The BTES project in Crailsheim (Germany) – Monitoring results

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1. Introduction

The **C**entral **S**olar **H**eating **P**lant with **S**easonal **S**torage (CSHPSS) in Crailsheim supplies a district heating network, which was built at a former military site. The heat demand for the district heating network as well as for a school and a gymnasium is about 4000 MWh/a. It is planned to achieve a solar fraction of 50% - based on the annual heat demand for space heating and hot water preparation. The system consists of 7410 m² flat plate solar collectors, a 39000 m³ Borehole Thermal Energy Store (BTES), two hot water buffer stores (100 m³ & 480 m³) and a 485 kW_{th} electrically driven compression heat pump, which was installed in August 2011. In this paper the system is described and monitoring results are given and explained.

2. Description of the BTES project

System description

The district heating network supplies heat for a school with gymnasium and about 230 accomodation units. The residential area consists of three existing, energetically refurbished multi-family buildings and about 150 new buildings, which were mainly constructed as single-family houses.

The CSHPSS is divided into two system sections, see Fig. 1: the first system section consists of 2492 m² solar collectors, which are installed on multiple dwellings (CBE-buildings), the school and the gymnasium, a 100 m³ hot water buffer store and a central heating plant with district heating as backup heating. The first system section supplies the heat demand in the district heating network.

The second system section is operated seasonally and consists of 4918 m² solar collectors, which are installed in large collector fields on two noise barriers, a 480 m² hot water buffer store, a 39000 m³ BTES and a 485 kW_{th} electrically driven compression heat pump. The both system sections are connected to each other; the second system section deliveres heat to the first system section mainly in autumn and winter, whereas the first system section deliveres surplus solar heat to the second system section mainly in times with high solar yield and low heat demand in the district heating network.

Both hot water buffer stores are used to store solar heat. The 480 m³ buffer store in the second system section is needed since the thermal power of the solar collectors is higher than the maximum charging power of the BTES. With the buffer store the BTES can be charged with solar heat 24 hours per day. The heat pump is installed between the two buffer stores and used to discharge the BTES.

The heat pump is realised to deliver high temperatures at the condenser outlet (65°C to 75°C), the minimum / maximum evaporator inlet temperatures are about 25°C and 52°C, respectively. The refrigerant R227ea is used to make the high source temperatures at the evaporator inlet usable.

