# 4.3 Nonfocusing solar heat collection (incl. seasonal heat storage)

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## 4.3.1 Summary

The growth rate of the solar industry is increasing. In the last 25 years an average annual growth of 20% could be noted. In Germany about 700000 square meters of collector surface were installed in 2004 only. The market is dominated by small plants for domestic hot water preparation, but there is also a growing market segment of plants for hot water preparation and heating supply. First large-scale projects have been implemented more then ten years ago, with solar supply for whole housing developments. This text gives an overview of the basics of solar energy use with non focusing systems, the system engineering and the different technical possibilities. Beyond that practical guidance for plant design a description of individual large scale projects is included.

## 4.3.2 Active use of solar thermal energy – range of application

With regard to the operation temperature, the thermal use of solar energy can be subdivided into three main categories: low, medium and high temperature applications (see Fig. 4.3.1). The higher the degree of concentration of the solar collector, the higher is the temperature level reached by the heat gained by radiation absorption. Different types of collectors and also system configurations have to be used within the different applications. In the low temperature range (20-150°C) the solar energy is for example used for swimming pool heating, domestic hot water preparation, space heating with short- and long-term storage, absorption cooling, drying and distillation processes. For these technical applications solar collectors without optical concentration are used.

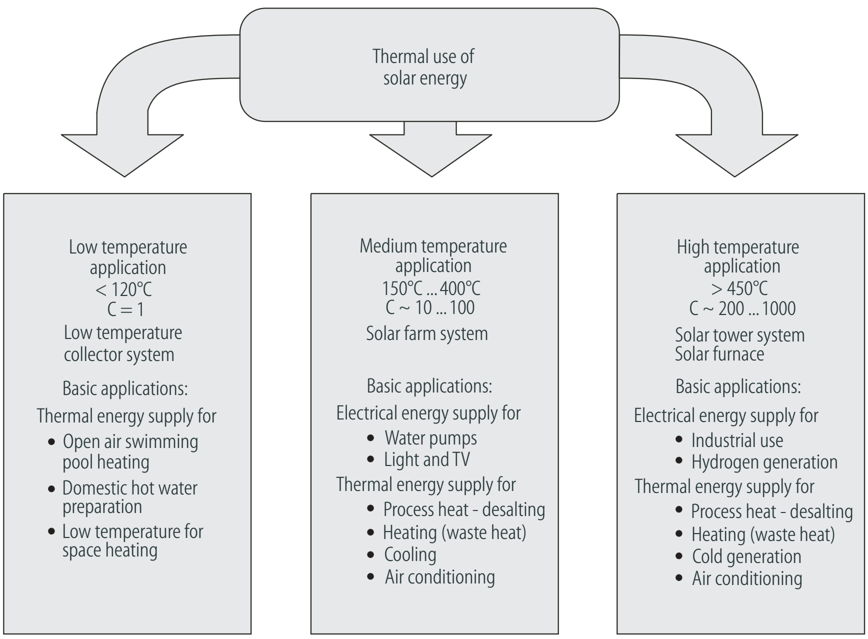



**Fig. 4.3.1.** Thermal use of solar energy.

Within these low-temperature applications three different kinds of collectors are available. A solar water heating system consists of a collector field (one or more collectors), one or several heat storages and, depending on the system, heat exchangers, pipes, pumps and an additional heating as well as regulation and control equipment. The simplest systems consist of unglazed collectors (i.e. absorber) for warming up the water of open air swimming pools or open air showers. Glazed collectors (flat plate collectors) are in use for solar plants for domestic hot water preparation or space heating, but vacuum tube collectors can also be used. Vacuum collectors reach a higher temperature difference (see Fig. 4.3.4), but also lead to higher expenditure in comparison to flat plate collectors.

The choice of the right type of collector depends on thermal, financial and architectural criteria. In combination with different storage systems an optimal plant-configuration could be realized for each application. Domestic hot water preparation is still the most common application, but the number of plants for hot water and space heating increases.

## 4.3.3 Basics

### 4.3.3.1 Collectors

Nowadays low temperature applications for domestic hot water preparation and space heating which can be used in the Northern part of Europe are on the rise. The main components of these applications are the collectors. In low temperature applications the most important component of the collector is the absorber whose surface must absorb the solar radiation as completely as possible. The absorber usually consists of a metal (e.g. copper, aluminum) or a polymer (e.g. polypropylene, ethylene-propylene-diene monomer) with a good thermal conductivity. A selective coating of the metal absorber induces a high degree of absorption in the solar radiation range and a low degree of emission in the infrared range. The most common selective absorber layers are still electroplated semiconducting layers of black chrome and black nickel ($\alpha$ = 0.9-0.95, $\varepsilon$ = 0.07-0.1). With sputtered nickel coatings, which have a lower energy demand during production, an advanced generation of coatings is offered today.

The heat developing during the absorption at the absorber surface is transferred to a medium (e.g. water, water/glycol mixture, oil or air) and dissipated from the collector. A good thermal contact between the absorber plate and the heat transfer medium is needed. For a high energy gain the thermal mass of the medium should be reduced (e.g. 0.4-0.6 l per square meter absorber surface in a rib-pip-absorber instead of 1-2 l/m² of a medium in a pillow-absorber). To reduce thermal losses and to improve the collectors' efficiency the absorber should be insulated on the side and to the rear. The covering plate of flat plate collectors consists of low-iron glass or transparent plastics with a high transmission ratio in the spectrum of solar radiation and should also be impermeable to the heat radiation of the absorber. For this reason, additional selective coatings are arranged on the undersurface of the glass. Semiconductor-materials like $SnO_2$ and $In_2O_3$ are used as infrared-reflecting coatings with high transparency in the solar spectrum. Figure 4.3.3 shows the energy transformation of a glazed flat plate collector.

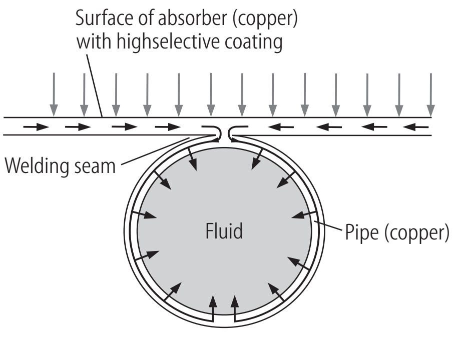



**Fig. 4.3.2.** Cross-section of a rib-pip absorber.

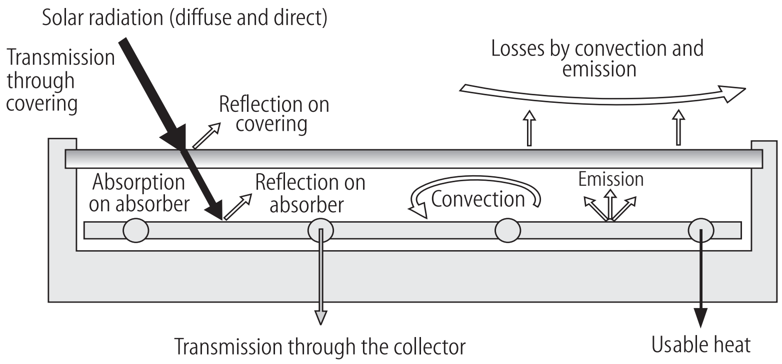



**Fig. 4.3.3.** Principal scheme of a glazed flat plate collector.

The heat attainable with a collector is described by its efficiency $\eta$. It is defined as the ratio between the usable heat energy released by the collector and the incoming radiation energy.

$$\eta = \dot{Q}_{\mathrm{use}} / A_{\mathrm{coll}} \cdot E_{\mathrm{glob,coll}} ,$$

with $\dot{Q}_{\mathrm{use}}$ the usable energy in [W], $A_{\mathrm{coll}}$ the collector's surface area in [m$^2$] and $E_{\mathrm{glob,coll}}$ the global radiation in the collector plane in [Wm$^{-2}$]. By plotting the collector-efficiency versus the temperature difference ($\theta_{\mathrm{A,av}} - \theta_{\mathrm{amb}}$) between mean absorber temperature $\theta_{\mathrm{A,av}}$ and ambient air temperature $\theta_{\mathrm{amb}}$ every type of collector can be described by an efficiency curve. These curves are slightly bent because the radiative heat losses increase over-proportionally with the temperature.

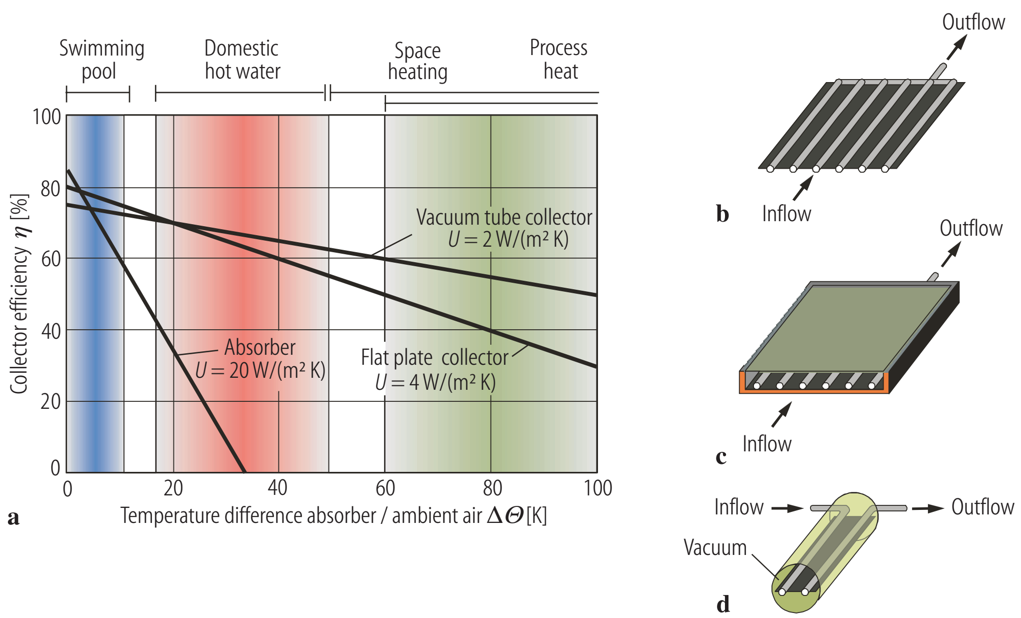



**Fig. 4.3.4.** Solar collectors for low temperature application. **(a)** Efficiency curves for an absorber, a flat plate collector and a vacuum tube collector. **(b)** Schematic of an absorber. **(c)** Schematic of a flat plate collector. **(d)** Schematic of a vacuum tube collector.

The collector efficiency depends on the design, meteorological conditions (incoming radiation, wind speed etc.) and operating parameters (inlet temperature of the heat carrier, mass flow rate etc.), so the efficiency factors for a certain collector form a characteristic curve field. However, for technical reasons only one characteristic curve is established. The characteristic efficiency curves for an absorber, a flat plate collector and a vacuum tube collector are shown in Fig. 4.3.4. The type of collector to be selected for the respective application can be approximately determined from this figure.

The average heat loss coefficient through the collector ($U_{eff}$-value) is another value to express its quality. The $U$-value is comparable to the gradient of the efficiency-curves in Fig. 4.3.4 and is defined as the sum of all heat losses related to a reference area and to the temperature difference between reference and ambient temperature:

$$U_{\text{eff,av}} = U_1 + U_2 \cdot \left(\theta_{\text{m,av}} - \theta_{\text{amb}}\right),$$

with $\theta_{m,av}$ the average medium temperature between inlet and outlet (collector), $\theta_{amb}$ the ambient temperature, $U_1$ the linear $U$-value in [$Wm^{-2}K^{-1}$] and $U_2$ the squared $U$-value in [$Wm^{-2}K^{-2}$]. For a comparison of different collectors the values must refer to a uniformly defined area, e.g. the area of the absorber or the aperture surface.

