Monitoring of a Large-Scale Solar Plant for Potable Water Heating in a Hospital in the Town Baden-Baden

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1. Introduction

Hospitals have relatively high hot water consumption continuously throughout the year. These are perfect conditions for large-scale solar thermal plants. In the town of Baden-Baden, in Southwest Germany, a solar thermal plant was built in 1999.

In the frame of the program “Solarthermie-2000” the plant was partly financed by the German government. Additionally an elaborate measurement system was installed and now allows a very detailed monitoring and evaluation of the functionality of the solar thermal plant.

The experiences also with other plants promoted in this program shows that the technology for large-scale solar thermal plants is advanced and can compete with other technologies for potable water heating. The results of the solar plant in Baden-Baden simulated with the weather conditions of Cuba show that this technology is even more efficient in countries with a nearly even distribution of solar radiation throughout the year.

Fig. 1: Flat plate collectors of the solar thermal plant in the hospital in Baden-Baden

2. Description of the plant

276 m² flat-plate collector panels are installed on the flat-roof of the hospital. The orientation is optimal to the south and the inclination is 45°. Figure 1 shows the collectors mounted on the flat roof.

Hydraulic Scheme

Figure 2 shows the hydraulic scheme of the solar plant. Large-scale solar thermal systems in Germany are usually designed with three cycles. The first heat exchanger separates the water/glycol mixture of the collector cycle from the water storage cycle. Glycol is needed to prevent the collectors from freezing in winter, which is obviously not necessary in all climate regions. Therefore this heat exchanger can be left out in areas with no danger of freezing.

The second heat exchanger separates the heating water from the drinking water due to hygienic reasons. Germs can grow easily in stored warm water and impacts the quality of the drinking water. So this separation between the solar plant and the potable water system is essential.

The solar energy is stored in three buffer storages of four m³ each. It is important to keep the storages at different temperature levels to ensure that the temperature back to the collector is as low as possible. This has a huge impact on the efficiency and the operating time of the plant. This can be achieved, either with valves, special charging devices of the storage in order to obtain a stratification or with a careful designed arrangement of the storages.

