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DETERMINATION OF SOLAR ANGLES FOR SUITABLE POSITIONING OF SOLAR SYSTEMS FOR PARTICULAR TIMES OF THE YEAR

Abstract: *By proper positioning of the solar system relative to the sun achieves significantly higher efficiency in their operation and energy production. This paper presents an analysis of solar angles for the development of a mechanism for positioning the solar system - the sun tracking mechanism. The assessment of angles, as well as the range of angles for convenient positioning of the solar panel as an interesting area in the city of Kragujevac, Serbia. The calculation was oriented on values for angles of incidence for the whole year and value for azimutnog angles for December 21st and June 21st. Based on the values of the angles a structural design solution can be derived and ultimately applied in practical use.*
Keywords: *sun-tracking, solar angle, energy efficiency, altitude angle, azimuth angle*

1. INTRODUCTION

Technological developments at the present time allow obtaining and exploitation of energy from renewable sources by using modern methods and systems. Exploitation of renewable energy provides many benefits such as energy efficiency and reduced carbon emissions. Using a system based on renewable energy sources is represented by an energy net zero energy building. The main idea behind these systems is to practice sustainability, eliminating the harmful effects of a parallel increase in beneficial effects.

The energy that is often exploited in practice, and in addition has an important perspective, is solar energy. This includes systems that draw the sun's energy and auxiliary systems which influence the effectiveness and efficiency of solar energy. Increasing attention is focused on systems that are used in solar technology to provide the highest possible utilization of this energy. One of the alternatives is sun tracking system.

Many authors in their research suggested a one-axis sun tracking systems solution [1-6]. By directing attention to the designs and determining the position of the solar panel during the day in order to achieve maximum efficiency. In addition, there have been many tests and experiments, and the results are often compared with fixed mounted solar panels. In addition to the one-axis sun tracking systems, two (double)-axis sun tracking systems are also the subject of intense study [6-8]. Such systems can increase efficiency, but on the other hand increases the complexity of the mechanism design, as well as the costs of production and maintenance.

The basic idea of the research related to sun tracking system is to increase energy efficiency. Authors of numerous studies are trying to determine to what extent it is possible to achieve higher efficiency by applying such systems [1-3, 9-11].

In order for systems that exploit renewable energy to be economically and functionally feasible it is necessary to actively work on their development. The motivation of this paper is to show the benefits provided by the exploitation of solar energy. The application of solar systems with zero net energy buildings has an important role, but it is essential that these systems are cost-effective, practical and applicable as well as increasingly effective. Defining the position needed to set up solar panels to maximize efficiency plays an important role. It is necessary to determine the extent to which efficiency would increase, and whether it is profitable to develop such a sun tracking system. This research is oriented to the territory of the Republic of Serbia with the aim of finding the results which can eventually be acceptable and practically applicable. Specific values in this study are presented for the city of Kragujevac in order to present the possibilities of exploiting solar energy to a greater extent in these areas. The idea of this research is the determination of the range of the angle from which it is possible to develop a sun tracking mechanism that would contribute to efficiency in the exploitation of solar energy.

2. PROBLEM STATEMENT

The energy that can be obtained from renewable sources is an important alternative in the development of net zero energy buildings, and also for the implementation of the established system. The importance of solar energy, in addition to its inexhaustible source reflected in the environmental characteristics, and the exploitation of this energy is an important step in preserving the environment. To make solar energy and the possibility of exploitation where practically acceptable, it is necessary to create systems that are sufficiently efficient and cost-effective. For this purpose there is a need for a higher efficiency of solar systems (PV panels, solar collectors, etc.). One solution is to increase the efficiency of exploitation of solar energy is the sun tracking systems. Solar systems have the highest efficiency at a 90° angle of incidence of solar radiation on the surface of solar collectors or PV panels. Therefore, it is necessary to find a range of incident angles in which it is possible to position the solar system according to which a sun trucking system can be made. Therefore, it is necessary to define the angle depending on the time in respect to which the solar system was set up at an angle of 90°. Authors Jasmin S. and others [11] investigated the optimal angles for fixed installation of solar collectors for the city of Belgrade which greatly simplifies this study.

