INFLUENCE OF NEBULOSITY ON USE OF SOLAR ENERGY IN LATVIA

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Abstract. Align with others environment – friendly renewable energy sources the solar energy is widely used in the world. Also in Latvia solar collectors are used. However in Latvia often is large nebulosity. Therefore it is important to study influence of the nebulosity on possibility of use of solar energy. There are daily sums of the received hemi-spherical solar energy of two surfaces – fixed, at noon perpendicular to the sun rays, and tracking the sun – in dependence on the nebulosity studied in this article. Data on the nebulosity from State agency "Latvian Environment, geology and meteorology agency" are obtained. Nebulosity has been evaluated in grades five times daily, after ever three hours. Measurements of the received hemi-spherical energy of both fixed and tracking the sun receivers after every 15 min were performed. These measurements have been performed in Riga at 2005 from April 1 till October 31 and at 2006 from March 1 till October 31. Daily sums of received hemi-spherical energy of both fixed and tracking the sun surfaces have been compared with each other and with theoretically calculated clear-day hemi-spherical energy sum for corresponding surface. There was in this period 53, or 12 %, clear days (with nebulosity 0 to 2 grades), 182 (40 %) partly sunny days (nebulosity 3 to 7 grades) and 222 (48 %) overcast (nebulosity greater than 7 grades) days. It has been found out that at medium nebulosity (3 to 7 grades) 60 to 85 % from theoretical energy sum can be received. At fully clear-sky conditions all 100 % from theoretical energy sum can be received, but at fully overcast only 20 %. At all season summary approximately 55 % from theoretical energy sum can be received by both tracking the sun and fixed receivers.

Key words: solar energy, nebulosity.

Introduction

Solar water heating and electricity production systems are used in many countries all over the world, mostly in southern ones, but the use of solar energy is possible also in Latvia [1, 3]. However, in Latvia because of its geographical and climatic conditions are some features in comparison with traditional solar energy using countries. One of them is frequently great nebulosity, which decreases the direct radiation, but increases the diffused one.

Therefore usual constructions of solar energy receivers are not efficient enough in Latvia, and new constructions are required, which would be able to use the diffused radiation more efficiently.

For better elaboration and evaluation of new constructions, also new, more precise, complete and convenient methods for calculation and forecasting of the received energy are required. Such calculations for clear-sky conditions are based on astronomical information. In addition only the diffused radiation, the atmospheric lucidity and the atmospheric mass must be known [2, 5].

More difficult is to forecast the received energy of some surface at cloudy conditions. There are in literature [4] several methods for evaluation of the impact of the nebulosity on beam, diffused and hemi-spherical radiation discussed. However, coefficients used in these calculations depend on local conditions.

The objective of this article is to develop suitable for local conditions of Latvia method for forecasting of the received, taking into account the nebulosity.

Materials and methods

For evaluation of calculations and used coefficients, the calculated energy received by flat tracking the sun surface has been compared with measured one. Measurements of the received energy in Riga from 1 April to 31 October 2005 and from 1 March to 31 October 2006 have been carried out (Fig. 1) Measurements have been done after every 15 minutes. Daily sums of received energy are analyzed.

Data on nebulosity at 2003 to 2007 from Latvia Agency of Environment, Meteorology and Geology have been obtained. Nebulosity evaluated in grades after every three hours, and then calculated mean value of the day.

Solar radiation consists of the beam radiation and diffused one. The diffused radiation can be considered as constant and independent on orientation of the receiving surface at the first approximation. The beam radiation received by some surface can be calculated from the elevation and the azimuth of the sun. On upper border of the atmosphere the incoming solar radiation is considered as constant and equal to solar constant S_0 = 1367 W m^{-2}.

