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# Central solar heating plants with seasonal storage in Germany

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**Abstract**

In the house building sector, central solar heating plants presently offer the most cost-favourable application of all possibilities of solar-thermal systems. By the integration of seasonal heat storage, more than 50% of the annual heating demand for space heating and domestic hot water can be supplied by solar energy. Since 1995, eight central solar heating plants with seasonal heat storage have been built in Germany within the governmental R&D-programme 'Solarthermie-2000'. This report describes the technology of central solar heating plants and gives advice about planning and costs. The pilot and demonstration plants for seasonal heat storage already built in Germany are described in detail to give an idea about possible system design and applications of central solar heating plants.


## 1. Introduction

The government of the Federal Republic of Germany has decided to reduce $CO_2$-emissions into the atmosphere by 25% by the end of 2005, as compared to the level of 1990. Private households have an energy demand of 30% of the total German end-use energy sector and therefore offer one of the most important saving potentials. In recent years, new concepts for the energy supply of housing districts have been developed which reduce the need of fossil fuels for the heating of a district by up to 50%. One important segment of these energy supply concepts is the use of solar-thermal energy in district heating systems with seasonal heat storage.

Germany's first solar assisted district heating projects were carried out as part of a governmental research and demonstration programme ('Solarthermie-2000—Part 3: Solar assisted district heating' of the BMBF [Federal Ministry for Education, Science, Research and Technology] and BMWi [Federal Ministry for Economy and Technology]). The scientific development and coordination were carried out by the Institute for Thermodynamics and Thermal Engineering (ITW) at the University of Stuttgart, Germany.

By now, eight demonstration plants with seasonal heat storage have been realised within the programme Part 3 as a follow-up of four central solar heating plants with short-term heat storage. All these facilities were carefully monitored within the frame of the scientific-technical accompanying programme (Benner et al., 1999). The detailed results of the monitoring programme were used to identify possible weak points and to improve or optimize the installations in order to make such concepts more economic. This is one main prerequisite to initiate market penetration of this technology. Fig. 1 shows a view of the first demonstration plant with seasonal heat storage in Hamburg, Germany.

## 2. System concepts

Block- or district heating systems are a prerequisite for the integration of economic large-scale solar heating systems. They consist of a central heating plant, a heat distribution network and, if necessary, heat transfer substations in the connected buildings. In Germany, space heating systems are usually water-based. Centralized heat production offers high flexibility in terms of the choice of fuel and allows for seasonal storage of solar

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Fig. 1. View of the demonstration plant in Hamburg, Germany (photo by Aufwind, Hamburg).

heat in summer to cover part of the heating demand in winter.

Solar assisted district heating systems can be subdivided into systems with short-term or diurnal heat storage, designed to cover 10–20% of the total yearly heat demand for space heating and domestic hot water with solar energy, and solar systems with seasonal heat storage with solar fractions of more than 50%. The solar fraction is that part of the yearly energy demand that is covered by solar energy.

Central solar heating plants with diurnal storage (CSHPDS) are mainly used to supply heat to large multiple dwellings, hospitals, hostels or to the district heating systems of large housing estates. They are designed for a solar fraction of the domestic hot water supply of 80–100% in July and August, that is about 40–50% of the annual heat demand for domestic hot water (these figures apply to central and northern Europe).

Central solar heating plants with seasonal storage (CSHPSS) aim at a solar fraction of 50% or more of the total heat demand for space heating and domestic hot water for a large housing estate (more than 100 apartments). The seasonal time shift between irradiance and heat demand is compensated by means of the seasonal heat storage. An example for a monthly energy balance is given in Fig. 2 for the CSHPSS-system in Friedrichshafen, Germany.

Most large-scale solar systems in Europe have been built in central and northern Europe, mainly in Sweden, Denmark, The Netherlands, Germany and Austria (Dalenbäck, 2003). Only a few systems exist in southern Europe—for example there is only one system with seasonal heat storage in Greece (Lykovrissi in Athens).

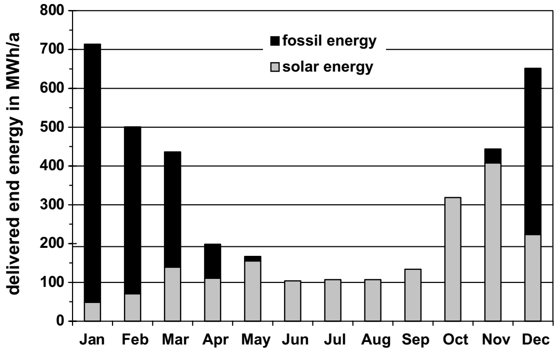


Fig. 2. Monthly energy balance for the CSHPSS-system in Friedrichshafen, Germany (simulated data).

