Large-scale solar thermal systems for buildings

*The sun provides hot water and supports room heating*
 Straight to the point

To date, the topic of solar collector systems has primarily involved small-scale standard systems for single-family and double-family houses. Here, we would like to focus on the numerous large buildings which could also be provided with solar heat. While many blocks of flats, housing estates, hotels, halls of residence, hospitals and commercial buildings have large unused roof surfaces, the facades and balcony balustrades, or the roofs of adjacent buildings such as garages, are also surfaces which could be used for the heat supply. Although photovoltaic systems of all sizes are currently in vogue, and the "small" solar collector systems are also selling well, the market for large-scale solar energy systems still needs to be stimulated.

The chances of success are high, because large-scale solar energy systems offer a number of advantages: they provide more heat per square metre of collector surface, and are more cost-effective than small-scale systems. But which buildings are particularly suitable for large-scale solar energy systems? What is more profitable: to generate hot water only, or to also supply the heating system with solar heat? What dimensioning is optimal with regard to costs? Which system concept is the best? What are the typical planning errors or installation errors which should be avoided? What are the success factors for successful projects?

These questions are discussed here, on the basis of the German Federal Ministry for the Environment’s energy research projects. The analyses relate to systems with a collector surface area of over 100 square metres, and buildings of various types. The emphasis is on the most cost-effective systems used purely for water heating, but initial results are also available for combined systems, which – with heightened heating costs – enable considerably more fossil energy sources to be saved.

Solar-supported local heating networks, systems for solar cooling or air conditioning, and process heat generation constitute another research area in the German Solarthermie2000plus programme, and are not discussed here.

Your BINE editorial team
redaktion@bine.info
Good arguments for solar heat

Large buildings often have large roof surfaces suitable for accommodating solar energy systems, allowing profitable utilisation of solar thermal energy, and thus making it possible to save fossil energy resources, which are becoming increasingly expensive.

Due to economies of scale, the heating costs are often lower with these systems than with small-scale standard systems, and losses are reduced because heat can be stored more effectively in large units. The usable solar heat gains can be maximised if the system is optimally adapted to the actual heat requirement profile.

As energy prices are continually increasing, the operating costs for domestic water heating and room heating are also on the rise. With the new energy certificate, ancillary costs of this kind become more transparent for potential tenants, who will pay more attention to this “second rent” in the future. Particularly in large blocks of flats, it is becoming increasingly common for ancillary costs to constitute the decisive factor as to the rentability of the property. A highly visible solar energy system serves as visual evidence of the ecological orientation of the building. Solar thermal systems can make a significant contribution to energy savings, and thus reduce the tenants’ ancillary costs and the operating costs of a building. Investment in a solar energy system makes it possible to decouple the heat generation costs from the increasing oil or gas prices, at least partially.

On the balance sheet, the energy prices, which are set to become ever more difficult to predict in the future, are replaced by calculable capital costs, which are unaffected by future increases in energy prices.

Today, well-designed, carefully installed and regularly serviced solar energy systems operate without any problems. The maintenance costs for large-scale systems are around 1 to 1.5% of the investment costs per annum – approximately the same as for a conventional boiler system.

Solar thermal systems have a service life of around 20 to 25 years, which exceeds that of conventional boiler systems, which usually operate for approximately 15 years.

The operating costs of solar energy systems are low. In large-scale systems, it takes about 1 kWh of electrical energy to generate around 40 to 50 kWh of heat. Naturally, this depends greatly on the complexity of the system. In recent years, the system technology has been improved, while the commercial competitiveness of solar energy systems compared to conventional boiler systems has increased. Significant savings in harmful emissions and a positive effect on the image of the operator are additional advantages entailed by the use of a solar energy system.

The degree to which system technology has developed varies between the various fields of application for solar thermal energy. For domestic water heating systems, guidelines and detailed publications are available, which offer assistance to planners and installers. With combined systems for domestic water heating and room heating, as well as with systems which are integrated into heating networks, there is a need for highly detailed planning and dimensioning. Corresponding guidelines are under development.

The integration of solar energy systems into the building should occur within the framework of an overall concept. If, for example, this integration is realised in connection with a renewal of the heating system, or a building refurbishment, the solar energy system can be installed optimally, with lower costs. Collector installation should occur in the course of a roof renovation, because the roof’s service life should be at least as long as that of the collectors.
The solar building check

Not every building is suitable for the integration of a solar energy system. With new buildings, there is usually considerable room to manoeuvre in terms of planning. However, in the existing stock of buildings, the status quo regarding building structure and heating technology must first be assessed, and the heating requirement analysed and optimised. In both cases, the components must be planned and dimensioned carefully in order for the system to be profitable.

For every solar energy system, there are alternative measures with which the building’s consumption of conventional energy can be reduced. For instance, the heating requirement is significantly affected by the building’s insulation and the quality of the windows. Heat can be provided efficiently via a low-temperature heating system with a condensing boiler, modern wood heating, combined heat and power plants, local heating networks, or heat pumps. Water-saving sanitary fittings and energy-optimisation of the hot water circulation reduce the amount of energy required for water heating.

The cost-benefit ratio of the various alternatives is a good selection criterion to help obtain an optimal result within an allotted budget. All realised measures are then to be taken into consideration when dimensioning the solar energy system, because if a solar energy system is oversized with respect to the reduced consumption, the efficiency is reduced considerably.

Thus, in practice, the sequential order is as follows:
1. Minimise the energy requirements of the loads to be supplied by the solar energy system (thermal insulation, window modernisation, sealing etc.)
2. Install a new, highly efficient boiler, the output of which is adapted to suit the new level of consumption
3. Install the solar energy system, adapted to suit the reduced consumption and the new boiler

Thus, the solar energy system only comes third. However, if, for cost reasons, its installation is postponed until a favourable point in time (e. g. building refurbishment), installation at that later point in time will be considerably more expensive. In such cases, this often means that the postponed installation never actually takes place.

Solar thermal systems operate most efficiently in buildings which have a heating requirement all year round — i. e. also in summer. Properties which, during holiday periods or on weekends, are used little or not at all, are less suitable, e. g. schools (due to the long summer holidays and the fact that there are no classes on weekends). In such cases, one alternative would be a heat pump or a wood pellet boiler, which are both only operated when energy is actually required.