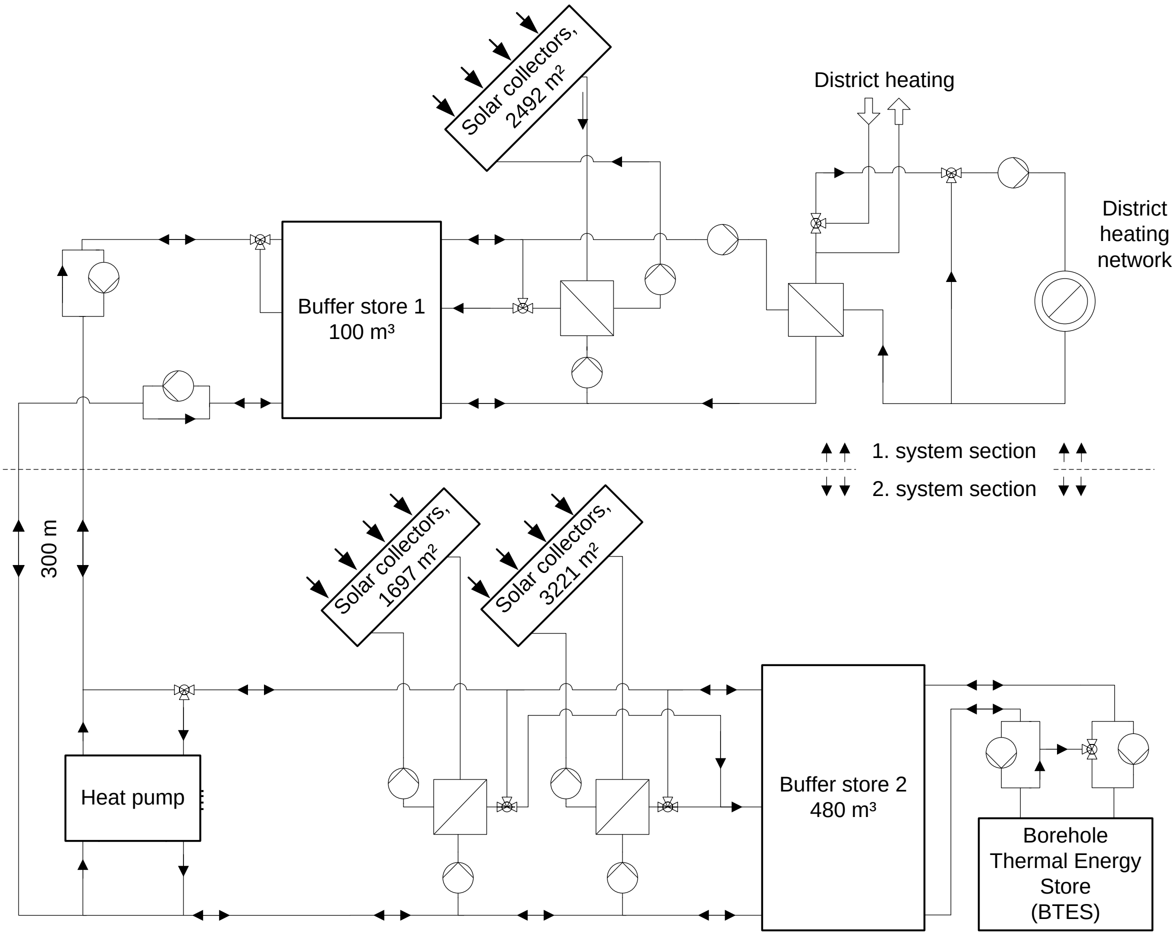

Fig. 1: Scheme of the CSHPSS in Crailsheim

Borehole Thermal Energy Store (BTES)

The BTES is used for seasonal heat storage: surplus solar heat is used to charge the BTES, mainly in spring and summer, whereas the BTES will be discharged in autumn and winter. The heat is stored directly in the ground and the BTES is charged and discharged by borehole heat exchangers (BHE). The heat transfer fluid, circulating in the BHE, is water. The Crailsheim BTES was built in 2008 and has a volume of 39000 m³ and a diameter of 30 m.

80 BHE (double-U-pipes) are installed in the Crailsheim BTES. In contrast to the Neckarsulm store, where Polybuten-BHE are installed, the BHE in the Crailsheim BTES are made of PE-Xa. According to the manufacturer Rehau the PE-Xa material is temperature resistant in the expected charging temperature range and insensitive against notches, stress cracks and aging. The dimensions of the BHE are 4 x 32 mm (outer diameter) with 2.9 mm wall thickness. The BHE have a distance of 3 m and always two BHE are connected in series.

Each BHE has a length of 55 m and the boreholes are filled from 5 m to 55 m below BTES top surface with a grouting material with a thermal conductivity of > 2 W/(m·K). The first 5 m are filled with a thermal insulation material inside a support pipe with a thermal conductivity of 0.12 W/(m·K) to minimise heat losses to the groundwater, which was found in this vertical range. The BTES is thermally insulated on top with a 0.4 m to 0.6 m layer of foam glass gravel which is covered by a drainage construction and a soil layer.

The BTES is divided into four identical sections with each 20 BHE. The flow direction is from the BTES centre to the BTES outside in the charging case and the flow direction is reversed in the discharging case. The BHE are connected to the main supply and return pipes in an inspection chamber, which is located in the centre of the BTES.

To ensure a uniformly flow through all BHE the total length of all BHE circuits is the same, which is realised by different lengths in the horizontal piping and thus no flow control valves are necessary.

In Fig. 2 the coils with the PE-Xa BHE (left) and an overview on the BTES construction site (right) are shown. The bottom end of the BHE, which is mechanically protected, can be seen right to the coil. On the right photo the central inspection chamber as well as the BHE coils can be seen.

Fig. 2: BHE coils (left) and overview on the BTES construction site (right)

Measurement equipment (BTES)

Inside the BTES and up to a distance of 30 m from the BTES centre a total of nine vertical rods with temperature sensors are installed to monitor the thermal behaviour of the BTES and its surrounding, see Fig. 3. With the arrangement of the temperature sensors the influence of the groundwater flow on the thermal behaviour of the BTES can be measured. The 83 temperature sensors are installed in differents depths from BTES surface up to a depth of 80 m. Furthermore the BTES is equipped with heat flux sensors in combination with temperature sensors to monitor the functionality of the insulation material (foam glass gravel).

