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SETTING THE OPTIMUM ANGLE OF SOLAR COLLECTORS SETTLEMENT

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ABSTRACT

The performance of any solar energy system depends very much on the availability of solar radiation and the orientation of solar collectors. Solar collectors need to be inclined at the optimum angle to maximize the receiving energy. In this work, we proposed to analyze the optimum tilt angle for compound parabolic collectors CPC with different concentration ratios. There are analyzed the energy gains when the collector keeps the same position during the whole year and when the collector changes its tilt twice a year, in summer and in winter.

KEYWORDS: solar collectors, CPC, orientation, optimum tilt angle, useful energy gain

1. Introduction

The conversion of renewable energies becomes more important day by day, because of the conventional fuels cost and the environmental pollution. Solar energy is one of these renewable energies which can be converted directly into electricity or into heat. The efficiency of solar collector depends on many factors: design, construction, position, orientation, climatic condition of the place, application for which they are used. The best way to collect maximum solar energy is to optimize the position and orientation of solar collectors.

The factors which affect the value of the optimum tilt angle are [1]:

–the type of application, i.e. stand alone or grid connected;

–maximization the amount of collectable radiation for the whole year or a certain period of time;

–actual climatic condition of the site, regarding snow fall, dust storms or polluted air.

Many papers present optimum tilt angle of the collectors for different locations. Moghadam et al [2], determined the optimum tilt angle for each month of the year, for the first half and the second half of the year and for the whole year. First half, second half and annual optimum tilt β were determined as $\beta=\Phi-23^o$, $\beta=\Phi+23^o$, $\beta=\Phi$, where Φ is the latitude. Shariah et al [3] concluded that for the chosen location, Jordan, the system is operating with sufficiently high solar fraction when the tilt angle is $\beta=\Phi+(0^o\rightarrow10^o)$ for the northern region and $\beta=\Phi+(0^o\rightarrow20^o)$ for the southern region. Skeiker [1] developed an analytical procedure to obtain formulas which require the least number of parameters to determine the angle β for any chosen day, latitude and for any value of the surface azimuth angle. The results of Gunerhan [4] and Elminir [5] suggest that for the systems which utilize solar energy throughout the year, the optimum tilt angle is taken to be equal to the location latitude, while for summer $\beta=\Phi-15^o$ and for winter $\beta=\Phi+15^o$. Yakup [6] concluded that changing the tilt angle 12 times in a year (monthly changing), the solar radiation gain increases by 4.5% more than the case of a horizontal stationary collector (β=0). Also, his studies show an increase of 3.9% of solar energy gain when the tilt angle is changed four times a year (seasonal optimum tilt angle).

Being stationary and producing concentration, the CPC collects solar radiation for a more limited time than flat plate collectors. This time depends on its design (concentration ratio) and orientation. To estimate the absorbed radiation it is necessary to determine the instance at which acceptance of the sun's beam radiation begins and stops for the considered collector [7].

This paper presents one comparison between useful energy gains for CPC for different tilt angles.

There was considered the tilt angle when the collector has the same position during the whole year and when the position of the collector is changed twice for a year (in spring and in autumn). The diffuse radiation and total radiation data values used in this work were taken from „Instituto Nacional de Meteorologia e Geofisica", [8] for the city of Porto, in Portugal. This city is located on latitude 41^o N and longitude 8^o W [8], in northern Portugal.

2. Sun's position

The azimuth angle (γ_s) and the zenith angle (θ_s) are the angles which describe the sun's position (Fig. 1) [9], [10].

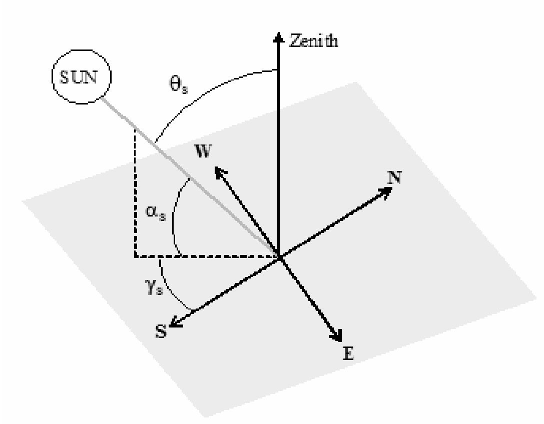

Fig. 1. *Sun's position*

These two angles are defined by the equations (1) and (2):

$$\cos\theta_S = \sin\delta\sin\Phi + \cos\delta\cos\Phi\cosh = \sin\alpha_S \quad (1)$$

$$\cos\gamma_S = \frac{\sin\alpha_S \sin\Phi - \sin\delta}{\cos\alpha_S \cos\Phi} \quad (2)$$

