PRACTICAL USE OF SOLAR COLLECTOR INTEGRATED IN COMBINED HEATING SYSTEM

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Abstract. Use of solar collectors becomes more and more widespread not only in southern countries, but also in Latvia. One reason for the growing popularity of solar collectors is increase of the price of electricity. The most popular kind of solar collectors is the flat-plate solar collector because of its simple construction, although it is not so effective in the morning and evening. This article deals with practical use of the flat-plate solar collector. There are many works of scientific studies of solar collectors, and many situations of practical use of solar collectors, but there are no investigations of solar collectors in practical use. Therefore, we studied the solar collector integrated in really used combined heating system. This system consists of a traditional wood-burning stove, flat-plate solar collector and for both common hot-water reservoir. Temperatures of the solar collector, water reservoir and tubes between the collector and reservoir have been measured. Water flow between the collector and reservoir is ensured by a pump, automatically switching on/off depending on the temperatures. Viewpoint of the user was that input from the solar collector is very small in the whole heating system, but analyzing the data suggests that the situation can be improved importantly by better thermal insulation of tubes between the collector and reservoir. The results show that even in October the solar collector can warm up to 80 ºC.

Keywords: solar energy, solar collector, water heating.

Introduction

The use of solar energy increases very rapidly in the world. Partly this growing interest is associated with a greater understanding of global climate change and its effects, partly with the depletion of fossil fuel stocks and other problems.Solar energy has been used not only in southern countries, but also in northern ones, where the height of the sun and intensity of solar radiation are noticeably smaller.

Also in Latvia, solar energy has been used more and more[1]. There are many investigations how to improve the use of solar energy in Latvia. There are suggestions to use other shapes of collectors than flat, for example, semi-spherical [2] or cylindrical [3], suggestions to improve the efficiency of the flat-plate collector using reflectors [4] and many others.

At the same time use of solar energy at households also increases every year faster, mainly for the production of hot domestic water and space heating using heated floors. There are mainly traditional flat-plate solar collectors used because of their simple construction. But there are almost no investigations of practical use of flat-plate solar collectors at real everyday situations in Latvia. Therefore, there such situation has been studied in this article. A home-made flat-plate solar collector integrated in the combined heating system for domestic hot water preparing together with the traditional wood-burning stove have been investigated in this article. Such combined heating systems have been investigated in Spain [5], but not in Latvia.

We tried to find the benefits from the use of the collector, common energy gain from it and its efficiency.

Measurements were carried out at the end of October and at the beginning of March, i.e. the time when use of solar energy in Latvia is possible, but energy gain is the smallest. The pump of heat carrier was switched on and off automatically, when the difference of temperatures of the collector and reservoir reached fixed value. After 15 of October and before 12 of March in this winter such situations did not occur.

Opinion of the user was that energy gain from the collector is insignificant, but the results of the measurements show that even in October and March energy gain is valuable.

Efficiency of the solar collector cannot be determined in such short period of measurements. Investigations must be continued for a longer period in order to determinate the exact efficiency of the collector. Measurements will be continued in summer.

Materials and methods

A flat-plate solar collector (Fig. 1) has been studied. The area of the collector is 2 m^2, tilt angle 45º. As heat transporting fluid an ethylene glycol solution, containing 50 % of ethylene, was used. Density of such solution is 1100 $kg \cdot m^{-3}$, but the specific heat is 3350 $J \cdot kg^{-1} \cdot K^{-1}$. The flow rate of the fluid was 1 $l \cdot min^{-1}$.

Fig. 1. **Flat-plate solar collector**

Such solar collector has been integrated in the combined heating system (Fig. 2), consisting of a traditional wood-burning stove, the solar collector and a hot water reservoir common for both.