## 3. Solar collectors

In Scandinavia the most economical location of collectors for systems with very large collector fields is directly on the ground next to the central heating plant. Because of the high cost for building sites, this method usually cannot be realized in central Europe and collectors have to be installed on the roofs of buildings.

There are three systems available:

- on-site installation with the collectors assembled directly on the roof,
- large collector modules industrially prefabricated with an area of 8–12 $m^2$, installed upon an existing roof construction,

- prefabricated solar roof modules including rafters, roof insulation and collector.

With on-site installation the collector field can easily be adapted to the shape of the roof area. Nowadays this approach is rarely used because it is time-consuming and the assembly is strongly dependent on weather conditions.

Large prefabricated collector modules can be mounted under almost any climatic conditions. Today a number of collector manufacturers offer reliable sealing systems so that the collector module system replaces the roof tiles and the collectors are mounted directly onto a sub roof. In this case, a collector field of 100 $m^2$ or more costs between Euro 180 and Euro 300 per $m^2$ of flat plate collector area, including planning, installation and piping on the roof (excluding VAT). If the collector modules have to be mounted on a substructure (e.g. on a flat roof), there will be additional construction costs of at least Euro 50 per $m^2$.

The so-called 'solar roofs' that have been developed in Germany and Sweden are complete roof modules, including rafters and heat insulation, which support a collector instead of the usual roof tiles. The timber works for the roof and the collector installation are combined and carried out industrially. The solar roof modules are delivered to the building site by trucks and can be mounted very fast by crane. Compared to a common tiled roof, solar roof systems have additional costs of about Euro 150–250 per $m^2$ of flat-plate collector area, completely mounted and with pipes connected (excluding VAT).

As a general rule, the whole collector area of a system should be installed in continuous fields that are as large as possible. The whole collector system is operated by a low, area-dependent flow rate of 10–15 $l/(m^2h)$. This low-flow technology reduces the necessary pipe diameters, the amount of the heat transfer fluid and the electrical energy required for the pumps. The collectors themselves are operated with high flow in order to obtain a high heat transfer coefficient. Hydraulically, as many collectors as possible are connected in series to collector rows. The collector rows are connected in parallel to each other. This requires collectors with parallel flow absorbers (instead of serpentine absorbers) and with small pressure losses. In order to obtain high system efficiency, stratified charging of the heat store is necessary.

## 4. Seasonal heat storage

Since 1984, the development of concepts for seasonal heat storage is being undertaken at ITW, nowadays in cooperation with several other institutions and consultants. Based on the experiences of earlier research projects, the following types of heat stores (see Fig. 3) have been developed. The decision to use a certain type mainly depends on the local conditions and, primarily, on the geological and hydrogeological situation in the ground below the respective construction site.

For all types, but particularly for aquifer and duct heat stores, a preliminary geological examination of the store site is essential. Approval of the water authorities must be obtained at an early stage. If different store types are possible, an economic optimization should be carried out with the building costs for the different types of heat stores and the heat deliveries of the solar systems taken into account.

### 4.1. Hot-water heat store

The hot-water heat store has the widest range of utilization possibilities. Because of the high specific heat

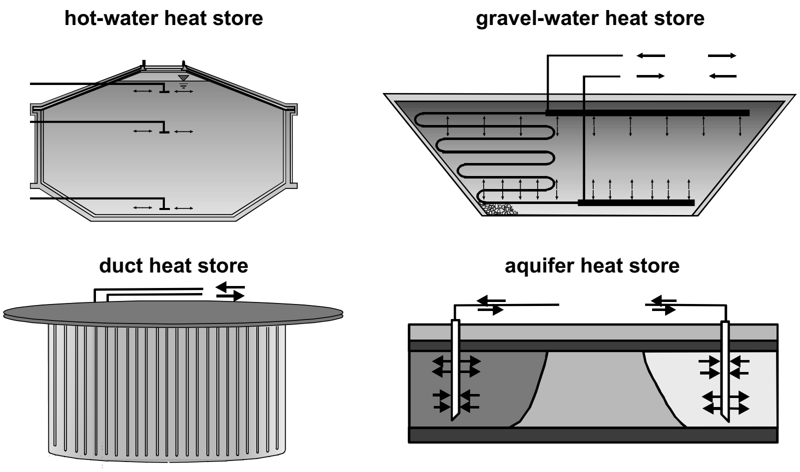

Fig. 3. Different types of seasonal heat stores.

capacity and the high capacity rates for charging and discharging it is the most favourable of the four storage types from the thermodynamic point of view. The water-filled tank construction of usually reinforced concrete is partly embedded into the ground and can be built almost independently from geological conditions. It is heat insulated at least in the roof area and on the vertical walls. To guarantee water tightness and to reduce heat losses caused by vapour transport through the walls, the demonstration stores in Hamburg (4500 $m^3$) and Friedrichshafen (12,000 $m^3$) have been built with steel-liners (1.2 mm stainless steel). In Hannover (2750 $m^3$), a new high-density concrete material with a lower vapour permeability has been used, making the use of an extra lining unnecessary.

