Vol. 10, No 2/2021, 45-52

DOI: 10.17512/bozpe.2021.2.06

Construction of optimized energy potential
Budownictwo o zoptymalizowanym potencjale energetycznym

ISSN 2299-8535 e-ISSN 2544-963X

Efficiency of solar energy use in domestic hot water systems in Poland

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Abstract: This article establishes the efficiency of a single-circuit thermosyphon domestic solar hot water system for Polish cities such as Warsaw, Lublin, Bialystok, Czestochowa and Szczecin, using two indicators, namely the solar fraction and the efficiency of solar collector. It was found that of the selected cities, Bialystok is the most attractive in terms of using solar energy for hot water supply systems, as the solar hot water supply system has the highest solar fraction $f = 0.64$, and the efficiency of the solar collector is $\eta = 0.553$. The lowest efficiency of the solar hot water supply system is observed for the city of Szczecin, which is characterized by indicators $f = 0.49$ and $\eta = 0.505$, respectively. These analytical studies show that the use of the solar hot water system in selected cities in Poland can save on traditional energy sources for hot water systems by up to 50%.

Keywords: solar energy, domestic hot water system, solar collector, solar fraction, efficiency

Please, quote this article as follows:

Savchenko O., Lis A., Efficiency of solar energy use in domestic hot water systems in Poland, Construction of Optimized Energy Potential (CoOEP), Vol. 10, No 2/2021, 45-52, DOI: 10.17512/bozpe.2021.2.06

Introduction

Heat supply systems are an important part of the thermal industry. They provide thermal energy to the hot water supply, heating, ventilation and air conditioning systems of residential and public and industrial buildings (Lis & Lis, 2019; Savchenko & Lis, 2020). Fossil fuels are largely used as a source of energy in Poland's heating supply systems (Wojdyga, 2016; Wojdyga & Chorzelski, 2017).

Thus, 75% of thermal energy is produced by the process of coal combustion, 3.9% by the combustion of natural gas and only 10.4% with renewable energy sources, taking into account biomass. As a result, Poland is one of the most environmentally harmful countries in Europe in terms of thermal energy production. That is why the EU promotes the use of renewable energy in Poland by co-financing the use of solar panels, geothermal heat pumps and biomass plants for thermal energy production.

Solar energy is undoubtedly one of the leading renewable energy sources in the world. In heating systems it can be used to generate heat for the needs of domestic hot water systems and heating systems. Solar heating systems, as well as heat supply systems with organic energy sources, can be centralized and local. Solar district heating is a system that uses active solar heating systems to generate heat from solar energy and distributes it through heating networks to many consumers (Pauschinger, 2016). Local solar heating systems are used to provide thermal energy to the system of individual buildings. In this case, thermal energy is supplied directly to the hot water supply and (or) heating systems, and if necessary, stored locally in the storage tank. Since hot water supply systems are year-round consumers of thermal energy, it is advisable to use solar heating systems to prepare hot water for their needs.

1. Purpose of work

This study aims to evaluate the efficiency of solar energy used in domestic hot water systems in Poland.

2. Analysis of existing research

Solar domestic hot water systems are designed to heat water using solar radiation and supply heated water to consumers. There are two main types of solar heating systems: active system, which uses a pump to circulate water between the storage and the solar collectors, and thermosyphon system, which uses natural water circulation. In addition, active solar heating systems can be direct or indirect. In direct systems, the coolant moves from the collectors directly to the storage tank by means of a pump. Such systems are best suited for climates where the outside air temperature rarely drops below zero. In indirect solar heating systems, there are two circuits: in the first closed circuit, a non-freezing coolant circulates between the collector and the heat exchanger, and in the other, water circulates between the heat exchanger and the consumer. The non-freezing coolant gives off heat to the tap water in the heat exchanger and returns to the solar collector, the cold water is heated in the heat exchanger and fed to the storage tank, after which it is supplied to the consumers if necessary. Indirect solar heating systems are used in cold climates, where there is a possibility of freezing of the coolant in the system (Shelke et al., 2015).

