air collectors operation in days with different radiative regime stability. Simulation results.

The method used here is to simulate the performance of the two solar air collectors described in Section 2.1 in days with different weather characteristics. Then, the performance of the collectors will be inter-compared. Finally, the results will be compared with the reference case shown in Fig. 2, which shows that the collector based on porous absorber is more effective than the collector based on U-corrugated absorber.

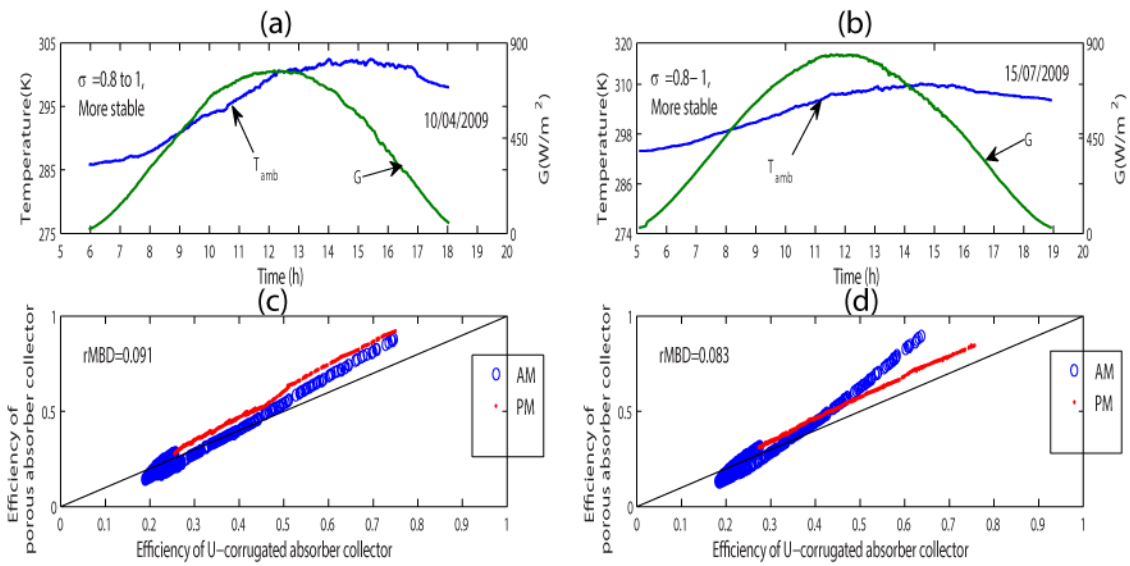

Fig. 3. (a) Time variation of measured ambient temperature and global solar irradiance on horizontal surface during 10 April 2014; (b) as (a) for 15 July 2014; (c) The efficiency η_{sol} of the collector with porous absorber vs the efficiency η_{sol} of the collector with U-corrugated absorber. Simulation results during 10 April 2014; The relative mean bias deviation (rMBD) between the two quantities is also shown (the reference is the efficiency of the collector with U-corrugated absorber); (d) as (c) for 15 July 2014.

Simulation results for two days with clear sky most of the time (σ_{day} between 0.8 and 1) are shown in Fig. 3. These days belong to Spring (10 April, H_{day}=5203 Wh/m^2) and Summer (15 July, H_{day}=6973 Wh/m^2), respectively. Solar irradiance during these days which are stable from the radiative point of view has the usual sine-like time variation. Also, the ambient temperature increases monotonously during the morning and reaches its maximum around 2 PM, as expected (see Fig. 3a and 3b). During the morning, the efficiency η_{sol} of the collector with porous absorber absorber is equal or higher than that of the collector with U-corrugated absorber (see Fig. 3c and Fig. 3d). During the afternoon, the porous absorber is obviously more effective than the U-corrugated absorber. This applies for both days of Fig. 3. At daily level, the relative mean bias deviation (rMBD) between the efficiencies of the two collectors is 0.091 and 0.083 in 10 April and 15 July, respectively. These simulation results for days with σ_{day} between 0.8 and 1 are in good agreement with the experimental results presented in Fig. 2 which show that during clear sky days the collector with porous absorber has better performance than the collector with U-corrugated absorber. Therefore, the simple models are able to mimic adequately the response of the solar collectors to environmental stimuli.

Note that measurements of Fig. 2 and simulations of Fig. 3 refer to days which are stable from a radiative point of view.

