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MONITORING RESULTS AND OPERATIONAL EXPERIENCES FOR A CENTRAL SOLAR DISTRICT HEATING SYSTEM WITH BOREHOLE THERMAL ENERGY STORE IN NECKARSULM (GERMANY)

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1. INTRODUCTION

The solar assisted district heating system with borehole thermal energy store (BTES) in Neckarsulm is being realized since 1997. In 2005 about 300 accommodation units, a school with gymnasium and a shopping centre were supplied with heat by the district heating system. So far 5263 m² of solar thermal collectors are installed; the volume of the BTES is presently 63360 m³ of ground volume. Solar heat is stored in the borehole thermal energy store from summer to winter. The BTES was extended twice; the operation of the first and second extension started in 1999 and in 2002, respectively. The maximum temperature in the borehole thermal energy 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, while it was 34% in 2004. The planned solar fraction of 50% is expected to be reached within the next years. This paper presents an overview of the present status of the system as well as operational experiences.

2. SYSTEM DESCRIPTION

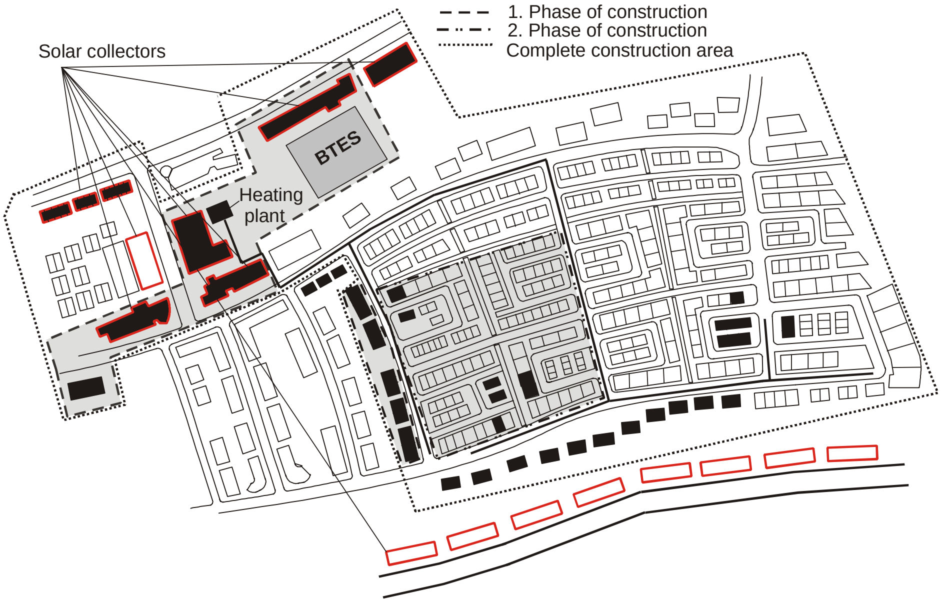

Figure 1: Plan of the site in Neckarsulm

The solar assisted district heating system presently supplies about 300 accommodation units and some public buildings with heat, see figure 1 (black colored buildings). 5263 m² solar thermal collectors are installed on different buildings as well as on a carport and a noise protection wall. 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 solar collectors. 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 BTES, 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 BTES was extended twice and presently contains a volume of 63360 m³ with 528 borehole heat exchangers (double-U-pipes, 30 m deep) for charging and discharging.

3. BOREHOLE THERMAL ENERGY STORE

The BTES is described in detail in Seiwald (2000), Benner et al. (2003), Nussbicker (2003) and Bodmann et al. (2005). In figure 2 the different extensions of the store and the positions for temperature measurement are shown. In figure 3 charging and discharging heat amounts as well as temperatures in the centre of the first and second extension in a depth of 10 m of the store are given. It is to be seen that discharging heat amount is very low until 2003. The store needs to be heated up in the first operational years to reach a yearly quasi steady state behavior. In steady state behavior the storage efficiency is expected to be about 70%.