In European countries, thermosyphon heating systems are mainly used for hot water preparation. These systems are reliable, efficient and easy to build, consisting of a solar collector with a capacity of 0.7 to 2.1 kW (collector area, respectively, from 1 to 3 m²) and a hot water storage tank with a capacity of usually 80 to 150 liters. Due to the circulation of the coolant between the collector and the storage due to natural convection, the storage tank of the solar heating system must be higher than the solar collector (Fig. 1).

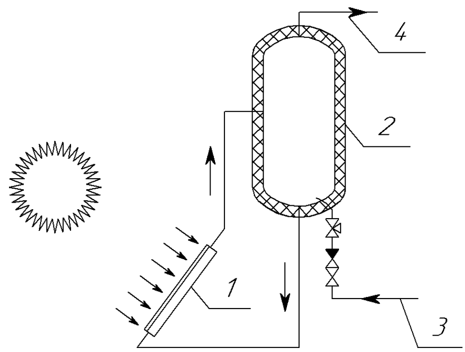

Fig. 1. Schematic diagram of a single-circuit thermosyphon solar heating system:
1 – solar collector, 2 – storage tank, 3 – cold tap water, 4 – heated water outlet

When using solar energy in hot water supply systems, the amount of solar radiation entering the surface of the solar collector, its distribution over time and availability for different cities are crucial. According to climatic conditions, the territory of Poland belongs to the regions with average intensity of solar radiation, so the average annual total amount of solar radiation per 1 m^2 of horizontal surface is in the range of 950-1150 kWh/($m^2 \cdot$year), which allows the use of solar heat for domestic hot water systems.

The intensity of solar radiation coming to the solar collector depends on the intensity of total solar radiation, the area of the collector and the type of its installation. Installation of solar collectors takes place on special structures that ensure their optimal orientation to the sun and reliable attachment to different types of surfaces (Savchenko & Kozak, 2019). For maximum solar radiation, the plane of the solar collector should always be perpendicular to the sun's rays, but the angle of inclination of the sun's rays to the horizon β varies, depending on the time of day and time of year. With year-round operation of the solar domestic hot water system and the southern orientation of the solar collector, the optimal angle of inclination is considered to be an angle equal to the place's latitude φ, where the solar collector is installed $\beta = \varphi$ (Skerlic et al., 2018). For seasonal solar heating systems, the angle of the solar collector is taken as follows:

– for the cold period of the year $\beta = \varphi + 15$;
– for the warm period of the year $\beta = \varphi - 15$.

According to the above, there are six ways to install solar collectors (Fig. 2). With stationary mounting, the orientation of the collectors and the angle of their inclination remain unchanged, and the collectors can be installed vertically or horizontally, or at optimal angles determined depending on the period of use of the solar collector.

At dynamic fastening the movement of solar collectors is carried out during the movement of the Sun (Savchenko & Kozak, 2019).

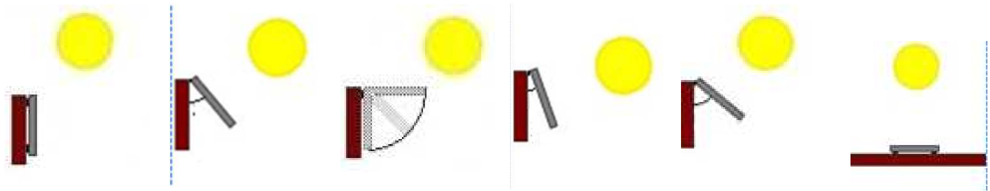

Fig. 2. Ways to installation solar collectors

The efficiency of solar energy use in domestic hot water systems is characterized by two indicators, in particular the solar fraction and the efficiency of the solar collector (Nshimyumuremyi & Junqi, 2019; Savchenko & Savchenko, 2021).

The efficiency of a flat solar collector is determined by the formula:

$$\eta = \frac{Q_{useful}}{Q_{inc}} \tag{1}$$

where: Q_{useful} – useful thermal energy provided by the solar collector, W; Q_{inc} – the amount of solar energy that enters the solar collector, W.