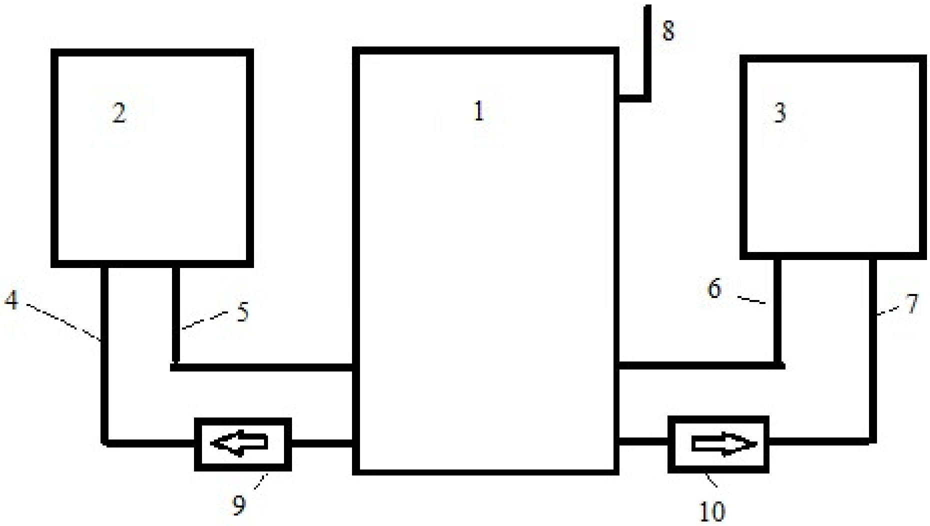

Fig. 2. **Combined heating system:** 1 – hot water reservoir; 2 – solar collector; 3 – wood-burning stove; 4-8 – tubes; 9 and 10 – circulation pumps

The circulation pump has been switched on and off automatically depending on the temperatures.

The measurements were carried out 5 days at the end of October and 10 days in the middle of March.

Temperatures of the fluid flowing from the collector to the heat exchanger of the reservoir and of that flowing back to the collector have been measured every minute. Then the power of the collector can be calculated using formula (1).

$$P = v \cdot \rho \cdot c \cdot (t_2 - t_1), \tag{1}$$

where P – power of the collector, W;
v – flow rate of the fluid, $m^3 \cdot s^-$;
ρ – density of the fluid, $kg \cdot m^{-3}$;
c – specific heat of the fluid, $J \cdot kg^{-1} \cdot K^{-1}$;
t_2 – temperature of the fluid flowing from the collector to the reservoir, ºC;
t_1 – temperature of back to the collector flowing fluid, ºC.

Energy gain from solar collector can be obtained by formula (2).

$$E = \sum P \cdot t \,, \tag{2}$$

where E – energy gain from the collector, J;
P – power of the collector, W;
t – time between two measurements, s.

Daily course of the collector temperature was compared to that of solar radiation received by the collector, calculated as shown in our previous work [6] by formula (3).

$$I = S \cdot L^m \cdot \cos\alpha \,, \tag{3}$$

where I – received solar radiation, $W \cdot m^{-2}$;
S – solar constant, S = 1367 $W \cdot m^{-2}$;
L – lucidity of atmosphere, r.u.;
m – air mass, r.u.;
α – incidence angle, degrees.

Lucidity of atmosphere according to our previous work [7] can be assumed as constant and equal to 0.78. Air mass is a value characterizing the thickness of the atmosphere layer, through which the solar beams , and according to literature [8] depends only on the height of the sun and can be calculated by formula (4).

$$m = \frac{1.002432\cos^2\theta + 0.418386\cos\theta + 0.0096467}{\cos^3\theta + 0.149864\cos^2\theta + 0.0102963\cos\theta + 0.000303978} \,, \tag{4}$$

where m – air mass, r.u.;
θ – zenith angle of the sun, degrees.

The cosine of the incidence angle of solar rays on some surface can be calculated by formula (5).

$$\cos\alpha = \sin\delta \cdot \cos\beta + \cos\delta \cdot \sin\beta \cdot (\cos A \cdot \cos B + \sin A \cdot \sin B) \,, \tag{5}$$

where α – incidence angle of solar rays on surface, degrees;
δ – height of the sun, degrees;
β – tilt angle of the receiving surface, degrees;
A – azimuth of the sun, degrees;
B – orientation of the receiving surface, degrees.

