SOLAR DISTRICT HEATING IN GERMANY – FINDINGS AND PROSPECTS

Dipl.-Ing. Dirk Mangold[1], Dipl.-Phys. Manfred Reuß[2]

[1] Solites, Steinbeis Research Institute for Solar and Sustainable Thermal Energy Systems,
Meitnerstr. 8, 70563 Stuttgart, Germany; www.solites.de; info@solites.de

[2] ZAE Bayern, Bavarian Center of Applied Energy Research, Div.1,
Walther-Meissner-Str. 6, 85748 Garching, Germany; www.zae-bayern.de, reuss@muc.zae-bayern.de

1. Introduction

Solar district heating especially with long-term heat storage is one of the most promising solar technologies to supply energy for space heating and domestic hot water at a high solar fraction. Since 1996 several pilot plants of different size and with different diurnal and seasonal storage were realized in Germany, mostly as pilot installations within German research and demonstration programs.

The latest systems realized in Germany are the plants in Munich (in operation since 2007), in Eggenstein (since 2009) and Crailsheim (since 2009). A key-component of such installations is the seasonal heat storage, requiring large storage capacities combined with an efficient heat transfer for charging and discharging.

Solar heat cost for the new plants are calculated to 24 €ct/kWh for Munich and 19 €ct/kWh for Crailsheim (without VAT and subsidies). This means, for only twice the price of fossil fuel costs the CO_2-emission of entire urban areas can be reduced to a half! To reach this goal, also other sustainable energy technologies like passive houses, combined heat and power production or biomass combustion are available. Depending on the distinctive prerequisites of every single project, solar assisted district heating with seasonal storage shows excitingly often competitiveness to these measures. Two main reasons are responsible for that: The large size of the system causes price reduction effects and the engineering progress that could be obtained by the R&D-programs leads also in storage technologies to substantial cost reductions.

2. Technology

2.1 Solar district heating

The integration of a large collector field in a block or district heating plant is the most economic opportunity to provide solar thermal energy in housing estates for the support of domestic hot water preparation and room heating. Block or district heating systems consist of a heating central, a heat distribution network and heat transfer substations in the connected buildings (Fig. 1). Centralized heat production offers high flexibility concerning the choice of the type of energy used. It allows the application of a seasonal storage in an energy- and cost efficient way. In case seasonal heat storage is included in the plant, over 50 % of the fossil fuel demand of an ordinary district heating plant can be replaced by solar energy. The seasonal heat storage is included in the plant to store solar thermal energy during summer and provide solar energy also through the heating period in winter.

Solar assisted district heating systems are differentiated in systems with direct integration of the solar circuit and a solar fraction of 3 to 7 %, with short-term or diurnal heat storage, designed to cover 10 to 20 % of the yearly heat demand for space heating and domestic hot water preparation by solar thermal energy, and solar systems with seasonal heat storage with solar fractions of 50 % and higher. The so called solar fraction is that part of the yearly energy demand that is covered by solar energy.

To gain solar thermal energy large collector areas are installed on buildings that are preferably near to the heating central (Fig 2). The heat obtained from the collectors is transported via a solar district heating net to the heating central and is directly distributed to the buildings. The surplus heat of the summer period is fed into the seasonal heat storage. All over Germany the sun provides over two third of its yearly energy supply only during the summer period. Thus during the room heating period, when an ordinary residential house needs more than 80 % of its yearly energy demand, the sun provides not sufficient energy for higher solar fractions. With the beginning of the room heating period, the seasonal heat storage delivers solar thermal energy that is transported to the houses via the district heating net.