Solar fraction is the amount of solar energy in the total load on the domestic hot water system, which is determined by the formula:

$$f = \frac{Q_{solar}}{Q_{load}} \tag{2}$$

where: Q_{solar} – the amount of thermal energy for the needs of the domestic hot water system, which can be covered by solar energy, W, i.e. $Q_{solar} = Q_{useful}$, Q_{load} – general needs for thermal energy by the domestic hot water system, W.

According to the methods (Nshimyumuremyi & Junqi, 2019; Savchenko & Savchenko, 2021), the main factors influencing the efficiency of the solar hot water system are divided into three groups: climatological parameters of the place of construction, technical characteristics of the solar collector and parameters of the domestic hot water system. Climatological parameters that affect the efficiency of the solar hot water system include the intensity of solar radiation, the number of hours of sunshine per day and the temperature of the outside air. The technical characteristics of the solar collector include the area of the collector, the coefficient of transparency of the glass, the absorption coefficient of the adsorber, the heat loss coefficient of the solar collector and the heat transfer coefficient of the solar collector. The parameters of the domestic hot water system, which affect the efficiency of the domestic hot water system, are the daily consumption of hot water, and the temperature of the water at the inlet and outlet of the domestic hot water system.

3. Material and methods

For evaluating the efficiency of solar energy use in hot water supply systems in Poland, single-circuit thermosyphon solar domestic hot water systems in the cities of Warsaw, Lublin, Bialystok, Czestochowa, Szczecin were compared. The domestic hot water system was designed for a house with a daily hot water consumption of 80 L/day. The flat solar collector auroTHERM classic VFK 135/2 D with the area $A = 2.35\ \mathrm{m}^2$ and such technical characteristics is accepted for perception of solar radiation: the coefficient of transparency of glass $\tau = 0.91$, coefficient of absorption of the adsorber $\alpha = 0.95$, coefficient of heat loss of a solar collector $U_L = 3.93\ \mathrm{W/m^2/K}$, coefficient of heat transfer of a solar collector $F_R = 0.69$ (Savchenko & Savchenko, 2021). In designing, it is assumed that the temperature of tap water in the cold period of the year is 5°C, in the warm period of the year is 15°C, and the temperature of hot water after the solar collector is 50°C.

The average monthly intensity of solar radiation coming to the solar collector, oriented to the south and fixed at an angle of inclination, equal to the optimal angle for year-round operation of the domestic hot water system and equal to the latitude for selected cities in Poland is shown in Figure 3.

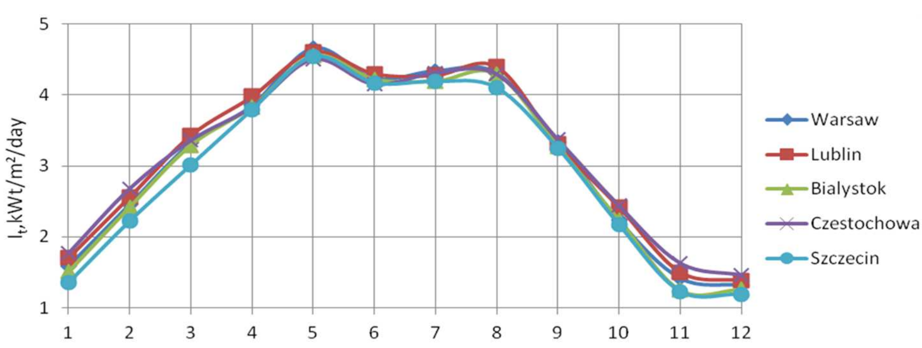

Fig. 3. Average monthly intensity of solar radiation per solar collector oriented to the south and at the optimal angle of inclination of the solar collector for Polish cities (*own research*)

As can be seen from Figure 3, the average monthly intensity of solar radiation for selected cities in Poland does not differ significantly during the year, the highest values of radiation intensity 4.50-4.66 kWh/m^2/day are typical for the month of May, and the lowest values 1.19-1.46 kWh/m^2/day for December.

