

## **TEST AND COMPARISON OF HOT WATER STORES FOR SOLAR COMBISYSTEMS**

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### **ABSTRACT**

Four hot water stores for combined domestic hot water preparation and space heating, so-called solar combistores, were investigated in detail. The thermal performance of these combistores was determined on the basis of prEN 12977-3.

In this article the principle structure of this test method, which was mainly developed at ITW, is described. The schematic setup of four particular combistores is explained and the test results are presented. The thermal behaviour of the combistores in a solar heating system is investigated and compared by means of system simulations. The results obtained for the different combistores are presented and discussed.

### **1. INTRODUCTION**

Systems for combined domestic hot water preparation and space heating have an increasing market share in many European countries. In Germany approximately one third of the solar heating systems sold for one family houses and multiple family dwellings are combisystems. For those systems the heat store is the key component, since it is used as a short-term store for solar energy and as a buffer store for the fuel or wood boiler. In a comparison test of German combisystems for a consumers' magazine different combistores were examined in detail.

### **2. STORE TEST METHOD**

The test method for combistores has been further developed from the test procedure for solar domestic hot water stores, which was presented at EuroSun 96 [1] and is now available as prEN 12977-3. The objective of store testing, as described in this standard, is the determination of parameters which can be used in combination with an appropriate numerical model, for the detailed description of the dynamic thermal behaviour of the store.

The test method can be subdivided into the three following steps:

- Performing the appropriate test sequences according to prEN 12977-3 with the store connected to the test stand. During the operation of the store temperatures and volume flow rates at the inlet and outlet as well as the ambient temperature are measured and recorded.
- Identification of parameters that are required in order to describe the thermal behaviour of the store in combination with an appropriate numerical model.
- Verification of the determined parameters by 're-simulation' of a verification sequence.