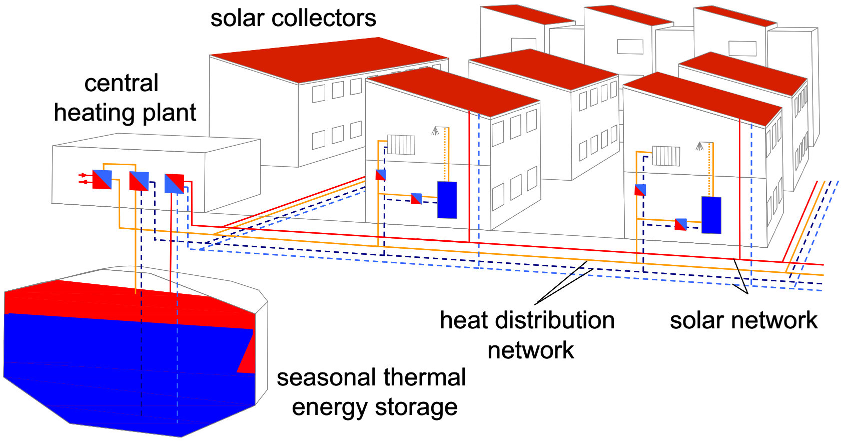

Fig. 1: Scheme of a central solar heating plant with seasonal storage

Fig. 2: Solar collector area for district heating net on retrofit buildings in Crailsheim, Germany

2.2 Seasonal heat storage

During the past fifteen years of research on seasonal storage technologies four different types of storages turned out as main focus for the ongoing engineering research. Figure 3 gives an overview for these storage technologies. They are explained in detail in the following. The decision for a certain type of storage mainly depends on the local prerequisites like the geological and hydro-geological situation in the underground of the respective construction site. Above all an economical rating of possible storages according to the costs for a kWh of thermal energy that can be used from the storage allows the choice of the best storage technology for every single project.

Tank thermal energy storage

Tank thermal energy storage is built as steel or reinforced pre-stressed concrete tank, and as a rule, partially built into the ground. The storage is heat insulated on the outer surface of the tank construction. The storage volume is filled with water as storage medium.

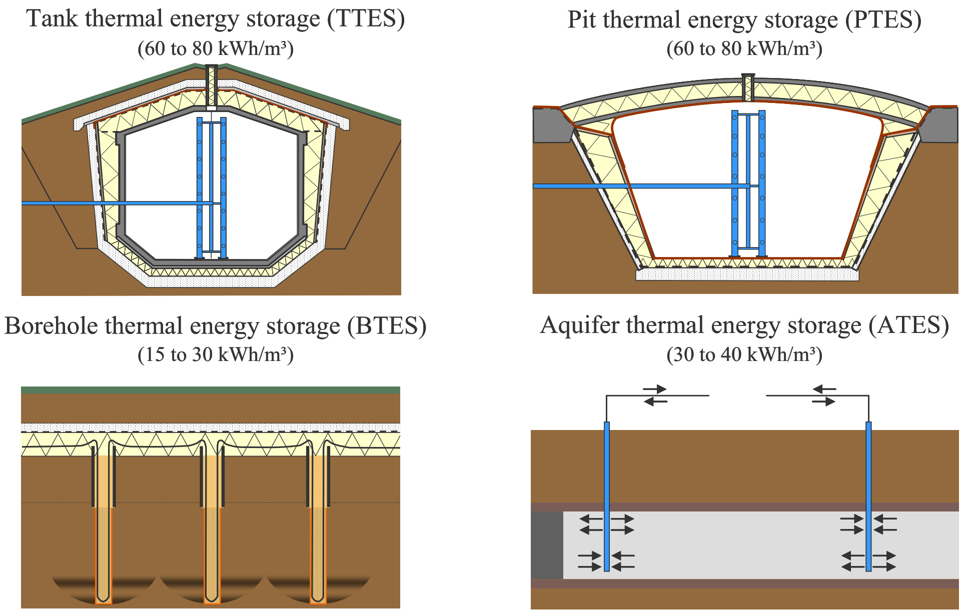

Fig. 3: The four technologies for storing solar thermal energy seasonally

Pit thermal energy storage

The usually naturally tilted walls of a pit are heat insulated and then lined with watertight plastic foil. The storage is filled with water and a heat insulated roof closes the pit. The roof can be floating on the water like in the storages in Denmark (Ottrupgard and Marstal) or is built like a self supporting structure as a rugged roof. Due to the fact that the construction of the roof over the storing "lake" is difficult and might be quite costly, the first storages were filled with a gravel-water mixture as storage material. Heat is fed into and out of the storage directly or indirectly.

Borehole thermal energy storage

In this kind of storage the heat is directly stored in the ground. U-pipes – the so called ducts - are inserted into vertical boreholes to build a huge heat exchanger. While water is running in the U-pipes heat can be fed in or out of the ground. The heated ground volume comprises the volume of the storage. The upper surface of the storage is heat insulated.

