COMPUTER PROGRAM FOR THE ANGLES DESCRIBING THE SUN'S APPARENT MOVEMENT IN THE SKY

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Abstract: *The paper presents software developed for the determination of the Sun-Earth geometry. The variation of solar radiation availability at the Earth's surface is easily understood from the geometry of the relative movements of the Earth. By means of a user-friendly interface, the computer program displays in a tabular or graphical manner the angles that describe the Sun's apparent movement in the sky and the radiation received by a horizontal or tilted surface, for a desired period of time and a specific location.*

Key words: *Sun-Earth geometry, climatological parameters, sunchart.*

1. Introduction

The information about the Sun-Earth geometry and how this affects the solar radiation received by a specific site or by a PV panel has a direct usage in the synthesis of discreet tracking computer programs.

Quick accessibility to these types of data facilitates the efforts on designing and developing solar energy systems.

In order to facilitate the processing of such a large number of records needed in the solar systems design, numerous computer programs have been developed.

The software described in this paper has been developed for determining the Sun-Earth geometry, as well as the radiation received by a horizontal or tilted surface and the climatological parameters.

For both professional and amateur solar systems designers, these aspects provide the basis for any solar energy analysis.

2. Computer Program's Objectives

The designed computer program takes into consideration the following objectives [1]:

- it should be used an advanced software, that allows the processing of a large number of records;
- the computer program should display a high degree of generality;
- the computer program's structure should allow of further development;
- solar angles modelling should be achieved for more locations in Romania;
- the computer program should permit both numerical (tabular data presentation) and graphical display;
- the program should calculate the following values: solar angles, tilt angle, solar radiation received by a horizontal or tilted surface, sunchart and climatological parameters such as: Linke turbidity factor, air mass, optical depth for a selected site from the default list or for the site desired, by entering its latitude.

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The proposed computer program uses original procedures developed for database computer modelling.

3. Computer Program's Theoretical Background for the Sun-Earth Geometry

The Sun's apparent movement in the sky is the consequence of the Earth's daily rotation and of the annual revolution movement. The Earth rotates around its polar axis during a solar day and around the Sun on an elliptical orbit during 365.25 days. The angle between the Earth's axis with respect to the elliptical plane remains constant 23.45° during the whole cycle, although the position of the Earth relative to the Sun changes (solstices and equinoxes). This cyclical movement of the Earth around the Sun is the main reason for the annual modification of the Sun's height above the horizon and, thus, for the sunlight quantity and intensity; it also produces the season's variation by controlling the duration and intensity of the sunlight received by the Earth's surface [5].

Therefore, the determination of the Sun's position in the sky is an important step in the design stage of a solar system. The angular position of the Sun, as seen from a particular place on the Earth's surface - the observer's plane - varies from hour to hour and from season to season.

In the observer's plane, the Sun's position is given as an azimuth (θ) and elevation (α) angle. The geometrical relations of the elevation and azimuth are described by the following parameters: the latitude of the site (φ), the day of year (j-Julian day), the time of day by means of solar time (t_s), the declination (δ) and the hour angle (T or ω).

Solar elevation angle is defined between the solar ray and the observer's horizontal plane.

Azimuth angle is defined as the angle between the north-south line and the projection of the solar ray on the horizontal plane of the site taken into consideration [3].

Technical literature in the field offers many geometrical relations for these parameters as well as for elevation and azimuth, but, for objective reasons, the authors worked with the following relations:

$$j' = \frac{2\pi j}{365.25}, \tag{1}$$

$$T = 0.261799(t_s - 12), \tag{2}$$

$$\sin\delta = 0.3978\sin[j' - 1.4 + 0.0355\sin(j' - 0.0489)], \tag{3}$$

$$\sin\alpha = \cos\varphi\cos\delta\cos\omega + \sin\varphi\sin\delta, \tag{4}$$

$$\cos\theta = \frac{\sin\rho\cos\delta\cos\omega - \cos\rho\sin\delta}{\left[(\cos\delta\sin\omega)^2 + (\sin\rho\cos\delta\cos\omega - \cos\rho\sin\delta)^2\right]^{\frac{1}{2}}}. \tag{5}$$

Determining the solar energy availability at any location is essential for the design stage of a solar system. The variation in seasonal solar radiation availability is the consequence of the relative movement of the Earth around the Sun.

