Thermal Energy Storage

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Keywords: The role of thermal storage in heating systems. Physical principles. Storage materials and capacity. State of the art of storage technologies. Hot water storage: concepts, design and system integration. Large sensible heat storage for central solar heating plants. Indirect heat storage for solar energy: bioenergy and ambient heat. Summary and conclusion.

1. Background

The need of thermal energy storage may often be linked to the following cases:

- there is a mismatch between thermal energy supply and energy demand,
- when intermittent energy sources are utilized, and
- for compensation of the solar fluctuation in solar heating systems.

Possible technical solutions to overcome the thermal storage need may be the following:

- building production over-capacity,
- using a mix of different supply options,
- adding back-up/auxiliary energy systems,
- only summer-time utilization of solar energy,
- short/long-term thermal energy storage.

In traditional energy systems, the need for thermal storage is often short-term and therefore the technical solutions for thermal energy storage may be quite simple, and for most cases water storage.

There are three main physical ways for thermal energy storage: sensible heat, phase change reactions and thermo chemical reactions. Storage based on chemical reactions has much higher thermal capacity than sensible heat but are not yet widely commercially viable. Large volume sensible heat systems are promising technologies with low heat losses and attractive prices.

2. Physical principles of thermal energy storage

When a thermal storage need occurs, there are three main physical principles to provide a thermal energy function:

- *Sensible heat*
  The storage is based on the temperature change in the material and the unit storage capacity [J/g] is equal to heat capacitance × temperature change.

- *Phase-change*
  If the material changes its phase at a certain temperature while heating the substance then heat is stored in the phase change. Reversing, heat is dissipated when at the phase

change temperature it is cooled back. The storage capacity of the phase change materials is equal to the phase change enthalpy at the phase change temperature + sensible heat stored over the whole temperature range of the storage.

- *Chemical reactions*
  The sorption or thermo chemical reactions provide thermal storage capacity. The basic principle is: AB + heat $\Leftrightarrow$ A+B; using heat a compound AB is broken into components A and B which can be stored separately; bringing A and B together AB is formed and heat is released. The storage capacity is the heat of reaction or free energy of the reaction.

Figure 1 illustrates the change of storage capacity Q for the three different thermal storage types as a function of temperature or fraction of compound (X=B).

The storage systems based on chemical reactions have negligible losses whereas a sensible heat storage dissipates the stored heat to the environment and need to be isolated.

3. Storage materials

Materials are the key issues for thermal storage. There are a large range of different materials that can be used for thermal storage as shown by Table 1. The most common storage medium is water. The classical example for phase change materials is the Glauber salt (sodium sulphate). Metal hydrides are well-known hydrogen stores in which hydrogen is absorbed into the metallic structure with the help of heat, or turning it around, adding hydrogen would release heat and removing hydrogen absorb heat. In this way metal hydrides also work as thermo chemical heat storage ($AB=MeH_x$).

One of the most interesting physical parameters of a thermal storage is its storage capacity and temperature range. These two parameters determine the size and suitability of the storage to an application, respectively. Table 2 gives a summary of the storage capacity and temperature range for some important potential storage materials.

Sensible heat energy storage has the advantage of being relatively cheap but the energy density is low and there is a gliding discharging temperature. To overcome these disadvantages *phase change materials* (PCM’s) can be used for thermal energy storage. The change of phase can be a melting or a vaporization process. Melting processes have energy densities in the order of 100 kWh/m^3 compared to 25 kWh/m^3 for sensible heat storage. Vaporization processes are combined with a sorption process. Energy has to be withdrawn at a low temperature when charging and be delivered at a high temperature when discharging the storage. Energy densities in the order of 300 kWh/m^3 can be achieved.

The storage capacity of water in a typical house heating application is about 60 kWh/m^3. For comparison, the storage capacity of oil is about 10 MWh/m^3. Phase change materials (PCM) based on hydrates or fatty acids have a phase change heat of the same order as the whole storage capacity of water. If adding the sensible heat of the PCM then the storage capacity of the PCM would be doubled.

Phase change materials can be incorporated into building materials and thus contribute to lower energy consumption and power demand by storing solar energy during the day and storing cold at night.