### 4.3.3.2 Storage

Due to the lack of coincidence between the supply of solar energy and the heat demand most thermal solar plants require heat storage with the exception of those for pool heating. It would be ideal to store energy from the summer up to the winter times (seasonal storage). For small houses such a storage must have a volume of several cubic meters and is difficult to integrate into the building (see Sect. 4.3.4.3), so short time storage is designed in most cases. They may be further differentiated by the kind of hot water integration into the storage. In northern climates double circuit systems with a non freezing medium in the solar circuit and drinking water in the storage are recommended. Plants with a collector area of up to 10 m² can be designed alternatively with or without an internal heat exchanger. For larger plants, storage with external heat exchangers is necessary. Similar to conventional heating systems a receiver for pressure balance and devices to empty the system has to be planned. Such a development leads to the complete integration of the solar plant into the heating system.

The storage tanks consist of high-grad, enameled or plastic coated steel. In a double circuit solar plant for domestic hot water preparation (DHW) a storage tank with two heat exchangers (solar and backup heating) is the usual solution (see Fig. 4.3.5a). The volume of the DHW-storage should be sized to store twice the daily hot water demand, 50-80 l volume per m² collector area (flat plate) or 80-100 l volume per person. A larger tank can store more energy; however, with the same collector surface it leads to a more frequent use of the backup heating because of the lower temperature level within the tank. Generally the tank temperature should be limited to 60°C (DHW). At higher temperatures calcium is deposited and the danger of calcification in the heat exchangers rises. For good temperature stratification the storage should be narrow and upright. The relation between height and diameter should be 2.5 to 1. Therefore the dimension of a storage tank is mainly restricted by the headroom of the place of installation.

A so called tank-in-tank-storage consists of two units (see Fig. 4.3.5b). A smaller tank for DHW is integrated in the hotter zone of a buffer storage. Such an installation is uncomplicated. All heat generators work on the buffer storage, as do heating consumers. The warming of the DHW takes place on the surface of the inner tank.

Buffer storage tanks (see Fig. 4.3.5c) are well known among heating device installers from wood fired systems and heating systems with a heat-pump. They are filled with a water glycol mixture which directly supplies the heating system or a heat exchanger for the DHW-preparation. They are used to avoid excessive alternating of the heating system. By heating up the storage, the burner of the heating system reaches longer operation times which increases its lifetime. Because burner emissions during ignition are much higher than the emissions during regular operation [01Kue], the emission behavior is also improved.

To use the hot water immediately, a zone of purely hot medium in the higher part of the storage is recommended. So for storage with a volume greater than 300 l (see Fig. 4.3.5d) the stratified storage was developed. This means a self-regulating charging system which guarantees a variable integration of the incoming load depending on its temperature. Warm water with a lower density than cold water moves upwards in a pipe with defined outlet-openings and will enter the tank in the zone with the same or similar temperature and density (see Fig. 4.3.6). With this a loading with a low velocity of the medium is achieved and a clean stratification is obtained in the tank. Stratified storage is used in Low-Flow-Applications (with 10-15 l mass flow per m² collector area and per hour).

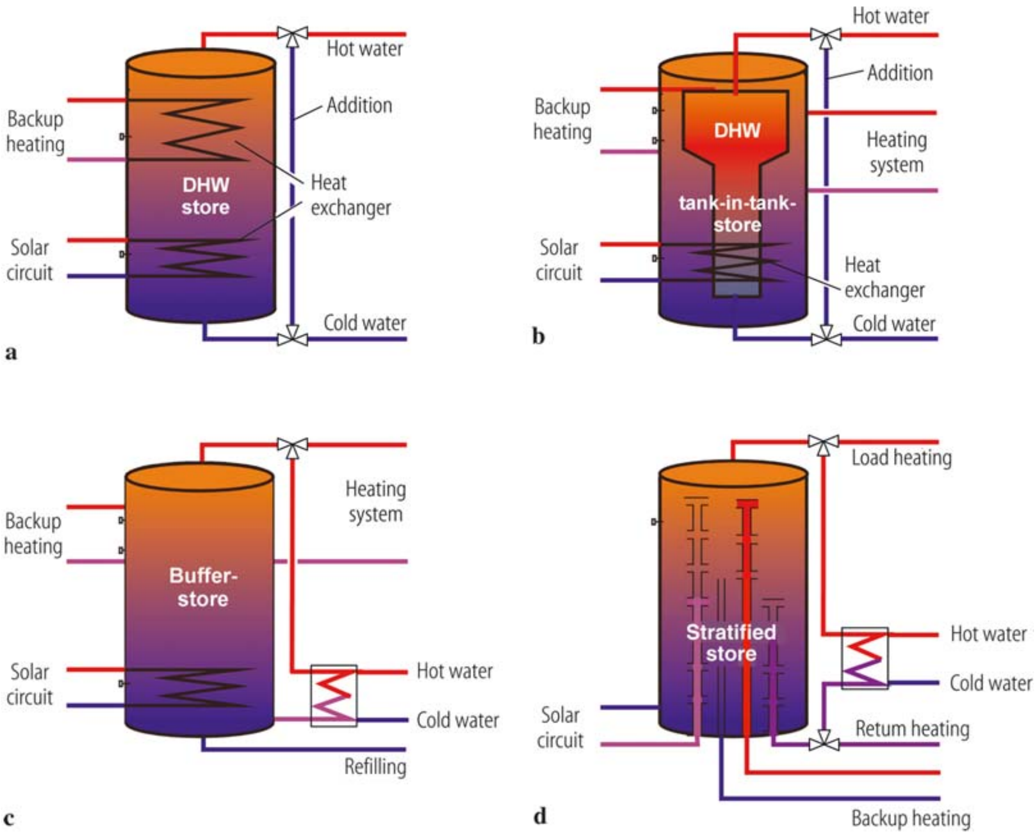



**Fig. 4.3.5. (a)** Storage tank with two internal heat exchangers. **(b)** Tank-in-tank storage. **(c)** Buffer-storage with a glycol/water filling and external DHW-heat exchanger. **(d)** Stratified tank storage.

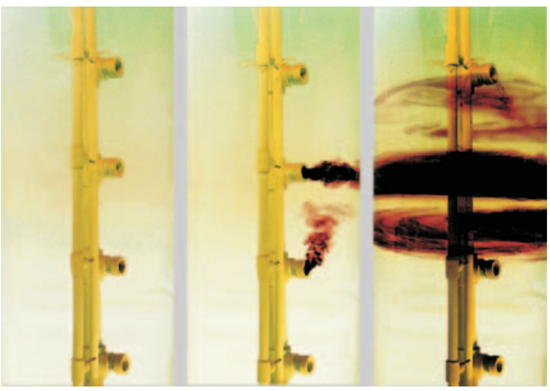


**Fig. 4.3.6.** Dyed water entering a stratified tank (storage: Solvis Energiesysteme GmbH, Braunschweig).

In steady state the stored energy is easy to determine: without stratification we can calculate the stored energy $Q_t$ in [Wh] with an average tank-temperature as

$$Q_t = m \cdot c_w \cdot (\theta_{t,av} - \theta_{i,c}) ,$$

with $m$ the mass of the tank medium in [kg], $c_w$ the specific heat capacity of the medium in [Wh/kgK], $\theta_{t,av}$ the average medium temperature between inlet and outlet (tank) and $\theta_{i,c}$ the (cold) inlet temperature. The energy flux balance for such a fully mixed storage with added or removed energy rates ($Q_{t,i}$ and/or $Q_{t,o}$) can be written as

$$(m \cdot c_w)_t \cdot \Delta\theta = Q_{t,i} - Q_{t,o} - (UA)_t \cdot (\theta_{t,av} - \theta_{amb}) \cdot t ,$$

with $\Delta\theta$ the difference in tank temperature over a time step $t$, $UA$ the coefficient of transmission losses in [$WK^{-1}$] and $\theta_{amb}$ the ambient temperature at the place of assembly.

In the same way as for the collector an average $U$-value of the storage tank can be defined. The product of the $U$-value with the surface indicates the rate of heat loss in [$WK^{-1}$], which should not exceed 2 $WK^{-1}$. For example, with a rate of 1.5 $WK^{-1}$ and a constant temperature difference of 35 K to the ambient, the storage loses 450 kWh per year. This corresponds to one additional square meter of collector area.

Highly stratified tanks will optimize the efficiency of the solar plant, because they provide the lowest temperature near the bottom of the tank. With a cold entering temperature a higher temperature rise is available inside the collector, and so a higher efficiency can be reached.

In the last years some new developments entered the market. One of them is the usage of phase change materials (PCM) for the heat storage. With conventional storage the temperature constantly increases by energy input. Phase change materials melt on a defined fusion temperature while the storage temperature stays nearly constant until the material is completely melted (so called latent heat storage). The melting point is adjustable between –30 and 80°C (paraffin waxes) or from 5 up to 130°C with salt hydrates. The discharging process runs recursively (see Fig. 4.3.7). Two main advantages could be found on the new materials: First of all it is possible to reach a high density of energy in a small band of temperature. Secondary there are less energy losses since the temperature level required for loading the material is lower compared to its conventional counterpart with same surrounding. Finally, a special ability of PCM is to make a time shift possible between the incoming heat and the discharging load – a situation that occurs very frequently in solar use.

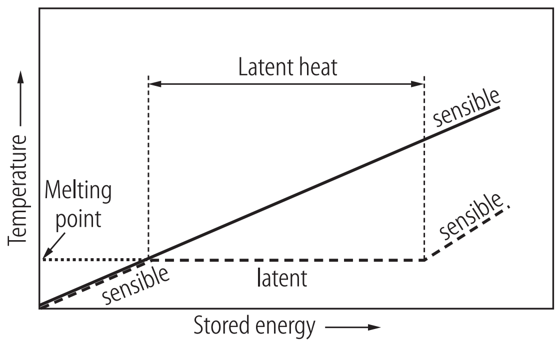



**Fig. 4.3.7.** Principle of latent heat storage (source: BINE information service, FIZ Karlsruhe).

## 4.3.4 Technical realization of low temperature applications

A system works satisfactorily only when the system configuration is adjusted to basic site conditions (local weather data and the amount and time profile of the DHW-demand) and if all components are well suited to each other. Common types of systems are

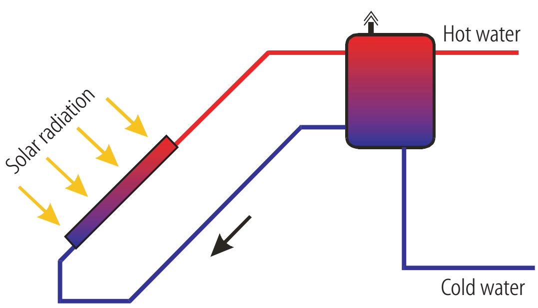
- thermosyphon or natural circulation systems and
- forced circulation systems.

In the case of the *thermosyphon or natural circulation system* the storage must be located higher than the collector (see Fig. 4.3.8). These plants can be built as open or closed systems. The circulation of the heat transfer medium between collector and storage occurs as a result of temperature-based differences in the density of the medium. The increase of the temperature of the medium in the collector causes a decrease of its density. The medium starts circulating once the buoyancy pressure exceeds the pressure drop of the entire circuit. Therefore the circulation depends on the hydrodynamic resistance of the system and the differences in temperature and static pressure. These systems require no additional energy and operate without control elements. Because single-circuit-thermosyphon-systems can freeze, they are preferably used on flat roofs in Mediterranean countries and in Southern Europe. To avoid freezing, double-circuit-systems with a water glycol medium for the solar circuit are in use, but they are not as widespread in Central and Northern Europe due to difficulties in integrating these systems.

In *forced-circulation systems* (see Fig. 4.3.9) the heat from the collector is transported to the storage by a heat transfer medium (water or water-glycol mixture for protection against frost damage). A pump is employed to circulate this medium. The heat exchanger for the heating of the water can be arranged inside (pipe coil, see Fig. 4.3.9a) or outside of the storage (e.g. as plate-heat exchanger). In most cases the storage is carried out as a DHW-storage (thermo glazed construction steel or stainless steel). Forced-circulation systems have the advantage that storage and collector can be arranged in any manner. The additional heat from the backup heating system can be fed into the upper part of the storage via a second internal heat exchanger. Another possibility is to switch the backup heating system in flow to put the preheated water on the demanded temperature level. Simple regulation (temperature control) is sufficient to control the system. The circulation pump in the solar circuit is switched on when the collector can deliver usable energy to the storage, i.e. when the temperature difference between collector and storage exceeds a threshold value which can be set at the control unit.

