# SOLARTHERMIE-2000: 10 YEARS OF RESEARCH AND DEVELOPMENT IN LARGE SOLAR HEATING SYSTEMS IN GERMANY

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**Abstract** – In the house building sector, central solar heating plants presently offer the most profitable application of all possibilities of thermal solar systems. Since 1993, the German R&D-programme 'Solarthermie-2000' focuses on research and development of large scale solar heating systems. The programme is split up in three parts:
In part one, about 20 year old large scale solar heating systems were investigated for long term stability of the solar collectors and system performance.
Part two is aimed at building up and operating thermal solar heating plants with at least 100 m² collector area for tap water heating. Prerequisites for the admission to programme part two is the compliance with severe economic requirements and the participation in a long-term monitoring programme.
Part three focuses on research on and development of central solar heating plants with seasonal heat storage. By now, eight pilot plants with seasonal heat storage have been realized as a follow-up of four central solar heating plants with short-term heat storage.
All these pilot plants are carefully monitored within the frame of the scientific-technical surveyance. The detailed results of the monitoring programme are used to find possible weak points and to improve or optimize the plants, in order to make these concepts more profitable. This profitability is one main prerequisite for a beginning market penetration of this technology. The report describes the technology of central solar heating plants and gives advice about planning and costs. The experiences gained in 10 years of research and development are summarized and a short description of perspectives is given.

## 1. THE R&D-PROGRAMME SOLARTHERMIE-2000

In 1993 the former BMF, German Federal Ministry for Research, started to fund the development of the technology for large scale solar heating systems and the construction of pilot plants by means of the energy research programme 'Solarthermie-2000'. From 1998 to 2002 Solarthermie-2000 has been carried on by the former BMWi, German Federal Ministry for Economy and Technology, and today is in the responsibility of the BMU, German Federal Ministry for Environment, Environmental Protection and Reactor Safety. The programme 'Solarthermie-2000' is split up in three different programme parts:

**Part 1: Long-term behaviour of thermal solar heating plants**

Within the framework of this programme part, some selected solar heating plants of the first R&D-programme ZIP (Zukunftsinvestitionsprogramm), already installed between 1978 and 1983, were tested for their behaviour in operation and for signs of deterioration after more than 15 to 20 years in operation. One main result of this examination was that a life expectation of solar heating plants of more than 20 years has been proven. Part 1 of the programme has been concluded in July 1997. Results are published in detail e.g. in /1/.

**Part 2: Large scale thermal solar systems on public buildings**

This part of the programme comprises the construction of up to 100 mid-size research- and demonstration plants with at least 100 $m^2$ collector area for thermal use of solar energy, predominantly for tap water heating. Plants in course of planning or construction are technically surveyed and scientifically monitored and analysed when in operation. The aim of this part of the programme is to further develop the system technology for such large scale thermal solar systems, to elaborate recommendations for planning and dimensioning as well as to establish this technology on the market.

**Part 3: Solar assisted district heating and seasonal heat storage**

It is the main aim of a solar assisted district heating with seasonal heat storage to achieve a solar fraction of about 50% of the annual heat demand for heating and tap water supply by means of seasonal heat storage. The collector area needed should measure at least 1000 $m^2$. Different promising concepts and technologies of – if possible – roof integrated large-scale solar collectors and heat storage systems are tested and evaluated in research and demonstration plants. Project development and plant dimensioning are equally scientifically accompanied as the planning and construction. As in programme part 2, the plant's mode of operation and the system's efficiency are evaluated over several years in a monitoring programme, accompanied by research work for the optimisation of system and storage technologies. This programme part is aimed at the development of efficient and economical technologies for solar assisted district heating and seasonal heat storage.

The scientific accompanying work of programme parts 2 and 3 is carried out by a network of university institutes and businesses spread all over Germany. The ZFS Rationelle Energietechnik GmbH is in charge of programme part 2. Since 1st February 2003 SWT-Stuttgart as successor of the Institute for Thermodynamics and Thermal Engineering (ITW) at the University of Stuttgart, Germany, is in charge of programme part 3. More detailed information about Solarthermie-2000 can be found under www.solarthermie2000.de.

## 2. R&D-PLANTS IN OPERATION

Within the programme part 2, by now 49 pilot plants are in operation and four more are in course of construction. Figure 1 shows the collector area and the buffer store volume of these plants, grouped according to the type of building in which the thermal solar heating plants have been installed. These plants gain solar heat costs in accordance with planning of 10 to 13 EuroCent/kWh, calculated according to the simplified standard Solarthermie-2000 /2/.

