The Central Solar Heating Plant with Aquifer Thermal Energy Store in Rostock - Results after four years of operation

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In Rostock the first German central solar heating plant with an aquifer thermal energy store (ATES) went into operation in 2000. The system supplies a multifamily house with a heated area of 7000 m² in 108 apartments with heat for space heating and domestic hot water preparation. On the roof of the building 980 m² of solar collectors are mounted. The ATES operates with one doublet of wells and is located below the building. The store works as a seasonal heat store to overcome the gap between high amount of solar energy in summer and highest heat demand of residential buildings in winter. The solar system was designed to cover half of the yearly heat demand for space heating and domestic hot water preparation by solar energy. This target could be reached in 2003 with a solar fraction of 49 %.
The plant is one out of eight demonstration plants that have been built within the German research programme "Solarthermie-2000" in the last eight years /1/. The supplied multifamily house, see Figure 1, was built in 1999 by the house building company WIRO, Wohnen in Rostock Wohnungsgesellschaft mbH, who still owns and operates the building. The main part of the heat supply system was designed by Geothermie Neubrandenburg GmbH (GTN). The project is evaluated by SWT, ITW and GTN for the part of the ATES. The paper gives a detailed description of the system and presents the main results from four years of operation.

System description

The solar collectors have been realised as solar roofs. This means that the complete roof construction including collectors, rafters, insulation, integrated windows and blind-elements without absorbers, was prefabricated by the collector manufacturer and delivered in big roof modules on site, see Figure 2.

Figure 1: Central solar heating plant with ATES in Rostock

The solar heat is delivered to a 30 m³ buffer heat store outside the building. During summer, when the solar gain is much higher than the heat demand of the building, heat is charged from the buffer heat store into the ATES. This is done with a maximum temperature of 50 °C to reduce heat losses to the surroundings and to prevent precipitation in the hydraulic circle of the ground water.
The additional equipment like heat exchangers, pumps etc. is installed in the basement of the building. In order to reach a high usability of the ATES a heat pump is integrated into the system. The remaining heat load is covered by a gas condensing boiler. Figure 3 shows a scheme of the heat supply system.

Figure 2: Solar roof with integrated windows and blind-elements without absorbers in temporarily shaded parts

