MONITORING RESULTS FROM GERMAN CENTRAL SOLAR HEATING PLANTS WITH SEASONAL STORAGE

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ABSTRACT

Since 1993 research and development on Central Solar Heating Plants with Seasonal Storage is supported in Germany by various federal ministries in the programmes "Solarthermie-2000" and "Solarthermie2000plus". At present eight demonstration plants are in operation and are evaluated in a monitoring programme.

The operational results from all the plants have demonstrated the capability of the solar systems and the individual components. However, especially experiences from the first plants showed a strong dependency between the quality of the conventional part of the heat supply system and the achievable solar yield. Up to now no serious malfunctions have been observed.

The demonstration plants as well as the state of the art of the solar systems and the seasonal heat storage technologies have been introduced and described in presentations at the ISES Solar World Congresses 2001 and 2003 [1-4]. The present paper focuses on three selected plants. It outlines monitoring results like heat balances and evaluations of selected components and boundary conditions. Reasons for reduced solar yields and system efficiencies are discussed.

1. INTRODUCTION

The German Central Solar Heating Plants with Seasonal Storage (CSHPSS) went into operation between 1996 and 2002. Solar collector areas range from 500 m² to 5,300 m² (corresponding to 350 kW to 3.7 MW), volumes of seasonal heat stores are between 1,500 m³ and 63,300 m³. The solar plants deliver heat for domestic hot water preparation and room heating to residential areas. The default design value for the solar fraction is 50 % of the total annual heat demand including distribution heat losses.

The following sections present results of the monitoring programmes of three selected plants: The Friedrichshafen plant was one of the first solar systems with seasonal heat storage in Germany and is in operation for eight years now. The Neckarsulm plant started in 1997. Collector area, storage volume and heat demand is continuously growing since that time. The plant in Rostock is a newer plant from 2000; experiences from previous plants enabled a very efficient system with a high solar fraction. For seasonal heat storage these plants are equipped with a hot water tank built out of concrete, a borehole thermal energy store (BTES) and an aquifer thermal energy store (ATES) respectively.

2. FRIEDRICHSHAFEN

In Friedrichshafen one of the first German solar assisted district heating systems went into operation in 1996, see Fig. 1. The system supplies a residential area that is realized in two phases. At present the second phase has been nearly finished with in total 390 apartments mainly in multifamily houses. Until August 2003 the installed collector area was 2,700 m². At this time it was increased to 3,500 m². In 2004 there was a second enlargement to 4,050 m² (2.8 MW). The ultimate collector area of the residential area was formerly planned to 5,600 m² (3.9 MW) after finalization of the second phase with in total 570 apartments [5].

