Seasonal Thermal Energy Storage in Germany

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ABSTRACT

The paper presents an overview of the present status of research, development and demonstration of seasonal thermal energy storage in Germany. The brief review is focused on solar assisted district heating systems with large scale seasonal thermal energy storage. This topic is part of “Solarthermie-2000” which has been funded in the 4th Programme “Energy Research and Technology” by the Federal Ministry of Economics and Works. Within “Solarthermie-2000” so far 8 large scale plants have been built and are being monitored. Significant progress has been achieved and resulted in the development of a second and third generation of solar assisted district heating plants with seasonal storage.

1. INTRODUCTION

In Middle Europe seasonal thermal energy storage offers a great potential for substituting fossil fuels by utilization of waste heat from cogeneration heat and power plants (CHP) and of solar energy for hot water preparation and space heating. For this reason the topic of seasonal thermal energy storage has been a major topic in the Programme “Energy Research and Technology” of the Federal Government in Germany. So far various seasonal storage concepts for two different application areas have been investigated. This paper only deals with large scale seasonal stores in centralized (solar assisted) district heating systems. For small scale decentralized heating systems of houses the alternative concept of thermo-chemical energy storage could be a favorable option.

The advantages of large scale seasonal stores in (local) district heating systems is quite obvious and well known [1]: by enlarging the system size the specific investment costs and the relative thermal losses of thermal energy storage systems are reduced drastically. On the other hand the implementation of the concept is still hampered by the high investment costs. Usually the local municipal utilities realize and operate district heating plants only if heat can be supplied to the customer at costs which are competitive with fossil fuels (gas). The inherent problem of a seasonal store, however, is that it can be charged and discharged only 1-2 annually. Therefore the investment costs of the seasonal store as well as the operational and maintenance costs have to be extremely low. This final goal of cost-effectiveness of seasonal heat storage at higher temperatures (between 50 to 100 ^{o}C) has not yet been achieved. Further cost reductions of both the storage systems as well as the total heating system is a challenge for the future.

Seasonal storage of surplus heat from CHP plants has been implemented in two aquifer projects at the Reichstag and adjacent Parliamentary buildings in Berlin and in the district heating system of the utility of Neubrandenburg. Both projects are included in Annex 12: “High Temperature Underground Thermal Energy Storage” of the IEA-Programme: “Energy Conservation Through Energy Storage”and are reported at this Conference by the Operating Agent Burkhard Sanner [7].

Compared with sensible heat stores (e. g. water, aquifer) thermo-chemical energy storage offers several advantages: high energy storage densities and no significant thermal losses even for long term storage. It provides a higher quality as the stored exergy can be used for a chemical heat pumping process. However, today available stable storage materials (various types of zeolithes and silicagel as solid adsorbents of water vapour) show storage densities in the order of 100 -200 kWh/m³ which is too small for seasonal storage. The high production costs of storage materials prevent cost-effectiveness.

Whereas still some R&D efforts in Germany are focused on the development of new thermo-chemical storage materials with improved properties (higher storage density, better long term stability, cheap production technologies), the application is now directed towards the use of thermo-chemical stores in a chemical heat pump cycle. By this concept fossil fuels can be used very efficiently with an annual COP factor of 1.3. New enhanced industrial efforts funded in the Programme may result in substantial technological progress already in the mid term.

2. SOLAR ASSISTED DISTRICT HEATING PLANTS WITH SEASONAL STORAGE

2.1 Programme Solarthermie-2000

*C*entral *s*olar *h*eating plants with *s*easonal *s*torage (CSHPSS) aim at a solar fraction of 50% or more of the total heat demand for space heating and domestic hot water preparation for a large residential area (more than 100 apartments). The seasonal time shift between solar irradiance and heat demand is matched by means of the long term heat storage. An example for a monthly energy balance is given in Figure 1 for the CSHPSS-system in Friedrichshafen, Germany.