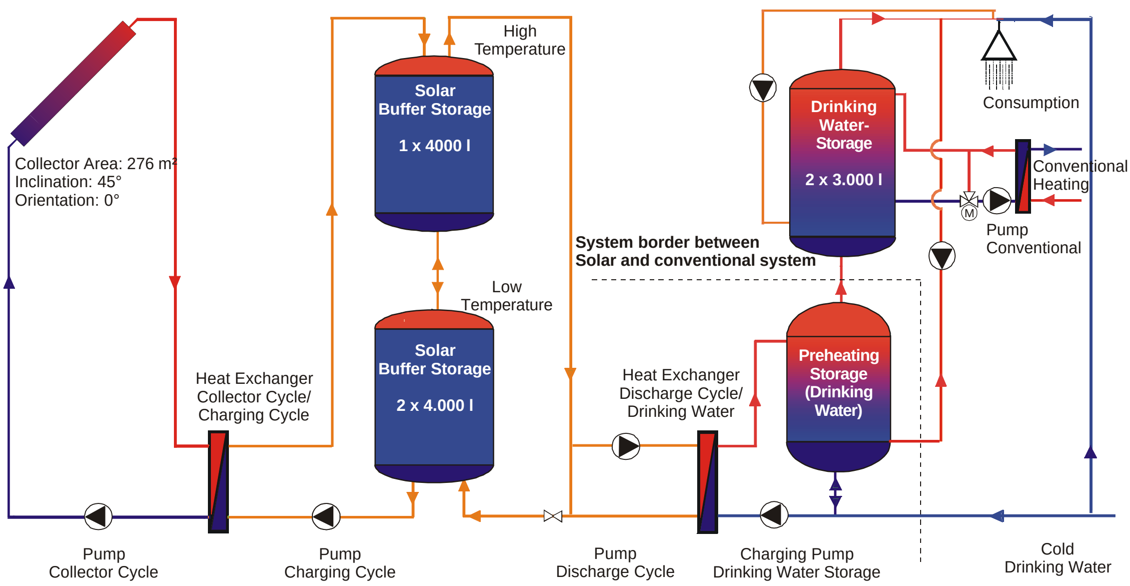

Fig. 2: Hydraulic Scheme of the solar thermal plant in Baden-Baden

Operation of the Solar Plant

The automatic control of the solar thermal plant is relatively simple but still causes often problems and disfunction. The pump in the collector cycle switches on when there is a higher temperature in the collector than in the storage. The second pump, the one that charges the storages, starts when a temperature difference occurs between the first heat exchanger and the storage. Next the energy is loaded into the storage. The discharging takes place when the temperature in the buffer storage is higher than in the pre-heating storage, this means the other two pumps will switch on. The temperature difference is set as controlled parameters.

When there is any use of hot water, the solar pre-heated water flows from the pre-heating storage in the drinking water storage and if it is necessary gets heated to the desired temperature with conventional energy natural gas.

Design Parameters

The most important parameter in designing this solar thermal plant is the hot water consumption and its distribution over the day, week and year. It is necessary to know the consumption especially in the summer, when the solar fraction is about 80 to 90 % (in the Central European Climate). The optimised cost and gain effective designing of the collector area and the storage size can be done with a dynamic simulation program. A rough approximation is 100 m² collector area for 7 m³ daily potable hot water consumption at 60 °C and the storage should be designed with 40 l/m² collector area.

In the Central European Climate, approximately 30 to 40 % of the yearly energy needed for hot water could be obtained by using solar energy. This means a solar fraction of about 80 to 90 % in the summer and 20 % in the winter.

At the solar plant in Baden-Baden the hot water consumption was monitored within a month and with the experiences of consumption in other hospitals extrapolated to the profile over the year. The result was a consumption of approximately 20 m³ per day during summer period, around 45 litres per patient per day.

The dynamic system simulation with TSol yield the following results:

- Solar radiation on the collector area: 382.786 kWh/a
- Solar gain: 143.820 kWh/a
- Efficiency: 37,6 %
- Fuel saving (natural gas): 16.000 m³/a
- CO_2 reduction: 32.000 kg/a

The cost of the entire system is about 196.000 €, which means 700 €/m² collector area. The biggest contribution to the investment costs have the collectors and the mounting on the flat roof (Fig. 3). Collectors which are integrated in a roof are usually much cheaper.

The resulting energy costs (not included the government aid) are 0,13 €/kWh, which is twice as much as the energy costs for heat conventionally produced with natural gas or oil in Germany (based on 20 years life time, 6 % interest; no maintenance costs included).

