RESEARCH OF SOLAR WATER HEATERS MODEL

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Annotation

This paper is inspired of idea to investigate possibilities to use solar energy for water heating in Lithuania. Lithuania is somewhere between central and north Europe. So that's mean that geographical position is not as favorable as it is in Mediterranean region but as harsh as it is northern Europe. The investigation is interesting and actual because this paper presents the first steps investigate small thermosiphon solar thermal system. Thermosiphon solar thermal systems are more common in south but not in central or even in north of the Europe. The author made theoretical calculation how water temperature in the solar water heater depends on the time and compare calculated data with real measurements.

Key words: *solar water heating, solar collector, collector efficiency, thermal energy measurement, thermosiphon solar thermal system*

Introduction

The basic principle common to all solar heat systems is simple: solar radiation is collected and the resulting heat converted to a heat transfer medium – usually a fluid. The heated medium is used either directly (example for heating tap water) or indirectly (heat exchanger).

This technology is mainly used for:

- domestic hot water and space heating,
- district heating,
- industrial process heat,
- air conditioning and cooling.

Generally, this paper is related to small domestic hot water heating. There to types of small domestic hot water heating thermosiphon systems and forced circulation systems.

In Southern Europe, solar domestic hot water (SDHW) preparation is mainly supplied by thermosiphon systems. These systems, robust, efficient and easy to build, consist of a solar collector with a capacity between 0.7 and 2.1 kWh (between 1 and 3 m^2) and a hot water storage unit with a volume of usually 80 to 150 liters for a family of four. A thermosiphon system relies on the natural convection principle to circulate the heat transfer liquid between collector and storage. In this type of installation storage must be above the collector [1].

Because of its simple principle – without the need for sensors, controllers or pumps – and because they are normally used in rather sunny regions and thus do not need to be very efficient, small thermosiphon systems can be very cheap. In the world's largest market, China, systems are available for less than 100 EUR; even in Mediterranean countries; the cost of a newly installed thermosiphon system often does not exceed 1000€ [2].

The only simple controllers sometimes used with thermosiphon systems to switch the backup heater. Simple controller can measure the temperature in the tank and switch the backup heater during the night or in the morning. Also it can be used in colder climate to protect system from freezing.

Forced circulation systems using a pump to move the heat transfer fluid between collector and storage are almost exclusively used in Central and Northern Europe, since it is not usually possible to install the storage tank on the roof above the collector. In addition, the integration of the solar thermal system in central heating systems is easier if the storage tank is located within the dwelling (typically the basement). In Central and Northern Europe, a typical SDHW system consists of 2 or 3 solar collectors with a capacity between 2.1 and 4.2 kWh (3 to 6 m^2) and hot water storage with a volume of 200 to 400 liters for a family of four. [1, 3].

Due to more complicated system the cost of a newly installed forced circulation system is between 3500-5000 1000 € (incl. VAT and installation). [2].

The aim of this paper is evaluate the heat exchange between the termosiphon type water heater and environment.

Tasks to reach objectives:

- Calculate energy losses through water tank wall due to different insulation thicknesses.

- Estimate the amount of time during which the water in tank from the maximum temperature decrease to the temperature which is still proper for consumption.
- Compare the theoretical calculations with the results of practical measurements

For years, larger solar thermal systems have been rigorously measured and often connected for remote monitoring and controlling. The rationale is that a failure or under performance of the system can quickly result in high costs – because heat, which could have been supplied by the solar thermal system, must then be generated by electricity, fossil fuels or biomass, all of which are not usually provided free of charge. With smaller systems, this is different: The additional costs of complex (remote) metering and monitoring are proportionally very high. Furthermore, as in smaller systems savings in absolute terms are also smaller, this makes the additional costs of metering and monitoring almost prohibitive. In Germany, a guideline from the Association of German Engineers (VDI 2167) recommends that the additional costs of metering should not be higher than half the expected annual savings. For smaller solar thermal systems this can be a very small amount. [2]

To upgrade (adding measurement features) small solar thermal system, which already have controller cost no more than 100 € (few temperature sensors and flow meter). But if the system was not designed for heat metering, such upgrading remains expensive about 400 €, plus installation costs).

For example, if small thermosiphon costs 800 €, an additional 100 or even 400 € for metering would increase the investment costs from 12.5 to 50%. Today, most small solar hot water systems (especially those of the thermosiphon type) are not metered at all and no information on the actual yield or even the correct performance of the system while in operation exists. And of course such system is not connected to a communications network.