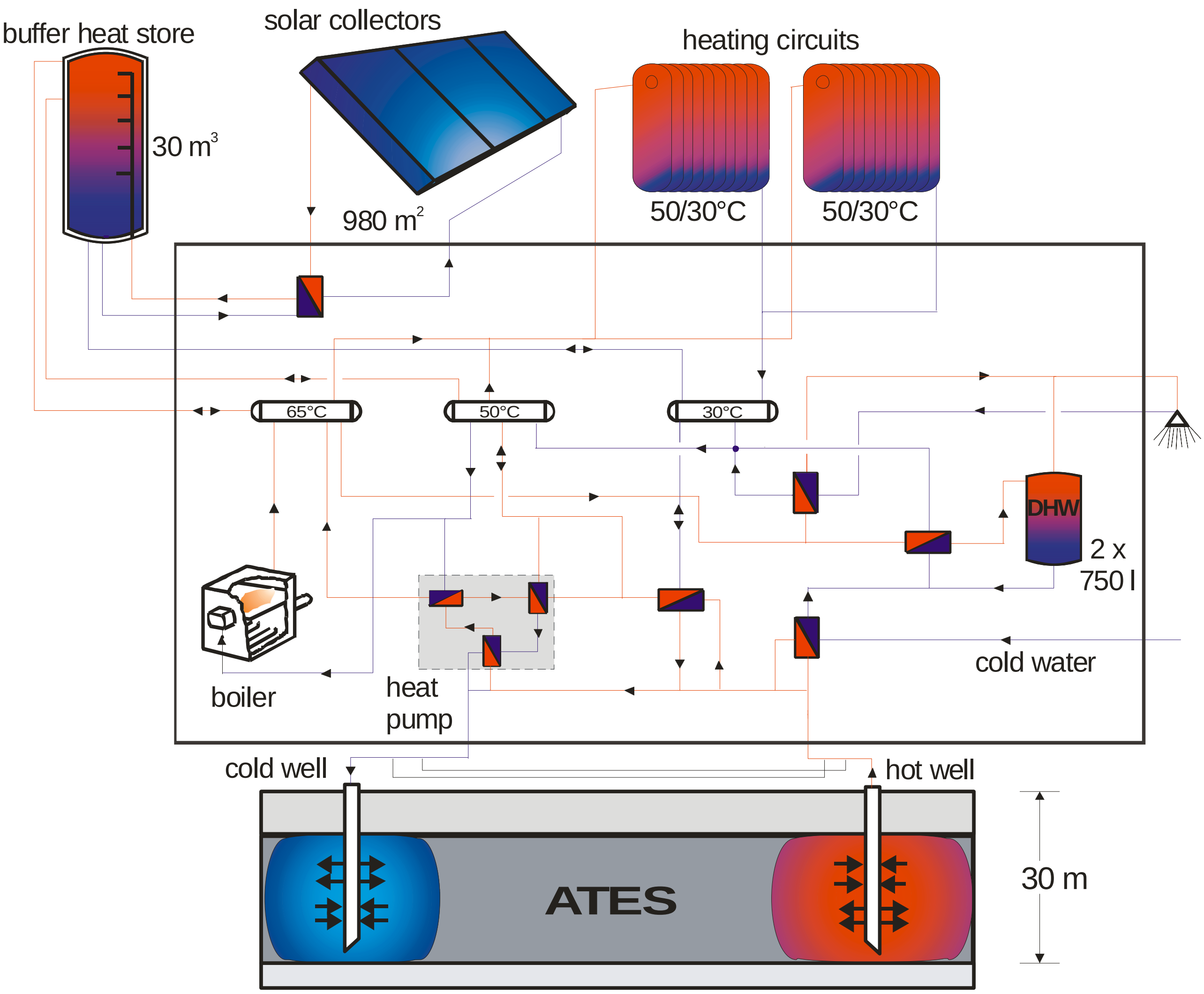

Figure 3: Scheme of the heat supply system (DHW: domestic hot water)

To guarantee good operating conditions for the solar system and the heat pump, a low temperature heat distribution system was realized. The domestic hot water is provided by two central 750-liter tanks.

The heat is supplied on two temperature levels: one on low temperatures of 45-50 °C for space heating, and a second one on a higher temperature of 65 °C for domestic hot water preparation. The return flow of the domestic hot water circulation is heated up by a separate heat exchanger (see Figure 3). This was changed subsequently to prevent mixing in the hot water tanks and to enable low return temperatures from this part of the system.

Aquifer thermal energy store

Because of suitable ground conditions an ATES is used for seasonal heat storage. A water-bearing ground layer in a depth of 15 to 30 m below ground surface was made accessible by two wells with a distance of 55 m. During charging-periods ground water is produced from the cold well, heated up by a heat exchanger and injected into the warm well. For discharging the flow direction is reversed: warm water is produced from the warm well, cooled down by a heat exchanger or the heat pump and injected into the cold well. The maximum design flow rate is 15 m³/h. Due to the changing flow directions both wells are equipped with pumps, production and injection pipes. To make sure that no oxygen can enter the ground water circle a pressurized nitrogen system fills the part of the wells above the groundwater level. An entry of oxygen into the aquifer system must be avoided because of a high risk of precipitation and well clogging. As a result of the low charging temperatures no water treatment is necessary.
The suitability of the ground layers has been investigated in advance by an extensive hydro-geological test programme. The hydraulic conductivity k_F of the aquifer was found to be between $6 \cdot 10^{-5}$ m/s and $9 \cdot 10^{-5}$ m/s in different parts of the layer, the mean volumetric heat capacity is 2.7 MJ/m³K, the mean thermal conductivity 3.2 W/mK.

Operational experiences

The solar system went into operation in April 2000. Table 1 shows the heat balances for the years 2001 to 2003.