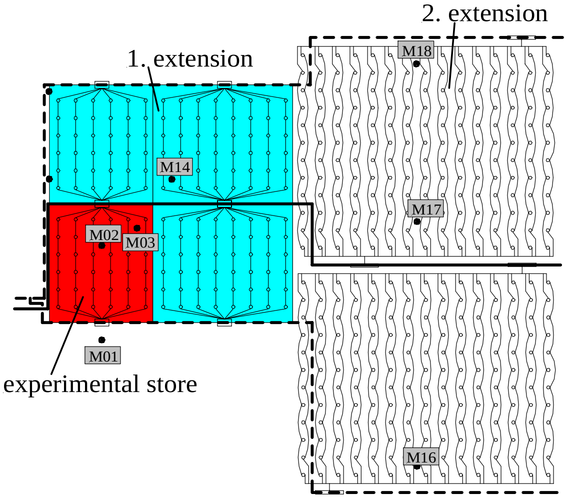

Figure 2: Plan of the BTES

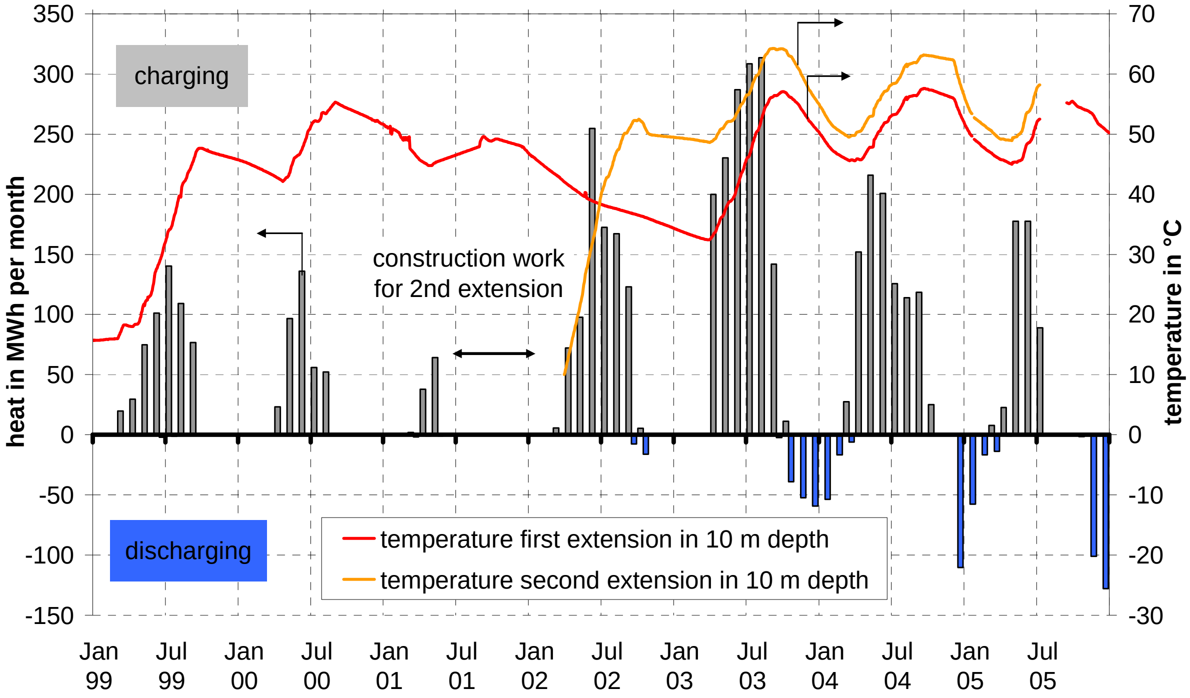

Figure 3: Charging and discharging heat amounts and temperatures in 10 m depth

In figure 4 temperatures in depths of 0 m, 10 m, 20 m and 32 m (2 m below store) are shown for the centre of the two extensions. The experimental store and the first extension were not charged in 2002 for fast temperature adjustment of the various store parts. Up to now temperatures in the 2nd store extension are higher than in the 1st store extension. The highest measured temperature in the 2nd store extension was approximately 65°C in 2003. The temperatures 2 m below store are increased compared to the undisturbed ground temperature due to heat losses of the store. For economical and constructional reasons the store is only insulated at the top.

