Glossary:

Solar Yield
Energy, which is transferred from the solar thermal system to the potable water and finally used for the heating of the water. The annual solar yield is measured at the border between the solar thermal system and the conventional system.

System Efficiency
Specifies the percentage of the solar energy that has been provided from the sun to the collectors and which is converted into useful solar heat. The system efficiency is basically influenced by energy losses of collectors, pipes and storage tanks.

Hot Water Consumption
The hot water consumption is a determining parameter for the dimensioning of a solar system for potable water heating. It should be measured before the designing of the system. If there is no possibility to measure the consumption (e.g. in a new building), the hot water consumption should be evaluated on the base of similar buildings. The consumption is converted to a hot water temperature of 60 °C to enable a standardisation of the consumption. For the dimensioning of a solar system, the consumption in summer (July/August) is the relevant value.

Specific Load
The specific load specifies how many litres of potable water (60 °C) every day are consumed per m² collector area (standardised hot water consumption per day in relation to the collector area). The larger the collector area in relation to the hot water consumption is, the higher is the solar fraction. But at the same time the costs of the solar system increase as well. A compromise between cost optimisation and adequate high solar fraction causes the following reference for the dimensioning of large-scale solar thermal systems for potable water heating: 1 m² collector area per 70 litres hot water consumption (60 °C) per day.

Solar Fraction
The solar fraction is the contribution of the useful solar heat to the total energy needed for potable hot water. The energy to cover losses of the hot water circulation, the storage tanks and the auxiliary heat are not included.

Cost of Solar Heat
The cost of solar heat describes the price for one kWh of solar thermal energy. They are calculated by the ratio of the system costs (complete construction costs for the solar thermal system planning and installation and the costs of capital, based on an interest rate of 6 % and a system lifetime of 20 years) to the solar yield throughout one year.

Guaranteed Solar Yield
Before the contractor gets the order for the solar thermal system installation, he has to guarantee an annual solar yield of the solar thermal system. This guarantee is calculated on the base of predefined values of weather and hot water consumption. After one year of systems operation the guaranteed amount of energy is verified on the base of the measured solar yield, the real weather and hot water consumption. If the adapted real amount of energy is more than 10 % below the guaranteed amount, the contractor has to optimise the system.

Costs

The average investment costs for planning and installing the solar thermal systems were 681 Euro per m² collector area (incl. tax). **Fig. 17** shows the specific costs per m² collector area, subdivided into individual costs of system components and the costs of planning. A broad bandwidth is apparent in the total investment costs and the costs of the system components. The main reasons for the difference in costs are due to the varying conditions for the installation. Such as the collector assembly (flat or sloped roof / in- or on-roof assembly) or the use of existing components (e.g. storage tank). The solar system in Holzgerlingen has the lowest specific cost due to the simpler connection of the local district heating network compared to the potable water heating systems. The highest specific costs were at the Wilmersdorfer Str. Freiburg. The reason for the high costs was the complex pipe installation and the elevation of the collectors on the roof. The collector array was divided on two roofs of the houses. In addition, one burried pipe and two standpipes mounting pillar were necessary.

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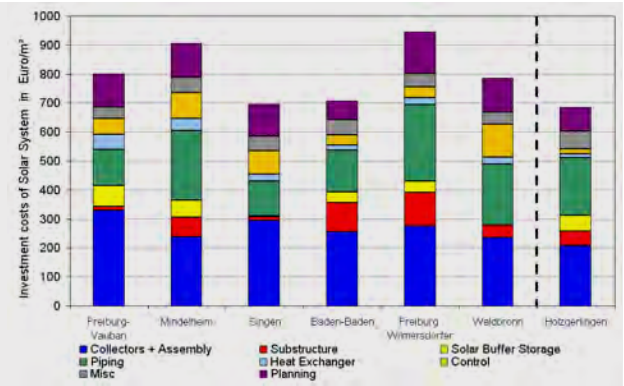

