Practical Application of An Alternative Solar Position Chart

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Humans, like every other living organism, are dependant on solar energy. If solar energy is to be used consciously, whether directly or stored, there is a need for precise assessment. The bigger the accuracy of the assessment, the greater the benefits of the application of solar energy will be. The simplicity and ease of application of a tool for such predictions would lead to solar energy resources assessment on a large scale. This would result in greater awareness of the potential of the sun energy and application of the solar energy on a larger scale, with all the benefits of using renewable energy resources.

Keywords and phrases: solar position chart, shading reduction, solar energy, solar energy assessment.

Introduction

The portfolio of solar technology has become quite rich throughout history. In ancient civilizations there could be seen examples of passive solar technologies. In 20th century quite a few branches of solar energy application emerged and thanks to the scientific approach they were described in detail. Currently, passive solar technologies are applied as a vehicle for maximizing solar energy gains, or for minimizing cooling loads. Nearly everybody has heard of photovoltaics. There is a great many solar thermal installations. With reference to the last technology mentioned a new record in the world capacity of installations is reached every year (between 2004 and 2009 the worldwide average annual growth rate in installed glazed water collector area was 20.8% [1]). Taking these facts into consideration, one could say that energy transition from fossil fuels to renewable resources is in effect, with increasing usage of solar energy (while global cumulative installed wind capacity in 2009 was 157 899MW [2]).

The visible part of solar energy reaching the Earth surface has a form of either beam or diffused radiation. The diffused fraction can be about 55% of total radiation, on a yearly basis (average value for Warsaw region [3, 7]). Some solar receivers can use both forms of solar radiation, when others can use beam radiation only, e.g. focusing installations. Especially in the latter case, it is crucial to know the availability and the structure of solar radiation.

In the literature there can be found a detailed description of a tool for representing the sun path. The tool in the form of a solar position chart presents apparent position of the sun in the sky. Values of the solar altitude angle are drawn against the solar azimuth angle, (γ_s, α_s) [3–6]. In this paper another kind of solar position chart will be presented, with values of the solar incidence angle drawn against the solar azimuth angle, (γ_s, θ). This chart describes solar energy availability with respect to a surface of any slope and azimuth angle. A comparison of the two charts, (γ_s, α_s) and (γ_s, θ), shows that the latter one gives more information on the sun operation. Short analysis of an example situation will underline some qualities of the proposed chart. A table with periods of the beam radiation availability will be formed as a conclusion of the analysis. At the end of the text one of the Solar Heating and Cooling Programme tasks and its objectives will be referenced.

1. How to learn about solar radiation variability?

Solar radiation reaches the Earth surface as beam and diffused (beam and diffused parts form total solar radiation). Usually the values of monthly average daily total radiation $\overline{H}$ and diffused $\overline{H}_d$ on a horizontal surface are recorded in the form of statistical data $\left(\left[\frac{W}{m^2}\right]\right)$. Thanks to appropriate formula, data for horizontal surface can be transformed for a surface of any orientation. In this paper, however, a tool for precise assessment of the angle of incidence of the incoming solar radiation will be described. Additionally, thanks to the imposing of the shading diagram, the chart presents exposure of the point in question to the solar radiation, whether or not the beam radiation reaches it.

A great many of solar radiation receivers have a fixed location and position, e.g. solar collector, a wall of a building, a window, etc. Thus, not only does intensity of solar radiation vary with time, but its structure changes as well. A solar receiver is affected by the shade cast by objects in its surroundings. To make use of statistical data mentioned it is necessary to know the direction of the beam radiation and how it varies with time at the location in question.

The angle of fundamental meaning for the chart described in this paper, is the angle of incidence of solar radiation θ, that is to say the angle between the beam radiation on a surface and the normal to that surface:

$$\begin{aligned}\cos\theta \quad = \quad & \sin\delta\sin\phi\cos\beta + \\ & -\sin\delta\cos\phi\sin\beta\cos\gamma + \\ & +\cos\delta\cos\phi\cos\beta\cos\omega + \\ & +\cos\delta\sin\phi\sin\beta\cos\gamma\cos\omega + \\ & +\cos\delta\sin\beta\sin\gamma\sin\omega\end{aligned} \tag{1}$$

Eqn. 1: angle of incidence.

