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Influence of irradiance and irradiation on characteristic parameters for a solar air collector prototype

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ABSTRACT

The research had the following objectives: to assess the efficiency of a collector and the reliability of the applied parameters such as the outlet air velocity, temperature increase depending on the intensity of solar irradiance, the influence of ambient temperature on the collector's efficiency and heat loss. The solar-air collector (1180 mm × 610 mm × 77 mm (height, width, depth)) was installed vertically on a South-faced wall and exposed to solar irradiance. The following parameters were measured in the course of study: intensity of solar irradiance falling on a vertical surface (the collector was installed in a vertical position according with the producer design), temperature and velocity of air flowing into the collector as well as the temperature and velocity of air flowing out of the device. The study indicates that the collector worked efficiently at an irradiance value of just 100 $W \cdot m^{-2}$ and heated up the flowing air by about 5 °C. This temperature increased together with increasing irradiance and reached the value of 20 °C at the irradiance value of 800 $W \cdot m^{-2}$. The analysis of the collector's efficiency showed that during its work (proper temperature and irradiance) the efficiency remained at a satisfactory level from 42 to 46%.

1. Introduction

The paper describes results of a study on a solar-air collector in which air is the heat transfer medium. The collector is equipped with photovoltaic cells, which power a fan that pushes heated air, hence no electric power from an external source is needed. Consequently, the collector's working time is limited to periods when direct solar irradiance of adequate intensity reaches the collector's surface absorbing solar energy. On the other hand, the collector uses the irradiance energy in a very simple manner, just the way energy from the sun can be captured by positioning a building with huge windows facing the south (Chwieduk and Bogdanska, 2004). This knowledge is taken advantage of when designing buildings with a low energy demand. More information can be found in the literature (Chwieduk, 2008, 2010).

Solar-air collectors equipped with an additional photovoltaic cell module are on the market relatively short time, unfortunately their advantages have not been enough described in the literature. Therefore are ongoing efforts to improve them (Touafek et al., 2013; Hussain et al., 2013; Kramer and Helmers, 2013). One of the main topic in relevant literature is the modeling of the functioning (Amrizal et al., 2013; Amori and Abd-AlRaheem, 2014) and efficiency of such collectors (Shan et al., 2014; Jin-Hee et al., 2014; Arkar et al., 2016). Studies have also been conducted on solar air collectors coupled with a water-heating system (Shan et al., 2013).

It should be emphasized that the collector described in this paper is a very simple construction, intended for self-assembly by users. Its main purpose is to make the vent on the southern wall of the building so that the heated air can flow inside. But absolutely not about heating for residential purposes here. Due to the insufficient amount of energy supplied to the Earth in certain geographical latitudes in the cold season, it is somewhat difficult. In small houses, mainly used seasonally, garages, sheds, storerooms, often without electricity access, the collector provides forced ventilation. Especially in autumn, winter and early spring, heated air limits the possibility of condensation inside the building, and thus, for example: mold growth (which causes unpleasant odors, sometimes damages the structure and equipment over time).

Obviously, solar collectors rely on a single source of energy such as the Sun, and the main climate's solar component is sunshine, which corresponds to the length of time when direct solar irradiance reaches the Earth's surface. The value of irradiance depends on the length of daytime, cloudiness and transparency of the atmosphere. In Poland, the highest solar exposure appears in the warm half-year (from March to

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September), with the peak in June in the northern parts of the country (214 h), while the lowest one occurs in the cold half-year (the minimum in December – 33 h), and the average annual cumulative solar exposure in Poland is 1526 h (3.1 h a day on average) (Farat, 2004; Kuczmarski, 1990; Kuczmarski and Paszyński, 1981). The distribution of irradiance in Poland finds its reflection in values of total solar irradiation, which has been estimated at the level of 3657 MJ m^{-2} (Bogdańska and Podogrodzki, 2000). Unfortunately, high year-to-year fluctuations are a distinguishing feature of a multi-year course of monthly irradiation values in Poland, similarly to annual and seasonal values (Podstawczyńska, 2007).

The main goal of the research was to check the collector's operation and efficiency. The collector designer, and also the owner of the company, was guided by the technical capabilities of its implementation and its own expert knowledge. The assumed elementary simplicity of assembling the collector prompted the manufacturer and the authors of the experiment to conduct the collector's research in a similarly elementary way. Without making any changes, eg as to the assembly method (only vertical checked).