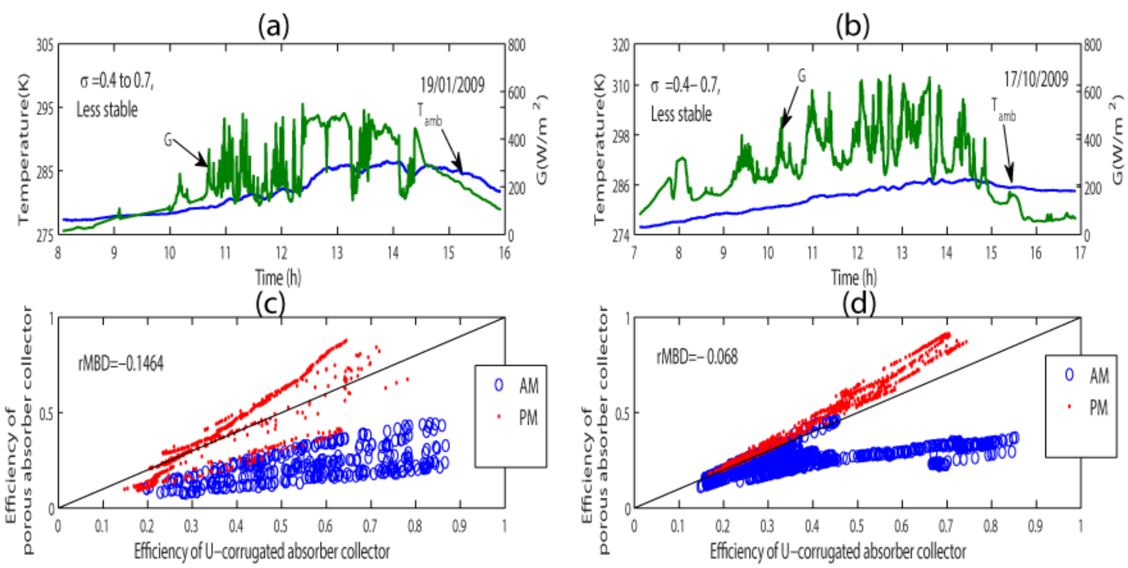

Fig. 4 as Fig. 3. (a) and (c) 19 January 2014; (b) and (d) 17 October 2014.

Simulation results for a Winter day (19 January, H_{day}=1432 Wh/m^2) and an Autumn day (17 October, H_{day}=2522 Wh/m^2) whose radiative regime is less stable are shown in Fig. 4. Both days belong to the same relative sunshine class (σ_{day} between 0.4 and 0.7) and the sky has medium cloudiness. Note that in these days the daily global solar irradiation is obviously different but the daily average value of the sunshine stability number is quite similar (see Table 2). The value of the solar irradiance is changing very often (Fig. 4a and 4b), as expected for days with less stable radiative regime. The ambient temperature shows the usual time variation. During the morning of both Winter and Autumn days, the collector with U-corrugated absorber has higher efficiency than the collector with porous absorber (Fig. 4c and 4d). This feature is different from what was emphasized when clear sky days were considered (see Figs. 3c and 3d). During the afternoon of the Autumn day, the porous absorber is more efficient than the U-corrugated absorber (Fig. 4d). However, during the afternoon of the Winter day there is no clear winner of the competition between the two collectors (Fig. 4c). At daily level, the relative mean bias deviation (rMBD) between the efficiencies of the two collectors is -0.146 and -0.068 in 10 April and 15 July, respectively. These show that generally the collector with porous absorber is less effective than the collector with U-corrugated absorber. This is obviously different from what was emphasized when stable clear sky days were considered (see Fig. 3c and 3d).