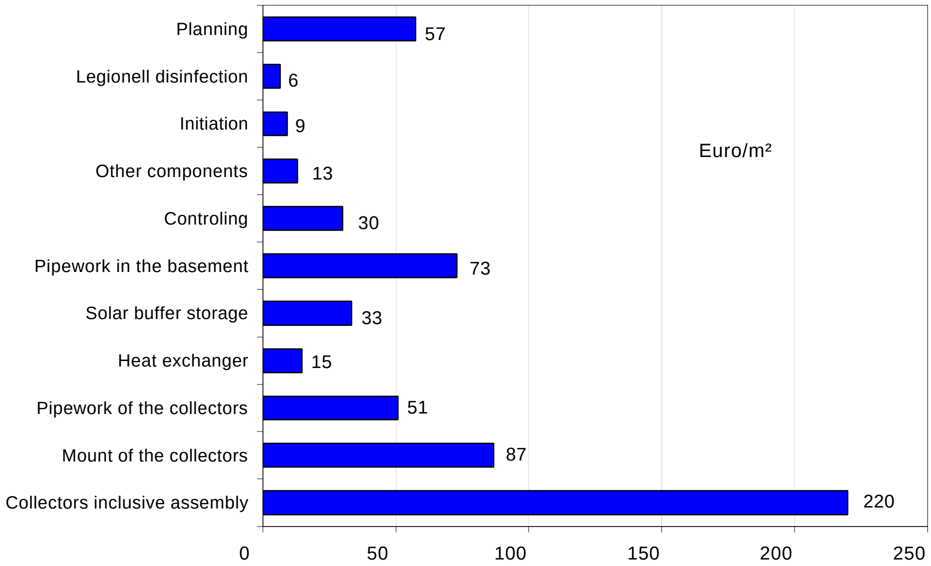

Fig. 3: Solar system costs fractionated on the components

3. Results and Discussion

The contractor had to guarantee a certain amount of solar yield calculated on base of a dynamic simulation during call for tenders. This guarantee was fulfilled over the last three years of operation in Baden-Baden. The main results, i.e. solar input, system efficiency, solar gain and the reached solar fraction, are shown in Tab. 1. The guarantee is considered as fulfilled when 90 % of the warranted solar yield or system efficiency is reached.

Table 1: Simulated and Measured Results (annual values)

	Simulation Result	01.08.00-31.07.01	01.08.01-31.07.02	01.08.02-31.07.03
Specific Solar Radiation	1.387 kWh/m²	1.214 kWh/m²	1.233 kWh/m²	1.368 kWh/m²
Solar Yield	521 kWh/m²	448 kWh/m²	427 kWh/m²	463 kWh/m²
Efficiency	37,6 %	36,9 %	34,6 %	33,8 %
Solar Fraction	60 %*	41 %	32 %	28 %

*based on incorrect assumptions for the hot water consumption

Figure 4 shows the distribution of the solar plant in the first year. The solar fraction was between 10 % and 80 %. The very low solar gain in August was caused by a calcification of the heat exchanger. The flow rate was non-existent and the entire system shut down. After the cleaning of the heat exchanger the plant function returned to normal.