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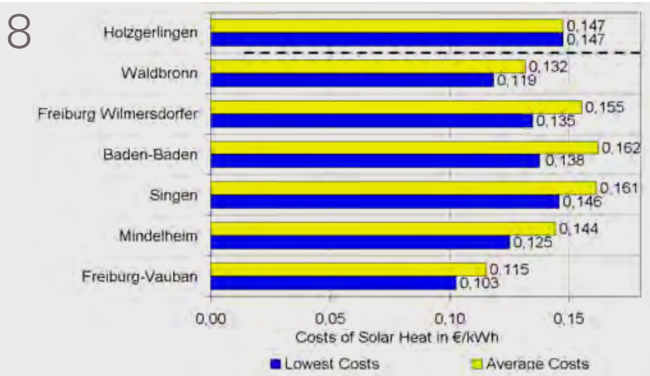

Fig. 18 shows the average costs of the available solar heat of the solar thermal systems and additionally the lowest costs of available solar heat. Here it can be seen that Freiburg-Vauban has the lowest solar heating costs because of the high utilisation. The solar systems with the highest heating costs are Singen and Baden-Baden. The reasons for that are the malfunctions of the systems.

Summary and Conclusion

The measured solar yields correspond approximately to the predicted values. This is documented by the fact, that all solar thermal systems have achieved the guaranteed solar yield. Therefore different long test periods of system operations combined with necessary trouble shootings and system optimisations were required. Without an intensive measurement and monitoring of the solar thermal systems many failures would not have been detected and it would have lead to a decrease in system efficiency and solar yield.
The resulting costs for solar thermal energy promise to be competitive with conventional heat production in the future.
The contribution of the eight monitored solar systems to the environment protection and fossil fuel saving is remarkable: Their operation achieves an annual saving of approx. 80,000 liters heating oil respectively 80,000 m³ natural gas. With these systems approximately 200 t of CO_2 emission are prevented annually.
During this project, large-scale solar thermal systems for potable water heating were standardised. With the gained knowledge, the basis for efficient solar thermal systems was created. The following programme Solarthermie2000plus supports solar thermal systems, which use the generated heat not only for potable water heating but also for other applications. The higher solar fraction of these systems leads to a further reduction of CO_2 emissions.
The programme Solarthermie2000plus supports solar thermal systems for local district heating, potable water heating, room heating and the combination of both applications as well as solar cooling, generation of process heat and longterm heat storage facility.

Programme Solarthermie2000plus

Project Financing:
Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU)

Project Management:
Projektträger Jülich (PTJ) für das BMU
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Title and Identfication Number

Solarthermie-2000, Teilprogramm 2 und Solarthermie2000plus:
Solarthermische Demonstrationsanlagen für öffentliche Gebäude mit Schwerpunkt in den neuen Bundesländern.
Wissenschaftlich-technische Begleitung der solarthermischen Demonstrationsanlagen in den südwestlichen Bundesländern.
Förderkennzeichen:
0329601 H, 0329601 M und 0329601 P

Reports

There are yearly updated reports about the monitored solar systems, wherein detailed information, experiences and results are shown.
These reports can be requested from the University Offenburg, team ST-2000.

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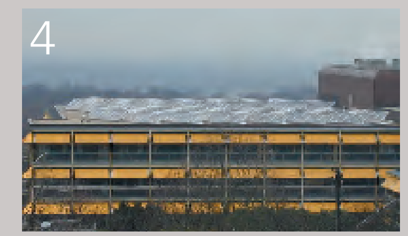
Student Residence Freiburg-Vauban (143 m²)

2

Hospital Mindelheim (120 m²)

3

Hospital Singen (264 m²)

4

Hospital Baden-Baden (276 m²)

5

Buildings Wilmersdorferstr. Freiburg (228 m²)

6

Hot Springs Alththerme Waldbronn (226 m²)

