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A New Method to Determine the Annual Energy Output of Liquid-Based Solar Collectors †

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Abstract: This article presents a new way of determining the annual energy output of solar thermal collectors. The proposed method, in the first stage, assumes the creation of a database that contains energy gains Q_{SC} from the solar collectors, the average annual solar irradiance intensity I_S, and the average temperature of the outside air θ_O. It can be made on the basis of detailed computer simulations. In the current case, EnergyPlus software was used to create this database. Next, mathematical relations for flat plate and evacuated tube collectors were developed using the linear regression analysis (multiple regression method). Based on these equations, one can calculate the value of Q_{SC} as a function of I_S and θ_O. In addition, two graphs for the estimation of the annual energy gains for the entire area of Poland and for the conditions of a typical meteorological year were prepared.

Keywords: energy gains; flat plate collectors; evacuated tube collectors; multiple regression method

1. Introduction

In order to perform any economic analysis related to the possibility of using renewable energy sources, there is a need to determine the energy performance of solar panels. Energy output from solar water heating systems (SWHS), in which solar energy conversion takes place, can be calculated in three different ways [1]. The first category is applied to systems, in which the average operating temperature of panels can be estimated and the amount of solar radiation is known. In this case, the best example is the utilizability method developed by Gordon and Rabl [2], and Pareira et al. [3]. This computational algorithm takes into account the results of experimental research in the last forty years. The second category includes methods that are the result of multi-variant detailed computer simulations and are in the form of multi-variable correlations. A representative example may be an f-Chart method [4]. This is a quick tool for assessing the energy efficiency of a given technical solution. The error of this method, due to the approximations used, is estimated to be 5–10% [5]. The last category is energy computer simulations, which are performed for any solar system configuration with the assumption of a weather database for a typical meteorological year. This type of comprehensive modeling can be made using the most popular computer programs such as TRNSYS, Energy +, Polysun, T * SOL, RETScreenl, GetSolar, and many others. This article presents a slightly different approach to performing analyses of SWHS. The main advantage of this method is the large simplicity of calculations in combination with high accuracy results.

2. Description of the Method to Determine the Annual Energy Output of Solar Collectors

One of the most important parameters affecting the energy yield of SWHS is the intensity of solar radiation. The second factor, which directly influences the energy balance of this system, is the

temperature of the outside air. Therefore, it was decided to develop a relationship that would allow these values to correlate, based on a multiple regression method.

In the first place, a series of energy simulations of the solar domestic hot water system (SDHWS) were performed. The test object is located on the roof of the Hotel for Research Assistants on the campus of Bialystok University of Technology (Poland), and includes 21 evacuated tube collectors, 35 flat plate collectors with the total gross area of almost 150 m^2, and eight tanks with a total capacity of 8 m^3. Description of the research facility, and the project under which it was built, can be found in [6,7]. The EnergyPlus v. 8.3 software was used to carry out these simulations. The calculation period covered one year with a one-hour step. A 3D model of this system is shown in Figure 1.

