Effect of water storage tanks design in solar combisystems efficiency

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Abstract: - One of the key components of a solar combisystem is the heat store. In the international literature the matter of storage necessity for solar systems is well justified. We build an experimental system assisted by a stratified storage tank and we estimate the significance of its design parameter on system efficiency. A sensitivity analysis support our research and justifies our outcomes for single-family houses, that larger storage tanks cannot contribute in substantial energy savings with a rational cost.

Key-Words: - storage tank, stratification, fractional savings

1 Introduction

One of the key components of a solar combisystem [1], [2] is the heat store(s). In the international literature the matter of storage necessity for solar systems is well justified. We will concentrate our interest in active storage systems and more specifically in water storage for short period (not seasonal storage) as this is the medium used in solar combisystems.

To supply the two heat consumers (domestic hot water and space heating), water should be simultaneously available at two different temperature levels. Operating different storage tanks with a 'clever' control unit acting on valves and pumps can do this. However, it is also possible to use a single storage tank if care is taken to avoid mixing water of different temperatures. As hot water has a lower density than cold water, hot water is always located in the upper part of the storage tank; conversely, cold water is found at its bottom. This feature is called vertical stratification of the storage tank.

2 Stratification in storage tanks

The degree of stratification in a real tank will depend on the design of the tank, the size, location, and design of the inlets and outlets, and flow rates of the entering and leaving streams. It is possible to design tanks with low inlet and outlet velocities that will be highly stratified [3] or [4]. Heat exchangers placed inside the store tend to create zones of uniform temperature above (in the case of charging) or below (in the case of discharging). For example, in the first case, heated water from an immersed heat exchanger rises and simultaneously mixes the water above the heat exchanger. Heat exchangers can therefore only create a limited amount of stratification and in some cases can destroy existing stratification (mixing). Direct charging and discharging can create good stratification, but only if the inlets are designed correctly and if the inlets and outlets are at heights that are well adapted to the total system design. The effects of stratification on solar process performance can be bracketed by calculating performance with fully mixed tanks and with highly stratified tanks.

Solar heat is stored in the lower part of the store and, if applicable, auxiliary heat in the upper part. The collector hydraulics influences the height of the collector loop outlet to the store. For high-flow collectors, this connection can be quite low. On the other hand, this connection should be higher or even better variable (stratifier) for low-flow collectors and the heat store should be prepared to enhance thermal stratification.

The zones indicated in Figure 1 represent different temperatures, and more specifically the temperatures required of the loads for domestic hot water and space heating. Stratification allows an optimal use of the store with limited heat losses and, in addition, can be used to ensure that the collector inlet temperature is as low as possible. However, it is not obvious or easy to maintain good stratification in the store. In fact, the terms stratified and stratifying are used for slightly different phenomena and approaches. To maintain stratification, all charging and discharging must be done in such a way as to improve or maintain the stratification. If only one heat source or sink causes significant mixing, it can destroy the benefit of the stratification created by other sources/sinks.

