Optimisation of large scale solar thermal combisystems in theory and practice

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Abstract

In Germany, large scale solar thermal combisystems (collector area approximately above 70 kW_{th} or 100 m²) for the heat supply of multi-family houses or small district heating net works are not yet state of the art, as demonstrated by the very different designs of existing systems. In this paper, three systems that where monitored in detail over a period of one year are presented. The analysis of the measured data did not detect significant functional problems of the systems; however some improvements for increasing the solar fraction could be identified. The suggested optimisations were verified by system simulations.

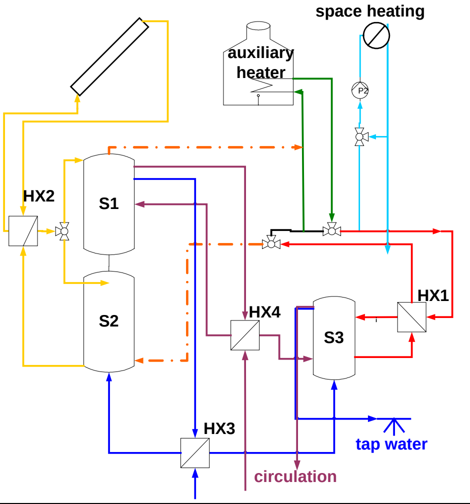
Keywords: solar combisystems, monitoring, optimisation, system simulation

1. Introduction

In one-family houses combisystems – solar thermal systems for domestic hot water preparation and space heating – are already state of the art. However, with regard to the design of large scale solar combisystems (collector area approximately above 70 kW_{th} or 100 m²) for the energy supply of multi-family houses or small district heating net works, there is still some uncertainty. This conclusion can be drawn from the very different designs of existing solar combisystems in Germany. The aim of this research project is the technical improvement of large scale solar thermal combisystems. Within the German research programme “Solarthermie2000plus” the design of large solar thermal combisystems will be further developed and standardised as well as design guidelines will be developped.
Within the present research project six existing and operating systems are monitored in detail. Three of these systems are monitored by ZfS-Rationelle Energietechnik [1]. The other three systems, which are presented in this paper, are monitored by SWT. Some of the identified weaknesses of the systems are explained using the measured data. Recommendations on how to improve the systems are given based on system simulations using TRNSYS [2].

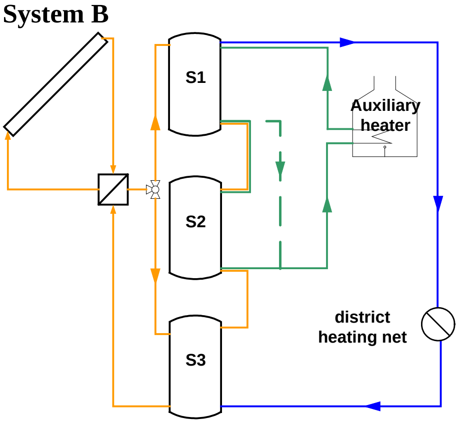
2. System Description

System A



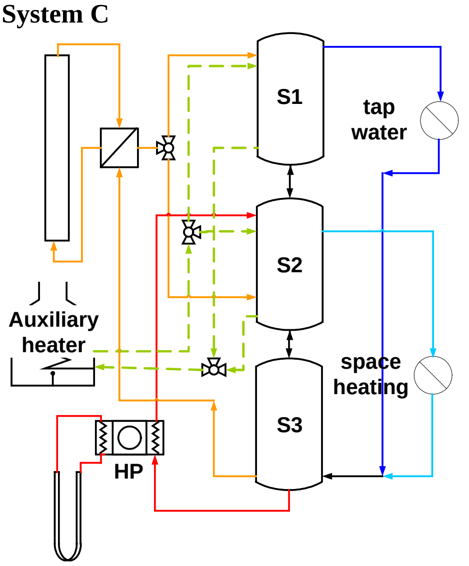
Buffer stores	2 stores, 2,5 m³ each (S1+S2) 1 store, 0,5 m³ (S3)
Collector	64,4 kW_{th} (92 m²), facing SE
Number of flats	28 in one multi-family house
Auxiliary heater	Gas burner
Solar fraction	14 % design value 15 % reached in 2005
Control strategy: solar circuit is operated when collector supply temperature is 8 K higher than lowest buffer store temperature. Depending on the temperature buffer store S1 or S2 is charged. Tap water and circulation are preheated by solar energy via heat exchanger HX3 and HX4 before being supplied to the seperate drinking water store S3. Auxiliary heating by gas burner: S3 in parallel, space heating in seriell.	