The configuration of solar plants can be subdivided as follows:

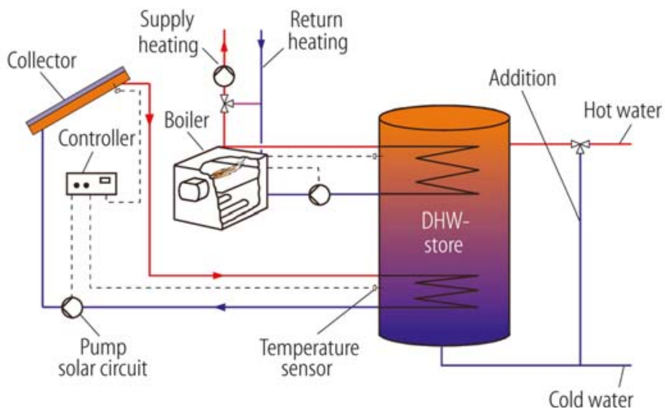
- Small plants for domestic hot water (DHW) preparation only or a combined operation of both DHW preparation and space heating (SH);
- Large scale plants with short term (diurnal) storage (DHW, DHW/SH);
- Large scale plants with long term (seasonal) storage (DHW/SH).




**a**

**b**

**Fig. 4.3.8. (a)** Schematic of a thermosyphon solar plant. **(b)** Roof-mounted thermosyphon solar plant installation.




a

b

**Fig. 4.3.9. (a)** Small solar system for DHW-preparation – typical configuration. **(b)** Residential house with a DHW-solar system.

**Fig. 4.3.10.** Solar plant for an open air swimming pool (350 m² absorber surface), Germany (Allgäu).

**Fig. 4.3.11.** Roof integrated absorber, Wilhelminenhof, Berlin. Absorber: Energie Solaire; architect: F. Augustin.

### 4.3.4.1 Plants with absorber

For the operation of open air swimming pools in the summer period a considerable amount of low temperature heat is needed. Nearly 10% of the total annual heat demand has to be supplied to heat up the pool at the beginning of the season. In comparison to solutions with gas or oil, solar heating of swimming pools is mostly the more profitable application. The temperature required for pools is low, usually not much above average ambient temperatures. Therefore inexpensive plastic absorbers (e.g. made of polypropylene or ethylene-propylene-diene-rubber) without transparent covering and heat insulation on the back can be used (see Fig. 4.3.10). The pool water flows directly (without a heat exchanger) through the absorber, and a monovalent mode of operation (i.e. without a conventional heating system) is possible. In cases of an unprotected location of the pool, relatively high water temperatures (e.g. 25-28°C) or a long operation period the integration of a pool covering in combination with plastic absorbers can be an economic solution. The scale of the absorber field can be estimated to be 40-70% of the water area.

The flow through the absorber field must be steady and relatively strong, so that the temperature difference is 8 K at most in the absorber during full sun exposure. Under these conditions the absorber obtains an annual energy gain of approximately 250-300 kWh per m² absorber surface. In relation to the annual solar irradiation it uses 25-30% of the incoming solar energy. The amortization period of an absorber plant for an open air swimming pool application can be estimated up to 2 or 3 years. The complete system costs of larger plants are approximately 75-125 € per m² absorber surface.

Low investment costs and good optical integration ability can occasionally lead to the use of metal absorbers for domestic hot water preparation or, like in the building in Fig. 4.3.11, for wall-tempering. These collectors have a lower efficiency than flat plate collectors because of the absence of glazing, frame and insulation. However, an annual energy gain of up to 600 kWh per m² absorber surface can be achieved. In an economic solution the absorber substitutes the roofing and should not be mounted.

### 4.3.4.2 Small solar plants and system configuration

Small solar plants for DHW-preparation and a combined operation for both DHW-preparation and solar assisted space heating (so called “solar combisystems”) in non-central applications are well developed and well suited systems with a long experience in operation. It is recommended to take a pre-mounted solution from one supplier, especially for one-family houses or smaller applications. The time for installation is reduced and the dimensioning is predefined. The function of these solar systems was confirmed in several tests carried out at the research and test center for solar plants at the ITW, University of Stuttgart and other institutes in Germany.

#### 4.3.4.2.1 Solar plants for domestic hot water preparation

Small solar plants for the DHW-preparation in one- or two-family houses are the most common applications of the thermal use of solar energy in Europe. In summer times almost the complete energy demand for the DHW-preparation can be covered by a well suited solar plant without activating the backup heating system. Also an essential part of the energy demand can be covered by solar energy in spring and autumn. 50% of the annual heat demand for DHW-preparation can be covered with these small systems. As opposed to a swimming pool application these systems operate throughout the whole year. When designing a solar plant for DHW some boundary conditions must be considered:

- Hot water consumption and the desired hot water temperature (40-60 l per day and person, depending on comfort, $\theta_{DHW}$ = 45°C). A higher load caused by dish washers and washing machines (if applicable) is appreciated.
- Orientation and slope of the collectors. A deviation of ±15° of the orientation of the collector from the south to a south-west or south-east orientation and from the optimum collector slope of 40° leads to a reduction of the solar gains of only 5%.
- Collector area of 1.0 to 1.5 $m^2$ per person and a storage volume of about 50 to 80 l per $m^2$ collector area.
- Efficiency of the collector and meteorological conditions.
- Volume of the storage tank, type and integration of the backup heating.

Figure 4.3.9 shows a typical scheme for a plant with DHW-preparation. Collectors and backup heating are integrated within one tank. A division into a solar storage and separate tank for backup heating leads to no advantages, but greater losses. The internal heat exchanger should have a transmission rate of 30 to 40 $WK^{-1}$ per square meter collector area and a flow rate of 25 up to 30 l/h. In summertime an electrical heating rod can replace the boiler. This configuration works reliably for plants with a collector area up to 30 m². Alternatively an external heat exchanger may be used for the solar circuit (obligatory for plants with a collector area greater than 10 m²). In this case the system should work in low-flow operation.

The costs for the components of a solar plant differ from country to country. In a normal solar plant for DHW-preparation (5 m² collector area, 300 l storage) the material costs range between 3000 and 6000 €. Installation costs have to be added, but in regular cases (no stand needed, building with no more than two floors, only minor changes required in the heating plant room) the work should be done in 2-3 days. The economy of a plant depends on the ratio between costs and benefits of the system. The life span of a solar plant can be assumed to be 25 years. During this time maintenance and service have to be done.

With interest and repayment the following calculation can be done (costs for Germany 2001):

| | |
|---|---|
| Credit and operation costs: | 450-750 €/year; |
| Solar energy gain: | 2000-2500 kWh/year; |
| Solar fraction of heat demand (DHW): | 50-60%; |
| Cost of solar energy: | approx. 20-40 €-ct/kWh. |

So one kWh costs between 20 and 40 €-ct in this example. In comparison the heating cost of an oil boiler lies between 8 and 14 €-ct/kWh, of an electrical instant water heater between 15 and 20 €-ct/kWh. The ecological break even period is about four years.

#### 4.3.4.2.2 Two special designs

Integrated collector-storage (ICS) systems and the so called *hybrid-collector* are two special designs of collectors. In ICS systems, the reservoir and the collectors are accommodated in the same housing. The heat loss from the reservoir, especially through the transparent covering, must be kept as low as possible. This is necessary in order to withdraw warm water for as long as possible after a sunny day and to protect the reservoir from freezing (the inlet and outlet still have to be protected!). The ICS is directly integrated into the water supply as shown in Fig. 4.3.12. For backup-heating an instantaneous water heater is connected at the outlet side. These systems did not become generally accepted on the market.

The hybrid-collector combines solar thermal energy gain with photovoltaics (PV). The PV-cells are installed on the upper surface of an absorber, with thermal connection to exhaust the heat. The electrical gains are similar to other PV-plants and the thermal energy gain reaches those of collectors without selective coating (Solarwerk Teltow). It is a relatively new design and it is uncertain whether it will become generally accepted on the market.

#### 4.3.4.2.3 Solar combisystems for DHW-preparation and space heating

The heating of buildings consumes relatively large parts of the end energy consumption in Central and Northern Europe (e.g. 35% in Germany). Solar combisystems (solar energy used for DHW and SH) can be economically used in new and retrofitted old buildings with an improved thermal insulation, at least at low-energy-standard with $Q_{SH} \leq 60$ kWh m$^{-2}$·a$^{-1}$).

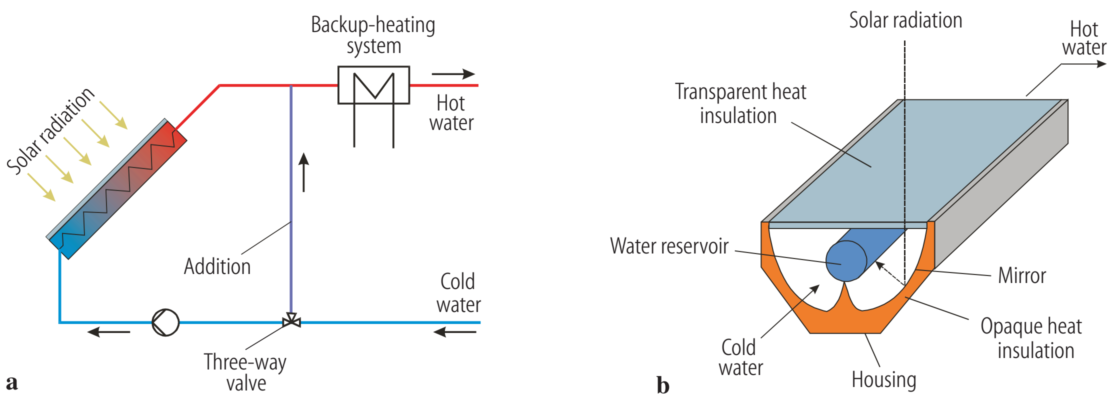



**Fig. 4.3.12.** Integrated collector-storage system (ICS). **(a)** ICS-system integration. **(b)** ICS-arrangement and components [93Fis].

In general solar combisystems can be subdivided into two-storage and one-storage plants. Two-storage plants (see Fig. 4.3.13) consist of the solar collector(s), piping, a DHW-storage, a buffer storage filled with heating water and a backup heating system. The volume of the DHW-storage should be twice the daily hot water demand; the total volume of both storage tanks should be dimensioned to 70-100 l per m² collector area. Depending on the thermal insulation standard the required solar collector area can be estimated to amount to 1.5-3.0 $m^2$/person or to a total area of 10-15 $m^2$.

In the single-storage plant the buffer storage is the central unit for the collection and distribution of heat. Different types of these storages are available on the market (see Sect. 4.3.3.2). An investigation about different varieties of tanks was instigated by the German "Stiftung Warentest" in 1998 [98STI]. In the most common systems the solar energy is fed into the lower part of the storage (solar buffer part). The storage in Fig. 4.3.14 is equipped with a stratifying device in which the heated water moves upward to the temperature level corresponding to its density. In these "low-flow" plants the heat carrier in the solar circuit is heated up to the operation temperature of about 60-70°C in a single run. With 10-15 $kgh^{-1}m^{-2}$ the mass flow in the solar circuit is low in comparison to conventional "high-flow" plants with a mass flow in the solar circuit of about 40 $kgh^{-1}m^{-2}$. Due to the reduction in the number of components the heat supply to the storage can be controlled more easily than in two-storage plants. As a result of this and due to the reduced investment cost and space demand for installation, the trend goes towards single-storage plants.

