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EXAMINING TECHNICAL SOLUTIONS FOR A PROTOTYPE OF A SOLAR-AIR COLLECTOR

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Abstract

The research was conducted in the framework of the project known as „Coupon for innovations – support for the smallest companies", endorsed by the Polish Agency for the Development of Business, and it had the following objectives: to assess the efficiency of the collector and reliability of the applied parameters such as the force of warm air blast, temperature increase depending on the intensity of solar radiation and the angle of the collector setup, influence of ambient temperature on the collector's efficiency and heat loss, the quantity of relative humidity reduction correlative with the heating up of the flowing air. Collector in a standard installation position – on a vertical wall.

The assessed solar air collector was exposed to solar radiation and the following parameters were measured in the course of study: intensity of solar radiation falling on a vertical surface and on the collector's surface (the collector was installed in vertical position, which is a standard installation method), temperature and velocity of air flowing into the collector as well as temperature and velocity of air flowing out of the device. The studies indicate that already at the radiation value of 100 W m^{-2} the collector worked efficiently and heated up the flowing air by about 5°C. This temperature increased together with radiation and reached the value of 20°C at the radiation of 800 W m^{-2}. The analysis of the collector's efficiency showed that during its work (proper temperature and radiation) the efficiency remained at a satisfactory level from 42 to 46%.

Introduction

Solar collectors are nowadays a commonplace on roofs, walls or detached constructions, both in newly erected as in modernized buildings. The purchase of collectors is often subsidized by authorities on a local and national level. An

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example of such policy is the program called: „Supporting dispersed renewable energy sources" implemented in Poland by National Fund for Environmental Protection and Water Management (NFOŚiGW). It involves mostly collectors which heat up a non-freezing fluid circulating in a closed circuit (e.g. a mixture of water with glycol etc.), which „transfers" the energy obtained from radiation to a battery in a form of a water tank. Such installation is relatively expensive and it requires electrical power supply in order to control and operate the circular pump. The device described and examined in this work is an air collector in which air is the directly heated factor. Additionally, this collector is equipped with photovoltaic cells propelling the fan which presses the heated air. Hence, it does not need an outer power supply but its work will be limited only to the time when it is exposed to direct sun radiation of an appropriate intensity. Thus, it can be stated that it uses radiation energy in a very simple way, similarly solar energy can be used by proper alignment of the building with the sun (CHWIEDUK, BOGDANSKA 2004). Knowledge on this subject is applied to build houses with low energy requirements, which is also described in literature (CHWIEDUK 2008, 2010).

Solar air collectors, which are additionally equipped with a photovoltaic module, have been produced only recently. Their advantages have been quite extensively described in the relevant literature and the research into improving them is still conducted (KHALEK et al. 2013, HUSSAIN et al. 2013, KRAMER, HELMERS 2013). Many studies have been also devoted to modeling the performance of such collectors (AMRIZA et al. 2013, KARIMA et al. 2014) and examining their efficiency (FENG et al. 2014, JIN-HEE et al. 2014, ABOLTINS et al. 2012, ABOLTINS, PALABINSKIS 2011), also some studies checked how they function in combination with water heating (FENG et al. 2013) and drying agricultural products (ABOLTINS, PALABINSKIS 2013).

Certainly collectors' performance depends on the sole source of energy, namely the Sun, and the main solar element of the climate is insolation, i.e. the time in which direct solar radiation reaches the surface of the earth. Insolation depends mostly on the length of the day, cloudiness and transparency of the atmosphere. It has been estimated that in the area of Poland the biggest insolation occurs in the warm half-year (from March to September), with the maximum value in June in the north of the country (214 h), whereas the smallest insloation occurs in the cold half-year (the minimum value in December – 33 h), and the average insolation sum in Poland is 1526 hours (on average 4.1 h during the day) (KUCZMARSKI 1990, KUCZMARSKI, PASZYŃSKI 1981). The distribution of insolation in Poland is reflected in the values of total solar radiation which was estimated to be at the level of 3657 MJ m-2 (BOGDAŃSKA, PODOGRODZKI 2000). Unfortunately big fluctuations on a yearly basis are a characteristic feature of the multiannual course of monthly values of insolation in Poland, similarly as in the case of annual and seasonal values (PODSTAWCZYŃSKA 2007).

