Bulletin of the *Transilvania* University of Braşov • Vol. 3 (52) - 2010
Series I: Engineering Sciences

TRACKING EFFICIENCY OPTIMIZATION FOR A SOLAR THERMAL PLATFORM

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Abstract: *Aiming to capture the most of the solar radiation using simple devices, this paper presents the modelling and the optimization of the elevation angles for a solar thermal system considering its tracking efficiency. An elevation tracking device is used, assuming a cloudless sky for the Braşov, Romania geographic area.*

Key words: *direct solar radiation, elevation angle, solar thermal collector, tracking efficiency.*

1. Introduction

As predictions on global warming impact have grown more alarming, EU has accelerated its own policies through a comprehensive climate and renewable energy package designed to reduce carbon dioxide emissions with 20%, by 2020, increase to 20% by 2020 the renewable energy share of the energy mix, and improve energy efficiency by 20% by 2020 [4].

CO_2 emission is one of the most important factors which contributes to the global warming therefore, the use of renewable energies is imperative. Solar Thermal Collectors (STC) represents one successful solution to reduce CO_2 emissions and to further diminish the negative impact on the climate.

The tracking design rests on two main orientation systems through which the sun ray can be described. One is the global system which uses the equatorial plane and the other is the local system which uses the observer's horizontal plane (Figure 1) [1].

Classically, the sun-ray orientation is described in the azimuth framework by angles altitude (α) and the azimuth (ψ); the expressions of these angles were established (see Figure 1), depending on the equatorial sun-ray angles ω and δ, in [1]:

$$\alpha = \arcsin(\cos\varphi \cos\delta \cos\omega + \sin\varphi \sin\delta), \quad (1)$$

$$\psi = (\operatorname{sgn}\omega) \arccos\left(\frac{\sin\varphi \sin\alpha - \sin\delta}{-\cos\alpha \cos\varphi}\right). \quad (2)$$

The homologous tracking angles corresponding to the STC system (versus solar angles α, ψ) are symbolised: α^*, ψ^*.

For the altitudinal angle of the STC system α^* were chosen eight different values from –30° to 45° which were compared to the solar altitudinal angle α computed with formula (1).

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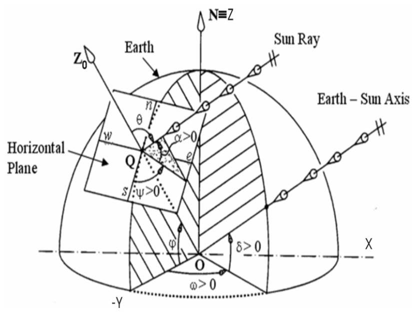


Fig. 1. *Global system* (*OXYZ*) *with solar angles:* δ (*declination*) *and* ω (*hour angle*) *and local system* ($QX_0Y_0Z_0$) *with solar angles:* α (*altitude and* ψ (*azimuth*) [1]

2. Solar Radiation Modelling

Transilvania University of Braşov aims to use renewable energies in the Research Campus; herein STC is an important option. The STC are used to satisfy the domestic hot water and the heating of the working spaces for almost one year needs, excepting the holiday period. Present study has to solve the problem of assuring the necessary STC energy from 1 September to 15 July. So during 16 July to 31 August the system has to deliver null energy.

The objective is to adjust STC's elevation angle α^* as to minimize the incidence angle ν (5) and, consequently, to maximize the absolute orientation efficiency η, for September to July period. Accordingly, in season 4 (Table 1) the solar rays must not fall on the STC surface (the solar incidence angle must be ≥90º), avoid thus the overheating. Therefore, STC is analyzed in two different cases: tilted at 45º, 30º, 15º for the working period and 0º, –15º and –30º for the vacation period.

A seasonal study was accomplished. Therein each season (S1, S2, S3, S4, S6 and S6) is considered through its beginning and ending days. In S3 and S1 the solstice days are considered, also the equinox days in season 2 and 5. The corresponding declination angles are shown in the Table 1.

The estimations were made for three representative days for each season (the extreme days, the equinox and the solstice days), considering different values for the STC altitudinal angle α^*, as in Figure 2.