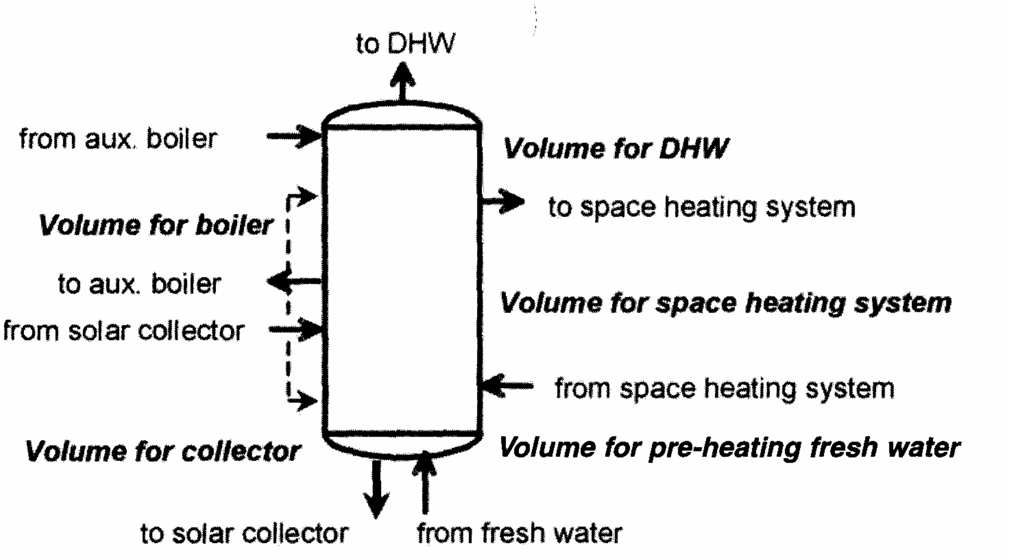


Fig. 1. Zones for the hot water store of a solar combisystem. [5]

These systems can be constructed in a variety of ways. The input and output of heat to the storage tank can be achieved either by direct inlets to the tank or by heat exchangers inside the tank. However, the use of heat exchangers often creates unwanted uniform temperature zones above the heat exchanger, which can destroy the stratification, which is a very important characteristic of the tank. Direct inlets and outlets to the tank could be a better option in order to achieve a good stratification level, but this requires thorough system planning and adjusting of the inlet and outlet heights in the tank to the optional levels.

Neither the internal heat exchanger nor the direct inlet is perfect for creating stratification, so different methods have been applied to improve stratification illustrated in Fig. 2.

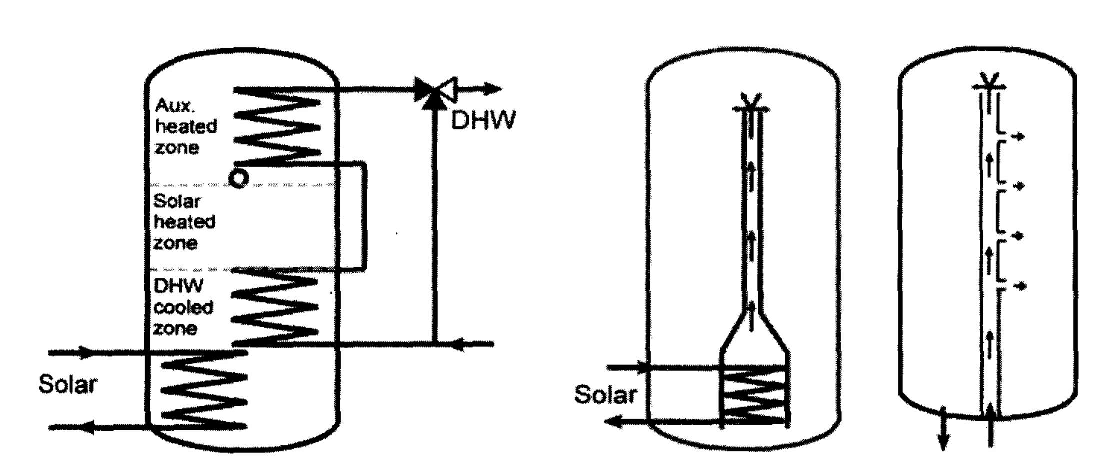


Fig. 2. Three different methods of causing stratification with internal heat exchangers: several internal heat exchangers (left); stratifying tube (middle); and stratifying unit with multiple outlets (right). The stratifying unit can be used with an internal heat exchanger or for other inlets that vary in temperature [6]

For combisystems with indirect integrated auxiliary heating, the inlet pipe from the heater is connected at the top. The height of the outlet depends on the peak hot-water demand, the outlet pipes to the heat distribution system and the volume needed for solar energy. The minimum operation time for the heater also determines the auxiliary volume.

Requirements are stricter for wood furnaces than for gas boilers. Another factor is the type of the heat distribution system, for example, connection from high-temperature radiators to the store should be higher than from a low-temperature heat distribution system.