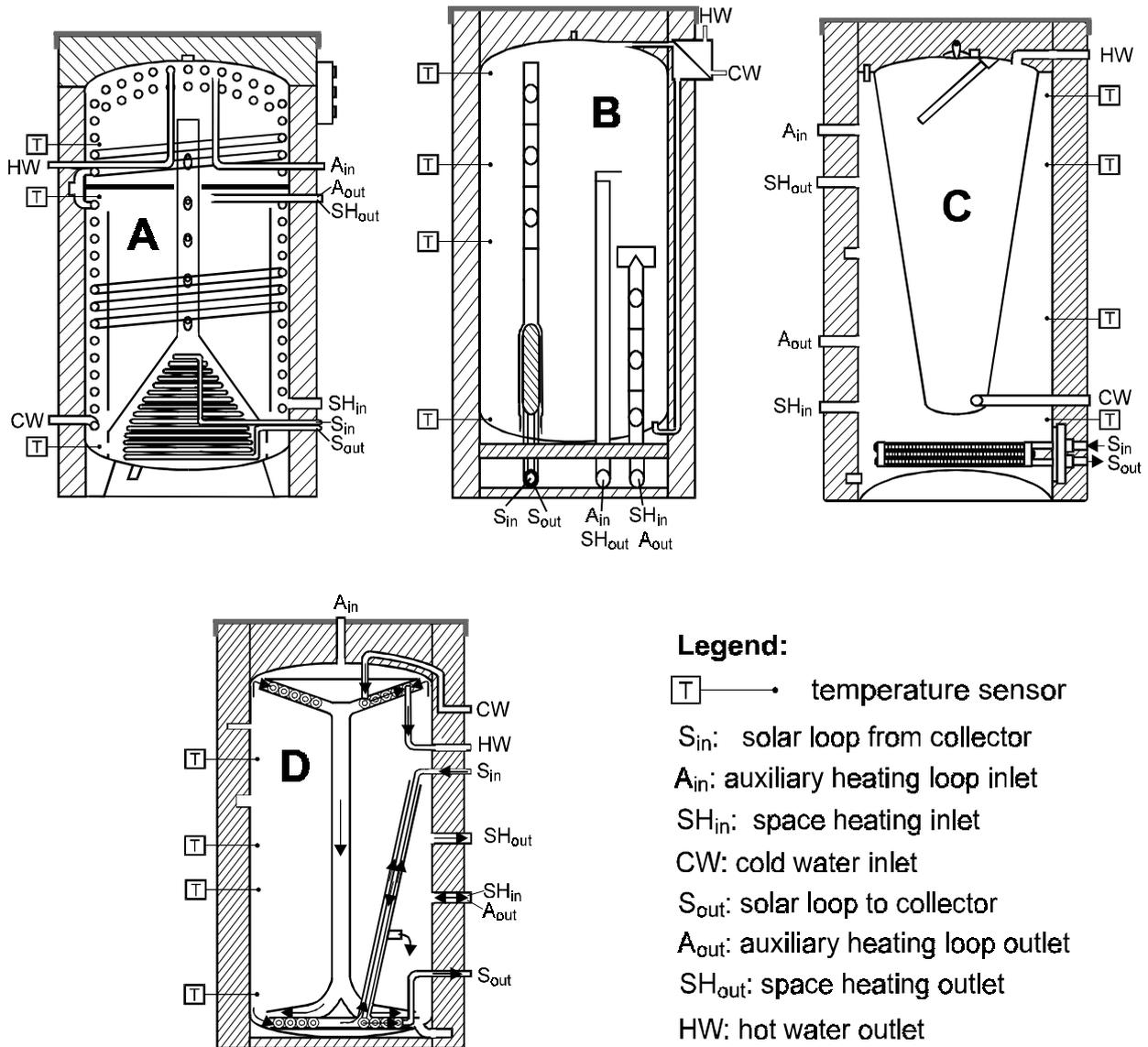
### 3. INVESTIGATED COMBISTORES

From the ten combistores tested, four typical ones were chosen for the following comparison (see Figure 1). The stores are thermally charged via an immersed heat exchanger. The domestic hot water preparation is also performed via an immersed heat exchanger (except for store B). For thermal insulation prefabricated pieces of foam are used. They are mounted after the store has been set up.

The peculiarities of the stores are described in the following:

**Store A:** For stratified charging a pipe with horizontal outlets is mounted above the solar loop heat exchanger. Due to the relatively large openings at the bottom of the stratification device the flow rate on the secondary side (inside the store) is two to three times as large as the flow rate through the solar loop heat exchanger.

For the preparation of domestic hot water a smooth tube heat exchanger made from copper is mounted on the inside surface of the store. The part of the store used as the auxiliary part for domestic hot water preparation is separated from the space heating part by a horizontal plate. This plate shall reduce the degradation of thermal stratification due to a reduction of the vertical heat transfer.



**Figure 1:** Schematic setup of the four investigated combistores

**Store B:** For stratified charging a pipe with horizontal openings which are equipped with flaps, is placed above the solar loop heat exchanger. In order to provide the high temperatures, which are required for building up a good stratification, this store has to be connected to a system where the collector loop works according to the lowflow principle.

The water returning from the space heating loop is also supplied to the store via a pipe with horizontal openings equipped with flaps.

The domestic hot water is prepared by means of a plate heat exchanger which is mounted outside the tank within the thermal insulation of the store.

**Store C:** This store is a so called 'tank-in-tank-store' since there is a second, smaller tank inside the main store containing the domestic hot water. The thermal energy is transferred to the domestic hot water via the surrounding water of the space heating loop.

The solar energy is supplied to the store via a horizontally mounted finned tube heat exchanger made from copper.

**Store D:** The solar loop heat exchanger as well as the domestic hot water heat exchanger of this store are equipped with devices for stratified charging and discharging, respectively. In order to provide the high temperatures which are required for building up a good stratification, this store has to be connected to a lowflow system.

#### 4. COMPARISON OF THE COMBISTORES

As a result of store testing, several parameters are determined which are required to describe the thermal behaviour of the store in combination with the numerical model 'MULTIPORT'. Some of these parameters, e. g. the heat loss capacity rate, can be compared with each other and assessed in a direct way. Other parameters, such as the vertical positions of the connections for direct charging and discharging as well as the positions of the temperature sensors are also important for the thermal behaviour of the store, since these parameters determine e. g. the volume of the auxiliary heated part or the buffer volume. However, these parameters cannot be compared or assessed in a direct way.

Figure 2 shows the domestic hot water draw-off profiles of the four combistores as well as the temperatures measured at the individual positions of the temperature sensors.

