INFLUENCE OF DIFFERENT CHARGE AND DISCHARGE STRATEGIES ON THE PERFORMANCE OF MEDIUM-SIZED SOLAR COMBISYSTEMS

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ABSTRACT

The influence of thermal stratification in the storage tank on the performance of medium-sized solar combisystems was investigated. Combisystems for single family houses with a storage volume of 3 m³ and a collector area of 20 m² were taken into account. Annual system simulations were carried out with the simulation tool TRNSYS.
In order to enhance thermal stratification in the storage tank, it was assumed that the water of each loop is able to enter the store in two different heights, instead of having just one fixed inlet position for each loop. Thus one valve each is needed for the collector loop and the space heating loop. It was found that the impact of these valves on the fractional energy savings $f_{sav,ext}$ of the investigated systems is relatively small. Depending on the reference conditions, $f_{sav,ext}$ could be increased by up to 0.8 %-points.

1. INTRODUCTION

Nowadays the majority of solar combi tanks in Europe are equipped with stratification devices in order to increase thermal stratification in storage tanks of solar combisystems –solar heating systems used for both, **D**omestic **H**ot **W**ater (DHW) preparation and **S**pace **H**eating (SH). These devices can either be internal ducts, plates, or perforators, placed inside the store, or valves, to direct the water to different storage connections from outside the tank.
The influence of these stratification devices depends strongly on the boundary conditions of the systems. Some devices even have a negative impact on the system performance, since heat losses are increased, parasitic flows are induced inside the tank or heat conduction of the stratification devices inside the tank degenerate the thermal stratification. Moreover, even if the stratification device functions well, the impact of enhanced stratification for water entering the store can be much smaller than generally expected.

In earlier studies it was found that for a small combisystem with a store volume of about 870 litres (A_{col} = 14 m²), the space heating loop influences the storage stratification predominantly, due to the large heat surplus during summertime and comparable large mass flow rates during the space heating season. Therefore, stratification devices for the water heated by the collector loop had very little impact on the overall system performance (Jordan and Vajen (2)). A minimum value for the difference of the fractional energy savings with one and six inlet heights, of about $\Delta f_{sav,ext}$ = 0.2 %-points was found. However, $\Delta f_{sav,ext}$ depends strongly on the reference conditions and parameter settings of the solar heating system. Lorenz et al. (5) investigated the influence of a stratification device for the space heating return flow on a typical Swedish combisystem of a similar size (V_{store} = 750 litres, A_{col} = 10 m²). He found that the effect of using an ideally stratified return inlet instead of one fixed inlet accounted for a small improvement of the thermal performance for low space heating return temperatures (25 °C) and for moderate improvements for higher space heating return temperatures (45 °C).

A general trend in Europe is that solar combisystems are becoming larger. In the following, a simulation study of a solar combisystem with a collector area of 20 m² and a storage volume of 3 m³ is presented. The influence of valves installed to enhance thermal stratification are elucidated, for different collector flow rates (high-flow, low-flow), design temperatures of the space heating loop, and with or without taking into account a domestic hot water circulation line. Moreover, the question whether the enhancement of thermal stratification in systems with larger stores leads to similar improvements of the performance is tried to be answered.

2. SYSTEM SIMULATIONS

2.1 Hydraulic Scheme and Reference Conditions

The hydraulic scheme for the investigated solar heating system is shown in Fig. 1. External heat exchangers are applied for both, the collector loop and domestic hot water preparation,. The storage water used to heat domestic water is taken from the top of the store and returned at the bottom. The upper part of the store is used as auxiliary volume with a temperature of 70 °C. A condensing gas boiler is used as auxiliary energy source. The water flowing into the space heating loop is taken from the lower part of the auxiliary volume. The optional circulation line has a length of 15 m and needs an additional pump. It starts from the hot water line shortly before the tapping points and joins the cold water line just before this enters the DHW heat exchanger. The reference conditions for the investigated solar heating system are listed in TABLE 1 and TABLE 2.