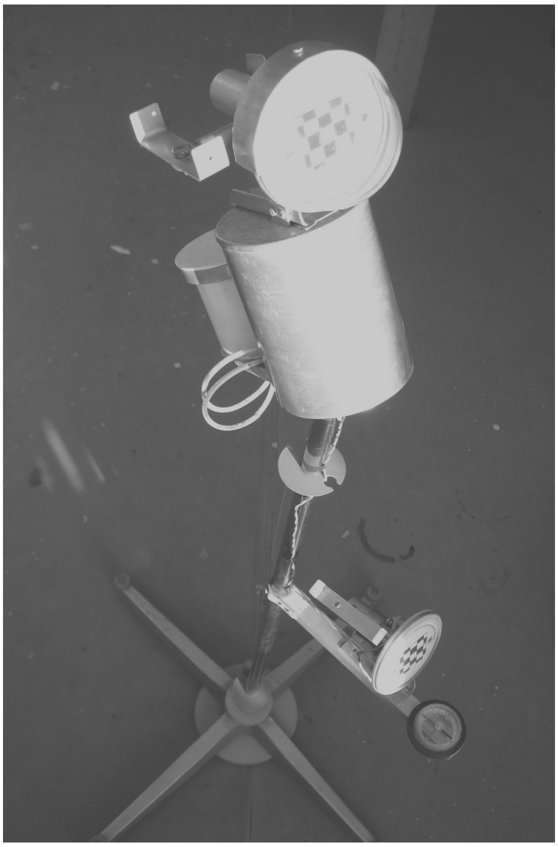

Fig. 1. **Device DM-4 for measuring the solar energy**

At the ground level the direct radiation I_B, received by perpendicular to the sun rays surface, from the well known coherence can be calculated

$$I_B = S_0 \cdot P^m \tag{1}$$

P is the lucidity of the atmosphere and m is the air mass, which depends only on the elevation of the sun and is equal to 1 when sun is at the zenith [5].

In order to find out the lucidity *P* of the atmosphere and the diffused radiation, which both can be considered as constant at the first approximation, the calculated hemi-spherical energy received by flat tracking the sun surface has been compared with measured one. It has been found that at our conditions the lucidity of the atmosphere is 0.78, but the diffused radiation at clear-sky conditions is 150 W m^{-2} [2].

For calculation of the air mass, as well as energy received by any surface not only perpendicular to solar rays, the elevation and the azimuth of the sun are required. Ecliptic coordinates of the sun are β=0 and λ, which changes evenly from 0 at vernal equinox to 360º during year, i.e., 365.25 days. Transforming from ecliptic coordinates to horizontal [6] we obtain the elevation of the sun

$$\sin\alpha = (\cos s \cos\lambda + \sin s \sin\lambda \cos\varepsilon)\cos\varphi + \sin\lambda \sin\varepsilon \sin\varphi\,, \tag{2}$$

where s – sidereal time, deg;
λ – celestial longitude, deg;
ε – longitude of the place, deg;
φ – latitude of the place, deg.

Then the beam energy received by a flat horizontal surface at clear-sky conditions can be calculated

$$I_{BC} = S_0 P^m \sin\alpha \ . \tag{3}$$

The air mass m accordingly to Young (Young, 1994) can be calculated

$$m = \frac{1.002432\cos^2 z_t + 0.148386\cos z_t + 0.0096467}{\cos^3 z_t + 0.149864\cos^2 z_t + 0.0102963\cos z_t + 0.000303978}, \tag{4}$$

where z_t – true zenith angle.

Hemi-spherical energy received by a flat tracking the sun surface at clear-sky conditions, calculated using these formulae and mentioned above values: the atmosphere lucidity 0.78 and the diffused radiation 150 Wm^{-2}, are in good accordance with measured one (Fig. 2).

Here must be taken into account that the calculated energy corresponds to clear-sky conditions, while measured one is real, at cloudy conditions, and therefore measured daily energy sum can be smaller, but not larger than calculated one.

