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Negoitescu Arina, Tokar Adriana

Solar Storage Tank Insulation Influence on the Solar Systems Efficiency

For the storage tank of a solar system for domestic hot water production was analyzed the insulation thickness and material influence. To this end, it was considered a private house, occupied by 3 persons, located in zone I of thermal radiation, for which has been simulated the domestic hot water production process. The tank outlet hot water temperature was considered of 45°C. For simulation purposes, as insulation materials for the storage tank were taking into account glass wool and polyurethane with various thicknesses. Finally, was carried out the comparative analysis of two types of tanks, in terms of the insulation thickness influence on the solar fraction, annual solar contribution and solar annual productivity. It resulted that polyurethane is the most advantageous from all points of view.

Keywords*: radiation, flat solar panel, storage tank, solar fraction, thermal insulation, temperature, annual productivity, annual supply*

1. Solar installation types

Solar systems consist of: solar expansion tank, the auxiliary heat source, automation and control system, and water storage system.

Heat storage is a key feature of the solar hot water system. Without it, hot water will be available only when the sun actually shines. The solar storage tank allows the system to operate whenever energy is available to provide power when needed.

A storage tank is characterized by its ability to effectively supply collectors with a fluid temperature as low as possible. To improve the temperature stratification in solar energy storage, the tank must be designed in order to optimize energy efficiency in the installation.

There are several types of solar installations [1], [2]:

- With separate heat exchanger and forced circulation;

- With integrated heat exchanger and forced circulation;
- Without heat exchanger;
- Thermosyphon with heat exchanger;
- Thermosyphon without heat exchanger (TWHE).

The solar tank should be well insulated so that heat losses to be less than 2W/m^{3}K [3].

The materials used for insulation must meet the following conditions:

- To have a low thermal conductivity coefficient;
- To be resistant to high temperatures, the variations in temperature and humidity, and variable weather conditions throughout the year;
- To have mechanical strength in order to not be damaged during operation;
- Easy to operate and maintain;
- Not be aggressive to the insulated object;
- To have a minimized weight;
- To be economic.

When choosing the insulation material is taken into account the most important characteristic values, thickness and thermal conductivity of the material [4]. Two materials for solar thermal storage tanks that meet these conditions are glass wool and polyurethane.

2. The analysis heat transfer through the solar water storage tank

In the case of solar water storage tank, insulated with an insulating material, heat is transmitted by thermal convection from water which is inside the tank to the interior wall surface, from the external surface of the insulating layer to the air around the tank, and by heat conduction through its wall and insulation.

2.1. Calculation of the heat flow transmitted by thermal conduction

By isolating the cylinder walls, inhomogeneous walls are obtained with n layers, for which the linear flow density in steady state, is expressed as [5]:

$$\dot{q}_l = \frac{\pi \cdot (t_1 - t_{n+1})}{\sum_{i=1}^{n} \frac{1}{2 \cdot \lambda_i} \cdot \ln \frac{d_{i+1}}{d_i}} \tag{1}$$

2.2. Calculation of the heat flow transmitted by thermal convection

The heat transmitted by thermal convection during τ, between a fluid with t_f temperature and a wall with t_p temperature, whose surface is S , is calculated with Newton's [5]:

$$Q = \alpha \cdot S \cdot (t_f - t_p) \cdot \tau \qquad [\mathrm{J}] \tag{2}$$

Where: α [W/m^2·K] is the coefficient of thermal convection.

The problem of heat transfer by convection is reduced, in fact, in determining the convection coefficient. Thus, are used similarity invariants for the thermal convection [5]:

- The Reynolds invariant, determinant in the forced convection:

$$Re = \frac{w \cdot l}{\nu} \tag{3}$$

- The Nusselt invariant:

$$Nu = \frac{\alpha \cdot l}{\lambda} \tag{4}$$

The Nusselt invariant occurs in the thermal conductivity fluid relation, where is taken into account the solid thermal conductivity. By combining these invariants it can be obtained:

- The Prandtl invariant, which has the advantage of depending only on the fluid physical properties.

$$Pr = \frac{Pe}{Re} = \frac{\nu}{a} \tag{5}$$

Where, c [J/kgK] is the thermal mass capacity. For gases , c_p will be considered.

The experimental research aims to determine the convection coefficient, which is considered in the Nu similarity criterion.

2.3. The global heat transfer

For an inhomogeneous cylindrical wall consists of n layers, which separates two fluids of different temperatures, in steady state, the heat flow linear density that is transmitted from the first fluid to the wall has the same value as that passed through the wall and from the wall to the second fluid [5]:

$$\dot{q}_l = \frac{\pi \cdot (t_{f1} - t_{f2})}{\frac{1}{\alpha_1 \cdot d_1} + \sum_{i=1}^{n} \frac{1}{2 \cdot \lambda_i} \cdot \ln \frac{d_{i+1}}{d_i} + \frac{1}{\alpha_2 \cdot d_{n+1}}} \quad [W/m] \tag{6}$$

Where:

t_{f1}[°C], t_{f2} [°C] – the temperatures of the two fluids;

α_1, α_2 [W/m^{2}K] – the convection heat coefficients;

λ_i [W/mK] – the thermal conductivity coefficients of the wall layers materials;

d_i [m]- the cylindrical wall diameters;
n – number of layers.
Equation (6) can be also written in the form:

$$\dot{q}_l = K_l \cdot \pi \cdot (t_{f1} - t_{f2}) \quad (7)$$

K_l represents the total linear heat transfer coefficient, which is obtained from equalizing the equations (6) and (7).