Table 1: Heat balances for the years 2001 to 2003

Year		**2001**	**2002**	**2003 [1)]**
solar irradiation on collector surface	[kWh/m²]	1158	1194	1387
mean ambient temperature	[°C]	9.1	9.7	9.3
heat delivered by collectors	[MWh]	348	364	456
per m² collector area	[kWh/m²]	355	371	465
heat charged into ATES	[MWh]	214	245	295
heat discharged from ATES	[MWh]	78	158	143
used solar heat [2)]	[MWh]	211	278	304
per m² collector area	[kWh/m²]	216	283	310
total heat demand	[MWh]	624	597	594
distribution losses	[MWh]	32	47	29
heat delivered by gas boiler	[MWh]	420	322	279
electricity demand of heat pump	[MWh_{el}]	24	44	40
COP [3)] of heat pump	[-]	4.1	4.3	4.5
solar fraction [4)]	[%]	32	43	49

1): failures in individual flowmeters occurred in 2003, missing values have been completed by data from the control system or by internal heat balance calculations
2): solar heat delivered to the building: sum of directly used solar heat plus discharge from ATES
3): coefficient of performance; 4): related to end energy use

In the first winter (2000/2001) there were some start-up problems with the heat pump. For this reason it was hardly possible to discharge heat from the ATES. This led to a higher fraction of heat that had to be delivered by the gas condensing boiler. The solar fraction still reached 32 % in 2001 due to a high direct usage of solar heat and the winter season 2001/2002 where the heat pump worked more reliably.

The total heat demand for space heating and domestic hot water in the first regular year of operation 2002 was 597 MWh/a. This was 20 % more than calculated during design (497 MWh). The solar collectors delivered a usable heat input of 278 MWh/a; 119 MWh/a were used directly, 158 MWh/a were provided by way of the ATES which worked with an energy return-ratio of 64 %. The electricity demand of the heat pump was 44 MWh/a, the gas boiler delivered 322 MWh/a. Referred to end energy use the solar fraction resulted to 43 %.

Figure 4 shows the monthly heat balances for the years 2002 and 2003. Due to optimized hydraulic adjustments and some improvements in the control system it was possible to increase the solar fraction to 49 % in 2003. Especially in the summer month the direct usage of solar heat could be increased (Figure 4). The summer heat load can still not be covered completely by solar energy. This is mainly caused by the strictly seasonal operation of the ATES (see also Figure 6). During summer the ATES is in charging mode; to avoid blockings of the well screens the flow direction should not be changed frequently to discharging mode and back. Therefore in the summer months only the storage volume of the buffer heat store can be used for a solar heat delivery during night or during days without sun.

