Solar assisted district heating system with seasonal hot water heat store in Friedrichshafen (Germany)

S. Raab, Institute for Thermodynamics and Thermal Engineering (ITW), University of Stuttgart
D. Mangold, Solar- und Wärmetechnik Stuttgart (SWT), ein Forschungsinstitut der Steinbeis-Stiftung
W. Heidemann, Institute for Thermodynamics and Thermal Engineering (ITW), University of Stuttgart
H. Müller-Steinhagen, Institute for Thermodynamics and Thermal Engineering (ITW), University of Stuttgart, Solar- und Wärmetechnik Stuttgart, German Aerospace Centre (DLR) Institute for Technical Thermodynamics

In Friedrichshafen, close to the Lake of Constance, a solar assisted district heating system with seasonal hot water heat store was put into operation in 1996. The seasonal storage is realised by a hot water heat store constructed from reinforced concrete. At present the solar assisted district heating system is extended and additional collector fields and buildings are connected to the system. In this paper the system heat balances of the last seven years and the most important experiences are reported.

System description

Figure 1 shows the planned development of the settlement in Friedrichshafen. It is divided into three phases of extension. In the course of the realisation of the 1st and 2nd extension solar collector fields are integrated in the district heating system. When realising the 3rd extension additional buildings will be connected to the system, but no additional collector fields will be integrated.

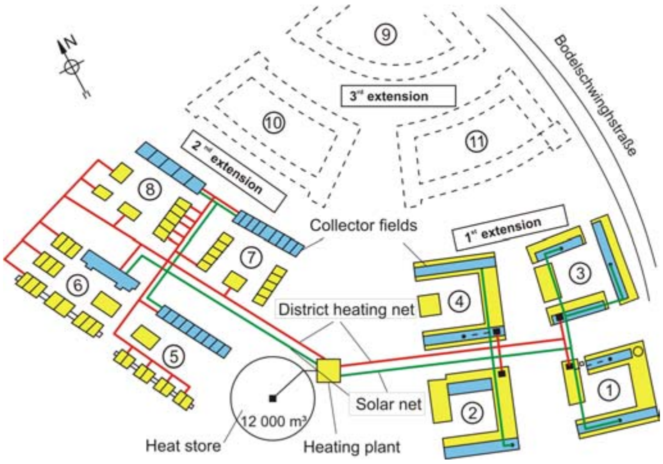

Figure 1: Location of the solar assisted district heating net

After completion of the first extension in 1996 280 apartments (in multi-family houses) and one kindergarten were connected to the district heating system. The heated area amounts to around 23 000 m². On top of the buildings of the first extension 2 700 m² of flat plate collectors have been mounted, divided into seven fields. The inclination angle varies between 20 and 25 °, the orientation deviates from ideal south orientation up to 110 ° to the north-west. The energetic optimum inclination angle range of the collector fields is between 30 and 45 ° facing to south. The seasonal hot water heat store, which was also built in 1996, has a water volume of 12 000 m³ and is energetically designed for the integration of an additional extension with 2 700 ² of solar collectors. The hot water heat store transfers the heat collected in summer by the solar collectors to winter when the heat demand in the district heating net is comparatively high. In figure 2 the schematic layout of the system is shown.

In 2002 the realisation of the second extension started. Contrary to previous planning of approx. 280 apartments (in multi-family houses) around 110 accommodation units mainly in terraced houses are being built. Originally the integration of 2 700 m² of solar collectors was planned for the year 1998. Due to the decreased roof area only around 1 700 m² of solar collectors will be integrated in the system after the completion of the second extension. In 2002 and 2003 two collector fields of 413 m² and 400 m² respectively have been installed as roof integrated field or mounted on a subconstruction. In figure 3 an example of a roof integrated collector field (multi-family house of the first extension) is shown.