It is generally more economical to install a solar thermal system in a new building than in an old one. The collector circuit’s pipes from the roof to the cellar can be laid very easily, and the cost of roof cladding is saved if the collectors are integrated into the roof. Nevertheless, in some cases, a solar energy system can be the better energy-saving alternative in old buildings as well, e. g. if it is difficult or too costly to apply thermal insulation to the exterior walls, or if this is prevented by legal stipulations (listed buildings). A collector array integrated into the roof barely disturbs the appearance of the building at all.

Before the planning of a solar energy system, the points listed in the following check list should be addressed:
Planning a solar energy system – check list:

**Installation area for collectors** A roof surface with as few subdivisions as possible, which is not shaded, and which is oriented between southeast and southwest is required. The optimal roof pitch for domestic hot water systems is around 20 to 45°; for heating systems around 35 to 50°. Systems are more cost-effective on sloping roofs than on flat roofs (raised mounting structure required); if there is insufficient roof surface available, facade integration can be considered. Raised mounting on ground areas is also possible.

**Roof condition** The roof should not be in need of refurbishment within the next 25 years – otherwise, the roof must be refurbished before installation of the collector array. Particularly near the edges, the roof’s static loading capacity must be tested with regard to the additional load entailed by the collectors (incl. any mounting frames) and wind loads.

**Space for solar storage tanks** Rooms which can accommodate tall, narrow, solar storage tanks are optimal. If there is no other possibility, the storage tank volume can be subdivided amongst a maximum of three containers, which are then connected in series and not in parallel. With increased thermal insulation and protection against moisture penetration, it is possible to install the solar storage tank outdoors. Check the dimensioning of conventional storage tanks, as these are often too large; it may be possible to use superfluous conventional storage tanks as solar storage tanks or solar preheating tanks.

**Control systems** Install permanent systems for functionality checks or yield analysis of the solar energy system; without such installations, faults in the solar energy system remain unnoticed because of the backup boiler.

**Preliminary installation** in new buildings, empty shafts from the roof to the cellar make it easier to install a solar energy system later. However, laying pipes “in reserve” is not recommended. The pipe diameters must suit the subsequently installed collector surface area, so that certain minimum and maximum flow rate values can be adhered to.

**Systems for domestic water heating**

**Domestic hot water consumption** The hot water consumption should be determined as precisely as possible. There must be a need for hot domestic water in summer as well. If the requirement decreases considerably in summer, the system design should take the summer’s low load requirement into account.

**Incorporation of domestic hot water circulation** The circulation network should be well-insulated and hydraulically balanced. It should also be minimised in terms of running time and volume flow. Energy losses are reduced by means of timer switches, circulation interrupters, and temperature-controlled pumps.

**Combined systems (domestic water heating and room heating support)**

**Energy requirement outside heating period** The existing domestic hot water circulation is to be integrated into the solar energy system (see information above). If possible, energy should be supplied to additional summer loads such as swimming pools or solar cooling systems.

**Heating system** For good solar energy system efficiency, a low-temperature heating system is require recommended. Heating systems with a higher temperature are possible, but not ideal. It is imperative to undertake hydraulic balancing.

**Solar energy system** Compared to domestic hot water systems, considerably larger collector arrays and storage tank volumes are required.

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Fig. 3 Planning a solar energy system

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The size makes the difference

Large-scale solar thermal systems can be used in blocks of flats, housing estates, public institutions, businesses, or industrial operations, for domestic water heating, heating support, generation of process heat, and solar climate control. The distinction between large-scale and small-scale systems is defined by the system technology more than by the collector surface area.

Unlike large-scale systems, small systems are often provided as standardised complete packages, and are mainly used in single-family or double-family houses. In these systems, the solar energy is stored in domestic hot water storage tanks.

Also for reasons of water hygiene, this principle is no longer applicable in larger systems, because Legionella protection measures become necessary. Thus, larger systems store the solar heat in buffer storage tanks filled with heating water, which also enables a connection to the building’s heating. There is a certain area of overlap, because although small-scale systems are used with collector surface areas of up to around 30 m², systems with buffer storage tanks are available for areas as small as 10 m².

Large-scale systems must be carefully adapted to the consumption profile, thus requiring individual planning and dimensioning. The heightened planning costs and the more elaborate technology make large-scale systems somewhat more expensive, but this disadvantage can be compensated for by higher specific system yields, higher CO₂ savings compared to small-scale systems with a similar surface area, and the economies of scale and price reductions which are achievable with large-scale collector surface areas. With large-scale systems, the solar heat generation costs are generally about twice as economical as those of small-scale systems, and for large-scale hot water systems, are already bordering on profitability with 8–10 cent/kWh.
System concepts for hot water

In buildings, hot water is generally required throughout the entire year. If solar energy systems are designed according to the summer load, the high irradiation in the summer months can be utilised to the full. These systems are cost-effective, and achieve a high degree of utilisation with high specific yields. However, the contribution made by systems used purely for heating domestic water remains restricted to a relatively small proportion of the heating requirement as a whole. If the domestic water circulation is integrated into the system as well, this proportion can be increased.

For large-scale solar energy systems, efforts should be made to keep the system structure as simple as possible, so as to achieve high operational reliability and to minimise the maintenance requirements. Basic system concepts are briefly outlined below. Due to the required thermal masses and the water hygiene requirements, large-scale systems generally operate with buffer storage tanks. Heat transfer, whether between collector circuit and storage tank, or between storage tank and domestic water, is generally realised with external plate heat exchangers. For the transfer of heat from the buffer storage tank, two different system variants have been developed.

Circulatory principle

Fig. 7 shows a solar domestic water system which follows the circulatory principle. For heat transfer, external heat exchangers are used, so three pumps are necessary in this schematic. Every time a tap is operated, cold water is channelled through the heat exchanger, and is heated like in a continuous-flow heater. When required, the water in the backup heating storage tank is heated to the target temperature, and kept at this temperature, by the boiler. These systems are also referred to as serial integration of domestic water, or “fresh water systems”.