At the Technical University of Ilmenau, Germany, a new wall construction for hot-water heat stores is under development to reduce the specific costs. The compound wall made of glass fibre reinforced plastics with an integrated heat insulation layer is prefabricated in cylindrical segments which are mounted together on site. Investigations are carried out at a 300 $m^3$ pilot store to examine the long-term durability and the performance of the materials.

### 4.2. Gravel–water heat store

A pit with a watertight plastic liner is filled with a gravel–water mixture forming the storage material. No load-bearing frame structure is required because forces are taken down to the side walls and to the bottom by the gravel. The store has a heat insulation, at least at the side walls and on the top. Heat is charged into and discharged out of the store either by direct water exchange or by plastic pipes installed in different layers inside the store. Because of the lower specific heat capacity of the gravel–water mixture, the volume of a gravel–water heat store has to be approximately 50% higher compared to a hot-water heat store to obtain the same heat capacity for the whole store.

Gravel–water heat stores are in operation at the University of Stuttgart (ITW, 1050 $m^3$), in Chemnitz (8000 $m^3$), Augsburg (6500 $m^3$) and Steinfurt-Borghorst (1500 $m^3$).

### 4.3. Duct heat store

In a duct heat store, heat is stored directly into the ground. Suitable geological formations for this kind of heat storage are e.g. rock or water-saturated soils. Heat is charged or discharged by vertical borehole heat exchangers which are installed into a depth of 30–100 m below ground surface (see Fig. 4). At the top of the store there is a heat insulation layer to reduce heat losses to the surface. A certain number of heat exchangers are hydraulically connected in series to a row and certain rows are connected in parallel. At charging, the flow direction is from the centre to the boundaries of the store to obtain high temperatures in the centre and lower ones at the boundaries of the store. At discharging the flow direction is reversed.

One advantage of this type is the possibility for a modular design. Additional boreholes can be connected easily and the store can grow with e.g. the size of a housing district. The size of the store has however to be between three to five times higher than that of a hot-water heat store to obtain the same heat capacity. Because of the lower capacity at charging and discharging usually a buffer store is integrated into the system. A duct heat store for temperatures up to 85 °C is in operation in Neckarsulm (63,400 $m^3$).

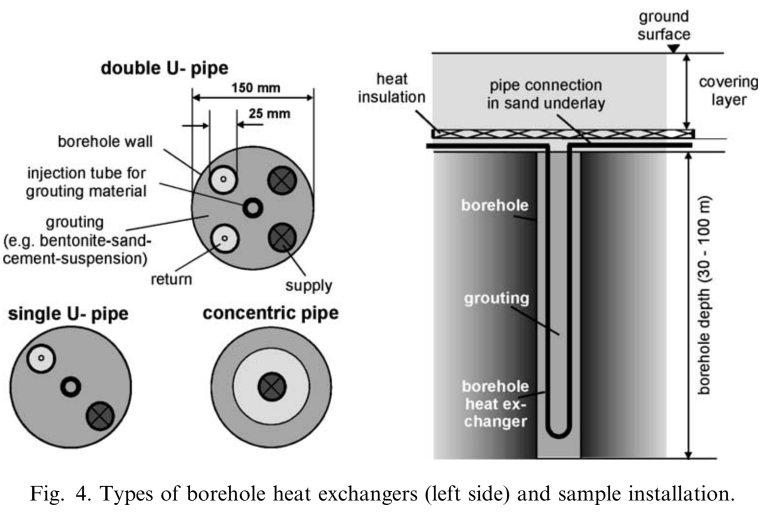


Fig. 4. Types of borehole heat exchangers (left side) and sample installation.

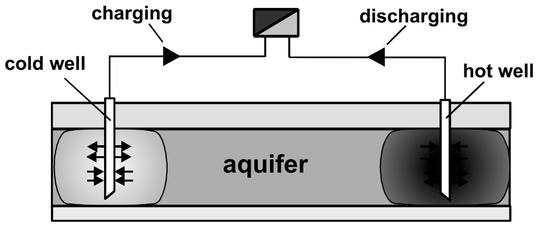


Fig. 5. Construction of an aquifer heat store.

### 4.4. Aquifer heat store

Aquifers are below-ground widely distributed sand, gravel, sandstone or limestone layers with high hydraulic conductivity which are filled with groundwater. If there are impervious layers above and below and no or only low natural groundwater flow, they can be used for heat (and cold) storage. In this case, two wells or groups of wells are drilled into the aquifer and serve for extraction or injection of groundwater. During charging periods cold groundwater is extracted from the cold well, heated up by the solar system and injected into the hot well (see Fig. 5). In discharging-periods the flow direction is reversed. Because of the different flow directions both wells are equipped with pumps, production- and injection pipes.