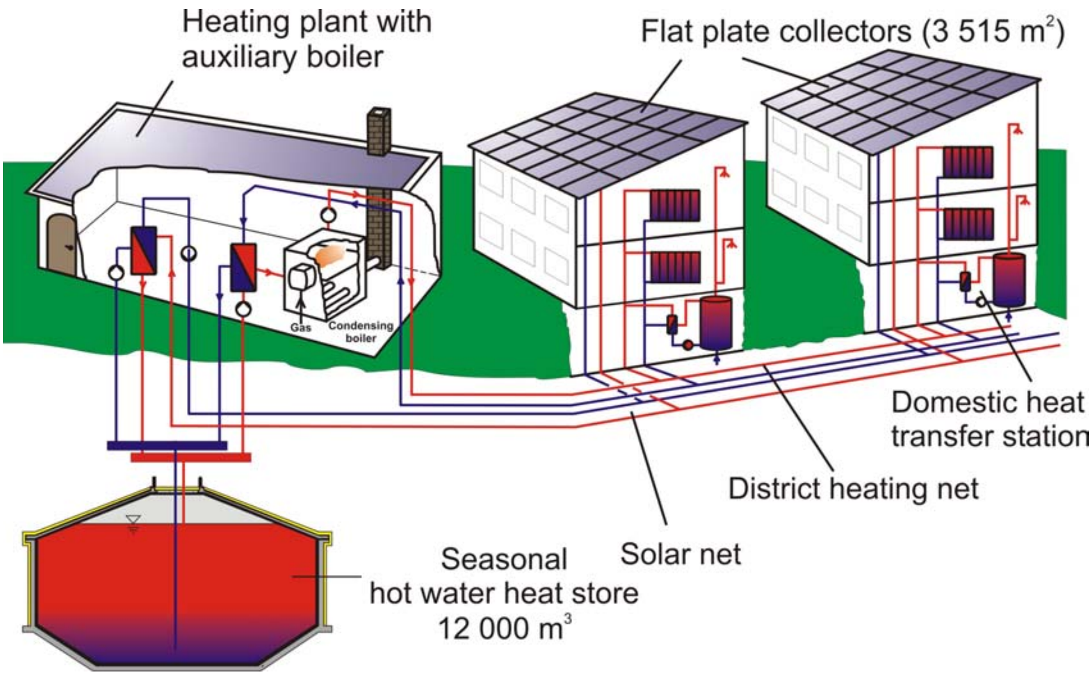

Figure 2: Schematic layout of the district heating system (present status)

Figure 3: Roof integrated collectors on top of a multi-family building in Friedrichshafen

Heat balances

In table 1 the system heat balances for the years 1997 to 2003 are shown. The achieved solar fraction (based on total heat demand) varies between 21 and 30 %. The design solar fraction related to the 1st phase of extension was calculated to 43 %. This value has not yet been reached due to several reasons. The heat consumption of the buildings (1st extension) is approx. 10 % higher than expected. Furthermore the design return temperatures of the district heating net were supposed to be lower than 40 °C (yearly average weighted by volume flow). In 2003 this value rose to 51.5 °C. The heat losses of the seasonal heat store are in the range between 322 and 360 MWh/a and are significantly higher than the calculated value of 220 MWh/a.

The efficiency factor of the gas condensing boiler during the last years of operation amounts from 94 % to 100 % (based on lower heating value H_u). The solar collectors' heat gain of the 1st extension amounted to 941 MWh in 2003 (gross solar heat gain including heat losses caused by collector pipes; as measured at the solar heat exchanger). This is around 5 % less than in 2002 whereas the irradiation on the collector plane is about 13 % higher. This is caused by stagnation of the collector field from 7/21/03 to 8/18/03 (corresponding to an irradiation on collector plane of 175 kWh/m²) because of necessary work in the heating plant.

The degree day value for 2003 amounts to 3 931 Kd and is high compared to the years 1997 to 2002 owing to relatively cold winter months. The overall heat delivery to the district heating net in 2003 (1st and 2nd extension) was 3 325 MWh. This is significantly higher than in the previous years, mainly due to the connection of new buildings in the supply area of the 2nd extension. In figure 4 the heat flow of the plant is depicted in a Sankey diagram for the year 2002.