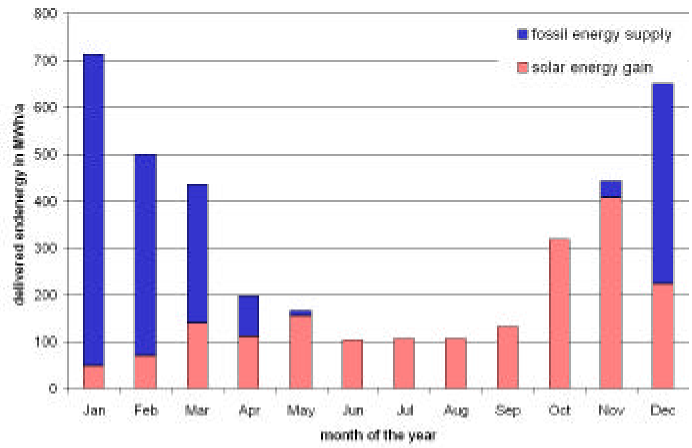

Figure 1. Monthly energy balance for the CSHPSS-system in Friedrichshafen, Germany (simulated data)

Research and development activities on CSPHSS-systems in Germany have been funded within the 4th Programme Energy Research and Technologies in the topic: "Solarthermie-2000". It was initiated in 1993 for a period of 10 years. Recently the accomplishments have been reviewed. It is intended upon approval by the Ministry of Environment which has taken over just recently the responsibility for “Solarthermie-2000” to extend it with some new priorities for the next 5 years.

A main aim of "Solarthermie-2000" has been to improve and demonstrate the technical and economic feasibility of various large scale seasonal thermal energy storage and system concepts including: hot water stores (pits and tanks) with and without liners, gravel/water stores, duct stores, aquifer stores and hybrid systems. The Programme comprises basic R&D on the storage concepts (e. g. material investigations) as well as the design, construction and long term monitoring and uniform evaluation of data from pilot and demonstration plants. So far 8 large scale CSHPSS-systems have been built which have been designed to cover between 34 and 60 % of the annual heat demand of new housing areas by solar energy.

A comprehensive presentation of “Solarthermie-2000” with a detailed description of the investigated CSHPSS-systems and explanation of the various storage concepts can be found in [1].

2.2 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 use energy and is calculated with an amortization according to VDI 2067 [2]. The figures are valid for the German market (calculation basis: market prices of 1997/98, without VAT, interest rate: 6 %).

It is vital for the optimum functioning of the solar system that it is correctly integrated into the conventional heating system and that the system is optimally designed– of both the solar part and of all other components of the heat supply system: the district heating network, the heat transfer substations and the HVAC-systems. For designing a seasonal heat store, detailed simulation is necessary which can be obtained by using the simulation programme TRNSYS [3].

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 (for comparison)	Central solar heating plant with diurnal storage (CSHPDS)	Central solar heating plant with seasonal storage (CSHPSS)
Minimum system size	–	More than 30 apartments or more than 60 persons	More than 100 apartments
Collector area	1–1.5 m_{FC}^2 per person	0.8–1.2 m_{FC}^2 per person	1.4–2.4 m_{FC}^2 per MWh annual heat demand
Storage volume	50–80 litres/m_{FC}^2	50–100 litres/m_{FC}^2	1.4–2.1 m_W^3/m_{FC}^2
Solar net energy	350–380 kWh/m_{FC}^2 per annum	350–500 kWh/m_{FC}^2 per annum	200–330 kWh/m_{FC}^2 per annum
Solar fraction (new building code)			
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 0.16–0.42/kWh

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 price of Euro 1000,- per m² flat-plate collector, large plants with diurnal heat storage reach about Euro 500,- per m² (including planning, without VAT) when integrated into new buildings [4]. CSHPSS-systems are more costly due to the seasonal heat store, but cover a much higher percentage of the total heat demand by solar energy.

2.3 Demonstration Plants with Seasonal Heat Storage in Germany

In Germany’s first constructed large scale solar-assisted district heating plants (Ravensburg and Neckarsulm), the roof integration and safety devices of large collector areas, as well as the system technology for solar-assisted district heating systems, were tested extensively and improved as a result of the experience gained.

The first demonstration plants for solar-assisted district heating with seasonal heat store were ready to operate in autumn 1996 in Hamburg and Friedrichshafen and in January 1999 in Neckarsulm. Table 2 gives the most important technical data of the ‘first-generation’-projects.