Aim topic of the investigation was examining technical solutions for a prototype of a solar-air collector and evaluation their work and eficiency.

Technical specifications of the collector prototype

The basic model of HC01S solar air collector consists of a welded frame from stainless steel which surrounds a plate made of multi-chamber polycarbonate, 5 mm thick, and a casing made from Al/Pe/Al composite plate (brand name Dibond TyhyssenKrupp). An absorber plate placed inside the casing is made of 1 mm thick aluminum sheet blackened on one side. The absorber is stiffened by a meander made from 23 × 30 × 2 mm aluminum angles. Collector's dimensions are 118 × 61 × 7.5 cm (height, width, thickness), weight: 9 kg. There is a 12 W/12 V photovoltaic panel, size 59 × 14 cm, built into the upper front part of the collector, in a separate chamber (for maintaining better thermal comfort, Fig. 1). In the upper rear part of the collector there is an inlet vent with a diameter of 100 mm (78.5 cm), in which a silent fan is installed – 92 mm, 3-18 V, max efficiency – 67,15 m^3 h^{-1}, 2400 RPM. Nine vents with diameters of 1 cm (together 7.07 cm) in the lower part of the casing allow the

Fig. 1. Measurement station with the vertically installed solar air collector and sensors for measuring the radiation

air influx. Thermal isolation of the collector was made from chamber foil covered with metalized film. The collector is operated by an electronic regulatory device – two cranks – turn-on threshold and hysteresis, power supply of 12 V. In the lower part of the casing there is a switch which controls the collector' work in two modes:

1) first switch position (I) – operating mode as follows: battery > temperature sensor > regulator > operating mode selector – a fan in the outlet pipe stub (the so called winter mode i.e. heating);

2) second switch position (II) – operating mode as follows: battery > operating mode selector > fan (the so called summer mode – cooling the casing and sucking out the excess of hot air through a pipe connected to a room).

Standard installation of the collector on a vertical wall – according to the rules specified in the collector installation manual.

Method of research

The assessed solar air collector was exposed to solar radiation and the following parameters were measured for the research purposes: intensity of solar radiation, on a horizontal plane and on the collector's plane (the collector was installed vertically, which is a standard installation position), temperature and velocity of air influx as well as temperature and velocity of air flowing out of the collector.

Specialist meteorological equipment was used for the purpose of the study. These were two solar radiation sensors (Kipp & Zonen), CM11 and BF5 (Delta-T Devices) (Fig. 2), which measured total and dispersed radiation, two

a *b*

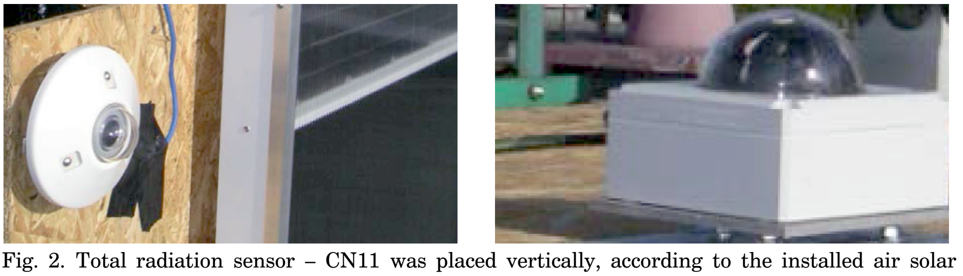

Fig. 2. Total radiation sensor – CN11 was placed vertically, according to the installed air solar collector (*a*) and total and dispersed radiation sensor – BF5 was placed horizontally (*b*)

sensors for measuring the temperature of incoming and outgoing air – E type thermocouples and IVL 10 channel speed and air temperature transducer (iBros Technic). All devices were connected to CR10X multichannel data logger with high measurement frequency (the recorder is built into the plug of the

USB interface, which ensures stable and effective monitoring of climate conditions, such as: temperature, insolation, air humidity etc.).