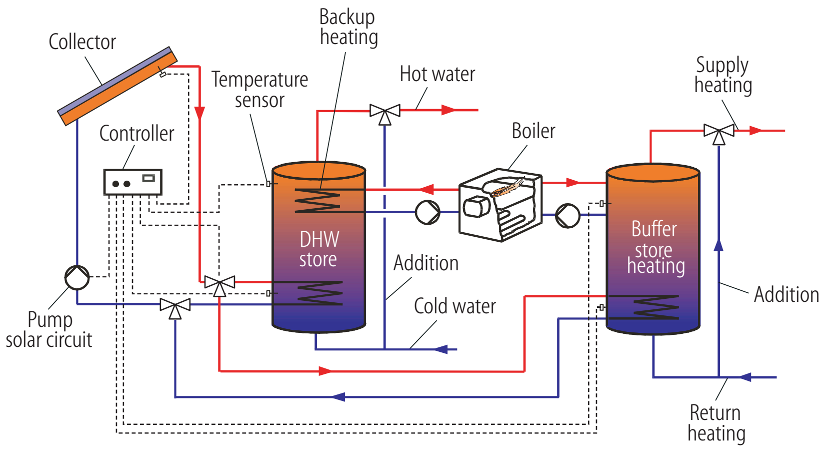



**Fig. 4.3.13.** Solar combi-system as two-storage-system.

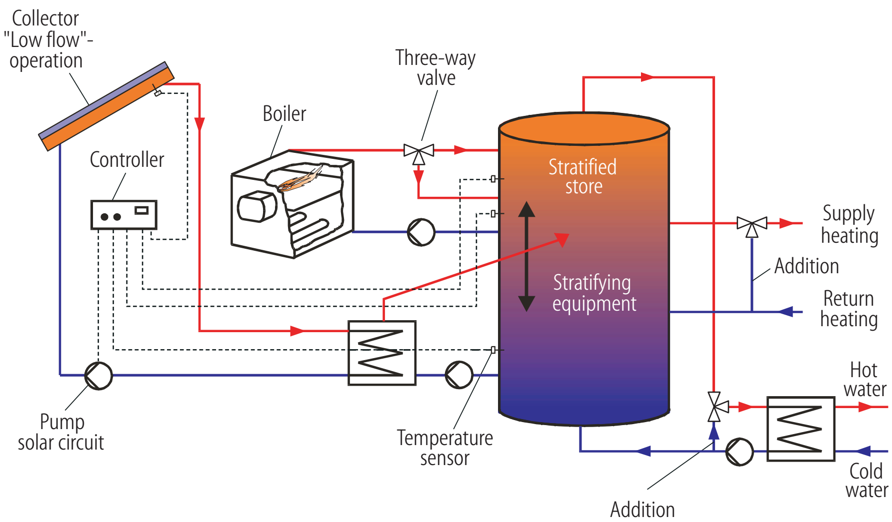



**Fig. 4.3.14.** Solar combisystem with "stratified storage" and "low-flow"-operation, external heat exchanger for DHW-preparation.

The latest development in the area of solar combisystems in non-central application is the direct integration of the backup heating system within the buffer storage itself (see Fig. 4.3.15). The burner of the storage integrated gas condensing boiler operates in a heating power range between 5 and 20 kW, the available storage volumes are 450-1450 l. The boiler is arranged in the upper third of the storage underneath the DHW-buffer part. The DHW-preparation is done by an external plate heat exchanger.

The fraction of the heat demand (DHW + SH) which can be covered by solar energy depends on the thermal insulation standard of the building (see Fig. 4.3.16). In buildings with a low thermal insulation standard only a solar fraction of 10-15% can be achieved. In buildings with a thermal insulation according to the valid German heat protection standard (EnEV; space heating demand $Q_{SH} \approx 50$ kWh m$^{-2}$a$^{-1}$), 20-25% of the demand can be covered by a solar combisystem. In extreme low energy houses ("passive house standard") with a net heating demand of only $Q_{SH} < 15$ kWh m$^{-2}$a$^{-1}$ a solar fraction from 60 up to 70% can be reached.

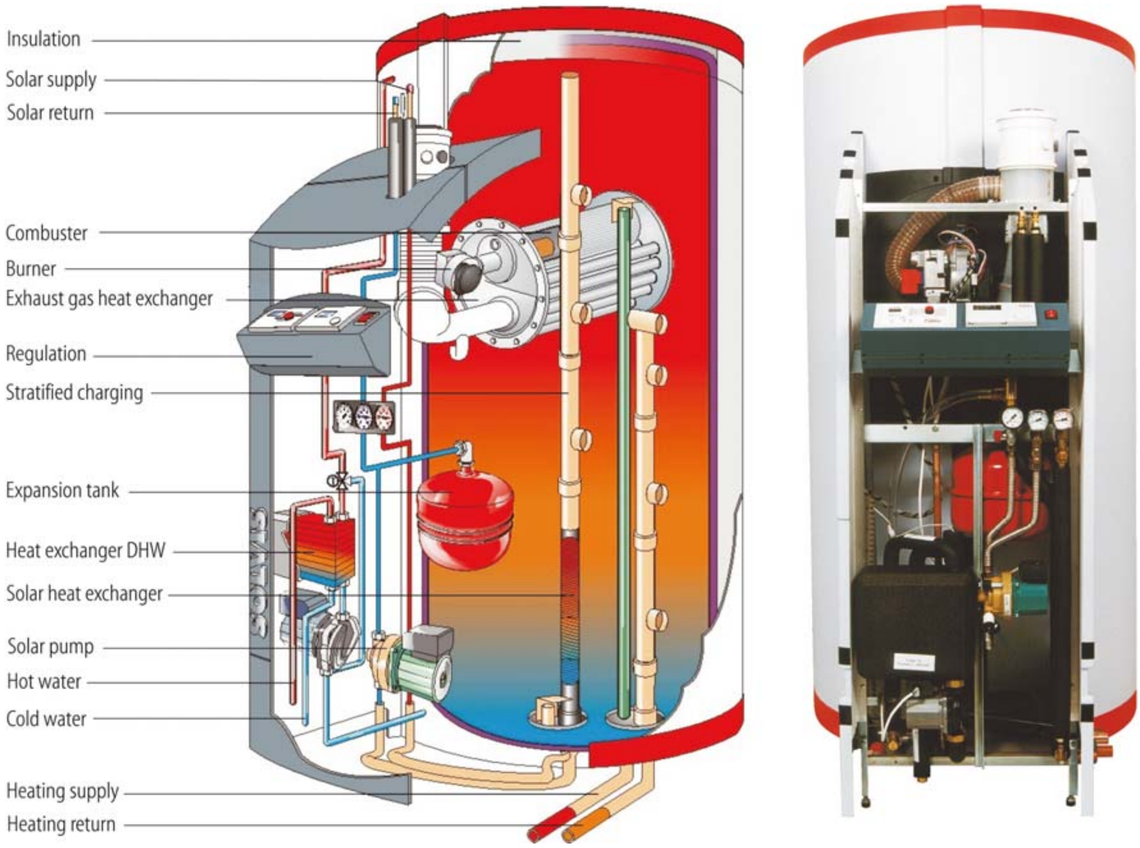



**Fig. 4.3.15.** Solar assisted gas condensing heat central; "Solar Max" heat central (source: product information Solvis Energiesysteme GmbH, Braunschweig).

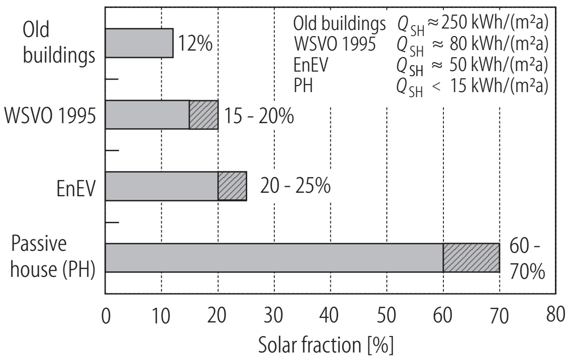



**Fig. 4.3.16.** Solar fraction of a 10 m² solar plant for buildings at different thermal insulation standards (living area is 120 m$^2$).

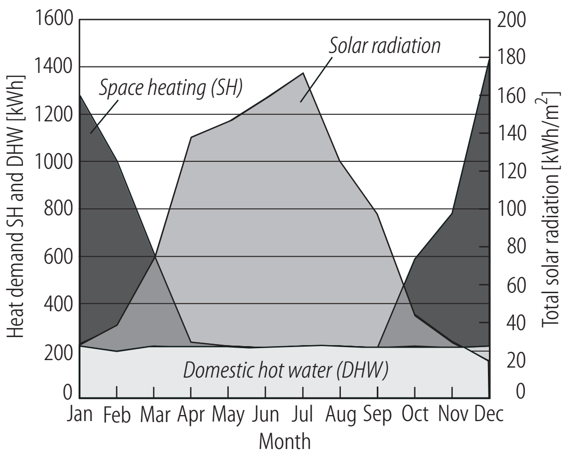



**Fig. 4.3.17.** Seasonal distribution of solar radiation and heat demand. Building: Row house in Ulm (Germany) with $A_{\text{floor}}$ = 122.3 m², heat demand for space heating $Q_{\text{SH}}$ = 30 kWh m$^{-2}$a$^{-1}$; global radiation in horizontal plane $E_{\text{glob,h}}$ = 1070 kWh m$^{-2}$a$^{-1}$.

### 4.3.4.3 Large scale solar plants with short- and long-term storage

To cover a greater heat-demand, large scale systems with a greater collector area and storage volume have to be realized. For large-load applications like multi-storey buildings, hotels or hospitals the real hot water demand and a daily schedule should be considered. Technical and economical reasons led to a central positioned storage, bundled collector fields and a low temperature level for distribution. In order to design and optimize these systems, simple simulation programs like F-Chart or T-SOL could be used.

Solar heating plants with short-term (diurnal) storage serve for DHW-preparation or both DHW-preparation and space heating. They can cover 50-60% of DHW demand and about 10-20% of the annual overall heating demand of a building or residential area. For this reason it is very important to specify the energy loads and temperatures as precisely as possible in an early design phase.

The seasonal offset between the supply of solar thermal energy and the demand of heat for space heating (see Fig. 4.3.17) leads to the use of long-term storage of solar thermal energy for heating. A solar contribution from 40 to 60% to the overall heating demand and thereby a large covering of the space heating can only be achieved by the use of long-term storage. The construction of a long-term storage to shift the energy from the summer into the winter can not be economically achieved for single buildings (see Sect. 4.3.4.3.2). Only when a number of dwellings (>100) are connected to one central solar plant, the costs for such large-scale systems becomes feasible. In the last years the first examples were projected and realized (see Table 4.3.1 and Sect. 4.3.4.4), scientifically supervised and validated. Although developing work still has to be done, the systems show the feasibility of these techniques.

The design of large applications differs from small ones (see Fig. 4.3.18). Depending on the required size special technical components and certain rules must be kept:

- The collector field should be designed with a low mass flow relative to the absorber surface. A flow from 10 to 15 $lm^{-2}h^{-1}$ reduces the power consumption of the pumps and allows smaller diameters of the pipes.
- By improving the stratification of the storage, the efficiency of the system is additionally increased.
- The collector itself should be designed with the maximum possible flow to reduce problems of airlocks in the system. Therefore as many collectors as possible should be connected in a row, resulting in a reduction of connection-pipes and investment costs.
- The collector has to be suitable for this hydraulics, which means that the flow has to run through parallel channels in the collector, while the collectors are connected in a row. In one Swedish example ten collectors (each with 12.5 m²) were connected in a row and flooded with 1320 $lh^{-1}$. A flow of 105 l per hour and collector and/or a flow of 10.5 l per hour and square-meter results.
- A simple control strategy with three or four temperature sensors is sufficient. The plant will be switched on if the temperature difference between storage and collector exceeds 8 up to 20 K, and it will be switched off if the difference between load and supply temperature (in the solar circuit) is lower than 1 K. Collectors, pipes and the heat medium have a thermal capacity and hence have to be heated before the charging of the storage begins. This is why in larger systems the collector circuit will be separated and heated up to a usable temperature. For internal heat exchangers this may be done with a 3-way valve. For external heat exchangers, two pumps (one in the collector circuit and one in the storage charge circuit) with a different control strategy will do.
- The heat exchanger in the collector circuit will be dimensioned for the maximum power of the collector field (around 600 $Wm^{-2}$ for Germany). This value is defined by a mean solar irradiation of 1000 $Wm^{-2}$ and a collector efficiency of 60%. Short moments of higher load will be accepted to keep the costs for the exchangers low.
- From a volume of the solar storage of about 3 m³ on, it may be economical to store the heat in a "normal" buffer-storage and keep the more expensive DHW storage smaller. This additionally reduces hygienic problems by shortening the standing periods of the water in the storage. Due to the second heat exchanger the collectors should work on a reduced higher temperature level.