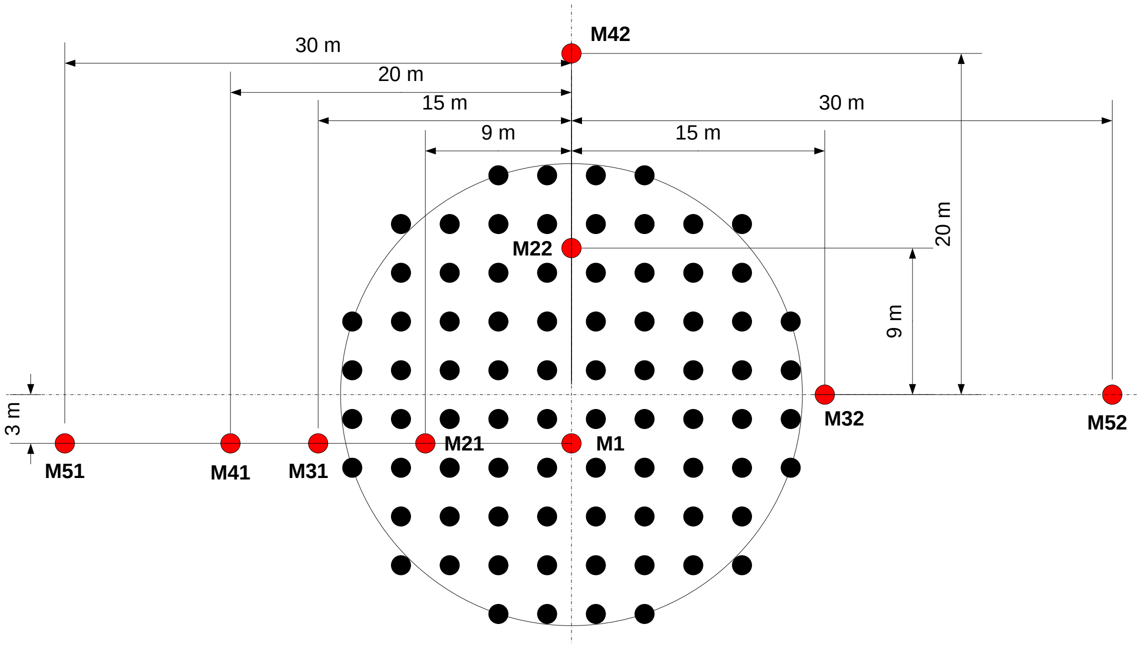

Fig. 3: Positions of the BHE and positions of the vertical rods with temperature sensors of the Crailsheim BTES

3. Results and discussion

In table 1 the most important data of the CSHPSS in Crailsheim are given. The designed values were taken from [3]. The collector area was extended from 1559 m² in 2008 to 7410 m² at the end of 2011. So the designed collector area of 7325 m² is already achieved. The total solar yield of the collectors was 2337 MWh/a in 2011. The designed solar yield was not yet achieved since 1697 m² of the 7410 m² collectors were installed and put into operation during the year 2011.

The solar heat amount into the district heating network consists of the directly used solar heat and the seasonal stored solar heat, which is discharged from the BTES. With a heat amount of 1342 MWh/a in 2011 the measured solar heat into the district heating network is less than the designed value of 2095 MWh/a due to the lower solar yield than planned (see above) and since the BTES was not yet discharged.

The overall heat delivery into the district heating network consists of the heat demand for space heating and hot water preparation in the buildings and the heat losses of the district heating network. The heat delivery design value is 4100 MWh/a and was almost achieved with a value of 4068 MWh/a in 2010. The heat delivery was due to less heat demand for construction heating for new buildings in 2011 less than in 2010. Furthermore some optimisations were implemented, e. g. the network supply temperature was decreased.

The backup heating, district heating from a neighbouring combined heating and power plant, was 2407 MWh/a in 2011 and therefore 40% higher than the designed amount of backup heating. The amount of backup heating will decrease if the BTES is discharged.

Up to now the BTES was only charged, in 2011 with a heat amount of 781 MWh/a. The BTES can be discharged either directly - if the temperature level in the BTES is sufficient - or discharged via heat pump. The heat pump was installed in August 2011, but not yet put into regular operation.

The designed solar fraction is 51% for a system with a collector area of 7325 m², a 37500 m³ BTES, two hot water buffer stores with 100 m³ and 600 m³, respectively, and a 258 kW_{el} heat pump (SPF 4.8). The values for the realised system differ comparatively little, exept the heat pump. The design maximum temperature in the BTES is 65°C whereas the design minimum temperature in the BTES is 22°C (average value for the whole BTES). In 2011 a solar fraction - based on the heat demand for hot water preparation and space heating - of 35.8% was measured.