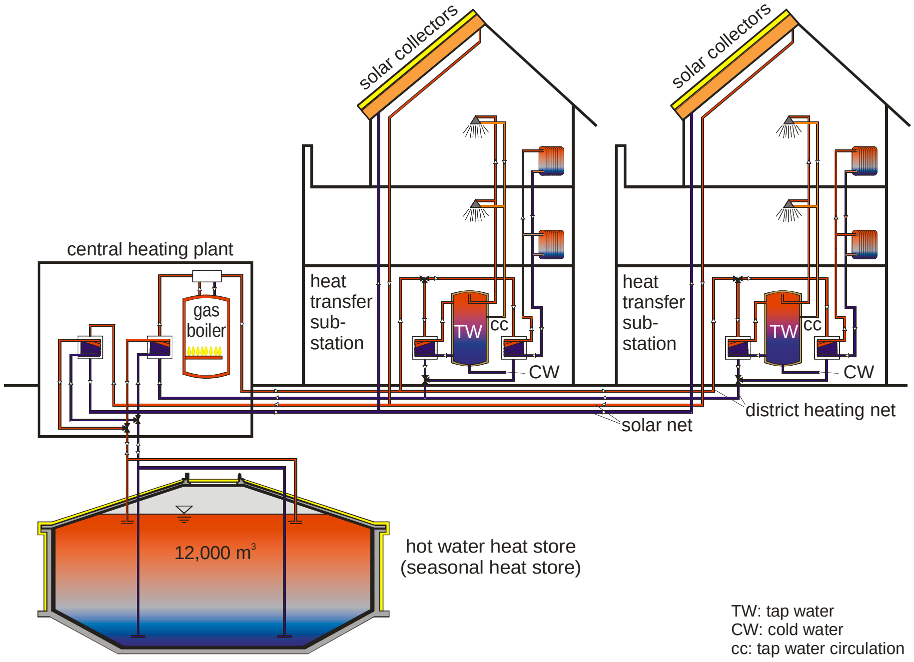

Fig. 1: Friedrichshafen CSHPSS with a concrete tank as hot-water thermal energy store

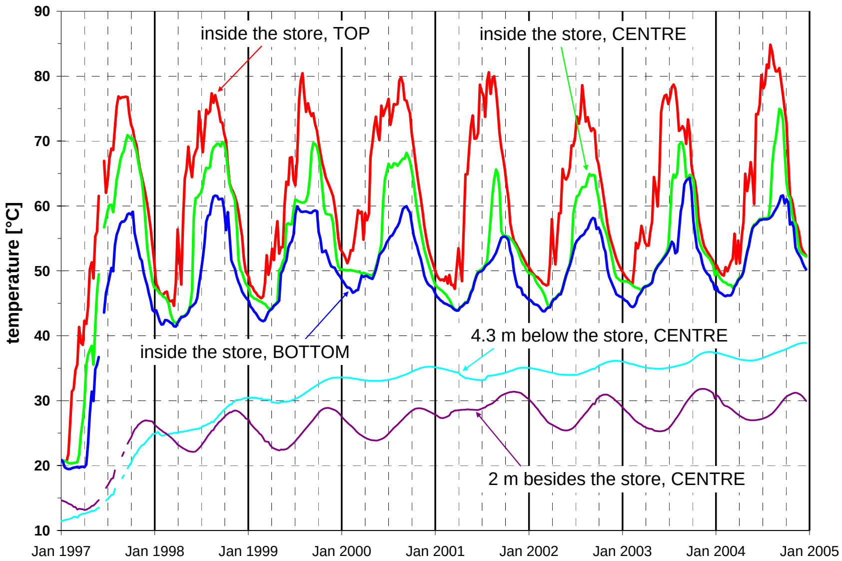

Fig. 2: Temperature development in the hot-water seasonal heat store in Friedrichshafen

TABLE 1: YEARLY HEAT BALANCES OF THE FRIEDRICHSHAFEN CSHPSS

		1997	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Heat from solar collectors	MWh	1,080	946	880	944	892	989	941[2)]	808[2)]
Solar net heat delivery[1)]	MWh	475	620	478	611	566	652	886	743
Heat from gas boiler	MWh	1,788	1,623	1,768	1,426	1,604	1,773	2,210	2,270
Total heat demand	MWh	2,262	2,245	2,278	2,033	2,173	2,423	3,325	3,013
Solar fraction	**%**	**21**	**28**	**21**	**30**	**26**	**27**	**27**	**25**
Yearly mean net return temperature	°C	44.7	44.1	48.6	49.3	48.4	47.5	51.5	51.9
Collector field size (end of the year)	m²	2,700	2,700	2,700	2,700	2,700	2,700	3,500	4,050

[1)]: solar heat delivered to the distribution network (including storage heat losses); [2)]: only for 2,700 m²

The seasonal heat store was realized as a non-pressurized hot water tank with a water volume of 12,000 m³ and a reinforced-concrete wall construction. At the inside a stainless steel liner was installed to reduce heat losses caused by vapour diffusion through the concrete walls and to prevent the insulation material (mineral wool) at the outside from wetness (in a more recent plant in Hannover an optimized high density concrete was used to enable a wall construction without steel liner).