Daily energy gain from the solar collector calculated by formula (2) was compared to daily sum of the received solar energy, obtained by integrating the result of formula (3) during all day and multiplying to the surface area of the collector.

Results and discussion

Daily course of temperatures (Fig. 3) shows that, as it usually can be observed, the temperature of fluid flowing from the collector to the hot water reservoir is lower than the temperature of the collector. It is a traditional situation, because fluid can never take all heat from the collector's absorber.

Another important characteristic is temperature of the fluid flowing back from the reservoir to the collector. In this case, this temperature increases only slightly, when the circulation pump is switched on. It means that heat exchange between the fluid and the water reservoir is good.

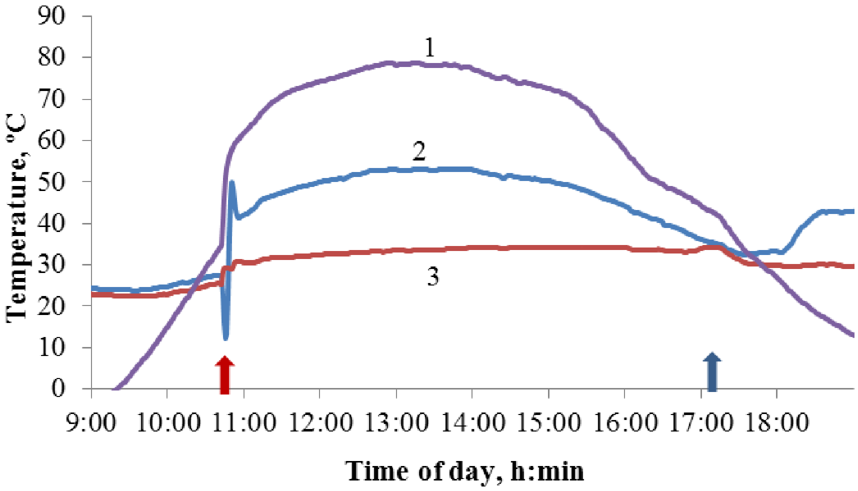

Fig. 3. **Daily course of temperature:** 1 – collector; 2 – fluid flowing from the collector to the reservoir; 3 – back from the reservoir flowing fluid; red arrow – circulation pump switched on; blue arrow – circulation pump switched off

Interesting is behavior of the temperature of the fluid flowing from the collector to the reservoir, when the circulation pump is switched on (Fig. 4). At start, this temperature drasticaly falls of about 15 ºC. It is because the fluid in the tube has been cooled at night. Therefore, it is important to have this tube as short as possible for smaler amount of fluid to be cooled, or to place this tube in a suny spot.

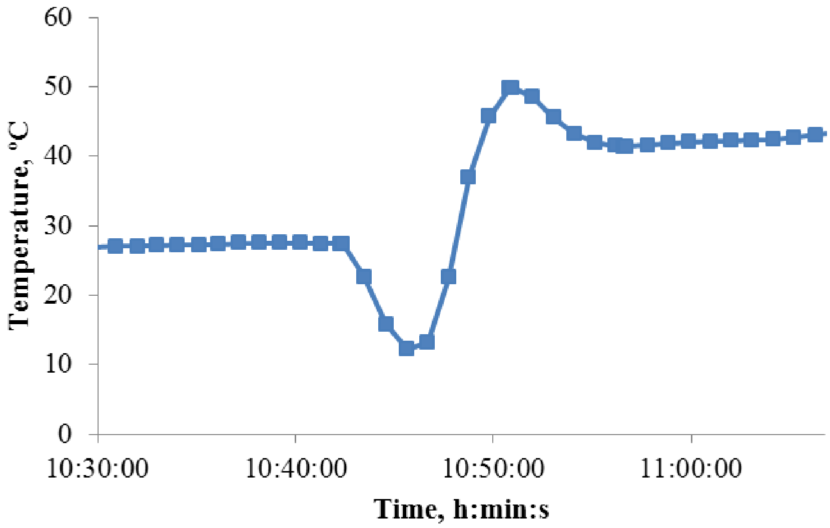

Fig. 4. **Changes of temperature of the fluid flowing from the collector to the reservoir at the moment of switching on the circulation pump**

Approximatly 10 minutes after the circulation pump is switced on the temperature reaches maximum – it is heat accumulated in the collector while there is no circulation.

