Ecostock 2006, Tenth International Conference on Thermal Energy Storage, May 31 – June 2, 2006, Pomona, USA

NEW STEPS IN SEASONAL THERMAL ENERGY STORAGE IN GERMANY

T. Schmidt and D. Mangold

Solites - Steinbeis Research Institute for Solar and Sustainable Thermal Energy Systems
Nobelstr. 15, 70569 Stuttgart, Germany
Tel: +49 711 673 2000 0, Fax: +49 711 673 2000 99
Email: schmidt@solites.de, Internet: www.solites.de

1. INTRODUCTION

Seasonal thermal energy storage is under investigation in Germany since the beginning of the 1980's. The first long-term thermal energy storage was built as a research installation in 1984 (Hahne, 2000). In the context of the R&D-program Solarthermie-2000 eight demonstration plants for solar assisted district heating with seasonal thermal energy storage were built from 1995 to 2002. The comprehensive monitoring data and experiences show that all investigated storage concepts are working without major technical problems (Mangold et. al., 2003).

In 2006 two new R&D-plants are realized with support from the German federal energy research program Solarthermie2000plus, a third one will be built in 2007. Solites carries out basic R&D on storage concepts and, together with the University of Stuttgart (ITW) and the Bavarian Center for Applied Energy Research (ZAE Bayern), the scientific-technical accompaniment for the new plants. The storages are integrated in central solar heating plants, storing solar thermal energy during summer to provide a district heating net with solar energy also through the heating period in winter. The designed solar fractions of the new plants amount to 47 and 50 % of the total annual heat demand for space heating and domestic hot water preparation. Each plant comprises an advanced or new storage technology:

- In summer 2006 the storage in Munich with 5700 m³ water volume will be built of prefabricated concrete elements. Together with a newly developed heat insulation system and a stratification device the construction cost is expected to considerably fall below those of formerly built concrete tank storages.
- In Crailsheim a borehole thermal energy storage with a ground volume of 37,500 m³ will be built. The integration of the thermal insulation system into the storage takes care of the groundwater flow in the upper storage levels.
- In Eggenstein a storage built as an insulated pit is in the planning process. The storage will transfer the results of a three years research project carried out at the University of Stuttgart into practical application (Ochs, 2006). The storage is going to be built in 2007, detailed information about this system will be published in due time.

2. THE MUNICH PROJECT

The project development for the solar assisted district heating system with seasonal thermal energy storage in Munich started in 2000. Figure 1 shows a site plan of the service area. Construction of the multifamily houses started in autumn 2005, the seasonal thermal energy storage will be built during summer 2006. The solar collectors will also be installed in summer 2006 on top of the multifamily houses. The heat supply system is expected to start operation in autumn 2006.

Table 1 gives the main data of the system and the involved project partners. Owner of the system are the Munich City Utilities, the scientific accompaniment within Solarthermie2000plus is performed by ZAE Bayern, Solites takes care of the scientific-technical supervision and develops the detailed storage concept in close cooperation with the planner.