In the first year the store had to be heated up to a minimum temperature level of 40-45 °C (see Fig. 2) that is determined by the lowest available temperature level in the system, i.e. the return temperature from the heat distribution network. Without a heat pump it is not possible to discharge the store below this temperature level. The heat from the first heating-up period (about 400 MWh) can not be reclaimed.
The maximum temperature in the store was between 80 °C and 85 °C in all the years of operation, the maximum vertical stratification was between 20 °C and 30 °C. The design maximum temperature for the store is 95 °C for the formerly planned final collector area of 5,600 m².

The temperature development in the ground around the store is exemplarily shown by two sensors besides and below the store (Fig. 2). During the first years of operation the surrounding ground is also heated up by the heat losses of the store. After 3-4 years the yearly mean values of the ground temperatures do not change significantly anymore and the store operates under quasi-steady-state conditions with lower heat losses than in the first years. This start-up period is even longer for storage technologies without a well defined and insulated storage volume, such as ATES and BTES.

Table 1 gives the monitored heat balances of the eight years of operation. Due to the fact that the heat load and the collector field size have not reached their final stage the solar fractions are below design values. However, it has to be conceded that also technical problems are responsible for reduced solar heat gains. First and foremost high system return temperatures were observed in this plant. Instead of design values of 30 °C yearly mean temperatures of more than 50 °C were monitored (see Table 1). This leads on one hand to a reduced efficiency of the solar collectors because of high operation temperatures, on the other hand it significantly reduces the available heat capacity of the seasonal heat store: not the design temperature difference of 65 K (95 °C – 30 °C) is usable but only 45 K. This means as a consequence only about 69 % of the original heat capacity is usable. Despite of many efforts to reduce the return temperatures no success could be achieved yet. The main responsibility is carried by design and hydraulic adjustment of the distribution systems inside the multifamily houses. They are owned by housing companies who do not show any interest in improving their buildings (at extra cost). The utilities therefore have no possibility to improve installations inside the houses.

3. NECKARSULM

In Neckarsulm a primary school, a gymnasium, a shopping centre, a home for elderly people and a residential area are connected to a CSHPSS (Fig. 3). The first buildings were constructed in 1997, the service area is still growing as more and more residential houses are built and connected to the district heating system. The solar collectors are installed on the buildings, on a carport and on a noise protection wall. Solar collector fields and buildings are connected to the heating plant by a three-pipe heat distribution and solar network (one single return flow pipe is used for both the heat distribution and the solar network). A detailed description of the system is given in [4, 6, 7].

With the increase of the number of connected buildings and the heat load also the solar system was extended in the last years. For the first time in Germany also the seasonal heat store was included into the extension of the solar system. This is an advantage of the storage concept 'borehole thermal energy store (BTES)' that is used for seasonal heat storage at this site, see Fig. 4. The present collector field size is 5,260 m² corresponding to 3.7 MW. The BTES comprises a ground volume of 63,300 m³.

TABLE 2: YEARLY HEAT BALANCES OF THE NECKARSULM CSHPSS (no values are available for 2001 due to construction work for the 2nd extension of the BTES)

		1999	2000	2002	2003
Heat from solar collectors	MWh	802	577 2)	1,696	2,050 3)
Solar net heat delivery 1)	MWh	224	213	822	782 3)
Heat from gas boiler	MWh	1,028	1,034	1,303	1,109
Total heat demand	MWh	1,252	1,247	2,125	1,891
Solar fraction	**%**	**18**	**17**	**39**	**39**
Collector area	m²	2,636	3,090	5,007	5,007

1): solar heat delivered to the distribution network (including storage heat losses); 2): only for 2,636 m²; 3) additional solar heat (71 MWh) from adjacent solar system

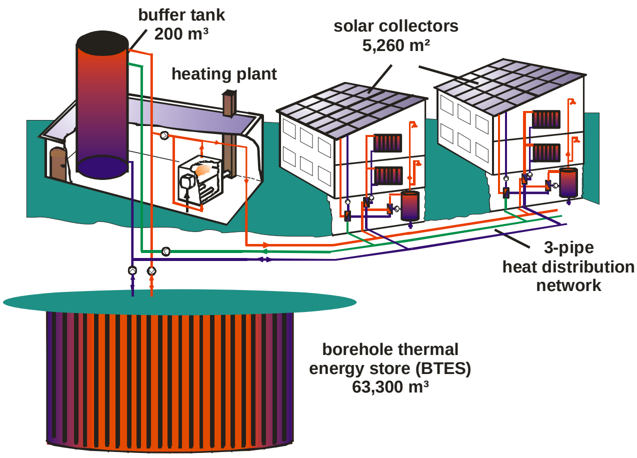

Fig. 3: Neckarsulm CSHPSS with a borehole thermal energy store (BTES)