The computer program generates the solar radiation using a model based on available climatic data.

Of the staggering amount of energy generated by the Sun, only a small fraction reaches the Earth. Because of the atmosphere content (air, water vapour, aerosols and dust particles), some of the radiation is absorbed, whilst some is scattered. Thus, the global radiation (G) received by the Earth's surface is the sum of direct (B) and diffuse radiations (D):

$$G = D + B \,, \tag{6}$$

$$B = 1367 \cdot \left[1 + 0.3344 \cdot \cos\left(\frac{2\pi j}{365.25 - 0.048869}\right)\right] \cdot \sin\alpha \cdot e^{(-0.8662 \cdot T_L \cdot m_{kast} \cdot \delta_{kast})} \,, \tag{7}$$

$$D = (49.04 \cdot T_L - 42.32)\,(1 - e^{(0.1 \cdot T_L - 0.0908\,\alpha)}) \,, \tag{8}$$

where: T_L - Linke turbidity factor; m_{Kast} - relative optical air mass (by Kasten's formula); δ_{Kast} - optical depth (proposed by Kasten 1980).

Considering the direct solar radiation onto a horizontal plane B, the radiation perpendicular to a surface inclined towards horizon with β angle has the expression [2]:

$$B_\beta = B\frac{\cos\theta}{\cos\alpha} \,, \tag{9}$$

where: α - solar elevation; θ - incidence angle of solar beam, expressed by relation:

$$\cos\theta = \cos(\varphi - \beta)\cos\delta\cos\omega + \\ + \sin(\varphi - \beta)\sin\delta, \tag{10}$$

where: φ - site latitude; δ - declination angle; ω - hour angle.

Considering the diffuse solar radiation onto a horizontal plane D, the diffuse radiation received by a surface arbitrarily inclined D_β is calculated using the following relation:

$$D_\beta = D\frac{1}{2}(1 + \cos\beta) \,, \tag{11}$$

where β is the inclination angle of the panel.

The methodology presented is implemented using Visual FoxPro 9.0, a software which allows the processing of a large data volume. It also allows the interface development using all the object-oriented computer programming tools (buttons, lists, actions implementing etc.) in order to design a user-friendly software.

4. Computer Program Simulation for Braşov Urban Area

Braşov is a medium-sized town situated at 45.39° north latitude and 25.35° east longitude, in a mountain area of the Carpathians arch, at 790 m above sea level.

These details are automatically generated by the computer program - sections 2, 3 and 4, when Braşov is chosen from the default list - section 1 (see Figure 1).

The next step consists in the selection of the time range for which the simulation is desired - section 6.

By clicking button 7, in the output data area - section 16 - the following values will be displayed: the day of year, the declination angle, the hour angle and the altitudinal angle calculated for the time range pre-selected.

In order to find the amount of radiation received by a horizontal surface, the user must select one of the buttons in section 9.

In the output data area - section 16 - all the components of solar radiation are displayed, either tabularly or graphically (see Figure 2).

The amount of solar radiation received by a PV panel can be significantly increased by inclining it towards horizon with a specific angle, and adjusting it throughout a year's time. By selecting the

