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EVALUATION OF ATMOSPHERIC LUCIDITY AND DIFFUSED RADIATION

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Based on measurements of the diffused and direct solar radiation intensity, the authors investigate the atmospheric lucidity and its variations that are characteristic of the Latvian conditions. They also consider the dependence of diffused radiation on the nebulosity. In the work it was established that the atmospheric lucidity in Latvia is usually in the range of 0.77±0.05, with only minor changes, so in the calculations it was assumed constant. The diffused solar radiation intensity was found to increase under medium nebulosity and to decrease at high its level. Since this dependence is also influenced by the type of clouds, for more precise calculations further research is needed.

Key words: *solar energy, direct radiation, diffused radiation, atmospheric lucidity, nebulosity.*

1. INTRODUCTION

Ever increasing use of solar energy worldwide has given rise to the interest in this energy also in Latvia. Nowadays, proofs have been obtained that solar energy can successfully be harnessed in Latvia [1, 2] despite its disadvantageous geographical and climatic conditions [3, 4]. These specific conditions are: low altitude of the Sun and a comparatively small maximal intensity of the solar radiation, as well as frequently occurring nebulosity. On the other hand, our advantage here in Latvia is long days in summer (and, hence, also a long path of the Sun). This means that the conventional flat plate solar collectors are useless under the local conditions. Therefore, new designs of solar collectors and solar cells are required [3, 4].

In order to develop such new designs also new simple methods are needed for calculations of the solar energy received by a definite surface. To perform them it is necessary to know the values of atmospheric lucidity and diffused solar radiation [3, 4].

The global solar radiation (the total solar radiation received by flat horizontal surfaces) consists of the direct solar radiation (called also the beam solar radiation) and the diffused one.

The intensity of the direct radiation received by a surface perpendicular to the solar rays can be expressed as

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

where I_B – intensity of direct radiation, W·m^{-2};
S_0 – solar constant (S_0 = 1367 W·m^{-2});
P – atmospheric lucidity, r.u.;
m – air mass, r.u.

To calculate the intensity of the direct radiation received by a horizontal surface we will use the following formula:

$$I_B = S_0 P^m \sin\delta , \tag{2}$$

where δ is the altitude of the Sun, degrees.

The air mass m characterizes the thickness of the air layer in the path of solar rays taking into account also the mean distribution of air density and the curvature of rays due to changes in the air density; its value depends only on the altitude of the Sun and can be derived from the empirical formula given in work [5].

The lucidity of the atmosphere characterizes the attenuation of solar ray intensity per unit of air mass. This value cannot be calculated theoretically, therefore relevant measurements are required.

The diffused solar radiation depends mainly on the altitude of the Sun and on the amount and type of clouds (in simplified calculations the nebulosity in grades can be employed). In work [6], efforts have been made to develop a formula for calculating the influence of nebulosity on the diffused radiation. The results confirm that the diffused radiation increases at medium nebulosity and decreases at large nebulosity. At the same time, it also depends on the type of clouds. For more precise evaluation special measurements are needed.

2. MATERIALS AND METHODS

Measurements of the global solar radiation as well as of the direct one have been carried out at the Institute of Physical Energetics (Riga). The direct solar radiation was measured using an ISO 1 class pyrheliometer (Kipp&Zonen) equipped with a tracking device. In turn, the global radiation was determined with an ISO 1 class piranometer CMP 6 (also provided by Kipp&Zonen).

The measurements were taken from 15 June to 30 August 2009, with automatic data collection every 6 minutes.

After that, the atmospheric lucidity, taking into account Eqs. (1) and (2), was calculated by the following formula:

$$P = \left(\frac{I_B}{S_0} \right)^{\frac{1}{m}} . \tag{3}$$

Since the atmospheric lucidity relates to direct radiation only and characterizes the atmosphere but not clouds, it can be evaluated only when there are no clouds in the path of this radiation. This means that only the largest values of everyday atmospheric lucidity should be taken into account, except for fully overcast days.