3. The solar thermal system sizing

3.1. The solar thermal system components

To highlight the influence of insulation thickness and material of the solar storage tank on the efficiency of solar thermal systems, was modeled a thermal collector plan. This system is used to supply the necessary heat in order to produce domestic hot water.

There was considered that the heating system consists of flat solar panels, boiler, pump system, automation system, and solar storage tank with heat exchanger built with forced circulation of the fluids (Fig. 6). The heat is used for domestic hot water for a private house with 3 occupants.

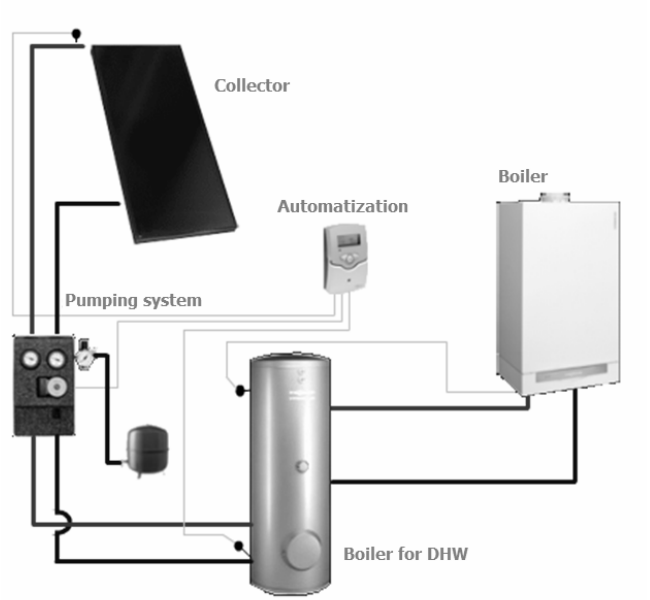

Figure. 1. The solar installation for domestic hot water production [6]

3.2. Calculation of the required for domestic hot water, with flat plate collectors

For sizing the solar thermal system is calculated the heat requirement for hot water consumption [5]. Hot water requirement values vary depending on the type of comfort relating to the buildings versions and the destination (Table 1).

Table 1. Specific requirements hot water in private houses [7]

Temperature [°C]	Consumption type		
	Reduced comfort [l/pers/day]	Normal comfort [l/pers/day]	Increased comfort [l/pers/day]
60	10…20	20…40	40…70
45	15…30	30…60	60…100

For calculation heat requirement, Q_{acm}, for hot water preparation is used the following equation [4]:

$$\dot{Q}_{acm} = \frac{m \cdot c_w \cdot (t_b - t_{ar})}{\tau \cdot 3600} \; [kW] \tag{8}$$

Where:

m [kg] – the hot water amount:

ρ [kg/m3] - the water density, which varies with temperature, but for calculations it can be considered $\rho = 1000$ kg/m^3;

n - number of persons;

t_{ar} - [° C] temperature of cold water into the boiler;

t_b [° C] - hot water heater temperature [° C];

τ [h] – the period of the water heating.

From equation (22) it is noted that the heating time is significant for the heat requirement calculation, used for domestic hot water. When a medium comfort is taken into account, the water amount is of 50kg. The temperature hot water inside the solar tank is considered 45°C, while the cold water temperature at the entry into the storage tank is 10°C. It results, the required heat:

$$\dot{Q}_{acm} = \frac{3 \cdot 50 \cdot 4{,}185 \cdot (45 - 10)}{8 \cdot 3600} = 0{,}7628 \; [kW]$$

Solar collectors surfaces depend on the percentage of annual heat demand which must be provided by those collectors (Table 2).

Table 2. Solar collector area required for DHW [7]

Percentage for DHW with solar energy 60% (spring-summer-autumn)	Percentage for DHW with solar energy 40-50% (summer-warm season)
1,2…1.5 m^2/pers.	1…1,2 m^2/pers.

Unitary thermal load, $\dot{Q}_{acm1}$, of solar collectors required for domestic hot water, is:

- During spring-summer-autumn:

$$\dot{Q}_{acm1} = \frac{\dot{Q}_{acm}}{S_1} = \frac{762{,}8}{0{,}8} = 953{,}5 \left[\frac{W}{m^2} \right]$$

- - During summer, only:

$$\dot{Q}_{acm1} = \frac{\dot{Q}_{acm}}{S_1} = \frac{762{,}8}{0{,}6} = 1271{,}33 \left[\frac{W}{m^2} \right]$$

Where S_1 – the solar collectors surface, recommended in Table 2.
For domestic hot water requirements of 150l/day, by taking into account the solar radiation of 1350kWh/m^2an intensity, that is specific to the zone I if radiation, and a collector area of 0.8 m^2/pers indicates that for domestic hot water are necessary two flat solar collectors.