As the PCM has a sharp change in the storage capacity at a single temperature point (phase change temperature), it can be used for temperature regulation. For example, mixing PCM into the building material could increase the thermal capacity of a wall manifold. A wall has typically an effective ΔT of around 10-15 ^{o}C which gives a storage capacity of 10 kWh/m^3 which is about 1/5th of that of paraffin. Mixing two different PCM's in a suitable proportion gives the possibility to match the phase change temperature exactly with the temperature of the application.

PCM's can also be includes in containers of different shapes. One common container is the plastic capsules (SLT) that is put into a tank where the heat transfer fluid (usually) water melts or solidifies the PCM. Several different PCM's with melting points ranging from -21°C up to 120°C are commercially available. Phase change materials and chemical reactions are also used for heating and cooling purposes in small applications like hand warmers (sodium acetate trihydrate).

Thermo-chemical storage materials have the highest storage capacity of all storage media. Some of the materials may even approach the storage density of biomass. Solid silica gel has a storage capacity which is up to about 4-times that of water.

Water storage is the main commercially available thermal storage systems. Small PCM storage units have been sold mainly for special applications. Both PCM and thermo chemical storage needs still R&D efforts to be practical.

Storage is a critical component of systems providing both space heating and hot water production. In order to achieve high efficiency both at an acceptable cost and in a "marketable" volume, a suitable material for high-density thermal storage should achieve at least triple the storage capacity of water in order to be a significant breakthrough. Such a material has not been found yet. Fundamental (chemical and physical) research is needed to find a material which can meet the requirements. Potential candidates materials include micro-encapsulated PCM (phase-change materials) and selective water sorption materials; Figure 2. The „sodium sulphide system" promises a potentially high energy density, but faces some problems concerning heat and mass transfer, corrosion, toxicity and vacuum tightness.

The *sorption or thermo chemical reactions* provide heat at different temperatures within different periods. For long-term store of solar heat the adsorption of hydro vapor in Silica gel is used Figure 3. The development of sorption storage for market deployment in the areas of long-term storage for solar energy as well as for peak load storage for co-generation plants, heat pump systems and district heating is coordinated both within EU- and IEA-Research Programmes at international level. Some prototypes are in the design and testing phase; Figure 4.

The main goal of a new international research project in the framework of the IEA-Solar Heating and Cooling Programme (TASK 32) is to investigate new or advanced solutions for storing heat in systems providing heating or cooling for low energy buildings.

4. Water storage technology

Possible "sensible heat" storage media are liquid (especially water) and solid materials (especially soil and stone).

The *hot water tank* is one of the best known thermal energy storage technologies. The hot water tank serves the purpose of saving energy when applied to, e.g., a solar tap water system or an energy supply system with cogeneration. The major aim of an electrically heated hot water tank in a tap water system is to shave the peak in electricity demand and consequently improve the efficiency of electricity supply.

Water tank storage technology has become mature and reliable; Figure 5a and b. Storage as sensible heat in water is still unbeaten regarding simplicity and cost. Further development of water storage could be focus on improving the storage efficiency by means of ensuring optimum stratification in the tank and vacuum insulation.

4.1 Design of water heat storage and system integration

The implementation of thermal storage in a heating system is of great importance for effective use of the intermittent solar radiation. Water tank concepts are one-storage and multi-storage systems adjusted to loading and discharging strategies with collector characteristics and the heat demand. Through thermal layers and loading of several storages according to priorities, respectively, a favourable as possible adjustment between solar heat and the effect of the solar installation is aimed at. This type of storage represents an ideal thermal storage. The inlet/outlet levels can be changed and may be considered as an advanced solar system for domestic hot water and space heating concept. Thermally stratified water tanks improve the annual system efficiency by about 20% and more. Figure 6 illustrate the principles of storage concepts.

For the thermal storage of solar energy via *sensible heat storage* short-term storage, mid-term and long-term storage, dependent on storage capacity, are offered.

Energy storage for intermittent thermal sources such as solar heating is important as the storage demand may be quite long. Especially, if the solar heating system is intended to provide a high solar fraction, i.e. most of the heat supplied over the whole year is solar heat, thermal storage becomes very important and challenging.

The storage need in a solar system is often determined by the ratio of the maximum to minimum monthly solar radiation; Figure 7. When the max-min ratio is less than 5, even wintertime solar may be enough to provide the heat load whereas values higher than 10 means such a large fluctuation that seasonal storage or back-up system is necessary. In high northern-Europe, the winter solar radiation falls under the utilization limit.