Seasons' days Table 1

Season	Season days
S1	1 Dec (N=335) to 28 Feb (N=59)
S2	1 Mart (N=60) to 30 Apr (N=120)
S3	1 May (N=121) to 15 Jul (N=196)
S4	16 Jul (N=197) to 31 Aug (N=243)
S5	1 Sep (N=244) to 15 Oct (N=288)
S6	16 Oct (N=289) to 30 Nov (N=334)
	Declination δ
S1	-22.24 to -8.29
S2	-7.91 to 14.90
S3	15.21 to 21.35
S4	21.18 to 7.72
S5	7.34 to -9.97
S6	-10.33 to -22.11

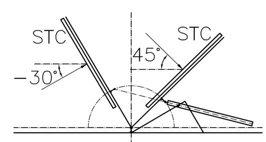


Fig. 2. *STC extreme elevation positions*

According with Figure 1, the sun ray was expressed as a unit vector in the local system ($QX_0Y_0Z_0$):

$$\bar{e}_{sr} = \begin{bmatrix} \cos\alpha \cdot \sin\psi \\ -\cos\alpha \cdot \cos\psi \\ \sin\alpha \end{bmatrix}_{x_0 y_0 z_0} . \quad (3)$$

The normal unit vector on STC absorbing surface has the same expression, but having the solar angles α and ψ replaced by STC angles α^* and ψ^*. Accordingly, the incidence angles, between the sun rays and the normal on STC plane, were determined using relation (4) obtained from (3).

For a mono-axial tracking system, the azimuth angular configuration ψ^* is constantly null ($\psi^* = 0$).

The direct solar radiation is modelled by relation (5) used by M. Meliss [2]:

$$\nu = \arccos[\cos\alpha \cdot \cos\alpha^* \cdot \cos(\psi - \psi^*) + \sin\alpha \cdot \sin\alpha^*], \quad (4)$$

$$B = 1367 \cdot [1 + 0.334 \cdot \cos(0.09856° \cdot N - 2.72°)] \cdot e^{\left(-\frac{T_R}{0.9+9.4 \cdot \sin\alpha}\right)}. \quad (5)$$

In the previous expression, N represents the day number in a year; T_R is the turbidity factor considered for Braşov, Romania equal to 3 [3] and α is the altitudinal angle of the solar ray, expressed in (1).

Using Lambert's law, the STC direct radiation can be obtained by transposing the solar direct radiation vector on the normal of the STC plane:

$$B_{STC} = B \cdot \cos\nu. \quad (6)$$

3. Numerical Simulations

In this section, several comparative analyses are done. After computing B_{STC} for every season, was noticed that the highest values were reached in S3. Therefore this season was chosen to be illustrated as a referential case in Figures 3, 4 and 5 through its beginning, ending and summer solstice days: N = 121, N = 196, N = 173. In Figure 3 are illustrated the variations of the following sizes: altitudinal angle of the solar ray α and of the STC α^*; the STC incidence angle ν; the solar direct radiation B and the direct radiation falling normally on the STC plane B_{STC}, for the first day of the season S3 (N = 121), with solar declination δ = 15.21°, for Braşov latitude φ = 45.65°.

In the Figure 3a can be observed that α is reached for α^* = 45° when solar time is T = 9.15. The case in which α^* = –30° was considered to be the appropriate extreme STC position for the vacation periods (S4) when the STC system is not working.

According to Figure 3b, the incidence angle ν was analyzed in dependence with α^* values. Herein, the lowest ν value is obtained at the noon, for α^* = 45° and it corresponds to the highest value for the direct radiation B_{STC} (Figure 3c).

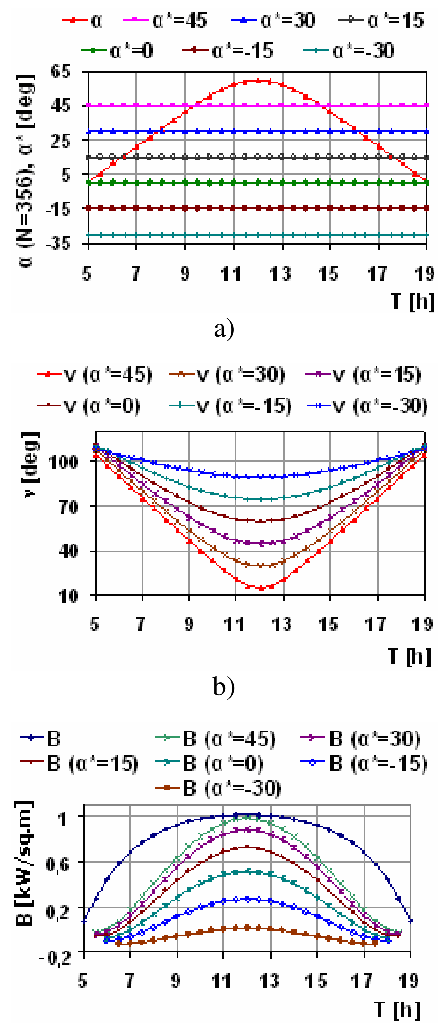
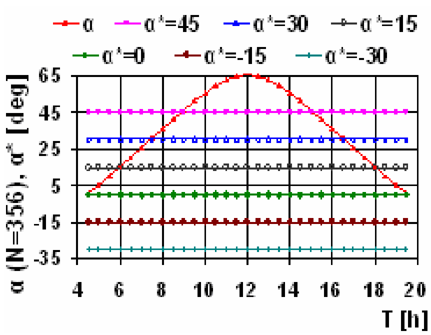


Fig. 3. *Variations of the: a) altitudinal angle of the solar ray* α *and of the STC* α^*; *b) incidence angle* ν; *c) direct radiation B and* B_{STC}, *for* N = 121, δ = 15.21° *and* φ = 45.65°

The highest ν values occurs for $\alpha^* = -30°$, when the B_{STC} is theoretically negative (Figure 3c) and practically null.

