SEMI-SPHERICAL SOLAR COLLECTOR FOR WATER HEATING

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Abstract. In Latvia because of its geographical and climatic conditions there are some features in use of the solar energy. There is a long path of the sun at summer, but frequently large nebulosity, which enlarges the necessity to receive the energy from all sides. Therefore, conditional flat plate solar collectors are not efficient enough, but new constructions of solar collectors are required. One of such new constructions can be a semi-spherical solar collector, capable to receive the solar energy from all sides. Such semi-spherical solar collector with radius 0.56 m that corresponds to the base area 1 m^2 has been made, and measurements of water heating have been carried out at summer 2009. Theoretical calculations of the energy gain from such collector have been performed and verified by comparison of the calculated daily energy sums with the measured ones, and good coincidence has been obtained. The results obtained from these calculations show, that the energy gain from the semi-spherical solar collector with the base area 1 m^2 is similar to that of tracking to the sun flat collector of 1 m^2 area. The tracking to the sun solar collector is complicated, expensive and not durable, but the semi-spherical solar collector is simpler, durable against the impact of wind and with good appearance. The measurements show, that the energy gain from such semi-spherical solar collector, made of simple materials, is similar to that from 1 m^2 of the industrially manufactured vacuum tubes solar collector. The energy gain from the semi-spherical solar collector can be increased by using in its construction contemporary special materials and technologies, such as special absorbing colours and selective coatings.

Keywords: solar energy, semi-spherical collector, water heating, modelling.

Introduction

Align with decrease of the reserves of fossil fuel, as well as the impact of use of fossil fuel on the climate, in the world more attention has been paid to renewable sources of energy, including solar energy.

Also in Latvia solar energy has been used, mostly in solar collectors for hot water production [1, 2]. However, in Latvia because of its geographical and climatic conditions there are some features in comparison with traditional solar energy using countries [3, 4]. In Latvia in summer the length of days excides twelve and maximally reaches seventeen hours, accordingly there is also a long path of the sun, but rather small height of the sun (maximally 56 degrees above the horizon) and therefore also small intensity of solar radiation.

There is also frequently considerable nebulosity. In winter the height of the sun is very small (10 ˚C) and the length of the day 7 h, therefore, use of solar energy in winter in Latvia is not possible.

Because of the mentioned above features a traditional flat plate collector without tracking to the sun is not appropriate enough for use in Latvia, but new collector constructions are required, that would be able to collect the energy from all sides as well as to use the diffused radiation more efficiently.

Such construction – a semi-spherical solar collector [5] can be proposed in the article. Such collector has been made and measurements of the heated water amount and temperature have been done. The obtained results have been compared with both calculated ones [3, 4, 6] and measured using the vacuum pipe collector.

Materials and methods

The solar energy received by the semi-spherical solar collector (Figure 1) has been measured in this work. The measurements have been carried out in Ulbroka, where both semi-spherical and vacuum tube solar collectors are situated on the roof of the Institute of Agricultural Machines (5 storey building).

The absorber of the collector is made of copper sheet (thickness 1 mm) shaped as a dome and coloured black. The collector is covered with a transparent polyethylene terephthalate (PET) dome. The radius of the collector is 1.12 m, what corresponds to 1 m^2 base area. Inside the absorber is a copper tube shaped close to the absorber, in which the heat remover (water) flows. The diameter of the tube is 10 mm, but the length 21 m. Water flow ensures the pump with productivity approximately 30 $l \cdot h^{-1}$.

Fig. 1. **Semi-spherical solar collector**

The measurements with semi-spherical solar collector have been carried out from 1 August till 31 October, 2009, almost every day from 8:00 till 19:00.

In order to measure the energy gain from the semi-spherical solar collector the water flow was measured as well as the temperature of incoming and outgoing water. The measurements of temperatures have been done using thermocouples and "Pico" TC-8 termologer, ensuring measurements automatically after every 5 minutes. Then the power of the collector can be calculated from Formula (1).

$$N = C \cdot K \cdot (t_2 - t_1), \tag{1}$$

where N – power of the collector, W;
C – specific heat of water, $J \cdot kg^{-1} \cdot K^{-1}$;
K – water pump productivity, $l \cdot s^{-1}$;
t_1 – cold water (input) temperature, ˚C;
t_2 – hot water (output) temperature, ˚C.

For calculation of the daily energy gain from the solar collector from these values of power the positive ones should be selected. Then daily energy gain can be calculated using formula (2).

$$E = \sum N \cdot \Delta t \cdot 10^{-6}, \tag{2}$$

where E – daily energy sum, MJ;
N – power of the collector, W;
Δt – interval between measurements, s.