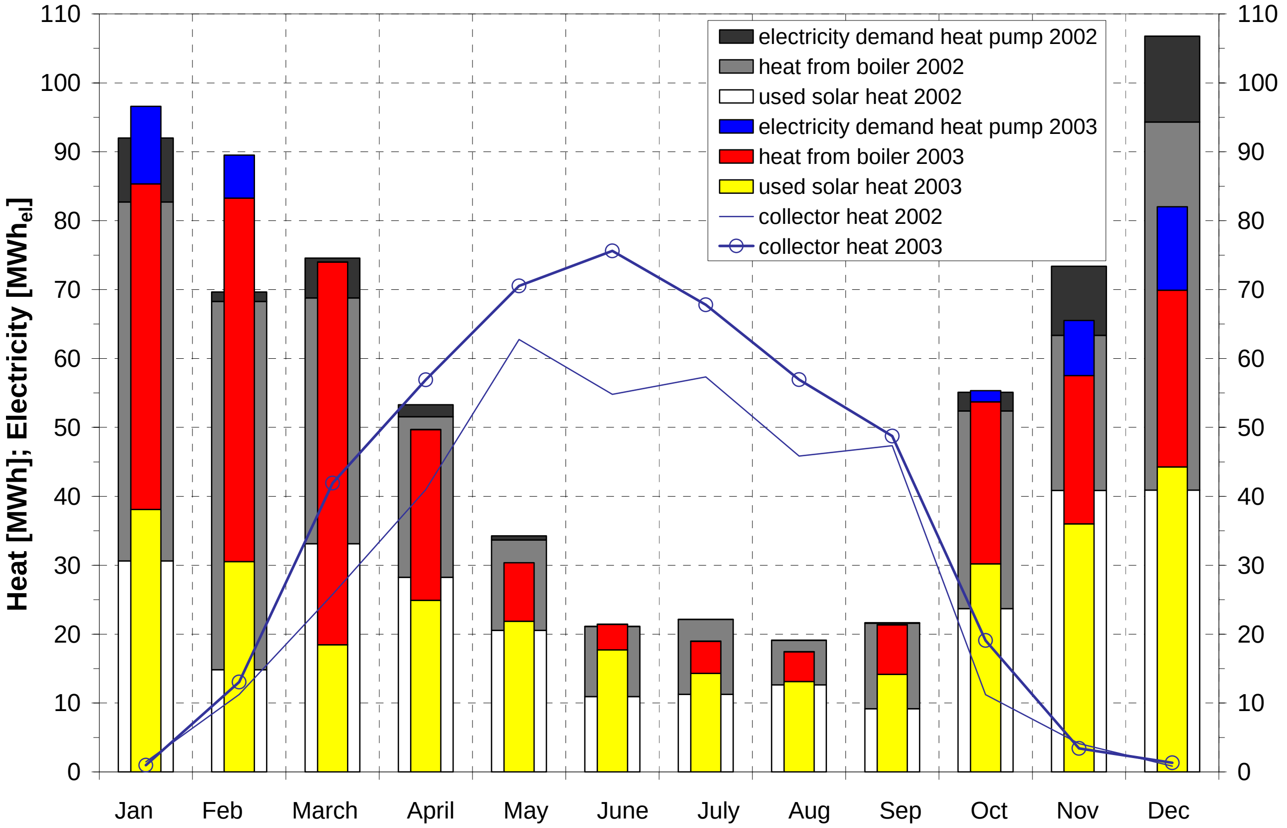

Figure 4: monthly heat balances for the years 2002 (background) and 2003 (front)

The yearly heat balance is indicated in an energy flow (sankey) diagram based on the results of the year 2003 in Figure 5.