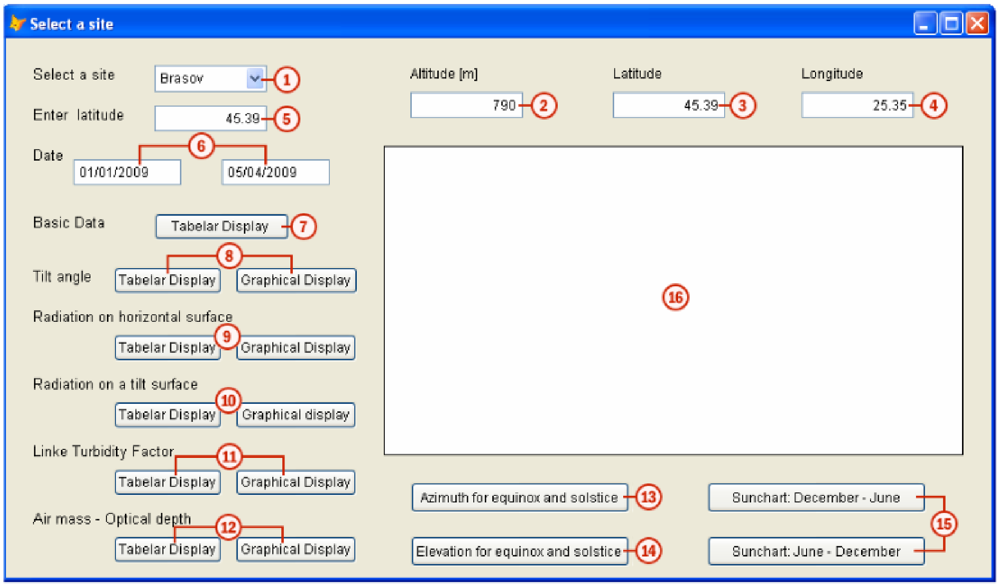
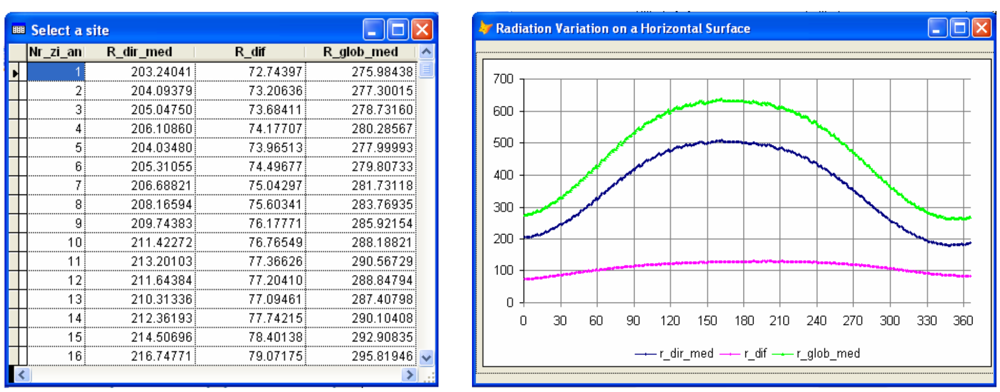


Fig. 1. *Computer program interface and sections*



Nr_zi_an	R_dir_med	R_dif	R_glob_med
1	203.24041	72.74397	275.98438
2	204.09379	73.20636	277.30015
3	205.04750	73.68411	278.73160
4	206.10860	74.17707	280.28567
5	204.03480	73.96513	277.99993
6	205.31055	74.49677	279.80733
7	206.68821	75.04297	281.73118
8	208.16594	75.60341	283.76935
9	209.74383	76.17771	285.92154
10	211.42272	76.76549	288.18821
11	213.20103	77.36626	290.56729
12	211.64384	77.20410	288.84794
13	210.31336	77.09461	287.40798
14	212.36193	77.74215	290.10408
15	214.50696	78.40138	292.90835
16	216.74771	79.07175	295.81946

Fig. 2. *Radiation on a horizontal surface*

buttons in section 8, the user can visualise the tilt angle generated for each day of the time period pre-selected (see Figure 3), as well as the amount of medium solar radiation for a tilted surface - section 10 (see Figure 4).

For a better understanding of how the solar radiation is directly dependent on the elevation angle, section 14 offers a graphical display of solar elevation for the key days of the year (see Figure 5).