Table 1: Data of the Crailsheim CSHPSS

		Design value	**2008**	**2009**	**2010**	**2011**
Collector area (31.12.)	m²	7325	1559	5714	5714	7410
Solar yield of collectors	MWh/a	2699	570	1735	1785	2337
Solar heat into district heating network	MWh/a	2095	484	674	864	1342
Overall heat delivery into district heating network	MWh/a	4100	2990	3497	4068	3750
Backup heating (district heating)	MWh/a	1715	2530	2832	3197	2407
Charging heat amount BTES	MWh/a	1135	-	849	779	781
Discharging heat amount BTES	MWh/a	830	-	-	-	-
Solar fraction	**%**	**51**	**16.2**	**19.3**	**21.2**	**35.8**

In Fig. 4 the monthly heat balance, the solar yield of the collectors and the solar irradiation on the collectors for the Crailsheim CSHPSS is shown for 2011. From March / April to September / October a significant proportion of the heat demand can be covered by solar heat, only in winter a high heat amount from the backup heating is required. From the curve for the solar irradiation it can be seen, that the solar irradiation was quite low in June 2011, this fact is also reflected by the curve for the solar collector yield. From April to October the solar yield of the collectors is much higher than the solar heat into the district heating network. The surplus solar heat was used to charge the BTES. The data for the solar irradiation are missing for the months January to March due to a failure of the data acquistion system.

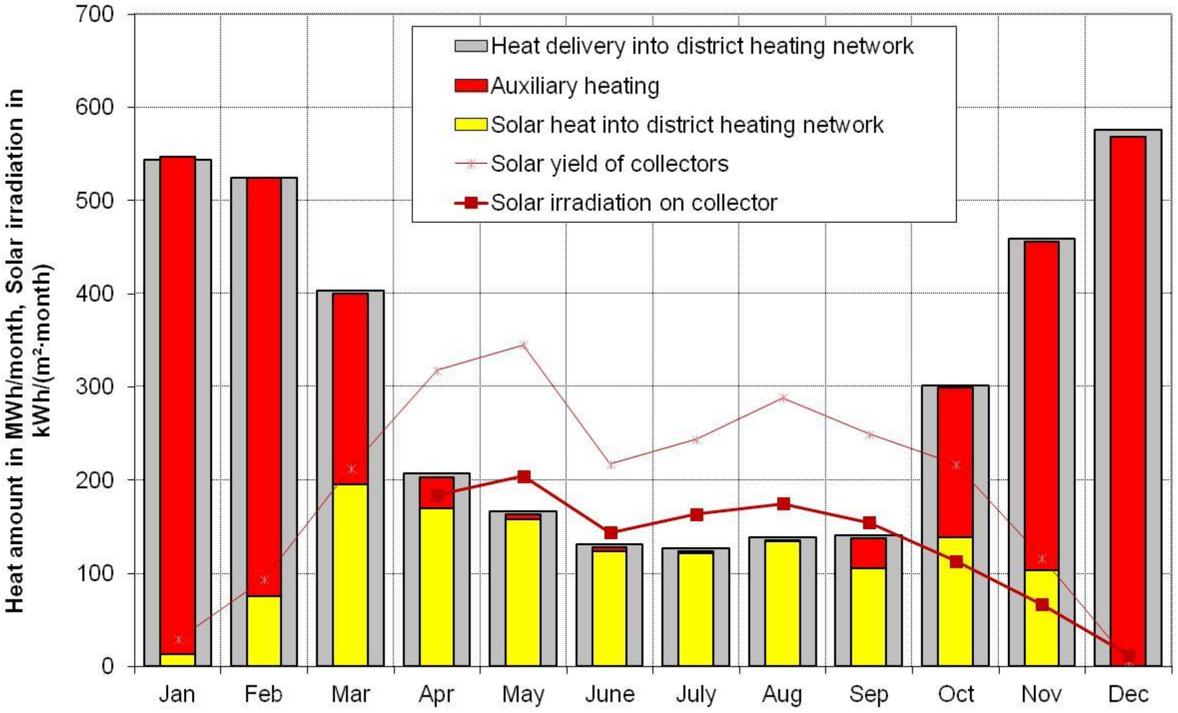

Fig.: 4: Monthly heat balance, solar collector yield and solar irradiation on collectors for the CSHPSS in Crailsheim for 2011

In Fig. 5 the monthly charging heat amounts as well as the temperatures in a depth of 30 m in and around the BTES in Crailsheim are shown for 2010 and 2011. The positions of the vertical rods with the temperature sensors can be found in Fig. 3. As already mentioned the BTES was not yet discharged. The charging heat amount per month depends on the solar irradiation and solar collector yield, respectively, the temperatures in the BTES and the heat demand in the district heating network. The charging heat amount is therefore usually highest in spring and summer.

The temperatures in the store (M1, M21, M22) decrease due to heat losses from January to April 2010 and increase then due the charging up to a maximum temperature of 51°C in October 2010. Not beeing in operation the temperatures in the store decrease, but in April 2011 they are still higher than in April 2010. In November 2011 a maximum temperature of 56°C was measured.

The temperatures outside the BTES (M31 and M32), about 1.5 m from the outside BHE, show a temperature difference between about 1 and 5 Kelvin. The temperature difference indicates a groundwater flow but nevertheless the temperature decrease is at the BTES border with about 1 to 2 Kelvin per month quite low.