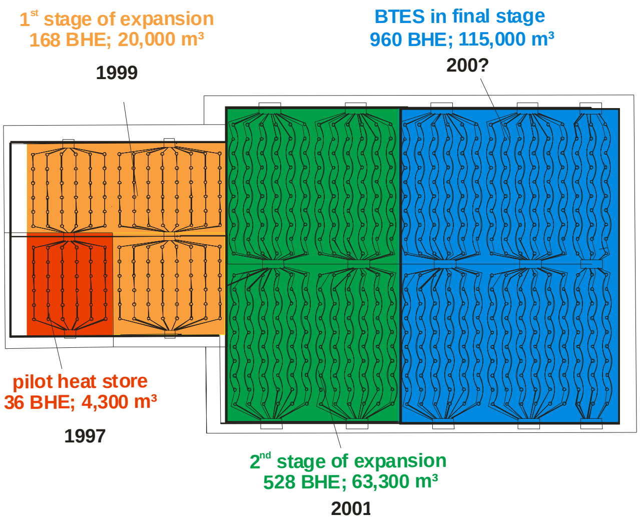

Fig. 4: Horizontal section of the Neckarsulm BTES, construction phases (BHE: borehole heat exchanger)

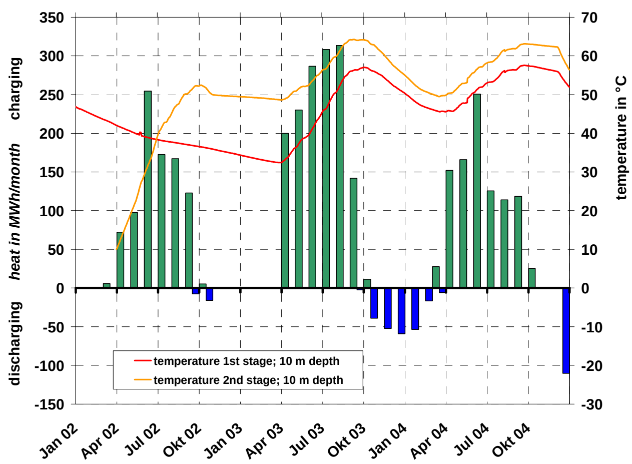

Fig. 5: Heat balance and ground temperatures of the Neckarsulm BTES from 2002 to 2004

In Table 2 the heat balances of the plant since 1999 are given. In the first years of operation the 1st part of the BTES (20,000 m³) had to be heated up and the solar fraction was below 20 %. In 2001 the 2nd extension of the heat store was built and for a second time a big part of the store had to be heated up. Because of the large collector field size still a solar fraction of 39 % was reached in the years 2002 and 2003. Fig. 5 shows the heat charged into and discharged from the BTES since the start of operation of the present storage size. In the first years hardly any heat could be recovered due to low storage temperatures. During start-up the mean temperature in the storage volume rises each year and after about 5 to 8 years quasi-steady-state conditions will be reached. According to simulations the heat store will then have an efficiency of more than 65 %, see also [4].

4. ROSTOCK

Fig. 6 shows a schematic picture of the solar heating plant in Rostock. The solar collectors are realized as solar roofs and have a thermal capacity of 686 kW (absorber area: 980 m²). For seasonal heat storage an aquifer thermal energy store (ATES) is used. It is located below the supplied multifamily house (108 apartments, 7,000 m² living area) in a depth of 15 to 30 m below the ground surface. The ATES is operated at maximum temperatures of 50 °C to reduce heat losses and to prevent well clogging and precipitation caused by chemical reactions of the groundwater. To increase the usability of the store an electrically driven heat pump is integrated into the system. For auxiliary heating a gas condensing boiler is available.

