DOI: 10.2507/35th.daaam.proceedings.xxx

OPTIMUM TILT ANGLE OF FLAT PLATE SOLAR COLLECTORS FOR DIFFERENT LOCATIONS IN BOSNIA AND HERZEGOVINA

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This Publication has to be referred as: Lulic, H[aris]; Gadara M[erima]; Metovic, S[adjit] & Softic A[lmira] (2024). Optimum tilt angle of flat plate solar collectors for different locations in Bosnia and Herzegovina, Proceedings of the 35th DAAAM International Symposium, pp.xxxx-xxxx, B. Katalinic (Ed.), Published by DAAAM International, ISBN 978-3-902734-xx-x, ISSN 1726-9679, Vienna, Austria
DOI: 10.2507/35th.daaam.proceedings.xxx

Abstract

This paper shows the determination of the optimal angle of inclination for solar collector for different locations throughout Bosnia and Herzegovina over the course of the year. The research was conducted on an established solar system model designed for heating sanitary water for a hotel. It was found that, for one-position systems, the maximum solar thermal energy can be collected when the tilt angle of the collector is between 30° and 45°. For two-position systems, the optimal tilt angle is 30° during summer period and 60° for the rest of the year.

Keywords: Optimal tilt angle; flat plate water cooled solar collector; solar energy; function of the thermal efficiency of the solar collector; TRNSYS.

1. Introduction

In the era of globalization and excessive fossil fuel consumption, humanity faces the challenge of mitigating climate change by reducing greenhouse gas emissions and preventing the rise in the temperature of the Earth's atmosphere. Ahmović et al. [1] demonstrated the increase in average annual temperatures in continental climates attributed to climate change. One of the proposed solutions is to intensify the use of renewable energy sources. From an energy point of view, solar energy is an underutilized resource available globally and can be a qualitative and quantitative substitute for conventional energy sources [2]. One way to utilize solar energy for heating and hot sanitary water preparation is the use of active solar systems. To increase the efficiency of this type of solar system, it is necessary to increase the efficiency of solar thermal collectors. To increase the efficiency of flat solar thermal collectors, it is essential to optimize the angle of inclination of the collector relative to the horizontal plane and its orientation.

To collect the maximum daily amount of solar radiation that reaches the collector plane, dual-axis systems can be used to track the trajectory of the Sun depending on its position throughout the year. However, these systems increase the investment costs of the entire solar system, as well as the exploitation and maintenance costs. Additionally, since they rely on electricity for operation, they can reduce the overall efficiency of the solar system. For this reasons, in practice it is more common to design solar thermal collectors with fixed orientation and optimal angle of inclination relative to the

horizontal plane. In his work, K. Skeiker [3] stated and explained the influence of several factors that directly affect the choice of the angle of inclination of solar collectors, namely:

- geographic latitude and altitude of the location,
- purpose of the solar system and period of use during the year,
- climatic conditions in the given locality.

In his work, V. H. Moncos [4] analyzed the correlation between the maximum solar irradiation on the collector plane and the angle of inclination relative to the horizontal plane for the site of Assuit, Egypt. Through the research, a mathematical model was developed that gives the possibility of determining the total solar radiation on an inclined surface of fixed orientation, for a certain day or period of the year. The results show that to maximize solar radiation collection on the plane of the solar thermal collector for a given location, its inclination angle relative to the horizontal plane should be adjusted eight times annually.

Similar research, using different methods of analysis, was carried out and presented in their work by Stanciu et al. [5]. Using the Hottel and Woertz model, the isotropic diffusion model and the HDKR model, they estimated the density of absorbed solar radiation on the collector plane. In the paper, they compared the values of the maximum incident solar radiation and the maximum absorbed solar radiation by the energy receiver. The results showed that at the optimal tilt angle, these values do not differ significantly.

D. Ibrahim [6] conducted a theoretical study of the optimal angle of inclination of flat solar thermal collectors relative to the horizontal plane for the area of Cyprus. During the research, the data, obtained by measurements, on the total solar radiation on the horizontal surface for the observed locality were used. The analysis included an assessment of the values of direct and diffuse radiation on the south-facing surface of the collector for different angles of inclination ranging from 0° to 90°. The results of the research are presented through the values of the optimal tilt angle of 48° for the winter period and 14° for the summer period.