Aquifer thermal energy storage

Naturally occurring self-contained layers of ground water – so called aquifers - are used for heat storage. Heat is fed into the storage via wells and fed out by reversing the flow direction. Aquifers cannot be found everywhere. Thus an extensive exploration program has to be passed for the building site before one can be sure that an aquifer thermal energy storage can be suitable.

3. Examples

3.1 Solar District Heating "Am Ackermannbogen" in Munich

3.1.1 System Concept

South of the Olympic Park in Munich a large military area was converted into a new residential estate. As the location is almost downtown Munich it has developed towards a prime residential area. The solar district heating "Am Ackermannbogen" supplies solar energy for space heating and domestic hot water for about 320 apartments in 12 multi-story dwellings with about 30,400 m² living area (Fig. 4). The system is designed to cover more than 50% of the annual heat demand by solar energy either directly or via the large seasonal thermal energy storage. Supplementary heating is provided by an absorption heat pump which is driven by the city district heating system using the seasonal storage as a low temperature heat reservoir.

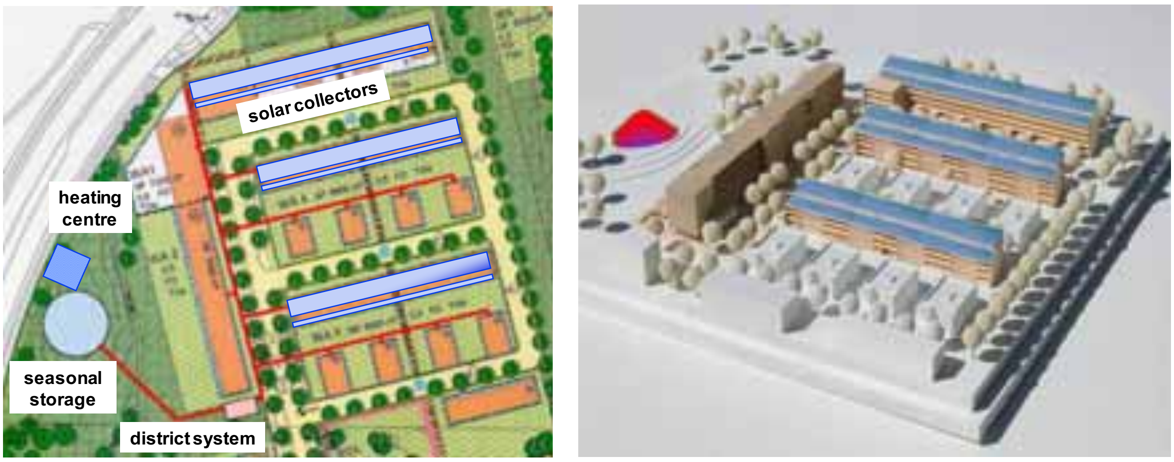

Fig. 4: Site plan and architectural model of the area

The hydraulic scheme of the solar district heating system is shown in Fig. 5.