The "cost-benefit-ratio" of large-scale solar heating plants (>100 m²) is approximately two to three times more reasonable compared to small plants (<10 m²) for domestic hot water preparation. The ratio between the investment cost of the solar plant and the yearly solar energy gain is shown in Fig. 4.3.19. Similar remarks may be made about the $CO_2$-emission and the reduction of energy consumption.

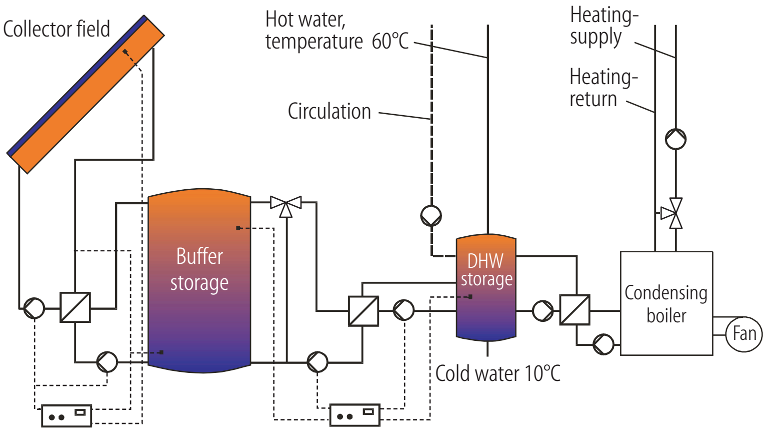



**Fig. 4.3.18.** Scheme of a larger solar system with buffer- and DHW-storage.

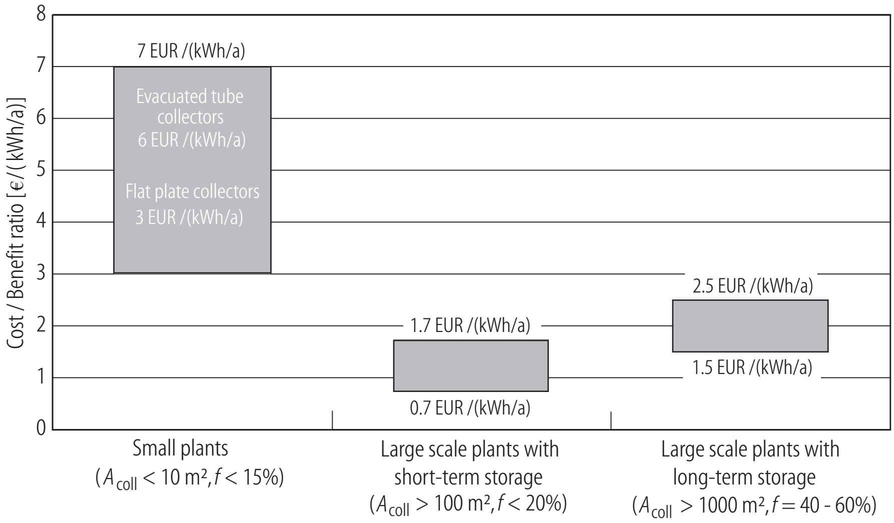



**Fig. 4.3.19.** Cost/benefit-ratio for solar supported small and large-scale plants with short- and long-term storage.

Figure 4.3.19 shows that even the large-scale plants with seasonal storage ("solar fraction" $f > 40\%$) have a more reasonable cost-benefit-ratio than small plants for domestic hot water heating (DHW) ($f < 15\%$). The lower costs are not only reasoned by a higher number of pieces or better conditions on market. A high reduction potential is based on an intelligent system design: large collector modules, a simple control strategy and technique and short connections are important for an economic solution.

### 4.3.4.3.1 Large scale plants with short-term storage

Large scale plants with short-term storage cover 10-20% of the total heat demand of a building or a residential area. A configuration with or without district heating distribution network can be envisaged. The storage may be integrated into a building to use its thermal losses. In combination with a distribution network, it may be positioned in a central heating station, where services and the adaptation of newer technologies could be done easily. The short-term storage is usually made out of steel. For volumes bigger than 6 m³ a number of smaller tanks have to be connected, or a special tank has to be mounted.

For the testing and development of collector and system technology a number of large scale solar plants with short-term storage have been built in the last years. Table 4.3.1 shows the first realized plants. The early ones (numbers 1 to 4) were constructed for domestic hot water preparation only. Due to the high thermal losses in extended networks, the use of a separate distribution network for domestic hot water should be restricted to compact residential estates. The experience with these plants can be summarized as a problem-free operation with solar energy gains of about 400 kWh $a^{-1}$ per $m^2$ collector area.

Figure 4.3.20a to 4.3.20c show the collector fields of the projects in Ravensburg (29 detached houses), Köngen "Burgweg West" (12 detached houses and 60 dwellings) and Neckarsulm-Amorbach I (details in Table 4.3.1). The installation of the collector fields in Stuttgart-Burgholzhof is shown in Fig. 4.3.20d. The scheme of the solar supported district heating system in Stuttgart-Burgholzhof is shown in Fig. 4.3.21. Due to the integration of the solar supply in the heat return line, the piping network can be reduced from a 4-pipe to a 3-pipe-system, leading to reduced investment and operation costs.

Important factors for the cost reduction and the improvement of the economic viability of large scale solar plants are the improvement of the technology of the different components, the system integration and the organization of the plants. The investment costs of large scale solar plants with short-term storage related to the collector area are shown in Fig 4.3.22.

The development of the solar roof technology with a corresponding cost reduction particularly contributes a great share to the total cost reduction of large scale plants. The collector-roofs combine rafters, insulation, solar collector and roof sealing in one component. This concept is ideal for large connected roof areas and can be optimally integrated into the architecture.

**Table 4.3.1.** Project overview of early German solar assisted heating plants with short-term storage.

| No. | Plant | Heat consumer | Year of con-struction | Total collector area [$m^2$] | Cost referred to collector field area [€ $m^{-2}$] [1]) | Solar energy gain [kWh $m^{-2}a^{-1}$] | Cost/ benefit ratio [€/(kWh/a)] | Solar heating cost [€/kWh] [2]) |
|---|---|---|---|---|---|---|---|---|
| 1 | Ravensburg 1 | DHW, 29 RH | 1992 | 115 | 481 | 443 [3]) | 1.09 | 0.11 |
| 2 | Ravensburg 2 | DHW, 107 DW | 1992 | 190 | 544 | 553 [3]) | 0.98 | 0.10 |
| 3 | Köngen | DHW, 12 RH+60DW | 1993 | 160 | 552 | 433 [4]) | 1.27 | 0.13 |
| 4 | Neckarsulm-Amorbach I | DHN, 325 DW/RH | 1993/94 | 700 | 306 | 508 [4]) | 0.60 | 0.06 |
| 5 | Schwäbisch Gmünd | DHW, 64 DW | 1994/95 | 100 tubes | 913 | 495 [4]) | 1.84 | 0.19 |
| 6 | Ravensburg/ Hochberg | SH/DHW, 50 DW | 1995/96 | 105 | 493 | 428 [4]) | 1.15 | 0.12 |
| 7 | Holzgerlingen | SH/DHW, 56 DW | 1995/96 | 120 | 563 | 500 [4]) | 1.13 | 0.12 |
| 8 | Reinbek | DHW,72 DW (high rise building) | 1995 | 150 | 634 | 360 [4]) | 1.76 | 0.20 |
| 9 | Waiblingen/ Neustadt | Indoor pool | 1995 | 200 | 547 | 500 [4]) | 1.09 | 0.11 |
| 10 | Suttgart/ Burg-holzhof | SH/DHW, ca. 1000 DW | 1998 | 1650 | 389 | 411 [4]) | 0.95 | 0.11 |

[1]) Cost (without VAT), incl. planning.
[2]) 6% rent per year, 20 years of use and 1.5% service or 15 years of use.
[3]) Measurement based values.
[4]) Design values.
Abbreviations: DHW - Domestic hot water; SH - Space heating; DW - Dwellings; RH - Row houses; DHN - Entering in district heating network.

**Fig. 4.3.20.** **(a)** Collector field (115 $m^2$) mounted on a garage in Ravensburg (No. 1 in Table 4.3.1). **(b)** 160 $m^2$ roof integrated collector area in Köngen "Burgweg West" (No. 3 in Table 4.3.1). **(c)** Collector fields of multiple dwellings in Neckarsulm-Amorbach (No. 4 in Table 4.3.1). **(d)** Installation of the collector fields in Stuttgart-Burgholzhof (No. 10 in Table 4.3.1).

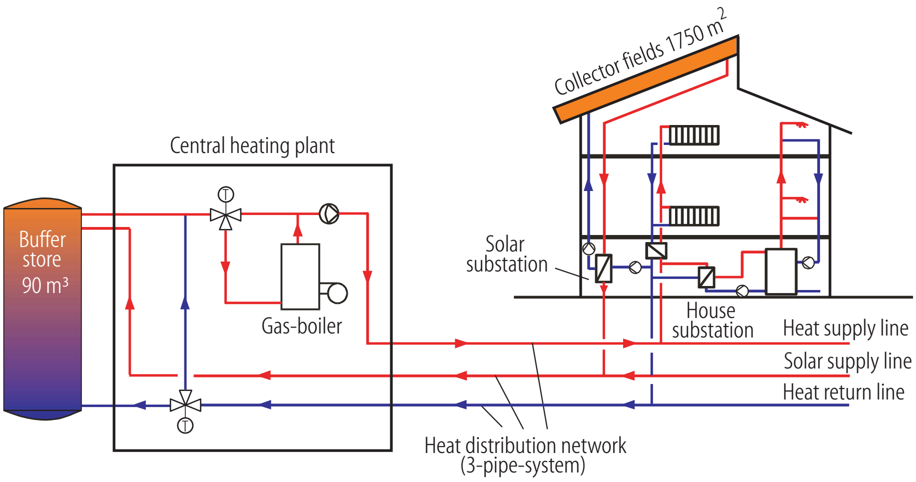
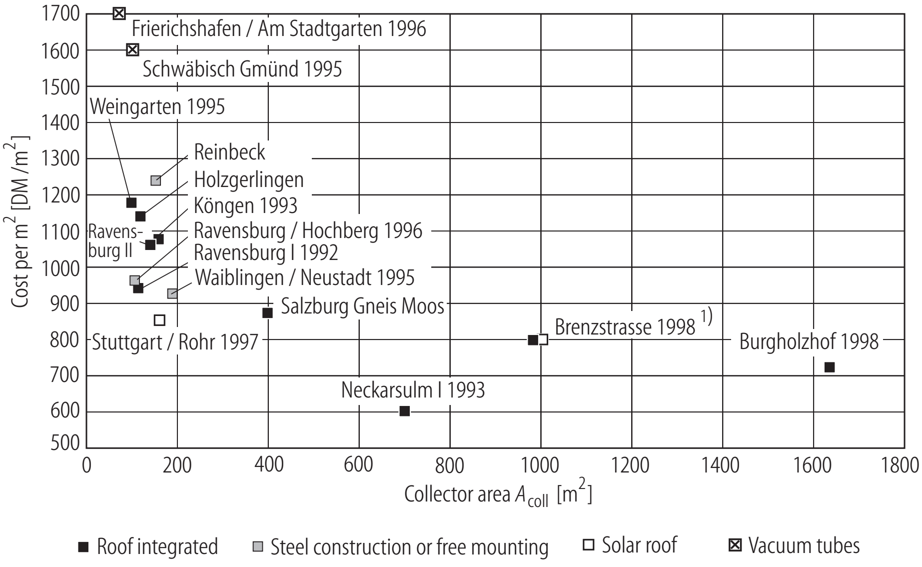



**Fig. 4.3.21.** Scheme of a solar supported district heating system with short-term storage (Stuttgart-Burgholzhof).




[1]) Collector field as solar roof, roof integrated and steel construction.

**Fig. 4.3.22.** System costs of large scale solar plants with short-term storage referred to the collector area incl. planning.