Jafarkazemi et al. [7] investigated the influence of the angular deviation of the direction of the axis of the plane of solar thermal collectors from the south direction on the optimal tilt angle. During the research, data on total solar radiation at different angles of inclination of the collector plane and different orientations were used. The optimal tilt angle for the south-oriented collector field was determined to be 22°, which in value almost corresponds to the latitude of the location where the study was conducted. Also, the results show that the values of the optimal angle of inclination of solar thermal collectors, on a monthly and annual level, decrease with an increase in the azimuth angle of the collector (angular deviation from the south direction).

A mathematical model, using the software tool MATLAB, for determining the optimal angle of inclination of the collector relative to the horizontal plane was presented in their work by Pourfayaz et al. [8]. Using their model, it is possible to determine the tilt angles at which the maximum values of solar radiation on the surface of the collector are obtained for five cities in Iran at different latitudes.

Similar research, in the same period, was conducted and the results were published in their work by Modarresi et al. [9]. The analysis they conducted was aimed at creating a model that predicts the optimal tilt angles of solar collectors for different locations in the southern and northern hemispheres. In doing so, it was shown that the value of the optimal angle of inclination at which the maximum value of solar radiation can be collected during the year does not depend on the longitude, but only on the latitude and the number of sunny days.

Analytical expressions for determining the optimal angle of inclination of solar thermal collectors for different geographical longitudes are given in the work of El-Kassaby et al. [10] and Aja et al. [11]. During the research, they used a fixed southern orientation of the collectors and hourly values of incident solar radiation.

Gunerhan et al. [12] in their work determined the daily, monthly and annual values of the optimal angle of inclination of the collector field at the site of Izmir, Turkey. The mathematical model used during the research also took into account the monthly level of atmospheric cleanliness in order to obtain the most realistic picture of the intensity of solar radiation that reaches the surface of the receiver. The results showed that the optimal tilt angle on an annual basis is 30.3°.

This paper presents the determination of the optimal tilt angle of collector for different locations in Bosnia and Herzegovina. The research was carried out on an already created model of solar system for the preparation of sanitary hot water for a hotel needs. The model was created in the TRNSYS software packages and the research was carried out over a year.

2. Potential of solar energy use in Bosnia and Herzegovina

Bosnia and Herzegovina has great potential for the use of solar and other energy sources and belongs to the countries of Europe with significant total solar radiation, which on an annual level ranges from 1250 kWh/m^2 in the north of the country and in mountainous areas up to 1600 kWh/m^2 in the south of the country.

If a comparison is made with the values of the total solar radiation on the horizontal surface in the countries of Central and Northern Europe, where the annual averages are 1150 and 1000 kWh/m^{2}year, respectively, the conclusion is reached that on average Bosnia and Herzegovina receives about 15% more solar energy compared to Central Europe, and 30% more than Northern Europe (Netherlands, Denmark, Great Britain). In the south of the country, in eastern and western Herzegovina, these percentages are even more pronounced, so that these regions lead in terms of the amount of available solar energy compared to central Europe by about 30% and compared to northern Europe by 50%.

The natural potential of solar energy in Bosnia and Herzegovina amounts to 67.2 PWh per year, if every day of the year, an average of 3.6 kWh of radiant energy falls on each square meter of the horizontal surface. This value exceeds the total energy consumption in Bosnia and Herzegovina many times over.

Despite the fact that Bosnia and Herzegovina belongs to the countries of Europe with significant solar irradiation, the use of solar energy in this area can be considered insignificant. However, the level of use of renewable energy sources, especially solar energy, is still not at a satisfactory level. One of the reasons is the relatively low coefficient of usefulness of solar energy conversion into electricity. On the other hand, in solar applications used for heating purposes, the problem of energy accumulation is evident, i.e. the disproportion between the time of the most intense solar radiation (summer period) and the time when the need for heat is greatest (night and winter period). An adequate solution to the problem of energy accumulation results in an increase in investment costs, and thus the economic justification is questioned [13].

The application of low-temperature solar collectors for the purpose of preparation of sanitary hot water, heating of water in swimming pools, heating and air conditioning of spaces, development of solar technology in the territory of Bosnia and Herzegovina is currently the most realistic. The role and importance of the solar collectors in a solar installation indicates the fact that the operation of the entire system largely depends on the correct choice and installation of the collectors. An important factor for designing solar systems is determining the optimal tilt angle of collector, at which it is possible to collect the most of the solar thermal energy [14].