Then the software for data gathering and analysis was prepared. The above mentioned meteorological parameters of air flux were measured every second, whereas average values of measurements were recorded every minute.

Results and discussion

Measurements of short-wave radiation falling on a vertical surface (as in the surface of the collector) and on a horizontal surface, which is called, according to meteorological terms, total radiation, were conducted in October 2013 (during 15 days in total). However, for technical reasons, they were not conducted continuously, but with periodical breaks (the power supply conditions and the memory storage capacity of CR10X data logger). According to previous expectations, it was established that, due to the increasingly lower solar zenith, values of radiation falling on a vertical surface placed in the southern direction were much higher than the values of total radiation (Fig. 3).

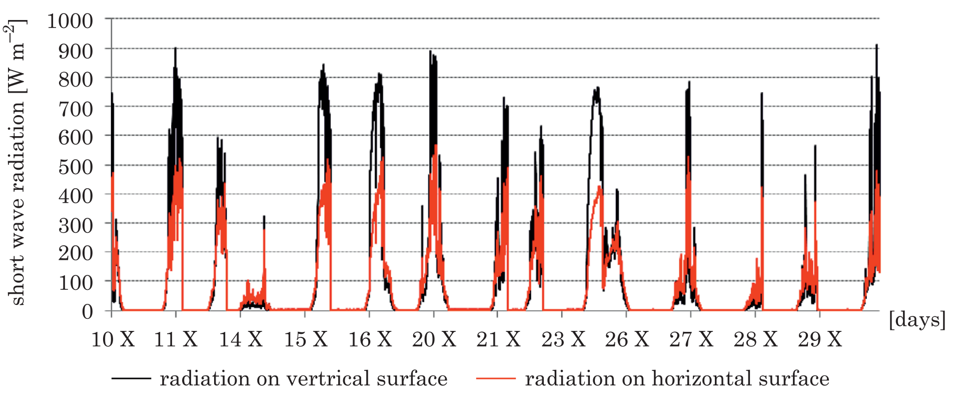

Fig. 3. Distribution of the measured short-wave radiation on a vertical surface (according to the collectors position) and a horizontal surface (total radiation), on 15 days selected in the period from 10 to 29 October 2013

The measured values as regards vertical surface sometimes exceeded 800 W m^{-2}, while the total radiation was merely of 500 W m^{-2}. It was very beneficial as regards the application of the assessed solar air collector. It can be definitely stated that the recommendation of the producer to install the collector on the southern wall in vertical position is very useful. In winter months (December-February) the differences between the radiation falling on vertical and horizontal surfaces will be even bigger. Then, taking into consideration that the device is dedicated to work in the autumn-winter period, the suggested solution deserves a complete approval.

Next, the correlation between the flux velocity of the air measured at the outlet pipe stub of the solar air collector and the value of radiation falling on a vertical surface, similar to the position of the photovoltaic cells propelling the fan, was examined (Fig. 4). When analyzing the presented diagram one should bear in mind that the fan was turned on when the outside temperature exceeded 20°C, which meant that in some cases the fan was not turned on at all and the air flux could have been close to zero, although the radiation value did not go above 100 W m^{-2}. A similar situation occurred when the radiation was very low or close to zero, and the measured air fluxes, at the velocities of up to 0.2 m s^{-1}, resulted from a blowing wind. The collector is not tightly closed and when wind blows from a proper direction or when we are dealing with hydrostatic air circulation due to temperature differences, then air flux may occur even when the fan is inactive. Naturally, the higher radiation values the bigger air flux velocity (Fig. 4).