### 4.3.4.3.2 Large scale solar heating with long-term storage

With the integration of a long term storage into the systems, the solar fraction of the energy demand can increase up to 60% (DHW and SH). For a reasonable solution a number of 100 or more dwellings to be supplied are recommended. For technical or economical reasons a volume of 1000 m³ or more has to be planned for a hot water storage (for other storage systems different dimensions are valid). A typical configuration is shown in Fig. 4.3.24. In a warm and sunny period a central storage is heated up to 95°C by the collectors on the roofs of the buildings. During the heating period the warm water from the tank is transported through a network of earth laid pipes to the single buildings. A backup heating system guarantees the intended supply temperature. Heat transfer stations transfer the delivered heat energy into the mains of the buildings.

It is important to integrate all participants in the projects as early as possible. A high level of determination should be reached in the master plan for a residential area (e.g. form of roofs, building distances, building orientation etc.). Demands to thermal insulation, required collector fields or a location for a seasonal storage could be defined right at the beginning of the planning. The incorporation of solar energy into a space-heating-system calls for in integrative concept with an improved thermal standard for the buildings. If possible, the solar plant and the supported district heating should be designed by one hand.

The efficiency of solar district heating systems essentially depends on the degree of the net return temperatures. The aimed return temperature should be lower than 35°C. This requires an adapted building engineering that makes a low temperature-level possible for both the heating system and the tap water heating.

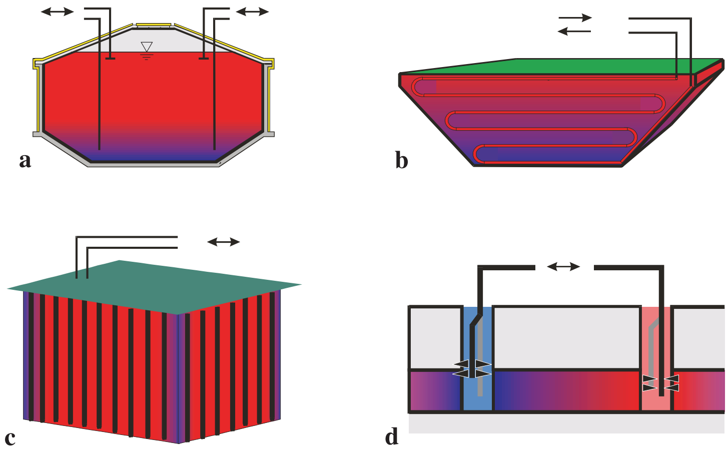



**Fig. 4.3.23.** Different concepts for long term storage. **(a)** Hot-water storage. **(b)** Gravel/water storage. **(c)** Earth-duct storage. **(d)** Aquifer.

The different kinds of *long term storage* are shown in Fig. 4.3.23. As a potential storage medium there is water or the ground or a combination of both. The decision between the two depends on hydrogeological and geological circumstances as shown in Table 4.3.2 as well as on the size of a project.

- *Hot water storage* should be built as cylindrical tanks out of reinforced concrete which are embedded in the ground. Alternative materials for the tanks may be steel or plastics reinforced with glass-fiber. They should be insulated on flanks and ceiling, thermal losses on the colder floor slab are accepted for statical reasons. The insulation has to be protected against hydrological influences. An inner lining of steam tight steel (1.2 mm) or a realization with nearly steam tight concrete [98Rei] could be used. On the outside a drain should be fitted. Furthermore the insulation material should be resistant against water and temperatures up to 100°C. The maximum storage temperature should be restricted to 95°C.
- For a *man-made aquifer* a mixture of gravel and water is the ideal storage medium. A water proof pit should be filled layer by layer with the mixture and covered with insulation and topsoil. A supporting structure is not needed. If possible the storage should be insulated on all sides. The feed and drain may directly flow through the storage or it may be led through flexible pipes between the layers. The maximum storage temperature should be restricted to 95°C because of the thermal resistance of the proofing materials. Instead of gravel even earth could be used as a storage medium.
- Soil or even rocks are the storage medium of *earth-duct storage*. The load flows through so called U-pipe-probes – coaxial heat exchanger ducts – which are embedded into drilled holes. Insulation is only possible on the entry. The earth-duct storage is suitable only for bigger volumes. The maximum storage temperature is 80°C because of the high losses. One great advantage of this concept is the possibility of expansion.
- In an *aquifer* storage natural ground water layers are used to store thermal energy. The layers have to be (naturally) sealed above and below, so a geological analysis is recommended in the design phase. The heat is directly brought into the layer through a drilling hole and also withdrawn. Insulation is not possible, because the proper layers are normally at a depth of 100 m below the surface. Regarding the high investment costs, a volume bigger than 100000 $m^3$ has to be designed [03Ben].

Additionally, the construction of the seasonal storage must be further developed. At present costs from between 75 and 100 € per $m^3$ water equivalent could be predicted, whereby the costs fall with rising storage capacity. Hence, a solar district heating plant is the more economical the larger the area to be supplied.

**Table 4.3.2.** Properties of different storage media ($k_f$: permeability value of ground).

| Type of storage | Capacity [kWh m$^{-3}$] | Type of ground; necessary depth [m] | Ground water table | Permeability of the ground |
|---|---|---|---|---|
| Hot water | 60-80 | Self standing; 10-15 | Without groundwater | With groundwater sealed, otherwise no requirements |
| Gravel/water | 40-50 | Self standing; 5-15 | No groundwater if possible, otherwise low flow speed | With groundwater sealed, otherwise no requirements |
| Earth-duct | 15-20 | Drillable, even rocks; 25-100 (depending on volume) | Groundwater favorable, low flow speed | With groundwater sealed ($k_f$ ca. $10^{-8}$ up to $10^{-12}$ m/s) |
| Aquifer | 30-40 | Proofed above and among with sealing soil strata (20-50 m strong) | Groundwater needed, low flow speed | High permeability, $k_f > 10^{-4}$ m/s |

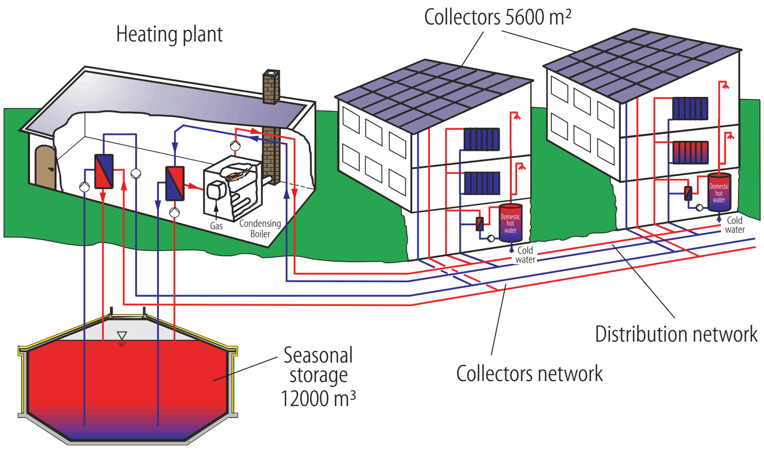



**Fig. 4.3.24.** System scheme of a solar plant with (seasonal) long term storage for district heating in Friedrichshafen, Germany.

### 4.3.4.4 Project examples

#### 4.3.4.4.1 Pilot project "Friedrichshafen-Wiggenhausen"

At the end of 1996 the first large-scale solar heating plants in Germany with seasonal storage started operation in Hamburg and Friedrichshafen. Figure 4.3.24 shows the schematic layout of the solar heating district in Friedrichshafen-Wiggenhausen. The plant in Hamburg-Bramfeld is technically very similar, so only the plant in Friedrichshafen will be regarded in the following text.

The area in Friedrichshafen is composed of 8 four-storied building blocks with approx. 570 dwellings, half of which were finished in the first phase of construction (see Fig. 4.3.25a). In Friedrichshafen the solar collectors on the roofs are run by the central heating with a water/glycol mixture. The collector circuit is coupled into the storage with a heat exchanger. In this way the stored water forms a closed system which is heated up to temperatures between 40 and 90°C by the solar collectors. The discharge from the storage is realized by a second heat exchanger coupled into the heating system. The supply line from the storage passes through the central heating plant and serves the district heating distribution network.

Figure 4.3.26 shows a schematic cross section of the heat storage (volume 12000 $m^3$): the concrete ceiling is conically shaped and does not need, unlike the storage in Hamburg, any pillars. It consists of a supporting structure of reinforced concrete with an outside heat insulation of mineral fiber. The insulation is only fixed at the vertical walls (ca. 30 cm) and at the ceiling (ca. 40 cm). The inside of the concrete container is lined with a steam tight 1.2 mm plate of stainless steel. The building cost referred to the volume amount to 123 €/$m^3$.

The end-use energy index (annual fuel consumption per $m^2$ residential area) for the project in Friedrichshafen accumulates to 55 kWh $m^{-2}a^{-1}$. The investment costs for the complete system in Friedrichshafen work out at about 5600 € per dwelling. The solar heat prices are approx. 0.15 €/kWh (Friedrichshafen) as a consequence, twice as high as costs for large-scale systems without seasonal storage. This demonstrates the necessity of economic storage concepts and clarifies that further research and development must be done. The first operation experiences and measured results of the first two solar district heating plants with seasonal storage are described in [98Ebe], [98Sta], [98Sch].



**Fig. 4.3.25. (a)** First phase of construction of the housing scheme with multiple dwellings in Friedrichshafen-Wiggenhausen. **(b)** Seasonal storage in Wiggenhausen under construction.

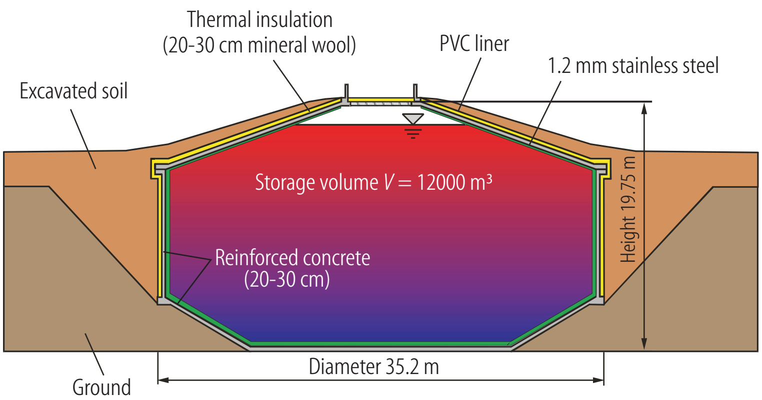



**Fig. 4.3.26.** Section through the hot water storage in Friedrichshafen ($V = 12000$ $m^3$).

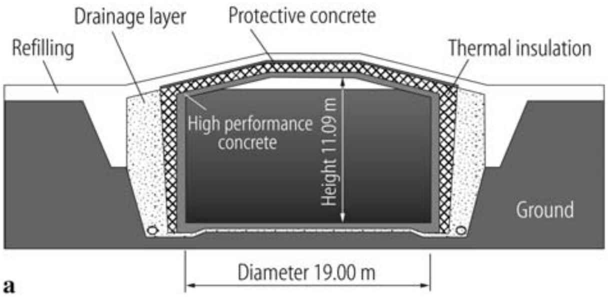




**Fig. 4.3.27. (a)** Simplified cross section of the storage in Hanover-Kronsberg. **(b)** Finished area surrounding the storage with a playground.

### 4.3.4.4.2 Solar district heating in Hanover-Kronsberg

As part of the World Exposition EXPO 2000, a solar assisted district heating system for 106 residential units was put into operation in Hanover-Kronsberg in the beginning of June 2000. Up to 40% of the heat demand for space heating and domestic hot water should be covered by solar energy. For this purpose, 1470 $m^2$ of roof-integrated collectors were installed and a hot water storage with a volume of 2750 $m^3$ was erected. The seasonal storage was the third of its kind in Germany and was constructed as a concrete cylinder with a roof which was formed as a conical shell, see Fig. 4.3.27a. The internal diameter reaches about 19 m with a maximum interior height of approx. 11 m. The storage was build 120 m away from the central heating unit.