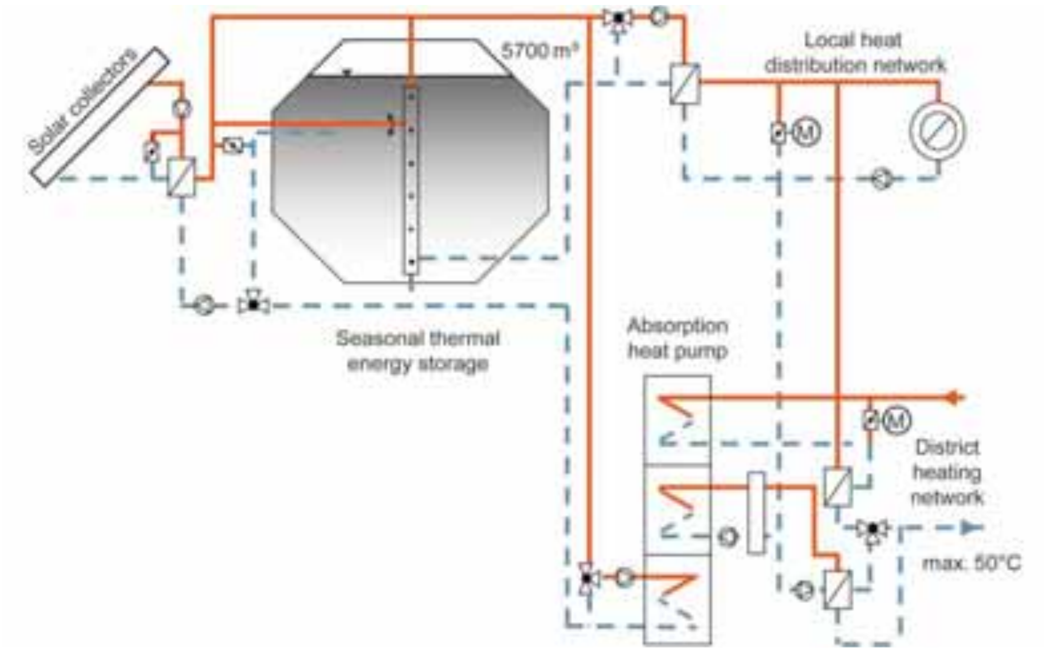

Fig. 5: Hydraulic scheme of the solar district heating "Am Ackermannbogen" in Munich

The local heat distribution network (Fig. 5) delivers the heat from the heating centre to each building and is there hydraulically directly connected to the heating system in each apartment. Domestic hot water preparation directly and on demand via fresh water heat exchangers in each apartment avoids the typical hot water boilers in the buildings as well as the circulation lines. These measures reduce the heat losses significantly and improve the hygienic status of the drinking water.

Because of the domestic hot water preparation the design supply temperature of the district system is set to 60 °C. An operational temperature difference of 30 K with a resulting return temperature of 30 °C reduces the thermal losses of the district system. Due to lower flow rates smaller pipe dimensions can be installed and the electricity demand for pumping is reduced.

3.1.2 Solar Collectors

The flat plate solar collectors mounted on the roofs of the three south facing buildings cover a total area of 3078 m² with 2761 m² of aperture area (Fig. 6). Within an architectural competition for the realization of the buildings aesthetic aspects of roof integration of solar collectors was one important requirement. The divided shed roof was selected as favorable solution. The collector roof is constructed from large elements of 12 m² each which are connected via the solar network and charge the collected heat into the seasonal storage.

Fig. 6: Solar collectors

3.1.3 Storage Concept

The site investigation in the conceptual phase showed already that the local hydro-geological situation with a rather high ground water level and a high flow velocity is not feasible for aquifer, borehole or pit storage. Thus a well insulated tank storage was selected which was finally integrated into an artificial hill to fit into the landscaping of the district. It is partially built into the ground with a distance of about 2 m from the highest ground water level. The storage itself is made of concrete that inside is covered with a stainless steel liner. While the bottom is made from in-situ concrete placed on an insulation layer of foam glass gravel the side walls and the top cover consist of prefabricated reinforced concrete elements. The side walls and the cover were insulated with an up to 0.70 m thick packed bed of expanded glass granules. Finally the whole tank was covered with soil and forms now a hill within the recreation area beside the building area. Fig. 7 shows pictures of the construction phase of the storage.

In total the storage has a volume of 6000 m³ and was filled with 5700 m³ cold water. It is operated as a non-pressurized tank and thus requires the additional volume of 300 m³ for thermal expansion.

The system concept implies several functions of the storage. In general it serves as seasonal storage for solar heat to be stored from summer to winter. The upper part, about 30 % of the volume, is also used as short-term buffer. This part is heated up with high priority to the supply temperature of the district heating of 60 °C to maximize the solar fraction. This is the typical operation in spring. In winter when the storage temperature falls below the return temperature of the district system the storage serves as low temperature source for the absorption heat pump (AHP). It is obvious that these different operation modes require a strong thermal stratification for an optimal use of the solar heat in order to achieve a high solar fraction. Therefore it is equipped with a stratification device and several fixed inlets and outlets. Thus the operational temperature of the storage varies from 10 – 90 °C as it is shown in Fig. 8. With this concept the storage volume can be used in an optimum way as the maximum possible temperature difference of a non-pressurized water storage is utilized.