The first plants in Hamburg and Friedrichshafen were built with a ground buried hot water tank made of reinforced concrete. To protect the concrete and the heat insulation outside the walls from hot water vapour diffusion, the inner side of the tank is sealed with a liner of 1.2 mm stainless steel.

In 1996, an underground 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 directly charged or discharged. The system is designed for an annual heat demand of 1,200 MWh/a and a solar fraction of 42 %. Since spring 2000 the store is charged with the solar collectors of the first phase of construction.

The long-term heat storage via vertical ducts in the ground has been investigated in a previous project. The data of the pilot duct heat store built in Neckarsulm in 1997 with a volume of approx. 4,300 m³ confirmed the research results. The first part of the store (with 20,000 m³) was built in 1998 as a first construction phase. In the same year, the project got the „Deutscher Solarpreis 1998“ (German Solar Prize), advertised by EUROSOLAR. In the year 2001 the storage volume was increased to 63,000 m³ in a second construction phase.

Table 2: Technical design data of the first generation CSHPSS systems in Germany

	Hamburg	Friedrichs-hafen	Chemnitz[1] 1. PoC	Neckarsulm	Hannover[2]
Year of initial operation	1996	1996	2000	1997/2001	2000
Supply area	124 AU	final stage: 570 AU	office building	140 AU, school, res. home, commercial centre	106 AU
Heated living area in m²	14,800	39,500	4,680	n.s.	7,365
Solar plant (design values)					
• Collector area in m²	3,000	5,600	540 VT	6,500	1,350
• Storage type	hot water	hot water	gravel/water	duct	hot water
• Heated storage volume in m³	4,500	12,000	8,000	63,300	2,750
Total heat demand at heating central in MWh/a	1,610	4,106	1. PoC: 573	3,960	694
Heat delivery of the solar system in MWh/a	789*	1,915*	1. PoC:169*	2,018*	269*
Solar fraction in %	49*	47*	1. PoC: 30*	50*	39*
Cost of the solar system in Mio. Euros	2.2	3.2	1. + 2. PoC: 1.4	n.s.	1.2
Solar heat cost in EuroCt/kWh (excluding financial subsidies and VAT, including planning)	25.7	15.9	1. + 2. PoC: 24.0	17.2	41.4

PoC: Phase of construction, VT: vacuum tube, AU: accomodation unit, *: values for long-term operation (calculated with TRNSYS), [1]: specifications TU Chemnitz, [2]: specifications IGS, Uni Braunschweig , n.s..: not specified

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

In August 1998, the pilot plant in Steinfurt-Borghorst went into operation. It could be established in the frame of the R&D-programme of the State Northrhine-Westfalia “50 solar settlements in Northrhine-Westfalia” and provides 42 apartments in 15 single-family and 7 multi-family houses with heat (see Table 3). As seasonal heat store, a gravel-water heat store is used which is charged and discharged via horizontal pipes. The project got the „Deutscher Solarpreis 2001“ (German Solar Prize).

The buildings in Steinfurt-Borghorst are equipped with floor heating systems to allow low operating temperatures for the district heating network. During the heating period, the net is operated on the low temperature level of the floor heating system in order to reduce network losses and to achieve the lowest possible return temperatures within the network. If higher temperatures for domestic hot water preparation are required, this is achieved via electrical backup heaters in each building.

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

Table 3: Technical design data of the second and third generation CSHPSS systems in Germany

	Steinfurt	Rostock[3]	Attenkirchen[4]	München[4]
Year of initial operation	1998	2000	2002	2004[#]
Supply area	42 AU	108 AU	30 AU	272 AU
Heated living area in m²	3,800	7,000	6,200	22,610
Solar plant (design values)				
• Collector areas in m²	510	1,000	800	2,700
• Storage type	gravel/water	aquifer	hybrid	n.s.
• Heated storage volume in m³	1,500	20,000	500 + 9,350	~ 5,700
Total heat demand at heating central in MWh/a	325	497	487	1,976
Heat delivery of the solar system in MWh/a	110*	307	415	988*
Solar fraction in %	34*	62	55[§]	50*
Cost of the solar system in Mio. Euros	0.5	0.7	0.26	1.7[#]
Solar heat cost in EuroCt/kWh (excluding financial subsidies and VAT, including planning)	42.3	25.5	17.0	16.0[#]