For the construction of the storage in this project a high performance concrete (which is nearly steam diffusion tight) was used for the first time [98Rei]. The bi-functional concrete not only carries the load but also has the function of waterproofing. The annual water loss caused by water steam diffusion amounts to about 4 l per $m^2$ storage surface. In this case no interior stainless steel liner was needed as used at the storage constructions in Friedrichshafen-Wiggenhausen and Hamburg-Bramfeld. Due to the water loss a water resistant insulation was necessary. Therefore, wall and roof of the storage were insulated on the outer side with pressure resistant recycling glass-granulate. The insulation thickness in the wall area increases from 30 cm at the bottom to 70 cm at the top. The roof insulation is 70 cm thick. The storage was integrated in a playground (see Fig. 4.3.27b).

The solar energy is collected by a collector system with a total area of 1470 $m^2$. The roofs which are orientated southwest- and southeastwards were pre-assembled “solar-roofs”. The heat is transported from the common collector circuit to the heating central which is situated in the cellar of a residential building. A heat exchanger is used to charge the storage circuit. The heat can either be directly used to pre-heat the water in the distribution network or it is stored in the seasonal storage. The storage can be charged and discharged at three levels, which allows simultaneous loading and unloading of the storage. If the discharged heat of the seasonal storage does not have a sufficient temperature, additional heat is supplied by the heat distribution network of the entire estate Kronsberg, which is connected to a heat and power plant.

The solar assisted district heating system in Hanover-Kronsberg has been in operation since June 2000. It has worked fail-proof apart from minor leaks in the piping of the collectors.

### 4.3.4.4.3 Neckarsulm-Amorbach – an extensible long term storage

Amorbach is a suburb of the city Neckarsulm in Germany. A new housing area had been projected and the local authorities decided that all houses in the settlement would have to fulfill a 25% better insulation standard as the actual building code requires. Furthermore a high solar fraction of more than 50% was anticipated by combining the reduced energy demand of the houses with solar heat and seasonal storage. The housing estate is developed in several steps (see Table 4.3.3 and Fig. 4.3.28).

**Table 4.3.3.** Overview of development in Neckarsulm.

| | Step I | Step II | Final |
|---|---|---|---|
| Realization | 1995-1999 | 2000-2003 | ca. 2010 |
| Residential units | 115 + school + business | + 116 | 739 |
| Power [kW] | 930 | + 960 | 4830 |
| Heat demand [MWh a$^{-1}$] | 977 | + 1870 | 8754 |
| Collector area [m$^2$] | 2637 | + 3700 | 12000 |
| Storage volume [m$^3$] | 20200 | + 43200 | 115000 |

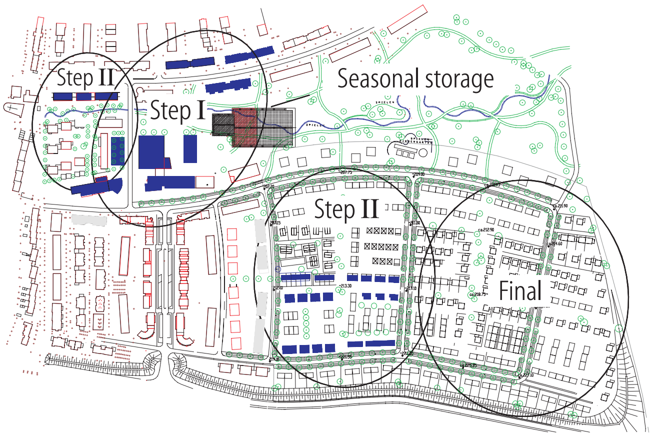



**Fig. 4.3.28.** Neckarsulm-Amorbach Solar City.

At the moment the first two steps are completed. In the end a quite large area with about 740 residential units will be connected to the central heating station with seasonal storage. In step I, 2640 m$^2$ of collector area have been installed on the roof of multi-family buildings, a school with sports hall, a shopping center and a residence for elderly people. In the second step, another 3700 m$^2$ collector area (2600 m$^2$ are supported by the EU) have been installed on top of a parking lot and on attached houses. In the end a collector with a total area of 12000 m$^2$ will be constructed. Surplus solar heat in summertime is stored in a seasonal duct storage (Fig. 4.3.29). For the first time a so called three-pipe district heating net was realized. In the usual 2+2 pipe systems, 2 pipes are required for the heat distribution and another 2 pipes for the collector net. In Neckarsulm one pipe is used either for the heat return (winter) or the collector return (summer), thus reducing the cost and heat losses for the district heating net.

During the construction of the first step, the building area of step II and III were modified. Because of the market situation, larger multi-family blocks were replaced by terraced houses. In the course of modification the building-orientation was changed from north-south to west-east to enlarge the usable roof area for solar collector application.

Originally the duct storage was designed for a depth of 50 m. Because of an unexpected ground water layer in 35 m depth, the U-tube heat exchangers are now limited to 30 m, which leads to a slightly lower performance of the storage. The storage is in operation since end of 1998. In the first years of operation the heat losses are higher than in the final, steady state status. Figure 4.3.30 shows the calculated temperature distribution inside the seasonal storage for steady state performance. Contrary to water storage a radial stratification instead of a horizontal stratification takes place. Ducts in the center of the storage are hotter than ducts at the edge of the storage.

In Fig. 4.3.31 a forecast of the heat balance for the constructed system including step II (6300 m$^2$ collector area, 63000 m$^3$ storage) is given. The solar yield (i.e. the used energy going into the district heating net) will be approx. 225 kWh m$^{-2}$a$^{-1}$, i.e. 50% of the total heat demand.

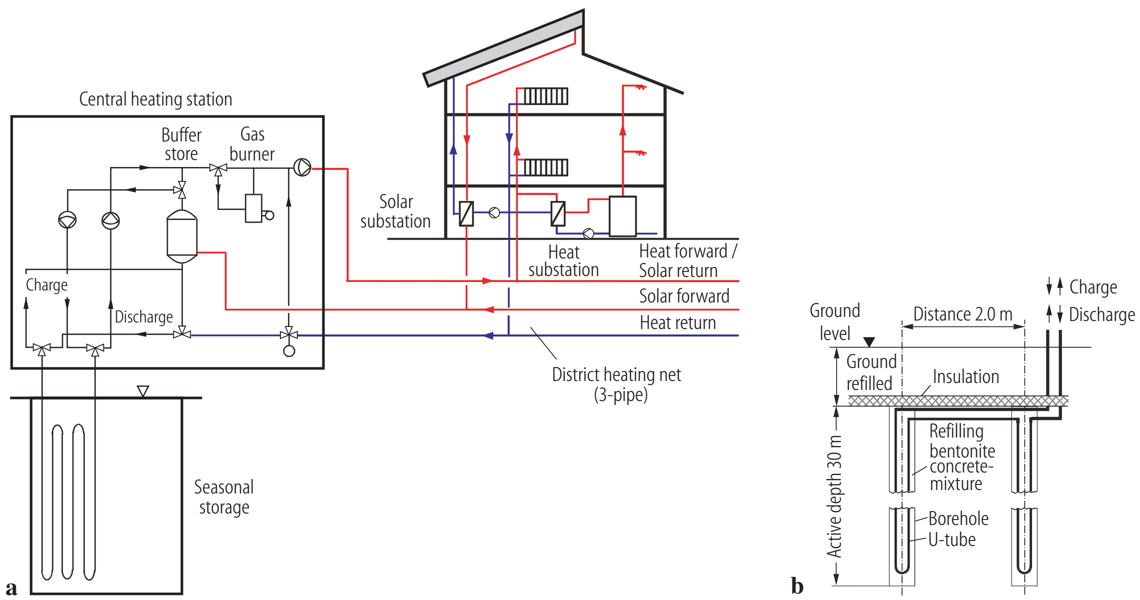



**Fig. 4.3.29. (a)** Hydraulic scheme of the solar heat system in Neckarsulm. **(b)** Detailed scheme of an earth-duct storage (source: ITW, University of Stuttgart).

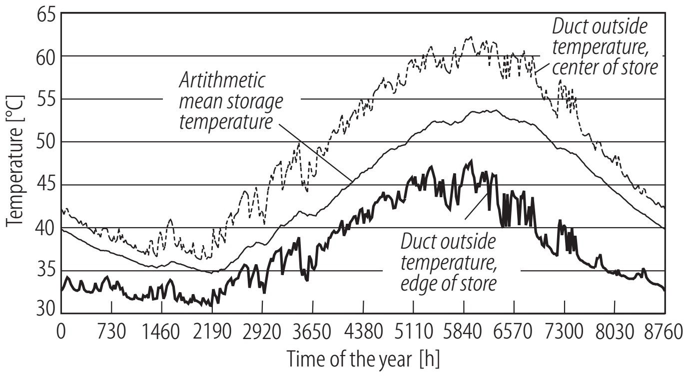



**Fig. 4.3.30.** Simulated temperatures in the storage (source: ITW, University of Stuttgart).

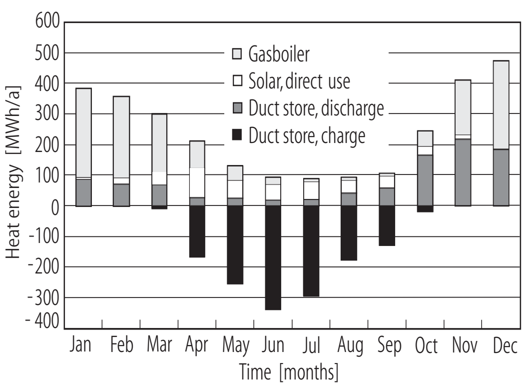



**Fig. 4.3.31.** Heat balance Step I+II (source: ITW, University of Stuttgart).

#### 4.3.4.4.4 Hannoversch Münden

In the context of the research project "$CO_2$-neutral heat supply for residential areas", a study was taken out for three existing multi-family buildings and an office building. In this study the buildings had a total energy demand of 312 MWha$^{-1}$ or 97 kWh m$^{-2}$a$^{-1}$, including the demand for domestic hot water preparation, and the dwellings had been supplied with single gas boilers before the retrofitting in 2005. Within the retrofitting a district heating with a combination of a wood-pellet boiler and a solar plant with 102 m² collector area is installed. With this field of vacuum tube collectors the plant reaches a solar fraction of 14% of the total energy demand.

The central heating unit is located in an extension of the office building (see Fig. 4.3.32). In addition to the four storage tanks in the heating central/station, separate storages are installed in the buildings. The DHW-preparation works with tap water in the direct flow principle (see Fig. 4.3.33c). In the same way the collectors are directly supplied with heating water, i.e. water with a glycol mixture. A special steering/regulation was integrated to avoid freezing.

The first two storage tanks are already in use (see Fig. 4.3.33b), and the solar collectors will be mounted in 2006. The tap water stations are monitored and optimized in regulation and functionality.

#### 4.3.4.4.5 Comparison of the above mentioned projects

The planning data of the residential areas, the climatic conditions at the site and the interpretation parameters of the solar plants are compiled in Table 4.3.4.