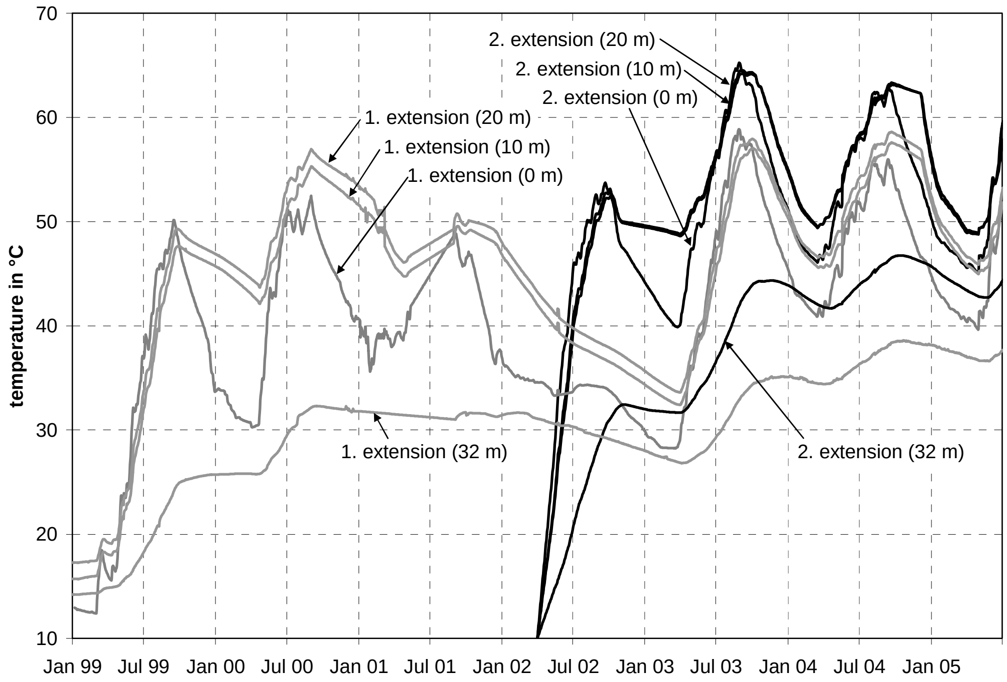

Figure 4: Temperatures in the 1st and 2nd extensions of the store in different depths

In figure 5 the vertical temperature distribution in the centre of the 2nd extension is shown for selected months in 2004/05. The highest temperature in October 2004 was 63°C, which was 2 K less than in 2003. At the end of the discharging period temperatures in the store were about 43°C. The store cannot be discharged below net return temperature which is the lowest temperature in the system. Decreasing net return temperature would therefore increase the usable heat content. Until now some minor problems related to the BTES occurred. In 2003 a sludge trap was installed since corrosion deposits were found in distribution pipes. Since the BTES is directly connected to the heat distribution system the borehole heat exchangers must be prevented from clogging.

