Solar assisted district heating system with seasonal duct heat store in Neckarsulm-Amorbach (Germany)

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The solar assisted district heating system with seasonal duct heat store in Neckarsulm-Amorbach is being realised since 1997. In 2003 about 200 accommodation units, a school with gymnasium and a shopping centre were supplied with heat by the district heating system. So far 5,263 m² of solar thermal collectors are installed; the volume of the duct heat store is presently 63,360 m³. In the duct heat store heat delivered from solar collectors is stored from summer to winter. The duct heat store was extended twice; the operation of the first and second extension started in 1999 respectively in 2002. The maximum temperature in the duct heat store is expected to be about 85 °C. In 2002 and 2003 a solar fraction based on the total heat demand (space heating and domestic hot water) of 39 % was reached. The planned solar fraction of 50 % is expected to be reached within the next years. This paper presents an overview about the present status of the system as well as operational experiences and characteristic data for the system.

System description

Since 1997 the first solar assisted district heating system with duct heat store in Germany is being realised in Neckarsulm-Amorbach. The solar assisted district heating system presently supplies about 200 accommodation units with heat. For the final extension stage approximately 1,300 accommodation units were planned.
Presently 5,263 m² solar thermal collectors are installed on different buildings as well as on a carport and a noise protection wall. The heat from the solar collectors is delivered to the heating plant and collected in buffer tanks which are used for short-term heat storage to balance peaks in heat delivery from the solar collectors, see figure 1.
The buildings are connected to the district heating system by a 3-pipe heat distribution net. The heat distribution net is supplied either by the buffer tanks or the duct heat store, depending on the temperature level. A gas condensing boiler supplies additional heat if none of the stores is able to deliver heat at the requested temperature level.
The duct heat store was extended twice and presently contains a volume of 63,360 m³ with 528 borehole heat exchangers (double-U-pipes, 30 m deep) for charging and discharging.

In table 1 an overview about the project history and the extension stages of the collector area and duct heat store volume is given.

Table 1: History of the solar assisted district heating system in Neckarsulm-Amorbach

1995	First geological investigations for the duct heat store
1996	First design of the district heating system
1997	Construction of the first buildings, the experimental duct heat store (4,320 m³) and 2,636 m² solar thermal collectors (school, shopping centre, senior residence)
1998	First extension of the duct heat store (total 20,160 m³)
2000	Installation of additional 454 m² solar thermal collectors (carport)
2001	Second extension of the duct heat store (total 63,360 m³) and installation of additional 808 m² solar thermal collectors (terraced houses)
2002	Installation of additional 1,109 m² solar thermal collectors (noise protection wall)
2004	Installation of additional 256 m² solar thermal collectors (nursing home)