7

District Heating Network Holzgerlingen (249 m²)

8

Festo AG & Co. KG Esslingen (1218 m²)

Hochschule Offenburg
University of Applied Sciences

Results of the Longtime Monitoring of Large-Scale Thermal Solar Systems by the University of Applied Sciences Offenburg in South-West Germany

Solarthermie 2000plus

Results and Experiences

Scientific-Technical Monitoring

In the frame of the programme Solarthermie-2000, partial programme 2, started in 1993, more than 70 large-scale solar thermal systems for potable water heating were installed in Germany until the end of 2007. Characteristic for these solar thermal systems is their collector area of at least 100 m². With these demonstration plants the technical and economical applicability for the use of active thermal solar systems should be demonstrated, their techniques should be advanced and the hydraulic system and the dimensioning should be standardised.

In a scientific-technical monitoring programme the solar systems are monitored from planning through completion to the first several years of system operation by independent institutes. Since 1999 the University of Applied Sciences Offenburg is responsible for the monitoring of the demonstration solar thermal systems in the southwest of Germany.

Its major tasks are:

- Suitability test of the application of a large-scale solar thermal system,
- Support of all concerned parties on planning, tender and installation,
- Conception and installation of the measurement system,
- Perennial data logging and data evaluation,
- Monitoring and evaluation of system operation,
- Failure analysis and proposals for system optimisation,
- Know-how transfer.

The University of Applied Sciences Offenburg monitors eight large-scale solar thermal systems. Five of these systems are used exclusively for the purpose of potable water heating. Additionally one system assists the heating of a swimming pool.

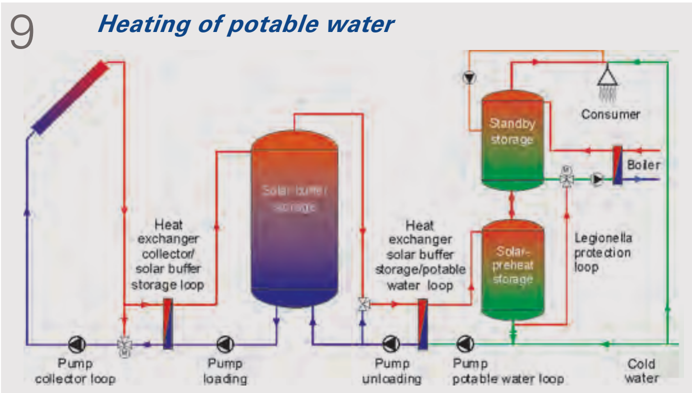
One of the two newest solar systems, that are already supplied by Solarthermie2000plus, feeds the heat in a local district heating network while the other solar system feeds the heating system of a private company. This heat is used for room heating and cooling.

The most important results and experiences from the scientific-technical monitoring of the eight solar thermal systems shown in **Fig. 1-8** are described below.

Hydraulic Schemes

Heating of potable water

Characteristic for large-scale solar thermal systems for potable water heating are their division into collector cycle, solar buffer storage cycle and potable water cycle, each separated by a heat exchanger.



9 *Heating of potable water*

The system with a potable water preheating storage tank (**Fig. 9**) is installed at the solar plants of Mindelheim, Singen, Baden-Baden and Wilmersdorfer Str. Freiburg. In this system an additional storage tank (preheating storage tank) is installed in the cycle of the potable water which is charged with solar energy from the buffer storage by a circulation pump. Because of hygienic reasons, the preheating storage tank has to be heated up to 60 °C once a day by the so called legionella protection loop. The system with the preheating storage tank has proved to be the most reliable system, particularly because of the separation from the loading of the preheating storage tank and the flow rate of hot water. However the system efficiency is reduced due to frequent high return temperatures of the buffer storage caused by high temperatures in the preheating storage tank.