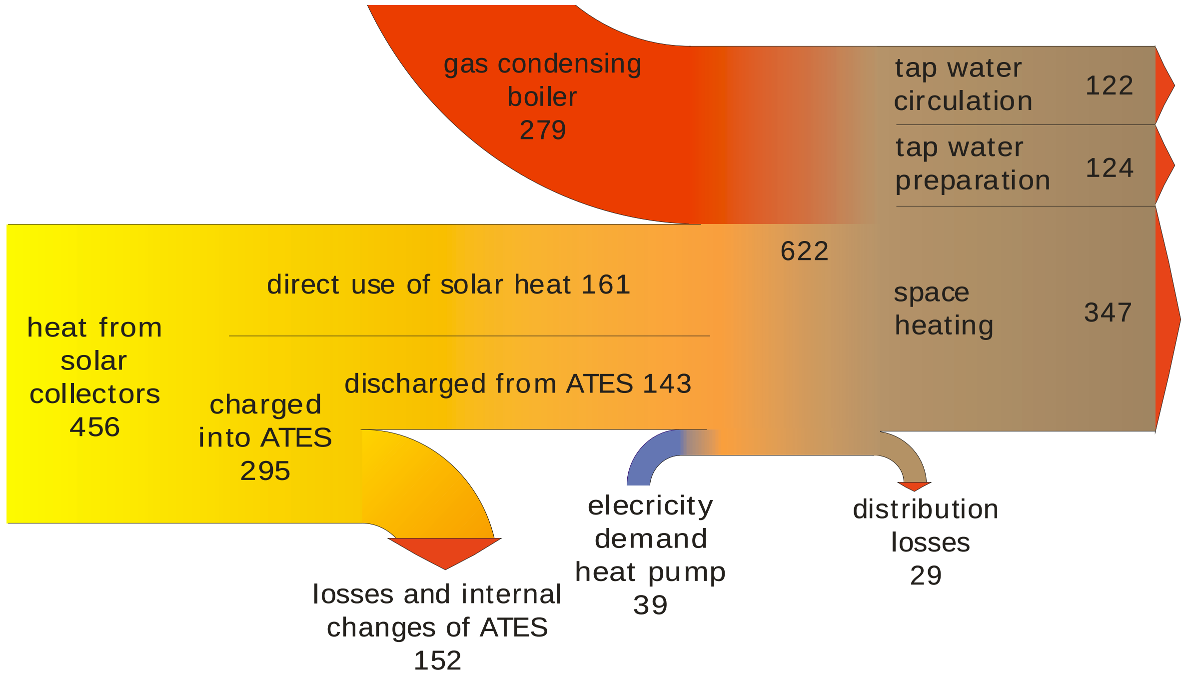

Figure 5: energy flow diagram for the year 2003, numerical values in MWh

In Figure 6 the heat balances of the ATES for the years 2002 and 2003 are illustrated. The already mentioned seasonal operation in a summer (charging) and a winter (discharging) mode can clearly be seen. Also an ATES-typical temperature decrease in the discharging mode can be observed. Only in the beginning of the discharging period a direct usage of the heat is possible. Afterwards the heat is discharged via the heat pump which has very good operating conditions in the beginning with COPs between 6 and 7 decreasing to approx. 3.5 at the end of the discharging period. The yearly mean values for the COPs can be found in Table 1.