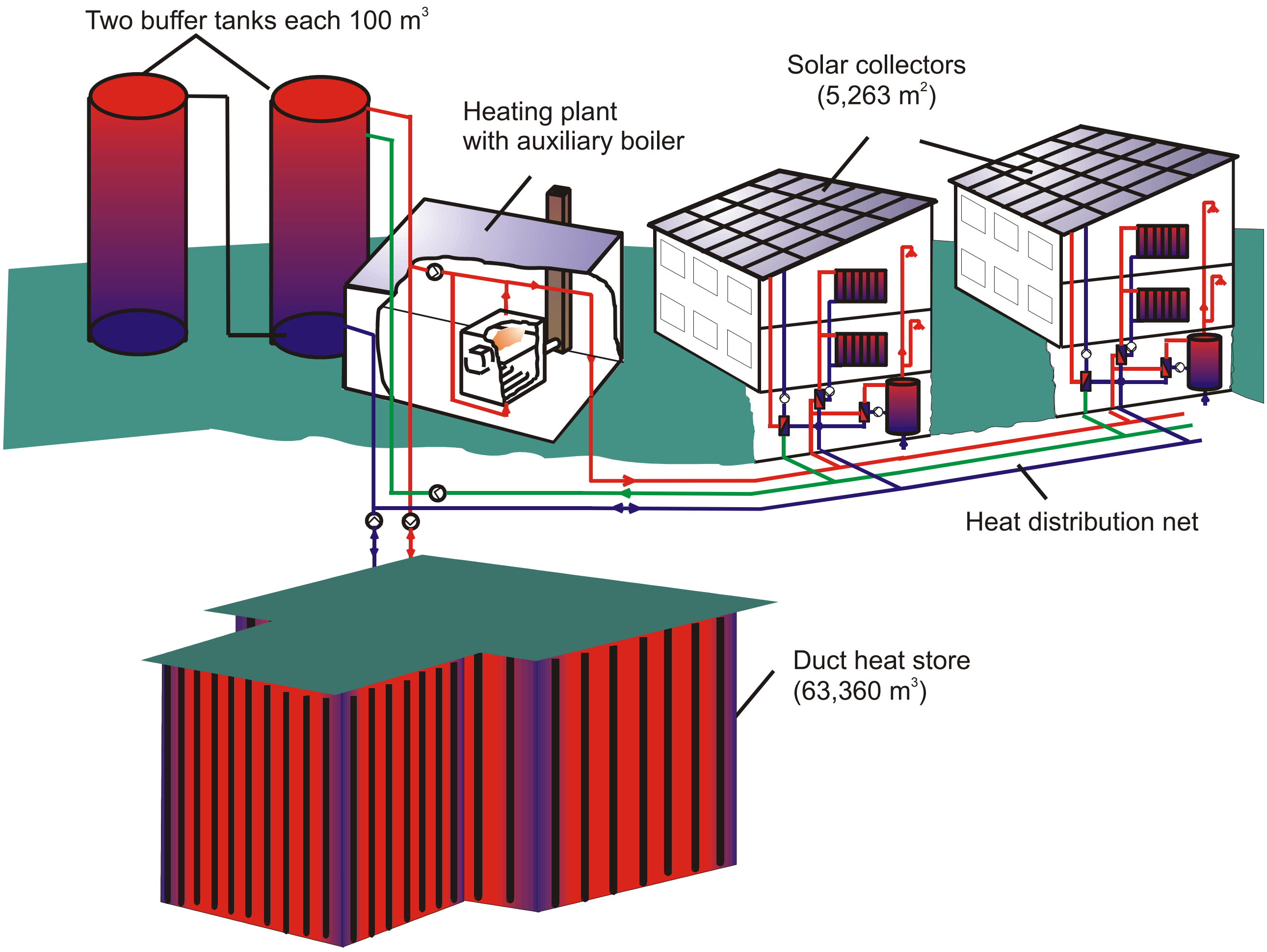

Figure 1: Schematic layout of the district heating system (present status)

Seasonal duct heat store

The duct heat store, which is used for seasonal heat storage, is described in detail in [1], [2] and [3]. In figure 2 temperatures in the centre of the first and second extension of the store are shown for different depths. The store was heated up from about 10 °C and has not yet reached the designed maximum temperature of about 85 °C due to its long heating-up time of 5-8 years. Nevertheless discharging started in 2003 and a steady state operation with storage efficiencies of about 70 % (for the completed store) is expected within the next 3-4 years.