In these equations, Φ is the location latitude, δ is the declination given by equation (3) and h is the hour angle determined by equation (4).

$$\delta = 23.35\sin\frac{360(284+d)}{365} \quad (3)$$

where d is the day of year starting from the first of January:

$$h = -15(12 - hour) \quad (4)$$

The position of the sun can be described by the terrestrial horizon coordinate system, where axis V represents the vertical direction, axis E points the east and axis S points south (Figure 2). In this coordinate system, the unit vector from the earth to the sun can be expressed by [7], [11]:

$$\overline{SUN} = (\cos\sigma\overline{S}\ ,\cos\xi\overline{V}\ ,\cos\pi\overline{E}\ ) \quad (5)$$

where:

$$\cos\sigma = -\sin\delta\cos\Phi + \cos\delta\sin\Phi\cosh \quad (6)$$

$$\cos\xi = \sin\delta\sin\Phi + \cos\delta\cos\Phi\cosh \quad (7)$$

$$\cos\pi = \cos\delta\sinh \quad (8)$$

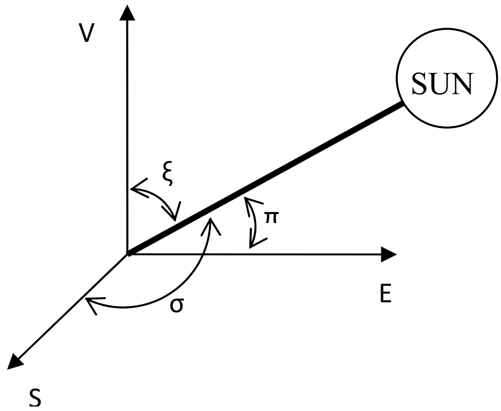

Fig. 2. *Angles for the Sun*

3. Collection angle

The collection angle (θ_c) must be calculated and compared to the acceptance half-angle θ_a (Figure 3), to determine when the CPC is receiving energy from the sun. This angle θ_c represents the angle between sun's position vector and normal to the collector surface projected onto the transverse plane (Fig. 3).

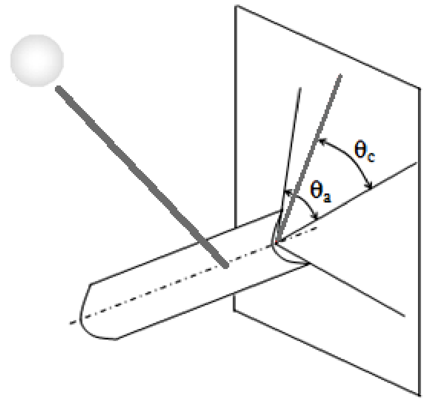

Fig. 3. *Representation of collection angle and acceptance half angle*

The position of a CPC collector is determined by three angles, the tilt β, surface azimuth and rotation ω. When all these angles are zero, the collector is horizontal and oriented east-west.

The tilt angle β represents the tilt of surface with respect to the horizontal.

The azimuth angle γ shows the orientation in relation to the east-west direction.

Therefore, when the azimuth surface angle γ=0^o, the collector is orientated east-west and when γ=90^o, it is orientated north-south. The rotation angle ω is resulting from a rotation around an axis perpendicular to the collector surface.

The collection angle is given by [7]:

$$\theta_c = \operatorname{atan}\frac{S_c}{V_c} \qquad (9)$$

where:

$$S_c = (\cos\omega\cos\beta\cos\gamma - \sin\omega\sin\gamma)\cos\sigma - \\ - (\cos\omega\sin\beta)\cos\xi + (\cos\omega\cos\beta\sin\gamma + \sin\omega\cos\gamma)\ \cos\pi \qquad (10)$$

and:

$$V_c = (\sin\beta\cos\gamma)\cos\sigma + (\cos\beta)\cos\xi + (\sin\beta\sin\gamma)\cos\pi \qquad (11)$$

4. Results and discussions

Table 1 presents the collector tilt optimized for different concentration ratios, for the whole year. The maximum useful energy gain is for a concentration of C=2 and a tilt of 15° less than the latitude of the location.

The results are presented in Table 2, where we can state that the optimal gain for summer is a concentration ratio of C=3 and a tilt of Φ -21, but for winter the optimal is for C=5 and Φ +13.

