Vol. 9, No 2/2020, 31-38

DOI: 10.17512/bozpe.2020.2.04

Construction of optimized energy potential
Budownictwo o zoptymalizowanym potencjale energetycznym

ISSN 2299-8535 e-ISSN 2544-963X

Comparing the efficiency of evacuated tube and flat-plate solar collectors in real installation conditions

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Abstract: The subject of the work is an analysis of two types of solar collectors: flat-plate and evacuated tube collectors in the same, natural working conditions during the period from 1st May 2017 to 30th September 2017. The scope of work includes a descriptive presentation of a measuring setup, located on the roof of the building of the Construction University of Warmia and Mazury in Olsztyn, and also the research methodology, as well as an analysis of the results and conclusions obtained. The measurements allow a comparison of the efficiency of the flat-plate and evacuated tube collectors by calculating heat yields, based on the following variants: average hourly irradiation, outdoor air temperature, temperature of the medium supplying the collectors and temperature of the returning medium. An analysis of the heat yield was made in relations to the individual absorber surface, to determine which of the tested collectors showed higher efficiency under real operating conditions during the spring-summer period.

Keywords: flat-plate solar collectors, evacuated tube collectors, efficiency of solar collectors

Please, quote this article as follows:

Jurczak M.A., Skotnicka-Siepsiak A., Comparing the efficiency of evacuated tube and flat-plate solar collectors in real installation conditions, BoZPE, Vol. 9, No 2/2020, 31-38, DOI: 10.17512/bozpe.2020.2.04

Introduction

Nowadays, a lot of emphasis is put on maintaining air quality and environmental protection has become very popular. This change in mentality is clearly evident in the construction industry through introducing energy-efficient technology or by improving the efficiency of existing systems. It is very important to benefit from existing energy resources, i.e. solar radiation, wind, and waves.

Recently, the market for solar collectors has developed considerably. Such an increase is the result of investment based on tenders and co-financial projects offered within municipalities and their neighborhood or through subsidies available from the government. At the moment writing, the most important support programs are e.g. „My current", „Clear air" or „Prosument 2". Additionally, support can be found from EU financial assistance or from low-percentage loans offered by banks.

Usable energy that can be obtained by solar collectors depends on many different factors. First of all, it is very important to estimate the size of the installation rationally and to select the individual components accordingly. A key factor is the amount of solar energy that reaches the earth's surface, which depends on the location and geographical conditions. It is very important to choose the type of collector and its location – tilt and orientation. Solar installations are mainly used for the preparation of domestic hot water, but there is an increase in the use of collectors for heating purposes. At the end of 2018, solar panels occupied 686 million square meters worldwide (480 GWh), of which annual energy yields in 2018 reached 396 TWh, corresponding to savings of 42,6 million tonnes of oil and 137,5 million tonnes of CO_2 (Solar, 2019).

Due to the proliferation of solar installations, it has become very important to estimate energy and economic efficiency for different locations. Computer simulations of collector collection potential, based on annually average meteorological and operational data, are very helpful. They allow the selection of components for the system and analyze the operating conditions of the installation, to estimate the degree of coverage needed for hot water or to check the ecological and financial aspect. The purchase of the collector is a serious investment, so before making a decision, it is necessary to analyze which type of installation will be the best solution.

The article discusses the comparison between flat-plate and evacuated tube collectors under real working conditions. The research facility is a solar installation installed in one of the buildings of the University of Warmia and Mazury in Olsztyn. The main assessment criterion was the heat yield per 1 m². The analysis was carried out on the basis of the authors' own studies conducted by the Institute of Construction in Olsztyn. These covered the period from 1 May 2017 to 30 September 2017.