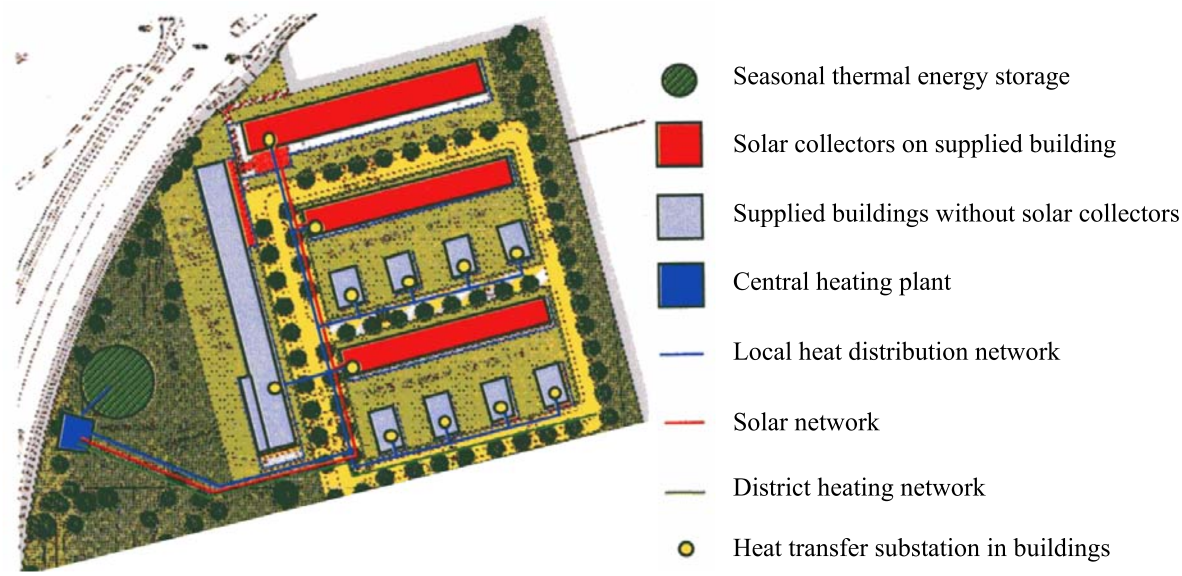

Figure 1: Site plan of the solar assisted district heating system in Munich (© City of Munich)

Table 1: Data of the solar assisted district heating system in Munich

Solar collector area	2,900 m²	Recipient of subsidies	City of Munich
Water volume seasonal thermal energy storage	5,700 m³	Owner	Munich City Utilities (SWM)
Service area	300 apartments	Planner system installations	Kulle and Hofstätter, Munich
Total heat demand	2,300 MWh/a	Planner thermal energy storage	Lichtenfels engineering consultant, Keltern
Absorption heat pump	1.4 MW	System concept	ZAE Bayern, Garching
Solar fraction	47 %[1)]	Scientific accompaniment	ZAE Bayern and Solites
Solar heat cost	0.24 €/kWha[2)]	Start of operation	autumn 2006

[1)] TRNSYS-Simulations ZAE Bayern; [2)]according to calculation guideline of Solarthermie2000plus (BMU, PTJ, 2006)

Figure 2 shows the concept of the heat supply system. The solar collectors charge heat into the heat storage when more solar heat is available than heat is demanded by the local heat distribution network. The main charging takes place during summer. During winter time the stored heat is used to supply the heat demand for space heating and domestic hot water preparation. To reach a high usability of the seasonal thermal energy storage (STES) an absorption heat pump is integrated into the system. The heat pump is driven by heat from a district heating network that also covers the remaining heat demand in the local heat distribution network. The supply flow to the local heat distribution network can be directly reheated by the district heating network to ensure the necessary supply temperature level. The return flow to the district heating network can be re-cooled by the return flow of the local heat distribution network to ensure a maximum return temperature of 50 °C to the district heating network that is required by the Munich City Utilities.