Especially for high temperature heat storage a good knowledge of the mineralogy, geochemistry and microbiology in the underground is necessary to prevent damage to the system caused by well-clogging, scaling etc. Aquifer heat stores are in operation in Rostock and Berlin (German Parliament).

## 5. Design guidelines and economics

Design guidelines for solar-assisted district heating systems in central and northern Europe are shown in Table 1. For comparison, guidelines for a small solar system for domestic hot water preparation are given as well. The solar heat cost represents the investment required to save 1 kWh of end energy use and is calculated with an amortization according to VDI 2067 (VDI 2067, 1983). The figures are valid for the German market (calculation basis: market prices of 1997/1998, without VAT, interest rate: 6%).

The perfect integration of the solar system into the conventional heating system as well as a high design quality—of both the solar part and the conventional parts such as district heating network, transfer substations, HVAC-systems in the buildings etc.—are vital for its optimum functioning. To dimension and design a seasonal heat store, detailed system simulations are necessary. These can e.g. be performed by using the simulation programme TRNSYS (TRNSYS, 2000).

When the solar heat cost of a CSHPDS system is compared to the cost of a small system for domestic hot water it becomes obvious that the cost per kWh of a small system is approximately two times higher than for CSHPDS systems. The price advantage of large plants compared to small ones is mainly caused by their more favourable system cost: while small plants come up to an average system cost of Euro 1000 per $m^2$ flat-plate collector surface, large plants with diurnal heat storage reach about Euro 500 per $m^2$ (including planning, without VAT) when integrated into new buildings (Mangold et al., 1997).

A substantial part of the investment cost of central solar heating plants with seasonal heat storage is caused by the seasonal heat store. Fig. 6 shows the investment cost of the realised heat stores. For comparison of the different concepts the abscissa shows the storage volume in water equivalent. The cheapest types of heat stores are duct and aquifer heat stores. However, they also make the highest demands on the underground on-site.

Table 1
Design guidelines for solar assisted district heating systems in central and northern Europe (FC: flat plate collector; w: water)

| System type | Small solar system for domestic hot water | Central solar heating plant with diurnal storage (CSHPDS) | Central solar heating plant with seasonal storage (CSHPDS) |
|---|---|---|---|
| Minimum system size | – | More than 30 apartments or more than 60 persons | More than 100 apartments (each 70 $m^2$) |
| Collector area | 1–1.5 $m^2_{FC}$ per person | 0.8–1.2 $m^2_{FC}$ per person | 1.4–2.4 $m^2_{FC}$ per MWh annual heat demand |
| Storage volume | 50–80 $l/m^2_{FC}$ | 50–100 $l/m^2_{FC}$ | 1.4–2.1 $m^3_{W}/m^2_{FC}$ |
| Solar net energy | 350–380 $kWh/m^2_{FC}$ per annum | 350–500 $kWh/m^2_{FC}$ per annum | 230–350 $kWh/m^2_{FC}$ per annum |
| *Solar fraction* | | | |
| Domestic hot water | 50% | 50% | |
| Total heat demand | 15% | 10–20% | 40–60% |
| Solar heat cost in Germany | Euro 0.15–0.3/kWh | Euro 0.08–0.15/kWh | Euro 0.17–0.40/kWh |

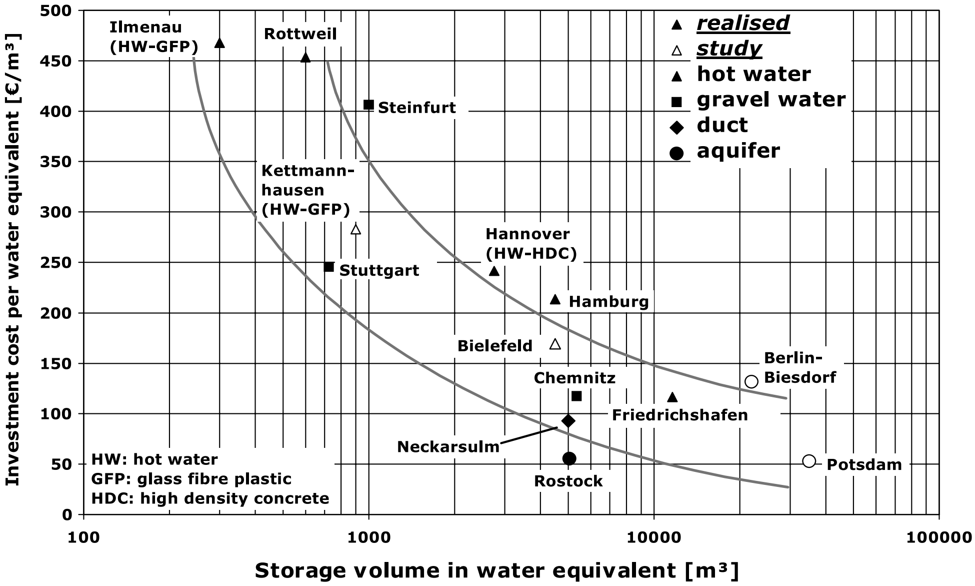


Fig. 6. Investment cost of seasonal heat stores.