The solar collector receives solar radiation for several hours a day, the amount of which depends on the season, clouds and the construction site of the installation. The average daily number of sunny hours by months of the year for selected cities in Poland is shown in Figure 4.

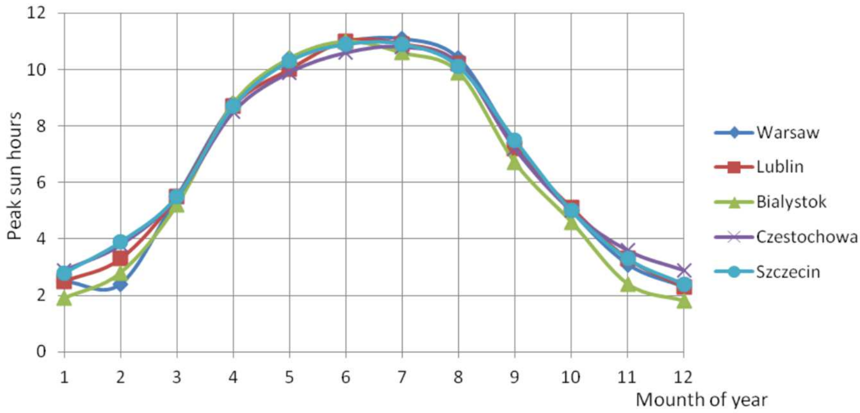

Fig. 4. The average daily number of hours of sunshine in the months of the year in some Polish cities (*own research*)

As can be seen from Figure 4, the average daily number of hours of sunshine in selected cities in Poland differs slightly, and vary from 1.8-2.9 hours in December to 10.6-11.0 hours in June.

The solar fraction for the solar domestic hot water system with a daily hot water consumption of 80 L/day was determined by formula (2). The average annual solar fraction can be defined as the arithmetic mean value of solar fractions by months of the year. The average annual fraction of the solar domestic hot water system for selected cities in Poland is presented in Figure 5.

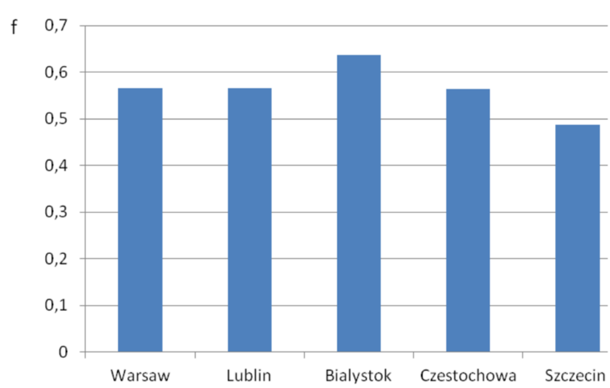

Fig. 5. The average annual fraction of the solar domestic hot water system for selected cities in Poland (*own research*)

As can be seen from Figure 5, solar fractions of the solar domestic hot water system in selected cities of Poland, designed for daily hot water consumption of 80 L/day, have an average annual solar fraction in the range of 0.49-0.64, which means that during the year in all cities, in addition to Szczecin, the solar domestic hot water system can provide heat energy to the hot water supply system by 50%, the rest of the water required for the hot water system must be provided by another energy source or the daily consumption of hot water must be reduced.

The efficiency of a flat solar collector depends on its technical characteristics and climatological parameters of the city of construction. The values of the efficiency of a flat solar collector when working in the solar domestic hot water system of a residential building in selected cities of Poland for different months of the year, determined by formula (1) are shown in Figure 6.