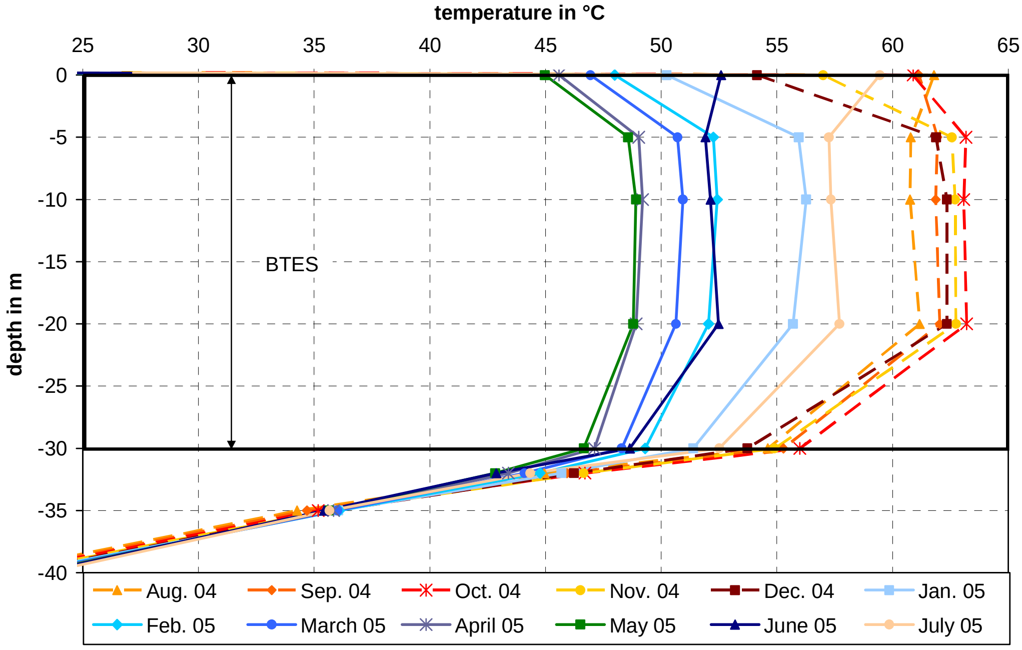

Figure 5: Vertical temperature distribution in the centre of the 2nd extension

4. SOLAR COLLECTORS

In figure 6 the solar gross heat gain of the different collector fields and the solar irradiation on collector plane (slope 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 BTES 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. 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. In **2004** and in **2005** solar heat gains were lower than in 2003 and 2002 due to lower solar irradiation and higher net return temperatures especially in summer, see figure 7. Additionally control failures e. g. after a lightning strike and defects at the conventional system engineering, e. g. modulating valves, caused lower heat gains.