System B



Buffer stores	3 stores, 3 m³ each
Collector	98 kW_{th} (140 m²), facing SSE
Number of flats	63 in one multi-family house and several terraced houses
Auxiliary heater	Wood pellet burner
Solar Fraction	12,6 % design value 13 % reached in 2004
Control strategy: solar circuit is operated when collector supply temperature is higher than lowest buffer store temperature. Depending on the temperature buffer store S1 or S3 is charged. In summer only S1 is kept at a certain temperature level by the auxiliary heater (return flow via dashed line), in winter S1 and S2.	

System C



Buffer stores	3 stores, 2 m³ each
Collector	84 kW_{th} (120 m²), façade, facing S
Number of flats	40 in five multi-family houses
Auxiliary heater	Heat pump/five borehole heat exchangers, gas burner
Solar fraction	20 %* design value 7 % reached in 2005 *based on incorrect assumptions
Control strategy: solar circuit is operated when collector supply temperature is higher than lowest buffer store temperature. Depending on the temperature buffer store S1 or S2 is charged with variable flow rate. Buffer store S1 is for tap water heating only, S2 and S3 are for the floor heating system. If the temperature in store S2 is too low, the heat pump starts, afterwards the auxiliary gas burner	

3. Analysis of measuring data and optimisations

In this section some weak points of the systems are explained and suggestions for system optimisation are given. The main focus is placed on System A.

3.1 System A: Collector circuit

Figure 1 shows the typical behaviour of the solar circuit of system A on a sunny day in May 2005. Temperatures in the solar circuit and the buffer stores are shown together with the operating signal of the solar pumps P5 and P6. The sensor locations are shown in figure 2. Pump 5 is switched off for safety reasons if the collector supply temperature TKF exceeds 98 °C. Figure 1 shows that this temperature is frequently reached on this day and the pump is hence switched off. As the temperature TKF is measured at the outlet outside of the collector, it drops quickly down to 80 °C, and the pump is switched on again. This process is repeated very often during the day, the pump is clocking. At the beginning of the clocking at 12:30 pm, the highest buffer store temperature is still far below the maximum temperature of 95 °C. This means that the buffer store is not fully thermally charged, and its heat capacity is not used properly. This could be achieved by allowing a higher switch-off temperature TKF of e.g. 120 °C in the collector circuit. In addition, a switch-off temperature for the buffer store would be necessary, to ensure that the highest temperature in the store does not exceed the maximum temperature of 95 °C.