- **Short-term storage**

The storage volume (hot water tank) of a solar hot water system will generally be between 1,5 and 2,0 times of the daily hot water demand. With short-term storage, too, a sufficient insulation has to be provided to minimize the heat losses within the system.

The efficiency of a solar thermal system is to a large extend defined by the heat demand (amount of hot water). With increasing heat demand the heat output per collector area rises and thus the heat costs are reduced. Figure 8 shows the design of collector area and storage volume for hot water preparation in an apartment house, and Figure 9 illustrates the relations of collector output and solar share. With the increase of the number of flats and thus the increase of hot water demand the specific collector area output rises, whereby the heat production costs decrease. The relation between collector area and heat costs is shown in Figure 10 for a detached house. These relations give important advices for an energy-economic design of solar hot water systems.

The solar share for hot water preparation should be about 50% to 70% (single-family-house) and about 40% to 50% (apartment house) in the annual average, which means that in summer the solar share rises up to 80% and more. To reach this aim, collector area and storage volume have to be planned according to Figure 9 and Figure 10.

- **Mid-term storage for solar supported district heating**

In order to cover the heat demand for hot water in district heating outside the heating season mainly by solar systems a thermal storage with a capacity for 3 to 5 days has to be installed; Figure 11; housing estate Gneiss-Moos/Salzburg. Even if, according to project data of a solar supported district heating plant - Figure 12 a and 12b -, the solar share for *space heating and hot water preparation* at the annual average is of about 14 %, the *solar share for hot water preparation* outside the heating season is more than 80%.

- **Mid-term storage for solar supported space heating systems**

Mid-term storage are used for solar combined heating systems: *Solar-Combisystems*. The solar contribution, i.e. the part of the heating demand met by solar energy varies from 10% for some systems up to 100% for others, depending on the size of the solar collector, the storage volume, the hot water consumption, the heat load of the building and the climate; Figure 13.

The design of collector area and storage volume as well as the storage strategy are of great importance for both the system-efficiency and the solar contribution. If the solar system is combined with a space heating system, the collector area as well as the storage volume have to be increased. In this case there exists some unused solar heat in the period without space heat demand. An efficient use of solar heat can be reached if an additional heat demand exists during the summer period. Typical examples are the operation of an outdoor swimming pools or the heating up of soil by operating a solar supported ground-coupled heat pump system. In cold climates as well as in alpine areas solar heat will provide the living quality also during the summer period.

In countries such as Switzerland, Austria and Sweden in which solar combisystems are preferably coupled with a biomass boiler, larger systems with high fractional energy savings are encountered. Typical systems for a single-family house consist of 15 m² up to 30 m² of collector area and a 1 m³ to 3 m³ of storage tank. The share of the heating demand met by solar energy is between 20% and 60 %; Figure 14.

Combining solar heating systems with short-term heat storage and high standards of thermal insulation allows the heating requirements of a single- or multi-family dwelling to be met at acceptable costs. Compared with systems using seasonal storage (the costs of which are currently not affordable for single-family houses), this combination provides a cost-effective system with high efficiency.

Generally, all conventional heating systems can be combined with solar systems. For *Sustainable Housing* renewable energy sources should be favoured. There exist three options.

Combination with:

- biomass boiler, e.g. pellets-boiler
- heat pump system, e.g. ground-coupled
- heat recovery system with air-heat pump, preheated through a ground heat exchanger.

New products on the market are integrated water storage for solar thermal collectors and gas-burner (Figure 15) as well as pellets burner; Figure 16 a and b.

- **Long-term storage for solar space heating**

Because of the discrepancy between solar radiation and space heat demand *monovalent* solar space heating in cold and temperate climates is only possible if a long-term thermal storage with a heat capacity of at least six months in existing housing and of about four month in low-energy housing is provided.

The application of hot water storage (water tanks made of concrete or steel) for seasonal storage require, even for a one-family house in low-energy building standard, a storage volume of about 80 m^3 in combination with a collector area of about 80 m^2. Figure 17 shows the energy balance of a solar system with seasonal storage for a one-family house. It was possible to realize a few pilot projects in Austria, for a market penetration on a large scale the costs are too high.

To increase the solar fraction in the traditional active solar heating system for a residential housing, would in practice require larger storage capacities than usually used. If for instance all of the heating demand load of a well-insulated house would be supplied by a up-to-date active solar heating system, a 25 m^2 collector area and 85m^3 storage water tank with 100 cm insulation around would be; Figure 18. This example demonstrates well the present technological state for single houses: the solar collector technology is already sufficient, but the storage technology is still too primitive and needs major improvements. Improving the energy storage capacity of the storage unit would also dramatically improve the practical possibilities for storage. The chemical storage concepts discussed earlier may thus be quite relevant in this context.