In S3, when B_{STC} have the highest values, it can be observed (Figure 3c) that B_{STC} (corresponding to $\alpha^* = 45°$) approaches best the solar direct radiation *B*, as compared to the rest of the seasons.



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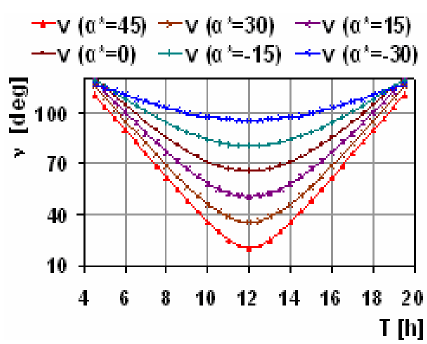

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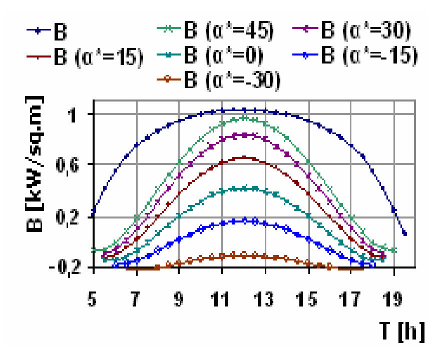

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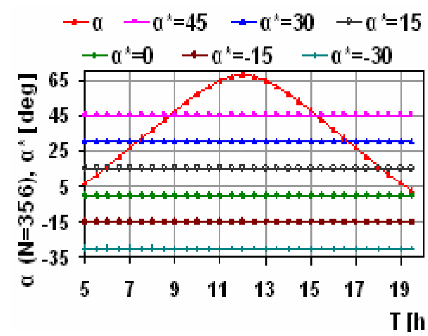
Fig. 4. *Variations of the: a) altitudinal angle of the solar ray* α *and of the STC* α^*; *b) incidence angle* ν; *c) direct radiation B and* B_{STC}*, for N* = 196, δ = 21.35° *and* φ = 45.6°



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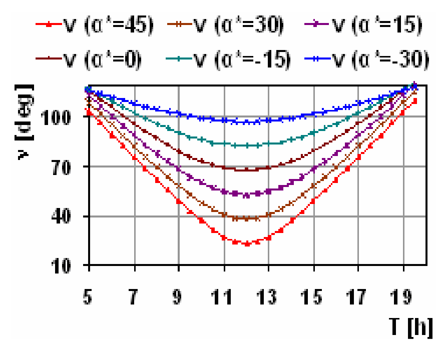

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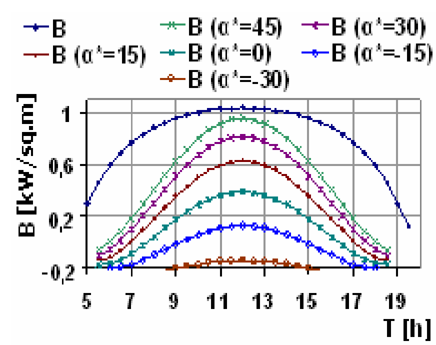

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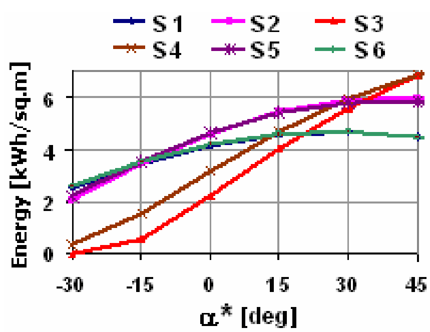
Fig. 5. *Variations of the: a) altitudinal angle of the solar ray* α *and of the STC* α^*; *b) incidence angle* ν; *c) direct radiation B and* B_{STC}*, for N* = 173, δ = 23.4° *and* φ = 45.65°, *corresponding to the summer solstice*

In Figure 4, according to the above mentioned case, the conclusions regarding the B_{STC} and ν are similar.