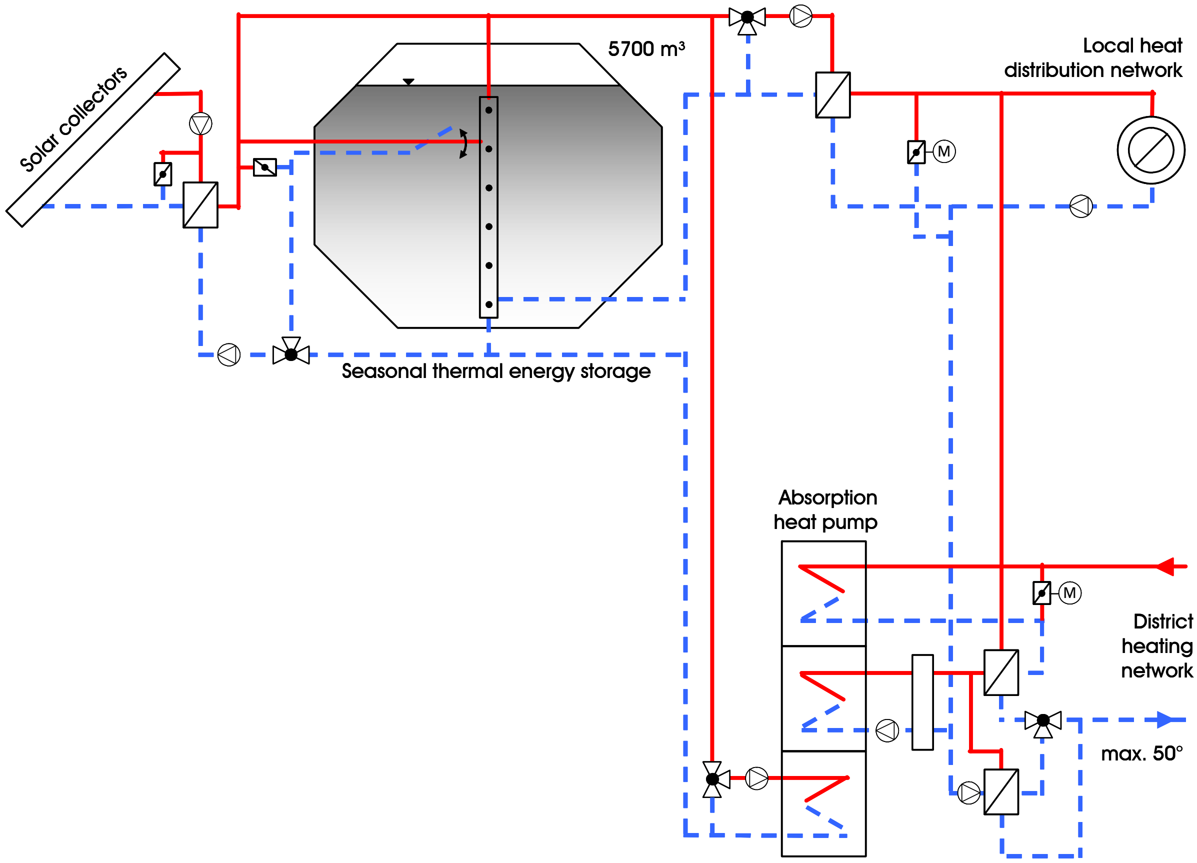

Figure 2: System concept of the solar assisted district heating system in Munich

The development of the storage concept considered the four main concepts that are in use in Germany so far (hot-water, gravel/water, borehole (BTES) and aquifer (ATES) thermal energy storage, see Schmidt et. al., 2004). ATES and BTES require special underground conditions that are not available at the site. In the progress of the project development it was found out, that the requirements regarding temperature stratification and capacity rate for charging and discharging can not be satisfied by a gravel/water thermal energy storage. For this reason a hot-water thermal energy storage was considered to be the best concept for Munich.

Figure 3 shows a vertical section and the construction of the storage. The frustum at the bottom will be built on-site while the side walls and the roof will be built of prefabricated concrete elements that have a stainless steel liner at the inner surface. The steel liners are used as formwork during production of the concrete elements. After the installation of the wall elements they will be prestressed by steel cables and the stainless steel plates will be welded together to ensure water- and vapor-tightness.

The storage will be insulated at the side walls and on top by expanded glass granules with a maximum thickness of 70 cm on top of the storage. A vertical drainage protects the insulation from moisture. The bottom of the storage will be insulated by a 20 cm layer of foam glass gravel because of its higher stability against static pressure.

The storage will be equipped with a stratification device to enhance temperature stratification and thereby the usability of the accumulated heat. Additionally during springtime the solar collectors will charge only the upper part of the storage to reach usable temperatures as fast as possible. When an adequate buffer volume is available on high temperatures the return flow from the solar collectors will be switched from the upper part of the storage to the bottom.