Storage tank charging principle

Fig. 8 shows a solar domestic water system which follows the storage tank charging principle. The heat is delivered from the buffer storage tank, via an external heat exchanger and an additional charging circuit, to a preheating tank, through which the cold water flows. The lower section of the backup heating storage tank is also used for this purpose to some extent. This system requires four pumps.

Both systems have proven themselves, with the following respective advantages and disadvantages:

Circulatory systems have a somewhat simpler structure, and are therefore cheaper. However, they require large, carefully dimensioned heat exchangers, and a controller which reacts very quickly. Complete fresh water stations in the various sizes are now available. In very large buildings, and if tap-use behaviour fluctuates greatly, this principle reaches its limits. Solar fraction of circulation losses is difficult, as the heat is only transferred when hot water is withdrawn from a tap.

The preheating systems which follow the storage tank charging principle are somewhat more elaborate, and thus more expensive. They require an additional pump and an additional (or larger) storage tank, as well as a so-called anti-Legionella circuit. The domestic water heat exchanger can be smaller, but should nevertheless be...
**If only one connection at storage tank: pipe as short as possible with large diameter; if possible: 2 lower connections**

**Incorporated energy, thermal disinfection must be deducted!**
dimensioned very precisely. This variant is used in larger systems in particular. There are other system variants, based on the different possible ways to integrate the circulation piping.

Fig. 9 shows the integration of the domestic hot water circulation into a storage tank charging system. Here, once the required temperature level is reached, the circulation return is switched from the backup heating storage tank to the preheating tank by means of a three-way valve.

Generally, upon integration of the circulation, its losses should be reduced as much as possible by means of the following measures: good thermal insulation of the hot water piping and circulation piping, reduction of the volume flow to the required dimension, use of timer switches and thermostatically controlled circulation pumps, and careful hydraulic balancing of the circulation network.

Design

The design of large-scale systems requires individual dimensioning, and cannot be estimated on the basis of the number of occupants. In a block of flats, the number of occupants is often unknown, the number of persons per accommodation unit often varies, and the individual hot water requirement depends on the average age of the occupants, the number of children, and the standard of living. Furthermore, as the desired share of coverage solar fraction naturally plays a role, systems with collector surface areas of between 0.5 m² and 2 m² per accommodation unit have been realised in blocks of flats.

In facilities such as halls of residence, clinics, sports facilities and schools, as well as in commercial facilities, hotels, or industrial operations, it becomes even more difficult to make an estimate. Values based on previous experience can be found in the relevant literature. It is advisable to measure the consumption first, and to then make simulation calculations.

When dimensioning storage tanks, a volume of 50 l or every m² of collector surface area can be used as a benchmark, as is also the case for small-scale systems. If the tap-use behaviour has a pronounced peak at midday, the optimal storage tank volume may be lower, but if tap-use behaviour peaks in the mornings and evenings, it may be higher. Here again, only simulation calculations provide reliable results.

With large collector arrays, the hydraulics must be planned carefully, so as to ensure uniform circulation, complete bleeding, and “forgiving” evaporation behaviour. Laying the pipes in strict “reverse return” adherence to the also called “Tichelmann” system is laborious, and does not guarantee that the specified conditions will be fulfilled. With large collector arrays, the “low-flow” concept with hourly volume flows between 15 and 20 litres per square metre of collector surface area has proven effective.
What makes systems efficient?

The planning of solar energy systems involves multidimensional optimisation. The usable solar energy yields are maximised, the system costs are minimised, and the interaction with the conventional heating technology is optimised. The final consideration is to maximise the fossil fuel savings.

The temperature level of the connected loads significantly affects the efficiency with which the irradiated energy can be converted to useful heat. The lower this temperature is, the better the degree of utilisation of the solar energy system, because as the load’s temperature increases, the temperature in the collectors must also increase, thus incurring higher thermal losses.

In domestic water heating, the water is heated from around 10 °C (cold water temperature) to around 60 °C (hot water temperature). The first part of this process in particular is very efficient, which is why preheating systems achieve particularly good yields. For this reason, a cold return is also advantageous.

With domestic hot water circulation, the temperature difference (return / supply) is somewhere between 55 and 60 °C. Here, it is clear that the integration of domestic hot water circulation into the solar energy system worsens the solar energy system’s operating conditions considerably, because around 35 – 75% of the domestic hot water system’s energy requirement is accounted for by the domestic hot water circulation, whereupon water constantly flows through the pipes at a high temperature level.

The utilisation degree of a solar energy system for room heating support depends greatly on the return temperature from the heating circuit, and thus also on the heating system. With surface heating (e.g. underfloor heating), this temperature is around 25 °C, with radiator systems, depending on the building standard and the design of the heating surfaces, it is 35 – 50 °C or even higher. Careful hydraulic balancing of the heating system is essential, so that such low return temperatures can actually be achieved in practice. In Fig. 10, the various application options of a solar energy system for domestic water heating only, domestic water heating with integrated circulation, and domestic hot water + circulation + space heating support are compared.

The graph shows the collector inlet temperature, degree of system utilisation, solar share of coverage, and heating costs which result from each application. In systems with circulation integration, heating, or in a heating network, the temperatures are higher, so the degree of utilisation decreases. Naturally, the absolute energy yield increases, which is why the share of coverage rises. The cost increase for the more complex systems is not so clearly evident, because the specific costs decrease with the size of the system. In order to save more conventional energy, and to reduce environmental impact, it is becoming increasingly common to install combined systems.

The shares of coverage, at 5 to 20%, seem low. This is due to the high heating requirement of an average building. For buildings which comply with the low-energy standard or even the passive house standard, the solar share can be many times higher, because the heating requirement for water heating gains significance in these buildings. With heating support systems and network-integrated district heating systems, a share of fraction of around 10 to 30% can be achieved if the collector array and solar storage tank size are selected appropriately. Higher shares of fraction generally only make sense in very large networks or solar energy systems, and with particularly large solar storage tanks (so-called seasonal storage tanks). Even 100% solar heat supply can be realised with the appropriate storage technology (and storage tank size). There are already buildings which have been equipped in this manner. These buildings are astonishingly cost-effective, as practically no heating costs are incurred.