Fig. 7: Construction of the seasonal tank storage: In-situ concrete bottom, side wall from prefabricated elements, side wall insulation and soil cover

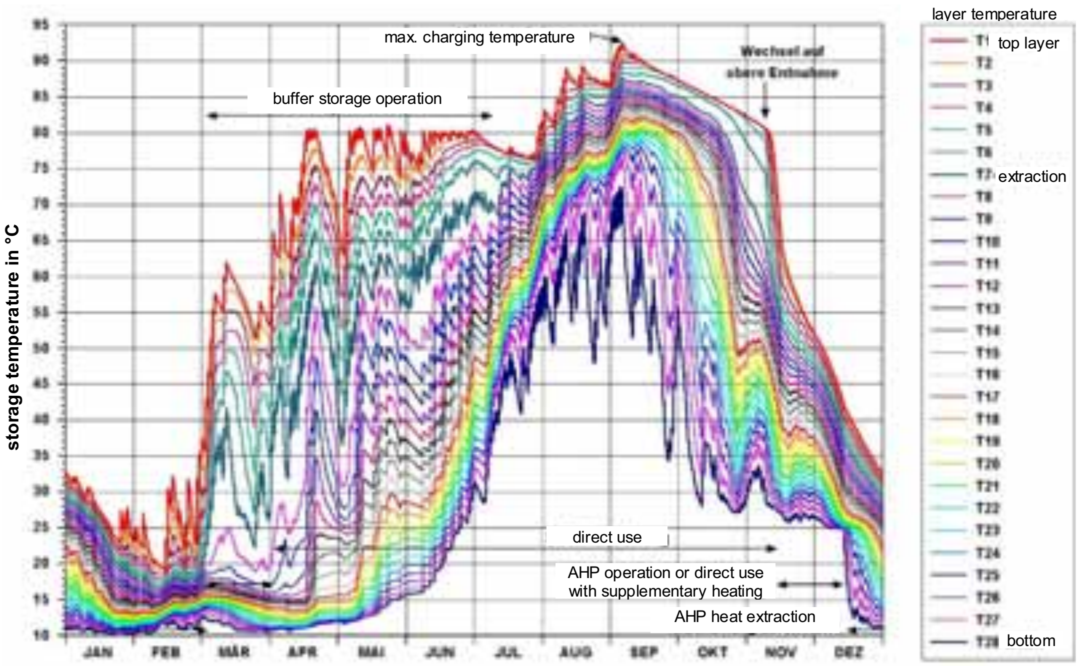

Fig. 8: Storage temperature profile over 1 year (simulated data)

3.1.4 Absorption Heat Pump

In this project for the first time an absorption heat pump (AHP) was integrated in a solar district heating system for supplement heating. The operational heat is provided from the district heating network at temperatures between 90 – 130 °C while low temperature heat is extracted from the lower part of the seasonal storage. The LiBr absorption heat pump is designed for a heating power of 200 – 560 kW with a COP of 1.5 – 1.7.

3.2 Solar district heating "Hirtenwiesen 2" in Crailsheim

3.2.1 System Concept

In Crailsheim-Hirtenwiesen a former military area is recently transferred into a new residential area (see Fig. 9).

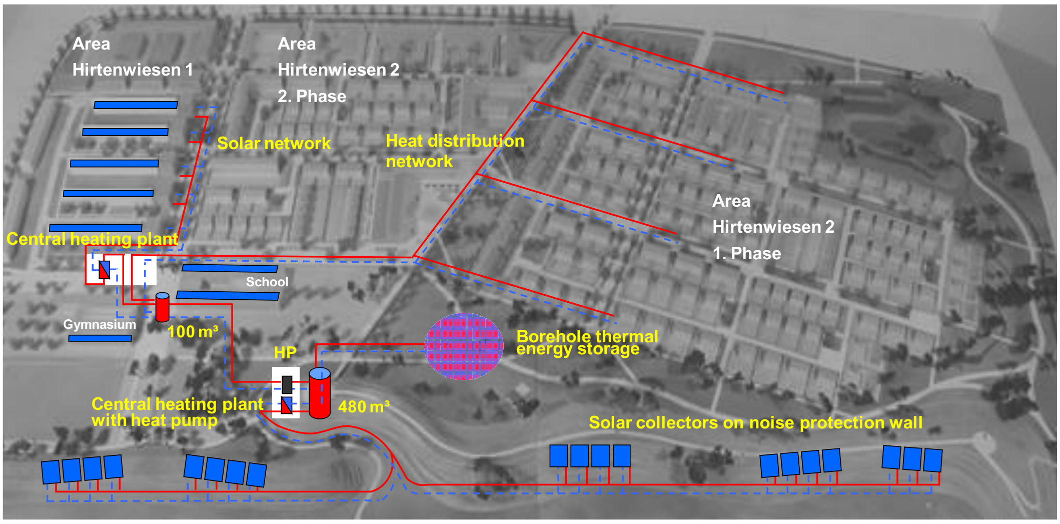

Fig. 9: Site plan of the solar assisted district heating system in Crailsheim, Germany