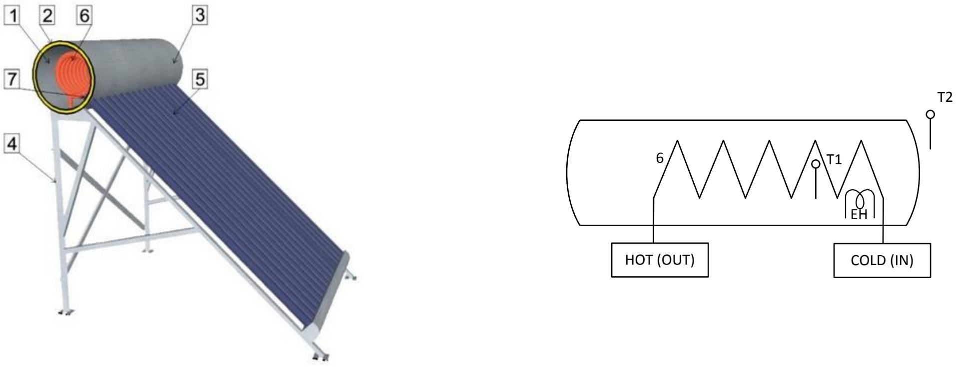
Thermal resistant and temperature dynamics of thermosiphon water heater

The thermosiphon water heater parameters are shown on table 1 and construction is shown in figure 1.

Table 1

Characteristic of water heater tank

Name of parameter	
Thickness of polyurethane foam thermal isolation, δ	0,055m
Inner length h_vid	1,860 m
Outer length h_isor	1,970 m
Inner cylinder diameter, d_vid	0,350 m
Outer cylinder diameter , d_isor	0,460 m
Conductivity of the insulation material, λ	0,03W/mK



a) b)

Fig. 1. Construction of the thermosiphon water heater

a) [4]; inner structure b). In figure: 1. 0,41 mm SUS304B the inner tank is made of stainless steel; 2. 55 mm polyurethane foam thermal isolation; 3. 0,5 mm SUS430 outer tank layer is made of Stainless steel; 4. 1,2 mm SUS201 holding construction is made of Stainless steel; 5. 24 units three-layered 58/1800 vacuum tubing solar collector; 6. SUS316 Stainless steel heat exchanger; 7. Stabilized silicone steel; T1 tank water temperature in level 15 cm; T2 – air temperature sensor; EH – electrical heater.

First of all, the effectiveness of the insulation material layer was calculated. When the inner (water) T_I and outer (weather) T_O temperatures were selected it is possible to calculate theoretical energy loses through water tank walls (Equation 1):

$$Q \quad = R \cdot S\,(T_I - T_O); \qquad (1)$$

where S surface area of accumulative water storage tank:

$$S = 2 \cdot S_s + S_p; \qquad (2)$$

S_s accumulative water storage tank sidewall surface area:

$$S_s = \pi d h; \qquad (3)$$

S_p accumulative water storage tank base surface area:

$$S_p = \pi \left(\frac{d}{2}\right)^2. \qquad (4)$$

The data required to calculate S_s and S_p are submitted in table 1.

The thermal resistance of water storage tank walls is calculated using formula 5:

$$R = \frac{\delta_n}{\lambda}; \qquad (5)$$

The thermal resistance of the insulation foam was counted for 4 different δ_n values: 0.055 m (current thickness of the device under test), 0.075 m, 0.1 m, 0.15 m.

The energy loss (Q, J), dependence on *dT* $dT = T_I - T_O$), using different thicknesses of insulation materials δ_n (different color lines), are given in Figure 2, (wind effect and loses through vacuum tubes was not taken in to account).

The calculation results observed in figure 2 are more theoretical. Observed curves showing losses when the difference between indoor and outdoor temperature is constant. So this calculation shows only theoretical losses, but does not reflect the situation when the temperature in the tank decrease, but the outdoor temperature remains stable. In this case, the difference between the temperature inside and outside of the water tank decreases, resulting in a decrease in energy losses.