3. Determination of the optimal tilt angle of collector for different locations in the territory of Bosnia and Herzegovina

The optimal tilt angle of collector relative to the horizontal plane depends on the specific application, and parameters such as the seasonal variations and daily usage patterns of collected solar energy. To determine the optimal tilt angles for different locations in Bosnia and Herzegovina, a simple solar system for preparation of sanitary hot water for hotel needs was used. The system consists of flat-plate VITOSOL 100 collectors, a storage boiler, a solar pump, an expansion tank and regulation components. The system was modelled using the TRNSYS software package for location in Sarajevo, Bosnia and Herzegovina.

When creating the model, already existing components owned by the library of the TRNSYS program package were used:

- Tank for the preparation of sanitary hot water "Type 4",
- Controller "Type 2b",
- Circulation pump "Type 3",
- Weather "Type 109",
- Diverter "Type 11",
- Printer "Type 65",

except for the collector component.

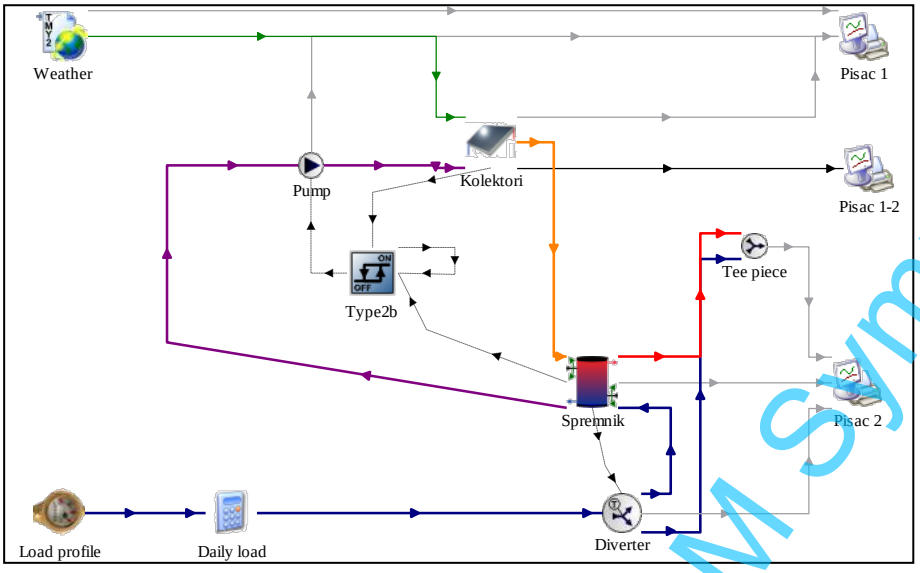

Fig. 1. Model of the solar thermal system for the preparation sanitary hot water for the hotel services [14]

A new "Type 1b" collector component was created, whose program is written in the FORTRAN programming language. The optical efficiency function for the "Type 1b" collector is represented by a modified efficiency function depending on the tilt angle of collector for the incidence angle of solar radiation $\theta > 30°$, and by the correlation of the standard function for the incidence angle of solar radiation $\theta \leq 30°$. The simulation time step used for this research is 15 minutes (from the offered values of the simulation time step, the minimum value was chosen, with the aim of achieving more accurate results) and was constant through the study [15].

The scheme of the model of the solar thermal system for the preparation of sanitary hot water for the needs of the hotel is shown in Fig. 1.

Determination of the optimal collector tilt angle was carried out for the following towns in Bosnia and Herzegovina: Sarajevo, Mostar, Zenica, Tuzla, Banja Luka and Livno. During research with the goal of maximizing solar thermal energy, the following tilt angles of collector φ were analyzed: 0°, 30°, 45°, 60°, 75°. The obtained results are presented in the form of a diagram (Fig. 2, Fig. 3, Fig. 4, Fig. 5, Fig. 6, Fig. 7).