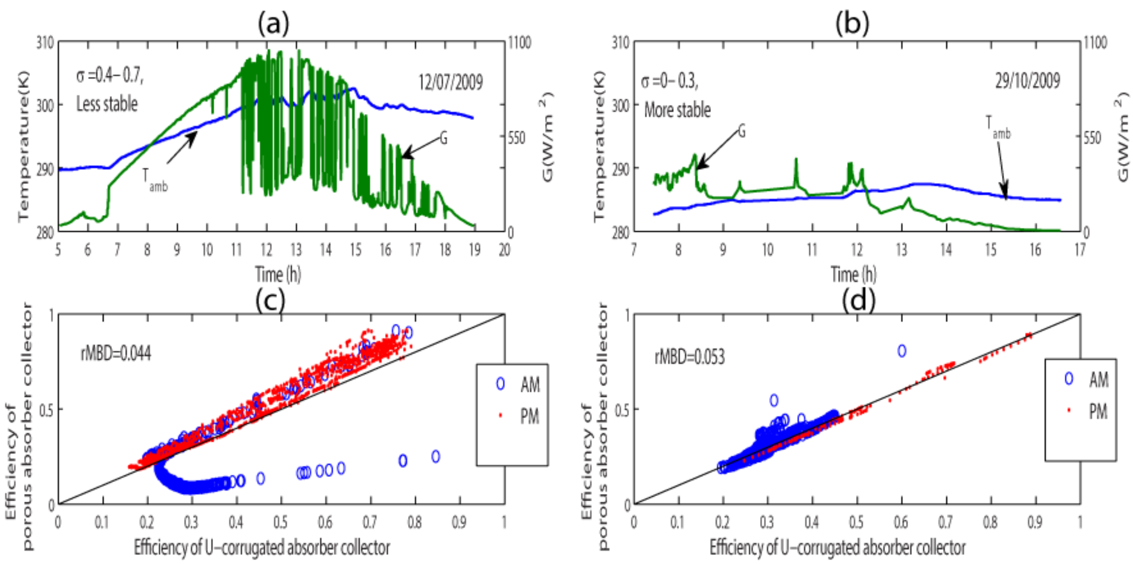

Fig. 5 as Fig. 3. (a) and (c) 12 July; (b) and (d) 29 October 2014.

Simulations for a Summer day (12 July, H_{day}=6101 Wh/m^2) belonging to the same relative sunshine class as the Winter and Autumn days of Fig. 4 (i.e. σ_{day} between 0.4 and 0.7) are shown in Fig. 5c. The daily solar irradiation is higher than in the Winter and Autumn days (see Table 2) and the time variation of the solar irradiance shows that this day is radiatively less stable (Fig. 5a). The efficiency of the collector with porous absorber is higher during the afternoon and most part of morning (Fig. 5c). However, the collector with U-corrugated absorber is sometimes more effective in the morning. The relative mean bias deviation (rMBD) between the efficiencies of the two collectors in 12 July is 0.044. Therefore, the collector with porous absorber is more effective generally than the collector with U-corrugated absorber.

This is similar with results emphasized when stable clear sky days were considered (Fig. 3) but different from results obtained for the less stable Winter and Autumn days (Fig. 4). Therefore, not only the class of relative sunshine and the stability of the radiative regime are important factors when the collector performance is considered but also the level of the incident solar irradiation.

A more stable Autumn day (29 October, H_{day}=1423 Wh/m^2) is considered in Fig. 5b. It belongs to the class of heavily cloudy days (i.e. σ_{day} between 0 and 0.3). Solar radiation is mostly diffuse. The solar irradiance is low level but its variation is slow. Simulations show that during the afternoon the two collectors have nearly similar performance but during the morning the collector with porous absorber has higher efficiency that the collector with U-corrugated absorber (Fig. 5d). The relative mean bias deviation between the efficiencies of the two collectors in 29 October is 0.053.

The results obtained for 29 October (Fig. 5d) should be compared with results obtained for 19 January (Fig. 4c). Both days have practically the same daily solar global irradiation. Therefore, the difference in results is due to the fact that the two days differ from the point of view of the relative sunshine and stability of the radiative regime.