For solar combisystems with a relatively small collector area (2-5 kW heat load), optimum heat store volume appears to be 50-200 litres per kW heat load. The optimum tilt angle is between 30° and 75°. Orientation is best between 30° east and 45° west.

3 Description of installation and model

In the experimental installation shown in Fig. 3 we employ the storage tank shown analytically in Fig. 4 and its data in Table 1. As we can see we use one storage tank to serve both consumptions (domestic hot water and space heating). Our storage is considered as a stratified tank, divided into 10 fully mixed equal volume segments (nodes).

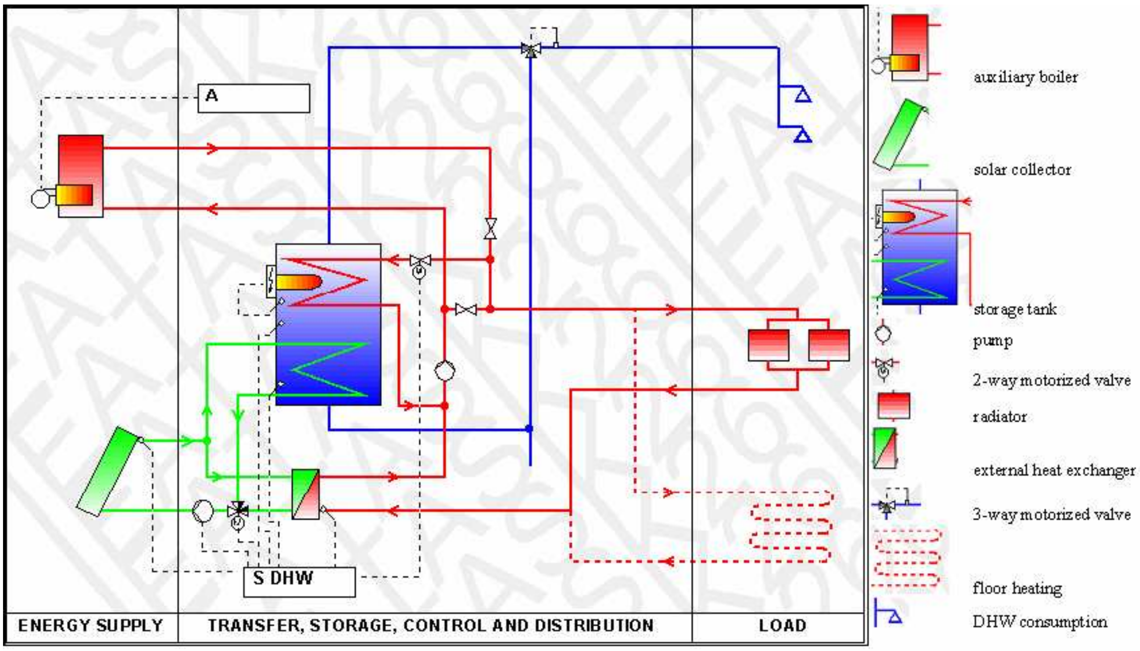


Fig.3 Layout of experimental installation

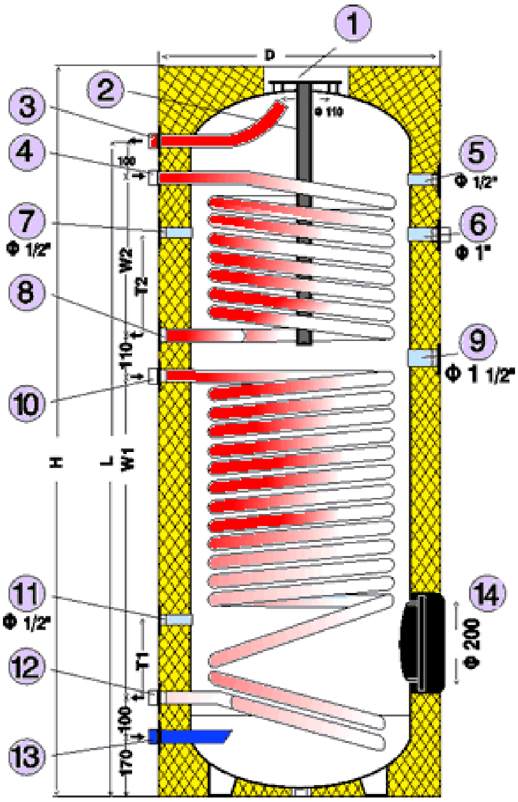
Since the working fluid of the collector loop is mostly not water but a mixture of water and "glycol" the solar energy is transferred by a heat exchanger into the store. Also, since the hot water consumption cannot be fully covered by the solar energy, an auxiliary heater is necessary. In our case it is achieved by an internal second heat exchanger, which is connected to the space heating boiler system. A necessary electrical heater is not integral part of our storage tank.