The computer program also allows the graphical display of the azimuth angle for equinoxes and solstices (see Figure 6).

In order to do that, it is necessary to select button "Azimuth for equinox and solstice" in section 13.

For a solar system designer, it is very important to be able to identify the Sun's position in the sky at any time of day, thus obtaining a schedule of the hours of sunshine availability.

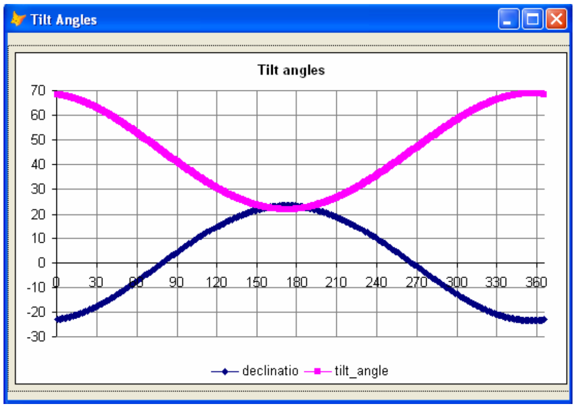


Fig. 3. *Tilt angle*

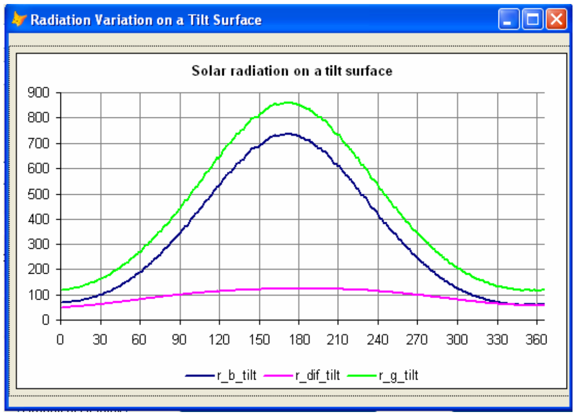


Fig. 4. *Radiation on a tilt surface*

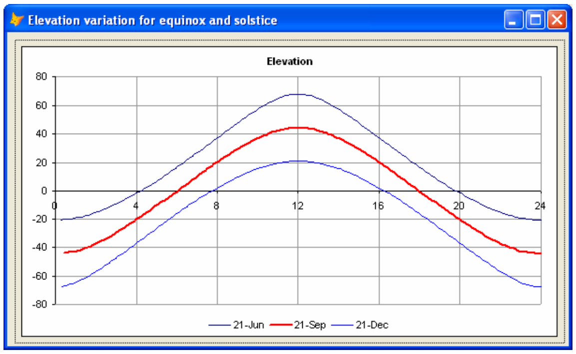


Fig. 5. *Elevation variation for equinoxes and solstices*

Even though the Sun's path changes from day to day and from one latitude to another, the Sun's position can be entirely predictable by means of the sunchart [4].

The sunchart is a basic solar energy designing tool. It maps out the Sun's position in the sky throughout a year, for a particular latitude, relative to elevation and azimuth, allowing for the optimum design of a solar collector. By plotting in Cartesian coordinates the position of the Sun at various times of day and various days of year, a cylindrical sunchart is obtained.

On the x-axis, the Sun's location is plotted in degrees eastwards or westwards to due south for the northern hemisphere or due north for the southern hemisphere, respectively. On the y-axis, the Sun's location above the horizon is plotted, with 0^{o} being on the horizon and 90^{o} being straight overhead.

One can notice that a separate chart has been generated for each half of the year. There are seven slopes, each one corresponding to one day per month, from December 21 to June 21 (Figure 7a) and vice versa (Figure 7b). This interval division has been established between solstices due to the fact that during these events the angles reach the extreme values.

Path curves are connected by solar time curves for sharp hour values, providing time-of-day information.

Suncharts are useful in designing and optimising solar systems, by predicting how obstacles (trees, buildings or geographical obstacles) will affect the amount of sunlight received by a particular location.