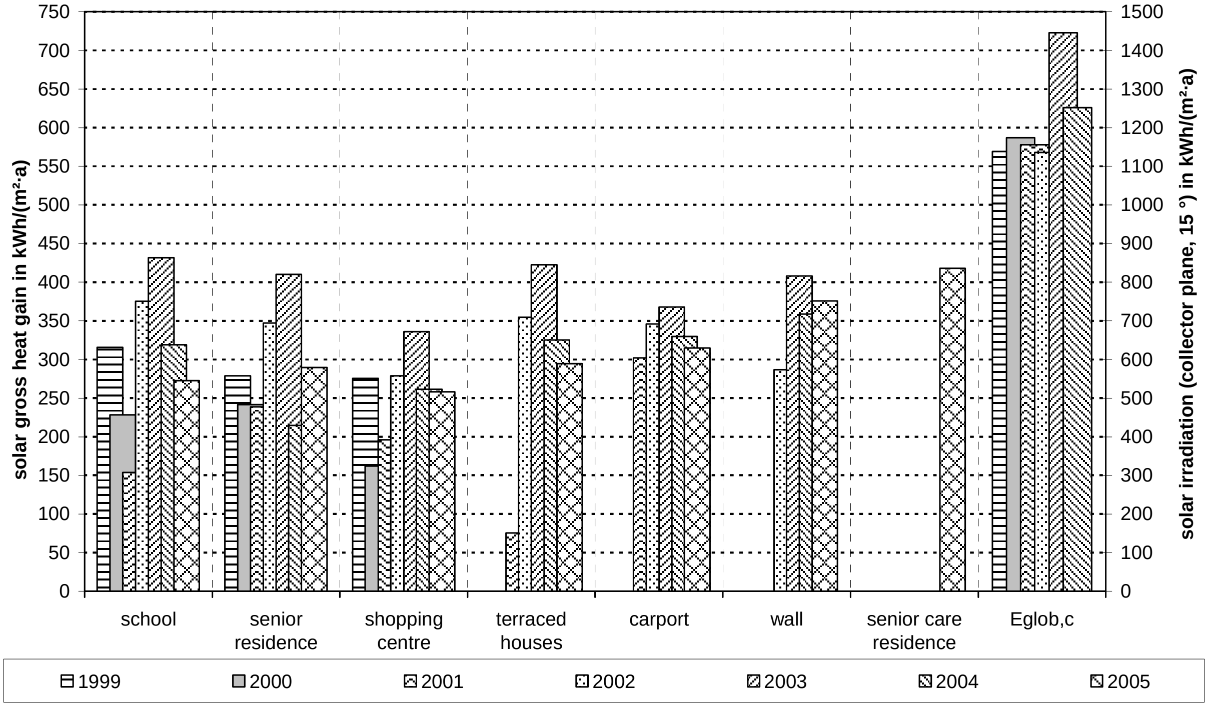

Figure 6: Solar gross heat gain of the collector fields and solar irradiation on collector plane (slope 15°)

5. DISTRICT HEATING NET

In figure 7 the temperatures and volumetric flow rates of the heat distribution net are depicted. In 2003 both supply and return temperatures increased in comparison to 2002. At the end of 2002 and in autumn 2004 new buildings were connected to the district heating system. High circulation flow rates and low heat demand caused higher net return temperatures than before. The short term increase of the volumetric flow rate in December 2002 and in autumn 2004 was caused by a temporary supply of an adjacent district heating system. It is also evident that net supply temperatures especially in summer are higher than required due to the hydraulic conditions in the 3-pipe heat distribution net. The collector volumetric flow rates are higher than the volumetric flow rate in the heat distribution net. Therefore not enough cold water is available to cool down the supply temperature by admixing cold return flow to the hot supply flow. The decreasing net return temperature in autumn 2005 was reached by connecting two parts of the network and supply buildings via the shorter connection with lower volume flow rates.