Mains connection and hot water outlet are considered as a pair of two pipes that belong to the same circuit. It is assumed, that the mass of water in the store is constant, so that the mass flow rates in both connections (in and out of the store) are equal. The inlet and outlet positions are placed at any arbitrary height of the store. If the inlet is placed below the outlet, then the flow direction is upwards (positive). If the inlet is above the outlet, the flow direction is downwards (negative). Stratified charging can be selected or not. In our case, if the store temperature at the inlet position is higher than the temperature of the water used for charging, in reality it is possible that the incoming water will sink down till it reaches a zone with the same temperature.

The heat loss capacity rate from the store to the ambient can be specified individual for the bottom and top of the store. We have chosen a uniform heat loss capacity rate. The heat capacity of the fluid in the heat exchangers is taken into account. All temperatures are calculated by solving a set of differential equations.

4 Results

To estimate the influence of storage tank main design parameter (storage volume) on the solar combisystem behaviour we use a characterisation factor, the fractional energy savings. The definition gives the fractional energy savings based on the saved fuel input of the solar combisystem compared to the reference heating system. This reference



1. Auxiliary flange
2. Magnesium anode
3. Hot water outlet
4. Inlet of space heating water
5. Thermostat position (point of temp measurement)
6. Recirculation connection
7 Heat exchanger's sensor position (point of temp measurement)
8. Outlet of space heating water
9. Electric resistance position
10 Solar loop inlet
11. Heat exchanger's sensor position (point of temp measurement)
12. Solar loop outlet
13. Cold water inlet
14. Side flange

Fig.4 Schematic draw of the storage tank of Renewable Energies Laboratory installation

Storage capability	420	lt
Net height	1570	mm
Net diameter	603	mm
Insulation thermal conductivity (expanded PUR foam)	0.028	W/mK
SOLAR HEAT EXCHANGER		
Heat transfer surface	1.35	m^2
DHW production *	220	l/h
BOILER HEAT EXCHANGER		
Heat transfer surface	1.06	m^2
Hot water production **	850	l/h

- for solar fluid temperature 80°C, 3.2 m^3/h & DHW temp diff 20°C
- for space heating fluid temperature 80°C, 3.2 m^3/h & temp diff 35°C

Table 1. Storage tank data

system, as prescribed for the research in IEA SHC Task 26 [7], included a domestic hot water tank with annual heat losses equal to 644 kWh and a boiler with an efficiency of 85%, but of course another one can be used (as it happens in our research).

$$f_{sav} = 1 - \frac{\dfrac{Q_{boiler}}{\eta_{boiler}} + \dfrac{Q_{el,heater}}{\eta_{el,heater}}}{\dfrac{Q_{boiler,ref}}{\eta_{boiler,ref}}} = 1 - \frac{E_{aux}}{E_{ref}}$$

with:
Q_{boiler} = thermal energy load of auxiliary boiler
$Q_{boiler,ref}$ = thermal energy load of the reference system
η_{boiler} = mean annual efficiency of auxiliary boiler

$\eta_{boiler,ref}$ = mean annual efficiency of the reference heating system

$Q_{el,heater}$= thermal energy load of electrical heating element

$\eta_{el,heater}$= mean annual efficiency of electrical heating element:

- 40% for systems that do not apply solely renewable energy sources
- 90% for systems that apply solely renewable electrical energy sources

E_{aux} = auxiliary energy consumption for a solar combisystem

E_{ref} = final energy consumption for the reference system boiler

The main result of the sensitivity analysis is, that f_{sav} is increasing with increasing store volume until the additional heat gains from solar equal the thermal heat losses of the store. The increase of f_{sav} can be seen only for relatively (to the collector area and the necessary load) small store volumes. This behaviour is shown in Fig. 5 and in Fig.6 for different tilt angles.

In Fig. 5, if we try to access the curve we would have the following polynomial function and the relevant regression factor.

$$y = -1E\text{-}07x^2 + 0.0002x + 0.5616$$
$$R2 = 0.9965$$

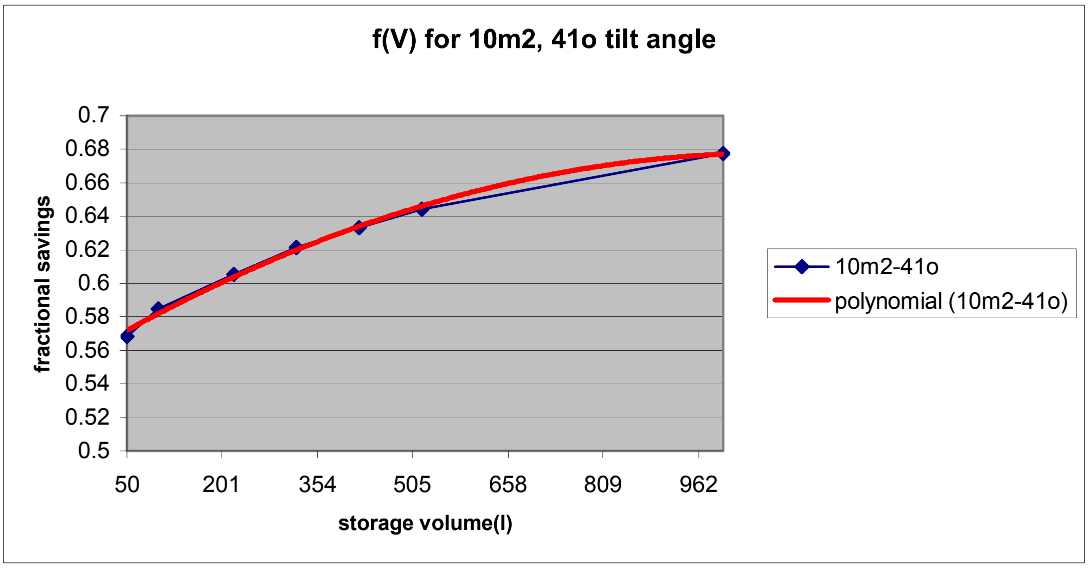


Fig.5 Dependency of f_{sav} on store volume

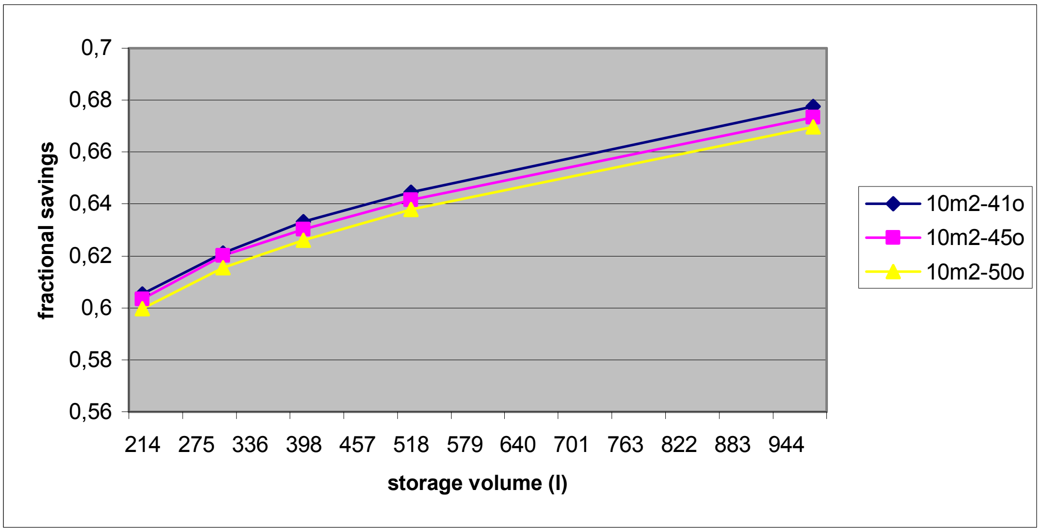


Fig.6 Dependency of f_{sav} with store volume for a certain collector area and different slopes