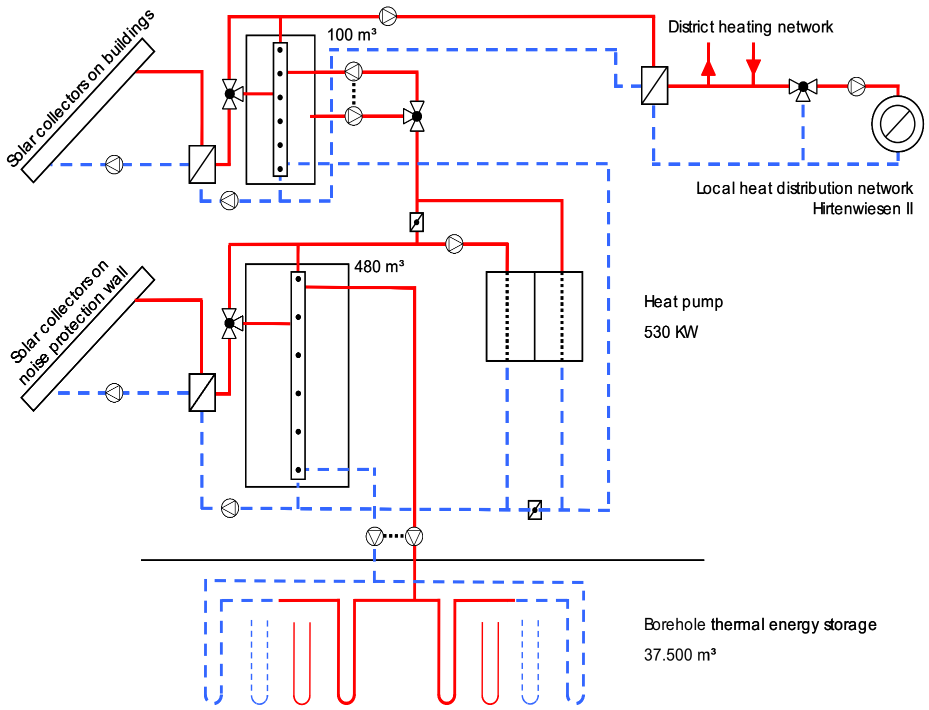

Figure 10: System concept of the solar assisted district heating system in Crailsheim, Germany

The solar system is separated into two parts: a diurnal and a seasonal part (Fig. 10). The diurnal part consists of the solar collectors on the modernized buildings, the school and the gymnasium (see Fig. 9) and a 100 m³ buffer tank that is located close 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 m³ 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 cannot 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 usability of the 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.

3.2.2 Solar Collectors

The solar collector area comprises altogether 7,500 m² of aperture area. A part of this area was realized within a energetic renovation as roof integrated solar collectors like shown in Fig. 2. The major part is situated on a noice protection wall (Fig. 11). To avoid high operation expenses for cutting the green around the collector fields a ecological concept was developed and realized for the south side of the noice protection wall.

Fig. 11: 3.500 m² of flat plate collectors on the noise protection wall in Crailsheim

3.2.3 Storage Concept

The storage consists of 80 boreholes with a depth of 55 m in a first construction phase. The storage volume (37,500 m³) is a cylinder with the boreholes situated in a 3 x 3 m square pattern, see Fig. 12. The ground heat exchangers are double-U-pipes made from cross-linked polyethylene (PEX). The storage volume will be doubled when the second part of the connected residential area is going to be built in some years.

The hydro-geological investigation showed an intermittent water movement in the upper part (5 m) of the storage volume. For this reason the boreholes were drilled with a bigger diameter in this part. After installation of the ground heat exchangers the lower part was filled with a thermally enhanced grouting material (thermal conductivity 2.0 W/mK), whereas the upper part was filled with a thermally reduced grouting material to reduce the heat transfer into this layer and thereby the thermal losses due to the water movement in this region. The horizontal piping on top of the storage is embedded into an insulation layer of foam glass gravel. On top of the insulation layer a protecting foil (water-tight but open for vapor diffusion) and a drainage layer (gravel) are installed below a 2 m layer of soil.