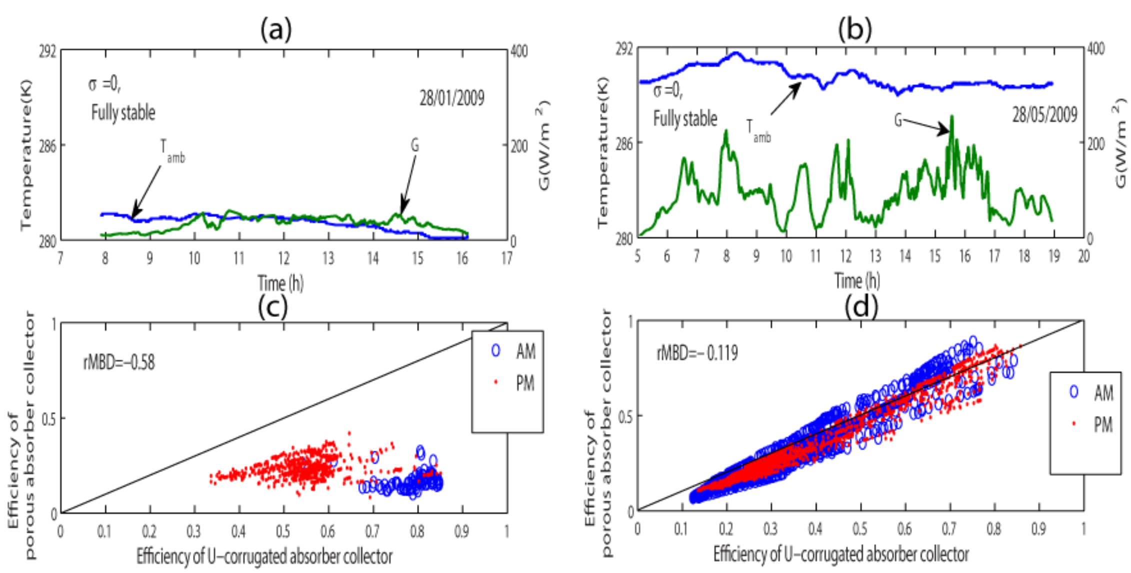

Fig. 6 As Fig. 3. (a) and (c) 28 January 2014; (b) and (d) 28 May 2014.

Simulations for two days with overcast sky ($\sigma_{day} = 0$) are shown in Fig. 6: a Winter day (28 January, H_{day}=301 Wh/m^2) and a Spring day (28 May, H_{day}=1352 Wh/m^2). They are fully stable from a radiative point of view. In both cases the solar radiation is diffuse but the level of daily solar irradiance is significantly different (compare Fig. 6a and 6b, respectively; also, see Table 2). In the morning and afternoon of the Winter day the efficiency of the collector with U-corrugated absorber is significantly higher than that of the collector with porous absorber (Fig. 6c). This may be explained by the larger mass of the U-corrugated absorber, ensuring a higher thermal inertia. The performance of the collector with U-corrugated absorber is higher during the afternoon of the Spring day (Fig. 6d). However, the collector with porous absorber is sometimes more effective in the morning. At daily level, the rMBD is -0.58 and -0.119 in 28 January and 28 May, respectively. These show that generally the collector with porous absorber is less effective than the collector with U-corrugated absorber. This is obviously different from what was emphasized when other stable days (but clear sky) were considered (see Fig. 3c and 3d).

6. Conclusions

Despite the case of the photovoltaic systems, the dependence of the performance of photothermal conversion systems on the stability of the radiative regime has not been very often considered in literature. The operation and economic performance of the solar domestic hot water systems have been treated by Badescu and Budea (2016) while the thermal inertia effects in solar water collectors were analyzed by Soriga and Badescu (2016). It has been shown that the stability of the radiative regime influences to some extent the performance of photothermal conversion systems based on water collectors but other factors such as daily solar irradiation or relative sunshine have to be considered. The objective of this paper is to estimate how much dependent is the performance of solar air collectors on weather characteristics other than the level of solar daily irradiation.

The method used here is to compare the performance of two solar air collectors in days with different weather characteristics. The two collectors are nearly similar but one of them is based on a porous absorber while the other is based on a U-corrugated absorber. The performance of the collectors has been analyzed and compared experimentally during clear sky days in Bucharest (Romania, South Eastern Europe). The collector based on porous absorber has higher efficiency that the collector based on U-corrugated absorber. This is defined as the reference case.

Dynamic models have been developed for both collectors. The models have been validated against measurements obtained in Bucharest.

Simulations have been performed for collectors operation under the climate of Timisoara (Romania), where a large meteorological and radiometric database consisting of recordings at time intervals of 15 s was available for the whole year 2014. Two indicators of radiative regime characteristics are used: the daily average relative sunshine and the daily average sunshine stability number. Eight days, covering all four seasons and belonging to different relative sunshine classes and different levels of the radiative regime stability, have been selected (see Table 2).

The method is based on the inter-comparison of collectors efficiency in days with different weather characteristics and result comparison with the reference case

Results show that the performance of the solar air collectors does depend on the stability of the radiative regime. The collector based on porous absorber is more effective or less effective than the collector based on U-corrugated absorber, depending on the radiative regime stability. Other factors such as the level of daily solar irradiation or relative sunshine are of significant importance.

More specific results are as follows:

1. The dependence of the collector efficiency on the stability of the radiative regime is more obvious during the morning than during the afternoon.
2. The collector based on porous absorber is generally more effective than the collector based on U-corrugated absorber during afternoons. Exceptions are the days with overcast sky (see Fig. 6).
3. The collector based on U-corrugated absorber is to be preferred in climates with often overcast skies.

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