The inlet heights for the pipes coming from the collector loop were determined according to Heimrath (1). In his simulation study, he found an equation that gives optimised inlet heights depending on the store geometry. The height of the upper inlet for the space heating return of 0.4 was found to be the optimum after running a number of simulations with different inlet heights. For the remaining inlets, standard values as used in previous studies (1,6) were taken (see Fig. 1).

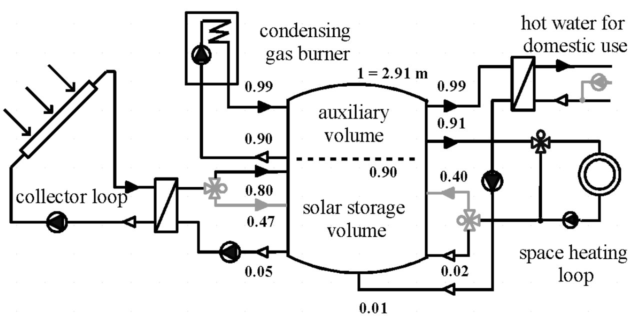

Fig. 1: Hydraulic setup of the investigated solar combisystem and the optional components (in grey) for the strategies with circulation line and the valves in the collector loop and space heating loop. The numbers show the height of each inlet relative to the full height of the store of 2.91 m.

2.2 The Simulation Tool

The simulations described in the following were done with the simulation tool TRNSYS (3). The "Template Solar Combisystem" that was defined within IEA-SHC Task 32 was used for the simulations. This system model was transferred at Kassel University from the available text-based version into Studio, the graphical user interface of TRNSYS 16 (4).

TABLE 1: Reference Conditions for the BASECASE

collector area:	20 m²
auxiliary volume:	0.3 m³
total store volume:	3 m³
UA-value of store:	8.1 W/K
DHW supply temp.	45 °C
DHW demand:	200 l/day (in total 3,040 kWh/a)
space heating demand:	8,440 kWh/a (with a max. power of 4.6 kW)
design temp. of SH loop:	40 °C/35 °C
auxiliary energy:	condensing gas boiler of 10 kW
set temp. for auxiliary volume:	70 °C
location:	Zurich
orientation:	South
tilt angle:	45°

2.3 Definition of Fractional Energy Savings

The parameter "extended fractional energy savings" ($f_{sav,\,ext}$) is used as indicator for the performance of the solar thermal systems. In the frame of IEA-SHC Task 26 it was defined as the saved "combined total energy consumption of the solar combisystem" (E_{total}), compared to the "combined total energy consumption of a reference system" without solar assistance ($E_{total,ref}$) (6):

$$f_{sav,ext} = 1 - \frac{E_{total}}{E_{total,ref}}$$

This definition not only takes into account the auxiliary energy consumption of the systems, but also the parasitic energy consumption for pumps and controllers.

2.4 Charge and Discharge Strategies

In several steps, the charge and discharge strategy is improved with the aim to enhance thermal stratification in the store (see Fig. 1). The strategies are as follows:

- strategy **no-valves:** One fixed inlet connection for each loop.
- strategy **valve-solar:** The fluid heated by the collector loop in the heat exchanger enters the store in two different fixed heights, depending on the temperature difference between the fluid entering the store and the temperature in the bottom of the store.
- strategy **valve-SH:** The fluid returning from the space heating loop is fed into the store at two different heights. As for strategy **valve-solar**, the switch between upper and lower level depends on the temperature difference between the fluid entering the store and the temperature in the bottom of the store.
- strategy **valve-solar&SH:** The effect of using both valves from strategies **valve-solar** and **valve-SH** together is tested.
- strategy **ideal:** All relevant inlets are assumed to work as ideal inlet stratifiers in order to access the maximum possible $f_{sav,ext}$ thanks to a well stratified store.

In order to find out whether the influence of the charge and discharge strategy is the same with changed boundary conditions, a sensitivity analysis with the parameter settings as listed in TABLE 2 is carried out.