The intensity of the diffused radiation can be calculated as

$$I_D = I_{Gmeas} - I_{Bmeas} \sin\delta , \tag{4}$$

where I_D – intensity of diffused radiation, $W{\cdot}m^{-2}$;
I_{Gmeas} – measured intensity of the global solar radiation, $W{\cdot}m^{-2}$;
I_{Bmeas} – measured intensity of the beam radiation on a surface perpendicular to solar rays, $W{\cdot}m^{-2}$;

Since considerable nebulosity is observed in Latvia quite often, it is important to know its influence on the diffused radiation*. Another − more precise − way to evaluate nebulosity is to measure the direct radiation. Then the nebulosity on the same ten grade scale can be calculated as

$$M = \left(1 - \frac{E_B}{E_{BT}}\right) \cdot 10 , \tag{5}$$

where M – nebulosity, grades;
E_B – measured daily total of the beam radiation, $MJ{\cdot}m^{-2}{\cdot}day^{-1}$;
E_{BT} – theoretically calculated daily total of the beam radiation, $MJ{\cdot}m^{-2}{\cdot}day^{-1}$.

This method gives more precise results of solar radiation, since it takes into account also the cloud position – do they cover the Sun or not. The method does not give momentary values of nebulosity; it characterizes only spots in the sky where the Sun could be seen, and is usable all day long.

The daily total of solar energy is obtained by numerical integration of the direct radiation intensities (both measured and calculated):

$$E = \sum I \Delta t , \tag{6}$$

where E – daily total of solar energy, $MJ{\cdot}m^{-2}{\cdot}day^{-1}$;
I – intensity of radiation (measured or calculated), $W{\cdot}m^{-2}$;
Δt – time interval between two measurements, s.

The integration (summation) should be done from sunrise to sunset.

The theoretical intensity of direct radiation is calculated using formulae (4) and (6):

$$I_{BT} = S_0 P^m \sin\delta . \tag{7}$$

Since in this formula the atmospheric lucidity is employed, the first step is to evaluate this parameter, and only after that its theoretical value and the nebulosity can be calculated.

* the relevant data are available from the Latvian Centre of Environment, Geology and Meteorology, where 22 meteorological stations evaluate the nebulosity visually on the ten-grade scale every 3 hours.

3. RESULTS AND DISCUSSION

The atmospheric lucidity was calculated by Eq. (3), using the data of all measurements. Its characteristic values in sunny days are shown in Fig. 1.

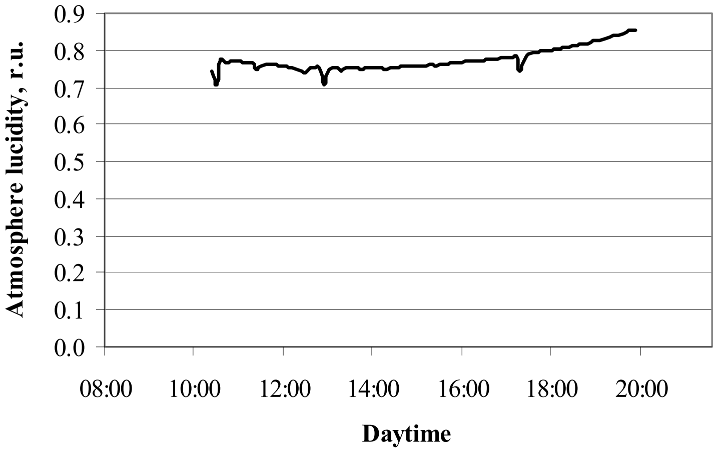

Fig. 1. Time dependence of atmospheric lucidity in a sunny day (20 August 2009).

It is interesting that in the middle of a day the atmosphere is less transparent than in the morning and evening, which however does not mean that we can then receive more solar energy. Anyway, the intensity of solar radiation in the morning (evening) is considerably lower due to larger air masses. At a summer noon these masses are approx. 1.2 r.u., at 7 a.m. − 2.5 r.u., while near the sunset they reach 28 r.u.

As mentioned above, the actual value of atmospheric lucidity is larger than that in the midday, since this value is defined for air and not for clouds. The variations in the atmospheric lucidity with daytime (in the morning) are shown in Fig. 2. Its value found from measurements is 0.77±0.05 r.u. (in calculations the root mean square error was used). If the required precision is not very high, the lucidity can be assumed constant.