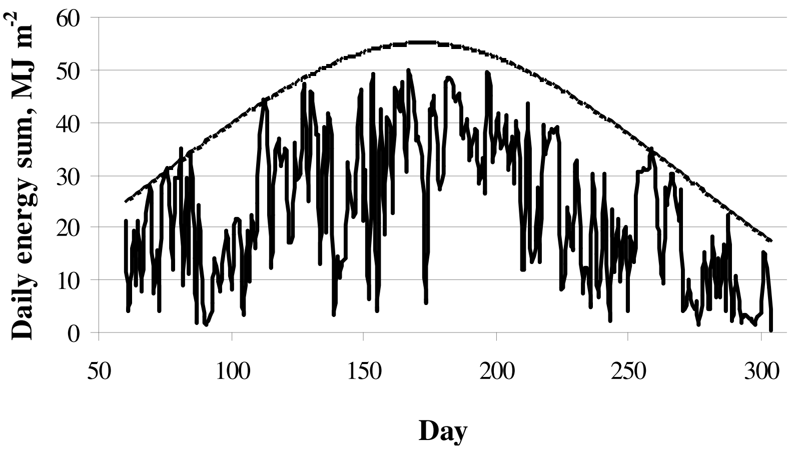

Fig. 2. **Measured (———) and calculated (═══) daily energy sums received by flat tracking the sun surface at 2006**

However in Latvia often is large nebulosity, only 12 % days are with nebulosity less than 3 grades (Fig. 3).

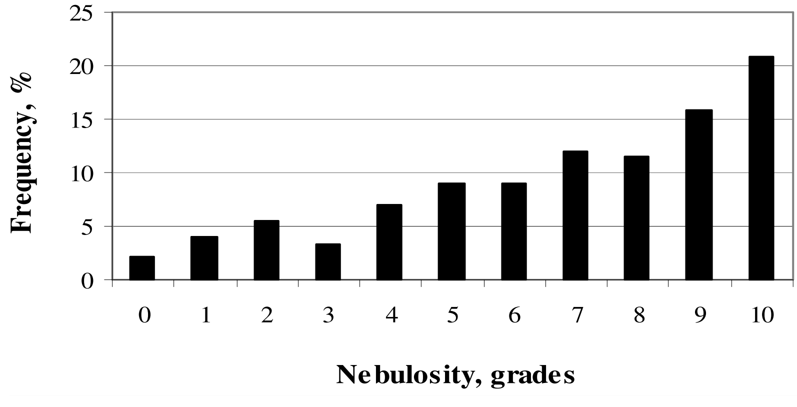

Fig. 3. **Nebulosity at the period of observing**

Therefore dependence of the received energy sum on nebulosity must be studied.

Results and discussion

Dependence of the daily energy sum, measured with tracking the sun flat receiver, on nebulosity is shown in Fig. 4.

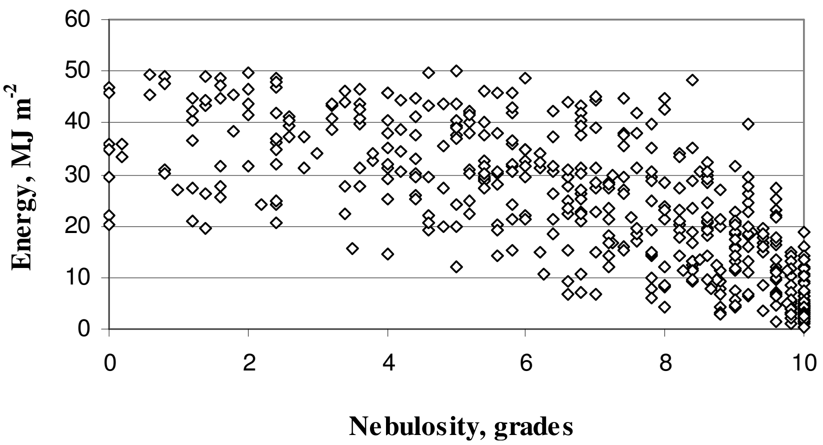

Fig. 4. **Dependence of the daily energy sum (MJ m^{-2}) measured with tracking the sun receiver on the nebulosity (grades)**

It is visible from this plot that data are with large dispersion. This dispersion can be partly due to seasonal changes of the length of the day and the maximal height of the sun. Therefore the daily energy sum can be calculated as percents from maximal possible (at clear-sky conditions) energy sum at the same date (Fig. 5). Also mean value from all energy sums measured at equivalent nebulosity can be considered.