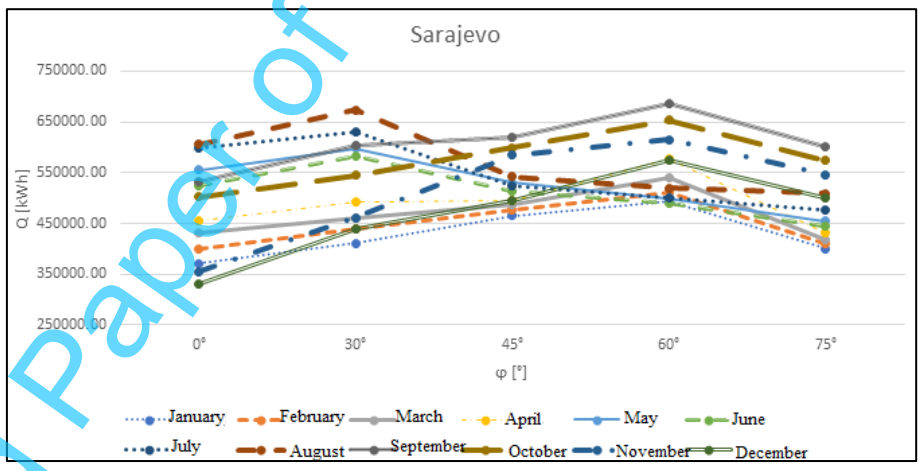

Fig. 2. Thermal energy collected for different tilt angle of collector, for the city of Sarajevo.

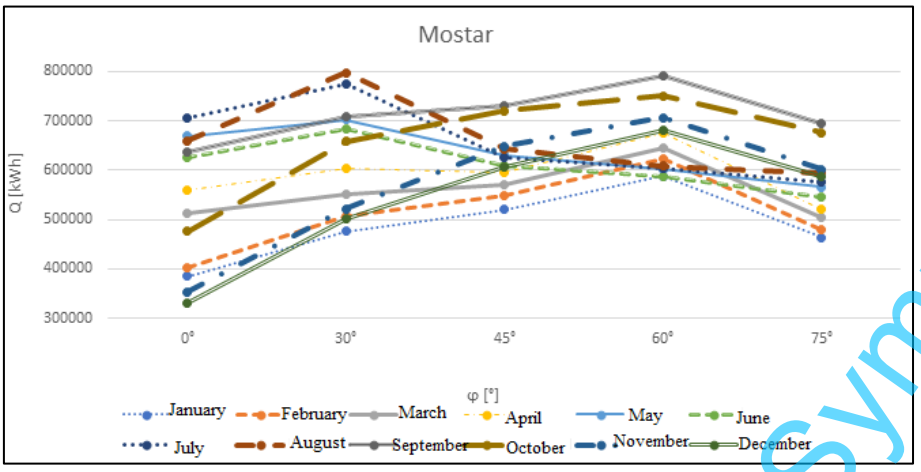

Fig. 3. Thermal energy collected for different tilt angle of collector, for the town of Mostar.

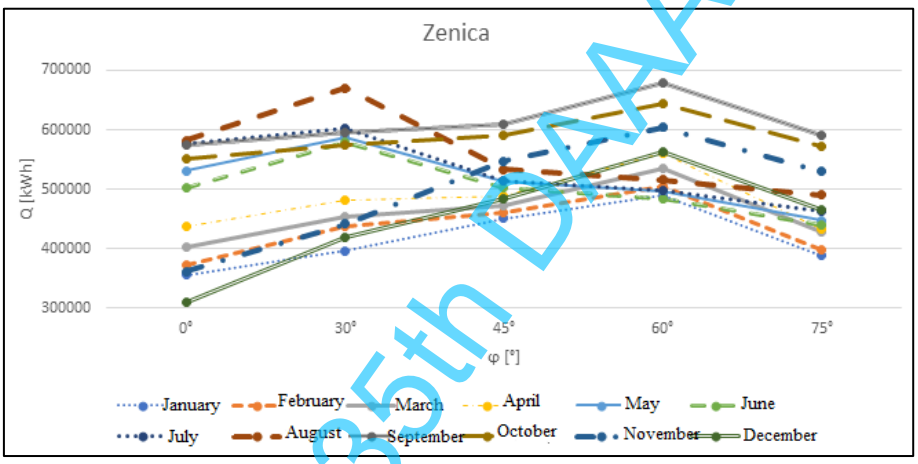

Fig. 4. Thermal energy collected for different tilt angle of collector, for the town of Zenica.