Through improved materials and collector technology, it may be perceived that collectors could be better optimized for low solar radiation conditions, i.e. especially for wintertime conditions. An analysis on the effect of the collector technology on the storage requirement is shown in Figure 19 where the required collector area and storage volume to fully satisfy the remaining heat load of a low energy house (6 MWh/a) through active solar heating is given. With a 70% solar fraction, the storage volume would drop to about one half. It is clearly seen that the collector area needed to supply the solar heat is less affected when $U < 2.0$ W/(m^2,K), whereas the storage requirement decreases steadily with improved collectors.

For seasonal storage with a larger storage volume the conditions are better. Therefore solar systems with seasonal storage for settlements in combination with district heating have a better potential in the future. The reason for that is that the specific collector area and storage volume can be reduced with a higher heat demand. Higher efficiency of solar system and reduced specific installations costs lead to lower heat production costs. Nevertheless, the heat production costs are still twice as high as the costs for conventional heating systems.

6. Central solar heating plants with seasonal storage

Due to technical and economic reasons, seasonal storage of solar heating is economic mainly on larger scale, i.e. for a group of houses utilizing a common large-scale heat storage through district heating.

One important advantage of a large size is that the relative heat losses decrease with increasing size. The relative heat losses are proportional to the perimeter area/volume, or, $V^{2/3}/V = V^{-1/3}$. Therefore as $V \rightarrow \infty$, the relative losses $\rightarrow 0$.

Central solar heating plants with *seasonal storage* (abbr. CSHPPS) are a promising solar heating technology for large-scale use of solar energy and this technology is already approaching cost-effectiveness in some applications. It may also be applied to old building stock and with other heat energy sources such as waste heat or biomass.

Seasonal storage solar heating technologies have been studied intensively in several northern countries and have also been a part of international collaborative work within the framework of the IEA Solar Heating and Cooling Programme. The national and international efforts over the last ten years have resulted in major improvements in technology and economics. Also, the concerns in the environment and the very recent disturbances in the world oil markets have brought the large-scale solar technology closer to realization.

Solar heating plant with seasonal storage may distinguish between a decentralized and a centralized approach; Figure 20 and Figure 21. In a decentralized approach, the storage and collectors are placed within the individual houses like in an ordinary active solar heating system but of a larger size. In the centralized concepts, these components are centrally situated, i.e. all solar heat is collected in one storage unit, from which the heat is distributed to the houses. The major advantage of having a centralized system is the reduced unit costs and heat losses from the storage. In general, a centralized system may make better use of the economy of scale (unit prices drop with the size) than a decentralized one.

Compared to an ordinary active solar heating system, the major technological difference is in the heat distribution and the storage. Large-scale storage is necessary for high yearly solar utilization and can be realized mainly through storage types employing either water or ground as the storage medium. Except for the on-ground water tank, all storage techniques are subsurface.

Figure 22 demonstrates the different large-scale sensible heat technologies available. Concepts like earth pits or rock caverns are large water reservoirs built into ground. Aquifer storage employs the storage capacity of water mixed ground. The aquifer storage is very simple and needs only a few wells to operate. Vertical pipes may be laid into ground enabling use of the thermal capacity of ground. Ground heat storage may also be employed effectively through heat pumps yielding a larger ΔT.

The most frequently used "seasonal" thermal storage technology, which makes use of the underground, is *Aquifer Thermal Energy Storage*; Figure 23. This technology uses a natural underground layer (e.g. sand, sandstone, or chalk layer) as a storage medium for the temporary storage of heat or cold. The transfer of thermal energy is realized by extracting groundwater from the layer and by re-injecting it at the modified temperature level at a separate location nearby. A major condition for the application of this technology is the availability of a suitable geologic formation.

Other technologies for underground thermal energy storage are borehole storage, cavern storage and pit storage; Figure 24. Pit storages are mainly used for offices and housing estates. Ground heat exchangers are also frequently used in combination with heat pumps, where the ground heat exchanger extracts low-temperature heat from the soil. Large underground water storage (e.g. cavern storage and pit storage) are technically feasible, but their application is still limited because of the high level of investment required.