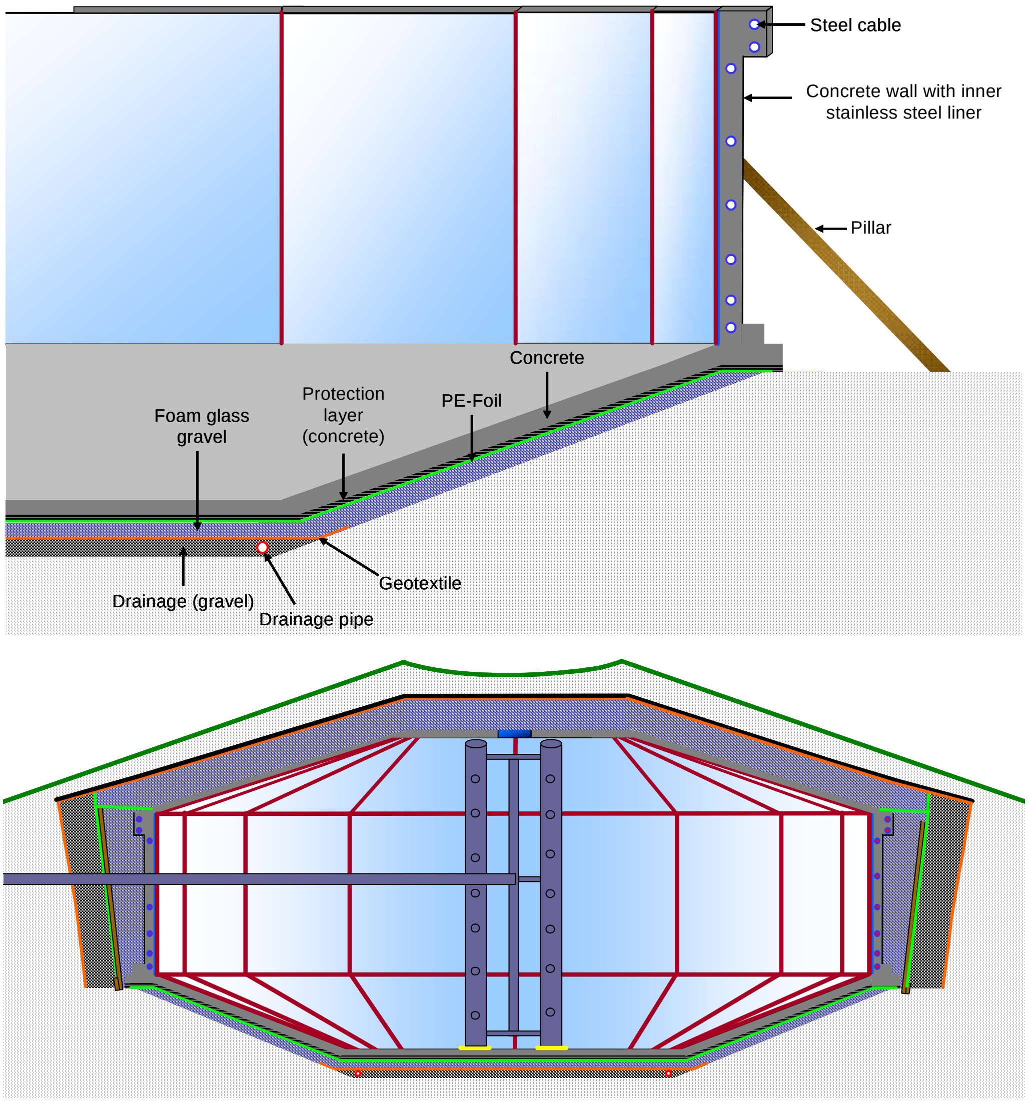

Figure 3: Vertical section of the Munich STES

The specific investment cost of this storage construction is expected to be significantly lower compared to those of the seasonal hot-water heat storages in the projects Friedrichshafen (12,000 m³) and Hannover (2,750 m³), although it will have an improved heat insulation and a stratification device.

3. THE CRAILSHEIM PROJECT

In Crailsheim-Hirtenwiesen a former military area will be transferred into a new residential area within the next years (see Figure 4). The smaller part of Hirtenwiesen 1 (left side in Figure 4) is covered with a couple of former military barracks buildings that are modernized and equipped with solar collectors on the roofs. The bigger area of Hirtenwiesen 2 will be covered mainly with small-sized buildings (single family, row and twin houses). A school and a gymnasium have already been built and equipped with solar collectors (700 m²). Hirtenwiesen 2 will be realized in two phases. Within the next years the 1st phase will be built, somewhere in a closer future the 2nd phase will be completed.
Facing south, the whole area is separated from a commercial area by a noise protection wall. On this noise protection wall the main part of the solar collector area will be built. Between the residential area and the noise protection wall a borehole thermal energy storage will be located that will be operated as a STES.