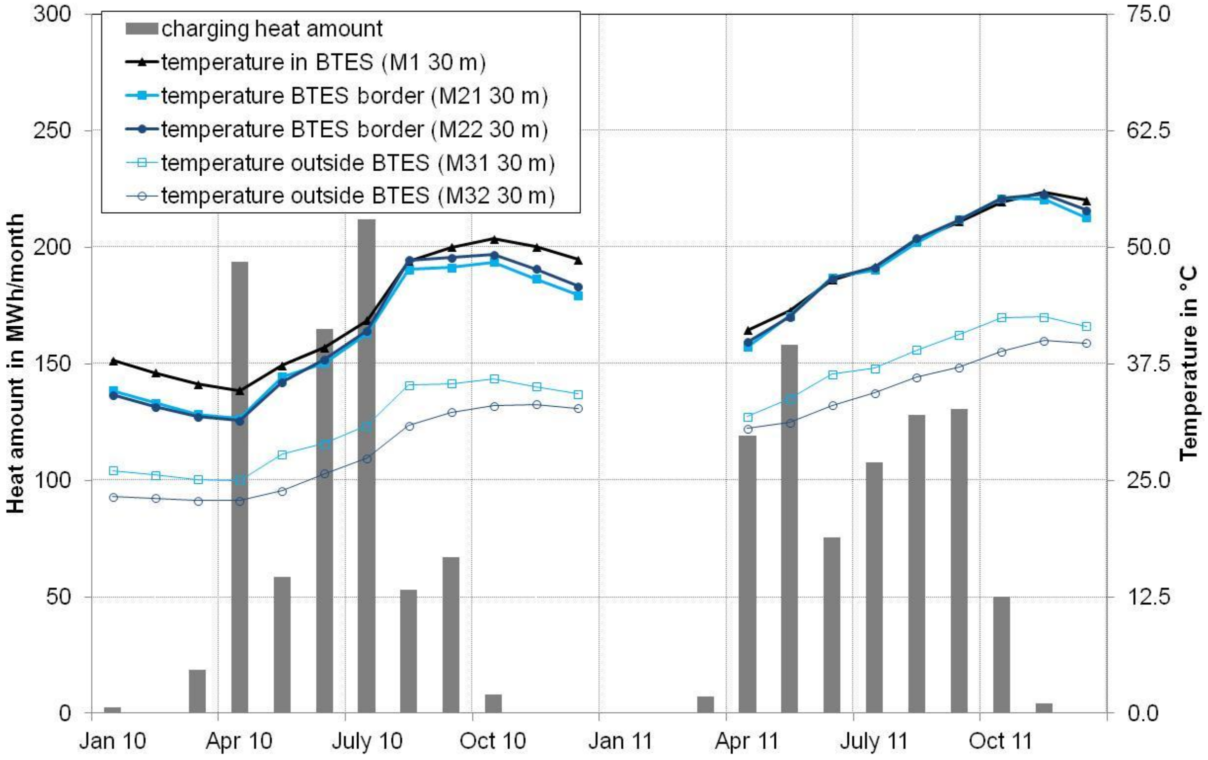

Fig.: 5: Monthly charging heat amount of the BTES and temperatures in and around the BTES

In Fig. 6 the vertical temperature profiles in the BTES centre (M1) are given quarterly. The BTES was heated up from an undisturbed ground temperature of about 12°C since spring / summer 2009. The "active" part of the BTES is from 5 m to 55 m below BTES top surface. The upper part (0 - 5 m) of the BHE is thermally insulated as mentioned in chapter 2. The temperatures below the BTES are measured to monitor the heat losses of the BTES. In a depth of 80 m almost no temperature increase was measured, whereas the temperature in a depth of 70 m, this means 15 m below the store, rose about 3 K.

The temperatures in the store are relatively uniformly distributed, which means that there are no areas with much higher hydraulic transmissivity and / or thermal conductivity as in the rest of the BTES, but the highest temperatures are measured in a depth of 40 m: the temperature in 40 m is 56.6°C and in 10 m the temperature is 53.8°C (01.10.2011). The temperature distribution is a result of the characteristic soil values (thermal conductivity and specific heat capacity) which vary with depth.

In Fig. 7 the vertical temperature profiles about 1.5 m from the outside BHE are given quarterly. The temperature increase is caused by the heat losses of the BTES since the store is thermally insulated only at the top. Therefore a BTES should be operated at the lowest temperatures as possible and the use of a heat pump to discharge the BTES is recommended.

