ANNALS of the ORADEA UNIVERSITY.
Fascicle of Management and Technological Engineering, Volume IX (XIX), 2010, NR4

# STUDY OF THE PV PANELS TRACKING EFFICIENCY FOR BRAŞOV URBAN AREA

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**Keywords:** Direct Solar Energy, Tracking Efficiency, 1 Axis and 2 Axes Orientation PV System

**Abstract:** The information about solar radiation (from the collection and processing meteorological data) are directly usable in the synthesis of the tracking discreet programs for the oriented PV (photovoltaic) panels and the oriented solar thermal collectors.

Referring to Brasov area, the paper proposes a study of the PV panels' solar income considering different inclination angles of these. There are presented comparative diagrams of the real solar income on a horizontal surface and on inclined surfaces and there are calculated the tracking conversion efficiencies.

## 1. INTRODUCTION

Nature offers a variety of options to produce clean energy with minimal cost. In fact one of the main problems is to find an efficient, sustainable and economical method to transform solar, wind, biomass or water energy into electricity, heat.

Energy received from the sun is converted either into electricity through photovoltaic panels (PV) or in heat through solar collectors.

Sustainable potential limits the potential of renewable energy for evaluating ecological and socio-economic factors [3]. Between the theoretical and the conversion potential there is a difference because the conversion rate of solar panels does not exceed 18% of the received solar energy [3]. For the increase of the solar systems efficiency and their performances, are studied in terms of absorbing material, tracking (one or two axes or fixt inclined) and positioning (preferable south facing), but also considering the environmental factors that can influence the amount of received direct solar radiation [2].

For a better understanding of the orientation possibilities of a solar system the paper will analyse the characteristic angles (inclination angle and incidence angle) from a maximization energy point of view.

These angles and the direct solar radiation are input parameters in developing discreet orientation programs for sun trackers (by determining the optimum values for the angles and having a accurate mathematical model for the direct solar radiation).

The data sets used in this study have been recorded with a local weather station Delta-T, positioned on the roof of the *Transilvania* University of Braşov. The data sets have been collected since October 2005 (one registration at 10 minutes) until now and they comprise:

- global solar radiation [W/m2], diffuse solar radiation [W/m2] and sunshine duration with a sensor type BF3 - UM -1.0;
- air temperature [$^0$C], with a sensor type RHT2 - UM -1.0;
- wind speed [m/s], with a sensor type AN4 - UM -1.0;
- wind direction [degrees], with a automatic weathercock;
- relative humidity [%], with a sensor type AT2;
- rainfall [pluviometric mm], with a sensor type RG2-UM-1.1;

In all primary solar systems, solar radiation can be adsorbed by a flat collector, a PV panel or can be concentrated using mirrors and optical lenses. Optimal choice of technology (fix or tracked) depends on energy needs, area and location-specific weather conditions.

## 2. SOLAR ENERGY INCOME SPECIFIC TO BRAŞOV URBAN AREA

The most of times, we record information concerning the solar radiation onto a horizontal surface. However, it is necessary to know the direct and diffuse components of the solar radiation onto the plane of a solar collector or a PV system.

Considering the direct solar radiation onto a horizontal plane B, the radiation, perpendicular to a surface inclined towards horizon at a β angle, has the expression [1]:

$$B_\beta = B \cdot \frac{\cos(\theta)}{\cos(\theta_z)} = R_b \cdot B, \qquad (1)$$

where: θ represents the incidence angle of the solar beam – the angle between the perpendicular and the solar beam direction; for a horizontal surface $\theta_z=\theta$.

For an arbitrarily oriented surface, the functions cos(θ) and cos($\theta_z$) are expressed by the following relations:

$$cos(\theta_z) = cos(\varphi)cos(\delta)cos(\omega) + sin(\varphi)sin(\delta), \qquad (2)$$

$$cos(\theta) = cos(\varphi - \beta)cos(\delta)cos(\omega) + sin(\varphi - \beta)sin(\delta), \qquad (3)$$

where: φ - represents the location latitude; δ - declination angle; ω - hour angle.