The formula for the calculation of the angle value is affected by all factors influencing the sun operation at the point in question, at a certain time, namely by the sun declination δ, the latitude of the location ϕ, tilt of the receiver surface β, the azimuth of the surface γ and the hour angle ω; thus the incidence angle gives the most information on exposure of a point to solar radiation.

The other angle to visualize the variability of the incidence of solar radiation is solar azimuth angle γ_s

$$\gamma_S = \text{signum}(\omega)\left|\arccos\left(\frac{\cos\theta_z\sin\phi - \sin\delta}{\sin\theta_z\cos\phi}\right)\right| \tag{2}$$

Eqn. 2: solar azimuth angle, where zenith angle θ_z is

$$\cos\theta_z = \cos\phi\cos\delta\cos\omega + \sin\phi\sin\delta \tag{3}$$

Eqn. 3: solar zenith angle.

The hour angle ω is the independent variable for the calculations of solar azimuth angle γ_s and the angle of incidence θ; $\omega = 15(\tau - 12^{00})$, [‘]. The result of the calculations in the form of series of values, are plotted as a solar position diagram (Fig. 2).

The beam solar radiation reaches a point on a certain surface provided that there is nothing between the surface and the sun, that is to say no shadow is cast on the receiver. Insolation of the point in question strictly depends not only on cloudiness, but on the surroundings as well. The shade and cloudiness affect the amount of solar energy reaching the receiver and its structure. The atmosphere turbidity affects registered sums of solar energy, but the shading by nearby obstacles must be addressed in the vast majority of solar installations and passive receivers.

Local conditions with respect to objects casting shadows on the receiver can be illustrated in the form of a shading profile. The framework for the profile consists of characteristic points of the objects, e.g. corners of buildings. Values of solar azimuth angle, γ_s, are obtained thanks to application of basic trigonometric calculations. With the calculation of the incidence angle, vector calculus can be applied. After calculations of the angles for characteristic points, series of values for intervening points are obtained to complete the profile.

Example

Drawing the solar position chart for a certain location is illustrated with the following example. Figure 1 consists of a plan of the situation. The point in question (K), for which the chart is plotted, is situated to the north of two buildings casting shadows at it. It was assumed that at point K the surface of interest is facing east at an angle of 45°; this assumption during calculations took the form of a vector N = [−1, 0, 1]. In table 1 characteristic points are listed. Thanks to the pattern described above a solar position chart for the situation could be plotted with shading profile superimposed (Fig. 2). The chart was plotted for the latitude ϕ = 52.11°N, for 12 recommended days of 12 months.

For the convenience of the analysis of the solar position charts, a computer application has been developed. Thanks to the program, alterations of circumstances and conditions description can be made easily. Although this tool is quite simple, an analysis

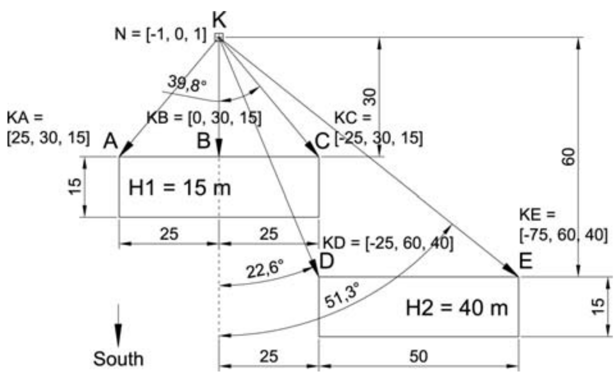

Fig. 1. Example situation.

Table 1. Geometry of obstruction objects for the example.

Object nr	Vertex nr	X	Y	Z
1	1	25	30	15
2	2	0	30	15
3	3	-25	30	15
4	1	-25	60	40
5	2	-75	60	40

of solar exposure of a certain point can be performed quite easily. The analysis show interesting details which influence solar receiver. Figure 2 presents a diagram for the example situation. Another quality of the solution was connected with the programming environment and ease for inclusion test, whether or not a polygon contains a certain point. The excerpt from the results of this test, for October and the location from the example, is presented in table 2.