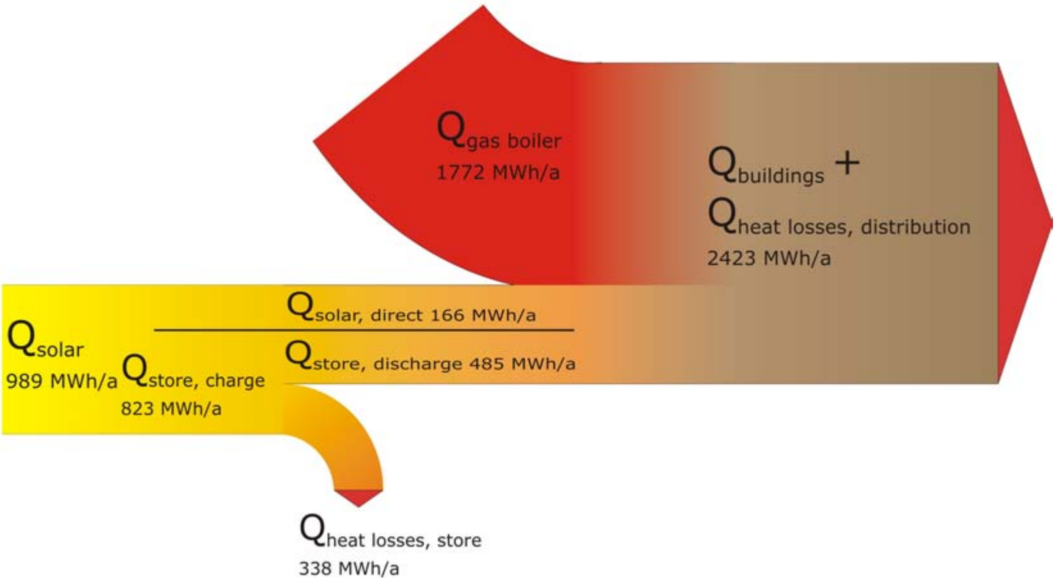

Figure 4: Heat balance for Friedrichshafen in 2002

Table 1: Heat balances of the system from 1997 to 2003 [1]

	Unit	1997	1998	1999	2000	2001	2002	2003
Irradiation on collector plane	[kWh/m²]	1 290	1 305	1 211	1 271	1 292	1 306	1 473
Degree day value *Gt* (9/1-5/31)	[Kd]	3 687	3 791	3 745	3 461	3 669	3 563	3 931
Heat gain of collectors (1st ext.)	[MWh]	1 080	946	880	944	892	989	941
per m² collector area[1)]	[kWh/m²]	400	350	326	349	330	366	348
Solar heat into the district heating net ($Q_{,Solar\ net}$)	[MWh]	475	620	478	611	566	652	886
per m² collector area	[kWh/m²]	176	230	177	226	210	241	-
Heat content of the store 12/31 (compared to 1/1/97: 105 MWh)	[MWh]	343	344	386	359	363	367	373
Heat losses of the store	[MWh]	357	325	359	360	322	333	-
Overall heat delivery into the district heating net	[MWh]	2 262	2 245	2 278	2 033	2 173	2 423[4)]	3 325[4)]
Heat consumption[1)]	[MWh]	2 100	2 063	2 115	1 957	2 067	1 976	2 179
per m² building area[1)]	[kWh/m²]	92	90	92	85	90	86	95
Heat losses of the district heating net[1)]	[%]	7.2	8.8	7.1	3.8	4.8	6.0	7.7
Heat delivered by the gas boiler	[MWh]	1 788	1 623	1 768	1 426	1 604	1 773	2 210[3)]
Gas consumption (H_u)	[MWh]	1 812	1 624	1 855	1 477	1 653	1 878	2 595
Gas condensing boiler efficiency (H_u)	[%]	99	100	95	97	97	94	94[3)]
Solar fraction (based on total heat demand)	[%]	21	28	21	30	26	27	27
mean net supply temperature[2)]	[°C]	70.5	71.3	69.5	71.3	71.0	71.8	73.1
mean net return temperature[1) 2)]	[°C]	44.7	44.1	48.6	49.3	48.4	47.5	51.5

[1)] related to 1st phase of extension and based on absorber area; [2)] weighted by volume flow; [3)] estimation; [4)] heat delivery to 1st and 2nd extension

Seasonal hot water heat store

Figure 5: Hot water heat store during construction

The volume of the heat store amounts to 12 000 m³ (height: 20 m, diameter: 32 m). Figure 5 shows the hot water heat store during construction. The charging and discharging behaviour for 2002 is shown in figure 6. Charging of the store mainly occurs from May to August, discharging in the autumn months. Approximately 20 % of the heat delivered by the solar collectors is used directly for preheating the district heating net. In figure 7 the variation of temperature in the store is depicted for the years 1997 to 2003. The seasonal variation of temperature can be seen easily. The highest temperatures reached in the store in the end of summer amount to 80 °C on the top and to about 60 °C at the bottom. This also means that the heat capacity of the store is not sufficiently used. The building development and the solar collector fields of the second extension are realised unexpectedly slow and different to the planning. The lowest temperatures reached in the store are about 40 to 45 °C at the bottom depending on the year, since the return temperatures of the district heating net, which are the lowest temperatures in the whole system, are higher than expected. The difference between the lowest temperature in the store and the start temperature in October 1996 (11 °C) represents the unusable heat content of the store which was needed to put the store into regular operation. Furthermore in figure 7 an increase of the temperature besides the store can be seen from November 2000 to April 2001. This is due to a defect of the drainage pump and the resulting wetting of the thermal insulation. The heat store is surrounded by a drainage system to protect the thermal insulation of the heat store from flooding by ground water. The water is collected in a drainage duct and delivered to a nearby lake by the drainage pump. After repairing of the pump the temperature around the store continuously decreased during the years 2001 and 2002. The thermal insulation seems to dry up.