## 6. Demonstration plants

In Europe, about 11.1 million m$^2$ of solar collectors have been installed until 2001 (ASTIG, 2002), corresponding to about 5500 MW of thermal power. Of this, 60 MW of thermal power is installed in large systems with collector areas of 500 m$^2$ or more. The ten largest plants are listed in Table 2.

Table 2
The ten largest European central solar heating plants (Dalenbäck, 2003 and own additions)

| Plant, country | Year of initial operation | Collector area (m$^2$) | Collector supplier, country | System type with store | Load size (GWh per annum) |
|---|---|---|---|---|---|
| Marstal, Denmark | 1996 | 18,300 | Arcon; Denmark | CSHPDS, 2100 m$^3$ water tank + 4000 m$^3$ sand-water store + 10,000 water pit (to be built in 2003) | 28 |
| Kungälv, Sweden | 2000 | 10,000 | Arcon; Denmark | CSHPDS, 1000 m$^3$ water tank | 90 |
| Nykvarn, Sweden | 1985 | 7500 | TeknoTerm; Sweden; Arcon; Denmark | CSHPDS, 1500 m$^3$ water tank | 30 |
| Falkenberg, Sweden | 1989 | 5500 | TeknoTerm; Sweden; Arcon; Denmark | CSHPDS, 1100 m$^3$ water tank | 30 |
| Neckarsulm, Germany | 1999 | 5044 | Arcon; Denmark; Paradigma, SET, Wagner; Germany; Sonnenkraft; Austria | CSHPSS, 63,400 m$^3$ duct heat store | 1.7 |
| Aerøskøping, Denmark | 1998 | 4900 | Arcon; Denmark | CSHPDS, 1200 m$^3$ water tank | 13 |
| Rise, Denmark | 2001 | 3575 | Marstal VVS; Denmark | CSHPSS, 4000 m$^3$ water tank | 3.7 |
| Friedrichshafen, Germany | 1996 | 3500 | Arcon, Denmark; Paradigma, Wagner; Germany | CSHPSS, 12,000 m$^3$ water-filled concrete tank | 2.4 |
| Ry, Denmark | 1990 | 3025 | Arcon; Denmark | Directly connected to district heating | 32 |
| Hamburg, Germany | 1996 | 3000 | Wagner; Germany | CSHPSS, 4500 m$^3$ water-filled concrete tank | 1.6 |

In addition, there are 28 systems with individual collector areas of about 1000–2700 m$^2$ and 27 systems with collector areas between 500 and 1000 m$^2$. The interest in large-scale solar heating has increased during recent years, especially in Germany and Austria (for further information, see Dalenbäck, 2003).

In the first German solar assisted district heating projects (Ravensburg, 1992 and Neckarsulm, 1994), the roof integration and safety devices of large collector areas as well as the system technology were tested extensively and improved as a result of the experiences gained.

The first demonstration plants with solar assisted district heating and seasonal heat storage were ready to operate in autumn 1996 in Hamburg and Friedrichshafen and in January 1999 in Neckarsulm. Table 3 gives the most important technical data of these 'first-generation'-projects. The given numbers for solar heat delivery and solar fraction are simulated values for long-term operation. Depending on the type of seasonal heat store, the systems have start-up times of three to five years to reach the normal operating conditions. Within this time the underground around the seasonal heat store has to be heated up and hence heat losses are higher than in the long-time operation. Because of this, the system efficiency is lower in the first years (see also Fig. 7).

The systems in Hamburg and Friedrichshafen were built according to a similar scheme (Fig. 8). The heat obtained from the collectors on the roofs of the buildings is transported to the central heating plant via the solar network and directly distributed to the buildings when required. The surplus heat in the summer period is charged into the seasonal heat store to be used for space heating and domestic hot water supply in autumn and winter.

The long-term heat storage via U-pipes in the ground has been investigated in a former project (Seiwald et al., 1995). The pilot duct heat store built in Neckarsulm in 1997 with a volume of approximately 4300 m$^3$ confirmed the research results. The first part of the store (with 20,000 m$^3$) was built in 1998 in a first phase. In the year 2001, the second phase with an increased volume of 63,400 m$^3$ was realised (see Table 3).

In 1996, a gravel–water heat store was built in Chemnitz in the course of a necessary soil decontamination. The store is designed for a maximum temperature of 85 °C and is charged or discharged by direct water exchange. The system is planned for an annual heat demand of 1200 MWh/a and a solar fraction of 42%. Since spring 2000, the store is charged with the collectors of the first phase.