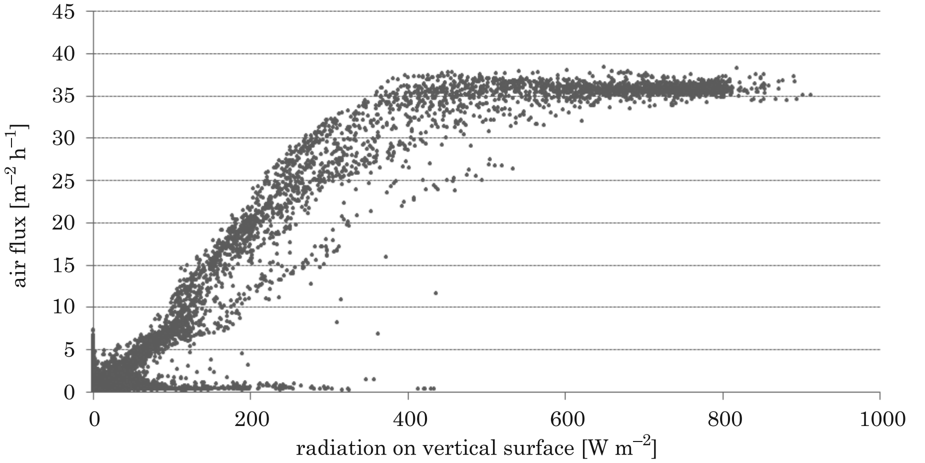

Fig. 4. Correlation between air flux at the outlet of the collector and the value of radiation falling on a vertical surface, compatible with the position of photovoltaic cells supply the fan

It is not a purely linear correlation and it is characterized by a relatively big dispersion, which is rather not surprising, just because of the fact that blowing wind may enhance or disturb the air flux. However, careful attention should be paid to the velocity of air flux in the outlet pipe, which increased to about 1.2 m s^{-1} (ca. 36 m^3 h^{-1}) reaching this value at the radiation of about 400 W m^{-2}.

Above this limit, despite the increase of the radiation value (up to 900 W m^{-2} during the measurements), the air flux did not become more intense. According to the producer the installed photovoltaic panel has the power of 12 W, which is several times bigger than the power of the fan, which leads to a conclusion that the above limitation does not stem from the lack of sufficient power. The producer claims the efficiency of the applied fan to be of about 60 m^3 h^{-1}, however the air resistance in the collector significantly reduces the air flux, although the fan works at the highest engine power. The solution would be to lower the air flux resistance by enlarging inlet vents, changing – „making smoother" – the path of air flux or using simultaneously a second fan (possibly of a higher power).

Further, the distribution of air temperature was analyzed, after the air flowed through the solar air collector, depending on the solar radiation falling on a vertical surface (Fig. 5). In connection with the above, first the air temperature was measured at the inlet to the collector and then at the outlet. The measurements were conducted in the pipe about 5 cm from the fan (and not inside it), in order to determine temperature of the air flowing into the room „heated" by the collector reliably.