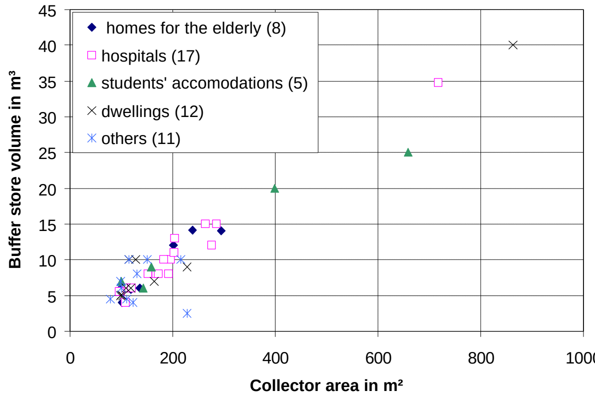


**Figure 1: Plants of Solarthermie-2000 part 2 in operation (in brackets the amount of plants)**

At present, the biggest plant within programme part 2 is the housing estate Burgholzhof in Stuttgart, Germany, with a collector area of 1543 m$^2$ and a buffer store volume of 90 m$^3$. This plant is not included in figure 1.

Tables 1 and 2 illustrate the basic data of the solar assisted district heating plants with seasonal heat storage accompanied within the programme part 3. The public utility company Stadtwerke Neckarsulm, Germany, was awarded the "Deutscher Solarpreis 1998" (German Solar Prize) for the project Neckarsulm-Amorbach. Another project, Steinfurt-Borghorst, built within the framework "50 solar settlements in North Rhine-Westfalia" was awarded the "Deutscher Solarpreis 2001" (German Solar Prize) by Eurosolar.

Presently, the plant in Munich is still in the phase of planning. It will be built as the first plant of the third generation at Ackermannbogen, close to the Olympic parks in Munich. As a means of heat-storage, a gravel-water as well as a hot-water heat store are in consideration. Following the tender of both concepts, the type of store which is more economical in this location will be realized.

## 3. RESULTS OF THE ACCOMPANYING RESEARCH

Below, some selected results of the scientific surveyance of the research and demonstration plants are presented. Further information can be taken from literature /2 to 7/.

### 3.1 Drawing up an energy concept

Before the realization of a large scale thermal solar plant, an energy concept should be drawn up, comparing the relation between the energy conservation obtained by the use of the solar heating plant, as well as the costs for investment, operation and maintenance required for this purpose on the one hand, and further possible energy conservation measures on the other. If the plant shall be installed for an already existing building, it is important to examine beforehand if other possibilities for a reduction of the energy demand, as for example heat insulations measures, a new heat generator or a roof renovation should be realized before the installation of a solar heating plant. It is not recommendable to integrate a solar system into a conventional heating system which is not energetically optimised. By having a closer look at the necessity and economy of different means of energy conservation, different measures can be combined in such a way that a thermal solar plant is included and that the investment and running costs are minimised.

Already before the beginning of the planning phase of a seasonal heat storage it has to be investigated if the aimed reduction of $CO_2$ emissions of e.g. 50% can also be achieved by the use of alternative technologies such as co-generation, the use of biomass or others with a better economy of the plant as a whole. The construction of a store is only recommendable, if by the use of a seasonal heat storage the aimed environmental protection, depending on local boundary conditions, can be achieved with the lowest additional costs.

**Table 1: Technical 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, residential 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 |
| • Store type | hot water | hot water | gravel/water | duct | hot water |
| • Heated store 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

**Table 2: Technical data of the second and third generation CSHPSS systems in Germany**

| | Steinfurt | Rostock[3] | Attenkirchen[4] | München[4] |
|---|---|---|---|---|
| Year of initial operation | 1998 | 1999 | 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 |
| • Store type | gravel/water | aquifer | hybrid | n.s. |
| • Heated store 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

### 3.2 Early project development

The realisation of a solar assisted district heating plant with seasonal heat storage makes demands on all project members that are often new and unused. Due to this, an early start of the project development is essential for the success of the project. The project development should start for new buildings before the setting up of the development scheme and for existing buildings before the beginning of the planning of renovation measures. The success of the project can be secured by an integrated planning process that comprises all systems and circumstances that influence a solar assisted district heating system with seasonal heat storage – from the development scheme to the heating system of the rooms and the tap water heating system. Especially for recent pilot projects with seasonal storage the legal agreement between public utilities as the system owner, the city as the seller of the building site and the building companies themselves is getting more and more important.

### 3.3 System concept and dimensioning

For part 2 of Solarthermie-2000 the ZFS Rationelle Energietechnik GmbH developed dimensioning parameters that for thermal solar plants for tap water heating lead to a solar fraction of 30 % referred to the used heated tap water (the tap water circulation being unconsidered). This concept of a tight dimensioning of thermal solar plants has proven itself. It avoids stagnation times of the collector field that are first of all uneconomic and second might have a bad influence on the lifetime of the solar circuit's components.