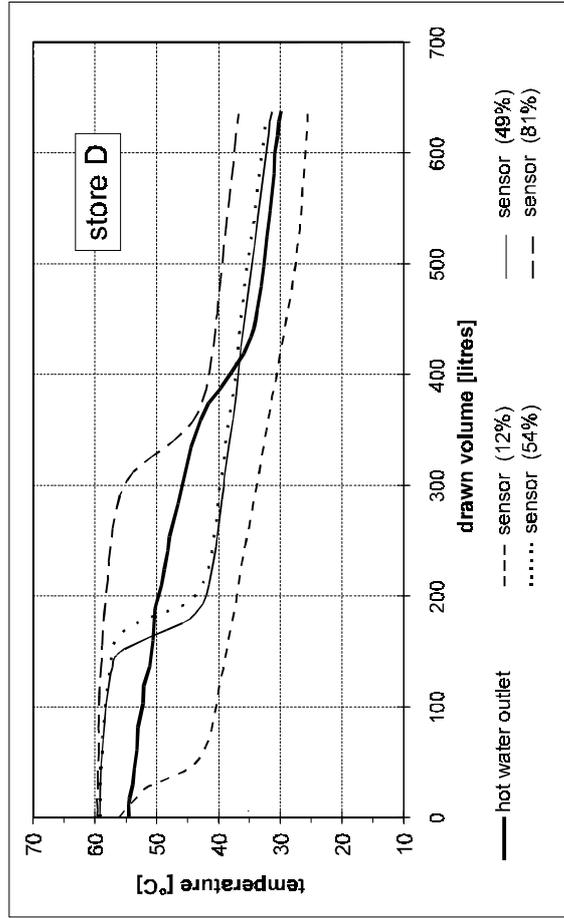
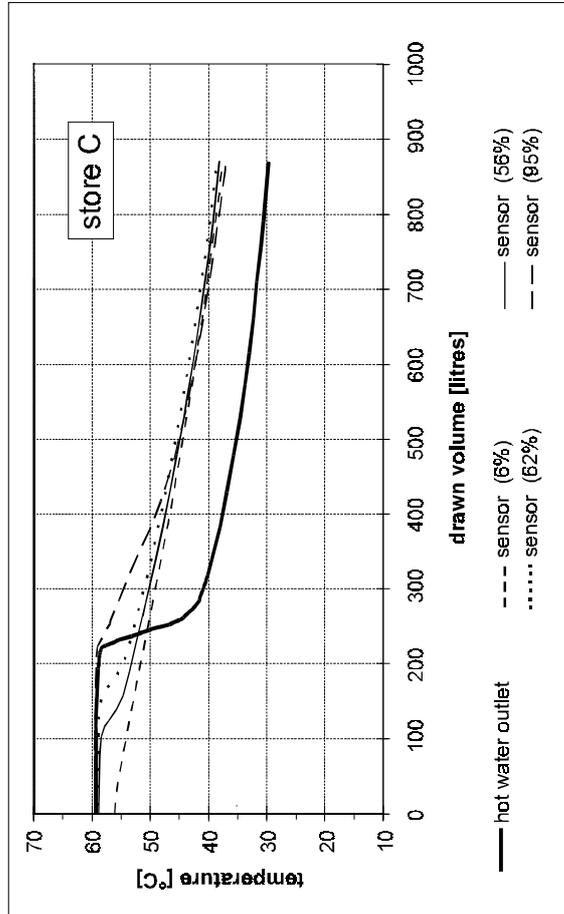
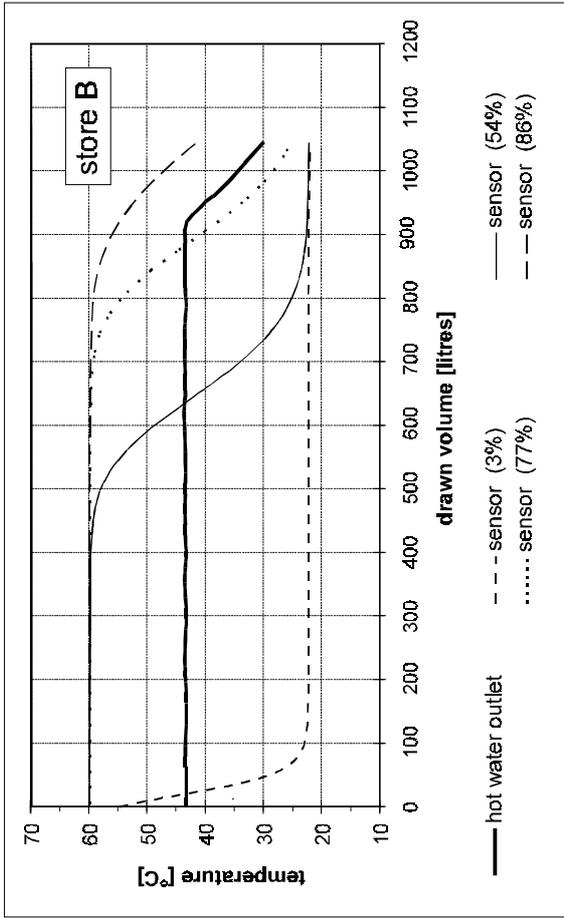
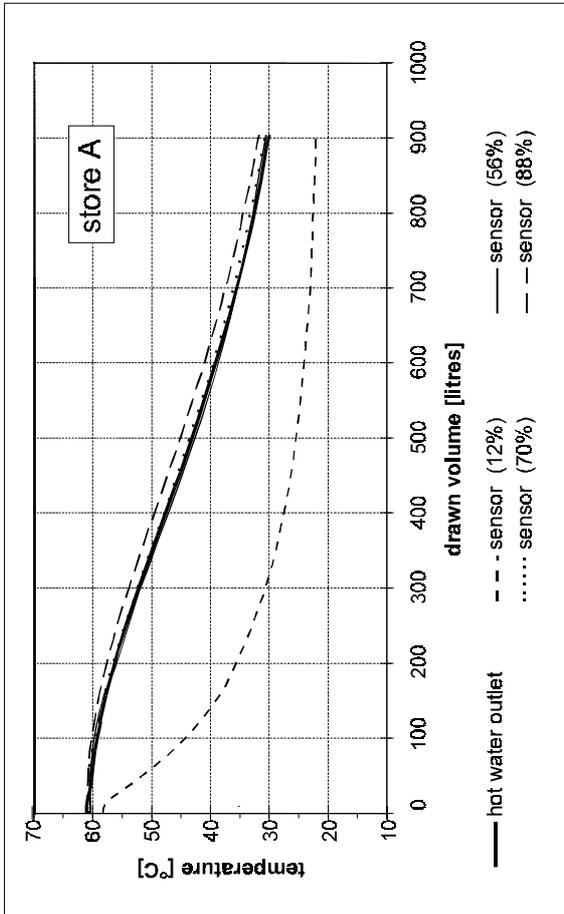
These tests were performed as follows:

- Charging the complete store with an inlet temperature of 60 °C until the outlet temperature at the bottom of the store exceeds 55 °C.
- Discharging via the domestic hot water loop with a flow rate of 600 l/h and an inlet temperature of 20 °C until the hot water outlet temperature drops below 30 °C.

In order to compare and assess the different draw-off profiles the following two effects have to be taken into account:

- Thermal stratification inside the store.
- Difference between the domestic hot water outlet temperature and the temperatures inside the store.

The draw-off profiles of the four stores presented in Figure 2 show, that the thermal stratification during discharge is nearly perfect for store B. Comparing the stratification during discharge for the stores with an internal heat exchanger for domestic hot water preparation (stores A, C, D) the stratification is the best for store D. However, the temperature difference between the domestic hot water outlet temperature and the temperature inside the store is also the largest one.



**Figure 2: Hot water outlet temperature and store temperatures during the discharge of the completely charged stores (vertical position of the temperature sensors in [%] of the height of the store)**

Considering the store as a whole, a complete comparison of the stores can only be carried out by means of system simulation. Therefore the different stores are included in a 'standard combisystem' with 10 m<sup>2</sup> flat plate collector area. With respect to space heating this system is a preheating system, with the boundary conditions described in [2].

The performance of the combistores is assessed by using the predicted yearly fractional energy savings. This quantity specifies the percentage of energy that can be saved by using a solar combisystem instead of a conventional system for space heating and domestic hot water preparation.

In order to cover the domestic hot water load on days without solar input, a certain amount of energy has to be stored in the auxiliary part. Since the performance of a combistore depends on the energy stored in the auxiliary part, the set temperature for auxiliary heating  $T_{aux,set}$  was adjusted in such a way that the domestic hot water load could just be covered. Auxiliary heating was performed with a flow rate of 450 l/h and an inlet temperature that is 5 K above  $T_{aux,set}$ .

Table 1 shows the effective store volume  $V_s$ , the effective vertical thermal conductivity  $\lambda_{eff}$ , the volume heated by auxiliary energy for domestic hot water preparation  $V_{HW,aux}$  and the overall heat loss capacity rate  $(UA)_{s,a}$  as the most important parameters determined from the test of the store. Furthermore the obtained auxiliary heating set temperatures  $T_{aux,set}$  is listed. In order to take into account the influence of the flow rate in the collector loop, the fractional energy savings  $f_{sav}$  are predicted for both highflow (50 l/(hm<sup>2</sup>)) and lowflow (12 l/(hm<sup>2</sup>)) operation of the collector loop.