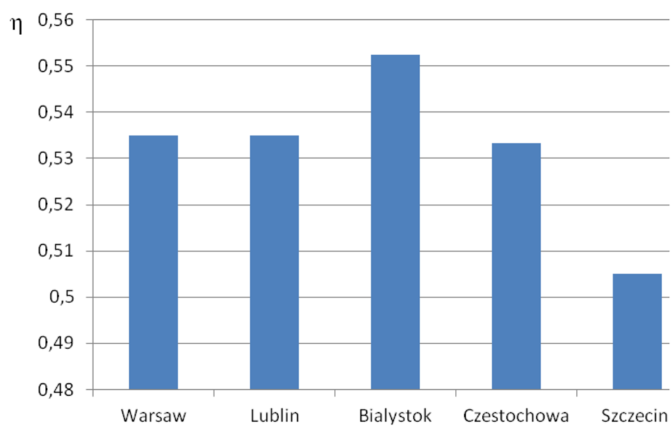

Fig. 6. The average annual value of the efficiency of the flat solar collector of the solar domestic hot water system for selected cities in Poland (*own research*)

As can be seen from Figure 6, the efficiency of the solar collector for all these cities is less than the values specified by the manufacturer, namely 0.782. The highest value of the efficiency of the solar collector during its installation in Bialystok is 0.553, the lowest value of the efficiency of the solar collector is in the city of Szczecin, which is associated with low average monthly values of outdoor air temperature and intensity of solar radiation.

Conclusions

This article establishes the efficiency of a single-circuit thermosyphon solar domestic hot water system of a residential building in selected Polish cities, such as Warsaw, Lublin, Bialystok, Czestochowa and Szczecin. In the analytical study, the efficiency of a single-circuit thermosyphon solar domestic hot water system was determined by two indicators, in particular, the solar fraction of the solar domestic hot water system and the efficiency of the solar collector for such a system were established. It is determined that with the same technical parameters of solar collectors and quantitative and qualitative needs of the hot water supply system, the main factors influencing the efficiency of the solar hot water supply system are the intensity of solar radiation, number of sunny hours per day and ambient temperature. It was found that of the selected cities, Bialystok is the most attractive in terms of using solar energy for solar domestic hot water systems, as the solar domestic hot water system has the highest solar fraction $f = 0.64$, and the efficiency of the solar collector is $\eta = 0.553$. The lowest efficiency of the solar domestic hot water system is observed for the city of Szczecin, which is characterized by indicators $f = 0.49$ and $\eta = 0.505$, respectively. These analytical studies show that the use of the solar domestic hot water systems in selected cities in Poland can save on traditional energy sources for hot water systems by up to 50%, and, accordingly, reduce the negative impact on the environment. In further research, it is advisable to conduct experimental measurements to determine the efficiency of the solar collector in the hot water supply systems of Polish cities.

Bibliography

Lis, A. & Lis, P. (2019) *Design and actual energy consumption of heating educational buildings, identification of differences.* BoZPE, 1, 37-45.

Nshimyumuremyi, E. & Junqi, W. (2019) *Thermal efficiency and cost analysis of solar water heater made in Rwanda.* Energy Exploration & Exploitation, 37(3), 1147-1161.

Pauschinger, T. (2016) *Solar thermal energy for district heating.* In: Wiltshire, R. (Ed.) *Advanced District Heating and Cooling (DHC) Systems.* Woodhead Publishing, 99-120.

Savchenko, O. & Lis, A. (2020) *Economic indicators of the heating system of a cottage in Ukraine and Poland.* BoZPE, 9, 97-102.

Savchenko, O. & Kozak, K. (2019) *Influence of type of solar modules anchorages on power of solar power station.* Energy Engineering and Control Systems, 5(1), 23-28.

Savchenko, O. & Savchenko, Z. (2021) *Estimation of solar water heating system operation for a residential building.* Energy Engineering and Control Systems, 7(1), 1-6.

Shelke, V.G., Patil, C.V. & Sontakke, K.R. (2015) *Solar water heating systems: A review.* International Journal of Scientific Engineering and Research, 3(4), 13-17.

Skerlic, Ja., Nikolic, D., Cvetkovic, D. & Miškovic, A. (2018) *Optimal position of solar collectors: a review.* Applied Engineering Letters, 3(4), 129-134.

Wojdyga, K. (2016) *Polish district heating systems – Development perspectives.* Journal of Civil Engineering and Architecture, 10, 268-279.

Wojdyga, K. & Chorzelski M. (2017) *Chances for Polish district heating systems.* Energy Procedia, 116, 106-118.