The optimum values for the store volume are dependent on heat load, collector area and of course on cost details. The higher the collector area the higher is the optimum store volume, as it is shown very well in Fig.7.

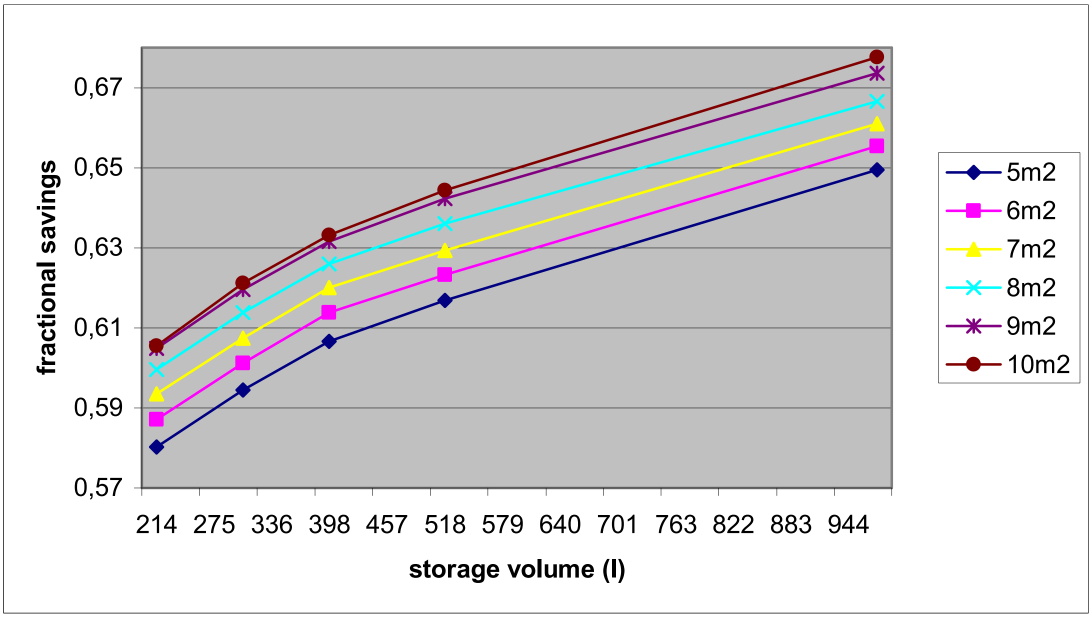


Fig.7 Dependency of f_{sav} with store volume for different collector areas

5 Conclusion

As we can see from our analysis, the fractional savings increase rapidly up to the volume of 420 litres and then continue to increase but with a much lower rate. That leads us to the fact that for single-family houses larger storage tanks cannot contribute in substantial energy savings with a rational cost. However the stratification succeeded in that magnitude of storage volume optimizes the system operation in comparison with non-stratified systems as we need different supply temperatures for different heat loads. In the examined range we have to introduce the proper collector area with insignificant tilt or azimuth preferences as a broad range of them can be used. Research is going on in the area of stratified storage tanks and we believe that our research would contribute significantly in that direction, in order to improve the efficiency of solar combisystems.

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