The heat losses of the store are between 322 and 360 MWh/a, corresponding to a moderate efficiency of 60 % for the seasonal heat storage. The calculated value amounts to 220 MWh/a. This difference is due to the operation of the heat store at higher temperatures than expected caused by the high net return temperature. It generates an offset of the store temperature of at least 10 K at the bottom and increases the heat losses significantly since the lower third of the heat store is not thermally insulated. It is also assumed that the thermal insulation of the heat store is partly wet due to insufficient drainage of ground water. Approximate calculations to take into consideration the wetness of the thermal insulation yield additional heat losses of 200 MWh/a.

The contribution of the connecting pipes between heating plant and heat store is also not negligible. The pipes have an overall length of 55 m. These pipes were used for charging and discharging operations for 6 600 h in 2002. Assuming a temperature drop of 0.5 K between in- and outlet of the pipes the resulting heat losses amount to 50 MWh/a.

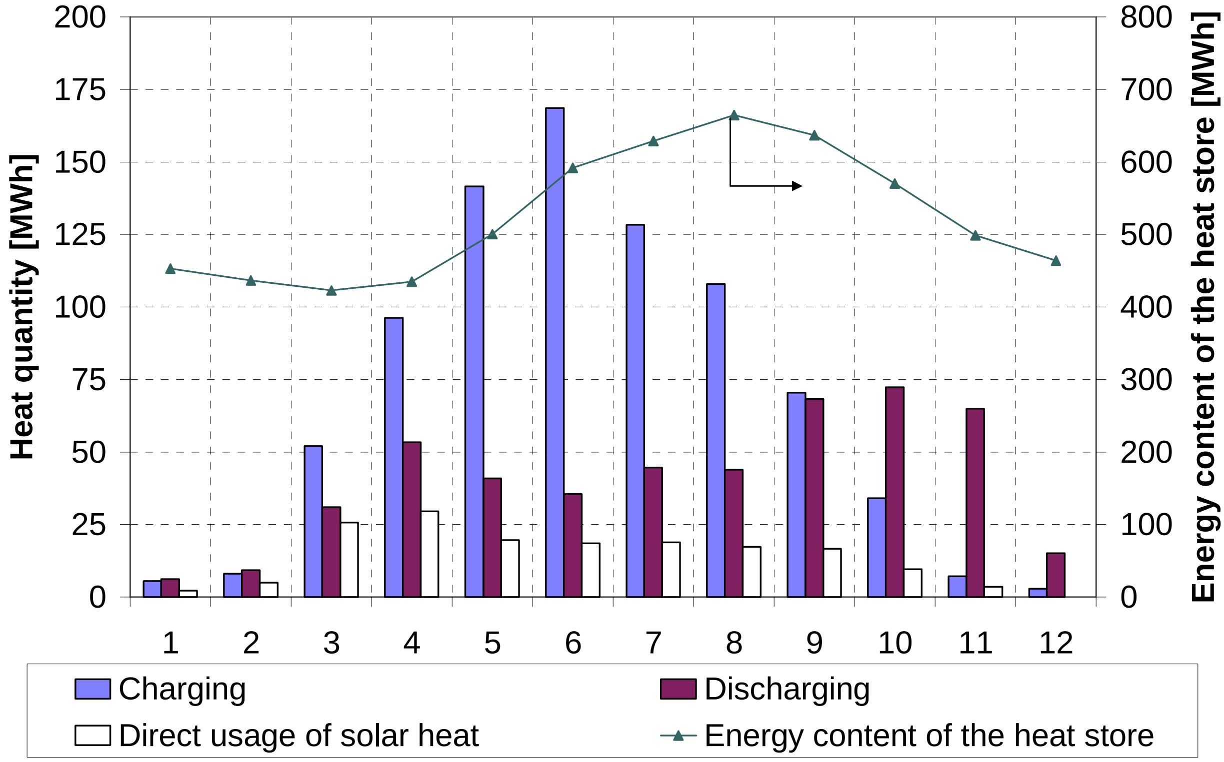

Figure 6: Charging and discharging of the heat store in 2002

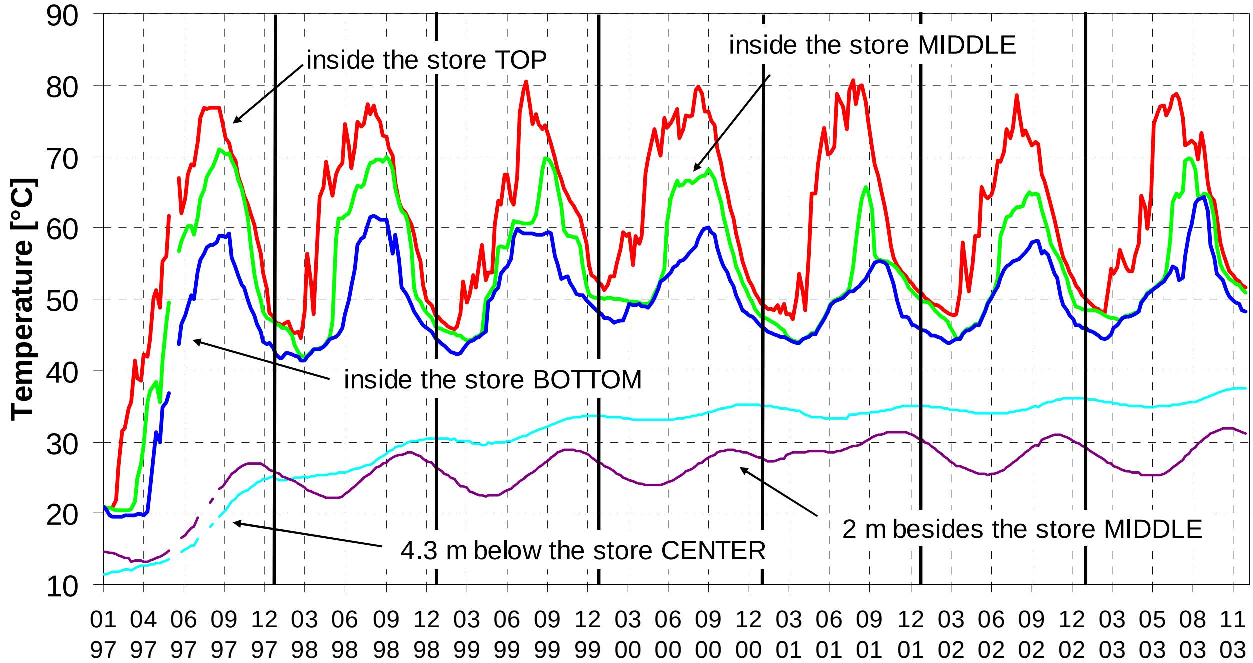

Figure 7: Temperatures in and around the heat store from 1997 to 2003

Solar collectors

The specific solar gross heat gained by the collectors amounts to 366 kWh/(m² a) in 2002 corresponding to an efficiency of the solar collectors of 28 %. The specific heat gain varies within a range of 326 to 400 kWh/(m² a) for the last seven operational years depending on the control strategy of the collector field and the solar irradiation. The high value of 400 kWh/(m² a) is mainly due to the low heat content of the heat store in spring 1997 at the start of operation (relatively low return temperatures to the collectors). In figure 8 the