3. MATHEMATICAL DESCRIPTION

3.1 General description

It was not possible to determine the range of incident angle without first defining the angle of incidence, which has the general equation [12]:

$$\begin{aligned}\cos(\theta) &= \sin(L)\sin(\delta)\cos(\beta)\\ &- \cos(L)\sin(\delta)\sin(\beta)\cos(Z_S)\\ &+ \cos(L)\cos(\delta)\cos(h)\cos(\beta)\\ &+ \sin(L)\cos(\delta)\cos(h)\sin(\beta)\cos(Z_S)\\ &+ \cos(\delta)\sin(h)\sin(\beta)\sin(Z_S)\end{aligned}$$

Where:

L – Latitude of the location,

δ – Declination,

β – Inclination of the horizontal,

Z_S – Azimuth angle,

h - Hour angle.

Some of the values present in the previous equation are presented in Figure 1:

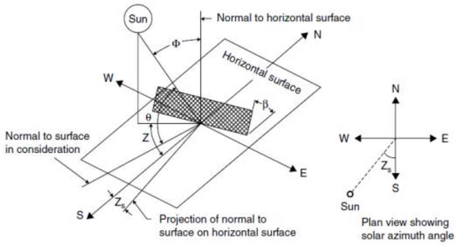

Figure 1. Incidence angle of solar radiation [12]

For horizontal surfaces this expression can be greatly simplified as the inclination of the horizontal *β=0°* and the angle of incidence of solar radiation can be presented as [12]:

$$\sin(\theta) = \sin(L)\sin(\delta) + \cos(L)\cos(\delta)\cos(h)$$

For the previous equation to be calculable, it is necessary to define the hour angle [12]:

$$h = \pm 0{,}25 \cdot \begin{pmatrix} Number\ of\ minutes \\ from\ local\ solar\ noon \end{pmatrix},$$

where the minus sign indicates the morning, while a plus sign indicates the minutes after noon.
Besides the hour angle to complete the equation (2) it is necessary to determine the declination. Declination can be defined as [12]:

$$\delta = 23{,}45 \cdot \sin\left[\frac{360}{365} \cdot (284 + N)\right]$$

where N is the number of the day of the year (0-364 days). Earth's rotational axis is always tilted at an angle of 23.45° to the normal of the revolution plane, which passes through the common point of the rotation axis and the plane of revolution. Change of declination depending on the day of the year is presented in Figure 2.

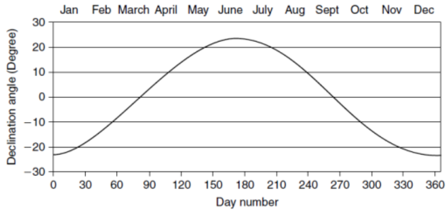

Figure 2. Declination

Previous expressions and descriptions are used for calculating the incident angle of rotation on the east-west axis, which determines the position of the solar panels on certain dates during the year. Based on the values of the incident angle it is simple to define the angle in which the mechanism is to be positioned in the horizontal plane by using the following expression:

$$\beta = 90° - \theta$$

For the sun tracking system to provide daily tracking of the sun it is necessary to calculate the solar azimuth angle. Azimuth angle can be calculated according to the formula [11], as depicted in Figure 1:

$$\sin(z) = \frac{\cos(\delta)\sin(h)}{\cos(\theta)}$$

If the projection of the sun on a horizontal plane behind the east-west azimuth angle in the morning takes the value $-\pi + |z|$, and for the evening, when the azimuth angle crosses the east-west value is $\pi - |z|$. Rotation of the sun tracking system for monitoring azimuth point is made around the north-south axis.

3.2 Modeling values and calculations

For the angles to be determined for practical applications, it is necessary to accurately determine the location of the application of this system in terms of latitude. This research is centered on the city of Kragujevac, whose northern latitude is $L = 44°22'$. It is also necessary to mention that in this study the value of incident angle calculated for subordination - 12 pm, which is to be defined by the hourly angle.

Calculating the azimuth angle is made for the interval from 8am to 4pm. To calculate the azimuth angle, which should be seen during the day it is necessary to determine the day for which it is observed. This study only considers the representative days, 21 December (solstice) – the 344th day and 21 June (Solstice) – the 172th day, because it is based on these values the range and extreme values of the azimuth angle can determined. For these days the interval between 8:00 am to 4:00 pm is observed.