From the analysis of equations (1)-(3) it can be observed that in order to maximize the amount of solar energy received by the capturing surface it is necessary to maximize cos(θ) factor, this being the only factor depending on beta. Determination of the optimum inclination angle (β), therefore is possible through the maximisation of this factor.

Figure 1 presents the daily inclination angles obtained for a south oriented fixed surface.

Daily optimum inclination angle has for Braşov area a large variation range ($68^o$ – winter solstice to $22^o$ - summer solstice; $45^o$ for equinoxes when $\delta = 0^o$).

Using these daily values to orientate the considered solar system, the solar radiation onto the capturing surface is increased compared to a horizontal surface; although a continuous daily orientation of the solar system is not preferable from technical, technologic and economic interest point.

Depending on the energy demand, the time period (daily and yearly), environment and climatic conditions that characterises a specific area, several types of solar tracking systems can be used: single axes tracking systems or two axis tracking systems.

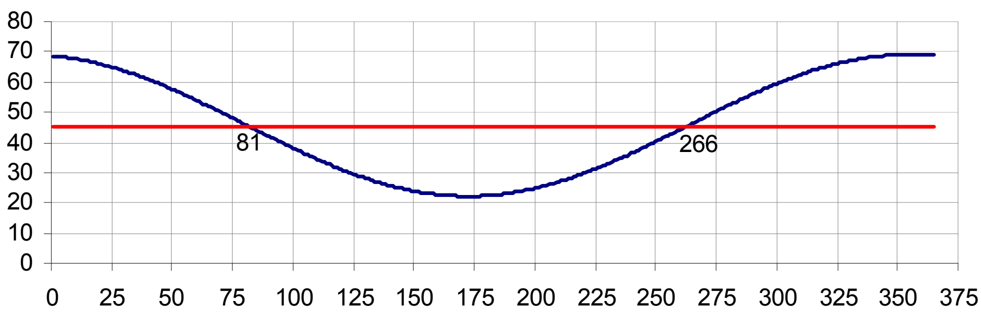


***Fig. 1. Daily optimum inclination angle, specific to Braşov during a year time period***

Figure 2 presents for summer and winter solstice the optimum values for the inclination angle calculated for both one and two axis solar tracker and the value for a constant daily inclination angle. Constraining the solar trackers to realise these optimum calculated values and in clear sky condition the PV panels efficiency will be able to reach it is maximum rate. Figure 3 presents the $R_b$ factor variation during two days of the year (representing summer and winter solstices), for different values of inclination angle; these values are the recommended values for the months of December (68$^o$) and June (22$^o$).