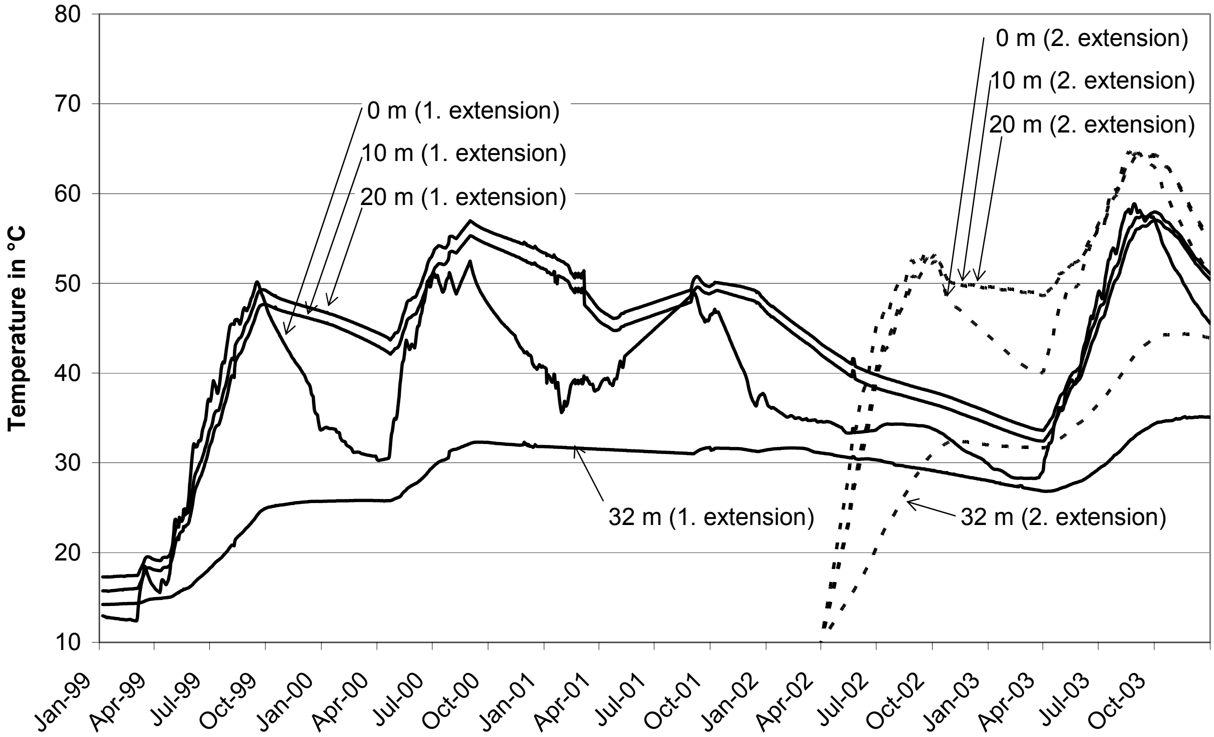

Figure 2: Temperatures in the seasonal duct heat store from 1999 to 2003

In figure 3 the temperatures in the centre of the first extension in different depths are shown for 2003. The highest temperature in this part was approx. 58 °C and was reached in October. At the end of October discharging started and the temperatures decreased. In the second extension, see figure 4, the maximum temperature was approx. 65 °C. The temperatures in the first extension are lower since this part was not charged in 2002 in order to reach a fast temperature adaptation of the various store parts. The temperatures below the store (depth 30 to 40 m) slightly increased due to heat losses of the store. For economical and constructional reasons the store is only insulated on top.

Until now some minor problems related to the duct heat store occurred. In 2003 a sludge trap was installed since corrosion deposits were found in distribution pipes. Since the duct heat store is directly connected to the heat distribution system the borehole heat exchangers must be prevented from clogging.

The temperatures in the various parts of the store vary (referring to same depth). The temperatures between the first and second extension vary because of different operating times. The analyses of the measured data also show different temperatures in the north and south part of the second extension of the store. Assuming equal hydraulic transmissivity in the ground, no groundwater flow and equal amounts of charging heat, temperatures should be the same. The most likely explanation for this observation is a poor hydraulic adjustment of the double-U-pipes.