1. Experimental setup

The study used a solar installation placed on the roof of the building of the Institute of Construction located at 4 Heweliusz Street in Olsztyn. The roof had a slope of 45° (Fig. 1). The collectors are oriented in a south-westerly direction, with a deviation of 30° west relative to the south. Heat yields were analysed from two Viessmann Vitosol 100 F SV1 flat-plate collectors with a total active absorber area of 4.64 m^2, as well as a evacuated tube collector Viessmann type Vitosol 200 T SD2A, consisting of 30 pipes, with a surface area panel 3.23 m^2 (VIESSMANN, 2011). Due to the different surface fields of the collectors (and absorbers), the results of the study were developed for 1 m² of solar installation. Empirical data was recorded using a controller and was processed and stored in the computer.

Fig. 1. Location of flat-plate collectors (on the left) and evacuated tube (on the right) on the roof of the building Institute of Construction in Olsztyn (*own study*)

In flat-plate collectors, the outer housing is an aluminum frame. The most important element is the absorber, which for Vitosol 100 F collectors is covered with black chrome, effectively absorbing sunlight. The absorber wires are shaped like a meander, which promotes uniform heat reception from the entire surface of the collector. The outer layer is a 3.2 mm solar glass, which effectively transmits the sun's radiation. The interior between the bottom plate and the absorber is filled with thermal insulation in the form of mineral wool (Fig. 2a). The working medium content (glycol) is 1.67 l at an acceptable operating pressure of 6 bar (VIESSMANN, 2011).

a) b)

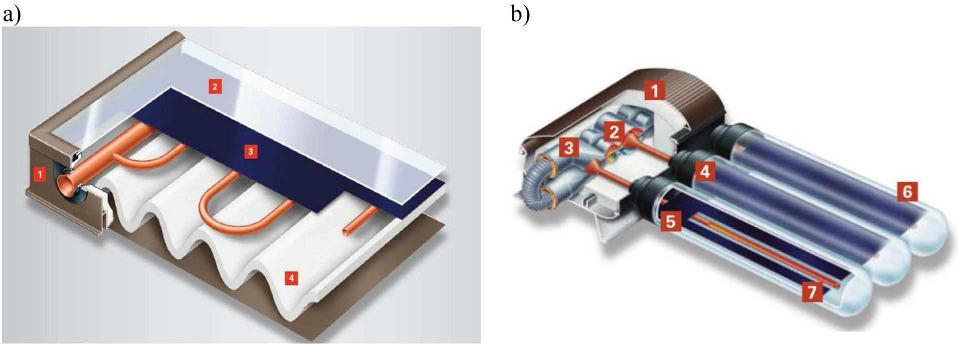


Fig. 2. Schematic of a collector: a) flat-plate: 1 – aluminium frame, 2 – glazing cover, 3 – absorber with copper wires in the form of a coil, 4 – thermal insulation, b) evacuated tube: 1 – thermal insulation, 2 – condenser connection to heat exchanger, 3 – heat exchanger, 4 – tight rotating head, 5 – absorber, 6 – vacuum space, 7 – „heat-pipe” (*own study*)

The tested evacuate tube collector is made up of 30 glass pipes filled with vacuum. Inside each pipe is a copper absorber, covered with a high-selective Sol--Titan coating. A heat exchanger is attached to the absorber plate in the form of two coaxial tubes ensuring direct flow of the heating factor, the content of which is 6.2 l at an acceptable working pressure of 6 bar. Vacuum tubes are mounted on rotatable heads for optimal alignment of the absorber in the direction of the sun (Fig. 2b) (VIESSMANN, 2011; Zimny et al., 2013).