TABLE 2: Parameter Settings for the Sensitivity Analysis

parameter	BASECASE	new value
flow rate in the collector loop in l/m²h:	15	35
design temp. for SH loop in °C:	45/35	55/45
running time of circulation line in h/day:	0	8

2.5 System Simulation Results

The annual system simulation with the reference conditions and strategy **no-valves** yields to a fractional energy savings $f_{sav,ext}$(ref,0) of 32.7 %.
All simulation results presented in the following will be compared to this reference value.

In Fig. 2 the differences $\Delta f_{sav,ext}$ of the calculated values $f_{sav,ext}$ and the reference value, $\Delta f_{sav,ext} = f_{sav,ext} - f_{sav,ext}$(ref,0), is shown over the number of strategies.

The curves show simulations carried out
A: with the BASECASE reference conditions
B: with a collector flow rate of 35 l/min (high-flow)
C: with slightly higher design space heating temperatures
D: taking into account a domestic hot water circulation line
E: all parameters **B** to **D**

A: Low-flow, SH 40/35, no circulation line
Both valves yield to a similar increase of $f_{sav,ext}$. For the valve in the collector loop these are 0.3 %-points and for the valve in the space heating loop these are 0.4 %-points. This corresponds to a decrease in E_{total} of 46 kWh/a and 57 kWh/a, respectively. If both valves are in operation simultaneously, $f_{sav,ext}$ increases by 0.5 %-points compared to $f_{sav,ext}$(ref,0), for ideal stratification by 1.4 %-points.

B: High-flow, SH 40/35, no circulation line
For high-flow, the collector loop marks the predominant influence on the thermal stratification in the tank. A high decrease of $f_{sav,ext}$ compared to the BASECASE is observed ($\Delta f_{sav,ext}$ = 2 %-points), which is also partly due to the higher electricity consumption of the collector pumps with higher flow rates.

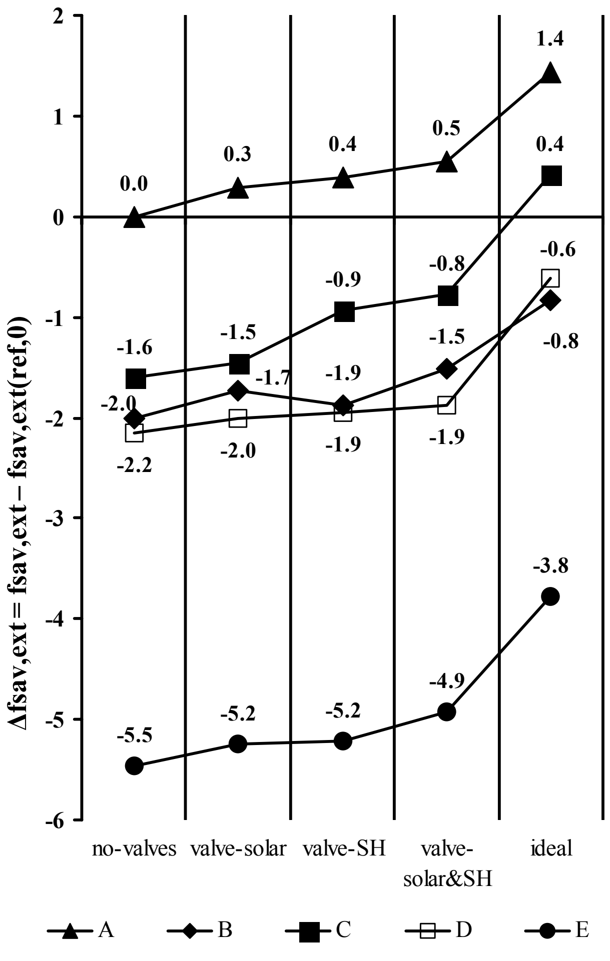

Fig. 2: Change of $f_{save,ext}$ with changed charge and discharge strategy and different parameter settings. To denote clearly values that arose from the same reference conditions, the symbols are connected with a line. This does not implicate any prediction about other strategies than the ones listed above.