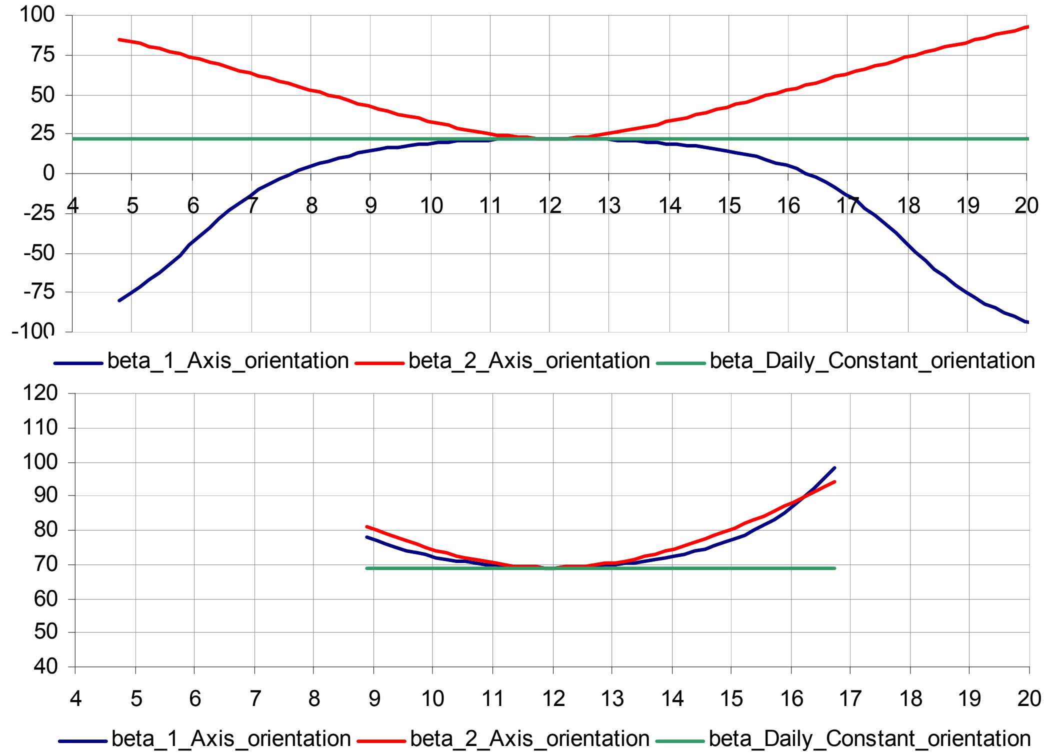


***Fig. 2. Optimum inclination angle characteristic for summer and winter solstice to Braşov***

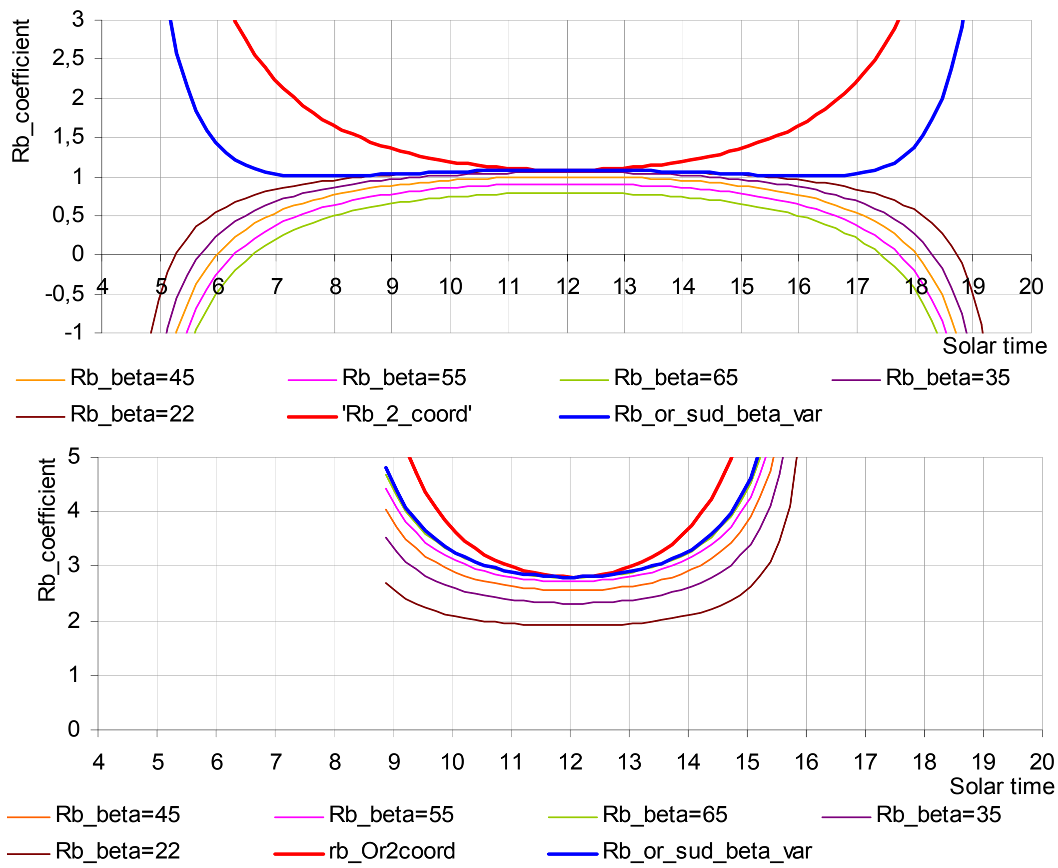


***Fig. 3. $R_b$ factor for different values of the inclination angles for solstice days (21.06 and 21.12)***

$R_b$ coefficient quantifies the influence of the inclination angle over the quantity of solar radiation that an inclined surface can receive at a given time period.