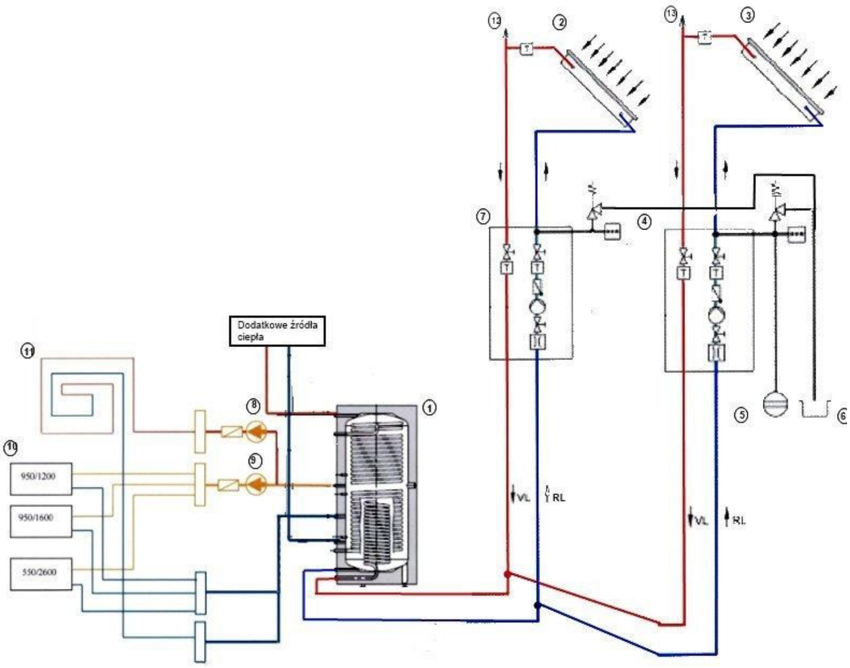


Fig. 3. Diagram of the analyzed solar installation: 1 – water buffer tank, 2 – flat-plate collectors, 3 – evacuated tube collector, 4 – pump module of a evacuated tube collector, 5 – expansion vessel, 6 – emptying tank, 7 – pump module of a flat-plate collector, 8 – floor circuit pump, 9 – radiator circuit pump, 10 – radiators, 11 – floor heating 4.75 m^2, 12 – vent valve installations of flat collectors, 13 – vent valve installations of vacuum collectors (Skotnicka-Siepsiak et al., 2018)

Figure 3 shows a diagram of the tested hydraulic installation. On the roof of the building there are flat-plate and evacuate tube collectors, on which fall the sun's rays that are converted by thermal conversion to heat. Manual venting valves are installed at the highest point of installation. A glycol temperature sensor inside the collectors is connected to the upper piping connection. The wires from under the roof swath are carried vertically down to the basement, where they are connected to the buffer tank by solar dividers (separate for flat-plate and evacuated tube collectors). As a result of heating of the liquid, it is extended, which leads to an increase in pressure in the installation. A co-installation vessel and a tank for emptying the installation were used to compensate for the effect of thermal expansion.

The resulting two power and return circuits for the collectors are connected by a galvanized steel pipe to the Vitocell 340 M multifunction buffer tank. When the temperature in the buffer reaches the set value, the accumulated heat is discharged through the radiator battery and the heating mat.

2. Methodology

Measurements were made during the spring-summer months from May 2017 to September 2017. The tests include average hourly irradiation, determination of external temperature, manifold feed temperature (glycol) and return agent temperature. The value of the solar irradiation was measured with the use of the Kipp&Zonnen CMP3 pyranometer. Its spectral range includes values from 300 to 2800 nm, sensitivity from 5 to 20 mV/W/m^2, response time – 18 s, directional error below 20 W/m^2, maximum irradiation 2000 W/m^2. The pyranometer operates in the temperature range from –40 to 80°C. A Siemens QAC22 sensor with a measuring range of –50 to 70°C, having an LG-Ni 1000 Ω/0°C sensor with a fixed time of about 14 minutes, was used to measure the average hourly outside temperature. The temperatures of the supply factor coming in and out of the collectors were measured by siemens QAP21.2 adjacent sensors, the measuring element of which has LG-Ni 1000 Ω/0°C resistance and a fixed time when mounted on a pipeline of less than 20 seconds. The measuring range of the sensors used ranges from –30 to 180°C (Skotnicka-Siepsiak et al., 2018).