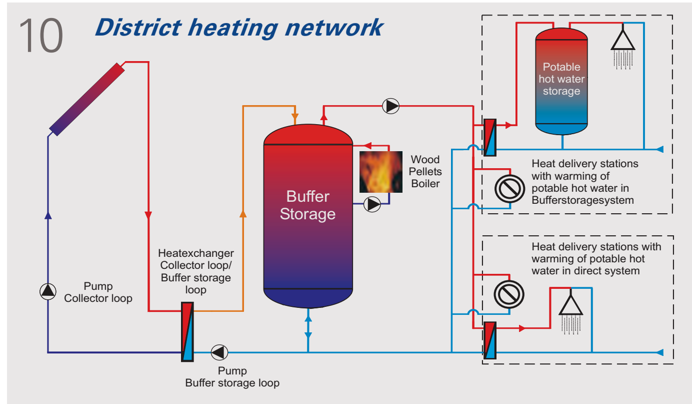
In the system with direct heating, as used in Freiburg-Vauban, the potable water is not inducted into a preheating storage tank but flows directly across a heat exchanger where it absorbs the solar heat of the buffer storage cycle. The volume flow in the buffer storage cycle corresponds ideally to the current volume flow of hot water consumption and therefore it is fluctuating.

The main advantage of systems with direct heating of potable water compared to systems with a preheating storage tank are the low return temperatures in the buffer storage and combined with it a higher system efficiency. Besides an additional storage tank and a fourth circulation pump can be dispensed. The required legionella protection loop in preheating buffer storage systems can be dropped as well. Correspondingly the system with direct heating has to be preferred to the system with a preheating buffer storage.

A special hydraulic system was implemented at the solar system Albtherme Waldbronn. Additionally to the potable water, the water of a swimming pool is heated with solar energy. This solar system was built without any buffer storage. The solar energy is either directly exchanged to the potable water preheating storage tank or to the fresh water of the swimming pool flowing across a second solar heat exchanger.

Feed in a local district heating network

The solar heat is fed into the buffer storages across a heat exchanger. As seen in **Fig. 10** the system consists of three separate storages to buffer the solar heat whereas buffer storage one is also used by the wood-pellet-boiler. The heating circuit water is preheated in buffer storage three with solar heat and from buffer storage one heated up to set-point temperature by the wood-pellet-boiler. Afterwards the heated water is fed in the local district heating network. Special emphasise should be laid on a low return temperature for this system type. This could be realised by choice of corresponding heat transmission stations. In case of the local district heating network Holzgerlingen were used heat transmission stations for potable water heating in a direct flow system if possible. The loading of the room heating takes place in direct flow rate by which a reduction of the return temperature can be gained, too.

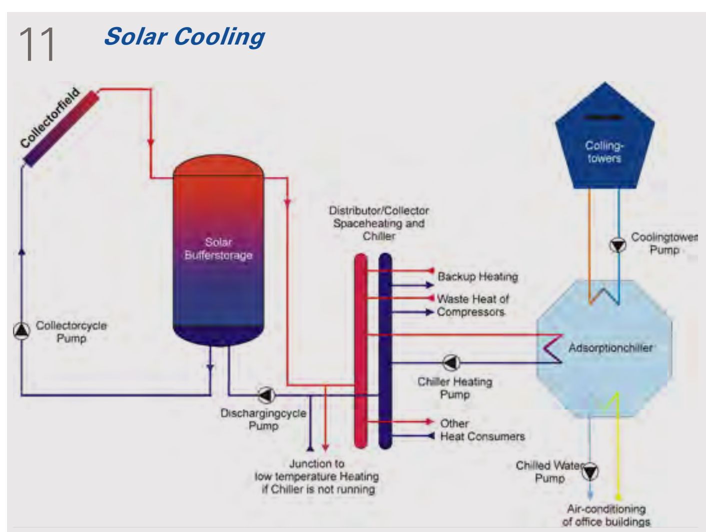


10 *District heating network*

Solar Cooling

The great advantage by using solar thermal energy as a heat source for cooling of buildings compared to other ways of utilisation is the concurrence of solar heat and cooling demand. The highest cooling demand is during daytime in summer, when the highest solar supply is available. Therefore buffer storages can be dispensed respectively they can be lower dimensioned and the solar system can be higher dimensioned. In summer stagnations due to low demand of solar heat can widely be avoided. In winter when there is no cooling demand the solar heat is fed into the heating system. Thereby the price for solar heat can be reduced compared to the single usage for cooling.