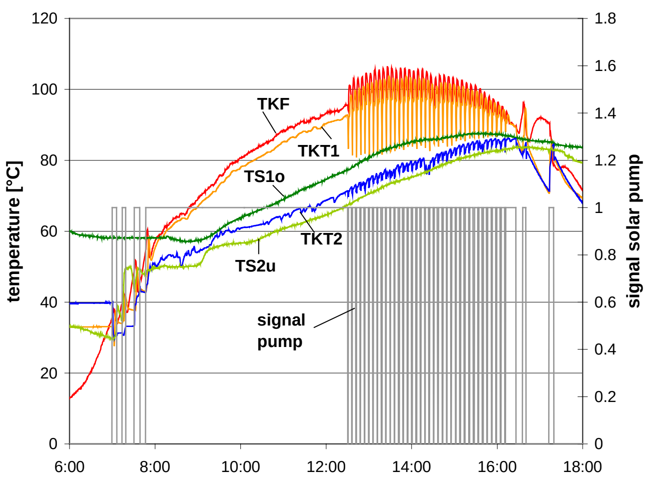
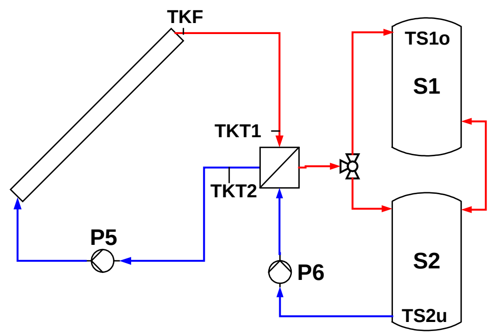


Figure 1: Temperatures in solar circuit and buffer stores, and solar pump signal



TKF: supply temperatur collector
TKT1: supply temperatur solar circuit
TKT2: return temperature solar circuit
TS1o: highest buffer store temperature
TS2u: lowest buffer store temperature

Figure 2: Schematic plan of solar circuit; system A

3.2 System A: hydraulic decoupling of the return temperatures

A weak point in the system is the connection of the space heating return flow VSH and the flow for reheating the domestic hot water buffer store VDHW. Figure 3 shows the important temperatures and flow rates for this process on three days in Oktober 2005. The sensor locations are illustrated in figure 4. The solar buffer stores S1 and S2 are only discharged when the mixing temperature TMix is lower than the medium solar buffer store temperature TS1m. (The dashed line is not yet to be regarded.)

It can be observed that the mixing temperature TMix is mostly above the medium buffer store temperature TS1m on these days, due to the high return temperature TDHW of the domestic hot water heating flow. As this is very often the case in autumn and spring, the solar buffer stores are not discharged properly. In contrast the space heating return temperature TSH is always lower than the medium buffer store temperature TS1m. Therefore the solar buffer stores could be used for preheating the space heating return flow. For improved operation, the two return flows should be seperated. This is shown schematically in figure 4. Instead of flowing from the heat exchanger to point 1, the domestic hot water reheating return flow VDHW should go directly to point 2 in the return pipe of the auxiliary heater (dashed line). In this case, temperature TMix automatically becomes temperature TSH, which means that the solar buffer stores can now be used for preheating the space heating return flow. The drinking water buffer store is still preheated by solar energy via the heat exchangers HX3 and HX4 (see schematic plan in section 2, system A) The effect of this optimisation has been studied by means of system simulations. The results are presented in section 4.