3. Development of research results

A constant heating factor density of 1035 kg/m^3 and the liquid's specific heat of 45°C equal to 0.9389 (W·h)/(kg·deg) was used for the calculation. The flow of liquid in the installation was variable over time, read using a rotameter. The resulting amount of heat from solar panels was calculated according to the formula (Wesołowski, 2006):

$$Q = \sum_{i=1}^{n} q(i) \cdot c_w \cdot V'(i) \cdot [\vartheta_V(i) - \vartheta_R(i)] \cdot \Delta t \tag{1}$$

where:

$q(i)$ – heating factor density [kg/m^3],

$V'(i)$ – average flow of the working factor [m^3/h],

$\vartheta_V(i)$ – temperature of the working factor lowering the collector [°C],

$\vartheta_R(i)$ – temperature of the working medium supplying the collector [°C],

c_w – specific heat of the working medium [(W·h)/(kg·deg)],

Δt – time, 3600 s.

The efficiency of the collectors was determined from the formula (VIESSMANN, 2013):

$$\eta = \eta_0 - \frac{k_1 \cdot \Delta T^2}{E_g} - \frac{k_2 \cdot \Delta T^2}{E_g} \tag{2}$$

where:

η – collector efficiency,

η_0 – optical collector efficiency,

k_1 – heat loss factor [W/(m^2·K)],

k_2 – heat loss factor [W/(m^2·K)],

ΔT – temperature difference between external air and absorber temperature at the working medium inlet to the collector [K],

E_g – radiation power [W/m^2].

Optical collector efficiency and heat loss factors were taken on the basis of the manufacturer's data compiled in Table 1.

Table 1. Optical efficiency and heat losses for flat-plate and evacuated tube collectors (VIESSMANN, 2011)

	Flat-plate	Evacuated tube
Optical efficiency [%]	74.3	78.9
Heat loss factor k_1 [W/(m^2·K)]	4.16	1.36
Heat loss factor k_2 [W/(m^2·K)]	0.012	0.008

4. Analysis of test results

During the analysis period from 1 May 2017 to 30 September 2017, no results were recorded on several days from 24 August to 4 September due to the stagnation of measuring devices. The daily average outside temperature was 16.44°C, the lowest 0.1°C recorded on 10 May and the highest 29.0°C on 1 August. Comparing air temperatures with a typical meteorological year, it should be noted that there were no negative temperatures during the analysis period, which often happens in May. In addition, a lower temperature frequency from 2-14°C and 26-30°C ranges was noted than in TMY (Fig. 4). Average hourly irradiation was at 180.42 W/m^2. The highest amount of solar radiation was in May, when the average intensity was 228.29 W/m^2. In relation to a typical meteorological year, intensities up to 100 W/m^2 and over 800 W/m^2 were more frequent (Fig. 5).

In Figure 6, the heat and efficiency of flat-plate and vacuum collectors in each month of the research period were compared.

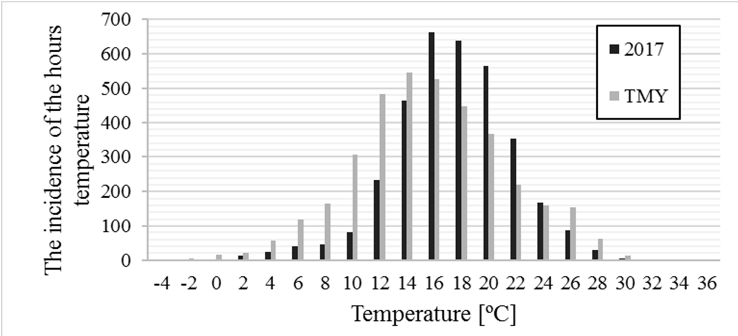


Fig. 4. Comparison of external temperature in 2017 with a typical meteorological year (*own study*)