*Table 1. Direct and global energy [kwh/m²] on horizontal surface and different inclination angles*

| 2007 Direct and global solar energy [kwh/m²] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Month | Global solar energy, Inclined surface at: | | | | Month | Direct solar energy, Inclined surface at: | | | |
| | 0° | 45° | 22° | 68° | | 0° | 45° | 22° | 68° |
| Jan. | 30,10 | 46,04 | 40,28 | 45,90 | Jan. | 12,12 | 30,69 | 22,96 | 33,54 |
| Feb. | 45,56 | 61,92 | 56,95 | 59,04 | Feb. | 20,56 | 40,58 | 32,85 | 41,86 |
| Mar. | 90,43 | 108,33 | 105,65 | 97,08 | Mar. | 48,93 | 72,91 | 65,67 | 68,56 |
| Apr. | 128,41 | 128,96 | 136,97 | 104,86 | Apr. | 72,68 | 81,39 | 83,27 | 66,56 |
| May | 147,13 | 132,06 | 148,52 | 99,89 | May | 80,58 | 75,26 | 84,40 | 54,15 |
| June | 145,29 | 124,20 | 143,80 | 89,27 | June | 89,79 | 76,82 | 90,31 | 51,13 |
| July | 179,24 | 158,28 | 180,22 | 116,33 | July | 114,37 | 102,92 | 117,72 | 71,75 |
| Aug. | 123,02 | 118,67 | 128,39 | 94,82 | Aug. | 63,37 | 67,75 | 70,91 | 53,83 |
| Sep. | 91,24 | 106,95 | 105,38 | 94,81 | Sep. | 49,96 | 71,72 | 65,60 | 66,44 |
| Oct. | 60,19 | 81,57 | 75,21 | 77,41 | Oct. | 29,49 | 55,37 | 45,63 | 56,31 |
| Nov. | 29,84 | 43,86 | 38,94 | 43,33 | Nov. | 10,77 | 27,59 | 20,57 | 30,22 |
| Dec. | 20,66 | 30,37 | 26,91 | 30,15 | Dec. | 6,28 | 18,10 | 13,05 | 20,26 |
| 2008 Direct and global solar energy [kwh/m²] | | | | | | | | | |
| Month | Global solar energy, Inclined surface at: | | | | Month | Direct solar energy, Inclined surface at: | | | |
| | 0° | 45° | 22° | 68° | | 0° | 45° | 22° | 68° |
| Jan. | 35,98 | 57,82 | 49,70 | 58,34 | Jan. | 16,09 | 40,84 | 30,53 | 44,66 |
| Feb. | 56,85 | 78,35 | 71,69 | 74,94 | Feb. | 26,81 | 52,71 | 42,74 | 54,30 |
| Mar. | 86,05 | 100,92 | 99,38 | 89,57 | Mar. | 46,34 | 67,03 | 61,12 | 62,28 |
| Apr. | 102,17 | 99,32 | 106,82 | 80,38 | Apr. | 47,41 | 52,58 | 54,05 | 42,74 |