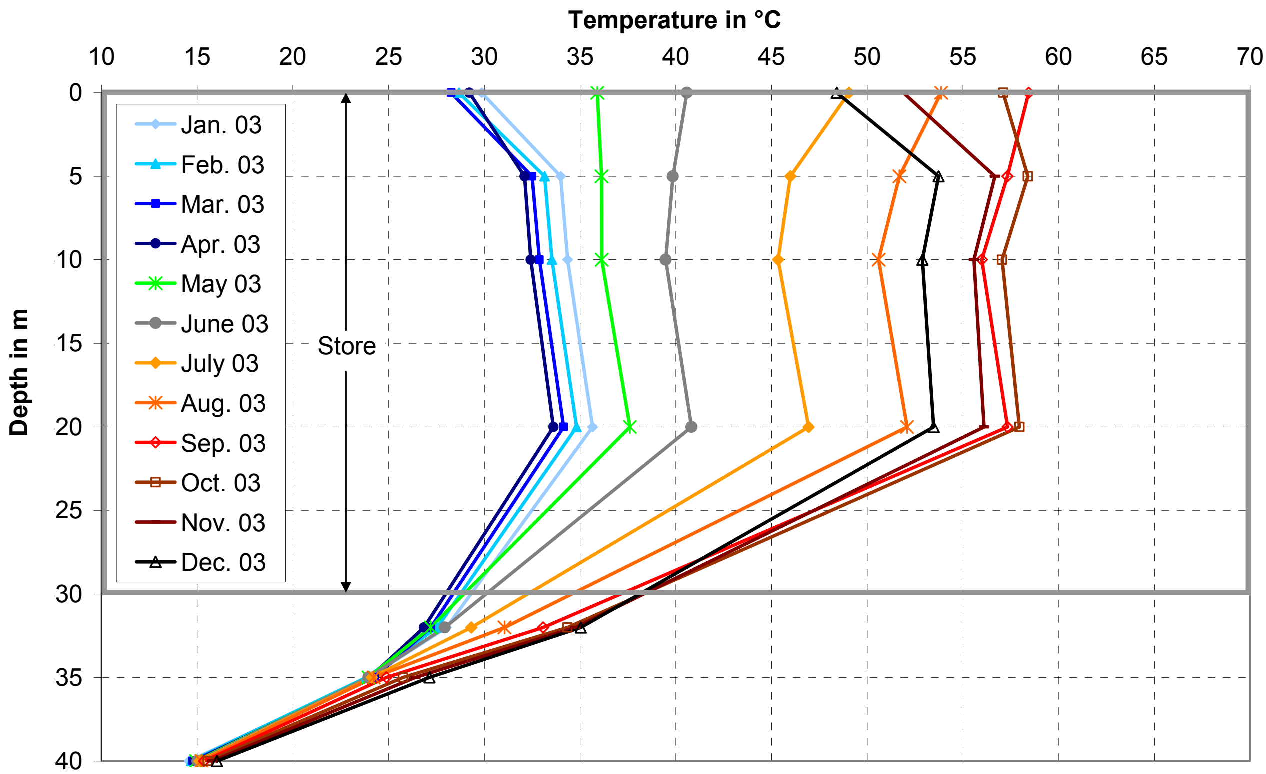

Figure 3: Temperatures in the seasonal duct heat store in 2003 (first extension)