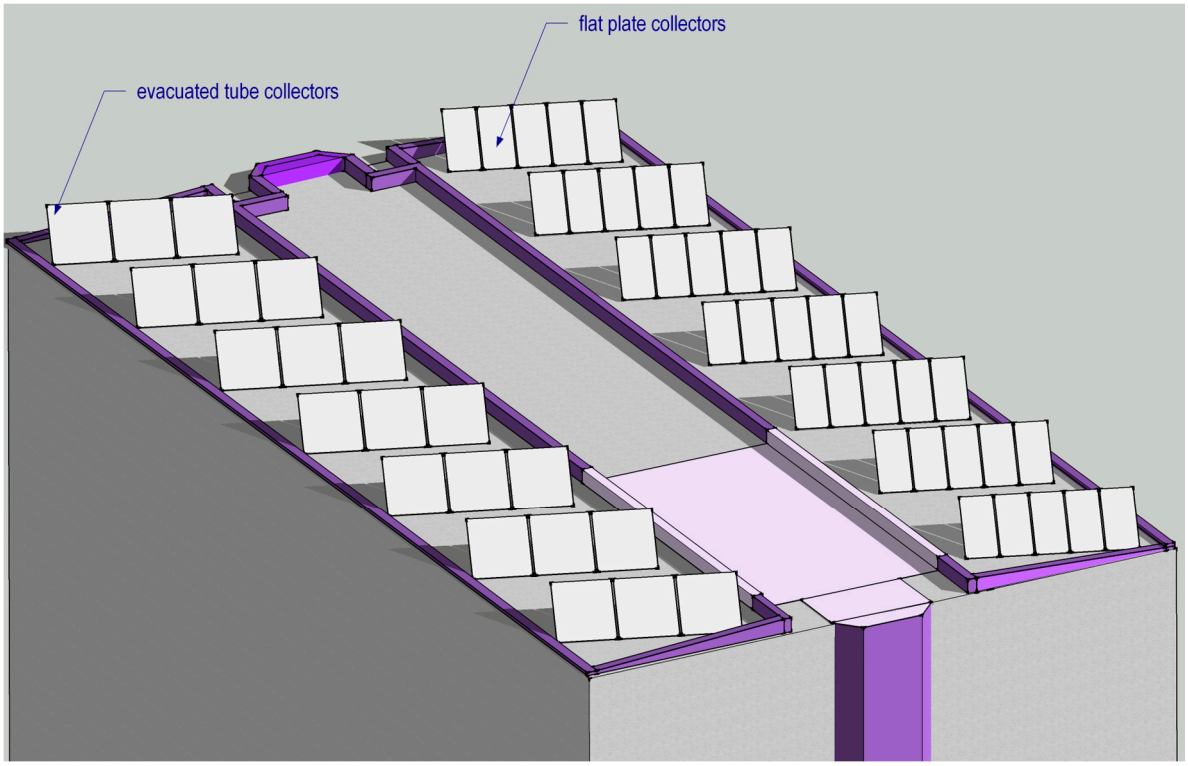


Figure 1. Model of solar domestic hot water system (SDHWS) developed in accordance with the requirements of energy simulations in the EnergyPlus environment.

3. Results and Their Discussion

As a result of multivariate calculations, the database consisting of annual energy yield per square meter of solar collectors Q_{SC}, the solar radiation intensity I_S, and average annual temperature of the outside air θ_O for the 24 locations in Poland was created. In the next step, the energy gains predicted by the model as a function of I_S and θ_O was developed. For this purpose, a multiple regression method was applied, the algorithm of which is implemented in the Statistica v. 13.1 software package. As a result of calculations, two equations were obtained. Equation (1) applies to flat plate collectors, and Equation (2) to vacuum tube collectors. On their basis, one can calculate the annual energy gains from 1 m^2 absorber surface of thermal solar panels. It should be noted that both functions are valid for an annual total radiation I_S in the range of 873–1140 kWh/m^2, and annual average outside temperature θ_O in the range of 6.37–9.01 °C.

$$Q_{SC_flat} = 0.506 \cdot I_S + 15.137 \cdot \theta_O - 173.117 \left[\frac{\text{kWh}}{m^2}\right]. \quad (1)$$

$$Q_{SC_evacuated} = 0.461 \cdot I_S + 2.487 \cdot \theta_O - 9.608 \left[\frac{\text{kWh}}{m^2}\right]. \quad (2)$$

The quality of the regression adjustment can be assessed as very good because of the value of the determination coefficient $R^2 = 0.986$ ($R = 0.993$) in the case of Equation (1) and $R^2 = 0.987$ ($R = 0.994$) in the case of Equation (2).

To estimate the amount of energy output from solar panels for a typical meteorological year, one can also use the specially created for this purpose charts. Figure 2 shows the distribution of Q_{SC} in Poland using flat plate panels, and Figure 3 applies to evacuated tube collectors.