daily heat gain of the collector fields as a function of the daily solar irradiation is depicted for the years 2000 to 2002. The specific heat gains of the collector fields at equal solar irradiation are lowest in 2001. For relatively high solar irradiation of 8.5 kWh/(m² a) the heat gain amounts to 2.9 kWh/(m² a) in 2001 und is around 0.5 kWh/(m² a) resp. 17 % lower than the heat gain achieved in 2000 resp. 2002 for similar conditions. Because of a relatively low volumetric flow rate at the cold side of the solar heat exchanger a comparatively high solar supply temperature can be reached, whereas the solar return temperature on the hot side of the solar heat exchanger is increased accordingly. In the summer of 2001 the solar return temperature to the collector fields was between 80 and 90 °C compared to 70 to 75 °C in 2000. The control strategy in 2001 leads to a relatively high useable solar temperature level, whereas the overall thermal efficiency of the collector fields is significantly lowered due to the increasing heat losses of the collectors.
In figure 9 the heat transfer rate of the solar heat exchanger for the years 1998 to 2001 is shown. The determination of the heat transfer rate is carried out based on measured data with TRNSYS [2] combined with DF [3]. The heat transfer rate decreases from 189 kW/K in 1998 to 131 kW/K in 2001. The logarithmic mean temperature difference for a typical duty of 1 300 kW rises from 7 K in 1998 to 10 K in 2001. In August 2002 a larger solar heat exchanger was installed. In figure 10 a typical plate of the old, replaced heat exchanger is illustrated. The green fouling deposits found on the primary (hot) side of the solar heat exchanger were examined and mainly consisted of organic material and copper. It is believed that the fouling deposits were caused by stagnation in the collectors during the construction phase when the collectors are not yet filled with heat transfer medium. Later, during regular operation, these components were dissolved and deposited in the heat exchanger which acted as a filter.