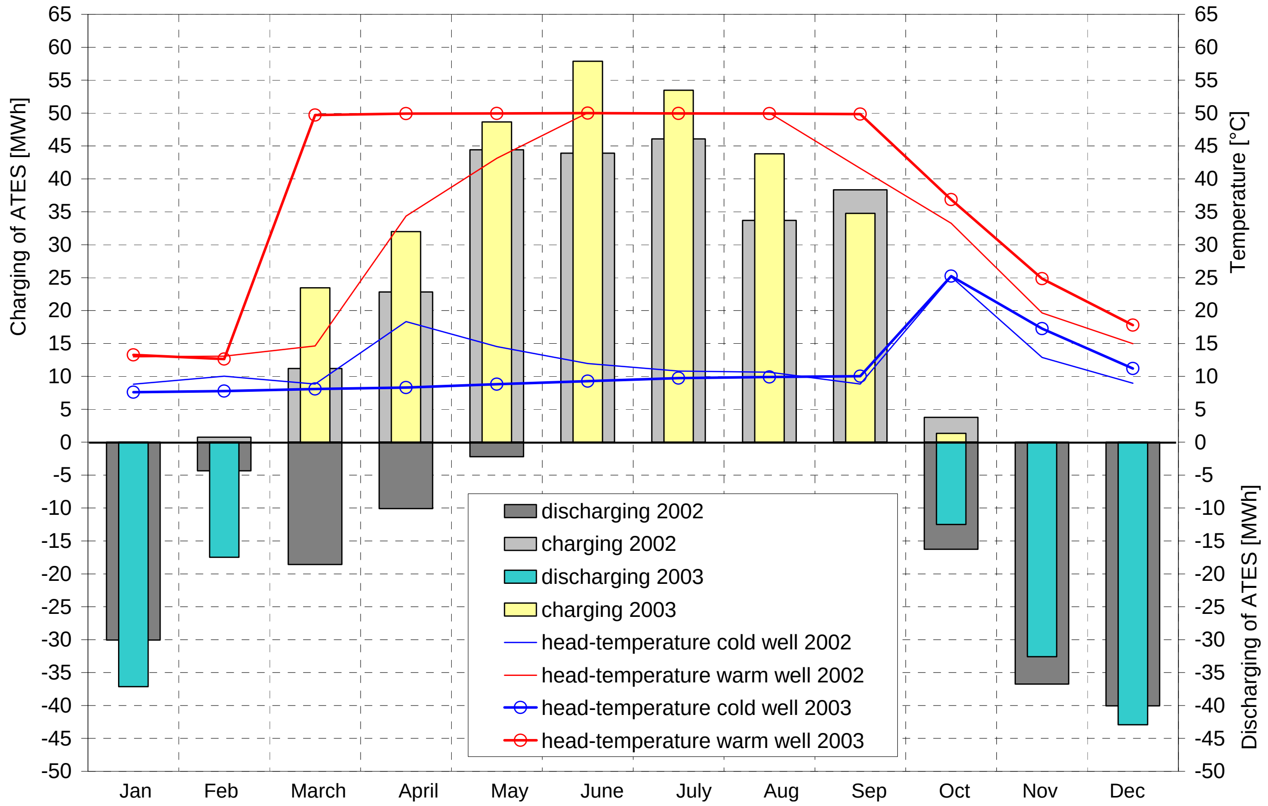

Figure 6: heat balances for the ATES for the years 2002 (background) and 2003 (front)

For monitoring reasons, seven additional boreholes have been drilled to be able to place more than 50 temperature sensors into the storage volume. Figure 7 shows ground temperatures of one complete storage cycle starting from the end of the discharging period in spring 2003 (01.03.2003) to the end of the charging period (01.10.2003) and the following discharging period until the end of 2003. A small part at the top of the aquifer layer can be observed, where temperature changes occur much faster then in the other parts. Obviously in this narrow part the hydraulic conductivity is much higher than in the rest of the aquifer layer and by this the groundwater exchange takes place preferably in this part. Other temperature values show that this effect is not symmetrical around the well but with a stronger tendency in the direction shown in Figure 7. The consequence of this is an irregular shape of the storage volume and a slightly lower efficiency due to higher losses to the surroundings because of a bigger surface. This has been investigated more detailed by GTN by calibrating a 3-dimensional finite-element model for coupled flow and heat transfer with the monitoring data /2/.