Solar thermal energy, key research area

Currently, combined systems for domestic water heating and room heating support constitute a key research area in Germany. Such combined systems were examined in the Solarthermie-2000 and Solarthermie2000plus support initiatives, as well as in another joint project. In these research projects, for instance, fundamental findings were made with regard to the ageing behaviour and stagnation behaviour of these systems.

The investigations show a multitude of system variants, with sometimes unnecessarily complex hydraulics. Research shows that simplification, standardisation, and unification of the systems is advisable. Prefabricated components should reduce installation errors and enable optimised complete systems.

Also regarding the large-scale systems which operate effectively, there are still many possibilities for increased system efficiency, for simplification of systems, and for adaptation of the solar energy system to suit conventional heating systems.

Local district heating systems:

For the research work on solar energy systems which are integrated into heating networks (without seasonal storage tanks), there are currently several demonstration systems and research systems from Solarthermie-2000 and Solarthermie2000plus available, for instance in Stuttgart, Hennigsdorf, Heilbronn, Speyer, Holzgerlingen, and on the island of Norderney.

Due to the fact that with these network-integrated systems, the network represents the only load, there are far fewer system variants than in the case of combined systems, with which three loads – the tapped domestic hot water, the domestic hot water circulation, and the room heating – must be integrated into the solar energy system. Essentially, network-integrated solar thermal systems only differ in terms of the integration of the conventional boiler (with or without buffer storage tank), the type of network (three-conductor or four-conductor network), and the structure of the heat transfer stations in the individual buildings. Specifically with regard to these heat transfer stations, there is still a significant need for research and development. There is also a particular focus on achieving low network return temperatures (see BINE-Projektinfo brochure 11/06).

Characteristic values

The technical properties and the performance of a solar energy system can be described in terms of various characteristic values. The most important are as follows:

- Degree of utilisation of the solar energy system (solar yield/solar irradiation)
- Solar share of coverage also solar fraction (solar-generated heat savings) (solar contribution/total energy demand)
- Conventional final energy or primary energy saved, and harmful emissions avoided (e.g. CO₂) by means of the solar energy system
- Solar energy system’s coefficient of performance (solar yield/auxiliary energy demand)
- Usage rate of the solar energy system (hot water demand/m² collector area)
- Costs of the final energy (or primary energy) saved by means of the solar energy system
Costs and benefits

The degree to which a solar energy system is beneficial in terms of energy is measured on the basis of the annual yield in kWh, usually in relation to the m² of collector surface area. This specific collector yield depends largely on the solar irradiation at the site, the tilt angle, the orientation, any shading of the collectors, and their average temperature level. The quality of the components, pipe lengths, and storage losses also play a role, albeit to a lesser extent.

In the German Solarthermie-2000 programme, the system costs for installed systems varied between 400 and 900 euros per m² of collector surface area, with an average of 673 euros per m² (incl. planning and VAT). There is also data available for a multitude of systems of various sizes, from the 2001 – 2005 market stimulation programme (Fig. 12). The costs determined here cannot be directly compared with those from Solarthermie-2000, as not all system components were taken into account. For instance, the costs of storage tanks which were already in place were often not included. However, the results demonstrate that as the system size increases, significant economies of scale are achieved.

On average, the annual servicing and maintenance costs can be estimated at 1% to 1.5% of the investment costs. The operating costs comprise only the electricity for pumps and control. The pumps only operate during solar irradiation, at most 2000 h each year.

One of the most important factors is the solar share of coverage. As the collector surface area increases, this share of the building’s heating requirement rises, and the absolute quantity of solar-generated useful heat also increases.

However, as a high share of fraction entails higher collector temperatures, and (in certain situations) surplus in summer, the system’s degree of utilisation behaves in the opposite way, and the specific yield decreases as the fraction rises. While the specific costs per square metre of collector decrease with larger surfaces, the heating costs increase with decreasing yields per m².

Thus, the optimisation process depends greatly on the defined objectives. Is solar heat to be generated at the lowest possible heating price, entailing a low share of fraction, or is the objective to achieve the greatest possible fuel savings with the solar energy system, even if the costs of the useful heat are then somewhat higher? Therefore, when designing solar energy systems, there is considerable leeway, within which there is no “right” or “wrong”. The decisive factor is whether the defined objectives are met in practice. For the decision-making process and the optimisation, simulation calculations with profitability assessment are recommended.
The user-investor dilemma:

In the housing industry, the so-called “user-investor dilemma” represents a significant hurdle. The landlord bears the investment costs for the installation of a solar energy system, but cannot transfer these to the tenants via the heating bill, because here, the landlord can only claim the operating costs. Nevertheless, the tenants profit from the saved energy costs. Even according to the amended German Heating Costs Ordinance (Heizkostenverordnung, HKVO), it is still only possible to include the non-solar-generated portion of the energy costs in the operating costs. Thus, it appears that the installation of a solar energy system is only in the investor’s interests if the investment costs, e.g. in the course of a refurbishment which simultaneously incurs energy savings, can be passed onto the rent.

Due to the operation of the solar energy system, fuel is saved in the conventional system, but the systems must remain available. Therefore, only the saved fuel costs can be applied as profit. The increased oil and gas prices have improved the economic viability of the systems enormously.

Furthermore, it is important to bear in mind other beneficial effects, such as the enhanced image of a company, the improved rentability of a building, the reduced ancillary costs, the advertising effect for a holiday complex etc. In the cost calculation for the saved final or primary energy, the following are to be taken into account:

- Maintenance costs (inspection, servicing and repair costs)
- Operating costs (e.g. auxiliary electrical energy)
- Degree of utilisation of a normally constructed, purely conventional energy supply system (without solar energy system)
- Degree of utilisation of the conventional energy supply system after installation of the solar energy system
- Any changes in the conventional system due to the solar energy system (e.g. elimination of a compression refrigeration machine (chiller), which is replaced by a solar thermal cooling system)
- Conversion of the useful heat supplied by the solar energy system into final energy (or primary energy) savings.