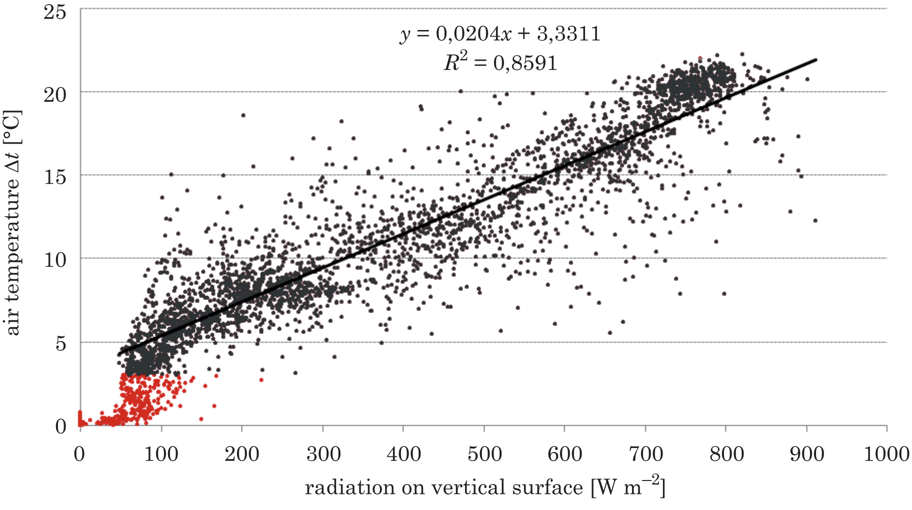

Fig. 5. Increase of air temperature after it flowed through the solar air collector in correlation with the radiation falling on a vertical surface (regression line was determined on the basis of only some minutes that had a temperature increase of more than 3.0°C)

Average minute values, when the temperature at the inlet and outlet of the collector was above 3.0°C, were marked in grey, which as the figure shows corresponded with the radiation of about 100 W m^{-2} and higher. Such radiation range overlaps with the time when the fan was at work. These data were also used to determine the regression line. Red color marks the remaining points, while the figure does not take into consideration hours with zero radiation, when the collector certainly does not work.

The determined regression line (Fig. 5) was quite well correlated with the radiation values, determination coefficient (R^2) was 0.86. At the radiation values of 100 W m^{-2} the air flowing out of the collector reached the temperature of about 5.0°C, whereas at the radiation of 800 W m^{-2} these values were at the level of 20°C. It should be pointed out that, because of the schedule of the project known as „Coupon for innovation", the research was conducted exclusively in October 2013, since the information about granting the funds for research and signing relevant contracts took place at the turn of September and October that year, and conducting the research, together with preparing the report was to have been finished until 31 October 2013. This research discipline resulted in its being conducted at the time when air temperature during the collector's work was in the range from 10 to 20°C, and only on one measurement day the temperature dropped slightly below 10°C.

Relative air humidity is the quotient of the current steam pressure in the air and its maximum quantity in a given air temperature. It is one of the parameters of air humidity which reflects best the human perception of whether the air is dry or humid. If this value exceeds 80% then most people will say that the air is humid, while if it is below 50% they will declare it to be dry. This definition also leads to a conclusion that if the air having the humidity of about 70% is heated then its relative humidity falls, which means a simultaneous increase of its evaporation potential (drying potential).

Figure 6 illustrates the estimated change in relative humidity of the air flowing through the collector in correlation with the value of radiation falling on a vertical surface.

For the needs of the presented assessment it was adopted that relative humidity of the incoming air is 70% (average monthly humidity of the air in October at 12 UTC according to The Climate Atlas for Wielkopolska Region (FARAT 2004). Thus, it is clear that with the highest solar radiation values (800 W m^{-2}) humidity of the outgoing air will be only 20% and it will have high evaporation potential. This shows that at the lowest examined values for the collector's work (100 W m^{-2}) the air at the outlet vent will have relative humidity of about 50%, which means that its evaporation potential is still relatively high. Summing up, the solar air collector should be quite efficient as a device for air heating and improving air drying potential.

On 25, 27 and 29 October 2013 there were changeable atmospheric conditions, but it was quite sunny and on each of these days the collector worked for several hours. Using the conducted measurements the amount