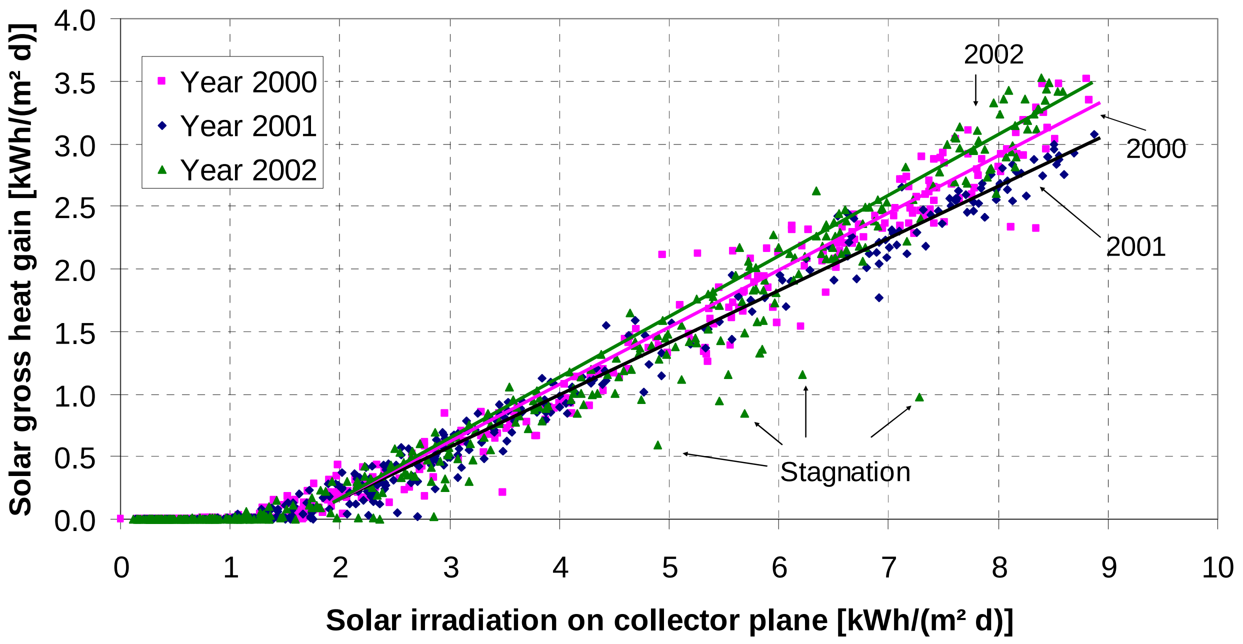

Figure 8: Input-output-diagram of the total solar collector field for 2000, 2001 and 2002