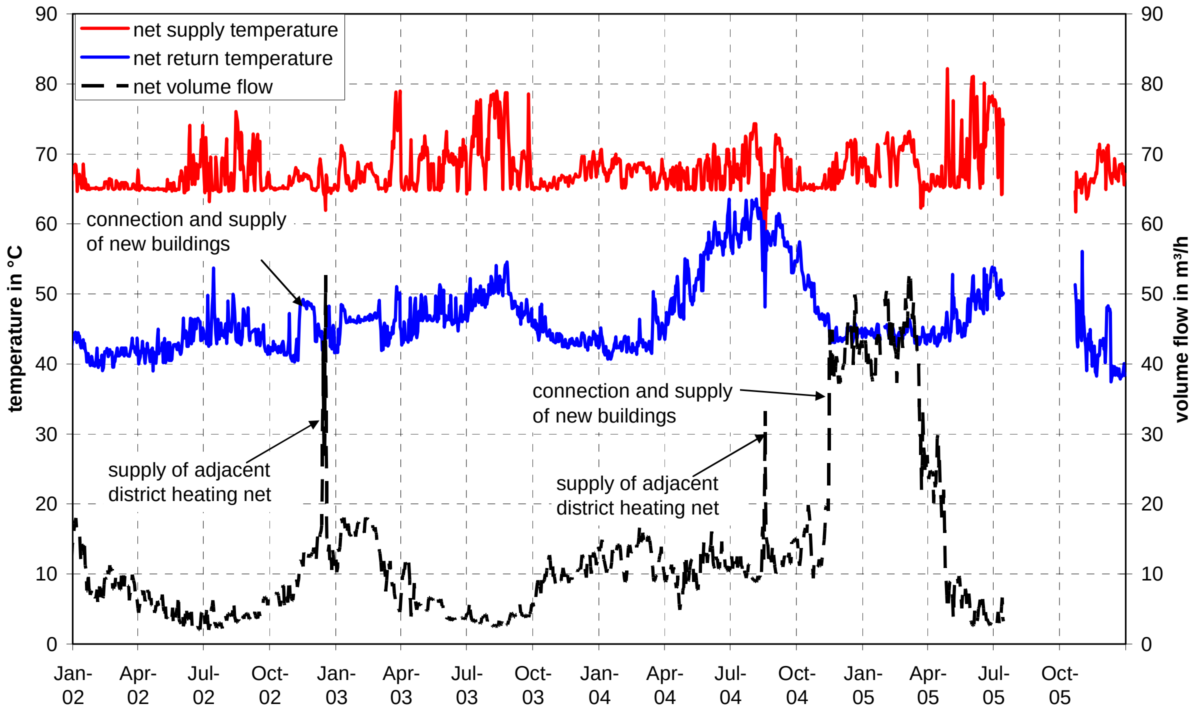

Figure 7: Temperatures and volumetric flow rates in the heat distribution net (2002-2005)

In figure 8 a schematic heat balance for the district heating system in Neckarsulm-Amorbach is depicted for 2004. About 50% of the total solar heat delivery (1667 MWh) was used to charge the BTES. 1481 MWh heat were delivered by an auxiliary gas boiler. The heat demand of the buildings amounts to 1559 MWh and the heat losses in the heat distribution and solar net to 757 MWh. 187 MWh were discharged from the BTES and 568 MWh of solar heat were directly used for heat supply in the heat distribution net. In 2004 a solar fraction of the total heat demand of 34% was reached. The heat losses in the heat distribution and solar net are high because the net is almost completely installed but fewer buildings are connected than expected. The discharged heat of the BTES is about 20% of the charging heat amount because BTES need a several years heating-up period to reach quasi steady state behavior. A significant increase of the storage efficiency is expected within the next years.

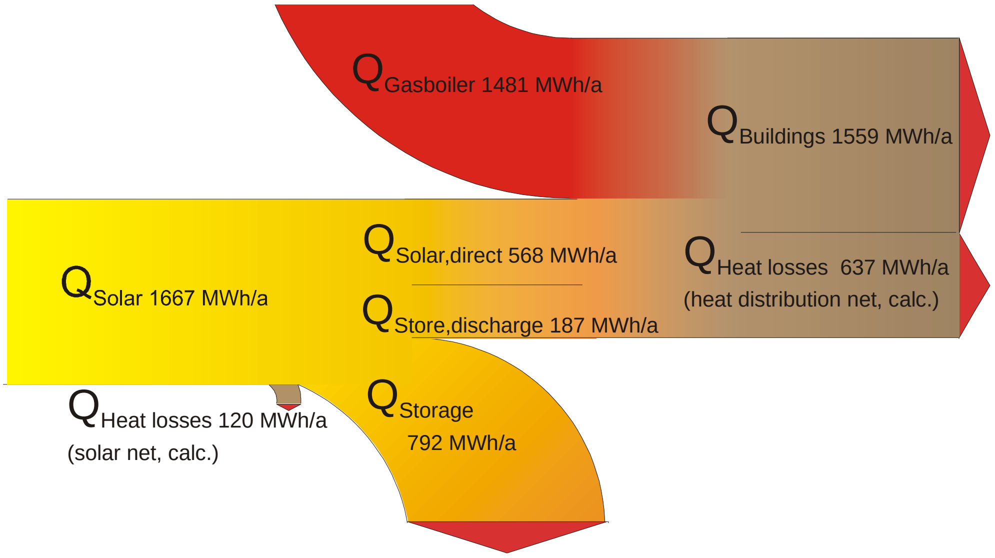

Figure 8: Schematic heat balance for the central solar district heating system with BTES in Neckarsulm in 2004

6. SIMULATIONS

Transient simulations applying the Superposition Borehole Model (SBM, Eskilson 1986) were performed to validate the prediction of the thermal behavior of the store and to optimize the charging and discharging processes. For that purpose the SBM model for TRNSYS (TRNSBM, Holst 1997) had to be adapted. The SBM model was chosen since the thermal interaction between a great number of Borehole Heat Exchangers (BHE) in various configurations can be considered as well as different hydraulic schemes with serial and parallel connections between BHE's. The BTES in Neckarsulm with its 528 BHE's, see figure 2, has a non symmetric shape. The calculated outlet and ground temperatures were compared with measured values. A sensitivity analysis was carried out including thermal ground parameters until the best fit for temperatures and charging & discharging heat amounts was achieved. The values for the thermal conductivity were increased from 2.0 W/(m·K) for 1997-1998 to 2.2 W/(m·K) for 2000-2002 and 2.4 W/(m·K) for 2003-2005 to take the increasing thermal conductivity with increasing temperatures into account.