The concept of seasonal storage may be applied generally almost everywhere, but the following limitations or requirements should be noticed:

- the design is *site specific* and requires careful design and sizing
- large-scale application, i.e. for loads over 500-1000 MWh/yr
- a yearly design solar fraction should be 70-80% of the total load
- the subsurface storage technologies are site dependent
- the project involves high investments and low running costs
- largest *cost savings* may be obtained already in the pre-design phase through careful system evaluation and component sizing.

For storage operation, two major cases can be identified: a high temperature storage from, which heat can be discharged directly into the houses, and a low temperature storage, for which a heat pump is needed for discharging. Normally, water-based storages operate at higher temperatures (up to 95°C) and ground storages at a lower temperature with a heat pump. In case of a heat pump use, the storage may operate at a lower average temperature but still have the same temperature swing (i.e. storage capacity) as a high temperature storage. Consequently, the collector performance would be better and the storage heat losses lower.

Heat distribution is accomplished through a district heating pipeline delivering heat to the individual houses. This technology is already well-known; Figure 25a and b; see chapter “Biomass heating systems”.

As solar thermal systems with seasonal storage are always site-dependent, the design has to be made accounting for the local conditions. Detailed simulations and systematic variation of design parameters are a necessity for design and the analysis of the overall performance and economics.

Technical developments with central solar heating plants with seasonal storage (CSHPSS) applicable for a group of houses and super-insulated water tanks for one-house low energy loads, have brought seasonal storage applications closer to reality.

When going into large storage systems other technologies than water tank may be employed. If the storage requirement is less than a few thousand m^3, or < 100 MWh, then ordinary insulated steel tanks are the cheapest alternative. For larger volumes, different subsurface storage concepts become interesting due to much lower costs. Thus the best sensible heat storage technology may change with the capacity needed.

The following example demonstrates the reduction of unit costs of storage when increasing the size of the storage and choosing the optimal storage concept:

- 1 m^3 water storage 1,000 EUR/m^3
- 10,000 m^3 earth pit 40 EUR/m^3
- 100,000 m^3 rock cavern 10 EUR/m^3 .

The CSHPSS systems are typically built for heat loads ranging in size from tens of houses up to hundreds of houses. The collector size of such systems may be in the range of 500 - 100,000 m^2 and the storage volume 1,000 - 500,000 m^3. The largest CSHPSS built so far has a 4,320 m^2 collector field and 105,000 m^2 rock cavern storage; Figure 20.

The main objective of present developments is to improve the overall cost-effectiveness of solar thermal systems with seasonal storage. Already in some special cases seasonal storage solar heating may be found economically justified, but this conclusion is not yet generally valid for other sites and applications. The major R&D efforts are directed towards *storage technologies and system design*.

7. Heat distribution network

To reduce the heat losses of the heat distribution system in larger buildings with more consumers as well as in district heating both the storage integration in the heat network and the concept of the heat distribution network is of high importance.

For solar-supported heating systems 4-pipe-networks and 2-pipe-networks are used.The evaluation based on experimental data shows clearly that 2-pipe-nets have obvious advantages over 4-pipe-nets when it comes to the plant efficiency and utilisation of the solar system. 2-pipe-nets reveal the lowest need for auxiliary energy in all building geometries and energy densities. The advantages of 2-pipe-nets concerning the need for auxiliary energy are greater in less compact buildings (low energy densities) than in compact buildings (multiple-storey buildings, high energy densities). On the one hand the 2-pipe-nets reduce the distribution losses and on the other hand the low temperatures from the energy distribution network offer optimum starting conditions for the thermal solar plant which translates into higher solar yields.

Regarding economic aspects, in very compact buildings with high energy densities, 4-pipe-nets may have some advantage compared to 2-pipe-nets, but when it comes to small and medium sized energy 2-pipe nets are to be given preference.

2-pipe network can be operated in combination with decentralised boilers in the row houses or in combination with decentralised heat exchangers; Figure 25a and Figure 25b. With individual storages it is possible to operate the network at different temperatures: lower temperature for space heating (about 40°C) and higher temperature for hot water preparation (about 65°C to 70°C) Therefore the heat losses in the network can be reduced compared with a network with heat exchangers, which to be operated on the highest temperature all the time. On the other hand, the investment costs for decentralised storages are higher than for heat exchangers.