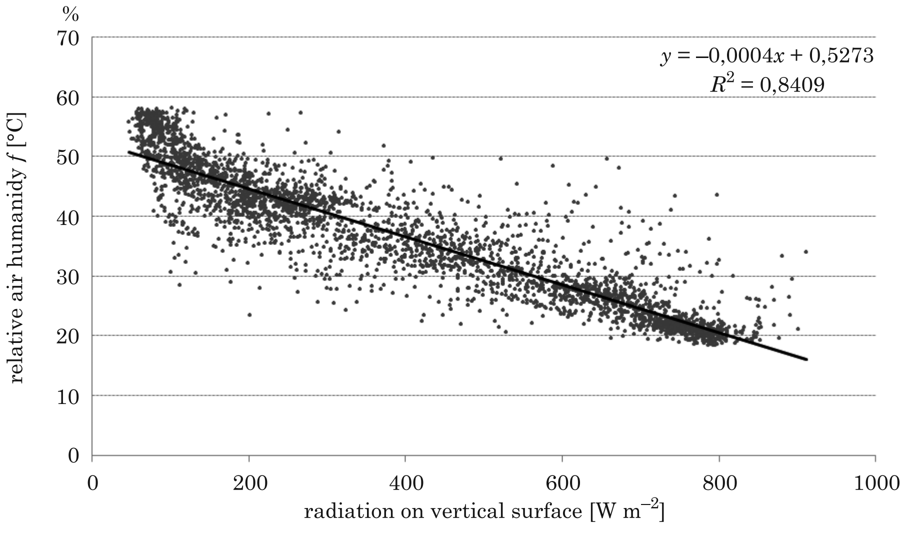

Fig. 6. Relative air humidity after flowing through the solar air collector in correlation with the radiation falling on the vertical surface, assuming that relative humidity of the air flowing into the collector is of 70%

of energy falling on the solar air collector was calculated, particularly on its part which serves for air heating. Only the time when the collector worked efficiently was taken into consideration, i.e. when its controller turned on the fan because temperature inside the collector exceeded 20°C and when simulatenously the radiation was strong enough to increase air flux through the collector to over 0.1 m s^{-1}. It turned out that on these days the collector's surface received cumulatively about 2580, 2700 and 3565 KJ respectively, whereas the air was heated to such an extent that the energy which transferred to the room had the values of 1180, 1140 and 1510 KJ respectively, and this in turn meant that the collector's efficiency at work was 46%, 42% and 42% respectively, a little more efficiensy was obtain by ABOLTINS et al. (2012) and ABOLTINS and PALABINSKIS (2011). Thereby, the energy obtained on each of those days could serve as latent heat (of evaporation) to evaporate about 0.5 kg of water. It is necessary to mention that on those days from 50 to 100 m^3 of air flowed through the collector and it ventilated the room on whose wall the collector was installed.

Summary and conclusions

1. The producer's recommendation to install the collector in vertical position on the southern wall of a building and adjusting it to work in this way is fully justified, because the measured values of radiation falling on a vertical surface sometimes exceed 800 W m^{-2}, while total radiation (on a vertical surface) reaches merely 500 W m^{-2}.

2. The resistance of air flux in the collector should be lowered by enlarging the inlet vents, changing – „smoothing" the way of air flux or using a second fan simultaneously (possibly of bigger power); because at the radiation of above 400 W m^{-2}, despite the fact that the fan's engine works at its highest efficiency, the air flux remains at the constant level of about 37 m^3 h^{-1} and does not reach the nominal efficiency value, i.e. 60 m^3 h^{-1}.

3. Using such solutions as the cover from multi-chamber polycarbonate, black surface with slats absorbing solar radiation and chamber foil isolation covered with metalized film seem good ideas in terms of construction, since the studies indicate that already at the radiation value of 100 W m^{-2} the collector worked efficiently and heated up the flowing air by about 5°C. This temperature increased together with radiation and reached the value of 20°C at the radiation of 800 W m^{-2}.

4. On the basis of the conducted measurements it should be concluded that the solar air collector should efficiently perform its function as a device which heats up air and increases its drying potential because, assuming that the average relative humidity of the air flowing into the collector is 70%, at the highest radiation values the air flowing out of the collector will have only 20% humidity and high evaporation potential, and at the lowest values under consideration for the collector's work (100 W m^{-2}), it will have relative humidity of 50%, which means that its evaporation potential is still relatively high.

5. Despite high air flux resistance mentioned in point 2 the analysis of the collector's efficiency showed that during its work (proper temperature and radiation) the efficiency remained at a satisfactory level from 42 to 46%, which allowed obtaining from 1000 to 1500 KJ of energy in this time.

6. The schedule of the project imposed an imperative that the research be conducted when air temperature during the collector's operation was in the range from +10 to +20°C, and only during one day of the measurements the temperature dropped slightly below +10°C.

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