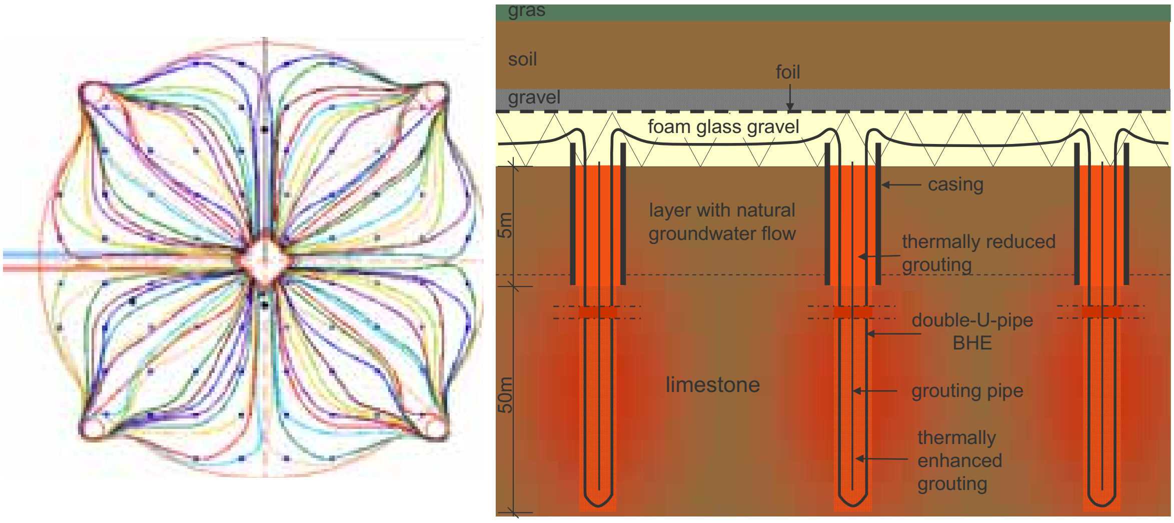

Fig. 12: Top view with horizontal piping (left) and vertical cross-section (right) of BTES in Crailsheim

4. Findings

4.1 Solar collector fields

Large collector fields require a careful planning and calculation of the tubing. Today most of the large collector fields in Germany are realized with minimized pipe length. If a lot of collector fields are connected in parallel like in Crailsheim (Fig. 11), a differential pressure regulating valve for each collector field secures the same flow through each field.

If a lot of collectors are connected in series, the linear thermal expansion of the piping can reach impressing high figures, especially if the collectors cannot be cooled e.g. in case of a pump failure. Some new deliverers unfortunately had to focus problems with this and had to adjust parts of the collector fields.

Even in complex solar nets like in Crailsheim (see Fig. 9) the security concept for the entire solar circuit uses only one security valve that is situated in the heating central.

In no one of the described systems there is an air vent in the collector fields itself. The only de-aeration possibility of the solar circuit is an air vent that is situated in the heating central.

4.2 Seasonal heat storage

Storage of sensible heat in large water tanks and in the underground in water pits, aquifer or boreholes are still the most economic solution for long-term respectively seasonal storage of large quantities of thermal energy. The selection of type depends on the local geological and hydro-geological conditions.

In case of a high ground water level with high flow velocity ATES, BTES and sometimes also pits are not feasible. Then tank storage situated above the ground water table has proven as alternative solution. From the economic point of view the temperature difference in the storage should be maximized. Thermal stratification is a highly desirable feature in water tanks to increase the direct use of solar heat. The experiences from the project in “Am Ackermannbogen” in Munich have shown that thermal stratification is not yet state-of-the-art and thus requires still intensive R&D efforts.

Well designed and constructed BTES is the most promising storage type from the technical and economic point of view. Nevertheless the local geological situation has to be analyzed very thoroughly in advance.

Proper design based on extensive site investigation and correct construction is compulsory to avoid any environmental impact while drilling or operation. New techniques for site investigation like the Thermal Response Test deliver valuable data for design. For construction quality control is an important issue, prefabricated and tested BHEs for high temperatures and connection techniques like manifolds as well as grouting materials and pumps for grout injection in boreholes are commercially available from industry.