8. Indirect heat store for solar energy

There are many possibilities to store solar energy *indirectly*. The function of "seasonal solar storage" fulfil sustainable used *bioenergy sources* in the form of firewood, bark and wood chips from the forests and as remnants from the wood processing industry are an obvious form of *"natural storage"* for solar energy, locally available, which can be stored, transported and grow again. Biomass is therefore an optimal form of "seasonal storage" for solar energy and an attractive auxiliary fuel for solar heating systems, both individual systems as well as in combination with district heating; see chapter "Biomass heating systems".

The *upper layers of the soil* are a good possibility for the thermal storage of solar energy. But since the temperature of the stored energy is low it has to be raised by heat pump technology; Figure 26. The heat extracted from the soil during the heating season will be returned to the soil by the absorbed solar energy. An especially favourable possibility for reducing the use of fuel in the heat supply of dwellings (space heating and hot water preparation) is the combination of a ground-coupled heat pump with a solar system. Outside the heating season a larger solar coverage of the hot water demand should be reached with the solar system. For the use in a one-family house a collector area of about 12 to 20 m^2 has proved sufficient, in connection with hot water storage of about 1,000 litre. With that the hot water preparation can be bridged during several days with bad weather. About 75% of the heat demand for space heating and hot water preparation can be attributed to solar energy: 20% of the direct use of solar energy and 50% of the indirect use of solar energy via ambient heat; Figure 27.

8. Summary and conclusion

The storage concept play a decisive role in use of solar thermal systems, especially in areas with a temperate and cold climate and larger seasonal differences. Short term and long-term storage are used. A seasonal storage of solar energy at a higher temperature level (over 30°C) via long-term storage is difficult because of the high costs for market penetration. Therefore solar systems with environmentally benign heating systems, generally in combination with heat pump technology or biomass are preferred. With the indirect use of solar energy via ambient heat and biomass the share of renewable energy sources for the heat supply in buildings has been remarkably increased.

More information:

Thermal energy storage
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http://www.ecbcs.org/.
http://cevre.cu.edu.tr/eces/

www.iea.org
www.iea-shc.org

Table 1. Examples of materials suitable for thermal storage

SENSIBLE HEAT
- water, ground, rock, ceramics
- T=60°C - 400 ^oC

PHASE-CHANGE
- inorganic salts, inorganic and organic compounds; classical examples :
- $Na_2SO_4 \times 10\ H_20$ +heat (24 ^oC) $\leftrightarrow$ $Na_2SO_4 + 10H_20$
- $CaCl_a \times 6\ H_20$ (30 ^oC)
- Paraffin (melting at 20°C - 60 ^oC)

CHEMICAL REACTIONS
- $S \times n\ G$ +heat $\leftrightarrow$ $S \times m\ G + (n-m) \times G$; G (g) $\leftrightarrow$ G(liqu)

G=working fluid/gas	S=sorption material
water	hydroxides ,hydrates
ammonia	ammoniates
hydrogen	metal hydrides
carbon dioxide	carbonates
alcohols	alcoholates

Table 2: Storage capacity.

Medium	Temperature [C-deg]	Capacity [kWh/m^3]
Water	DT=50 °C	60
Rock		40
$Na_2SO_4x10H_20$	24	70
$CaCl_2x6H_20$	30	47
paraffine	20 - 60	56
lauric acid	46	50
stearic acid	58	45
pentaglycerine	81	59
butyl stearate	19	39
propyl palmiate	19	52
Silica gel N+H_20	60 - 80	250
Zeolite 13 X +H_20	100-180	180
Zeolite + methanol	100	300
$CaCl_2$ + ammonia	100	1000
MeHx + H_2	50 - 400	200 - 1500
$Na_2S + H_20$	50 - 100	500