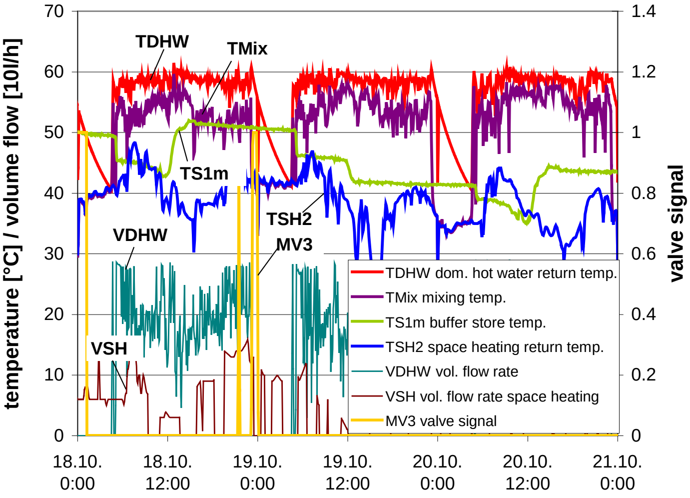


Figure 3: Temperatures and flows for buffer store discharging

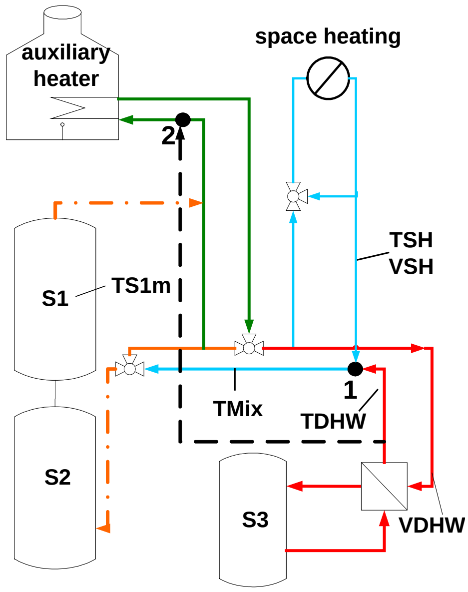


Figure 4: Schematic plan of system A; hydraulic optimisation (dashed line)

3.3 System B: District heating net return flow

The district heating net return flow is always passed through all three buffer stores. As the net return temperature is often higher in winter than the lowest buffer store temperature, the buffer stores are heated up by the net return flow which leads to additional heat losses. An optimised hydraulic design would allow the district heating net return flow to go directly to buffer store S1, if the net return temperature is higher than the lowest buffer store temperature.

3.4 System C: Solar charging of the buffer stores and solar flow rate

Depending on the temperature level, the supply flow of the solar heat exchanger is fed either into buffer store S1 or S2. It was found that the solar inlet of buffer store S2 is located at the bottom of the store. As a consequence of this, the volume of buffer store S2 is not used for storing solar energy but only buffer store S3 is charged by solar energy. This effect could be proved by analysing the measured temperatures in the buffer stores and the corresponding volumetric flow rates. In order to use buffer store S2 effectively it is suggested to place the solar inlet at the top of this store.

Another point in the analysis of the measured data was the flow rate of the solar circuit. It was only 9.2 kg/h per m² collector area instead of the design value of 15 kg/h. This may be one additional reason for the relatively low system performance.

According to the design of system B, the district heating net return flow is led through all three buffer stores. As the buffer stores are used by the heat pump as well, the temperature level is always above the net return temperature. Therfore, this kind of piping is no disadvantage in terms of additional heat losses in this system.

4. System simulation

In this section the simulation results of some of the suggested optimisations are given.

4.1 System A: hydraulic decoupling of the return temperatures

The suggested modification according to section 3.2 was simulated with the commercial software package TRNSYS [2] in two variations. Variation 1 represents the described suggestion exactly and the domestic hot water heating return flow VDHW is always transferred directly to point 2 (see figure 4, dashed line). In variation 2 the return flow VDHW and the space heating return flow VSH can still be mixed if the temperature TDHW is lower than the medium buffer store temperature TS1m. For the simulation, the measured data of system A for the period from February 2005 to January 2006 for solar radiation and environmental temperature as well as return temperatures and flow rates for space heating, domestic hot water and circulation were used as inputs for the simulation. The results are compared in table 1.

Table 1 : Simulation results of system A without (base) and with optimisations (variation 1 and 2)

		base design	variation 1	variation 2
charging buffer store S1+S2 QHX2	[kWh]	24.620	23.850	25.010
auxiliary heater Qaux	[kWh]	165.500	166.600	160.600
space heating QSH	[kWh]	126.100	126.100	126.100
domestic hot water heating QDHW	[kWh]	39.190	39.250	39.240
circulation Qcirc	[kWh]	18.890	18.890	18.890
Discharging Buffer store S1+S2 QSVH *)	[kWh]	6.847	4.952	7.488
solar fraction f_{Sol}	[%]	13,0	12,5	13,5

*) via the dot and dash line as shown in figure 4

The table shows, that the solar fraction of variation 1 is 3 % (relative) below the solar fraction of the base design. In contrast, in variation 2, where the domestic hot water return flow is only partly redirected, the solar fraction is 4 % (relative) higher than the solar fraction of the base design. The solar buffer stores are less discharged in variation 1 because part of the domestic hot water return flow for heating is missing. The discharging heat amount QSVH decreases by 28 % whereas it increases by 9 % using variation 2. These 9 % are solely used for preheating the space heating return flow. So the use of the solar system to preheat the space heating circuit increases by 13 % using variation 2.