Sun versus boiler

Although it may seem otherwise at first glance, the solar share of fraction, i.e. the solar-generated useful heat’s share of the total required heat, does not correspond exactly to the gas or oil savings, because the solar energy system influences the operating behaviour of the conventional boiler, and can reduce its efficiency:

- Due to the solar preheating, the water flows back to the boiler at a higher temperature. With a condensing boiler as typically used today, this reduces the utilisation of calorific value, and the boiler efficiency decreases.
- Additional efficiency losses can occur with boilers which do not have their own buffer storage tanks. If, due to the solar preheating, the return temperature in the boiler is already near the supply target temperature, the residual heating requires only a low burner output, for which the burner is usually not designed. As its heat output is too high, it begins to switch on and off at short intervals. This usually reduces the boiler efficiency. Although a minimum burning time reduces the number of burner starts, it causes excessive boiler supply temperatures, and thus additional losses.

In more unfavourable systems, the difference between the solar share of fraction of the heating requirement and the share of saved final energy can be as much as 20%.

Combined regulation of the solar energy system and the boiler, as well as optimised hydraulic integration of the solar energy system into the conventional system, minimises such boiler efficiency losses. For this purpose, it is necessary to optimise the operating behaviour of the whole system, particularly with regard to the dynamic behaviour of conventional boilers. In actual operation, it is to be expected that the degree of boiler utilisation will be lower than the efficiency measured for stationary operating conditions. Research work into optimisation of the entire system must aim toward maximising the primary energy savings – and not the solar yields, as has previously been the case.
In the complete conversion of what used to be a 6-storey precast concrete building (Fig. 16) in Gera, not only was a thermally insulating facade installed, but also a roof-integrated and facade-integrated solar energy system for water heating. The comprehensive construction measures provided for a storey removal, completely new floor plans for each flat, with maisonette flats and additional top-floor flats, the addition of recessed balconies, and barrier-free lifts. For this refurbishment, innovative in terms of construction and energy, the housing cooperative was awarded the 2003 Building Contractor Prize by the Bund Deutscher Architekten (Federation of German Architects), the Deutscher Städtetag (German Association of Towns and Cities), and the Bundesverband Deutscher Wohnungsunternehmen (Federal Association of German Housing and Real Estate Companies) (Fig. 17).

Solar energy system
As a “solar roof”, the solar collectors simultaneously function as a roof and exterior facade. They are integrated as a monopitch roof, and are also integrated into the facade of a top-floor flat. The system technology and measuring equipment are housed in the building’s cellar. Here, due to a lack of space, the cellar-welded 5 m³ solar buffer storage tank had to be recessed into the floor by one metre.

Operating results
The three-year measurement phase was completed in July 2006. After optimisation of discharging in 2003/2004, the system complied with the guaranteed yield in the last two years of measurement. Since then, the system has operated in a reliable and fault free manner. The yields, the irradiation on the collector level, and the hot water consumption in the last three years are compared in the following table. The degree of system utilisation indicates how much of the irradiated energy is ultimately transferred to the load (hot water). The final figures for 2008 are not yet available, as they depend greatly on the weather conditions in the remaining months.

### Development of solar yields and costs of useful heat

<table>
<thead>
<tr>
<th>Residential building in Gera</th>
<th>Guarnished solar yield [%]</th>
<th>Guaranteed system utilisation [%]</th>
<th>Costs of useful heat in period of system use [Euro/kWh]</th>
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<tr>
<td>Planned solar yield</td>
<td>51,668</td>
<td>-</td>
<td>0.128</td>
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<td>Corrected solar yield</td>
<td>48,791</td>
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<td>2nd year of measurement (31/03/05–30/03/06)</td>
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<td>3rd year of measurement (30/03/06–29/03/07)</td>
<td>41,959</td>
<td>102.1</td>
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</table>

- **Solar energy system characteristics**
  - Operator: WBG Aufbau Gera
  - Collector surface area: 98.5 m²
  - Solar buffer storage tank: 5 m³
  - Solar share of fraction of heating requirement for domestic water heating: 39.7%
  - Fossil energy savings: Approx. 4,000 m³ of natural gas p.a.
  - Total costs of solar energy system incl. measurement equipment (collectors, network, storage tanks, measurement equipment, operation, VAT / excl. external ST 2000 measurement equipment): 100,205.46 Euro
  - of which solar energy system costs (incl. planning and VAT): 1,017 Euro/m²
Stagnation of the collector circuit

In any solar energy system, a situation may arise, in which the available solar thermal energy cannot be accommodated by the system. This can occur because of a fault, for example a pump failure, or when the heating requirement is already covered, such that temperature limits no longer permit further heat influx into the storage tank. In this event, the collector heats up until it reaches a stagnation temperature (over 200 °C for flat plate collectors, around 300 °C for evacuated tube collectors) at which point, irradiation gains and losses cancel each other out. Usually, the medium in the collector then begins to boil, and steam spreads throughout the collector and, in certain situations, also throughout the system. Solar energy systems must be designed so that they can overcome this so-called “stagnation” state without becoming damaged.

The type of collectors and the hydraulics in the collector array have considerable influence on the system’s evaporation behaviour in this situation. With a low-mounted collector connection, the generated steam can press the remaining medium out of the collector and into the expansion vessel (which must be dimensioned sufficiently), and the evaporation phase remains short (forgiving evaporation behaviour). With high-mounted connections, the medium is not displaced, but is instead evaporated in a long boiling phase, until the collector has been “boiled empty” (unforgiving evaporation behaviour). Large volumes of steam are pressed into the system, and can have considerable impact on the components.

In domestic water preheating systems, this situation occurs very rarely, or only in the event of a fault, as they are designed so that even in low load periods during summer, the heating requirement is always higher than the maximum solar yield which can be expected. Thus, solar surplus is practically ruled out. In domestic water systems with a high solar share of coverage, or heating support systems, solar surplus in the summer months, and thus more frequent stagnation situations, are almost inevitable.

Therefore, with these systems, a design with forgiving evaporation behaviour, a high-temperature-resistant heat exchanger, and sufficient expansion capacities are particularly important. Fundamental research work and results pertaining to stagnation behaviour from the joint project “System tests on large-scale combined solar thermal systems” are available at www.solarkombianlagen-xl.info.

The planner and the operator – two expert opinions

Dipl.-Ing. Michael Guigas
Employee at Ingenieurgesellschaft EGS-plan and the Steinbeis-Transferzentrum EGS with a focus on planning in the field of local solar heating.