Per about 65 to 70 l of daily hot tap water consumption a maximum of 1 m² of flat plate collector area should be installed. For the buffer store volume about 50 l per m² collector area are recommended.

In compliance with these conditions, the solar heat gain only falls 7 % compared to an optimal collector orientation (south and tilt angle of 45°) if the tilt angle is varied to 20° or 50° to the horizontal while the orientation is within south east to south west.

Before the application of a seasonal heat storage, an exact system dimensioning with the aid of detailed system simulations, dynamically calculating the thermal behaviour of heat generators, the heat store itself, and where required also the district heating net and the heat consumers is essential. With these system simulations the function of the planned system should be additionally proofed and, if necessary, be optimised for an energy saving equal as high as possible and for low additional heat costs caused by the usage of thermal solar energy. To obtain the best possible solar heat gain, the collector areas have to be orientated south +- 20° and tilted against the horizontal about 35° to 45°, depending on the type of the overall heating system. The realisation of pilot plants has shown that especially for multi family buildings the architectural integration of such high tilted roof-integrated collector areas is difficult. On this account, a lot of the installed large roof-integrated collector areas are only tilted between 15° to 25° against the horizontal. Compared to optimal tilted collector areas, the lower solar heat gain of these collectors has to be compensated by means of an enlargement of the collector area. As a rule, the collector area has to be enlarged by about 13 to 15 % if the tilt angle is only 15° against the horizontal.

For all large scale thermal solar plants the flow temperature towards the collector area is the decisive factor for the efficiency of the thermal solar plant and thus also significantly influences the profitability of the system operation.

Therefore, system concepts have been developed for the large thermal solar plants of part 2 of Solarthermie-2000, allocating the low temperature level of the cold water flowing into the tap water store to the collector area preferably in direct use. If the energy demand needed to heat up also the tap water circulation net should partly be covered by thermal solar energy, the integration of the circulation back flow in the whole heating system has to be planned and installed very carefully /3/.

In a district heating net the net back flow temperature strongly affects the flow temperature towards the collector area. A net back flow temperature lowered by 1 K rises the solar fraction of a thermal solar system with seasonal storage to 1 % (absolutely) on an average! Due to this fact, low-temperature room heating systems are used in newer pilot plants of part 3 of Solarthermie-2000 (Steinfurt-Borghorst, Rostock, München). If possible, the tap water is heated by flow heaters without tap water circulation.

As a basic principle, the system structure and the control strategy should be as simple as possible in order to reduce the sensitivity to operational faults and the complexity of maintenance and service as well as to achieve a high operational reliability.

## 4. STATUS OF DEVELOPMENT AND PERSPECTIVES OF LARGE SCALE THERMAL SOLAR PLANTS

With the first research and development plants like e.g. the plant in Ravensburg (1993), the collector manufacturing and the solar system technology for large roof integrated collector areas (more than 100 m²) were developed. Nowadays, at least eleven companies on the German market offer a good quality standard for the mounting of and service for large collector areas. With the construction of the pilot plants in Hamburg and Friedrichshafen ITW initiated a reasonable technical evaluation for large collector areas in the German Dampfkesselverordnung (steam boiler regulation). In part 2 of Solarthermie-2000 sample statics for collector areas, mounted on flat roofs, were drawn up and low-cost technologies to build up the sub-constructions were developed /8/.

For all thermal solar plants of Solarthermie-2000 part 2 the installer has to guarantee a minimum solar heat gain per year. For the calculation of this heat gain the installer is provided with consumption values for different time periods (acquired by preliminary monitoring) and climatic data for the respective location of the plant by the scientific accompanying institute. Due to the fact that this dimensioning data can never be exactly achieved under practical operation conditions, the guaranteed solar heat gain is recalculated referring to the real monitoring data and then compared to the monitored achieved solar heat gain /2/. The monitored solar heat gain must reach at least 90 % of the recalculated value to fulfil the guarantee.

Figure 2 shows the percentage of the monitored solar heat gain referred to the recalculated value for all 34 plants of Solarthermie-2000 part 2 that are in operation at least since one year. All but 8 plants reach the minimum of 90 % of the guaranteed value. Some plants even exceed the 100%-level.

6 of the 8 plants with an output deficit fall only slightly below the minimum of 90 %. It is expected that in the upcoming years the guaranteed value can be achieved by minor system optimisations. The two plants achieving only about 60 % of the guaranteed value suffer from deficits resulting from the system itself. Here major modifications are required.