Fig. 11 shows the scheme of the solar cooling system of the Festo AG & Co KG located in Esslingen. In that system the heat exchanger between collector-cycle and storage-cycle can be dropped because of it is operated with a pure-water-system. Frost protection agent is not used. In case of frost water is pumped up from the storages to the collectors to avoid freezing water in the collector-cycle.



11 *Solar Cooling*

The solar heat is transmitted across a separate heating distribution device which is connected to the cooling machines and to additionally heating consumers, to the end consumers. Thus the solar heat can be used optional for heating or cooling purposes. It is possible to increase the efficiency of the collectors at a lower temperature level in order to feed directly in a special cycle of facility tempering of a connected building. Due to the mentioned facts the efficiency can be more increased compared to the adsorption cooling machine in single operation.

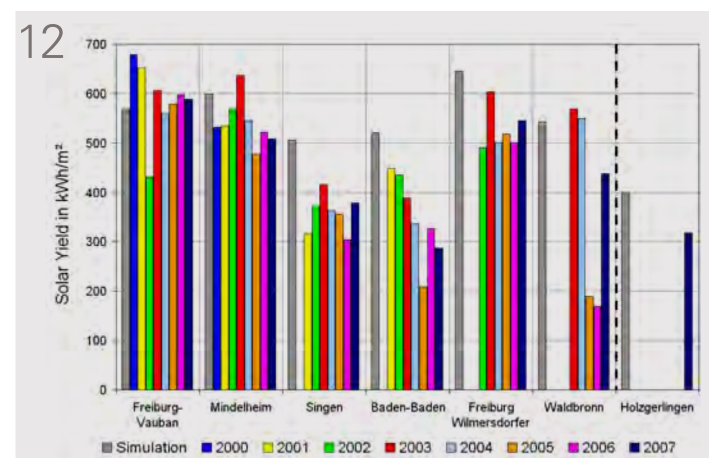
Solar Yield

In 2007 the solar yield of the seven assisted solar systems amounts ca 630,000 kWh, related to the total collector area of 1,506 m² corresponds a specific solar yield of 418 kWh/m² and year.

Fig. 12 shows the annual solar yield of the measured data of every system related to the collector area. For comparison the predicted yield is also shown, based on simulations running before the installation of the solar system started. It shows partly big differences of the yields between the several solar systems but also fluctuations of the annual yield of the particular system. The reason for that is that the yield of the solar system depends on various factors: weather, hot water consumption, concept of control, operation method of the conventional technique, troubles and failures of the solar system etc.

The solar system of Freiburg-Vauban had its lowest solar yield in 2002. During an installation of compact stations within a research project of the Fraunhofer ISE, the solar system was out of order for long periods. Due to that a reduced solar yield could be realised. In the following years the solar yields did not achieve the high amounts of the beginning because of the reduced power of the new heat exchanger, even though the performance of water usage was improved by a better detection system.

In the first measuring year the solar yield in Singen was lower than the guaranteed value of the manufacturer. Thereupon the solar system was modified in 2001. The main modification was the change from four parallel-connected potable water storages to a series connection by pairs. Since then the storages are separated into two preheating and two stand-by storages, which are heated by the supplementary heating to set-point temperature. Moreover optimisation measures of control and thermal insulation of the solar storages were realised. Through this the solar yield increased distinctly between 2002 and 2005. In 2006 the yield was reduced again by many troubles, but in 2007 they were all remedied and the yield increased again.