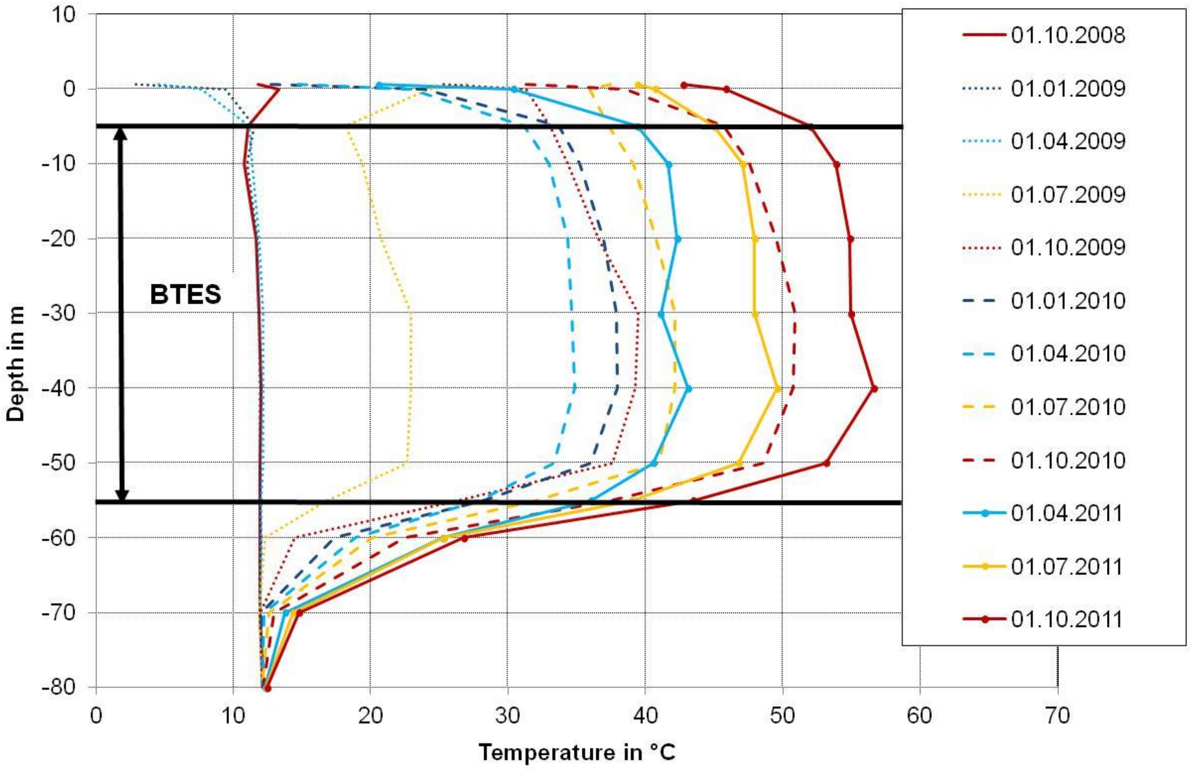

Fig.: 6: Quarterly vertical temperature profile in the centre of the BTES (M1)