Complete tables with results present numerical form of the diagram. Value of 88° was chosen as the limit for the angle of incidence θ and the zenith angle θ_z (value of 88° was chosen arbitrary to avoid complications with calculating $R_{b,avg}$ coefficient, since it was not the most important question in this paper); 90° indicates sunrise over the surface and actual sunrise, respectively. Other presented values in the result table were mentioned above. The average ratio of beam radiation on a tilted surface to that on horizontal surface, $R_{b,avg}$, was calculated as described in [4]. New value is the effect of the inclusion test, whether or not a certain point on a curve of the graph was inside the shading profile, that is to say whether the point in question was shaded at certain time.

2. How to apply the knowledge of solar radiation variability?

There is a number of benefits from application of the proposed solar position chart. The first of them is the possibility of estimating solar energy gains. The shading profile on the diagram shows when direct solar radiation

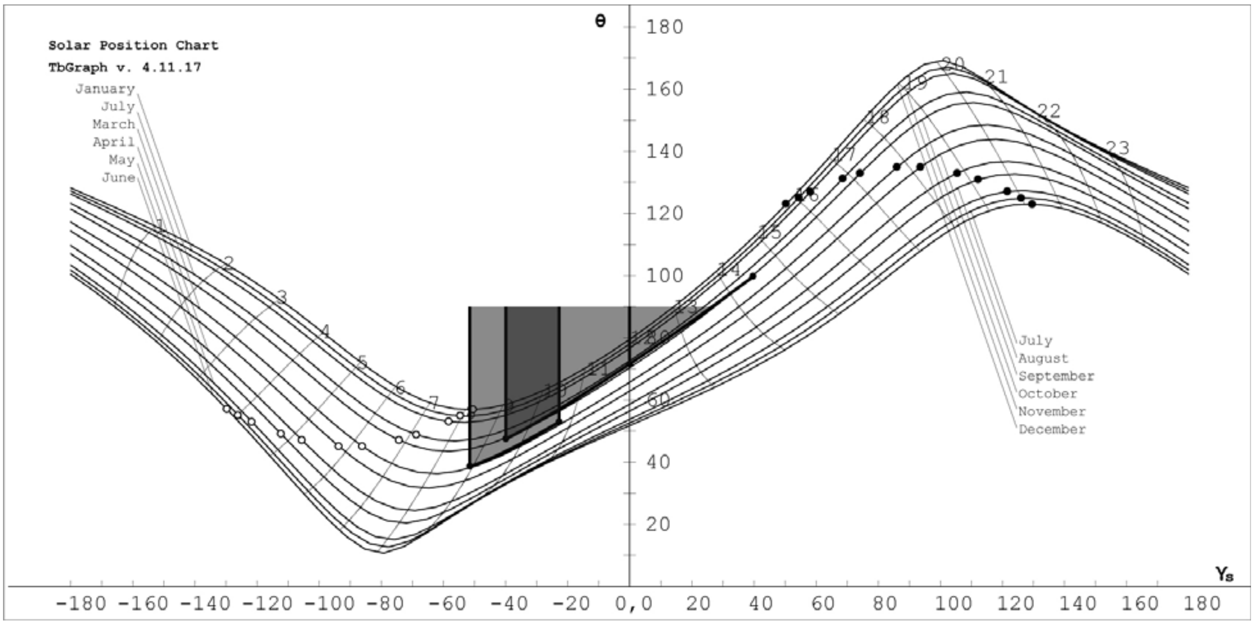

Fig. 2. Solar position chart for the example situation.

Table 2. Excerpt from the table of the results generated by a program drawing solar position charts.

L.p.	τ	ω	γ_s	a	b		Shadow
1	07:19	70.2	68.473	0.044	0.005	9.633	false
…	…	…	…	…	…	…	…
6	8:31	52.2	53.378	0.045	0.015	3.007	false
7	08:45	48.6	50.178	0.045	0.017	2.653	true
…	…	…	…	…	…	…	…
14	10:26	23.4	25,634	0.036	0.027	1.36	true
15	10:40	19.8	21.824	0.034	0.028	1.246	false
…	…	…	…	…	…	…	…
27	13:33	23.4	25.634	0.001	0.027	0.054	false

is available, at the point in question, and how this availability changes during a year and during a day. Curves on the chart, each for specified day of year, present the variability of the angle of incidence of solar radiation, reaching the surface in question, at specified slope and the azimuth angle. Thus, when combined with statistical data on solar radiation, an evaluation of solar energy reaching a point is possible.