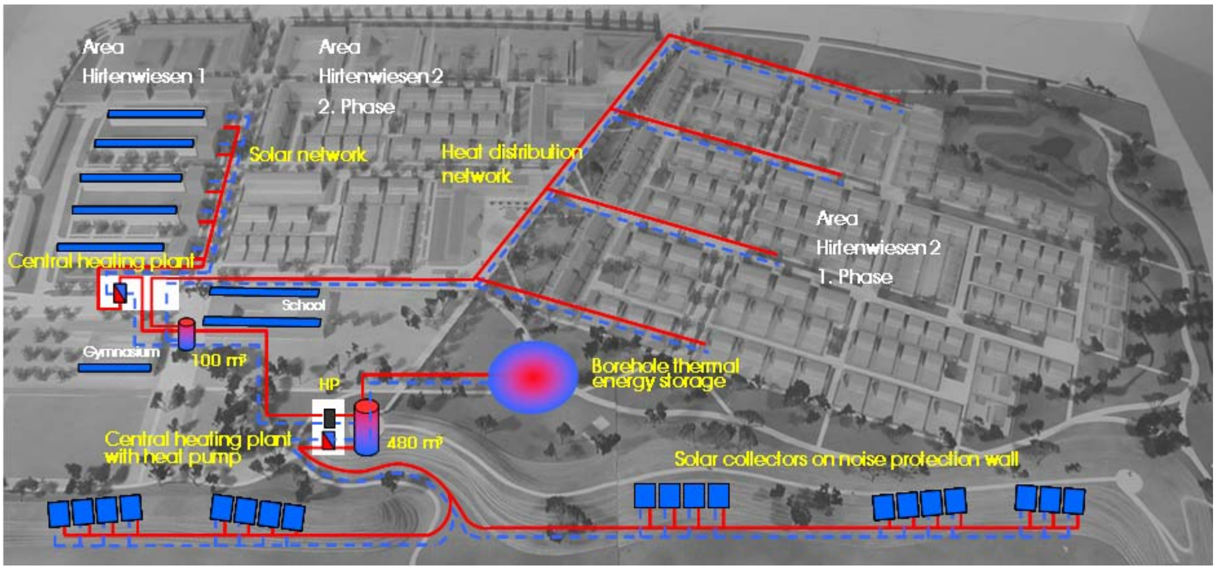

Figure 4: Site plan of the solar assisted district heating system in Crailsheim

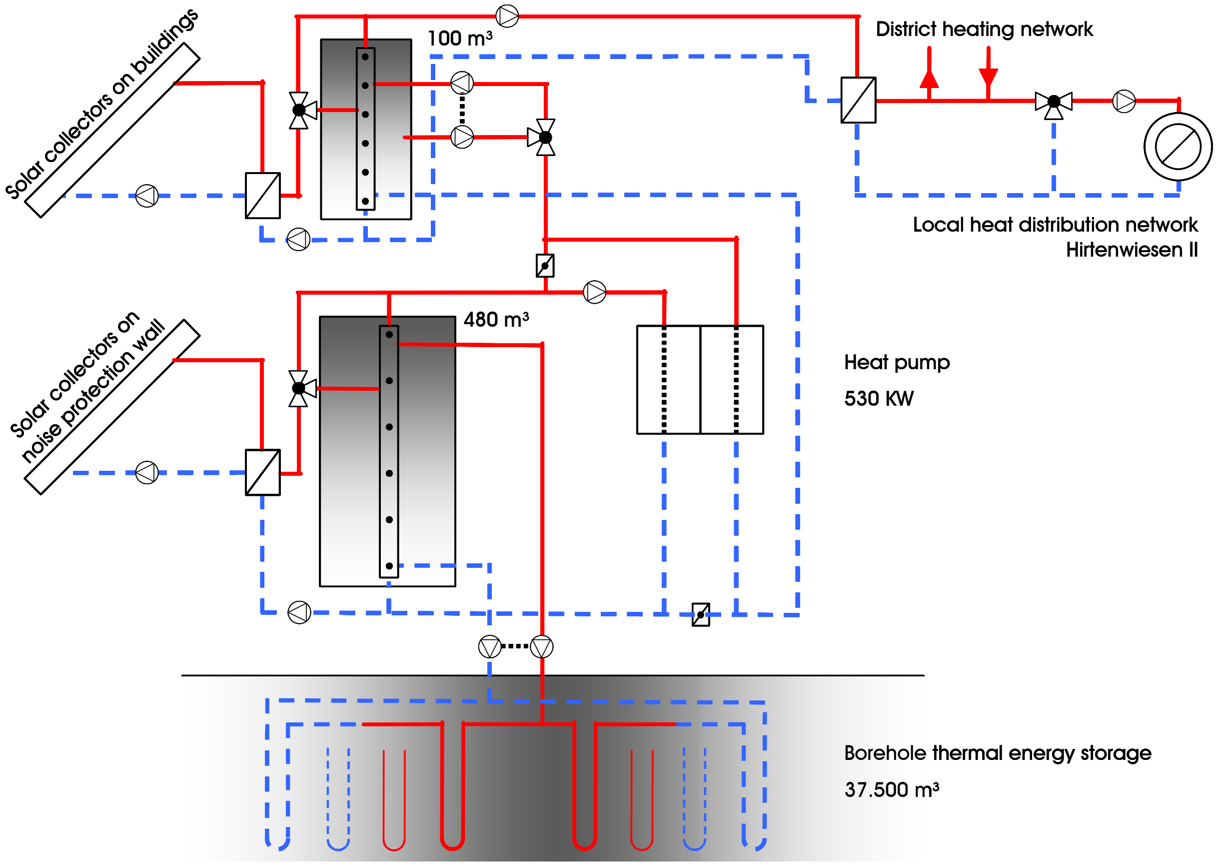

Figure 5: System concept of the solar assisted district heating system in Crailsheim

Figure 5 shows the concept and Table 2 the main data of the system. The solar system is separated into two parts: a diurnal and a seasonal part. The diurnal part consists of the solar collectors on the retrofitted buildings, the school and the gymnasium and a 100 m³ buffer tank that is located next to the school. The solar energy from this part can mostly be used directly to supply the heat demand from the Hirtenwiesen 2 area.

The solar collectors on the noise protection wall together with the BTES and a second water tank with 480 m^3 present the seasonal part of the system. The water tank of the seasonal part was added because of the high capacity rate of the solar collectors during summer. This high capacity rate can not be charged directly into the BTES during daytime but has to be distributed over a longer time period.