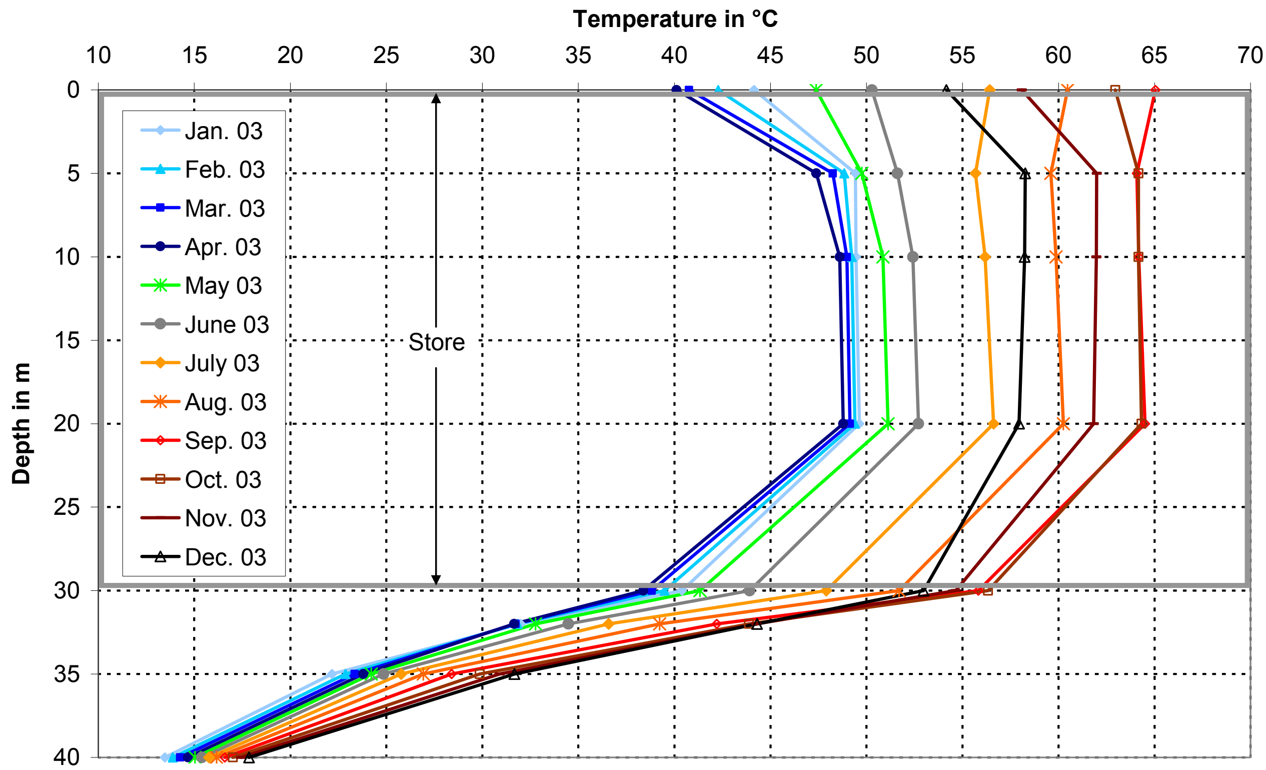

Figure 4: Temperatures in the seasonal duct heat store in 2003 (second extension)

Solar collectors

In figure 5 the solar gross heat gain of the different collector fields and the solar irradiation on collector plane (15 °) are shown. The solar heat gain varies in the different years due to the following reasons:

In 2000 the control unit failed and the collectors were operated manually for several months. In addition, the second buffer tank was installed which caused service interruption. Furthermore some components such as a heat exchanger and a pump failed which was not immediately detected.

In 2001 the duct heat store was extended during summer and therefore no heat storage was possible. Since the heat demand in the heat distribution net in summer is less than the heat delivery from the solar collectors some collector fields were manually taken out of operation.

In 2002 only minor operational and technical problems occurred and therefore the solar heat gain was higher than in the previous years.

In 2003 the highest solar heat gains were reached. This was the result of a solar irradiation which was significantly above average. In figure 6 it is seen that the solar gross heat gain for the same solar radiation values tends to be lower in 2003 than in 2002. This is caused by higher preheating temperatures of the collectors due to higher return temperatures from the heat distribution net and the duct heat store than in 2002, see figure 7. Furthermore some minor problems occurred, for example collector damage due to heavy storm. The heat exchanger of the collector field “shopping centre” was cleaned since it was clogged.

The differences in heat gain, in 2003 between 336 and 432 kWh(m²·a), of the different collector fields are mainly caused by different return temperatures from the heat distribution net from the buildings to the collector fields.

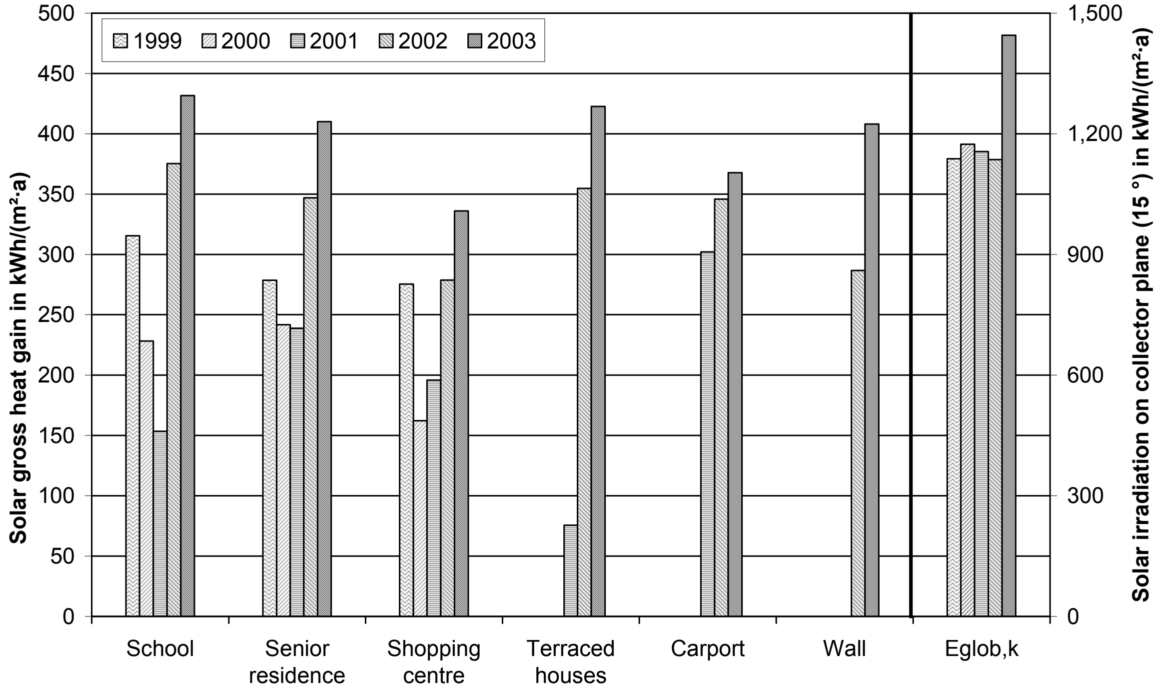

Figure 5: Comparison of the solar gross heat gain of the collector fields and the solar irradiation on collector plane (15 °) from 1999 to 2003