For stores A to D the maximum deviation of  $f_{sav}$  is 2.5 % (absolute), which corresponds to approximately 470 kWh or approximately 12 % relative difference in  $f_{sav}$ . However, these are the results determined for the stores physically existing.

store	$V_s$ [litre]	$\lambda_{eff}$ [W/(mK)]	$V_{HW,aux}$ [litre]	$(UA)_{s,a}$ [W/K]	$T_{aux,set}$ [°C]	highflow $f_{sav}$ [%]	lowflow $f_{sav}$ [%]
A	693	1.80	208	3.43	54	20.8	20.0
B	769	1.01	231	2.53	49	20.2	20.8
C	755	1.71	128	3.59	43	20.2	19.2
D	549	1.06	104	3.48	52	18.3	18.3

**Table 1:** Test results and predicted fractional energy savings

In order to investigate the influence of the store design itself (e. g. positions of the connections, stratification devices), additional simulations were carried out using a uniform  $(UA)_{s,a}$ -value of 2.5 W/K and a store volume of approximately 750 litres for all four stores. The results of these simulations (store A\* to D\*) are listed in Table 2. Now the maximum difference in  $f_{sav}$  is halved. However, there is still a difference of 1.3 % (absolute).

For store A\*  $f_{sav}$  increases by 0.2% (absolute) and for store C\* by 0.8 % (absolute) due to a smaller  $(UA)_{s,a}$ -value resulting in lower heat losses. For store B\* a homogeneous  $(UA)_{s,a}$ -value of 2.5 W/K results in a decrease of  $f_{sav}$  by 0.3 % (absolute). This is due to the fact that for the store tested, the heat loss capacity rate was not uniformly distributed over the surface of the store since the insulation at the top and the mantle was thicker than the one at the bottom. The overall  $(UA)_{s,a}$ -value of this store was determined to 2.5 W/K. Hence a homogeneous  $(UA)_{s,a}$ -value of 2.5 W/K causes higher heat losses.

store	$V_s$ [litre]	$\lambda_{\text{eff}}$ [W/(mK)]	$V_{\text{HW,aux}}$ [litre]	$(UA)_{s,a}$ [W/K]	$T_{\text{aux,set}}$ [°C]	highflow $f_{\text{sav}}$ [%]	lowflow $f_{\text{sav}}$ [%]
A*	693	1.80	208	2.50	54	21.0	20.2
B*	750	1.01	225	2.50	49	19.9	20.5
C*	755	1.71	128	2.50	43	21.0	20.1
D*	750	1.06	143	2.50	50	19.7	19.7

**Table. 2:** Predicted fractional energy savings with a  $(UA)_{s,a} = 2.5$  W/K and  $V_s \approx 750$  litres.

Regarding store D\* there is a total increase of  $f_{\text{sav}}$  by 1.4 % due to a lower  $(UA)_{s,a}$ -value and a larger store volume (1 % is due to the lower  $(UA)_{s,a}$ -value and 0.4 % due to the larger store volume). However, the use of this store still leads to the lowest value of  $f_{\text{sav}}$ . This is mainly due to the positions of the connections for the space heating loop and the auxiliary heating loop outlet ( $A_{\text{out}}$ ). For an optimal configuration of these connections the performance increases by approximately 1 % (absolute).

It is well known that good lowflow concepts as well as small auxiliary volumes and low auxiliary heating set temperatures are leading to higher fractional energy savings. But why is it store A\* with almost the largest auxiliary volume and the highest set temperature that performs quite good under highflow conditions?

The reason is the large heat transfer capacity rate (under highflow conditions) and the effective working stratification device of the solar loop heat exchanger. However, further simulations showed that for lowflow operation  $f_{\text{sav}}$  could reach approximately 21.3 % if the heat transfer capacity rate of the solar loop heat exchanger did not decrease by a factor of two for lowflow conditions and if the stratification device was optimised.

## 5. CONCLUSIONS

Four combistores were tested and their performance in combination with a standard solar combisystem was compared. It can be concluded that the most important parameters for a well performing combistore are low heat losses due to a good thermal insulation. A well dimensioned (as small as possible with respect to hot water comfort) auxiliary volume in combination with a low set temperature due to a high heat transfer capacity rate of the heat exchanger used for domestic hot water preparation.

In order to keep the collector inlet temperature as low as possible, the heat transfer capacity rate of the solar loop heat exchanger should be large (approximately 80 W/K per m<sup>2</sup> collector area). Furthermore the connections for the auxiliary and the space heating loop should be on the appropriate positions.

Only if these requirements are fulfilled, it is advisable to use certain devices for stratified charging or discharging in order to achieve an additional performance increase.

## ACKNOWLEDGEMENTS

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