The influence of the valve in the collector loop (strategy **valve-solar**) has approximately the same effect as in **A** (BASECASE), while the valve in the space heating return (strategy **valve-SH**) yields to only very small improvement ($\Delta f_{sav,ext}$ = 0.1 %-points). This is because the higher flow rate in the collector loop leads to a greater mixing in the store. This destroys the positive effect the valve in the space heating return has on thermal stratification in the store. Therefore the simultaneous use of both valves (strategy **valve-solar&SH**) also does not result in a significantly higher increase in $f_{sav,ext}$ than using the valve in the collector loop only.

C: Low-flow, SH 55/45, no circulation line

When the design temperature for the space heating loop is increased, the space heating loop predominates the thermal stratification in the tank. Due to the higher temperature of the return flow into the store the temperature in the bottom of the tank is higher. This leads to a reduced collector gain which results in a considerable drop of $f_{sav,ext}$ of 1.6 %-points (in comparison to $f_{sav,ext}$(ref,0)). With both valves in operation, $f_{sav,ext}$ increases by 0.8 %-points, whereas the impact of the valve in the collector loop is negligible ($\Delta f_{sav,ext}$ = 0.1 %-points from strategy **no-valves** to **valve-solar**). At least a part of the reduction in $f_{sav,ext}$ can thus be compensated by the valves.

With ideal stratification a significant increase of 2 %-points compared to strategy **no-valves-C** could be reached.

D: Low-flow, SH 40/35, with DHW circulation line

With a circulation line in operation, a considerable amount of heat is lost in the additional piping. This can only partly be covered by additional solar energy gains during summer. For all strategies $f_{sav,ext}$ is smaller than $f_{sav,ext}$(ref,0), mainly because the additional pump in the circulation line also increases the parasitic energy consumption. In general, the circulation line causes a greater mixing of the store. This cannot be compensated by the use of switching valves. Its effect on thermal stratification is even smaller than for **A** (BASECASE). In contrast to that, with ideal stratification a significant increase of 1.6 %-points (compared to strategy **no-valves-D**) could be achieved. Another valve in the return flow from the DHW heat exchanger to the store might help to better utilize this potential. Yet, this was not part of this study.

E: High-flow, SH 55/45, with DHW circulation line

The simultaneous change of all parameters yields the worst system performance. The highest decrease of $f_{sav,ext}$ compared to the BASECASE, is observed ($f_{sav,ext}$(ref,0) = 5.5 %-points). The high flow rates from all loops (the collector loop, the space heating loop and the DHW loop) and the in general higher temperatures of the fluids entering the store constantly degenerate thermal stratification. The use of valves in the collector loop and the space heating loop cannot help much to preserve the thermal stratification. Their impact on $f_{sav,ext}$ is as small as in **A** (BASECASE).

3. CONCLUSIONS

A system simulation study is presented for a medium-sized solar combisystem with a storage volume of $V_{store} = 3\ m^3$ and a collector area of $A_{col} = 20\ m^2$.

The impact of thermal stratification in the storage tank is investigated, induced by two inlet connections to the store for both, the water heated by the collector loop and the space heating water entering the store.

The simulations reveal that the impact of these strategies is below **0.8 %-points** (corresponding to a decrease of E_{total} by 75 kWh/a) for the reference conditions taken into account. This corresponds to the findings of previous studies on small-scale systems. The predicted energy savings potential for ideal stratification compared to the reference with only one inlet pipe in each loop varies between **1.2 %** and **2 %-points** (187 kWh/a to 321 kWh/a).

Meanwhile, the change of the parameter configuration (i.e. the increase of the collector flow rate to high-flow, the increase of the design space heating temperature and the operation of a circulation line) leads to considerable higher impacts of **1.6 %** to **5.5 %-points** compared to the BASECASE reference conditions.

It can be concluded that the investigated parameter and system settings play a more important role than the installation of valves to enhance thermal stratification.

4. REFERENCES

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