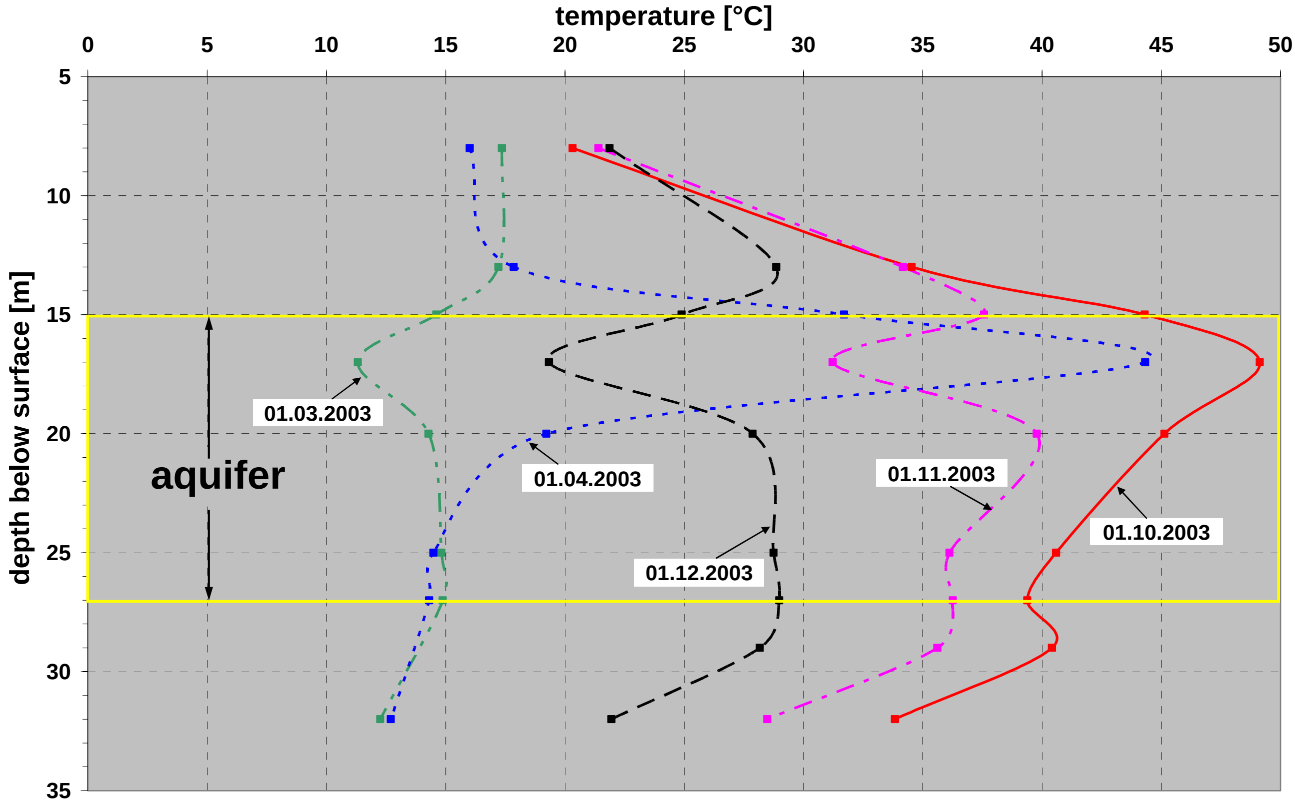

Figure 7: temperatures in the ATES in 5 m distance from the warm well

In February 2001 a breakthrough of groundwater to the ground surface occurred at the cold well while discharging the store with a high flow rate. An investigation of the well showed large blocked parts in the screen which caused a higher pressure in the well. Additional failures in the connection of the well piping caused the breakthrough to the surface. An operation with a by 20 % reduced flow rate was still possible until the problem was fixed in August 2002 by cleaning the screen and installing a new well piping inside the old one.

Economics

Table 2 gives a summary of the investment cost for the heat supply system. For the ATES a specific cost of 39 Euro/m³ water equivalent can be calculated (without VAT, including design). This is very favourable compared to other types of seasonal heat stores that have been built in Germany /3/.

Table 2: investment cost in thousand Euros (without VAT)

solar roof:		378.6
	solar collector part	211.6
	roof construction	167.0
ATES:		152.9
buffer heat store with stratification system:		31.8
heat pump:		16.8
boiler:		40.0
domestic hot water preparation:		14.2
piping (including pumps, fittings…):		178.3
control system:		72.7
design:		119.9
others:		13.0
total cost:		**1 018.2**
total cost solar and ATES:		**685.7**

Based on the given cost, with operational cost and maintenance included, and the solar heat delivery from the year 2003 the solar heat cost turns out to 26 Ct./kWh (calculation according to VDI-Guideline 2067, interest rate 6 %, life time for solar collectors 20 years, life time for the ATES 40 years).

Conclusions

The demonstration plant in Rostock is the first central solar heating plant with a seasonal aquifer thermal energy store in Germany. The results of the first four years of operation prove the technical feasibility and reliability of all components of the heat supply system. With a solar fraction of 49 % in the year 2003 the design target was reached after some improvements in the hydraulic adjustments and the control system.

Acknowledgements

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References

/1/ M. Benner, M. Bodmann, D. Mangold, J. Nußbicker, S. Raab, T. Schmidt, H. Seiwald: Solar unterstützte Nahwärmeversorgung mit und ohne Langzeit-Wärmespeicher (Nov. 1998 bis Jan. 2003); Report to the Research Project 0329606S (solar assisted district heating with and without seasonal heat storage, in German), ISBN 3-9805274-2-5, University of Stuttgart, 2004

/2/ J. Bartels, F. Kabus, T. Schmidt: Seasonal Aquifer Solar Heat Storage at Rostock-Brinckmanshöhe – First Operational Experience and Aquifer Simulation; Futurestock 2003 9th International Conference on Thermal Energy Storage, Warsaw, Poland

/3/ T. Schmidt, D. Mangold, H. Müller-Steinhagen: Seasonal Thermal Energy Storage in Germany, ISES Solar World Congress 2003, Gothenburg, Sweden