4. RESULTS AND DISCUSSION

Calculating the previous expression and using the defined angle of incidence, θ, values for noon observed throughout the year gets in the range of about 22.3° to 69.23° as illustrated in Figure 3:

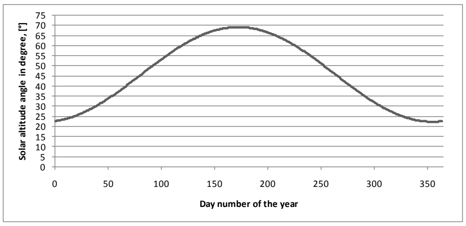

Figure 3. Changing the angle of incidence for the year

In practical terms on a daily basis, incidence angle changes from 0 ° in the morning hours to extremes and again to 0 ° for hours of the evening. According to the developed concept of sun tracking the system should have a change on an annual basis, or more precisely one day the angle of the system is not changing. Based on the angle of incidence, the angle of the sun tracking system in the horizontal plane is in the range of about 20.8 ° to 67.7 ° as illustrated in Figure 4.

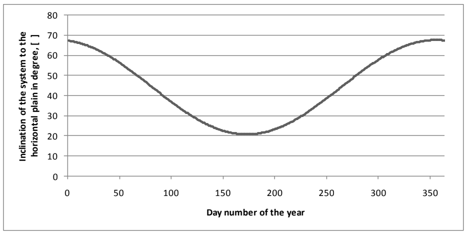

Figure 4. Changing the angle of inclination of sun tracking system in the horizontal plane for a year

By using aforementioned mathematical expressions it is possible to calculate azimuth angle for an exact date of the year. For December 21 and 21 June, the hour interval from 8 am to 4 pm azimuth angle z has values as shown in Figure 5. Sun tracking systems should follow azimuth angles every day. Rotation of the sun tracking system around the north-south axis is also performed, keeping in mind that the solar trackers are oriented to the south. The observed day, 21 December azimuth angle is in the range of about -52.7 ° to 52.7 °, where the angle at 12 am has a value of 0 °. For June 21st the azimuth angle has a value of about -75.2 ° to 75.2 °.

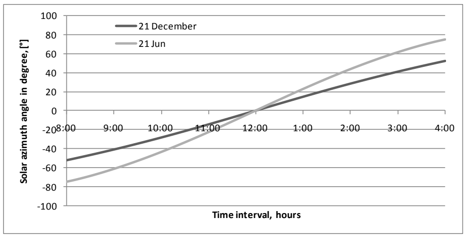

Figure 5. Change azimuth angle of 21 May and 21 June at hourly intervals from 8 am to 4 pm

To analyze the azimuth angle any day can be taken into account, since different selected days have different values within the range of angles presented in Figure 5. Negative angle values are discernible in the morning; at noon the angle is 0°, while after 12 am the angle is positive. Changing the angle of each day is subject to a linear change which simplifies the development of sun tracking system.

5. CONCLUSION

This research is a significant step forward for the implementation of solar tracking and systems of the general area of Kragujevac and Serbia's territory. Analysis of these results is not concentrated in any one-tracking systems, or traditional two tracking systems. This paper presents the idea that the sun follows two independent axes, but independently of each other. This idea arose because of design alternatives sun tracking system that will be economically justified, adjusted for roof installation of solar systems and has a satisfactory efficiency.

Incidence angle, observed for noon on all the days in the year, ranges from a minimum value of about 22.3° to a maximum of 69.23°. The minimum value of the angle is on the 21st of December, on the Solstice and the maximum on June 21st, on the Solstice. The angle of inclination of the solar panel is in the range of about 20.8° to 67.7°. A range that is necessary to provide for the change point in creating a sun tracking system is about 46.9°. The average angle change per day is about 0.26°, which can have a very important role in the continuous tracking of the sun.

Azimuth angle in this study was viewed for the 21st of December. The values of this angle range from about -52.7° to 52.7°. Angle range for tracking the sun for the day is about 105.4° for the period from 8 am to 4 pm. To 12 pm this angle is also 0°. For each day this angle has a different range. The best solution when creating sun tracking system is the optimal value of the change in the angle with which it is possible to linearly follow the sun around the north-south axis. If the sun tracking system developed for solar systems that are mounted on the roof of the building and put south, azimuth angle should be observed for a period when they are not behind the east-west line.

Tracking systems can be developed to monitor the steps (Step tracking), where the angles change takes place in certain periods of the optimum positions. Also, it is possible to develop systems for linear tracking of the sun which is a demanding solution. These modes are approximate solutions for a satisfactory efficiency. In addition there is the possibility of creating a system that follows the sun to its exact position, but the effectiveness of these systems is still not justified. The development of these solutions is a possible direction for further research.

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