Heat from the seasonal part can be transferred to the diurnal part by a 300 m district heating pipeline either directly or via a heat pump. The heat pump allows a higher usable temperature difference of the seasonal heat storage and thus a higher storage capacity. In addition it reduces the temperature level in the storage and therefore results in lower storage heat losses. Furthermore the efficiency of the whole solar system becomes much more robust against high return temperatures from the heat distribution network.

Table 2: Data of the 1. phase of the solar assisted district heating system in Crailsheim

Solar collector area	7,300 m^2
Buffer storages (water tanks) Seasonal thermal energy storage (BTES)	100 m^3 480 m^3 37,500 m^3 ground volume
Service area	260 apartments, school and gymnasium
Total heat demand	4,100 MWh
Heat pump	530 kW
Solar fraction	50 %[1)]
Solar heat cost	0.19 €/kWha[2)]

Recipient of subsidies / Owner	Crailsheim City Utilities
Planner system installations	HGC GmbH, Hamburg
Planner hot-water heat storages	Lichtenfels engineering consultant, Keltern
Planner BTES	EWS GmbH, Lichtenau
System concept	ITW, University of Stuttgart and Solites
Scientific accompaniment	ITW, University of Stuttgart and Solites
Technical developments	Solites and planners
Start of operation	autumn 2006

[1)] TRNSYS-Simulations ITW; [2)] according to calculation guideline of Solarthermie2000plus (BMU, PTJ, 2006)