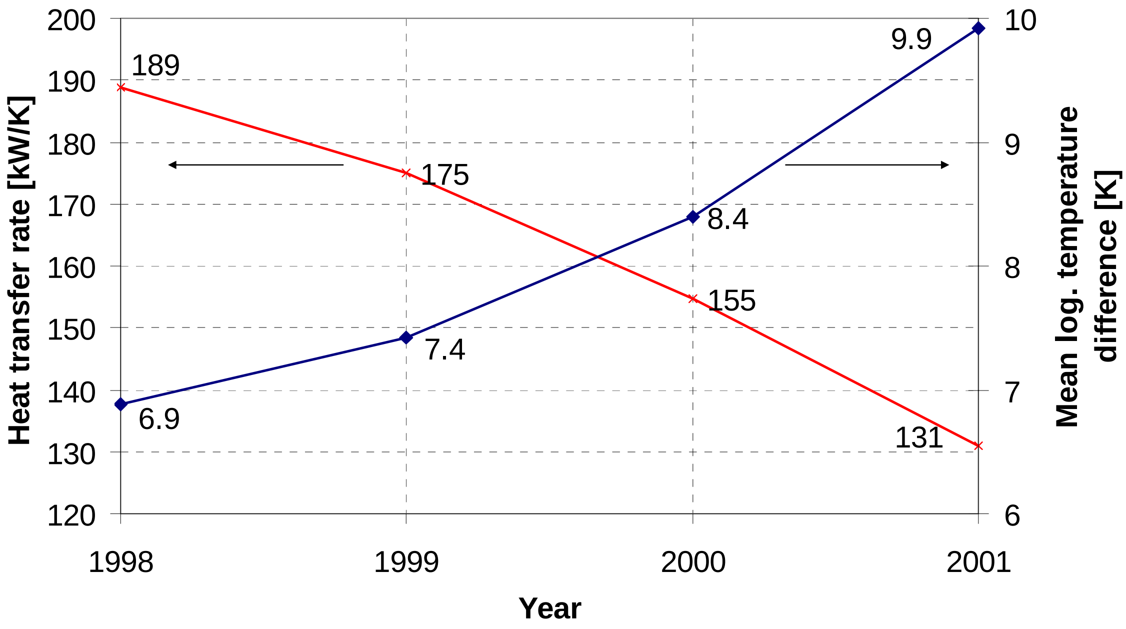

Figure 9: Heat transfer rate of the solar heat exchanger for the years 1998 to 2001

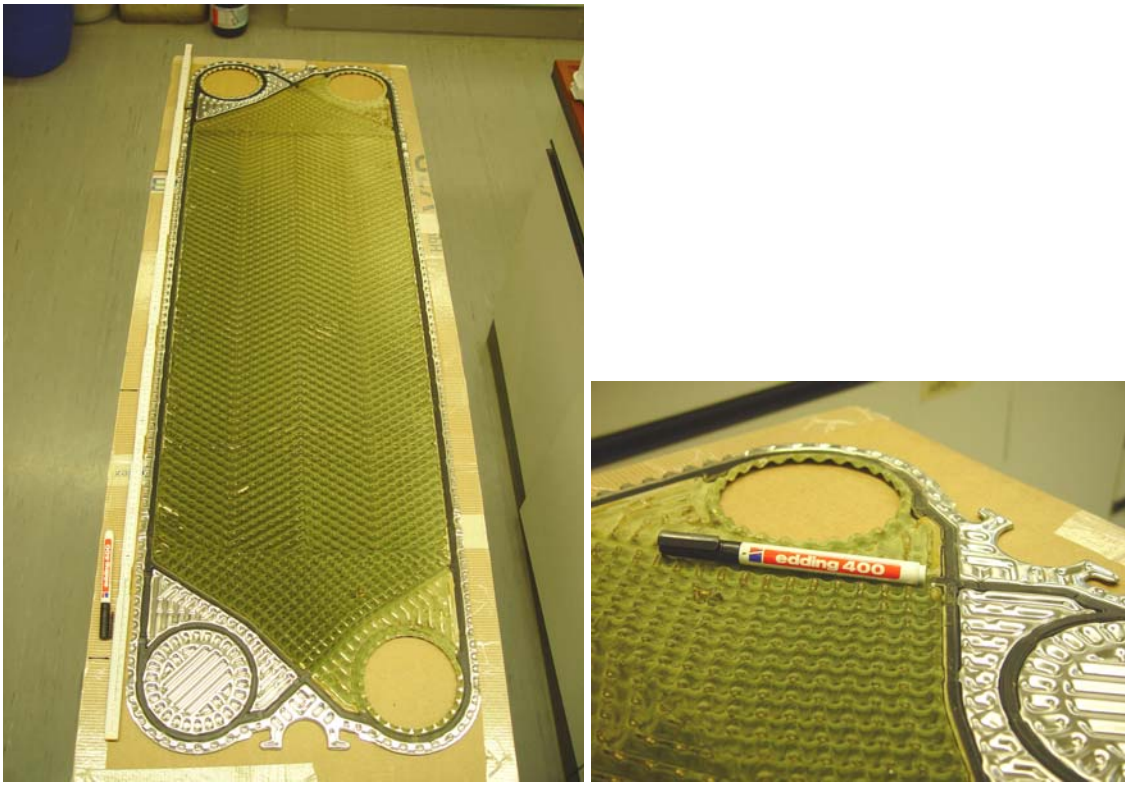

Figure 10: Fouling deposits on the solar heat exchanger

Conventional heating system

The conventional heating system consists of two condensing boilers (720 kW and 900 kW) fired by natural gas. The gas consumption and the efficiencies are given in table 1. A buffer store (volume of 1.5 m³) is installed in parallel to the boilers. For high thermal loads a continuous operation of the boiler is guaranteed. For low thermal loads below the modulation limit of the burner (in general 30 % of the maximum thermal power) the gas boiler begins to pulse. This happens mainly, when high thermal power is delivered by the solar collectors. The minimum possible power of the boiler leads to a significant over-shoot of the set point net supply temperature. Since there is no installation to admix the return flow to the supply flow, the net supply temperature rises up to more than 80 °C, increasing also the net return temperature. The pulsing frequency can be significantly reduced by installing a low power gas boiler for low thermal loads.