The summarizing in formula (2) must include all positive (output water temperature higher than input temperature) values of the day.

At the same time the measurements of water heating have been done also using the factory-built vacuum tube solar collector "Vitasol" (Figure 2), and the energy gain from both collectors has been compared.

In this case it was not possible to measure temperatures of incoming and outgoing water, but the temperature of water within the water storage tank (capacity 300 l) was measured automatically after every 30 min. Because of regular water consumption from this tank it was considered that increase of the temperature characterizes the energy gain from the solar collector according to formula (3).

$$Q = C \cdot m \cdot \Delta T, \tag{3}$$

where Q – heat obtained between two temperature measurements, J;

C – specific heat of water, $J \cdot kg^{-1} \cdot K^{-1}$;
m – mass of the heated water, kg;
ΔT – difference between two subsequent measured temperatures, ˚C.

Fig. 2. **Vacuum tube solar collector "Vitasol"**

For calculation of the daily energy gain from the solar collector all positive values of the obtained heat within the day must be summed (formula 4).

$$E = \sum Q \cdot 10^{-6} \ . \tag{4}$$

In order to evaluate the efficiency of the collector, measurements of direct and global solar energy also have been carried out at the same time. The direct solar radiation has been measured using "Kipp & Zonen" class 1 pyrheliometer equipped with a tracking device. The global radiation has been measured using ISO 1 class pyranometer CMP 6 from "Kipp & Zonen". The measurements have been carried out automatically after every 5 minutes. The available daily energy sum can be calculated by formula (5).

$$E = \sum I \cdot \Delta t \cdot 10^{-6} \ , \tag{5}$$

where *E* – daily energy sum, MJ;
I – intensity of solar radiation, measured with pyranometer, W;
Δt – time between two measurements, s.

One of the methods how the efficiency of the solar collector can be evaluated is the graphical one. The daily energy gain from the solar collector via the daily available energy sum measured with the pyranometer must be plotted. Then the best fit line must be drawn using the method of smallest squares, and setting intercept equal to zero. The slope of this line can be considered as the efficiency of the collector, which is defined as the ratio between the solar energy received by the absorber of the solar collector and the energy gain.

The dependence of the daily energy gain of the solar collector on nebulosity also can be interesting. Data on nebulosity, measured in grades (ten grades scale, where zero grade corresponds to clear sky, but ten grades to overcast) have been taken from the homepage of the Latvian Environment, Geology and Meteorology Centre.

Results and discussion

Figure 3 shows a plot of the daily energy gain from both semi-spherical and vacuum tube solar collectors via the daily available energy sum measured with the pyranometer. Best fit lines drawn using the method of smallest squares for both semi-spherical and vacuum tube solar collectors also have been shown. Intercept for these lines is set equal to zero. Then the slope of the line (what can be considered also as the efficiency of the collector) for the vacuum tube collector is 0.32 with the coefficient of determinacy R^2=0.45, but for the semi-spherical solar collector the slope of the line (efficiency) is 0.23 with R^2=0.84. It can be seen that the efficiency of the semi-spherical solar collector is only 1.4 times smaller than that for the vacuum tube collector. It is rather a good result if taking into account that the vacuum tube solar collector is factory-built using up-to-date materials and technologies and is rather expensive, while the semi-spherical solar collector can be considered as home made of very simple materials and the efficiency of it can be substantially increased using up-to-date materials and technologies.

It is interesting that the coefficient of determination R^2 of the best fit line for the semi-spherical collector is considerably greater than that for the vacuum tube collector (0.84 and 0.45 respectively). It can suggest of smaller dependence of the energy gain of the semi-spherical solar collector on the weather and several other circumstances than that for the vacuum tube one.

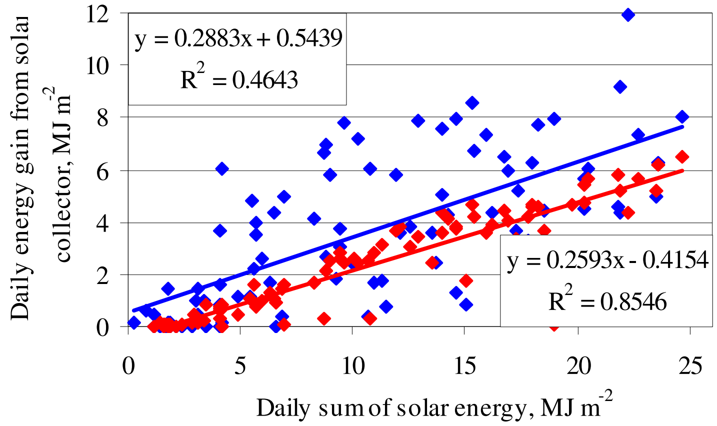

Fig. 3. **Daily energy gain from vacuum pipe (blue dots and best fit line) and semi-spherical (red dots and best fit line) solar collectors**

Also the dependence of the daily energy gain of both semi-spherical and vacuum tube solar collectors on nebulosity shown in Figure 4 confirms this assumption.