In August 1998, the demonstration plant in Steinfurt-Borghorst was put in operation. It could be established in the frame of the governmental R&D-programme "50 solar settlements in Northrhine-Westfalia" and provides heat for 42 apartments in 15 single-family and 7 multi-family houses. As seasonal heat store, a gravel–water heat store is used. It is charged or discharged via horizontal heat exchanger pipes. The buildings in Steinfurt are equipped with floor heating systems to allow low operating temperatures for the district heating network. During the heating period, the network is operated on the lower supply-temperature level of the floor heating system in order to reduce network losses and to achieve the lowest possible return temperatures within the

Table 3
Technical data of the first generation CSHPSS systems in Germany

| | Units | Hamburg | Friedrichshafen | Neckarsulm, Phase I (Phase II) | Chemnitz (partially built)[a] |
|---|---|---|---|---|---|
| Housing area | | 124 terraced single-family houses | Planning: eight multi-family houses with 570 apartments | Six multi-family houses, commercial centre, school, etc. | Planning: one office building, one hotel and one warehouse |
| Heated living area | m$^2$ | 14,800 | 39,500 | 20,000 | 4680 |
| Total heat demand | MWh per annum | 1610 | 4106 | 1663 | First phase: 573 |
| Solar collector area | m$^2$ | 3000 | 5600 | 2700 (5000) | 540 vacuum tubes |
| Heat storage volume | m$^3$ | 4500 (hot-water) | 12,000 (hot-water) | 20,000 (duct) (63,400) | 8000 (gravel–water) |
| Heat delivery of the solar system[b] | MWh per annum | 789 | 1915 | 832 | First phase: 169 |
| Solar fraction[b] | % | 49 | 47 | 50 | First phase: 30 |
| Cost of the solar system (excluding subsidies) | Million Euro | 2.2 | 3.2 | 1.5 | First and second phases: 1.4 |
| Solar heat cost[b] (excluding VAT and subsidies) | Euro/MWh | 256 | 158 | 172 | First and second phases: 240 |

[a] According to Technical University of Chemnitz.
[b] Calculated values for long-time operation.

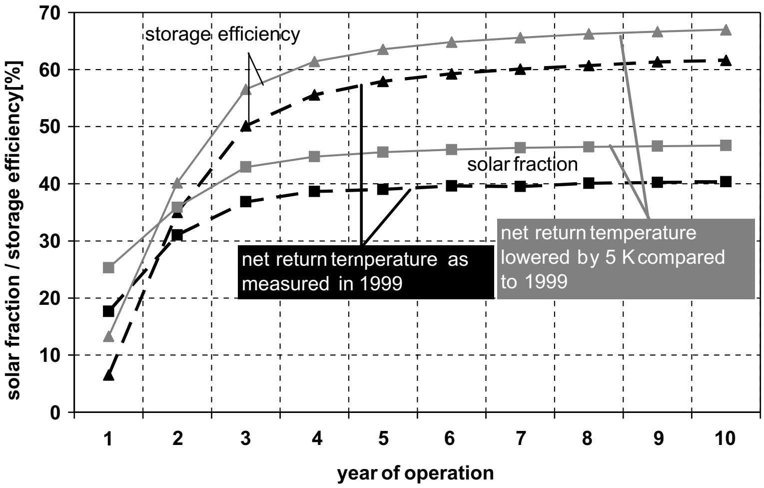


Fig. 7. Simulated storage efficiency and solar fraction for the CHSPSS in Neckarsulm (Seiwald, 2000).

