MEASUREMENTS AND THEORETICAL CALCULATIONS OF DIFFUSED RADIATION AND ATMOSPHERE LUCIDITY

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Abstract. Align with other environment – friendly renewable energy sources solar energy is widely used in the world. Also in Latvia solar collectors are used. However, in Latvia because of its geographical and climatic conditions there are some specific features in comparison with traditional solar energy using countries. These features lead to the necessity to pay more attention to diffused irradiance. Another factor affecting the received irradiance of any surface is lucidity of atmosphere. This factor has not been not studied in Latvia yet. This article deals with evaluation of diffused irradiance, and also of lucidity of atmosphere. The diffused irradiance can be measured directly or as a difference between the global irradiance and the beam one. The lucidity of atmosphere can be calculated from the measurements of both global and beam irradiance, if the height of the sun is known. Therefore, measurements of both global and beam irradiance have been carried out, and the diffused irradiance calculated as a difference between the global irradiance and the beam one. For measuring of the global irradiance the dome solarimeter has been used. For measuring of the direct irradiance tracking to sun pirheliometer has been used. The measurements were performed in Riga from October 2008 till March 2009. The measurements were executed automatically after every 5 minutes. The obtained results have been analyzed taking into account also the data on nebulosity from the State agency "Latvian Environment, Geology and Meteorology Agency". Also efforts to calculate theoretically the diffused irradiance from the height of the sun and the data of the nebulosity have been done. These calculated values have been compared with the measured ones. Good accordance is obtained.

Keywords: solar energy, diffused radiation, atmosphere lucidity, 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, 2]. However, in Latvia because of its geographical and climatic conditions there are some specific features in comparison with traditional solar energy using countries. One of them is frequently great nebulosity, which influences both direct and diffused irradiance.

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 the new constructions, also new, more precise, complete and convenient methods for calculation and forecasting of the received energy are required. In this article an attempt to forecast the diffused solar radiation has been done. The authors have dealt with this question also in earlier works [3-5]. Now new data have been measured and therefore new more precise formulae have been developed.

Another important value affecting the received solar radiation is lucidity of atmosphere. If the value of the lucidity of atmosphere has been established, the direct solar radiation can be forecasted. This value can be calculated from the direct solar radiation and the height of the sun. Such calculations also have been done in this work.

Matherials and methods

Both the global and the beam solar irradiance were measured from 26 October 2008 till 6 March 2009. The measurements were carried out Riga. The global irradiance was measured using ISO 1 class piranometer CMP 6 from Kipp&Zonen shown in Figure 1.

Measurements of both global and beam radiation were carried out at automatic mode after every 5 minutes. The beam normal solar irradiance (on the surface perpendicular to solar rays) was measured using ISO 1 class pirheliometer from Kipp&Zonen equipped with a tracking device, shown in Figure 2.

Fig. 1. **Pyranometer**

Fig. 2. **Pirheliometer with tracking device**

Data on nebulosity in the period of measurements from the Latvia Agency of Environment, Meteorology and Geology were obtained. Nebulosity was evaluated in grades after every three hours, and then the mean value of the day was calculated.

Calculations were done using the methods stated in [3-8].

The diffused solar irradiance is the difference between the global solar irradiance and the beam solar irradiance on a horizontal surface. The beam solar irradiance on a horizontal surface can be calculated from the beam normal irradiance and the height of the sun

$$I_B = I_{B0} \sin \alpha \tag{1}$$

where I_B – beam solar irradiance on horizontal surface, W m^{-2};
I_{B0} – beam normal solar irradiance, W m^{-2};
α – height of the sun, deg.

.The height of the sun can be calculated using the expression explained in [3-5, 8]

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

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

An attempt to find the dependence of the daily sum of the diffused irradiance on nebulosity and the maximal height of the sun has been made using a graphical method [6], used also in previous works by the authors [3-5]. This method contains a graphical plot of calculated values via measured ones. The validity of the model (formula) under consideration can be evaluated from the slope of linear graph (must be near to one), intercept (must be near to zero), and largest coefficient of determination R^2.