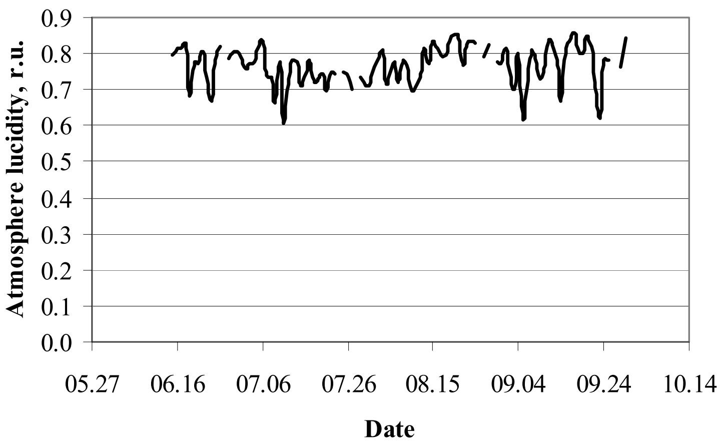

Fig. 2. Variations of the daily maximal atmospheric lucidity.

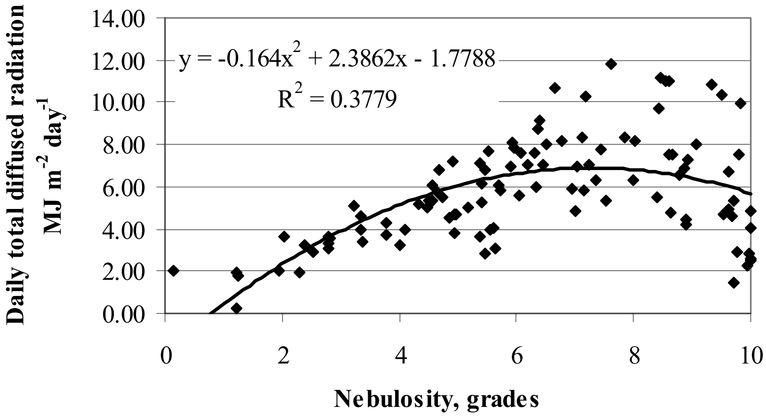

Fig. 3. The daily sum of the diffused solar radiation *vs.* nebulosity.

The diffused radiation was calculated as the daily energy total from formulae (4) and (6). The results are shown in Fig. 3. It is evident that the intensity of the diffused radiation at small and medium nebulosity increases with its grade, reaches maximum at 6–7 grades, after which it decreases. However, the diffused radiation cannot be calculated from the obtained expression because of large scatter in the data (the coefficient at determination of R^2 is only 0.38).

Therefore, an attempt was made to increase the coherence using the ratio between the measured energy sum of the diffused radiation and the theoretically calculated direct energy sum, instead of using only the former. Such an approach was expected to exclude the spread in the results due to changes in the day duration and the maximum altitude of the Sun. However, this approach has not given the expected results, with the coefficient of R^2 determination increasing only to 0.42. The results (with the mentioned ratio used) are shown in Fig. 4.

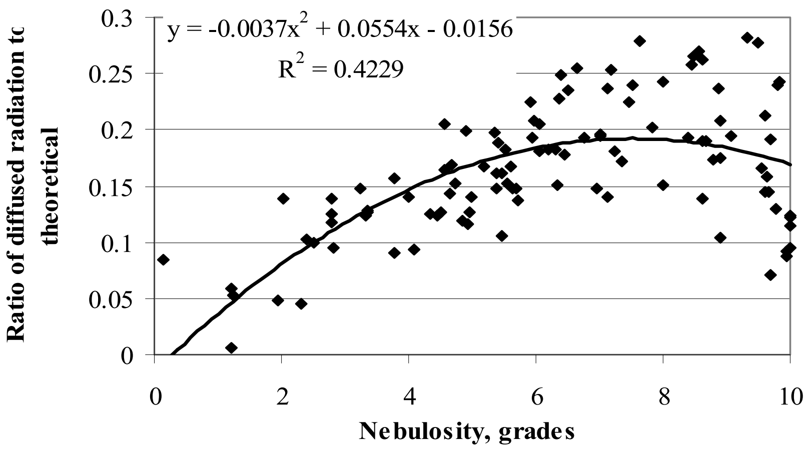

Fig. 4. The ratio of the daily diffused radiation energy sum to the theoretically calculated direct radiation *vs.* nebulosity.