To provide good operating conditions for the solar collectors and the heat pump the heat distribution system for room heating is designed for moderate temperatures of 50/30 °C (supply/return design temperatures at -12 °C ambient temperature, heat distribution is water based).

TABLE 3: YEARLY HEAT BALANCES OF THE ROSTOCK CSHPSS

		2001	**2002**	**2003**
Heat from solar collectors	MWh	348	364	456
Solar net heat delivery[1)]	MWh	211	278	304
Heat from gas boiler	MWh	420	322	279
Electricity demand heat pump	MWh_{el}	24	44	39
Total heat demand	MWh	655	644	622
Solar fraction	**%**	**32**	**43**	**49**
Yearly mean net return temperature	°C	34	36	35

[1)]: solar heat delivered to the distribution network (including storage heat losses)

Fig. 7 shows the high solar contribution to the heat supply during the year 2003. Compared to other CSHPSS, where the solar contribution decreases clearly during the winter period, the heat pump enables a further discharge of the ATES, and hence an extended usage of solar heat, even when the temperature level in the store is below the return temperature level of the heat distribution network. For the year 2003 a solar fraction of 49 % was calculated based on end energy use (without consideration of the efficiencies of the electricity production and the transformation of gas into heat).

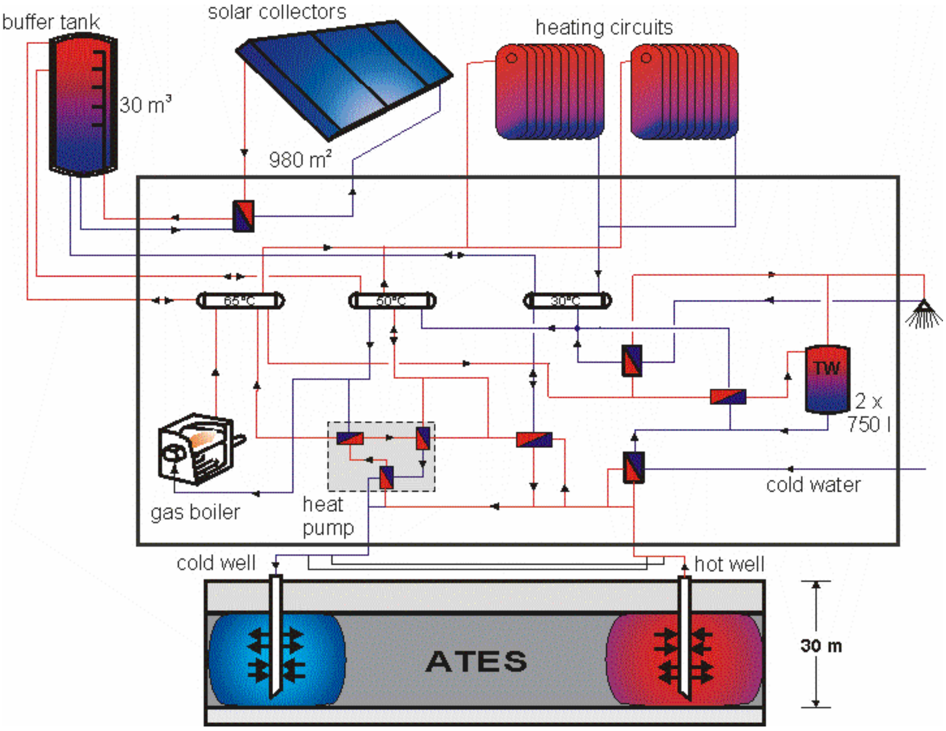

Fig. 6: Rostock CSHPSS with an aquifer thermal energy storage (TW: tap water)