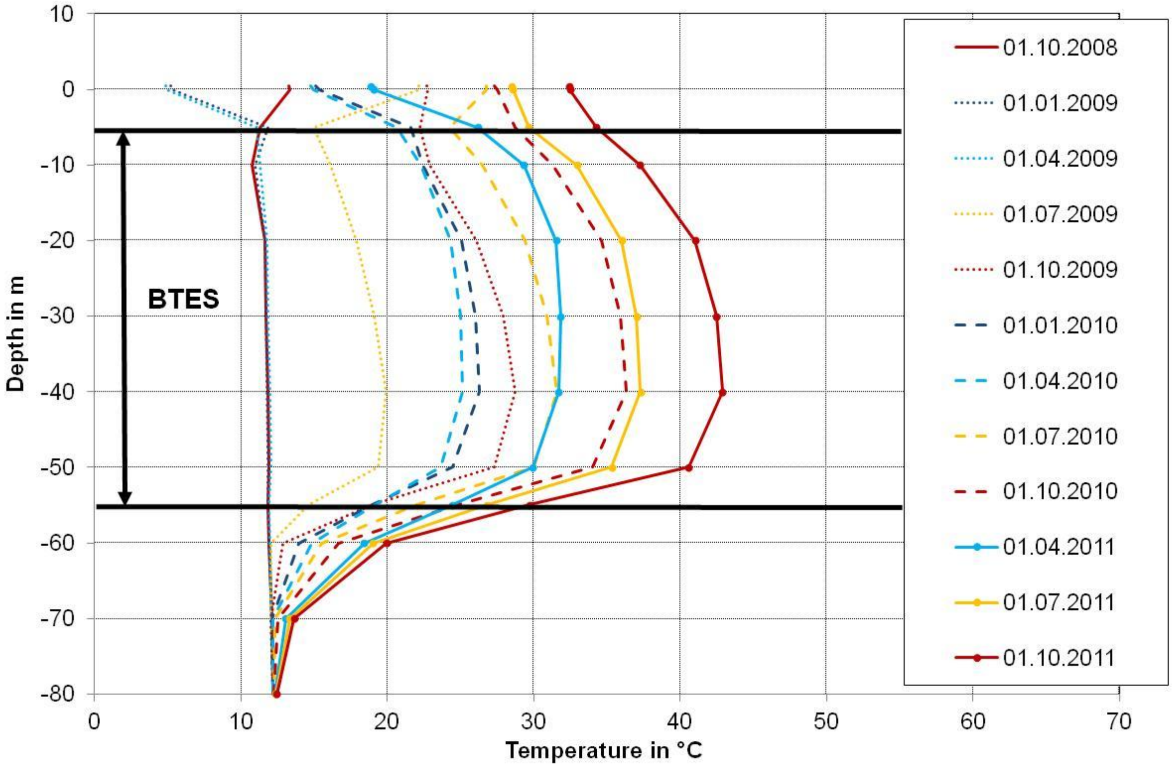

Fig.: 7: Quarterly vertical temperature profile outside of the BTES (M31)

Operational experiences

Experiences from the monitoring program show the necessity of a regular and long-term monitoring. On the one hand by a regular monitoring the failure of components can be detected and the malfunction can be fixed: leakages, e. g. at a weld, were found at both hot water buffer stores, the vacuum breaker of the buffer stores failed, leakages in the solar collector circuits occurred, valves didn't work correctly and had to be adjusted, sludge collectors clogged, etc. On the other hand there is a high optimisation potential regarding the control strategy. Some improvements will be discussed consecutively.

The measured district heating network supply temperature was higher than the target district heating network supply temperature. It was found that the control sensor was installed at an unsuitable position (too close to a junction of two pipes). The district heating network supply and return temperatures as well as the volume flows are shown in Fig. 8 for 2010 and 2011.

Due to wrong programming of the control strategy the return temperature at the primary side of the heat exchanger between the buffer store 1 and the district heating network rose sometimes to temperatures over 65°C, see Fig. 9, but it should be as low as possible. The design network return temperature is 35°C (yearly average) and the temperature difference between the return temperatures at the heat exchanger should be less than 3 K. The high temperatures occurred when the volume flow at the primary side was much higher than at the secondary side.

The maximum charging temperature for the BTES was increased and the maximum volume flow through the BTES decreased to achieve higher temperatures in the BTES and to prevent stagnation in the solar collectors.