Knowledge of the variability of the sun operation allows for alteration of solar energy gains or loads. During conceptual phase of a project of an installation, the location of the receiver can be changed and the results of the change affect the chart. For example, if the surface of the receiver is fixed (that is to say with a fixed azimuth and tilt), the distances from the obstacles in the surroundings can be manipulated to a satisfactory change of the shading profile and thus bigger solar energy gains, or smaller cooling loads. In case of fixed location of the receiver and the obstacles, there might be a chance of getting better effect thanks to alteration of the receiver surface and its slope.

The chart shows periods when energy gains of a collector are biggest. If there is no possibility of changing the location of the receiver, there might be an option of increasing its area. Additionally, the capacity of the energy storage appliance in the system can be increased. As a result, the time interval of intense solar radiation will be exploited or energy will be stored for later use.

If the receiver in question is a passive solar receiver such as a room of a building with a window, solar position charts give insight into when extremal heat gains, or loads, occur. When combined with statistical data on solar energy in the area, predictions of values of gains, or loads, can be obtained.

In the case last mentioned, shading devices used for minimizing cooling loads in the summer are overhangs and wingwalls. During the winter the same overhangs allow for penetration of solar energy, when the sun ascends much lower in the sky and its operation results in a desirable heat gain (the case for bigger values of latitude, e.g. in Poland) [3]. Since the chart is plotted for an object of given azimuth and slope, it presents the variability of solar incidence angle θ with reference to the point in question. Knowledge of the variability of that angle is essential for designing of shading elements matching the needs. Thus solar position chart described in this paper, may assist in the design of overhangs and wingwalls.

Solar position chart gives general idea of the sun operation at specified point, during certain period, such as a year, or a month. When exact numbers are needed, results in the form of a table, as shown in the example, give detailed view into the chart (tab. 2).

Conclusion

Solar position chart described in this paper was the chart with values of solar incidence angle θ drawn against solar azimuth γ_s. Superimposing of the shading diagram on the chart gives the full picture of the exposure of the point in question to solar radiation. This chart allows for predictions of solar energy gains or loads, depending on the object and time.

Each curve on the diagram represents variation of solar incidence angle θ. Value of that angle and value of zenith angle are necessary for calculation of ratio of beam radiation on tilted surface to beam radiation on horizontal surface R_b:

$$R_b = \frac{\cos\theta}{\cos\theta_z} \qquad (4)$$

Eqn. 4: Ratio of solar incidence angle to zenith angle.

This coefficient is necessary for calculation of total solar radiation reaching a surface, according to isotropic diffuse model (derived by Liu and Jordan), and anisotropic sky model (HayDaviesKlucherReindl model). Combining output data of the computer application mentioned, especially in the numerical format, with statistical data, results in predictions of the amount of solar energy reaching a surface.

The idea of presenting the variability of the sun operation when joined with recorded data on solar radiation can lead to predictions of the amount of solar energy reaching a surface. Forecasting of this nature can be essential in case of solarthermal installation and passive receivers. In latter case the tool described in this paper can be useful while designing shading devices, such as overhangs and wingwalls.

Features of the chart mentioned in last paragraphs and its possible application lead to the International Energy Agency and its activities. On official website of the Agency we can read [8]:

The International Energy Agency (IEA) is an autonomous organization which works to ensure reliable, affordable and clean energy for its 28 member countries and beyond.

One of the first programmes of IEA was the Solar Heating and Cooling Programme. Goals of the IEA and SHCP involve "collaboration in the research, development and demonstration of new energy technologies" [9]. These objectives are essential for the transition to renewable energy resources. One of the current task of the SHCP is task 46 "Solar Resource Assessment and Forecasting". Its basic objectives are [10]:

1. evaluation of solar resource variability that impacts large penetrations of solar technologies;
2. standardization and integrating procedures for data bankability;

3. improving procedures for shortterm solar resources forecasting;
4. advanced solar resource modeling procedures based on physical principles.

The chart proposed in this paper, in its simplest form, can be a tool for: basic evaluation of the operation of the sun (1), and basic forecasting of solar resources (3). If farther developed, as an engine of a computer application, for example, coupled with statistical data on solar resources, tailored precisely according to specific needs, even advanced models of solar resources can be constructed (4).

Solar position chart described in this paper, wrapped in a computer application, can be an answer to the task 46 of the SH&CP.

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