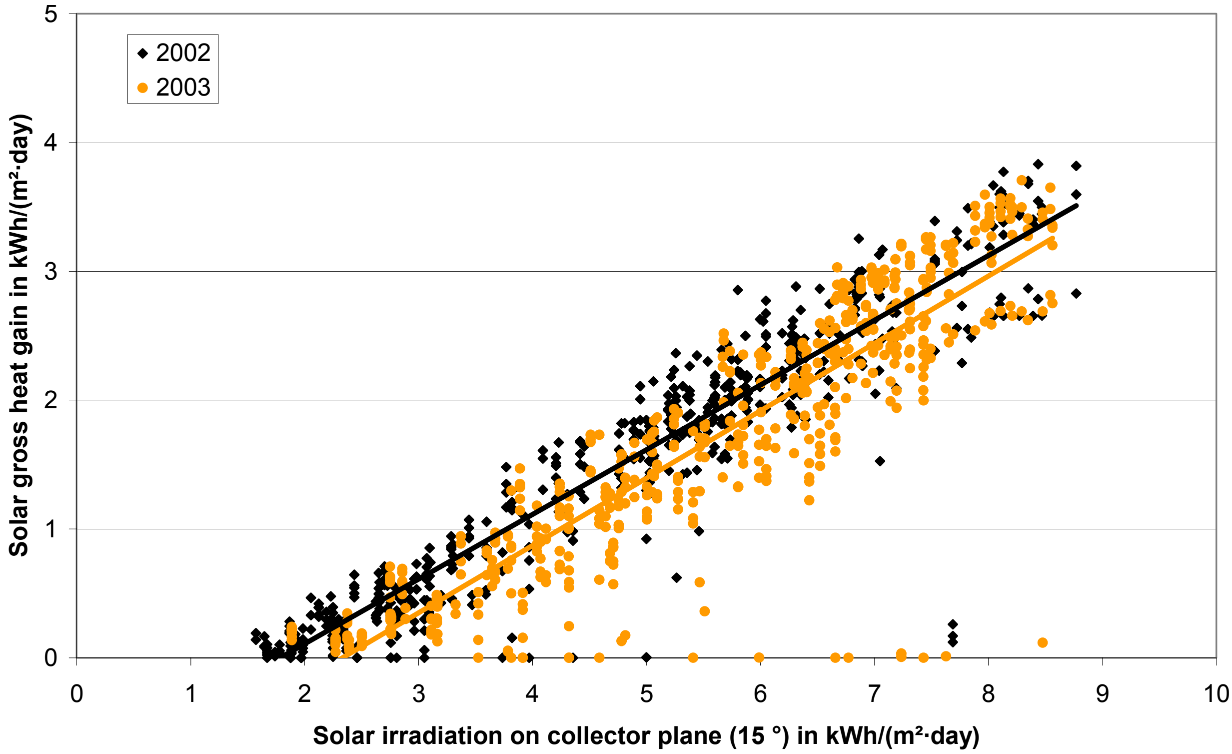

Figure 6: Gross heat gain of solar collectors versus solar irradiation on collector plane

Conventional heating system

In figure 7 the temperatures and volumetric flow rates of the heat distribution net are shown. In 2003 both supply and return temperatures increased in comparison to 2002. At the end of 2002 some new buildings were connected to the district heating system by an approx. 1000 m long pipe. Because of high circulation flow rates and a low heat demand this part of the net causes net return temperatures. The short-term increase of the volumetric flow rate in December 2002 was caused by a temporary supply of an adjacent district heating system.