Figure 9 shows a comparison between measured and calculated temperatures for borehole M14 (in the centre of experimental store and 1st extension, see figure 2) in a depth of 5 m, 10 m and 32 m. A depth of 32 m corresponds to a depth 2 m below the active storage volume. The 1st extension is charged since 1999; therefore no measured values are available before. Increasing temperatures before 1999 are caused by heat losses from the experimental store. The calculated temperatures in this part of the store are at the beginning higher than the measured temperatures since the complete store was simulated with parameters which are valid for the 2nd extension. Some parameters such as borehole diameter changed between experimental store, 1st and 2nd extension.

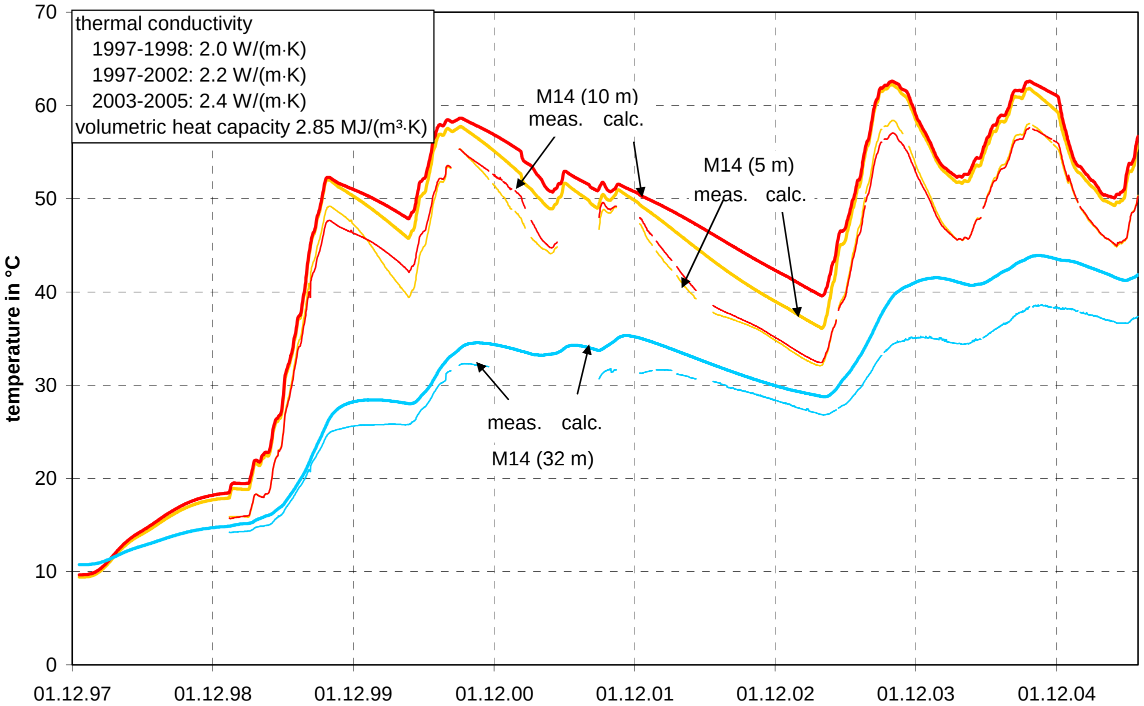

Figure 9: Comparison of measured versus calculated ground temperatures in the centre of experimental store and 1st extension

In figure 10 measured and calculated temperatures for the centre of the 2nd extension are plotted. It can be seen that the temperature increases due to heat losses from the 1st extension. The heat losses are predicted correctly by the SBM model. The agreement between measured and calculated temperatures for the 2nd extension which represents 2/3 of the store volume is quite good.