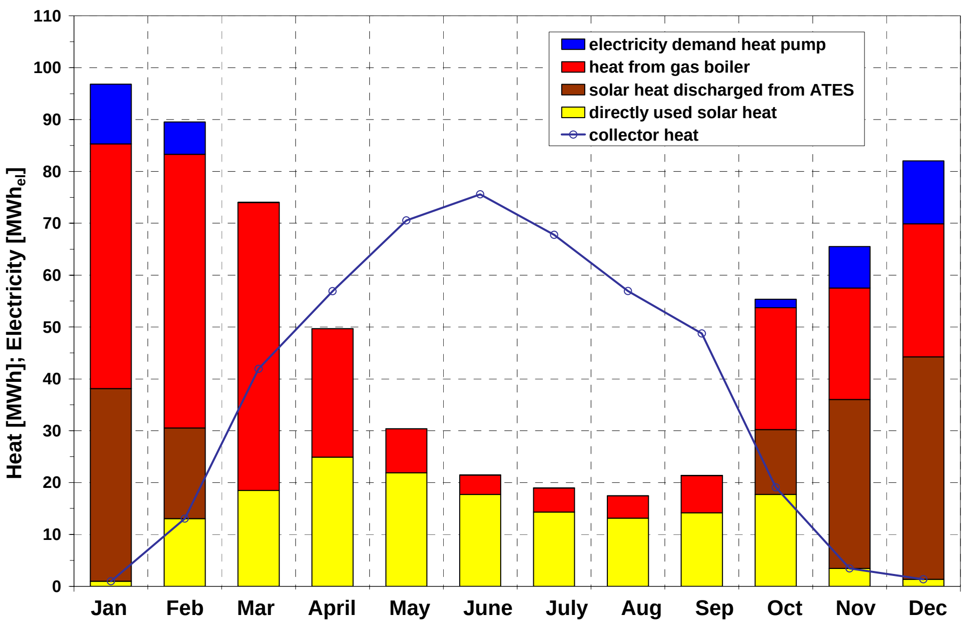

Fig. 7: Rostock monthly heat balances 2003 (monitoring data)

Table 3 shows the heat balance data for the years 2001 to 2003. A Sankey diagram of energy flows is shown in Fig. 8 for the year 2003.

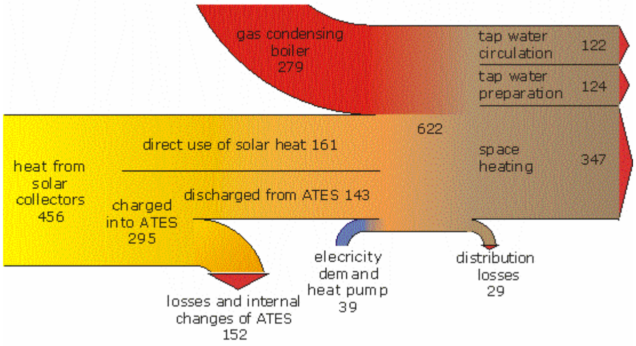

Fig. 8: Sankey diagram for the Rostock plant (numbers: monitoring data 2003 in MWh)

5. SUMMARY AND OUTLOOK

Since 1996, eight demonstration plants for solar assisted district heating with seasonal heat storage have been built in Germany. New projects in Crailsheim and Munich are in a final stage of development at present. Four concepts for seasonal heat storage have been further developed and evaluated in the course of these projects. The technical feasibility and high efficiency of the technology is proved - no serious malfunctions or breakdowns were observed.

System efficiencies were less than predicted in the first projects. This was mainly caused by optimistic presumptions in the pre-design phase. Especially the return temperatures from the district heating net turned out to be the crucial point. In newer plants more attention was paid to the complete system design including e.g. heat distribution systems in the connected buildings to optimize the interaction between the components. Future work will focus on improvements of the cost-efficiencies of system and storage concepts.

Solar heat cost of CSHPSS systems today ranges between 16 and 30 Euro-Cent/kWh. Compared to heat from fossil fuels (4-5 Euro-Cent/kWh in Germany) profitability can not be reached yet. However, rising conventional heat cost caused by shortage of fossil fuels together with other reasons (political, social etc.) on one hand and falling heat cost for solar systems because of higher system efficiencies, better establishment of renewable energies in the market etc. on the other hand will lead to cost-efficiency in the future.

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