In Eggenstein-Leopoldshafen a pit thermal energy storage was built in 2007. It is the first storage where the call for tender ended in contracting one of Europe’s leading building companies for a turn-key realization of the entire seasonal heat storage. All storages could not be realized turn-key ready.

4.3 System integration

Decisive for the optimum function of the solar system is its correct integration into the conventional heating system and the careful design of the solar part as well as of all other components for heat supply: district heating network, heat transfer substations and building services.

Direct hydraulic coupling of the heating system in the buildings to the solar district network has shown several advantages. First of all the district system can be operated at low supply temperatures, typical temperature drops at heat exchangers are avoided. Also low return temperatures down to 30 °C can be realized as show in the project “Am Ackermannbogen” in Munich. Thus heat losses on the return line of the district system are negligible small. Direct domestic hot water preparation via a heat exchanger in each apartment avoids hot water boilers and hot water circulation. Thus the heat losses are reduced and the hygienic status is improved. Within the two years monitoring program the success of this concept could be proven.

4.4 System performance

In general heat pumps are a favorable option to increase the useful temperature difference in storages and thus improve the economics of the storage. Additionally the operation in case of high return temperatures can be improved. The projects have shown the successful implementation of compression and absorption heat pumps.

The control has a significant high impact on the system performance and therefore requires concentration on this subject.

In the monitoring phase of the project “Am Ackermannbogen” in Munich a reduced solar gain by 15 % was identified due to a new absorber type in the collectors with reduced efficiency. Also the charging unit for thermal stratification did not meet the requirements of the planning. Additionally the control program requires significant optimization. Therefore the solar fraction found for the 2nd year was only 45 %. A total revision of the control program may allow reaching the set point of 50 %.

5. Prospects

The increase of efficiency in heat supply and the energetic renovation of the building stock form together with the expansion of renewable energies in the heat market the basis to meet the German goals of CO_2 emission reduction in the heating sector.

The strategies to meet these goals developed in the national Lead Study 2010 as well as the previous versions initiated by the German Federal Ministry of Environment, Nature Conservation and Nuclear Safety assume a reduction of the heat demand of buildings by approx. 50 %. Half of the left energy demand should be covered by solar, geothermal and biomass which amounts to about 360 TWh/a. This study assumes for 2050 about 45 TWh/a covered by solar district heating which is about 13 % of the heat delivered by renewable energies. The increase of new estate developments in Germany will be limited. Also the rate of refurbishment of buildings is in the order of 1- 2 %/a. In order to achieve the goal of the Lead Study 2011 system concepts and technologies have to be developed to introduce solar district heating in the building stock even with limited energetic renovation of the buildings.

The advantages of solar district heating are obvious. For the building stock it is one of the few possibilities to integrate renewable energies and in a lot of cases it is more cost effective than passive house retrofit.

With regard to variable conditions of the building stock new concepts have to be developed to meet the requirements regarding heat demand and temperature levels of the heating systems with solar district heating. With increasing refurbishment of the buildings in the future the heat demand will decline which can be compensated by expanding the district heat by connecting further consumers. Heating systems in existing buildings typically require high supply temperatures with a rather small difference between supply and return temperature. Integration of heat pumps can solve such problems.

The major problem for a fast implementation is still the high initial investment. But if this obstacle could be overcome, the known capital costs together with low maintenance and operation costs can guarantee prize stability for thermal energy on a long-term perspective.

In the upcoming years, further large-scale systems with seasonal heat storage will be built not only in Germany. Within the last years the interest on seasonal solar thermal energy storages internationally raised: Europe's largest central solar heating plant with over 19,000 m² of collector area, that is situated in Marstal, Denmark, was complemented with a seasonal pit heat storage of 10,000 m³ (www.solarmarstal.dk). In Canada the first seasonal solar thermal energy storage was built in 2006 in the residential area Drake Landing Solar Community in Okotoks as borehole thermal energy storage (www.dlsc.ca).

Ongoing R&D will focus on improving the cost-effectiveness of the storage technologies by a further reduction of the specific storage construction costs and by increasing the technical efficiency and durability and by this the useable heat output of the storage. More cost effective storage technologies are considered for the implementation in different applications like combined solar and biomass systems.

6. Acknowledgements

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