| May | 157,62 | 141,03 | 158,94 | 106,23 | May | 87,95 | 81,56 | 91,80 | 58,34 |
| June | 171,36 | 146,62 | 169,52 | 105,90 | June | 102,21 | 87,59 | 102,88 | 58,37 |
| July | 162,52 | 143,57 | 163,30 | 105,99 | July | 100,06 | 90,25 | 103,10 | 63,05 |
| Aug. | 154,65 | 150,24 | 162,42 | 119,25 | Aug. | 90,80 | 95,74 | 100,89 | 75,37 |
| Sep. | 84,08 | 92,63 | 93,88 | 79,88 | Sep. | 43,75 | 58,21 | 55,02 | 52,16 |
| Oct. | 70,36 | 100,51 | 90,81 | 96,79 | Oct. | 38,26 | 73,11 | 59,87 | 74,73 |
| Nov. | 46,21 | 79,58 | 66,86 | 81,27 | Nov. | 25,82 | 62,17 | 47,21 | 67,25 |
| Dec. | 28,35 | 48,28 | 40,58 | 49,59 | Dec. | 12,21 | 34,51 | 25,03 | 38,51 |
| 2009 Direct and global solar energy [kwh/m²] | | | | | | | | | |
| Month | Global solar energy, Inclined surface at: | | | | Month | Direct solar energy, Inclined surface at: | | | |
| | 0° | 45° | 22° | 68° | | 0° | 45° | 22° | 68° |
| Jan. | 29,27 | 42,23 | 37,76 | 41,52 | Jan. | 10,10 | 25,87 | 19,29 | 28,35 |
| Feb. | 35,55 | 52,81 | 46,84 | 51,90 | Feb. | 16,45 | 36,51 | 28,43 | 38,77 |
| Mar. | 79,26 | 86,59 | 87,73 | 75,43 | Mar. | 32,12 | 46,35 | 42,31 | 43,03 |
| Apr. | 137,82 | 139,94 | 147,89 | 114,38 | Apr. | 79,56 | 90,22 | 91,76 | 74,34 |
| May | 155,00 | 139,96 | 157,08 | 105,80 | May | 89,18 | 83,77 | 93,65 | 60,56 |
| June | 163,96 | 138,86 | 161,43 | 99,50 | June | 97,45 | 82,09 | 97,34 | 53,79 |
| July | 179,33 | 160,13 | 181,31 | 118,56 | July | 115,64 | 105,77 | 119,94 | 74,78 |
| Aug. | 135,92 | 131,31 | 141,95 | 105,04 | Aug. | 69,92 | 74,98 | 78,35 | 59,68 |
| Sep. | 104,68 | 119,52 | 119,17 | 104,74 | Sep. | 56,12 | 78,07 | 72,38 | 71,36 |
| Oct. | 61,97 | 80,88 | 75,71 | 75,84 | Oct. | 28,56 | 52,36 | 43,52 | 52,87 |
| Nov. | 37,55 | 59,91 | 51,64 | 60,31 | Nov. | 16,83 | 42,23 | 31,67 | 46,07 |
| Dec. | 21,50 | 32,75 | 28,65 | 32,79 | Dec. | 7,20 | 20,54 | 14,86 | 22,96 |