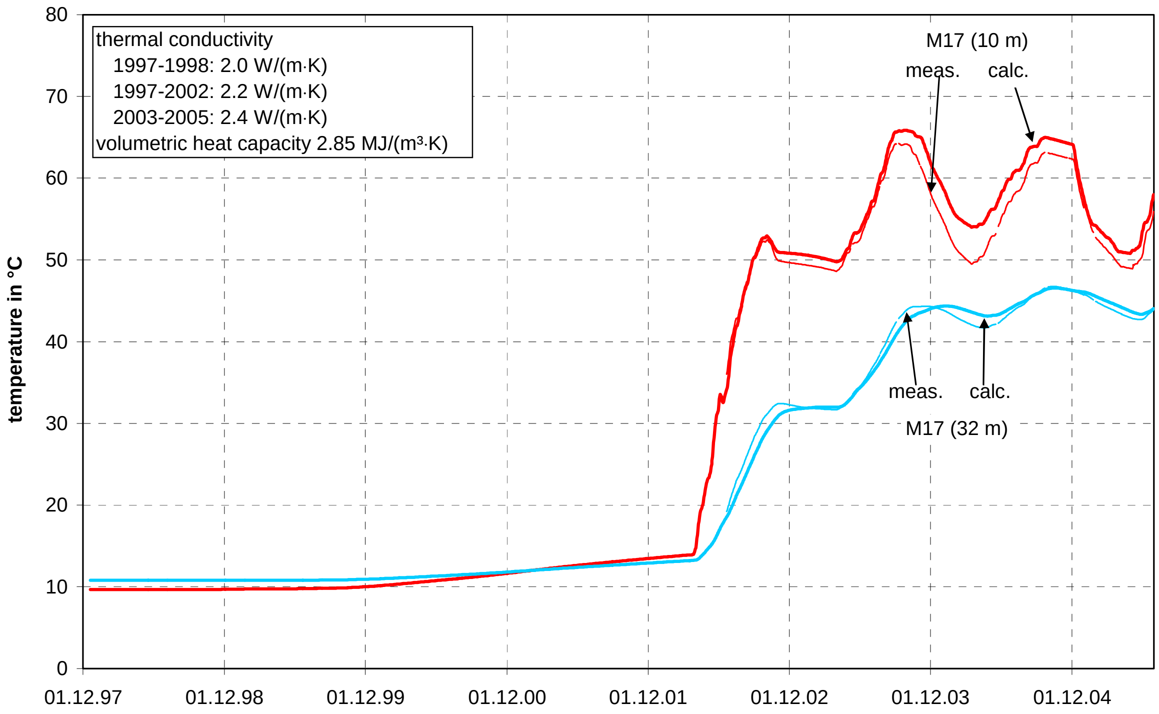

Figure 10: Comparison of measured versus calculated ground temperatures in the centre of 2nd extension

As mentioned above the identified thermal parameters of the ground are 2.0 to 2.4 W/(m·K) for the thermal conductivity and 2.85 MJ/(m³·K) for the volumetric heat capacity. Those values are almost the same as those from earlier field tests and simulations (Seiwald 2000). But for higher store temperatures a higher thermal conductivity was found.

7. CONCLUSIONS

Almost nine years of operating the solar assisted district heating system with seasonal heat storage show that solar fractions and storage efficiencies depend not only on planed values. Those systems are also strongly influenced by local realities and many different circumstances. In Neckarsulm the major problem is a higher net return temperature which causes lower solar heat gains and less discharged heat from the store than planned. To increase storage efficiency the installation of a heat pump is taken into consideration which would increase the usable temperature level of the store.

The results also show a great variability in solar heat gains. On the one hand solar heat gains depend on the net return temperature and on the other hand on facts like solar irradiation which can strongly differ in different years. Also operational and control failures and their detection strongly influence the solar heat gain. It is recommended to check the proper operation of solar collectors in periods of at least once a week.

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