Table 1. *The optimum tilt angles for different concentration ratio, when γ=0 and ω=0 for entire year*

C (concentration ratio)	**β (tilt angle)**	**Q (useful energy gain)**
		[kWh/m^2]
1	Φ-20	96.431
1.2	Φ -19	95.042
1.5	Φ -18	97.898
1.7	Φ -20	98.556
2	Φ-15	100.89
2.5	Φ -9	99.795
3	Φ -9	91.809
3.5	Φ -18	91.658
4	Φ -16	89.088
4.5	Φ -22	78.928
5	Φ -21	77.676

Table 2. *The optimum tilt angles for different concentration ratio, when γ=0 and ω=0 for summer and winter*

C (concentration ratio)	**β (tilt angle)**	**Q (useful energy gain)**	**β (tilt angle)**	**Q (useful energy gain)**	**Q (useful energy gain)**
		[kWh/m^2]		[kWh/m^2]	
	Summer		Winter		Year
1	Φ -23	86.065	Φ +2	11.91	97.975
1.2	Φ -23	84.258	Φ +2	12.668	96.926
1.5	Φ -23	85.747	Φ +3	14.435	100.182
1.7	Φ -23	87.035	Φ +4	15.686	102.721
2	Φ-23	89.248	Φ +5	17.419	106.667
2.5	Φ -25	91.248	Φ +4	19.771	111.019
3	Φ -21	92.923	Φ +8	21.376	114.299
3.5	Φ -18	91.658	Φ +10	22.522	114.18
4	Φ -16	89.088	Φ +13	23.396	112.484
4.5	Φ -22	78.928	Φ +15	24.089	103.017
5	Φ -21	77.676	Φ +13	24.2	101.876

In Fig. 4 is shown the energy gain when the collector tilt is optimizing for different concentration ratios for the whole year (ω=0, γ=0) compared to the energy gain when the tilt angle is equal by latitude.

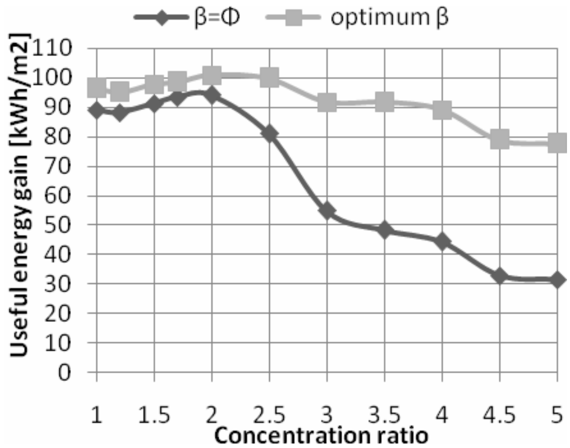

Fig. 4. *Energy gain for the tilt equal by latitude and the optimum tilt*

Another possibility for enhancing the useful energy gain of the whole year is to change the position (tilt) of the south facing collector twice a year, one angle for the summer and another for the winter.

We considered that the tilt angle in changed seasonally twice a year, one time in April and the second time in October. Fig. 5 shows the increase of useful energy gain when the tilt angle is changed twice for a year.

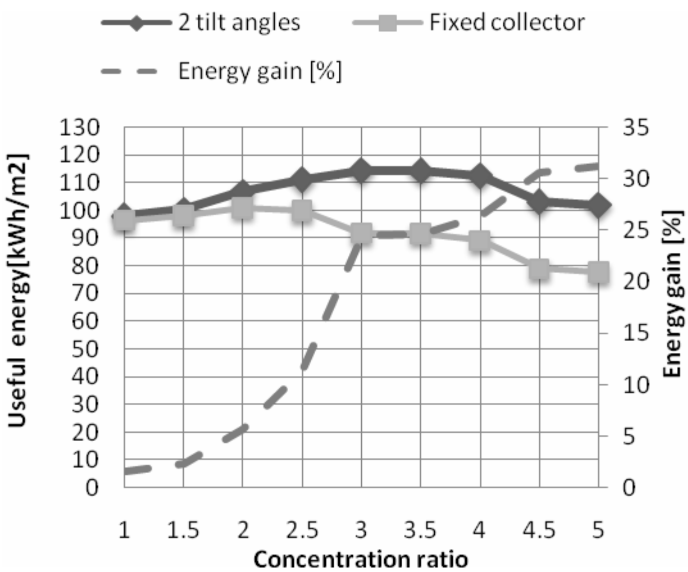

Fig. 5. *The useful energy gain against concentration ratio and collector tilt angle for fixed collectors and changing the tilt angle twice (summer and winter)*

5. Conclusions

In this paper were analyzed the influence of the tilt angle when the collector has the same position during the whole year and when the tilt angle is changed twice for a year (in spring and in autumn).

From this study the following conclusions can be drawn:

1) When the collector tilt is optimizing for different concentration ratios for the whole year (ω=0, γ=0), the result was the same, with the maximum useful energy gain being for a concentration of C=2 and a tilt of 15º less than the latitude of the location.

2) When the tilt angle is changed twice in a year, the useful energy gain increases. The gain is better for concentration ratio up to C=3 and it is more than 23%.

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