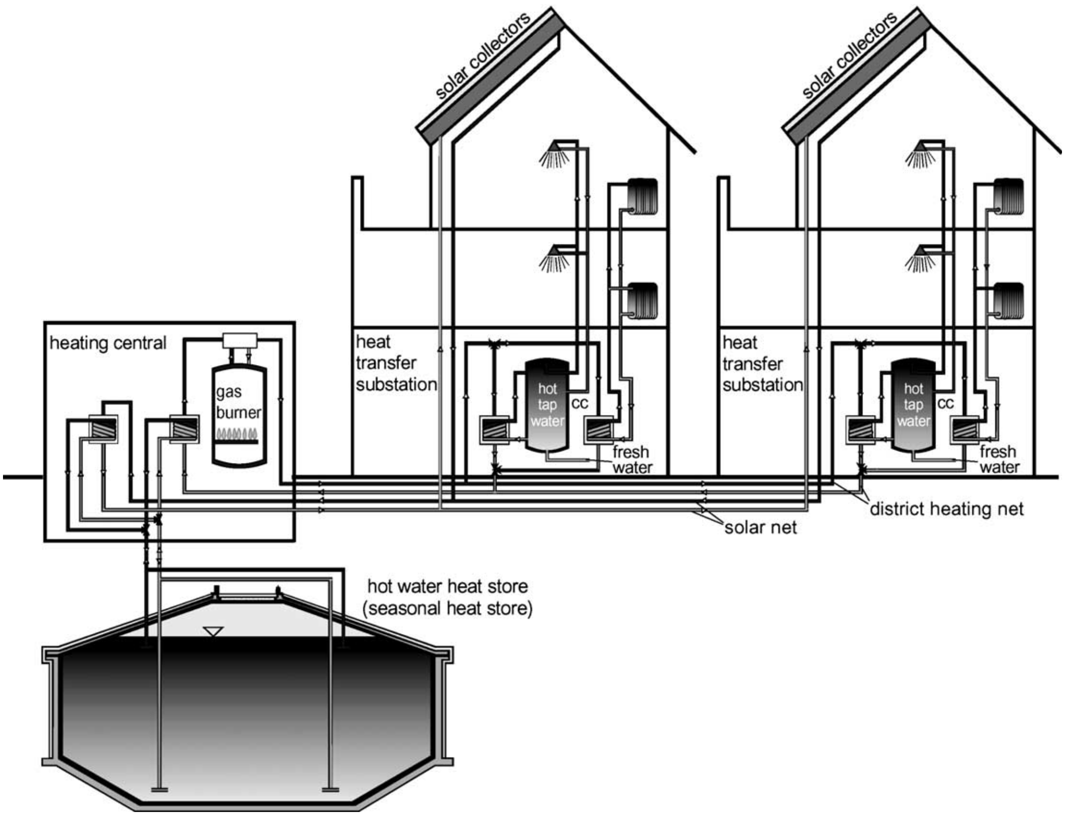


Fig. 8. Scheme of the CSHPSS-system in Friedrichshafen, Germany (cc: tap water circulation).

network. If higher temperatures for domestic hot water preparation are required in the connected houses, this is achieved via additional electrical heaters in each building.

In Rostock, the first CSHPSS-system with an aquifer heat store went into operation in 2000. The plant provides heat for a large multi-family house with 108 apartments. The store is situated in a depth of 15–30 m below ground surface and is operated at a temperature level of maximum 50 °C in order to reduce the heat losses and to avoid water treatment. To achieve a high storage efficiency, a heat pump is integrated in the heat supply system. For heat distribution, a low-temperature heating system with radiators has been realised in order to maintain low operating temperatures (maximum supply temperature 45 °C) and consequently favourable operation conditions for the solar system and the heat pump.

In Hannover, a hot-water heat store made of a new high-density concrete material was built for the first time. This material has such a low vapour permeability that an additional liner can be omitted. Another development was achieved by fixing an additional charging and discharging device with a variable height in the middle of the storage volume. With this device, the temperature stratification in the store can be improved and simultaneous charging and discharging becomes possible. This plant is in operation since June 2000.

The most recent plant is situated in Attenkirchen. 30 low energy houses are supplied by the solar system with a collector area of 800 m$^2$. The heat store is a combined hot-water and duct heat store. A central concrete tank with a volume of 500 m$^3$ is surrounded by 90 ducts (30 m deep). Depending on the temperature levels in the two parts of the store, heat pumps use the ducts as heat source and deliver heat into the hot-water tank or use the hot-water tank as heat source and supply heat into the district heating network.

## 7. Experiences

The scientific and technical accompaniment and the monitoring of the realised CSHPDS and CSHPSS systems confirm, with very few exceptions, the predicted performances of the solar plants. Problems occurred mainly during start-up and in connection with the conventional part of the heating system.

One general conclusion is the importance of a comprehensive, system-wide consideration in the design phase. In the first years of operation of the first generation plants (see Table 3) the storage efficiency and the solar fraction were less than expected due to higher return temperatures from the district heating network. For example, simulations for the system in Neckarsulm showed an increase of the solar fraction by six percentage points with a decrease of the return temperatures by 5 K compared to the 1999 measured values (yearly mean value in 1999 approximately 50 °C, see Fig. 7; Seiwald, 2000). The return temperature gives the lowest temperature level in the system and the minimum discharging temperature for the seasonal heat store. Therefore, in the end, a higher return temperature means a lower heat capacity of the heat store. The main reasons for the high return temperatures are improper design and construction of the heat distribution systems and of the tap water circulation systems in the buildings.