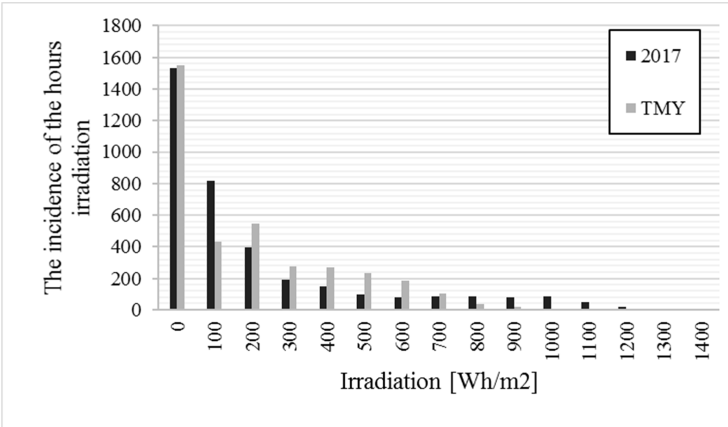
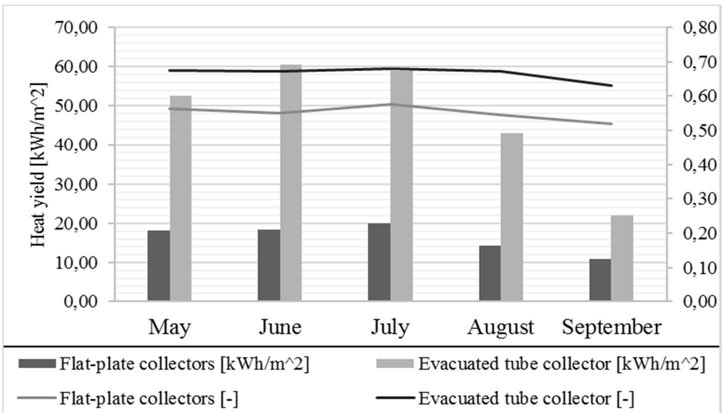


Fig. 5. Comparison of solar irradiation in 2017 with a typical meteorological year (*own study*)



*) missing data from 2017.08.24 to 2017.09.04

Fig. 6. Heat yield and efficiency of flat-plate and evacuated tube collectors in each tested month (*own study*)

Total energy yield from flat-plate collectors was 378.81 kWh (81.64 kWh/m^2), while the evacuated tube collectors was 765.01 kWh (236.85 kWh/m^2). Therefore, the amount of heat obtained from 1 m^2 of evacuated tube collector was almost 3 times higher than from a flat-plate collector. In Figure 6, it can see that the most energy from the collectors was received in June and July, when there was peak solar irradiation. The lowest heat yields were achieved in September, when the lowest sunlight reached the absorber. In Figure 6, the efficiency of both types of collectors is also marked. It is clear that evacuated tube collectors with an average value of 67% are more efficient (average for flat-plate collectors – 55%), as reflected in higher energy yields. The efficiency is highly dependent on the temperature difference between the collector cavity and the external environment – the bigger the difference, the lower efficiency of the collectors.

Conclusions

It was observed that the higher the irradiation value, the higher the energy yields that were obtained. As many as 251 more sun hours (with an average intensity $\geq$ 800 W/m^2) were recorded than in a typical meteorological year. With regard to efficiency, it was noted that it is greatest when the difference between the operating factor temperature inside the installation and the ambient temperature is zero, which means that the collector does not give heat outwards and so reaches optical efficiency. As the temperature difference increases, the efficiency of the installation decreases. In evacuated tube collectors, this decrease is smaller than in flat-plate models, which is associated with effective air insulation in this type of installation. From the results obtained, it is concluded that evacuated tube collectors are more efficient in the spring-summer period than flat-plate collectors.

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