**Table 4.3.4**. Interpretation of the data of the residential areas and solar plants in Friedrichshafen, Hamburg, Neckarsulm and Hannoversch Münden.

| Residential area | Friedrichshafen | Hannover | Neckarsulm | Hannoversch Münden |
|---|---|---|---|---|
| Building type | Multistorey | Multistorey | Multistorey | Multistorey |
| Number of buildings/dwellings | 8/586 | 6 | 6 | 4/49 |
| Total living area [m$^2$] | 39500 | 20000 | 20000 | 2795 |
| Heat insulation standard | 20% < WSVO95 | | | EnEV |
| Total gas consumption [MWh a$^{-1}$], reference without solar | 4106 | 1663 | 1663 | 366 (with pellets) |
| Referred to living area [kWh m$^{-2}$a$^{-1}$] | 104 | 83 | 83 | 131 |
| Climate | | | | |
| Heat degree days [K d] | 3717 | | | |
| Global radiation (horizontal plane) [kWh m$^{-2}$a$^{-1}$] | 1177 | | | 1041 |
| Solar plant | | | | |
| Collector area [m$^2$] | 5600 | 1350 | 2700 | 102 |
| Storage volume [m$^3$] | 12000 | 20000 | 20000 | 6.6 (short term) |
| Supply/return running temperature [°C/°C] | 70/40 | | | 80/50 |
| Gas consumption (incl. solar) [MWh a$^{-1}$] | 2191 | | | 313 |
| Referred to living area [kWh m$^{-2}$a$^{-1}$] | 55 | | | 112 |
| Solar fraction (dimensioning) [%] | 47 | 38 | 50 | 14.4 |


**Fig. 4.3.32.** Site plan of Hannoversch Münden.

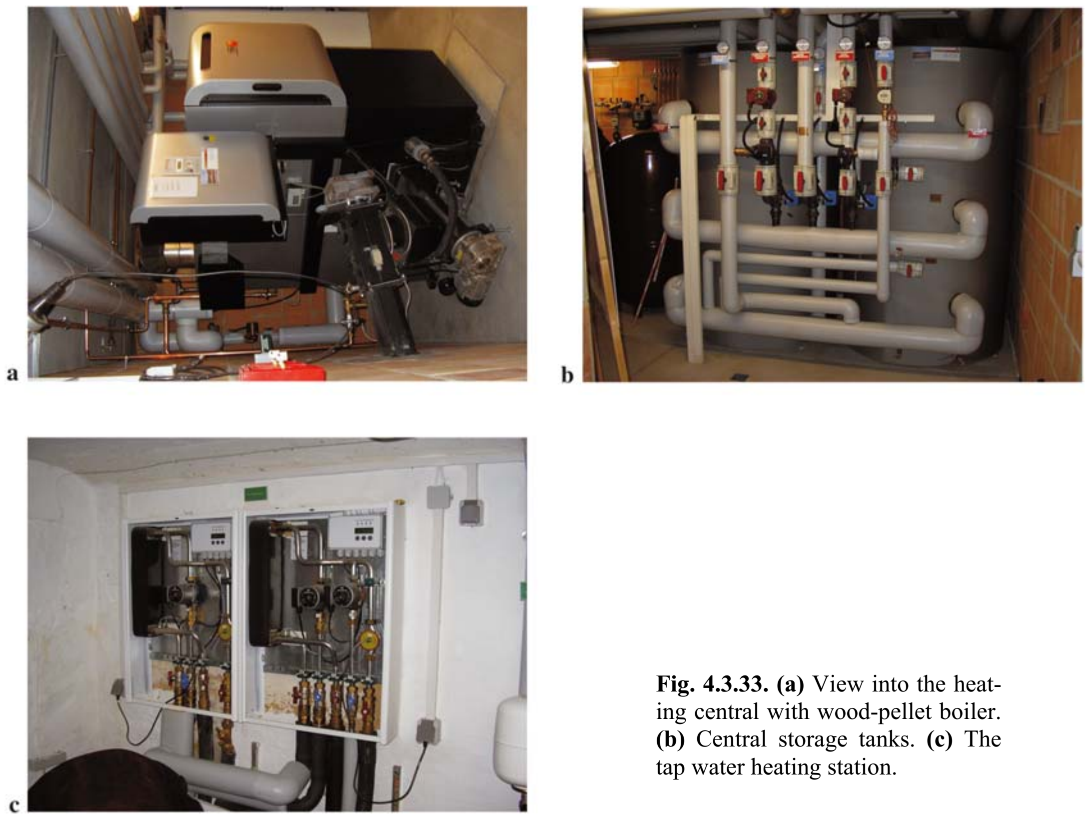


**Fig. 4.3.33. (a)** View into the heating central with wood-pellet boiler. **(b)** Central storage tanks. **(c)** The tap water heating station.

## 4.3.5 Market development and potential of solar thermal plants

### 4.3.5.1 Cost development of small scale solar thermal plants

The positive developments of the nineties regarding the thermal use of low-temperature solar energy (< 100°C) are marked by product improvement, power increase and considerable cost reduction of components and systems. The decisive aspects are innovative and at the same time simple ("as simple as possible") and by this means also economical solutions. In the last ten years the small plants have turned out to be highly reliable and are economically efficient because of continuous improvements of the components and of the offered standard systems.

The development of yearly installed collector areas in Germany is shown in Fig. 4.3.34 (swimming pool absorbers are not even numbered). Since the early nineties the increase of the collector market is mainly influenced by the discussion about climate change due to the emissions of carbon dioxide by fossil fuels. Subsidy programs ranging from 15 to 20% of the total costs have supported the market introduction for years. From 1995 to 1997 yearly increase rates of more than 20% were achieved in Germany. In 2001 about 900000 $m^2$ of collector area were sold. Among them the main part of 86% were flat plate collectors and circa 14 % were vacuum tube collectors. In 2002 subsidy programs changed and the market significantly slowed down. The price development of fossil fuels leads to a new rise, though. In 2005 a cumulated collector area of 6.7 million $m^2$ is installed in Germany, which corresponds to 4690 $MW_{th}$.

With an increase of the installed collector area, a reduction of plant cost could also be achieved. For the installation of a solar plant for domestic hot water in a four person household with a solar fraction of about 50% a customer had to pay about 8800 € in 1995. In 2002, the price still is 6100 € (average including mounting and VAT) for a typical plant size with DHW-preparation , a collector area from 4 to 6 $m^2$ with flat plate collectors or 3 up to 4 $m^2$ with vacuum tubes, respectively. The cost reduction of about 31% mainly resulted from a cost reduction of the single components, whereas the mounting cost did almost not change. Plants which support heating usually have a collector area of 8 to 15 $m^2$.

The future cost development can be estimated from the observation of the previous market development. Figure 4.3.35 shows the learning curve for small plant prices and the previous course due to market growth and product development. The development after 2002 shows a decrease in demand and higher production cost. Hence for small plants a further cost reduction was expected but not achieved. This is reasoned by the relatively high wages in Germany and again by more expensive energy costs in production and transport as well.

Considering the further development of installed collector area, an annual installation of about 1.5 million m² can be expected, assuming that approx. 500000 heating plants must be retrofitted or installed, respectively, every year and that every second plant will be equipped with about 6 m² of collector area. In comparison with the previously realized numbers, this shows a clear increase and lets us expect a further strengthening of the branch for the future.

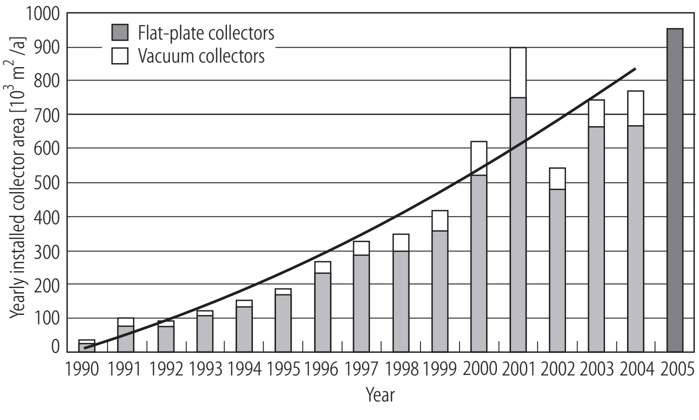



**Fig. 4.3.34.** Yearly installed collector area in Germany (source: Deutscher Fachverband Solar).

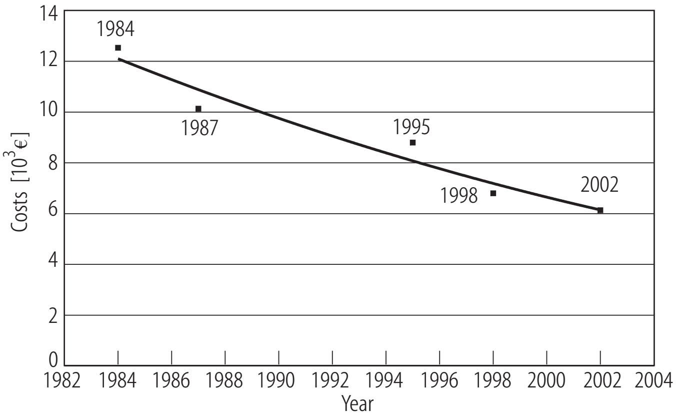



**Fig. 4.3.35.** Learning curve of the plant price for small plants for DHW preparation incl. installation and VAT (source: Stiftung Warentest, based on 01/2002 prices).

### 4.3.5.2 European solar thermal market

During the last decade the solar thermal market in Europe has constantly grown. On average the number of glazed solar collectors sold annually grew by 14% from 1994 to 2001. In 1994 about 480000 m$^2$ of glazed collectors were sold, and seven years later the yearly market were nearly quadrupled (1.7 Mio. m$^2$, see Fig. 4.3.36). The total collector area in Europe has more than doubled from 4.5 to 11.1 Mio. m². The use of solar energy for domestic water and room heating has developed out of a market niche into a small industrial branch within the last 25 years. But the political targets are clear: In 2001 the White book "Renewable Energies" [01KEG] passed the European Commission and prescribed an installed collector area of 100 Mio. m² for 2010. To reach this benchmark the annual growth has to be doubled from 14 to 28%.

Within the European solar thermal market the contribution of installed collector area and capacity in the individual European countries varies wildly. Figure 4.3.37 shows this share of the European solar collector market in 2003. Almost 75% of the installed capacity installed in Europe were sold in Germany, Greece and Austria. France and Spain follow with about 450000 m$^2$ each and are in competition for the fourth place. All other countries have market shares of less than 4% each, amounting to less than 20% of the European market. But even in leader countries like Germany or Greece, there is still a large unexploited potential, despite widespread solar campaigns or a well established solar plant market.

Overall there is still much work to be done to give the European solar thermal markets the drive they need to reach the targets set. The industry has only started to move into these energy markets. Solar technology is more and more frequently on offer from conventional heating technology traders which helps the market to grow substantially. The increasing information and motivation of the population is also important. Hence the development of a country's solar thermal market depends on the following factors:

- Motivation of the population;
- Improvement of the cost/benefit ratio;
- Technical product development;
- Effective distribution and sales network;
- Education and training programs for salesmen, planers, installers, etc.;
- Demonstration projects/architecture competitions;
- Subsidy programs as incentives to install a solar plant.

The experiences of the more advanced countries show that it takes more than a product and a subsidy program to help solar energy becoming an interesting part of household technology. There must be a wide offer of adapted products, integration in the heating technology market and development of distribution nets, acceptance and training of specialists as well as the motivation of the population induced by subsidy programs, information and image campaigns. In addition new market segments have to be opened up beyond hot water supply in private households, for example solar heating, large-scale solar plants and solar cooling. They will all play important roles in the solar economy of the 21st century.

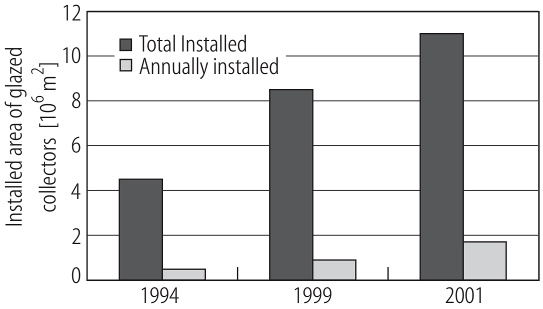



**Fig. 4.3.36.** Development of the solar collector market in Europe [05Wei].

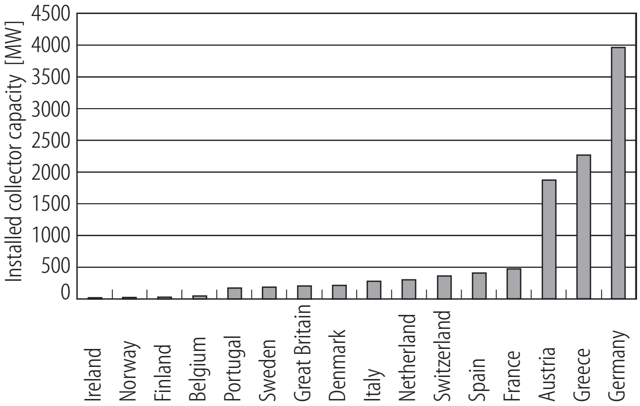



**Fig. 4.3.37.** Share of the European solar collector market in 2003 [05Wei].

## Note of thanks

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