4. The insulation efficiency comparative interpretation

Following the computation of the solar panel was selected as a model the Vitosol 200F solar flat panels, whose technical characteristics are presented in Table 3 [8].

Table 3

TYPE			SV2
Collector surface		m^2	2.51
Absorption surface		m^2	2.30
Opening surface		m^2	2.32
Dimensions	Length Width Height	mm	1056 2380 90
Weight (thermal insulation)		kg	52

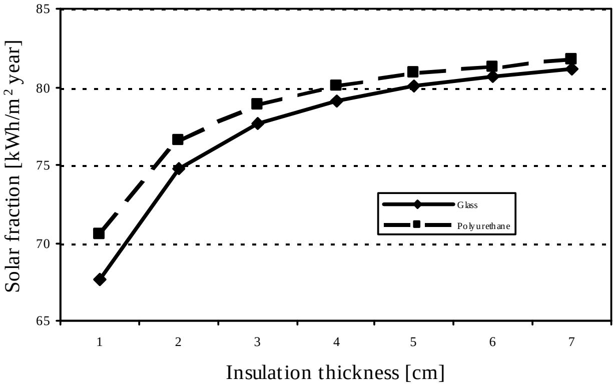

Figure 2. Solar fraction depending on glass insulation thickness for different solar installation types

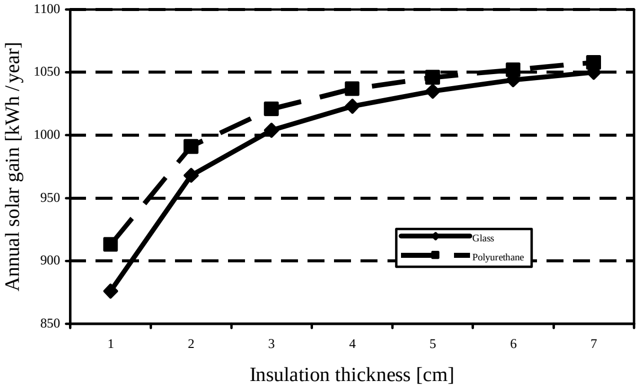

Figure 3. Annual solar gain depending on glass insulation thickness for different solar installation types

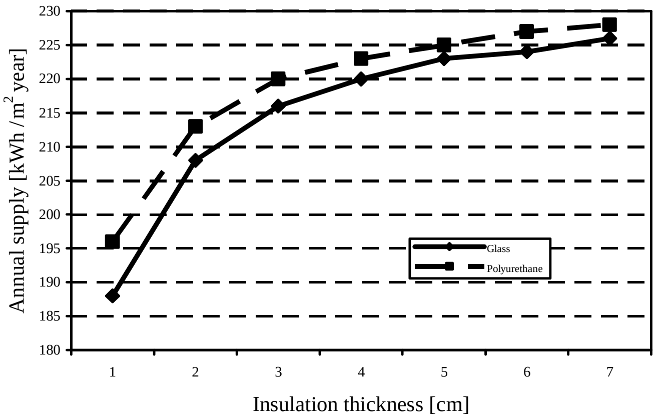

Figure 4. Annual supply depending on glass/polyurethane insulation thickness for different solar installation types

For the considered model (private house located in zone I of thermal radiation, inhabited by 3 people) was simulated the heating system with flat panels for two insulation materials and different insulation thicknesses. For the solar storage tank, glass and polyurethane were considered as insulation materials, and it was simulated the solar system operation, for various tank insulation thickness.

Following the simulation, there have resulted for the storage tank with integrated heat exchanger and forced fluids circulation, as it follows: the solar fraction, the annual solar gain and annual supply of installations, according to the glass versus polyurethane insulation thickness.

5. Conclusions

Insulation thickness in the range 1-4cm, both for glass and polyurethane significantly influences the variation of solar fraction, the annual heat supply and annual productivity. This shows that within the specified thickness, insulation materials have a major contribution in heat losses reduction through the solar storage tank walls. On the other hand, rising above the insulating layer thickness of 4 cm, there are no significant benefits irrespective of the analyzed insulating material. Graphs from Fig.6, Fig.7 and Fig. 8 points out that, in terms of solar storage tank insulation, polyurethane is more efficient. As additional advantages, polyurethane is lighter and has lower costs compared to glass.

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Addresses:

- Lect. Dr. Eng. Arina Negoiţescu, 1Mihai Viteazu Blv., 300222 Timişoara, arina.negoitescu@yahoo.com
- Lect. Dr. Eng. Adriana Tokar, Faculty of Civil Engineering, University "Politehnica of Timişoara, 2 Traian Lalescu Street, 300223 Timişoara, adriana_tokar@yahoo.com