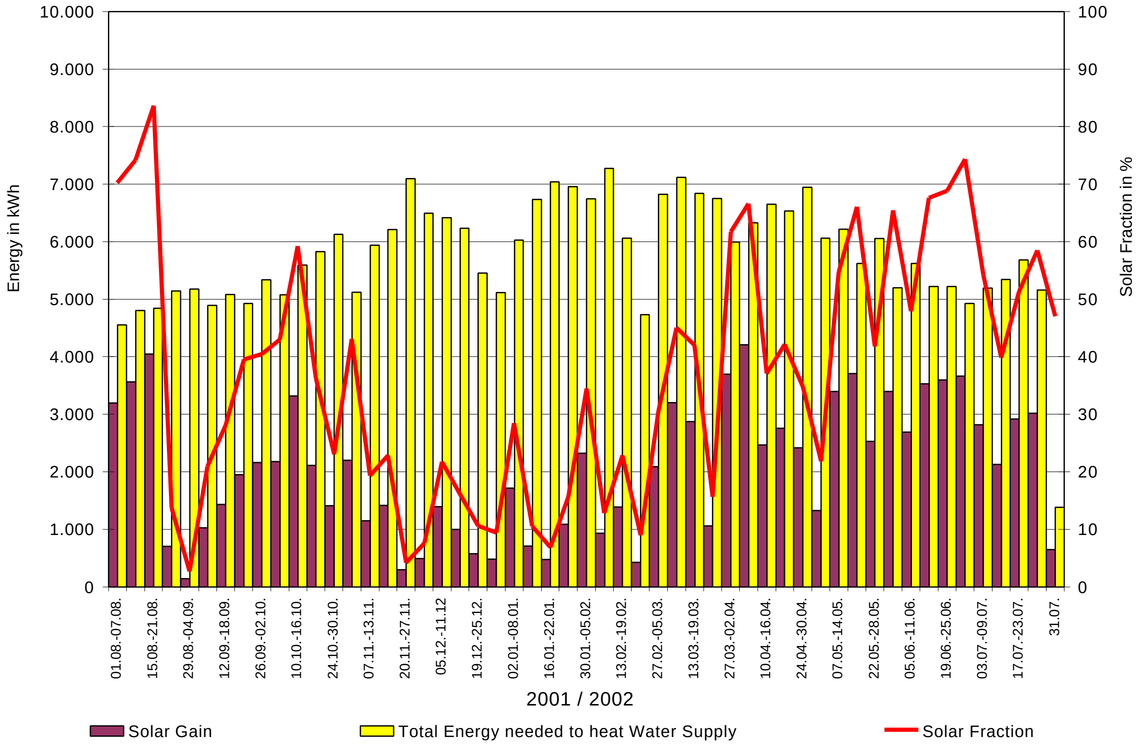

Fig. 4: Solar fraction, solar gain and total energy needed for potable water heating and solar gain in the monitored period from 01.08.2001 – 31.07.2003 in the solar plant in Baden-Baden

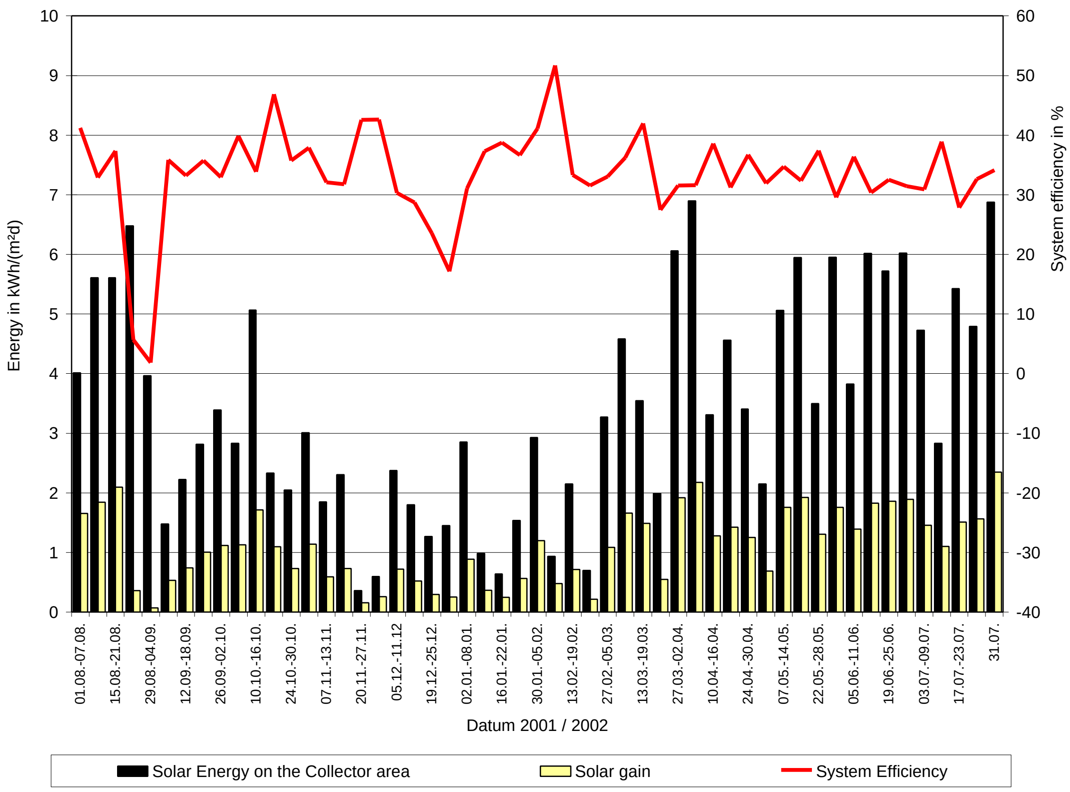

Fig. 5: Solar gain and system efficiency in the first monitoring period 01.08.2001 - 31.07.2002 in the solar plant in Baden-Baden

Figure 5 shows the system efficiency in monthly values. With other plants of the Solarthermie-2000 project efficiencies of up to 60 % (weekly value) were reached.