On the other hand, the direct normal irradiance can be expressed with the well known formula

$$I_{D0} = S_0 \cdot P^m \tag{3}$$

where I_{D0} – direct normal solar irradiance, W m^{-2};
S_0 – solar constant, W m^{-2}; S_0 = 1367 W m^{-2}
P – atmosphere lucidity, relative units;
m – atmosphere mass, relative units.

The atmosphere mass can be calculated using the formula given in [7]

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

where z_t – true zenith angle, deg.

If the direct normal solar irradiance is measured, the atmosphere lucidity can be calculated from the formula (3).

Results and discussion

The daily course of solar irradiance is various and depends not only on nebulosity, but also on the kind of clouds. There is the daily course of global (a), beam normal (b) and diffused irradiation on 18 November shown in Fig. 3. The mean nebulosity on this day was 5 grades. It is interesting that approximately at 12:30 when the beam irradiation rapidly decreases obviously due to the clouds the diffused irradiation initially increases and decreases later. It is not a particular case, such course is usual for the diffused irradiance.

However, regardless of the various course of the diffused irradiance its daily sum shows a rather strong dependence on the maximal height of the sun (or length of the day – they are correlated values) and on nebulosity. From analyzing this dependence the following formula for calculation of the daily sum of the diffused radiation can be obtained

$$D = (A\sin^2\alpha + B\sin\alpha + C)\cdot(E\cdot M^2 + F\cdot M + G) \tag{5}$$

where D – daily sum of the diffused irradiance, MJ m^{-2} day^{-1};
α – height of the sun, deg;
M – nebulosity, grades;
A, B, C, E, F, G – coefficients.

From the measurements the values of the coefficients obtained are those shown in Table 1.

Table 1

Values of coefficients in formula (5)

Coefficient	A	B	C	E	F	G
Value	40.628	-8.9819	1.1338	-0.0079	-0.0339	1.7825

The calculated from this formula values of the daily sum of diffused irradiance have been plotted via the measured ones. This plot is shown in Fig. 4. Approximating this dependence with linear graph the slope 1.04±0.12 and intercept 0.053±0.036 have been obtained, and the coefficient of determination R^2=0.87.