District heating net

In figure 11 the temperatures of the 1st extension are shown for 2003. In the summer months (June to September) the net return temperature varies between 55 and 60 °C due to the indirect preparation of domestic hot water by storage charging systems. In the summer months normally there is no heating system required. In 2003 the installation of the 2nd extension results in a disconnection of the heat store from 7/21/03 to 8/06/03. In the winter months with high heating demand the return flow temperature is slightly below 50 °C. Since the net return temperature is the lowest temperature in the whole system, the seasonal heat store can not be discharged to temperatures below 50 °C. This results in higher heat losses to the environment compared to the design net return temperatures of below 40 °C. The integration of a heat pump into the system would lead to an improved discharging of the store increasing the efficiency of all components due to lower heat losses to the environment.

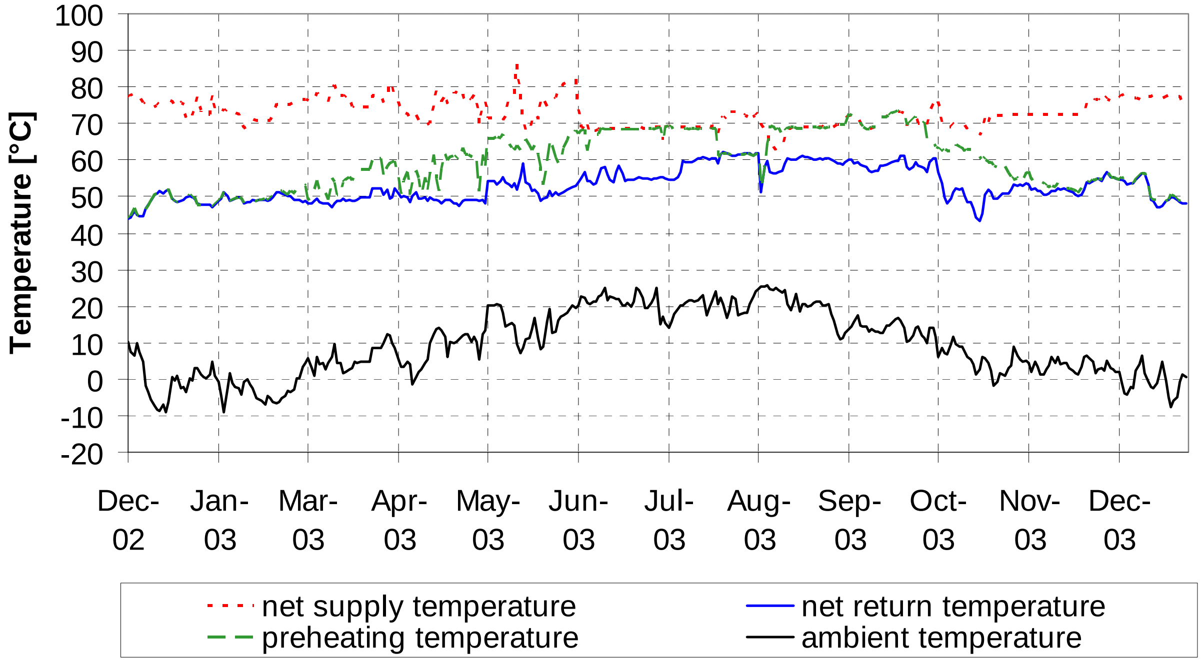

Figure 11: Ambient temperature and temperatures in the district heating net in 2003

Summary and outlook

Between 1997 and 2003 solar fractions from 21 to 30 % were reached. The specific solar heat gains vary from 330 to 400 kWh/(m² a) resp. 176 to 241 kWh/(m² a) (gross resp. net). One major reason for not reaching higher solar fractions are the net return temperatures of around 50 °C which are more than 10 K higher than expected value of less than 40 °C (yearly average weighted by volume flow). In addition, the heat losses of the heat store are higher than expected, mainly due to wet thermal insulation, and the connecting pipes with a length of 55 m. Apart from this no major problems occurred during the last seven operational years.

References

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[2] TRNSYS Version 15.0 – User Manual. Solar Energy Laboratory, University of Wisconsin, Madison und Transsolar, Stuttgart.

[3] DF- Dynamic Fitting Version 2.7, InSitu Scientific Software, c/o W. Spirkl, Germering, Germany.

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