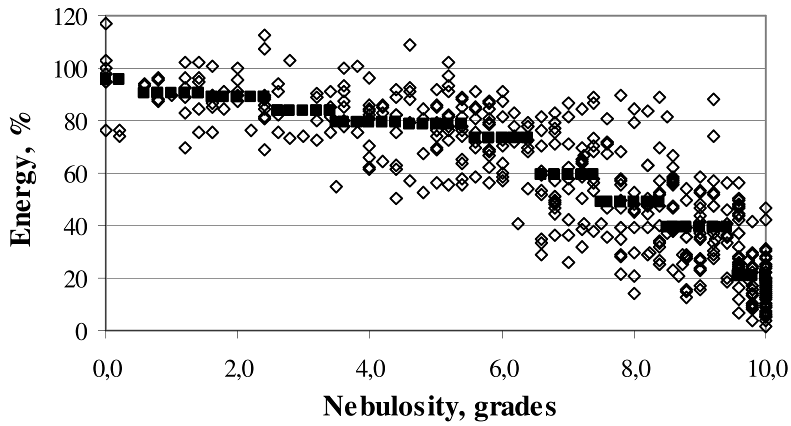

Fig. 5. **Dependence of the measured (◇) and measured mean (■) daily energy sum received by tracking the sun surface, expressed as percentage from maximal possible one, on the nebulosity**

Similar plot is obtained also for the fixed receiver. It can be seen from this plot that at medium nebulosity (3 to 7 grades) 60 to 85 % from theoretical energy sum can be received. At fully clear-sky conditions all 100 % from theoretical energy sum can be received, but at fully overcast only 20 %. At all season summary approximately 55 % from theoretical energy sum can be received by both tracking the sun and fixed receivers. Dependence of the received daily energy sum on nebulosity was searched for at parabolic form. Because largest energy sum corresponds to nebulosity 0 grades (Fig. 5), simplified parabolic model (with coefficient $B = 0$) was used

$$I_G = I_{GC}\left(AM^2 + C\right), \tag{5}$$

where M – nebulosity, grades;
A and C – coefficients.

Accordingly to literature [4], validity of such models can be evaluated from plot calculated energy via measured one. Then the best model is that, which gives slope of the graph nearest to one, intercept nearest to zero, and largest coefficient of determination R^2. These values for mentioned above models are R^2 = 0.74 for real measurements or 0.97 for mean values, slope is 0.74 and intercept 14.7. Comparison of results obtained from this model with measured values is shown at Fig. 6.

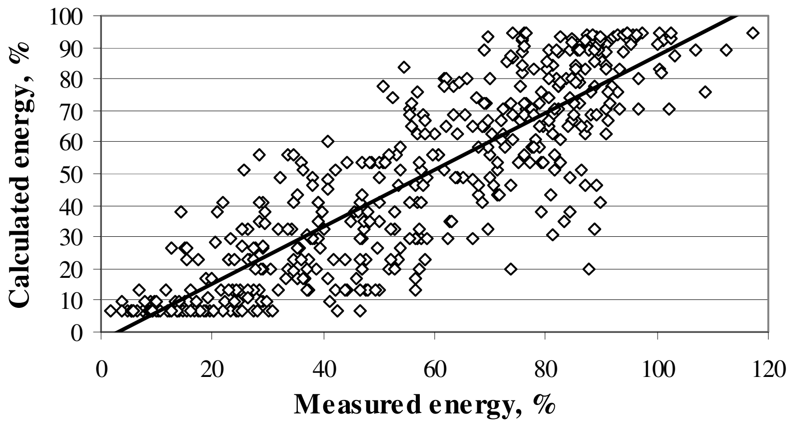

Fig. 6. **Comparison of the calculated daily energy sum received by tracking the sun receiver with measured one, both expressed as percentage from maximal theoretical (clear sky)**

However, in these models the diffuse energy at clear-sky conditions has not been measured, but evaluated from better conformity between calculated and measured daily energy sums (Fig. 2). Furthermore, for calculations of the energy received by receiver of any shape, also curved not only flat, separate calculations of beam and diffuse radiation are necessary. Therefore models are builded up separately for beam radiatiom I_B and diffuse one I_D, and the global radiation is expressed as sum of them

$$I_G = I_B + I_D . \tag{6}$$

The beam radiation has been searched as in formula (8), only coefficients are different

$$I_B = I_{BC}\left(AM^2 + B\right). \tag{7}$$

where I_{BC} – theoretical beam radiation at clear-sky conditions, calculated from (3), W m^{-2};
M – nebulosity, grades;
A, B – coefficients.