2. Technical specification of a collector prototype

A prototype of the HC01S solar-air collector was made from a welded stainless steel frame set around a 5-mm-thick multiwall polycarbonate plate, and a casing box made of Al/Pe/Al composite plate (the manufacturer's name Dibond TyhyssenKrupp). Inside the box, there is an absorber plate made of 1-mm-thick aluminum sheet, black finished on one side. The absorber comprises a meander made from aluminum angle bars 23 mm × 30 mm × 2 mm in size. The size of the collector is 1180 mm × 610 mm × 77 mm (height, width, depth), and the weight is 9 kg. A photovoltaic panel 12 W/12 V size 590 mm × 140 mm is fitted in the upper front part of the collector, in a separate chamber (to maintain better thermal conditions) (Fig. 1).

In the top rear part of the collector, there is an outlet vent 100 mm in diameter (78.5 cm^2) with a fitted, silent running fan. The fan's parameters are as follows: 92 mm, 3–18 V, max. volumetric flow rate 67.15 $m^3 \cdot h^{-1}$, 2400 RPM. The air inlet consists of 9 holes 1 cm in diameter each (in total 7.07 cm^2) made in the lower part of the casing. The thermal insulation of the collector was made of bubble foil coated with metalised foil. The collector can be operated by setting the switch-on threshold and hysteresis, and there is an additional switch to set the collector's operation mode in one of two systems: a battery > temperature sensor > regulator > operating mode switch – a fan in the outlet pipe stub (the so-called winter mode, i.e. heating), or a battery > operating mode switch > a fan in the outlet (the so-called summer mode, i.e. cooling the casing and sucking excess warm air through a pipe connecting to the building's interior)

Fig. 2. Total irradiance sensor CM 11 mounted vertically, in line with the mounted solar-air collector.

3. Research methodology

The described solar-air collector, for the purpose of this study, was mounted on a vertical wall of a structure imitating a building (Fig. 1), directed to the south (± 5° longitude) and the following parameters were measured to acquire data: solar irradiance intensity relative to the collector's absorbing surface (the collector was mounted in a vertical position, which is a standard installation solution), temperature of air flowing into the collector, as well as the temperature and velocity of air exiting the collector.

Solar irradiance measurements were taken with a CM 11 sensor (Kipp&Zonen) (Fig. 2), the temperature and velocity of air flowing into and out of the collector were measured with two type-E thermocouples and an IVL 10 channel speed and air temperature transducer (iBros Technic). All the instruments were connected to a multi-channel CR10X data logger (Fig. 1) with high sampling frequency (a recorder built on a USB interface plug, thus ensuring stable and effective monitoring of climate conditions). The software Loggernet (Campbell Sci) was used for communication with the data logger and for data collection. The above meteorological and air velocity parameters were measured at one-second intervals, while the recorded means were derived from values measured over one-minute time periods.

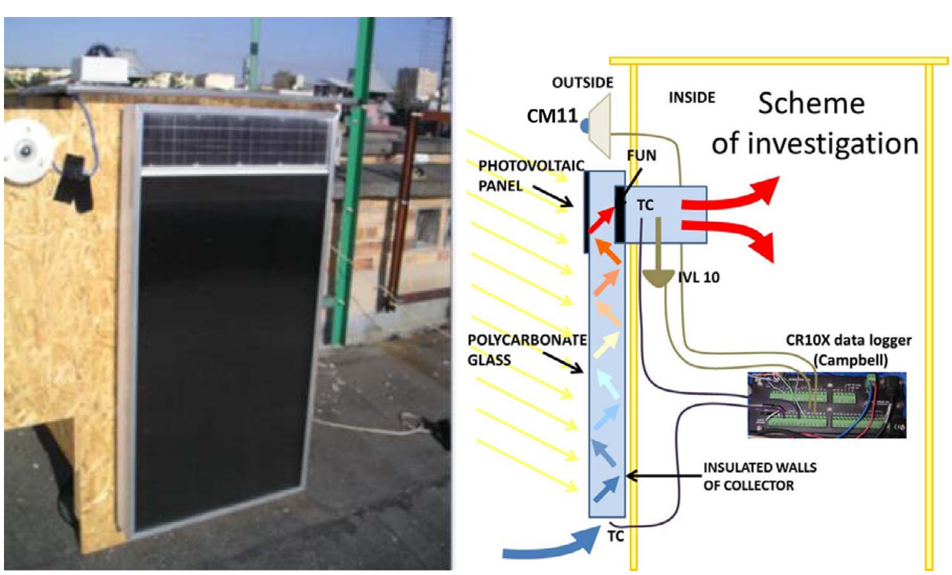

Fig. 1. Scheme of experimental stand.