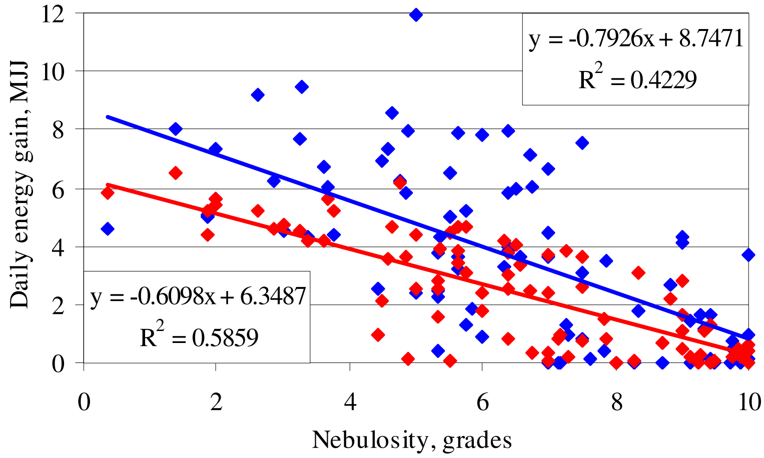

Fig. 4. **Dependence of daily energy gain from semi-spherical (red dots and line) and vacuum tubes (blue dots and line) solar collectors on nebulosity**

The slope of best fit line drawn using the method of smallest squares is –0.81 for the vacuum tube solar collector and –0.60 for the semi-spherical one, what suggests that the energy gain of the semi-spherical solar collector is less dependent on nebulosity than that of the vacuum tube one.

The total amount of the energy gain in all period of the measurements (1 August till 31 October) is 205 MJ for the semi-spherical solar collector and 332 MJ for the vacuum tube one.

Conclusions

1. The solar collector with semi-spherical absorber can be used for water heating in Latvia.
2. The energy gain from the home-made semi-spherical solar collector is comparable to that from the factory-built vacuum tube solar collector (1.4 times smaller).

3. The energy gain of the semi-spherical solar collector is less dependent on nebulosity.

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References

1. Kancevica L., Navickas J., Ziemelis E., Ziemelis I. Increase of the Efficiency of Solar Collectors. Proceedings of the 2nd International Scientific Conference "Biometrics and Information Technologies in Agriculture: Research and Development", Lithuanian University of Agriculture, 2006, pp. 89-92.
2. Ziemelis I., Iljins U., Navickas J. Economical Comparison of Some Parameters of Flat-Plate Solar Collectors. Proceedings of the International Research Conference "The Role of Chemistry and Physics in the Development of Agricultural Technologies", Lithuanian University of Agriculture, 2004, pp. 23-25.
3. Pelece I. Influence of nebulosity on use of solar energy in Latvia. Proceedings of the International Scientific Conference "Engineering for rural development", Latvia University of Agriculture, 2008, pp. 28-33.
4. Pelece I., Iljins U., Ziemelis I. Theoretical calculation of energy received by semi-spherical solar collector. Proceedings of the International Scientific Conference "Engineering of Agricultural Technologies": proceedings, Lithuanian University of Agriculture, 2008, vol. 6, pp. 263-269.
5. Saules enerģijas kolektoriekārta ar sfērisko enerģijas kolektoru un tās pielietojumi (Solar energy collecting device with spherical energy collector and its applications), patent No. 13550, international classification index F24J2/42, No. of application P-06-125: date of submission 15.11.2006.]. U.Iljins, Ē.Ziemelis, I.Ziemelis, I.Pelēce. Latvijas Lauksaimniecības universitāte. Patenti un preču zīmes, Nr.5, 2007, 637. p.
6. Pelēce I., Iljins U., Ziemelis I. Forecast of energy received by solar collectors. Proceedings of the International Scientific Conference "Applied Information and Communication Technologies": proceedings, Jelgava, LUA, 2008, pp. 62-67.