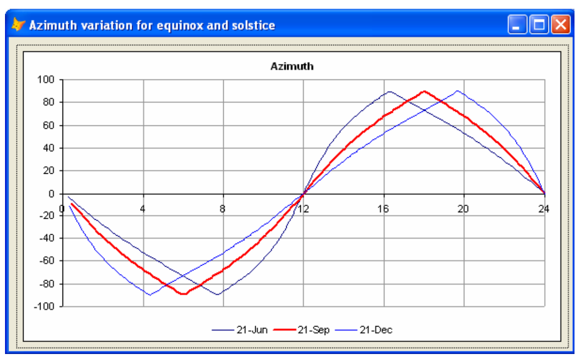


Fig. 6. *Azimuth variation for equinoxes and solstices*

The shadowing effects should be taken into consideration in a mountainous area like Braşov, because radiation values can dramatically decrease, especially when the Sun's position is at low altitudes.

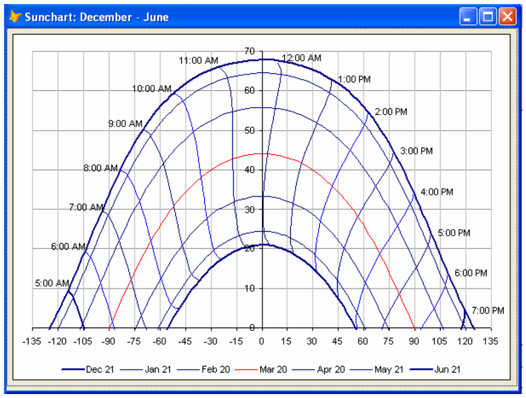
The computer program developed plots suncharts under theoretical conditions, but there can be recurring meteorological conditions (morning fog, marine layers) that will minimise the quantity of solar energy which a site receives. In these situations, it is recommended to shade off the portion of the sunchart up to the approximate solar time, when this condition usually disappears [4].

Reading Braşov's sunchart, several important observations can be made:

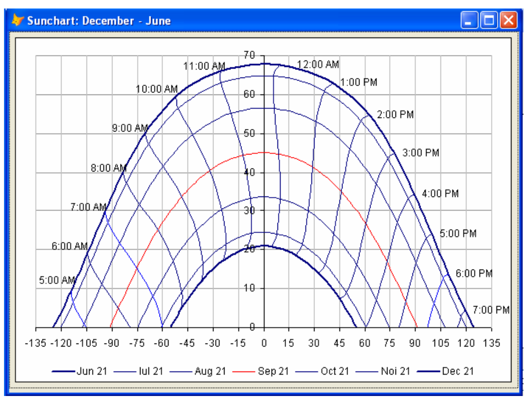
- Time of sunrise. The Sun rises earlier in the summer months and later in the winter months.
- Time of sunset. The Sun sets earlier in the winter months and later in the summer months.
- The time range for a horizontal sundial - sunrise to sunset (the sunshine hours).
- The Sun rises exactly in the east and sets exactly in the west during spring and autumn equinoxes.
- The Sun reaches its zenith at a point due south to the observer (at solar noon).
- The Sun's zenith is closer to the horizon

during winter, and is higher in the sky during summer.

Suncharts can be used to enhance the design efficiency and to optimise the position of solar collectors, PV panels, passive solar homes, green houses and other solar devices.



a)



b)

Fig. 7. *The suncharts for Braşov:*
a) *December - June period; b*) *June - December period*

5. Conclusions

The software developed can be used to determine the angles that describe the Sun's apparent movement in the sky, and to evaluate solar radiation onto horizontal and tilted surfaces in different Romanian cities. The simulations can be made either by selecting a city from the default list, or by introducing the altitude, latitude and longitude of the desired site.

Being equipped with a user-friendly interface, the program is practical and easy to use by both professional and amateur solar systems designers.

Apart from this, the computer program offers quick accessibility to data needed in the design stage of solar systems and allows of further development.

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