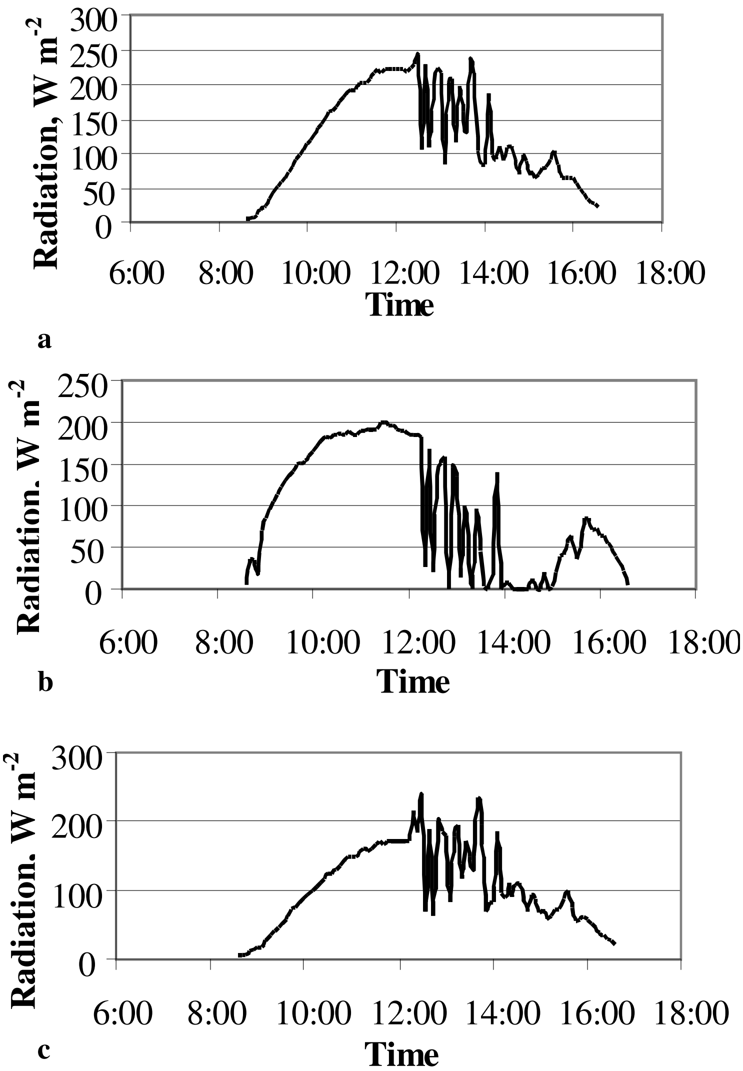

Fig. 3. **Solar irradiance:** a – global, b – beam and c – diffused, on 21 January 2009

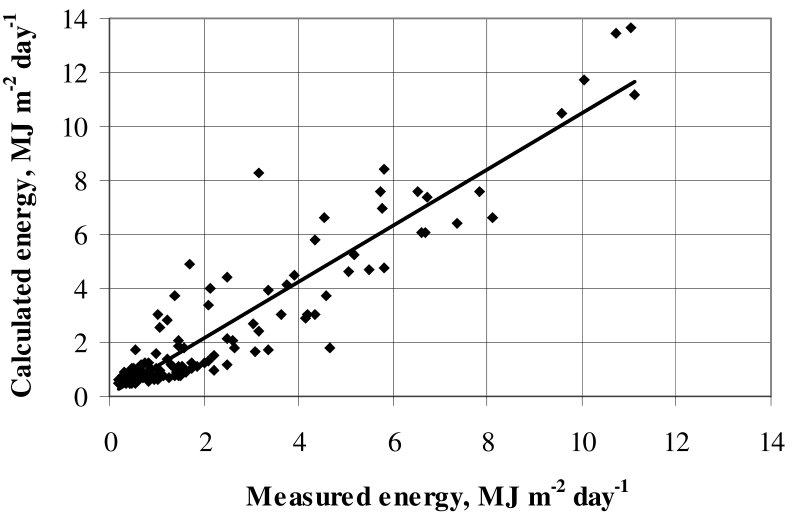

Fig. 4. **Measured and calculated daily sums of diffused energy, MJ m^{-2} day^{-1}**

The atmosphere lucidity has been calculated from the measurements of beam normal irradiance using the formula (3). For example, in Figure 5 the daily course of the atmosphere lucidity on 17 November is shown. It is rather difficult to separate the influence of the atmosphere lucidity from that of the clouds. Largest values can be assumed as atmosphere lucidity, while sharp decreases are related with clouds. If so, the atmosphere lucidity in most cases is between 0.65 and 0.77. However, a larger number of more precise measurements is required.

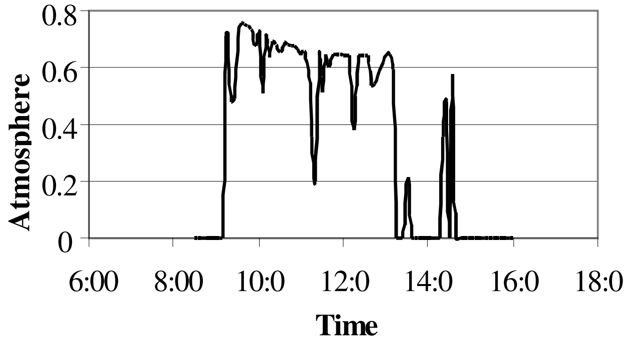

Fig. 5. **Atmosphere lucidity on 17 November 2009**

Conclusions

1. The diffused solar irradiance can be predicted from the maximal height of the sun and nebulosity.
2. Such model gives good accordance (R^2=0.87) with the measurements.
3. The atmosphere lucidity is between 0.65 and 0.77, but additional measurements are required.

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