During the summer solstice, represented in Figure 5, the solar radiation has the highest values in the year. In this case, when $\alpha^* = 45°$ the best values for ν and B_{STC} are accomplished.

Even if the expression (5) leads to negative values for B_{STC}, practically these values are considered null.

Similar studies were made for every season, to obtain the tracking absolute efficiency η of the STC (Figure 6). The tracking efficiency is defined as the ratio between the seasonal energy of the received direct solar radiation falling normally on STC absorbing surface and the seasonal energy of the available direct solar radiation.



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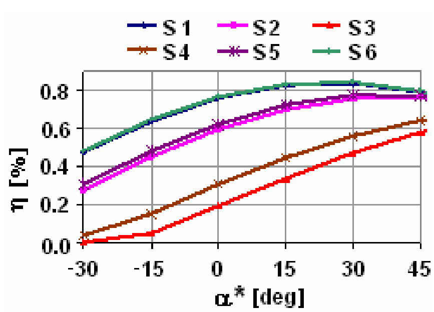
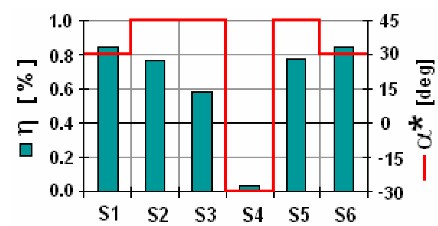


b)

Fig. 6. *Seasonal variations, versus STC elevation angles α^*, of the: a) energy of STC direct radiation; b) tracking absolute efficiency η of the STC*

From Figure 6a and 6b, for seasons S1, S2, S3, S5 and S6, the optimum α^* can be set to α^* for which STC direct received energy is maximum (Figure 6a) and the consequently maximum STC tracking efficiency is accomplished (see Figure 6a and b). Therefore the solutions are: $\alpha^* = 30°$ for S1 an S6, $\alpha^* = 45°$ for S2, S3 and S5. Opposed to these, for the season S4 (when the STC must deliver 0 energy), the optimum value is $\alpha^* = -30°$. These results are graphically illustrated in Figure 7 and shows the following seasonal variations: *a*) the STC



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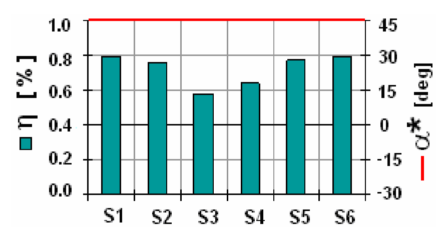

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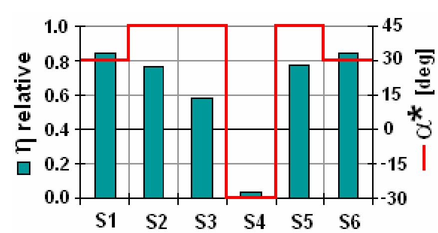

c)

Fig. 7. *Seasonal variations and their corresponding altitude angles α^*: a) maximum tracking absolute efficiency η; b) tracking absolute efficiency η for a fixed STC tilted at 45°; c) tracking relative efficiency as a ratio between the previous two cases*

absolute tracking efficiency when the elevation angle is adjusted at optimal values (Figure 7a); *b*) the STC absolute tracking efficiency when the elevation angle is set to the constant value $\alpha^* = 45°$ (Figure 7b) and *c*) the relative efficiency of the STC when the elevation angle is adjusted at the optimum values versus the same system with $\alpha^* = 45° =$ constant: $\eta_r = \eta$ (optimum adjusted α^*) versus η ($\alpha^* = 45° =$ ct.).

The comparative analysis based on Figures 6 and 7 highlights that the STC system with adjustable elevations angle delivers a reduced energetic gain versus the same fixed system with $\alpha^* = 45° =$ ct.

4. Conclusions

The numerical results obtained by analytical modelling and numerical simulations, to optimise the STC system energetic delivery, according to the in-field demands, lead to the following optimal tracking solutions: a six seasons division of the year (S1, …, S6); $\psi^* = 0°$, $\alpha^* = 45°$ for S2, S3 and S5; $\psi^* = 0°$, $\alpha^* = -30°$ for S4 (when the STC has to give null energy) and $\psi^* = 0°$, $\alpha^* = 30°$ for S6 and S1. Comparing with the same fixed system (with $\alpha^* = 45° =$ constant), the optimal solution brigs a small energetic gain, therefore the adjustable elevation should be used only in season S4 to assure the system safety.

Solar tracking systems allow increased returns on investment [5].

Acknowledgements

This paper is supported by the Sectoral Operational Programme Human Resources Development (SOP HRD), financed from the European Social Fund and by the Romanian Government under the contract number POSDRU/6/1.5/S/6.

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