It is also evident that net supply temperatures in summer 2002 / 2003 and in 2003 even in spring are higher than required. The reason therefore are the hydraulic conditions in the 3-pipe heat distribution net, see [3]. Because the collector volumetric flow rate is higher than the volumetric flow rate in the heat distribution net not enough cold water is available to cool down the supply temperature by admixing cold return flow to the hot supply flow.

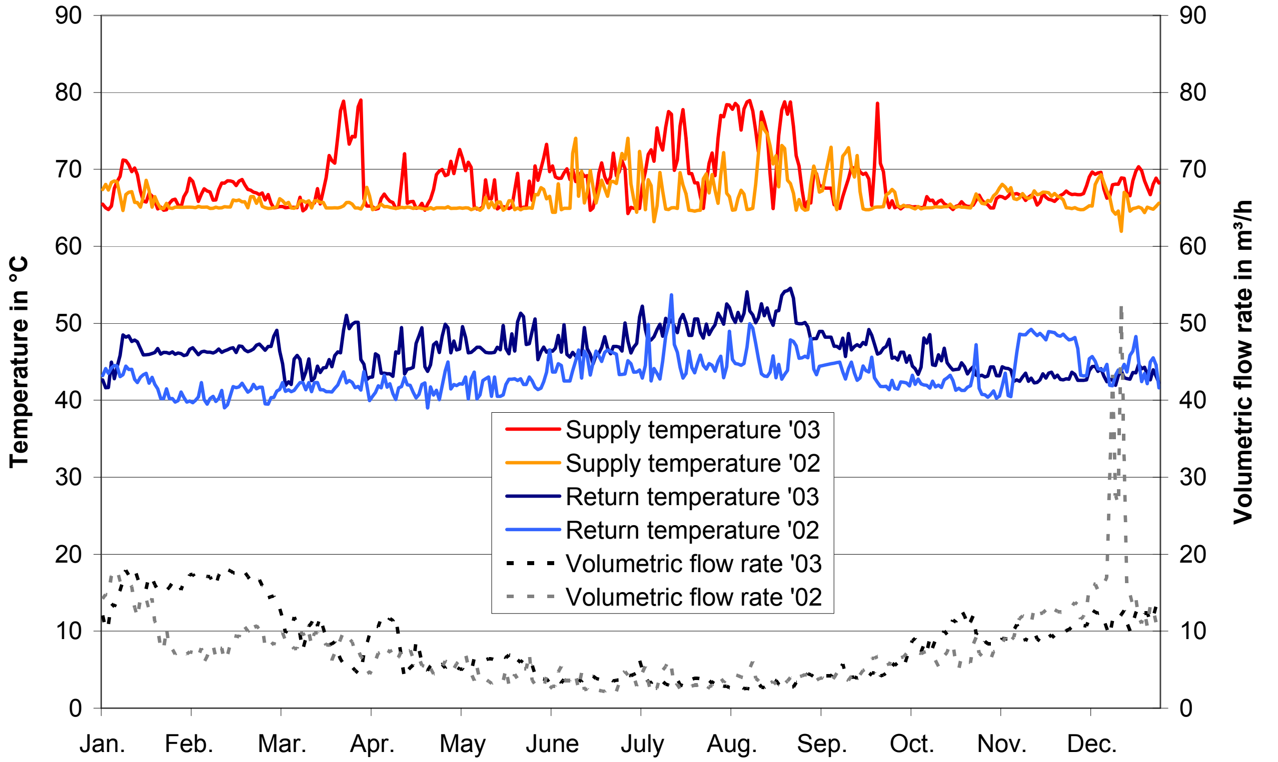

Figure 7: Temperatures and volumetric flow rates in the heat distribution net (2002 & 2003)

Heat balances

In figure 8 a schematic heat balance for the district heating system in Neckarsulm-Amorbach is depicted for 2003. About 70 % of the total solar heat delivery (2,121 MWh) was used to charge the duct heat store. 1,109 MWh heat were delivered by an auxilary gas boiler. The heat demand of the buildings amounts to 1,305 MWh and the heat losses in the heat distribution and solar net to 586 MWh. 153 MWh were discharged from the duct heat store and 548 MWh of thermal solar heat were directly used for heat supply in the heat distribution net. In 2003 a solar fraction of the total heat demand of 39 % was reached.

The heat losses in the heat distribution and solar net are high because the net is almost completely installed but less buildings are connected than expected. The discharge of the duct heat store is about 10 % of the charging heat amount because duct heat stores need a 5-8 years heating-up period to reach a quasi-steady-state behaviour. A significant increase of the storage efficiency is expected within the next years.