The investigations were carried out at real hose-hold, not in laboratory; therefore, solar energy was not measured. Therefore, calculated data of clear-sky solar energy were used.Fig. 5 shows daily course of the collector temperature in comparison to that of the calculated solar radiation received by the surface tilted 45°, on 12 of March 2016. The day was partly cloudy, therefore there is decreasing of temperature before midday. Other asymmetry can be due to obstacles shading the collector slightly in the morning and evening.

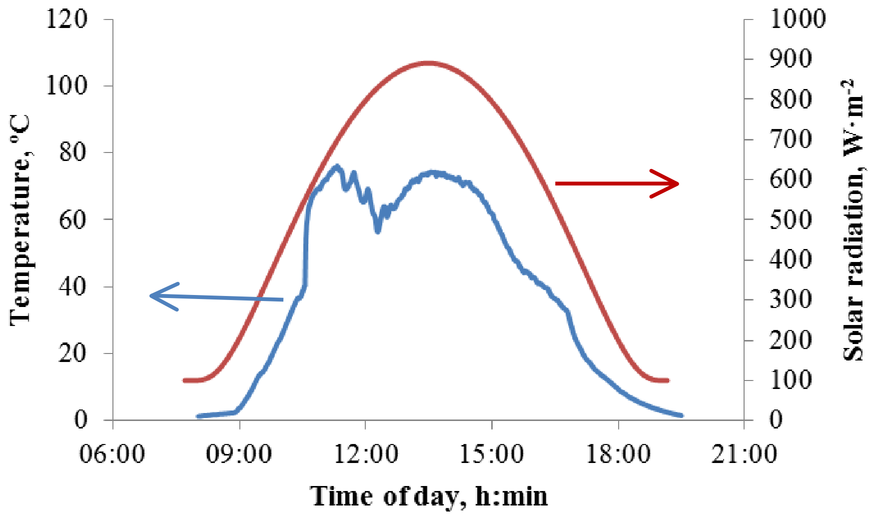

Fig. 5. **Daily course of collector temperature in comparison to that of solar radiation**

Table 1 shows the daily energy gain from the collector in comparison with the calculated maximal energy gain on a clear day from the collector with size 2 m^2 and tilt 45°.

Table 1

Energy gain from solar collector

Date	Energy gain, MJ		
	Measured	Theoretical on clear day	%
2015.10.11	1.4	37.3	3.7
2015.10.12	12.4	36.8	33.7
2015.10.13	4.0	36.3	11.1
2015.10.14	10.6	35.6	29.8
2015.10.15	11.8	35.1	33.8
2016.03.12	11.6	43.2	26.8
2016.03.16	2.6	45.3	5.8
2016.03.17	7.4	45.9	16.1
2016.03.18	2.4	46.3	5.1
2016.03.20	8.1	47.2	17.1
2016.03.22	1.6	48.3	3.2

Ratio of the measured and calculated values on a clear day shows the efficiency of the collector. On cloudy days this ratio is less. It can be seen that the efficiency of this collector can reach 33 %, although there was no fully clear day in the period of measurements. Some days in this period were overcast and the circulation pump did not switch on. Therefore, it is important to have a big and well insulated reservoir for hot water to keep it warm also on overcast days. Instantaneous efficiency has been measured up to 77 %.

For exact determination of the efficiency of the collector measurements must be carried out for a longer period.

Conclusions

1. Solar collectors can be used in Latvia together with other heat sources.
2. Even in October and March water can be heated up to 55 °C.
3. Even in October and March the daily energy gain from a flat-plate solar collector can be up to 7 MJ from square meter of the collector.

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