An investigation of the ground parameters showed good prerequisites for a BTES. By a Thermal Response Test thermal conductivities of 1.95 W/mK for the upper 20 m and of 2.46 W/mK for the upper 80 m below ground surface were identified. The volumetric heat capacity is 2,600 kJ/m^3K for the upper 20 m and 2,400 kJ/m^3K for the upper 80 m below ground surface. In the first 3-4 m below ground surface a noticeable natural ground water flow exists and has to be considered by the storage concept.
A feasibility study for the whole heat supply system performed by ITW, University of Stuttgart showed the best economy (lowest solar heat cost) for the system concept showed in Figure 5. According to the simulations the BTES will be heated up to 65 °C at the end of September, the lowest temperatures at the end of the heating period will be 20 °C. Maximum temperatures during charging will be above 90 °C.
The storage concept showed in Figure 6 was developed for the BTES to meet the mentioned boundary conditions. The storage will contain 80 boreholes with a depth of 60 m. The storage volume will be a cylinder; the boreholes will be placed in a 3 m x 3 m square pattern. The ground heat exchangers will be double-U-pipes. At the moment, two different materials for the U-pipes are under discussion: a newly developed high-temperature polyethylene (PE-HT) and cross-linked polyethylene (PEX). Both materials have never been used for a high temperature storage application so far, although PEX has been used for cold and hot water distribution and for hydronic radiant heating systems for many years. A disadvantage of PEX is that connections can not be welded but have to be assembled by metallic press-fittings. The durability of this connection in wet ground conditions is discussed controversially. PE-HT on the other hand can be welded on-site but is a new material without any long-term experiences. The final decision for the pipe-material will be made also based on the warranty conditions given by the manufacturers.
The upper part (5 m) of the boreholes will be drilled with a bigger diameter than the lower part. After installation of the ground heat exchangers the lower part will be filled with a thermally enhanced grouting material (thermal conductivity $\lambda = 2.0$ W/mK), while the upper part will be filled up with a thermally reduced grouting material to reduce the heat transfer into this layer and thereby the thermal losses due to the ground water movement in this region. The horizontal piping on top of the storage will be embedded into an insulation layer of foam glass gravel. On top of the insulation layer a protecting foil (water-tight but open for vapour diffusion) and a drainage layer (gravel) will be installed below a 2 m layer of soil.