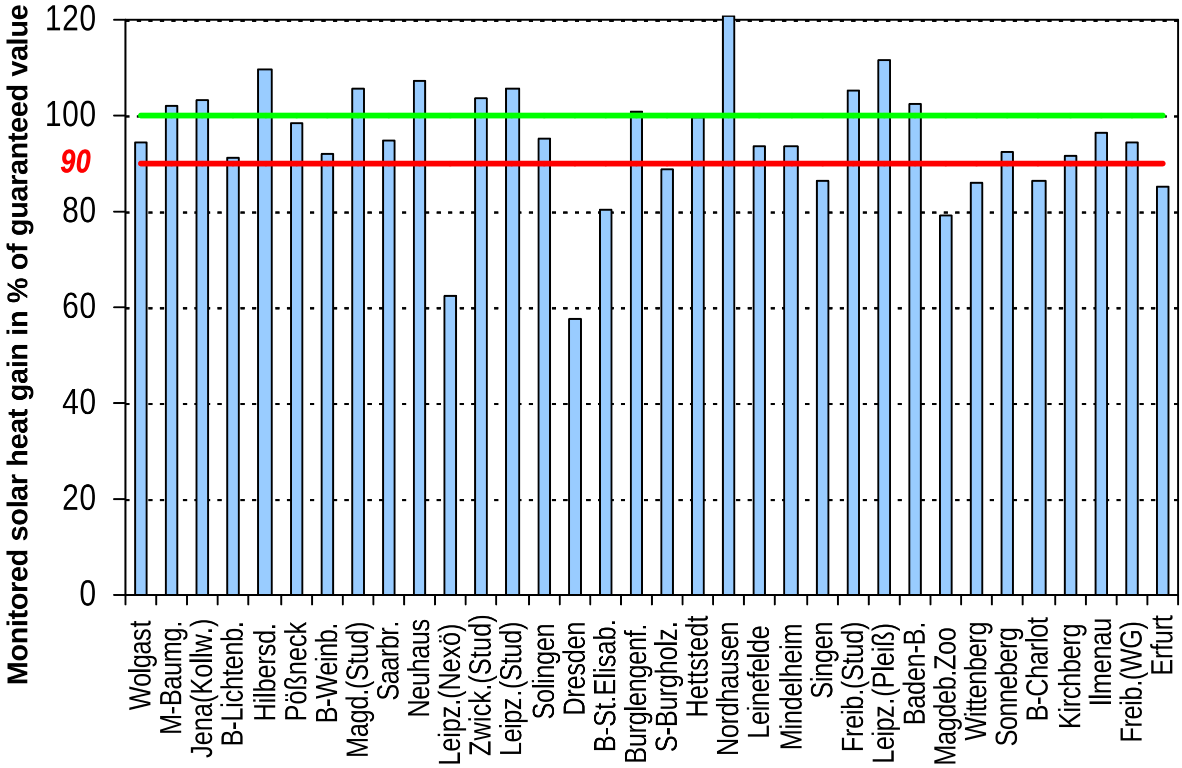


**Figure 2: Monitored solar heat gain in % of the recalculated guaranteed value for the pilot plants of Solarthermie-2000 part 2.**

A lot of the suggestions for system design, system dimensioning and dimensioning of the system components, derived from the experiences of the scientific surveyance, were already adopted by planers, installers and manufacturers. In summer or autumn 2003 the VDI-standard 6002 part 1 for large thermal solar plants for tap water heating will be released as green print.

Higher energy savings than with thermal solar plants for tap water heating can be achieved, if the room heating system is also connected to the solar system. For small thermal solar plants, with a collector area of up to about 30 m², these so called combi-systems have been installed increasingly within the last years. For large thermal solar plants, the system configuration, dimensioning and connection to the conventional system is considerably more complex. In future, basic principles for planning must be elaborated by analyses and evaluations of research and development plants in order to initiate a similar development for large plants.

For seasonal heat storage four concepts were developed: hot-water, gravel-water, duct and aquifer-heat stores. Since the beginning of the year 2000 each storage concept is built and in operation in at least one pilot plant. It could be proven that seasonal heat storage on a large scale is applicable in practice and works /9/.

The interest in solar assisted district heating systems and seasonal heat storage rises noticeably and the knowledge for this technology has found its way to the target sectors like cities, public utilities, building companies and consultancies. The further development of these technologies shall result in a continuing decrease of costs to a level of about two times the heat costs of conventional district heat, that amounts to 4 to 6 EuroCent/kWh. Important extensions of the application possibilities of seasonal heat storage are the opening of existing heating plants and the integration of large stores into heat and cold management systems, also in industry- and office buildings.

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