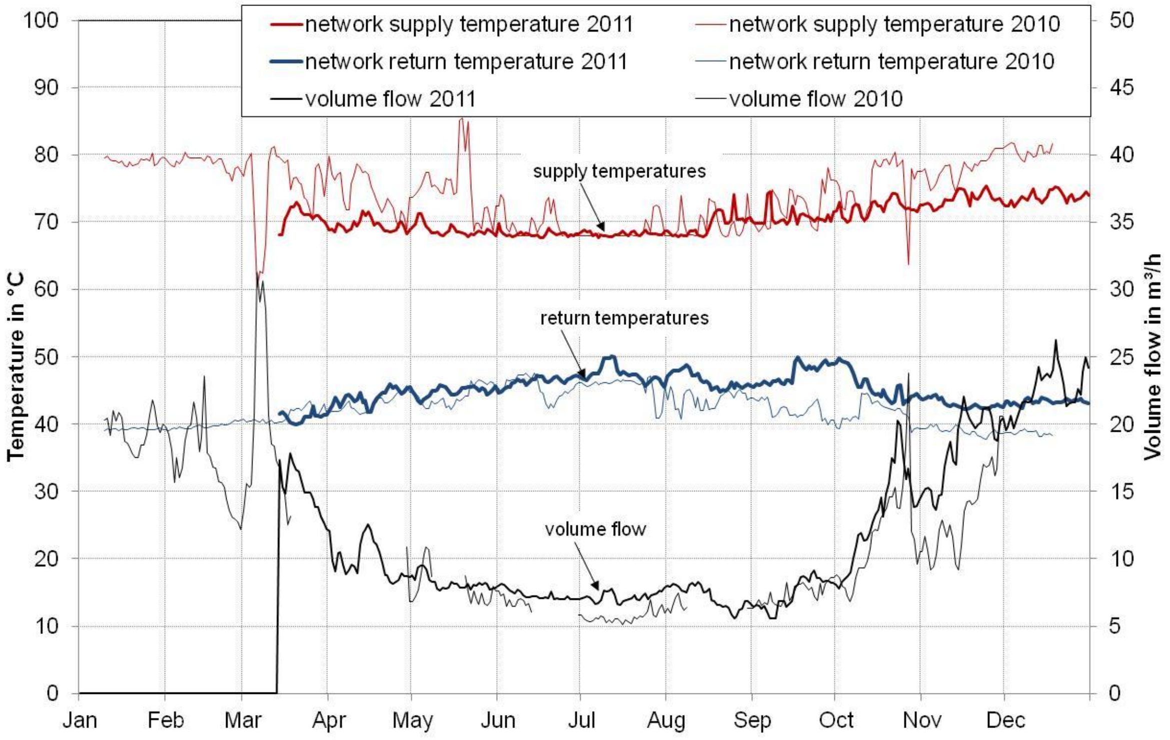

Fig.: 8: District heating network supply and return temperatures and volume flows for 2010 and 2011

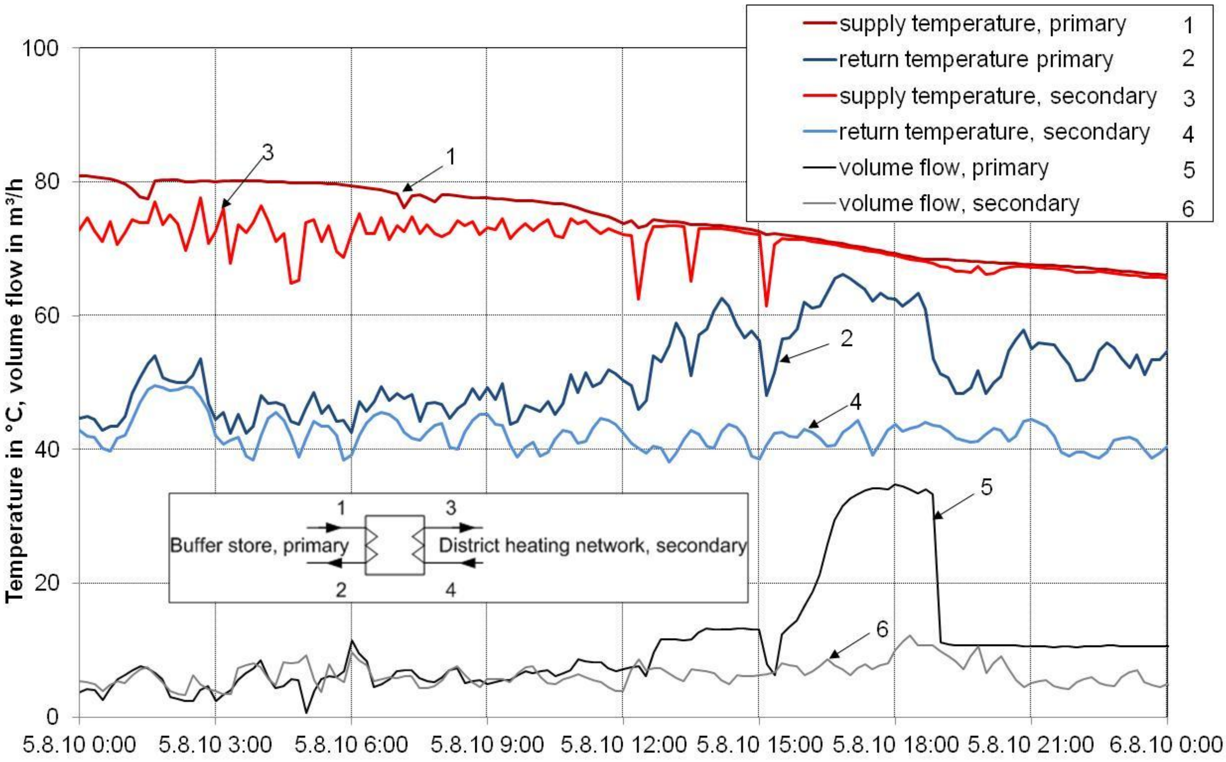

Fig. 9: Supply and return temperatures and volume flows at the heat exchanger between buffer store 1 and district heating network

4. Conclusions

In Crailsheim at the area of a former military site a Central Solar Heating Plant with Seasonal Storage was built. The seasonal store was built as Borehole Thermal Energy Store. So far the heat demand in the district heating network was covered by solar collectors and backup district heating. In summer the surplus of solar heat was used to charge the BTES, which was only charged - but not discharged - since commissioning up to now. The heat pump, which is essential to discharge the BTES, was installed in August 2011. The accompanying monitoring discovered optimisation potential, e. g. regarding the control strategy.

5. References

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6. Acknowledgements

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