Profitability is almost always the deciding factor for the realisation of large-scale systems. Payback times longer than ten years and high initial investment often prevent systems from being implemented. Only with careful planning of the entire heat supply system, can system costs of less than 500 euros per m² of collector surface area be achieved. In this regard, it is of decisive importance that planning interfaces are minimised, and that the integration of collector surfaces is taken into account early during building planning. Taking subsidies into account, these systems are already economically viable today, compared to gas-based or oil-based supply. The integration of collector surfaces into sloping roofs is cost-effective, as the costs of the unneeded roof skin are eliminated. Elevated mounting of collectors on flat roofs makes the systems 20 to 30% more expensive. Standardised system concepts are now also available for large-scale systems. Basically, the following always applies: construct the system hydraulics as simply as possible, and try to minimise system temperatures.

Dipl.-Ing. Dierk Schneider
Authorised representative and Head of Heat Contracting at GBH Mieterservice Vahrenheide GmbH (MSV), Hannover.

In the housing industry, cost-effective and CO₂-neutral heat supply can be realised with solar thermal energy and wood pellets. With heat contracting at MSV, solar thermal systems can be incorporated into the housing industry’s financing structures.

The operating experience and solar yields obtained in various projects in Hanover have proven that solar thermal systems can be operated profitably in Northern Germany. The results have validated the planning, and provide encouragement for further projects.

It is a particular concern of ours to consciously present solar thermal systems on roofs in an architecturally appealing way. For example, the collectors in the solar energy system on Magdeburger Strasse in Hanover are visible from afar due to the elevated structure, and they complement the building’s architecture. With a display on the roof of the building, and a presentation panel by the footpath, our achieved goals, such as solar yield and CO₂ reduction, are presented so as to communicate the interest in climate-friendly and resource-saving technologies to the residents of the district.
Combined systems – the next step

In an average residential building in Germany, water heating and circulation account for only about 20 percent of the heating requirement. 80 percent is required for room heating. Thus, solar energy systems which not only heat water, but also support the space heating, tap into considerable potential for savings. However, this does incur increased heating costs.

As the sun makes itself scarce in winter, at a time when the heating requirement is high, solar energy systems for heating support require large collector surface areas. This results in a surplus of solar energy in summer, which in the absence of large seasonal heat storage tanks, simply goes to waste. This is called “stagnation”.

There are various strategies to reduce the frequency of surplus heat, and to thus decrease the impact on the collectors and on the system.

- One quite simple option is to install the collectors at a very steep tilt angle, or else vertically on the facade. This increases the yields when the sun is low in the sky, and reduces the surplus when the sun is high in the sky during summer. Naturally, this has a significant influence on the building’s architecture.
- In the so-called “aqua system”, water without antifreeze is used in the collector circuit. Evaporation in the collector is easier to keep under control with pure water, and there is no risk of damage to the antifreeze. In winter, frost protection is ensured by feeding energy back into the collector at night, so as to keep it frost-free. This method can only be implemented with evacuated tubes.
- In the “drain-back” method, the collector array automatically empties itself after the pump is switched off, and is refilled when it is switched on. Water can be used in the collector circuit, as when the pump is switched off, the water can neither boil nor freeze in the collector.
- The solar storage tank is dimensioned in such a way that it can accommodate surplus in summer, so as to make it available in winter (seasonal storage tank).
- The surplus heat in summer is used for solar climate control (e.g. for hotels, office buildings, hospitals, nursing homes, etc.).
- Surplus energy from the solar buffer storage tank is redischarged by means of the pump being switched on at night, and releasing heat via the collector.
- An additional heat load (e.g. a swimming pool) accepts surplus energy.

Due to the higher return temperatures in the heating system, the solar energy system operates less efficiently when providing solar heating support, than when heating cold domestic water, and during winter, because of lower outdoor temperatures, the collectors also operate less efficiently. For these reasons, the annual degree of utilisation of combined systems is lower than with systems used only for domestic water heating. This is also reflected in higher specific heating costs.

The performance of such a solar energy system can be increased by keeping the return temperature in the heating system as low as possible, for instance by means of a design with large radiator surfaces, or with underfloor heating.

The optimisation of usable solar yields and costs is realised by means of selecting a system concept and a storage concept which are tailored to suit the application to the greatest possible extent, and by means of the specific dimensioning and design of the system. As with systems used for water heating, there are numerous circuit variants for heating support. One essential distinction is made between serial heating connection, whereupon the solar storage tank, boiler, and heating are connected in series, and the parallel connection of the boiler to the upper section of the (solar) buffer storage tank, from which the heating is fed.

Alongside the optimisation of the solar energy system itself, the influence of the solar energy system on the operating behaviour of the boiler must also be taken into account.

In systems used for solar room heating support, it is important that the solar energy system, the conventional boiler, and the heating system are all coordinated with each other.

For the large single-family house market, complete packages are available, which include the solar energy system, storage tank, boiler, water heating, and control; in some cases, this is all integrated in a single device.
In preassembled systems, the components are optimally coordinated with each other, and the most important control parameters are preset. The risk of errors during installation is reduced to a minimum. Also for blocks of flats, there are prefabricated modules, compact stations, and solar energy centres available for heating support.

**Dimensioning**

The dimensioning of combined systems can vary greatly. The system can be enlarged according to the desired solar share of coverage. Even year-round full solar fraction of heating and water heating is possible – with the corresponding expenditure. While conservative strategies recommend enlarging the system for water heating with integrated circulation by a factor of 1.8, ambitious suppliers calculate 1 m² of collector surface area per 10 m² of living area for solar heating support, or even recommend a solar surface area 20% the size of the living area.

Figure 22 shows the costs of solar-generated useful heat (as defined in Solarthermie-2000 programme) in relation to the solar share of coverage of the building’s total heating requirement, for various load integrations. The costs are standardised at the lowest value achieved with a system used for domestic water heating (without integration of circulation into the solar energy system). Here, two buildings with different insulation standards are examined:

In the low-energy house, a combined system’s share of fraction of the heating requirement becomes four times that of a system used solely for water heating, if 35% higher heating costs are accepted. In the refurbished old building, significant increases are also possible, but the share of fraction remains rather small. Financially, the integration of circulation only becomes worthwhile if the system for domestic water heating is enlarged by a factor of at least 1.8. For heating support, minimum costs are achieved with enlargement by a factor of 3.2 compared to the reference system, whereby the flat gradient of the curve certainly allows larger dimensions as well.