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Since the initiation of the solar system in Baden-Baden the solar yield decreased gradually until 2005. Because of calcification in the heat exchanger on the potable water side, the heat transmission to the potable water got worse. Steady flushing with citrus acid brought temporary betterment but the steady deterioration of the transmission capacity could not be prevented. Not before modifying the system in 2006 a definite decrease of the calcification could be attained and with it an increase of the solar yield. Due to restructurings the demand of hot water in 2007 was distinctly lower, consequently the solar yields were reduced again.

In Waldbronn arose a shutdown for a longer period in 2005 and 2006 because of density problems at the heat exchanger. The replacement of the heat exchangers and the restart of the preheating for the pools increased the solar yield in 2007 again.

The solar systems in Mindelheim and Freiburg Wilmersdorfer Str. had over the whole maturity less failures without any impact to the yield.

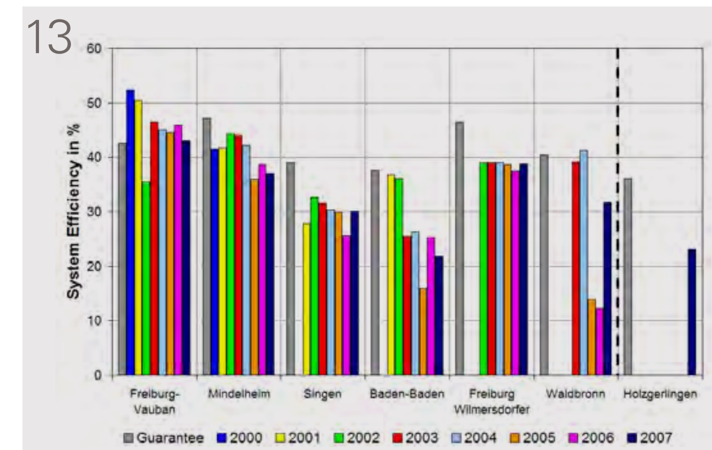
In total the solar system in Freiburg-Vauban achieved the highest specific solar yields with averagely 587 kWh/m². The highest yields of most other solar systems could be realised in 2003.

The results of Holzgerlingen had to be viewed separately because the application as a local district heating network is different. These solar yields are partially comparable with solar systems for potable water heating.

System Efficiency

The annual system efficiency at normal operation lay between 30 % and 52 %. Due to system failures there were efficiencies below 30 % as well. The average system efficiency, averaged over all seven solar plants was 35 %.

The average system efficiencies of the particular solar systems are shown in **Fig. 13**. The predicted efficiencies, which were calculated based on dynamic simulations, are also shown. Interesting in this comparison is that Freiburg-Vauban has higher rates of utilization versus the other solar systems.



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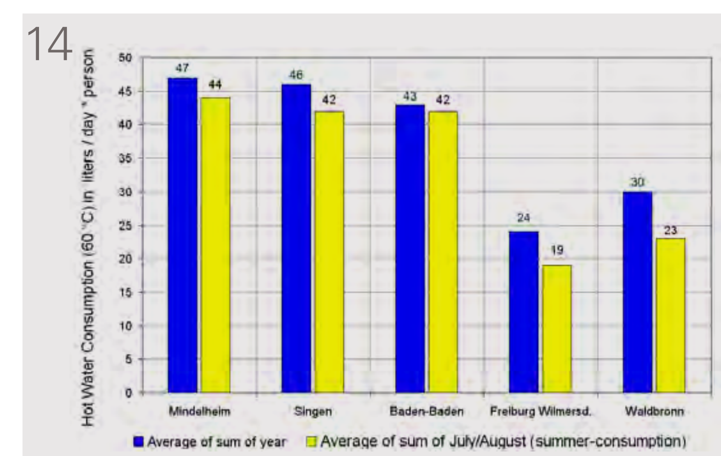
Hot Water Consumption

Fig. 14 shows the measured hot water consumption, diagrammed as consumption per day and per patient, resident or visitor.