AU: accomodation unit, *: values for long-term operation (calculated with TRNSYS), [3]: specifications GTN, Neubrandenburg, [4]: specifications ZAE Bayern, Garching, n.s..: not specified, [§] primary energy savings; #: present design values

The actually newest plant in operation is situated in Attenkirchen. For seasonal heat storage a hybrid storage concept has been developed, which consists of a 500 m³ underground not thermally insulated concrete water tank in the centre and surrounding vertical borehole heat exchangers (ducts), which open up an additional ground volume of 9,350 m³. The inner tank works as a buffer and short term store, the duct store is used as a low temperature seasonal store. The integrated heat pumps can either be used to transfer heat from the duct store into the buffer tank, or, when the temperature in the concrete tank is too low for heat distribution, to deliver heat from the buffer tank into the heat distribution network.

2.4 Results and experiences

The first plants erected within "Solarthermie-2000" are in operation since 1996. The data and experiences show that all investigated storage concepts are working well without major technical problems (e. g. no water leakage of the pits). Reduced system efficiency is often caused by conditions of the the non-solar part: e.g. the annual heat output of the stores strongly depends on the return temperatures of the district heating network which is determined by the heating system of the connected houses. Obviously a low temperature heating system of buildings is necessary to optimize the solar-thermal output of the seasonal store systems. The effective storage capacity can be increased by a heat pump. This makes it possible to use heat at temperatures below the return temperatures and thus makes the system more robust and independent from conditions that sometimes can not directly be influenced by the utilities operating the solar plant with storage.

Some of the demonstration projects are constructed in several consecutive phases of construction over several years. Experiences show substantial changes between heat demand and collector area realized compared to original design. If the seasonal heat store has to be designed according to a final stage of a residential area, this may lead to over- or under-sizing due to these changes. So far only extendable storage-concepts like e.g. duct heat stores are able to overcome this problem, tank-constructions like pits etc. have to take this into account during their design phase.

Table 4 shows some selected monitored values from the demonstration plants in comparison to the design values. Although the predicted solar fractions have not yet been reached in some plants for different reasons, all the plants are running well and deliver a large contribution to the heat supply of the connected residential areas. The solar heat costs that have been reached today by CSHPSS-systems in Germany are, depending on the size of the system, between 16 and 42 EuroCt/kWh. In Germany, this is still more than 3 times higher than heat supply from fossil fuels.

Table 4: selected monitored values from 2002 compared to design values

project		Friedrichs-hafen	Neckarsulm	Hannover[1]	Steinfurt[1]	Rostock
Supply temperature[2] in °C	monitored 2002	72	66	69[4]	43[4]	44
	Design value	70	60	70	50	50
Return temperature[2] in °C	monitored 2002	47	43	46[4]	34[4]	36
	Design value	40	40	40	25	30
Solar fraction in %	monitored 2002	27[3]	39[3]	28	34	43
	Long term planning	43[3]	50	39	34	62

[1]: specifications IGS, Uni Braunschweig, [2]: mean values, weighted by flow rate, [3]: referred to realised phase of construction; [4]: year 2001

3. CONCLUSIONS AND PROSPECTS

The results achieved so far show the technical feasibility of the constructed solar assisted district heating plants. The design values of the performance, however, have in some cases not been achieved due to unfavorable conditions of the district heating- and the heat supply system in the buildings. In particular the high return temperatures of the district heating system have an adverse effect on the solar fraction of the total heating demand. This strong dependance on the system is still a weak point of the concept. Improved solutions have to be developed and demonstrated to surmount this problem.

In the coming years, it is intended to realize further large-scale plants with long term heat storage– and not only in Germany. New concepts for seasonal heat storage systems and the integration into the heating system will be applied and the storage technology, tested within the existing pilot plants, will be further developed to reduce the specific construction costs of stores without losing the thermal performance and life time of the plant. Solar renovation of existing district heating systems will become increasingly important as a way of reducing fossil fuels consumption 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. Nowadays, systems with short-term or diurnal heat storage can provide the best cost–benefit ratio of all solar thermal applications for heat supply.

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