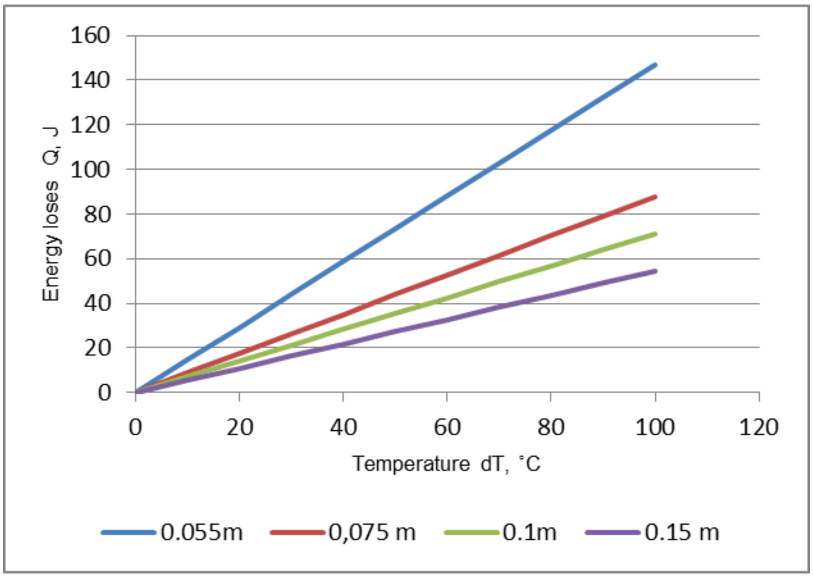


Fig. 2. The energy loses Q dependence on *dT*, using different thicknesses of insulation materials δ_n (different color lines)

According calculation results (figure 2) it is possible to reduce energy loses: ~ 40 % if the insulation thickness increased from 5.5 cm to 7.5 cm, by ~ 51 % if the insulation thickness increased from 5.5 cm to 10 cm; ~ 63 % if the insulation thickness increased from 5.5 cm to 15 cm when outside temperature is + 10 ° C.

The calculation how the temperature of the water in the tank changes according to time was performed. Equation 1 allows calculating instantaneous losses (J). The equation 1 was modified to equation 7 which allow calculating energy losses in time interval ($\Delta\tau$).

Heat flow through the walls of the water storage tank during time period:

$$Q_k = R \cdot S\,(T_I - T_O) \cdot \Delta\tau; \qquad (7)$$

where *R* – thermal resistance obtained from formula 5 (according parameters from table 1); T_I – water temperature; T_O – weather temperature; S – the surface area of the water storage tank obtained from formulas 2 – 4; $\Delta\tau$ – time period for calculation of energy loses.

When calculating the energy loss through water tank walls over time, it was assumed that accumulated energy is not used for tap water heating. Also was assumed that the system does not have any external influences as wind and etc.

In order to calculate the temperature of tank water dependence over time using equation 7, it is necessary to know the amount of energy accumulated in the tank water.

Accumulated energy in the tank water:

$$Q_{H2o} = c_{H2O} \cdot m \cdot (T_{I1} - T_{I2}); \qquad (8)$$

Where c_{H2O} – specific heat capacity of water (c_{H2O} =4200 J/(kg·°C) or 1,163 (W·h)/(kg·°C)), T_{I1} – max. temperature of water T_{I2} – min. temperature of water, *m* - the water mass calculated from the volume *V*:

$$V = \pi r^2 \frac{d\_vid}{2} = 178{,}953\ \mathrm{cm3}; \qquad (9)$$

If accepted that ρ_{H2O}=1000 (kg/m^3)), water mass *m* = 179 kg.

Further it was assumed that the reason of decrease water temperature in the tank is losing water energy Q_{H20}, because of heat Q_k loss through the tank walls to environment, over the time $\Delta\tau$.

From this assumption, can be stated that the water temperature in the tank is a function of time, energy loss through thermal insulation and the amount of stored energy in the water:

$$T=f(Q_{H20},, Q_k, \Delta\tau), \qquad (10)$$

In this case, equating equation 7 with equation 8, the next expression was created:

$$Q_k = Q_{H2o} \qquad (11)$$

In equation 7 and 8 was used such note (because the system of energy exchange between water and air is being studied):

$$T = T_I = T_{I1}. \qquad (12)$$

In further calculations was assumed that the outdoor minimum temperature $T_O = 10^{\circ}\mathrm{C}$. Such a temperature is more typical for the early autumn or for the later spring nights, when the solar water heater collects energy per day and needs to keep high temperature of the water overnight. During the summer, the amount of solar energy is excess and the night temperatures are higher. Using the equation 11, the temperature T function from the time $\Delta\tau$ was extracted:

$$T = \frac{16747 + 14{,}5 \cdot \Delta\tau}{209 + 1{,}45 \cdot \Delta\tau}, \qquad (13)$$

This function is suitable for use at a positive outdoor temperature.

Using equation 13, the water temperature drop curve in water heater was obtained. (Figure 3). It was assumed that there was no solar energy during the calculated period.