The diffuse radiation is prospective to be largest at medium nebulosity, therefore daily sum of diffuse radiation has been searced as

$$I_D = L\left(CM^2 + DM + E\right), \tag{8}$$

where L – lenght of day, s;
M – nebulosity, grades;
C, D, E – coefficients.

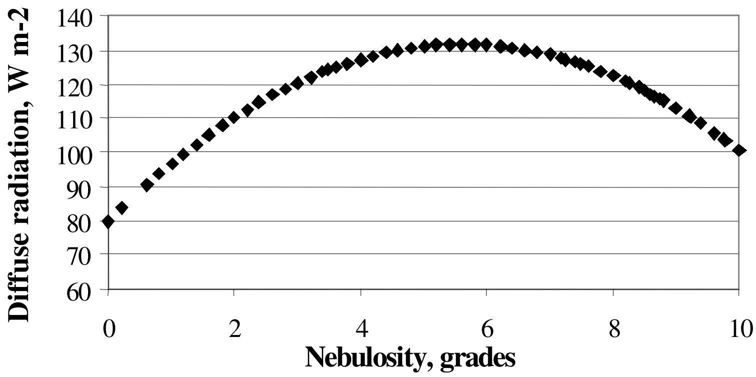

Fig. 7. **Dependence of the calculated diffuse radiation, W m^{-2}, on the nebulosity, grades**

Coefficients A, B, C, D and E has been searched so, that correspondence between calculated energy sum and measured one would be as good as possible. So we found that the diffuse radiation can be expressed as

$$I_D = L\left(-1.63 * M^2 + 18.3 * M + 80\right). \tag{9}$$

This expression gives following dependence of the diffuse radiation on nebulosity (Fig. 5)

The beam radiation can be expressed as

$$I_B = I_{BC}\left(-0.83 * M^2 + 94.6\right). \tag{10}$$

Then the calculated summar energy (Formula 9) shows good correspondece to measured one (Fig. 6). Slope of this plot is 1.01, intercept -0.5, but R^2=0.81 for real measurments with tracking the sun receiver.

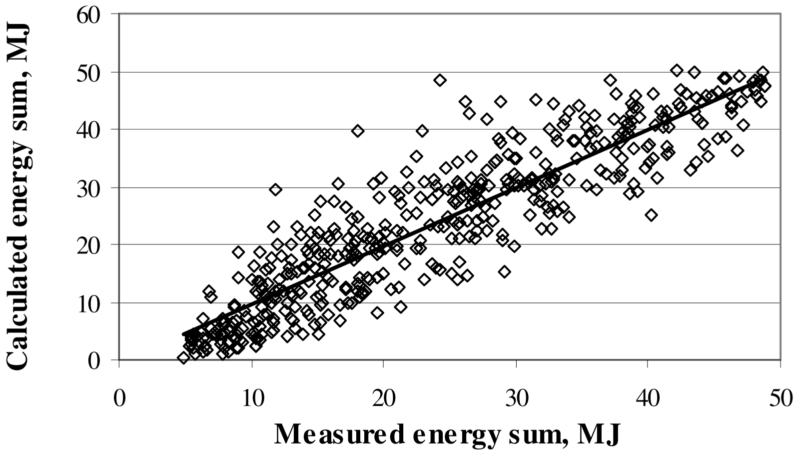

Fig. 8. **Comparison of the calculated daily energy sum received by tracking the sun receiver with measured one, both in MJ**

Conclusions

1. Influence of nebulosity on the received daily energy sum can be expressed separately for the beam radiation and diffuse one.
2. Such model gives good correspondence (R^2 = 0.81) between the calculated energy sum and measured one.

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