This means that, apart from nebulosity, also other factors affect the intensity of the diffused radiation. A convincing example of that and also of increasing diffused radiation with nebulosity is shown in Fig. 5, where the daily course of the global solar radiation is presented for two days: one mostly clear whereas the other cloudy.

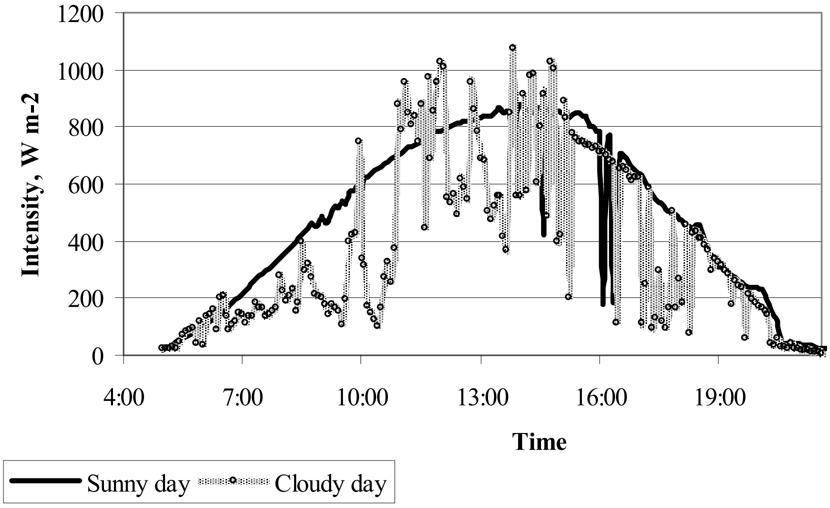

Fig. 5. Daily course of global solar radiation in a clear day (30 June) and a cloudy day (5 July).

It is seen from the graph of Fig. 5 that when clouds appear the global solar radiation might considerably increase (about 200 W m^{-2}). Since such an increase in the direct radiation cannot be explained, it should most probably be related to diffused radiation and considered as radiation reflected from clouds (usually not assumed to be a separate kind of radiation but included in the diffused one). The same graph shows also that the dependence of diffused radiation on the nebulosity is varying with the type of clouds – some of them only reduce the global radiation but never increase.

So far, we have no data on the type of clouds for every time span. More profound research into the influence of several type clouds on the global and diffused radiation is to be carried out in the future.

4. CONCLUSIONS

1. Lucidity of the atmosfere in Latvia can be assumed constant and equal to 0.77 r.u..
2. The intensity of diffused radiation increases at a medium nebulosity and decreases at a large one.
3. The diffused radiation depends not only on the nebulosity but also on the type of clouds.

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ATMOSFĒRAS DZIDRUMA UN IZKLIEDĒTĀS RADIĀCIJAS NOVĒRTĒJUMS

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Kopsavilkums

Lai efektīvāk varētu izmantot saules enerģiju Latvijas ģeogrāfiski-klimatiskajos apstākļos, nepieciešami aprēķini atsevišķi par tiešā un izkliedētā saules starojuma intensitāti. Savukārt tiešā starojuma intensitātes aprēķināšanai nepieciešams zināt atmosfēras dzidrumu.

Šajā darbā, balstoties uz globālā un tiešā saules starojuma intensitātes mērījumiem, veikts pētījums par Latvijas apstākļiem raksturīgām atmosfēras dzidruma vērtībām un to izmaiņām, kā arī par izkliedētā saules starojuma intensitātes atkarību no mākoņainuma.

Konstatēts, ka atmosfēras dzidrums Latvijā parasti ir 0,77±0,05 vienības, un mainās maz, ja nav nepieciešama ļoti augsta aprēķinu precizitāte, var tikt uzskatīts par konstantu.

Izkliedētā saules starojuma intensitāte pieaug pie vidējām mākoņainuma vērtībām, bet samazinās pie lielām (4. att.). Tomēr šo atkarību ietekmē arī mākoņu veids, tāpēc precīzākai atkarības noskaidrošanai nepieciešami papildus pētījumi.

20.10.2010.