The graph in Fig. 22 was compiled on the basis of the situation in a refurbished old building and in a low-energy house. It can only be considered a rough guide, because in practice, there is no fixed relationship between hot water requirement and heating requirement. While the energy required for hot water depends on the number of persons, their usage habits, and the circulation losses, the heating requirement depends on the size of the living area and the building standard.
Well-supported results are available for the dimensioning of storage tanks. Usually, for systems used for domestic water heating, 50 litres are allocated for each square metre of collector surface area. Various sources also cite this ratio for systems used for heating support. Simulation calculations for combined systems show that the buffer tank volume should not increase linearly in relation to the collector surface area, but rather that the most economically favourable results are achieved with an overproportional enlargement. For this overproportional enlargement, an exponential approach can be taken. For instance, if a solar energy system for domestic water heating is enlarged for heating support by a factor of $x^2$, this factor is raised exponentially to a power between 1.3 and 1.35 when calculating the storage tank size. The result is the enlargement factor for the storage tank volume.

**Loads and the solar energy system**

As the efficiency of a solar energy system depends greatly on the operating temperatures, the yields can be increased significantly by reducing the return temperatures. In combined systems, the heating of domestic water, the supply of heat to the heating system, and the compensation of circulation losses each call for very different load temperatures and temperature differences. These are as follows:

- For tapped hot water (with heat exchanger transfer of 5 K): 15 – 65 °C, depending on the system variant
- For hot water circulation return (with heat exchanger transfer of 5 K): 60 – 65 °C
- For heating (without heat exchanger transfer, as no heat exchanger required): 22 – 65 °C, depending on the building’s heating system and the weather

In all cases, each of these three loads should be coupled to the solar energy system according to its respective temperature level, with its own heat exchanger. This also ensures clear hydraulic separation. The hot water tapping system requires the highest temperatures with the greatest temperature difference, but also delivers low return temperatures. The supply is connected at the very top of the storage tank, and the return should feed into the solar buffer tank at the bottom. Due to the fluctuating temperature range, stratified feeding is appropriate, e.g. via stratification fittings inside the storage tank.

As the system with the highest return temperature is the hot water circulation, its feeding must be realised at the very top in the solar buffer tank. Due to the low variation in temperature, stratified feeding is not necessary here. The height at which the return is fed from the heating system depends on what type of heating system is in place. With low-temperature heating systems, feeding occurs at a lower position than with radiator systems, which have smaller dimensions and a higher operating temperature. Due to the return temperature’s dependency on the outdoor temperature, stratified feeding is advisable. Switching valves ensure that the return lines from all three load circuits are channelled past the solar buffer tank and into the boiler buffer tank when their temperature is higher than in the upper section of the solar buffer tank – otherwise, the solar buffer tank would be heated by conventional energy, and the work of the solar energy system would be reduced.

In the system circuit shown in Fig. 23, a boiler buffer tank is provided for the boiler. The purpose of this buffer tank is to ensure a minimum running time for the boiler, and to prevent the boiler from being frequently switched on and off.
The rehabilitation clinic’s solar energy system is the first system constructed as part of the German Federal Ministry for the Environment’s support programme “Solarthermie-2000”, in which solar heat is used not only for domestic water heating, but also for heating the supply air of patient rooms’ sanitary modules, and for two exercise pools. The building complex, inaugurated in March 2000, comprises 4 main buildings, each with three storeys, and contains a total of 196 patient rooms. Roof-integrated large-scale collectors occupy the entire roof surface of each of the two inner building sections.

Heat supply
Two gas condensing boilers, each with 860 kW output, supply the water heating and the heating system. Flat plate collectors on two roof surfaces of the main building support the conventional system. The two solar subsystems supply the respective sanitary modules’ ventilation systems with heat. The sanitary modules’ air preheating is performed by a ventilation and air extraction system with heat recovery from the exhaust air. For backup heating, the conventional heating system and the solar energy system are integrated via two additionally installed heat exchangers. For the swimming pool heating and domestic water heating, the heat from the solar arrays is combined in a shared buffer storage tank.

Once a day, some of the swimming pool water is replaced, whereupon the heat of the waste water is used to preheat the domestic water by means of a heat recovery system with a heat pump.

Operating experience
Since the beginning of the measurement programme in April 2004, optimisation measures have caused the system to achieve a higher yield each year. During the four years of accompanying scientific research, the system achieved a total solar yield of 914,024 kWh. In spring 2008, due to structural deficiencies, the roof surfaces of the two solar roofs had to be completely recladded (under guarantee) and around 48% of the collectors had to be replaced. Thus, in 2008, the system was out of order for about 4 months. During the repair phase, there were periods when solar yield could be generated only with half of the collector surface area. Therefore, a final year of measurement is to begin upon completion of the system in the fourth quarter of 2008.

Despite the implementation errors regarding the collector arrays, it was possible to demonstrate that the carefully dimensioned and optimised solar energy system represents a profitable and technically sophisticated supplement to the conventional heat supply. With the achieved solar share of fraction, and with the solar yields, which have now become very good, this demonstration project can contribute to broader application of this technology.

**Solar energy system characteristics**

- **Operator**: Deutsche Rentenversicherung Bund (German Pension Insurance Association)
- **Collector surface area**: 646 m²
- **Solar buffer storage tanks**: 35 m³ (4 x 7.5 m³; 1 x 5 m³)
- **Solar share of fraction**: 39.7% (1/1 - 30/9/2007)
- **Fossil energy savings**: Approx. 22,000 m³ of natural gas p.a.
- **Total costs of solar energy system incl. measurement equipment, excl. external ST 2000 measurement equipment**: 543,800 Euro
- **of which solar energy system costs (incl. planning and VAT)**: 714 Euro/m³
- **Planned solar yield**: 298,440 kWh/a
- **Corrected solar yield under real operating conditions**: 253,886 kWh/a

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<th>Development of solar yields and costs of useful heat</th>
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<td><strong>Bad Frankenhausen rehabilitation clinic</strong></td>
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*Photographs: Xtoday-Media Verlag; TU Ilmenau*
The "roadmap" to solar heat utilisation

In dialogue with a large number of experts, the German Federal Ministry for the Environment developed a "roadmap" for solar heat supply in 2006 and 2007. The development goals discussed here are part of this ambitious roadmap, which is especially geared toward stimulating development with regard to solar heating costs and the degree of utilisation of solar energy systems.