Analysing Figure 3 it can be seen that for both days the highest value of the $R_b$ coefficient is obtained for the 2 axes sun tracker; although for a winter day $R_b$ has a value of 3.5, the energy gain is not so high because of the smaller corresponding real direct solar energy.

Mean monthly values of direct and global solar irradiations for three years time period (2007 – 2009) are presented in Table 1, considering four particular values for the inclination angle ($0^o$, $45^o$, $22^o$ and $68^o$). There can be observed the quantitative solar energy received by the capturing surface of a solar system for the same month (same solar potential) but with different beta angles. The highest obtained values for the monthly global and/or direct energy are highlighted with red that makes easier to identify the angles' corresponding value.

For 2009, it can be noticed that for October – February period, a $68^o$ inclination is much more efficient with an energy increase of ≈ 140%; for considered summer period (April - August) a $22^o$ inclination brings an energy increase of ≈ 8% (although the increase rate is smaller that the one corresponding to the cold period it has a higher impact because of the different characteristic values of the real solar radiation on a horizontal surface); a $45^o$ inclination angle increases the energy gain with ≈ 41% for March and September.

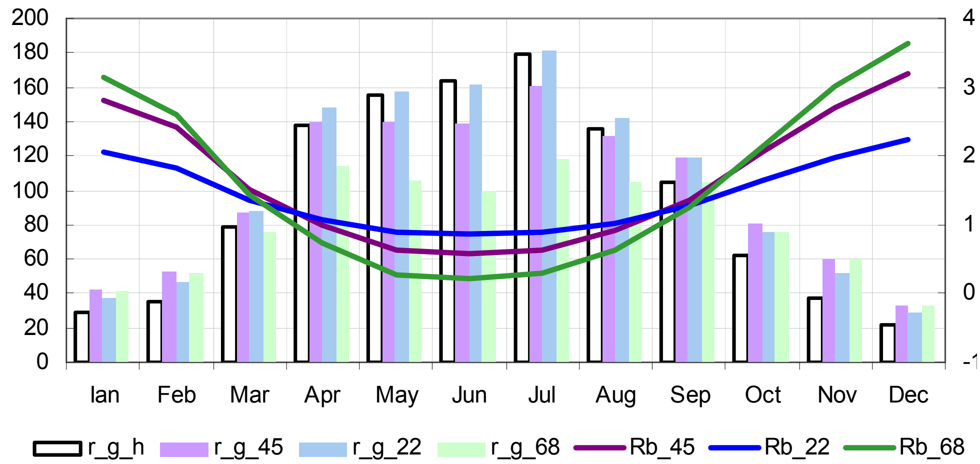


*Fig. 4. Monthly global solar energy income for a horizontal surface and for an inclined surface with specific values of beta angle*

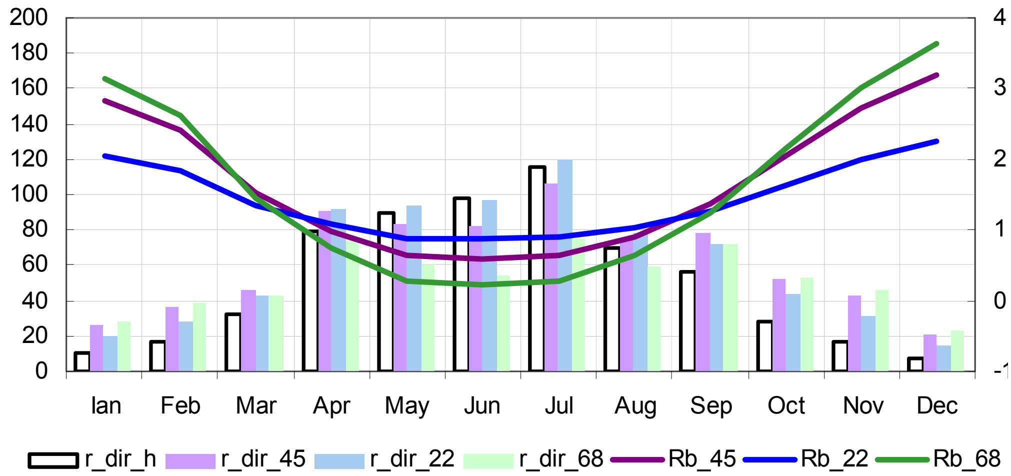


*Fig.5. Monthly direct solar energy income for a horizontal surface and for an inclined surface with specific values of beta angle*

Superimposed diagrams for monthly global and direct solar energy income and the calculated $R_b$ coefficient are presented in Figure 4 and 5.

The following conclusions can be worded based on the analysis of Figure 4 and 5:

- More energy will be collected by the PV or solar collector if these are inclined with the optimum calculated angle specific for the given time period (daily values, Figure 1);
- Although the $R_b$ coefficient has higher values for the cold season the energetic gain is small comparative with the one corresponding to the warm season with a lower coefficient, because of the diffuse solar energy that has a higher rate from the total amount of solar energy specific to that period;
- It can be seen that for the monthly direct solar energy income compared with the quantity received by a horizontal surface the optimum values for the inclination angle are those presented in Table 1.

## 3. CONCLUSIONS

Considering the above presented, the following conclusions can be worded:

- More energy will be collected by the PV if it is installed on a solar tracker (one or two axes), and if the solar collector has an optimum inclination angle;
- The quantity of gained energy due to the tracking system can improve the solar system overall efficiency;
- The solar tracker is giving a higher efficiency to the PV system;
- To increase the energy gain with minimal costs it is recommended to use a monthly oriented solar system;
- After the complete analysis of all three years an increase of energy depending on optimum inclination angles is observed:
    - for a $22^o$ inclination a increase of ≈ 17% is achieved for the global solar energy and ≈ 42% increase for the direct energy;
    - for a $45^o$ inclination a increase of ≈ 20% is achieved for the global solar energy and ≈ 63% increase for the direct energy;
    - for a $68^o$ inclination an increase of ≈ 8% is achieved for the global solar energy and ≈ 58% increase for the direct energy.

## ACKNOWLEDGEMNT

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/ and ID59321.

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