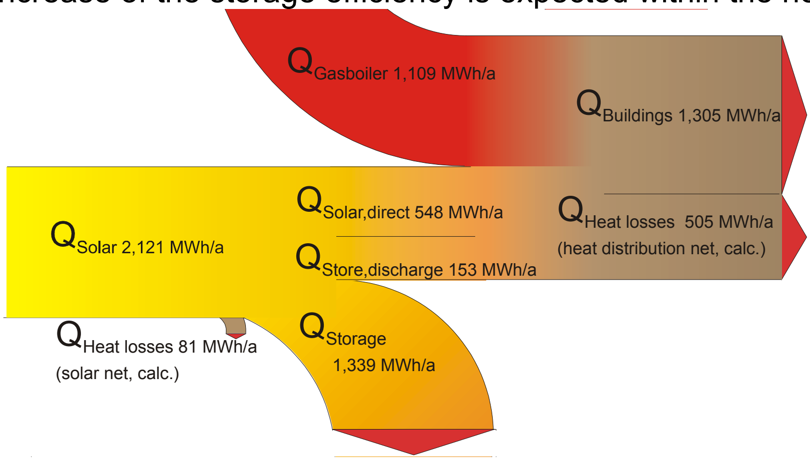

Figure 8: Schematic heat balance for Neckarsulm-Amorbach in 2003

In table 2 some characteristic data for the heat distribution system in Neckarsulm-Amorbach are listed. In 2003 the heat demand decreased eventhrough more buildings were connected to the district heating system. The solar fraction increased from 18 % in 1999 to 39 % in 2002 and 2003. The planned solar fraction of ~50 % is expected to be reached in the next years due to the heating-up period of the duct heat store.

Table 2: Characteristic data for the district heating system in Neckarsulm-Amorbach, modified from [2]

		1999	**2000**	**2002**	**2003**
Collector area (31st Dec.)	m²	2,636	3,090	5,007	5,007
Heat delivery of solar collectors (secondary side of solar heat exchanger)	MWh/a	802	577	1,696	2,050 +71 1)
per m²	kWh/(m²·a)	304	219 2)	331 3)	396 3), 4)
Solar heat delivery to heat distribution net	MWh/a	224	213	822	629 4)
per m²	kWh/(m²·a)	85	81	164	126 4)
Total heat demand and heat losses in heat distribution & solar net 5)	MWh/a	1252	1247	2126	1891
Heat delivery by gas boiler	MWh/a	1,028	1,034	1,303	1,109
Solar fraction (based on total heat demand)	%	18	17	39	39

1) Solar heat gain from adjacent district heating system (Eugen-Bolz-Straße)
2) Jan.-Sep. 2002 2636 m³; from Sep. 2002 3090 m²
3) area weighted
4) only Neckarsulm-Amorbach
5) including heat losses, temporary supply of adjacent district heating system (Eugen-Bolz-Straße)

Outlook

A further extension of the duct heat store is planned when the heat demand in the residential area increases. However instead of extending the duct heat store, the installation of a heat pump will be taken into consideration to increase the usable temperature level of the duct heat store.

References

[1]
J. Nußbicker, D. Mangold, W. Heidemann, H. Müller-Steinhagen: Erfahrungen aus Betrieb und Ausbau der solar unterstützten Nahwärmeversorgung mit Erdsonden-Wärmespeicher in Neckarsulm-Amorbach. Proc. of 12. Symposium Thermische Solarenergie, Staffelstein, Germany 24.-26.04.2002, pp. 471-475

[2]
M. Benner, M. Bodmann, D. Mangold, J. Nußbicker, S. Raab, Th. Schmidt, H. Seiwald: Solar unterstützte Nahwärmeversorgung mit und ohne Langzeit-Wärmespeicher (Nov. 98 bis Jan. 03), Forschungsbericht zum BMWi-Vorhaben 0329606 S, ISBN 3-9805274-2-5, Stuttgart, 2004

[3]
J. Nußbicker, D. Mangold, W. Heidemann, H. Müller-Steinhagen: Solar assisted district heating system with duct heat store in Neckarsulm-Amorbach (Germany), Proc. of ISES, Göteborg (Sweden), June 14-19, 2003

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