4.2 System C: reasons for the low solar gains

The specific solar gain of this system was about 206 kWh/m² in 2005. The system simulation was used to detect the reasons of this result.

At first, the flow rate of the solar circuit was set from the measured 9.2 kg/h per m² collector area to the design value of 15 kg/h per m² collector area. The solar gain of the collectors could be increased by 3 % (relativ) from 206 kWh/m² to 212 kWh/m² per year.

Originally a variable flow rate of the solar charging circuit for the buffer store to keep the supply temperature at 70 °C was planned but not implemented in the system. The simulation of a variable flow rate did not result in a change of the solar fraction.

The minimum solar radiation, when the solar pump is switched on, is 300 W/m². This value was set to 200 W/m² in the simulation. The solar gain of the collectors could be increased by 5 % from 212 kWh/m² to 222 kWh/m² per year. Here the higher flow rate of 15 kg/h per m² collector field was already applied in the simulation.

Another point was the tilt angle of the collector field. As mentioned in the system description in section 2, the system has façade collectors with a slope of 90 °. In the simulation, the tilt angle was varied from 90 ° down to 30 °. For this simulation, a possibly lower heat demand of the buildings, due to an additional thermal insulation by the façade integrated collectors was not taken into account. The result of the simulations can be seen in figure 5. The solar fraction increases from 222 kWh/m² at a tilt angle of 90 ° to 459 kWh/m² at a tilt angle of 30 °. It has to be noted that these considerations are only hypothetically, since the collector tilt angle in this system cannot be changed.

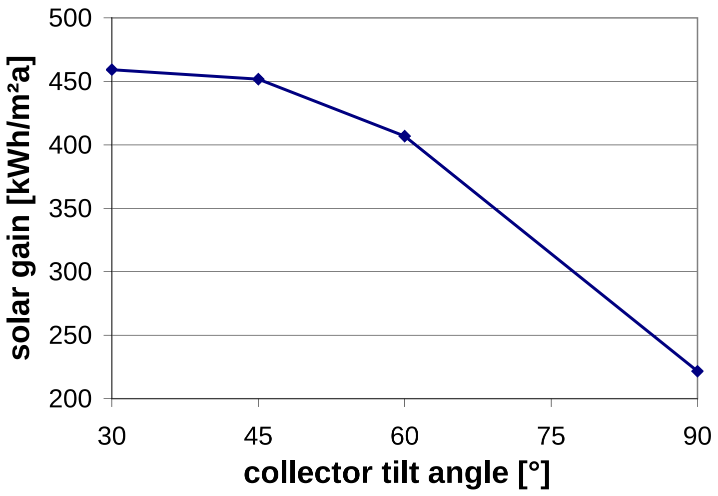


Figure 5: Influence of the collector tilt angle on the solar fraction in system C

5. Summary and future prospects

Within the present project six solar thermal combisystems were monitored in detail. The three systems monitored by SWT did not show serious functional problems. However, the investigations indicated an existing potential for optimisation. This was shown e.g. for system A where a simple modification in the hydraulic design increased the solar fraction by 4 % (relative). Consequently, different return flows should not be mixed - it is better to handle them seperately. Furthermore, by-passing of buffer stores by the return flow with a temperature higher than the lowest buffer store temperature is recommended, in order to avoid additional heat losses especially in winter.

In the next steps of the project all three systems will be further optimised based on system simulations. Furthermore general system designs will be defined to allow recommendations for future solar thermal combisystems. For that purpose, energetic and economic aspects will be considered. Additional information and future results will be available at [3].

References

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