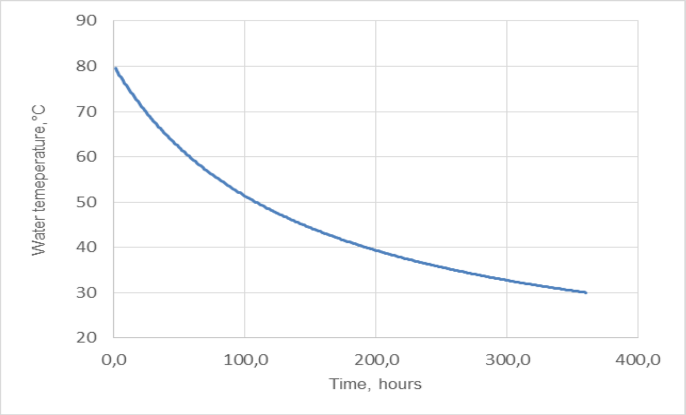


Fig. 3. The water temperature in the solar water heater depending on the time, (the temperature loss is only due to the difference between the outside and the internal temperature) when outdoor temperature is $T_O = 10°\mathrm{C}$.

The authors accepted that the minimum temperature of water which are suitable for domestic use is +40°C – +45˚C. According this acceptation and curve from figure 3 can be stated that the temperature decrease from 80˚C to 40 – 45˚C within 140-180 hours or 6-7 days. Also was assumed that the system does not have any external influences such as wind or water consumption which can decrease temperature much faster than it was shown in figure 3.

Another important factor was to calculate the dynamics of the internal temperature of the solar water heater at a negative outdoor temperature. It was calculated assuming that the outdoor temperature $T_O = -10°\mathrm{C}$. This minimum temperature is typical for January – February months. Using equation 11, the temperature T function from the time $\Delta\tau$ was extracted:

$$T = \frac{16747 - 14{,}5 \cdot \Delta\tau}{209 + 1{,}45 \cdot \Delta\tau} , \qquad (14)$$

Practical examination

The experiment was held in winter time so the electrical water heater was use to increase the temperature of water in tank (described table 1 and figure 1) till +65°C. When the temperature reached 65°C, the electrical heater was switched off. The weather temperature outside and water temperature inside the tank was measured using digital temperature sensors. The weather temperature T_O during experiment was between $-5°\mathrm{C} \div +2°\mathrm{C}$. After switching off the electric heater, the temperature variation in the water tank was observed and the comparison with the theoretically calculated data was executed. Theoretical calculation was made using equations 13 and 14. The results are given in Figure 4.

In figure 4 large differences between real situation and theoretical calculation was observed. The main reason can be the wind effect which was not included in theoretical calculation but make big influence in real situation; other reason energy loses through vacuum tube connection and improper quality of insulation material or insulation layer.

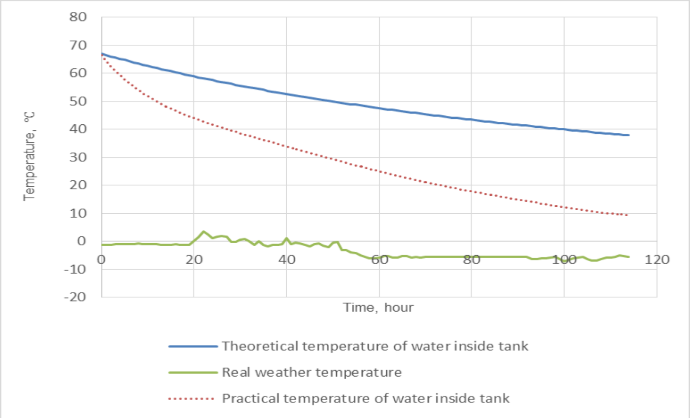


Fig. 4. Comparison of the actual temperature in the water tank with theoretical calculations (for theoretical calculation the temperature loss is only due to the difference between the outside and the internal temperature) when outdoor temperature is $T_O = -5°\mathrm{C} - +2°\mathrm{C}$.

Conclusions

According calculation it is possible to reduce energy loses by 40% if the insulation thickness increased from 5.5 cm to 7.5 cm, when outside temperature is + 10°C.

Theoretical calculation shows that the water temperature decrease from + 80°C to + 40 – 45°C in 6 – 7 days period, when outside temperature is + 10°C.

Temperature curve obtained after practical measurement have the same trend as theoretically calculated, but the measured and theoretically calculated temperatures still have large difference. This difference can be explained using inaccuracy of theoretical model and possible shortage of tested water tank.

Future works

Improve theoretical calculation model by introducing wind effect.

Check the quality of insulating layer using thermovisor.

Create metering and remote monitoring system for small thermosiphon type water heating system.

Measure produced solar thermal heat in thermosiphon type water heating system.

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