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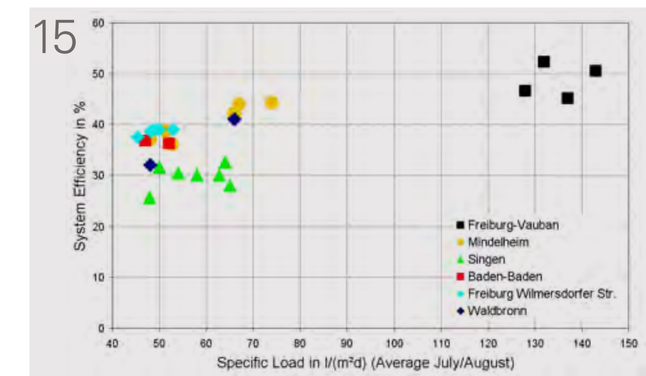
To enable a comparison, the average consumption per day (averaged from the sum of one year) and the average consumption of a summer day (relevant hot water consumption for dimensioning) is shown. It can be seen that there is a significant difference between the residential buildings of Wilmersdorfer Str. Freiburg and the hot springs Albtherme Waldbronn with respect to consumption in summer and over the whole year (approx. -25 %). In case of determining the hot water consumption for dimensioning the solar thermal system, it is necessary to consider the consumption in the summer period, when the highest output of solar irradiation is provided.

The hot water consumption per resident in the student residence Freiburg-Vauban is not diagrammed because there are no reliable values about the number of residents. There is a remarkable difference in the student residence between hot water consumption in summer (semester break) and the annual average of approx. 40 %. This has to be considered when designing the solar system. At the local district heating network in Holzgerlingen the heat is used for potable water heating and additionally for room heating. According to this no useful values are measurable.

Specific Load

Fig. 15 shows the average specific load of the solar thermal systems in summer and their relation to the system efficiency. A higher specific load normally causes a higher efficiency. The specific load is mainly between 50 and 70 litres per day and per m² of collector area. An exception is the student residence Freiburg-Vauban, where the specific load is much higher. In that case the number of residents increased considerably compared to the planning stage. Due to that the hot water consumption and the specific load increased, too. Holzgerlingen could not be estimated because the heat is not only used for potable water heating.



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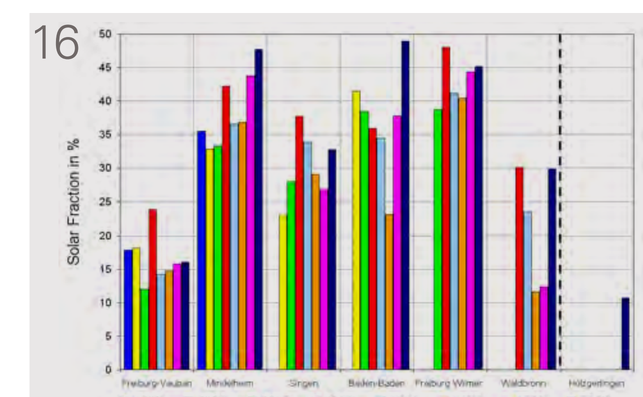
Solar Fraction

Fig. 16 shows the annual solar fraction according to potable water heating respectively the release of heat quantity to the local district heating network. The solar fraction is normally in the range of 30 % up to 40 %. This is a characteristic value for solar thermal systems, which are designed as solar preheating systems.



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The solar thermal system in the student residence Freiburg-Vauban lies outside the normal range because of the relatively high hot water consumption. Freiburg-Vauban is different due to the high hot water consumption compared to the small collector area. The solar fraction in Holzgerlingen is much lower as the roof area is limited and cannot be enlarged.