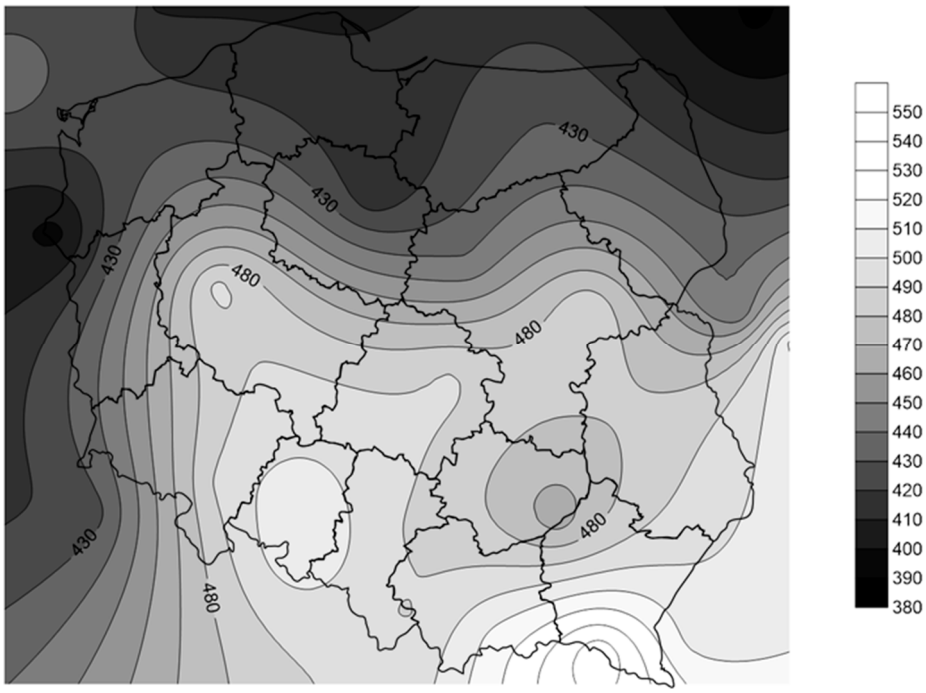


Figure 2. Distribution of the annual energy output of flat plate solar collectors in kWh on 1 m² of absorber area.

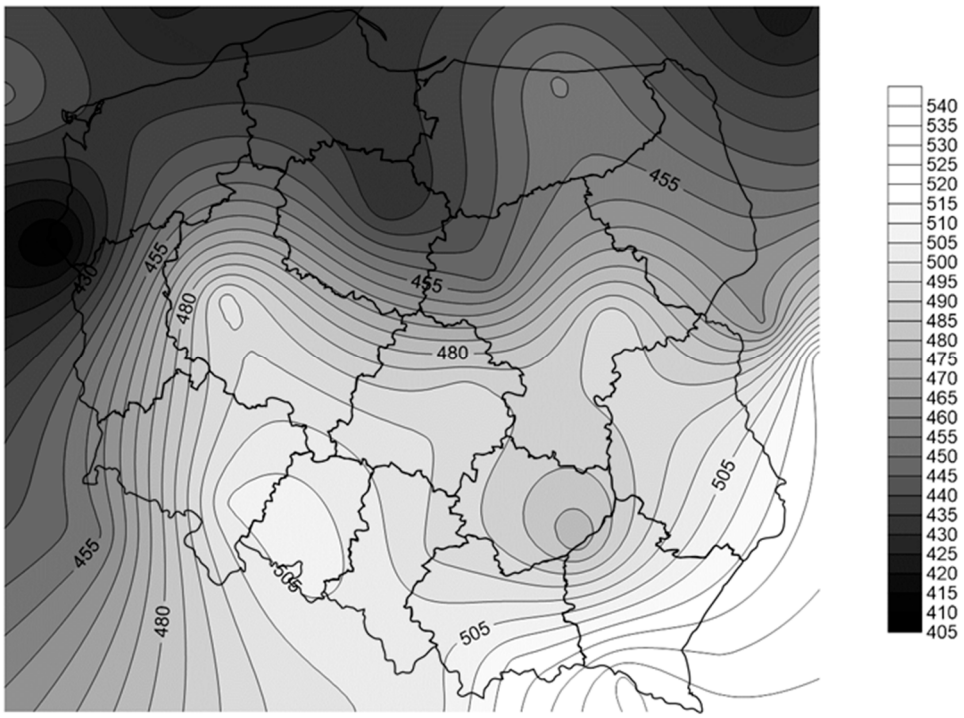


Figure 3. Distribution of the annual energy output of evacuated tube collectors solar collectors in kWh on 1 m² of active area.

Knowing the demand of domestic hot water Q_{DHW}, solar fraction SF coefficient [7], and calculating the Q_{SC} value (Equation (1) or Equation (2)), one can determine the required area of solar collectors A_{SC}

$$A_{SC} = \frac{SF \cdot Q_{DHW}}{Q_{SC}} \text{ [m}^2\text{]}. \quad (3)$$

4. Summary and Conclusions

A new method to determine the useful energy gains that can be obtained from solar thermal panels is presented in this article. By using the mathematical relations Equations (1) and (2) one can determine Q_{SC} if the average annual intensity of solar radiation I_S and temperature of the outside air θ_O is known. The graphs, shown in Figures 2 and 3, can also be used to determine the useful energy gains from 1 m^2 absorber surface of two basic types of solar panels.

It should be mentioned that the equations presented in the article concern solar collectors with a typical thermal performance and optical properties. If an unusual solar heating system is planned to be installed, then new energy simulations for this specific case should be performed.

The similar relationships and diagrams, shown above (Figures 2 and 3), can be developed for any country in the world that has a relatively detailed database for a typical meteorological year. The same algorithm can also be used for solar air heaters and photovoltaic panels. Of course, it is possible to specify mathematical dependencies for the selected season of the year.

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Author Contributions: M.Z. developed the method, reviewed the literature, made graphs, wrote this paper; P.R. made computer simulations, created data base, developed equations.

Conflicts of Interest: The authors declare no conflict of interest.

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