To show the potentials of large-scale solar thermal plants in other climates, the solar system which is installed in Baden-Baden was simulated with the weather from Camaguey, Cuba. Figure 6 shows the possible solar fraction and solar yield of a solar plant type "Baden-Baden" situated in Cuba. The great advantage of this climate is not only the approximately 30 % higher solar irradiation but also the distribution over the year is more even, therefore the solar plant can be used most effectively throughout the year. And the solar system was not even optimised for this climate in this first step. The annual yield was calculated with 220 MWh which means 790 kWh per m² collector area.

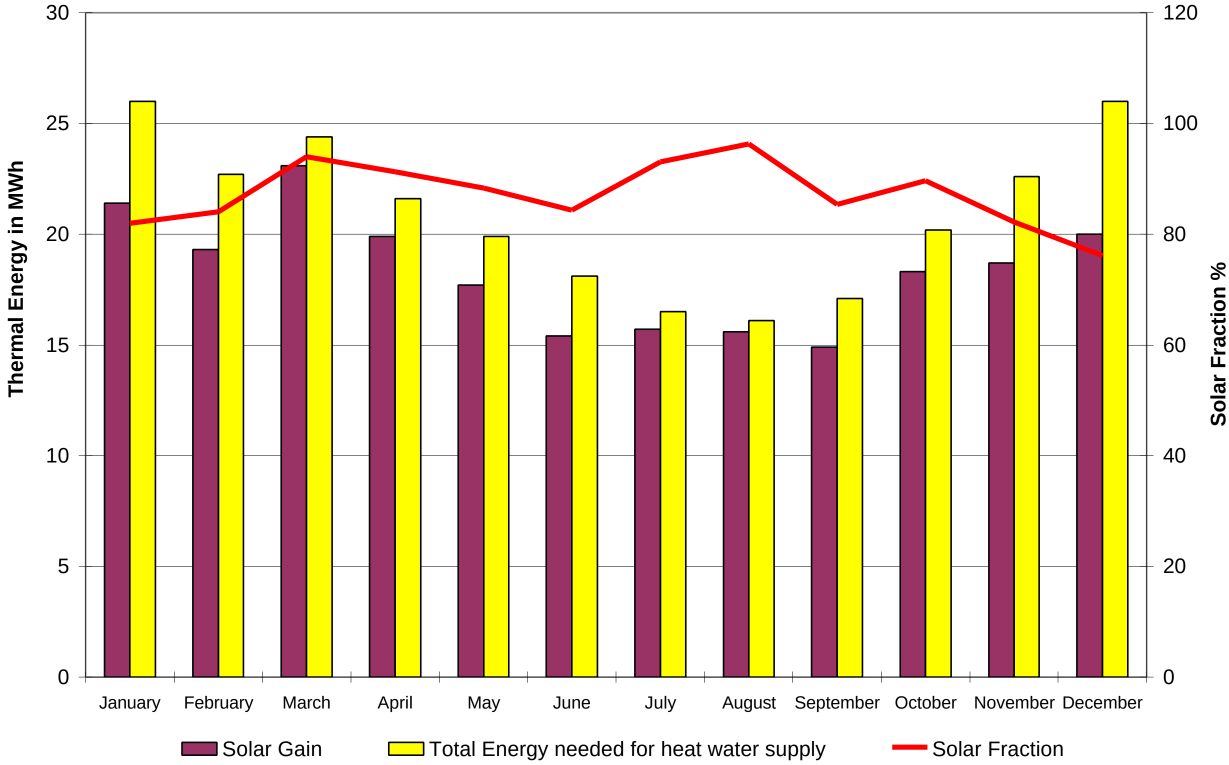

Fig. 6: The solar system of Baden-Baden simulated with the weather data of Camguey in Cuba

Assuming the same system costs as in Germany, the solar energy would cost 0,08 € per kWh which is competitive to the prices of conventional energy, especially when the potable hot water is normally heated with electricity.

4. Summary

The analysis of large-scale solar thermal plants shows that the technology is reliable and has been thoroughly investigated. Nevertheless, it is necessary to monitor the operation especially in the starting process. With the results obtained, it is now feasible to introduce this technology to a wide spread market as a competitive energy source.

References

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