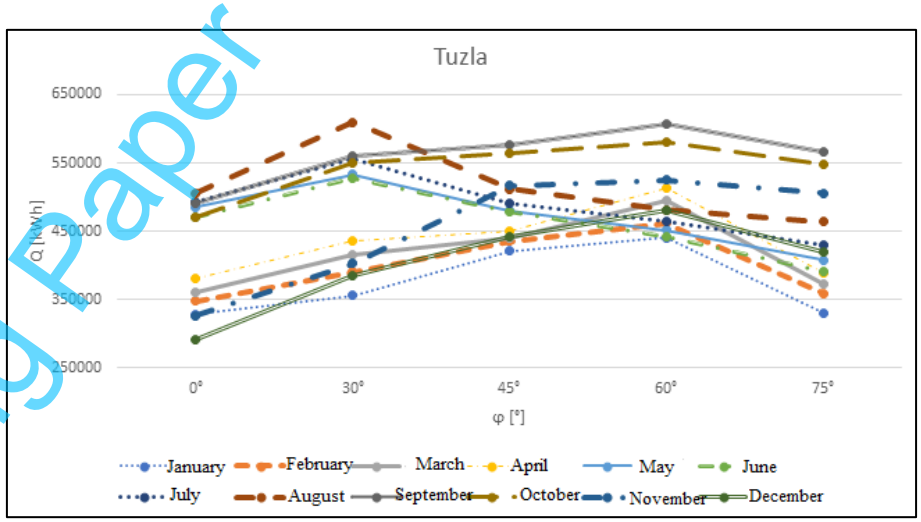

Fig. 5. Thermal energy collected for different tilt angle of collector, for the town of Tuzla.

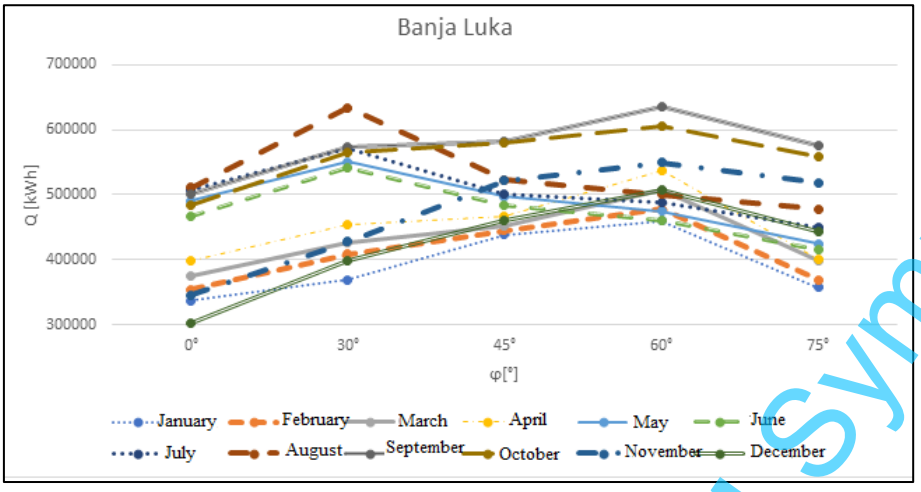

Fig. 6. Thermal energy collected for different tilt angle of collector, for the town of Banja Luka.

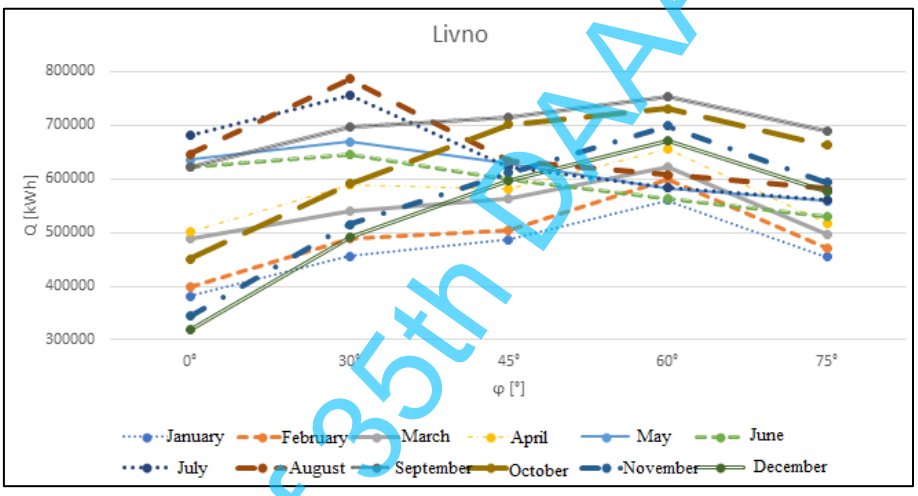

Fig. 7. Thermal energy collected for different tilt angle of collector, for town of Livno.