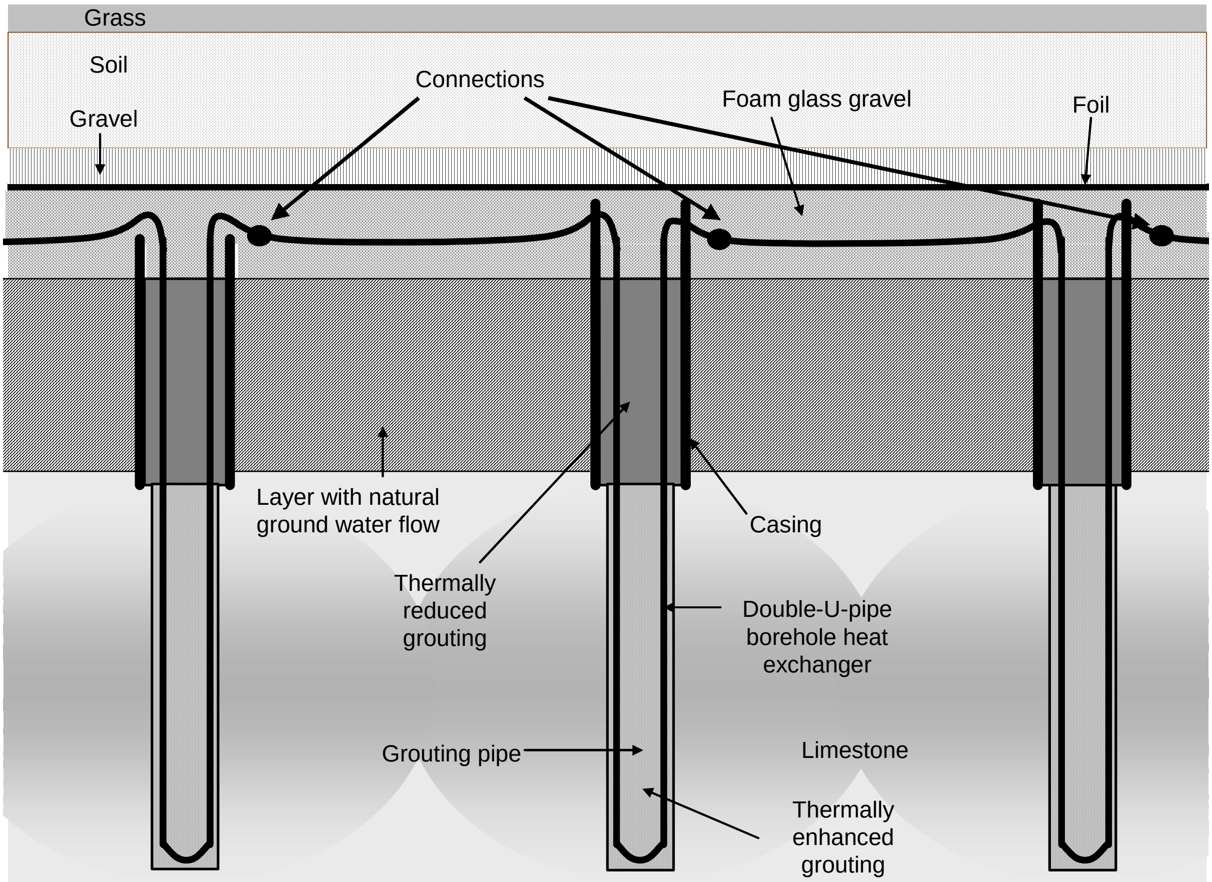

Figure 6: Vertical section of the BTES in Crailsheim

4. SUMMARY AND OUTLOOK

Since 1996, eight demonstration plants for solar assisted district heating with seasonal thermal energy storage have been built in Germany. The new projects in Crailsheim and Munich are under construction at present. Solar heat cost for the new plants are calculated to 24 Euro-Cent/kWh for Munich and 19 Euro-Cent/kWh for Crailsheim (without VAT and subsidies). Compared to heat from fossil fuels (7-8 Euro-Cent/kWh in Germany today) profitability can not be reached by these systems yet. However, rising conventional heat cost caused by shortage of fossil fuels together with other reasons (political, social etc.) on one hand and falling heat cost for solar systems because of increasing system efficiencies, better establishment of renewable energies in the market etc. on the other hand will lead to cost-efficiency in the future.

Ongoing R&D will focus on the improvement of the cost-effectiveness of storage technologies by a further reduction of the specific storage construction costs and by an increased annual heat output of the storage. More cost effective storage technologies are considered for the implementation in different applications like solar and biomass systems.

ACKNOWLEDGMENTS

Solites carries out the scientific-technical accompaniment of these projects on behalf of the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU, Contract No. 0329607L). The authors gratefully acknowledge this support. The authors are responsible for the content of this publication.

The construction of the projects in Munich and Crailsheim is funded by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), the Ministry of Economics of the state of Baden-Württemberg and the Cities of Munich and Crailsheim.

REFERENCES

Hahne, E. (2000). The ITW solar heating system – an oldtimer fully in action. Elsevier, Solar Energy Vol. 69, No. 6, pp. 469–493

Mangold, D., Schmidt, T. Lottner, V. (2003). Seasonal Thermal Energy Storage in Germany, Proc. FUTURE-STOCK 2003 9th International Conference on Thermal Energy Storage, Warsaw, Poland

F. Ochs et al. (2006), Soil-Water Pit Heat Storage with direct Charging System, ECOSTOCK 2006, 10th International Conference on Thermal Energy Storage, Richard Stockton College, New Jersey, USA

Schmidt, T., Mangold, D., Müller-Steinhagen, H. (2004). Central solar heating plants with seasonal storage in Germany, Elsevier, Solar Energy Vol. 76, pp. 165–174

BMU, PTJ (2006). www.solarthermie2000plus.de