Since 1990, system efficiency has improved significantly in all types of application (Fig. 27). This was achieved by means of various measures:

- System design adapted to consumption
- Improved system technology, incl. appropriate integration of the solar energy system with the conventional building services equipment
- Optimised collectors and conventional components

In the coming years, the degree of utilisation of solar energy systems is expected to increase, but this requires further development steps. The development of improved thermal storage tanks is sure to be an important focal area. Particularly with regard to combined systems, and systems which are integrated into heating networks, there is considerable development potential.

Also in terms of costs, there has been significant success over the last 20 years. The development to date, and the ambitious targets up to the year 2020 are shown in Fig. 28.

The costs specified in the roadmap are based on the degrees of utilisation of solar energy systems shown in Fig. 27, whereby a slight cost regression due to further optimisation of system technology and longer system service lives in the future was assumed. The system service life is to be increased from today’s 20 years to between 25 and 30 years by 2020.

The larger the solar energy system, the lower its specific costs per square metre of collector surface area. Therefore, large-scale solar thermal systems (solid lines) achieve lower heating costs than small-scale systems (dotted lines). However, the graph shows the costs of all systems dropping to, or even below, 10 ct/kWh by the year 2020. This would make them far lower than the costs of conventional energy sources.

Furthermore, the costs of the final energy saved increase as the solar share of coverage of the building’s total heating requirement rises (see also Fig. 22). However, in the future, they fall in line with each other to an ever greater extent, so it becomes increasingly beneficial to strive toward larger solar shares of coverage.

Nevertheless, the values predicted in the roadmap can only be achieved if the components are continually improved, and the system technology is also further optimised and standardised.
Still keeping fit in old age

In September 1978, the solar house in Freiburg-Tiengen marked the start of a ground-breaking pilot project for solar energy research in Germany, which was then still in its infancy. The twelve-family house was not only equipped with what in those days was above-average thermal insulation, it also had a solar energy system with evacuated tube collectors (brand new at the time). It was scientifically analysed over many years.

Now, thirty years later, the solar energy system continues to function faultlessly, with low maintenance costs and high yields. Its service life has thus gone far beyond what was originally predicted. On the occasion of the 25-year jubilee, the researchers calculated that the solar energy system had saved around 65,000 litres of heating oil.

Many other systems dating back to the beginnings of this technology were examined in the research programme Solarthermie-2000. These systems, some of which were purely experimental, also astonished the researchers with their durability, even despite teething problems such as corroding steel absorbers, broken collector covers, or leaky hose connections, which have since been consigned to history.

Looking back, the Freiburg solar house was not just an internationally observed research project, but it also sparked the flame of solar research and energy research in Germany. Over the decades, under the influence of the second oil price crisis, and with public subsidisation from Solarthermie-2000 and Solarthermie2000plus programmes, a boom was initiated in the solar industry, and it continues to this day.

Rising share of coverage of the building’s total heating requirement

- • Small-scale systems
- ➤ Large-scale systems

- ○ Small-scale systems for domestic water heating and room heating (SFHs/DFHs)
- • • Small-scale systems for domestic water heating only (SFHs/DFHs)
- ➤ Very large network-coupled systems with seasonal storage tank
- ○ Large-scale systems for domestic water heating and room heating and network-coupled systems without seasonal storage tank
- • Large-scale systems for domestic water heating only (large = all except SFHs/DFHs)
Outlook

Today, solar domestic water heating in large-scale systems is state-of-the-art. As energy prices continue to increase, carefully planned systems can also compete with conventional systems financially. Combined generation of hot water and heating energy achieves even greater fuel savings than solar water heating. Demonstration systems show that optimised combined systems in residential buildings, hospitals, halls of residence, hotels, guest-houses, and sport & leisure facilities, make a significant contribution to the heat supply.

With the support programme Solarthermie2000plus, the German Federal Ministry for the Environment has made large-scale combined systems (for solar-supported heating networks, solar cooling, and solar process heat systems) a key research area. In all fields of application, the costs of the saved final energy decrease further as cheaper, more efficient system components with longer service lives come onto the market. The depression of system costs and the higher fossil energy prices have made the framework conditions more favourable for large-scale solar energy systems.

In addition, the subsidy conditions have also improved significantly: the German Federal Government’s market stimulation programme has been strengthened, the application procedure has been simplified, and the subsidy conditions for large-scale systems have been improved. The Kreditanstalt für Wiederaufbau (German Reconstruction Loan Corporation) programmes also offer attractive conditions. And by no means least, the German Renewable Heat Sources Act (Erneuerbare-Energien-Wärmegesetz, EEWärmeG), which will come into effect at the beginning of 2009, also provides new impetus. This act makes it obligatory to implement renewable energy sources when building new residential and non-residential buildings as of 2009.

The implementation of the research results in building practice depends greatly on the players on the market. Planners and tradespeople will only take the new tasks on board if they feel that they have been prepared for them sufficiently by means of corresponding publications and instruction. This is to be aided by a publicity campaign, which is to present the technology to a broader public in a target-group-specific manner. Architects, planners and installers are to be addressed by means of specialist articles, planning aids, and information brochures. Competence centres are to be established, so as to support planners and building contractors. This is all supplemented by an Internet portal, online consultation tools, and a technology & investors hotline.

More from BINE


Links

- www.erneuerbare-energien.de
- www.solarthermie2000plus.de
- www.solarthermie-2000.de
- www.forschungsjahrbuch.de

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11055 Berlin
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Project Management Organisation Jülich
Research Centre Jülich
52425 Jülich
Germany

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0329604 A

Contact · Info

Questions regarding this Themeninfo brochure?
We can offer you assistance:
+49(0)228/92379-44

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