4. Discussion of the results

Based on the obtained diagrams (Fig. 2, Fig.3, Fig.4, Fig. 5, Fig.6, Fig.7) it is evident that the optimal slope in relation to the horizontal plane depends on the dynamics of the consumption of collected solar energy during the year.

Solar applications that use solar energy in the months: May, June, July and August for the preparation of sanitary hot water in hotels, camps and other tourist facilities, the most of the solar energy can be collected at a tilt angle of collector φ=30°. If we are talking about solar applications that use solar energy in the months: January, February, March, April, September, October, November and December, the most collected solar energy can be achieved at a tilt angle of collector φ=60°.

Maximizing the collected solar energy for the preparation of sanitary hot water in hotels, camps, etc. in Bosnia and Herzegovina throughout the year can be achieved by using the so-called two-position collector tilt, where the collector tilt angle φ for the months: May, June, July and August is 30°, while for the months: January, February, March, April, September, October, November and December, the value of the collector tilt angle is 60°, as already stated.

For the practical application of solar energy, i.e. for designing and optimizing devices for using solar energy, it is necessary, in addition to the value of insolation on a horizontal surface, to know the amount of irradiated energy on inclined and vertical surfaces, as well as the radiation structure - the ratio of diffuse and direct radiation. For most applications, it is most advantageous to orient the solar radiation receivers (collectors) in the south direction, with the deviation from the azimuth angle of the collector ±10° (toward the east or west) slightly reduces the total energy arriving

at the collector plane. Optimizing the slope results in an increase in the total irradiated solar energy, i.e. the influence of the direct component of solar radiation is intensified, while the diffuse component and the component of reflected radiation only add up.

The results of the conducted research show that the most of the solar energy throughout the year per unit of surface, can be obtained if the slope of the surface, facing south, is equal to a tilt angle of 30° to 45°.

5. Conclusion

This work presents the results of research on the optimal tilt angle of solar thermal collectors for various locations in Bosnia and Herzegovina, with a modified thermal efficiency function of the collector. Deviations of the standard instantaneous thermal efficiency function of solar thermal collectors from the efficiency function depending on different tilt angles of the collector relative to the horizontal plane, as presented in studies [13] and [15], range from 7-10%. This directly impacts the conversion of solar radiation into thermal energy and, consequently, the efficiency of the entire solar thermal system. All simulation models incorporate a standard instantaneous thermal efficiency function based on the type of collector and manufacturer, without correction for efficiency depending on the collector's tilt angle, which can lead to calculation discrepancies.

The aim of this study was to modify the existing component of a flat water-cooled solar collector in the TRNSYS software package, specifically the efficiency function for incident solar radiation angles less than and greater than 30°, and to simulate the operation of a simple solar water heating system for domestic hot water preparation for various locations in Bosnia and Herzegovina. The research results show the optimal tilt angles of south-oriented solar collectors relative to the horizontal plane at which maximum solar radiation conversion to thermal energy is achieved for different periods throughout the year.

The following conclusions can be drawn from this work:

- If it is a one-position system, the most solar energy can be collected, if the tilt angle of collector 30° and 45° and the surface of the slope facing south.
- If it is possible for the solar system to be in two positions during the period of use, then the optimal tilt angle of collector in the summer months is 30°, while in the rest of the period it is 60°.
- Optimizing the slope results in an increase in the total radiated solar energy, that is, the influence of the direct component of solar radiation is intensified.

Given that the installation of solar thermal systems depends on the slope and orientation of the roof surface and that, especially in cases of retrofit installations, it is sometimes impossible to achieve the ideal, southern orientation of the collectors, it may be interesting for future research to explore changes in the standard thermal efficiency function of the solar collector with changes in the azimuth angle.

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