To reduce the possible consequences of these problems, the plants of the second generation (see Table 4)

Table 4
Technical data of the second generation CSHPSS systems in Germany

| | Units | Steinfurt | Rostock[a] | Hannover[b] | Attenkirchen[c] |
|---|---|---|---|---|---|
| Housing area | | 42 apartments in 22 houses | 108 apartments in multi-family houses | 106 apartments in multi-family houses | 30 apartments in single-family houses |
| Heated living area | m$^2$ | 3800 | 7000 | 7365 | 6200 |
| Total heat demand | MWh per annum | 325 | 497 | 694 | 487 |
| Solar collector area | m$^2$ | 510 | 1000 | 1350 | 800 |
| Heat storage volume | m$^3$ | 1500 (gravel–water) | 20,000 (aquifer) | 2750 (hot-water) | 500 + 9350 (hot-water + duct) |
| Heat delivery of the solar system[d] | MWh per annum | 110 | 307 | 269 | 415 |
| Solar fraction[d] | % | 34 | 62 | 39 | 55[e] |
| Cost of the solar system (excluding subsidies) | Million Euro | 0.5 | 0.7 | 1.2 | 0.26 |
| Solar heat cost[d] (excluding VAT and subsidies) | Euro/MWh | 424 | 255 | 414 | 170 |

[a] According to GTN, Neubrandenburg.
[b] According to IGS, University of Braunschweig.
[c] According to ZAE Bayern.
[d] Calculated values for long-time operation.
[e] Primary energy saving.

are designed with low-temperature heating systems. Furthermore the design and realization of these parts are checked carefully during the construction phase.

## 8. Summary and prospect

In the beginning of the 1990's the technology and safety concepts for large collector areas were developed and tested in first demonstration plants. Meanwhile the fabrication and installation of large collector modules and solar roofs and the integration of large collector fields in the heating system are well known.

Each of the four described types of seasonal heat stores has been built in at least one plant in Germany. There were no major problems during construction and the operational performances of the stores are in an expected range.

The monitoring of existing CSHPDS and CSHPSS systems shows in general good agreement with the simulations performed during the design studies.

In future years, further large-scale systems with seasonal heat storage will be built—not only in Germany. New concepts for seasonal heat storage systems will be applied and the storage technology, tested within the existing demonstration plants, will be developed to reduce the cost of the stores. Efforts in cost reduction related to the collectors are also being made (Hahne et al., 1998).

Solar renovation of existing district heating systems will become increasingly important as a way of reducing fossil energy demand and $CO_2$-emissions in existing urban areas.

For solar assisted district heating systems with seasonal heat storage, the mid-term aim for solar heat cost is, at maximum, twice as high as the present conventional heat cost. Already, systems with short-term or diurnal heat storage can provide the best cost/benefit ratio of all solar thermal applications for heat supply. Due to the introduction of a new building code in Germany in February 2002, where for the first time renewable energies can be taken into account to meet the required limits for primary energy consumption, these systems reach in many cases an economic level compared to other possibilities for energy savings. This will lead to an increase in the usage of these systems in the future.

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## References

Benner, M., Mahler, B., Mangold, D., Schmidt, T., Schulz, M., Seiwald, H., Hahne, E., 1999. Solar unterstützte Nahwärmeversorgung mit und ohne Langzeitwärmespeicher, Report to the BMFT-research programme 0329606C, ITW, University of Stuttgart, ISBN-Nr.: 3-9805274-0-9 (Solar assisted district heating with and without seasonal heat storage, in German).

Dalenbäck, J.-O., 2003. European Large Scale Solar Heating Network, hosted at Institutionen för Installationsteknik, Chalmers Tekniska Högskola, Göteborg, Sweden. URL: http://www.hvac.chalmers.se/cshp/.

Hahne, E., Benner, M., Mahler, B., Mangold, D., Schmidt, T., Schulz, M.E., Seiwald, H., 1998. Solare Nahwärme—ein Leitfaden für die Praxis, BINE-Informationspaket. TÜV Verlag Rheinland (Solar assisted district heating —a manual for practice, in German).

Mangold, D., Schmidt, T., Wachholz, K., Hahne, E., 1997. Solar meets business: comprehensive energy concepts for rational energy use in the most cost effective way. In: Proceeding of the ISES Solar World Congress, Taejon, Korea. Korea Institute of Energy Research.

Active Solar Thermal Industry Group, ASTIG, 2002. www.astig.org.

Seiwald, H., 2000. Bericht zum Projekt Neckarsulm-Amorbach, internal report, ITW, University of Stuttgart (Report to the project in Neckarsulm-Amorbach, in German).

Seiwald, H., Kübler, R., Fisch, M.N., Hahne, E., 1995. Saisonale Wärmespeicherung mit vertikalen Erdsonden im Temperaturbereich von 40 bis 80 °C, Report to the BMFT-research programme 0329126A, ITW, University of Stuttgart (Seasonal heat storage with vertical ducts in the temperature range 40–80 °C, in German).

TRNSYS, 2000. A Transient System Simulation Program, Solar Energy Laboratory, University of Wisconsin, Madison, USA and Transsolar, Stuttgart, Germany.

VDI 2067, 1983. Berechnung der Kosten von Wärmeversorgungsanlagen. VDI-Verein Deutscher Ingenieure, Düsseldorf (Calculation of the costs of heat generation systems, in German).