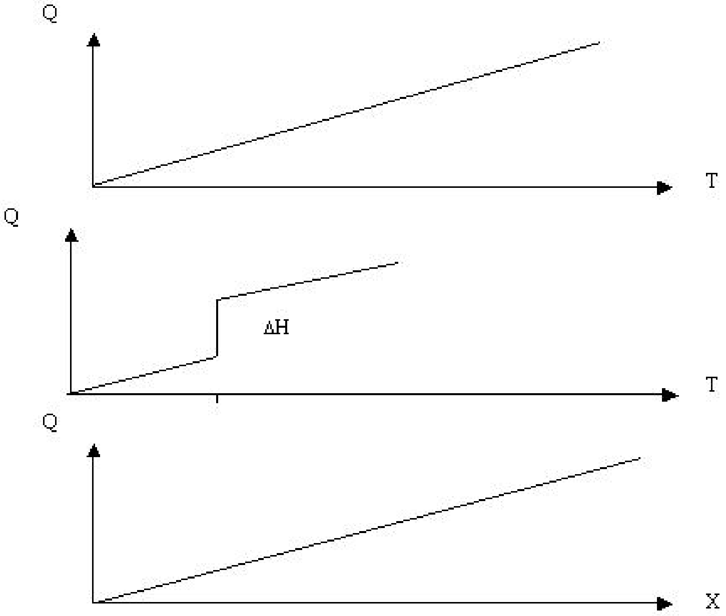


Fig. 1: Storage capacity Q for different thermal storage systems

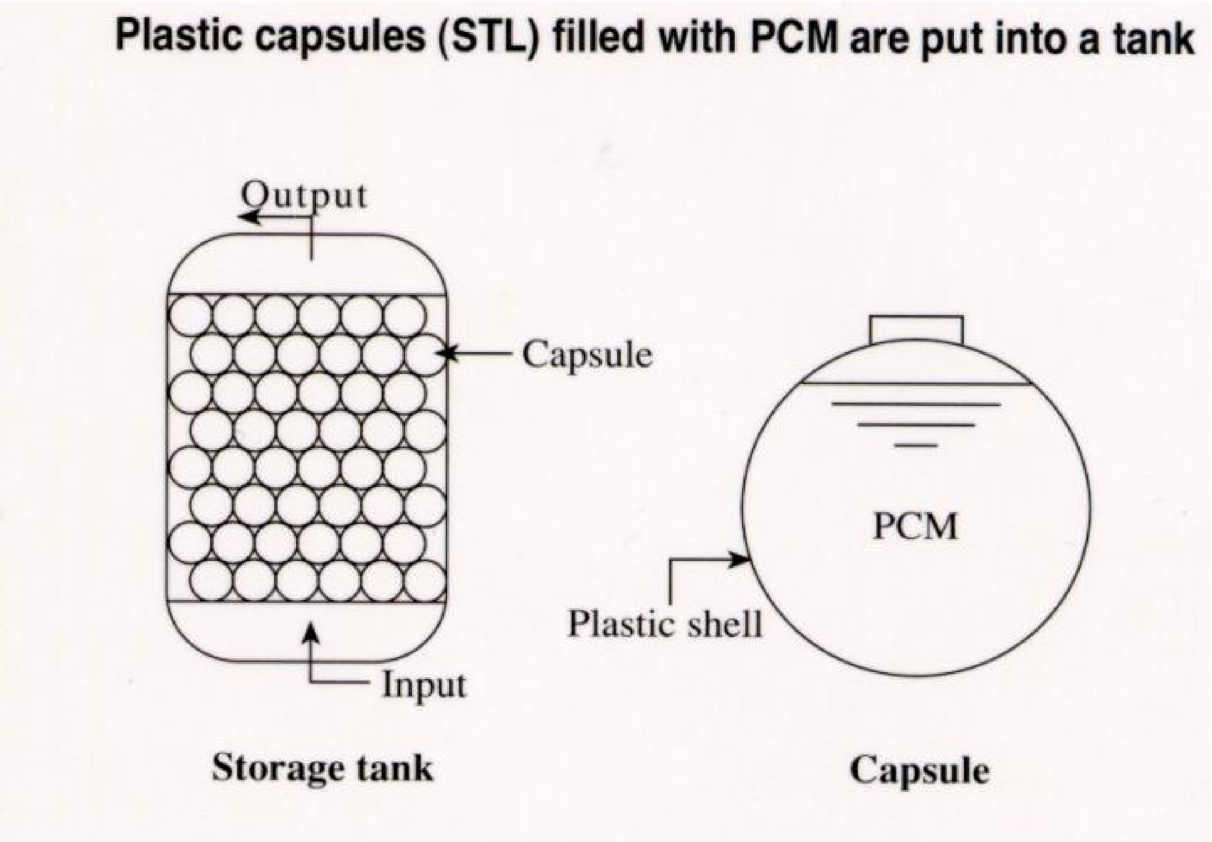

Plastic capsules (STL) filled with PCM are put into a tank

Fig. 2: Principle PCM or chemical reaction storage

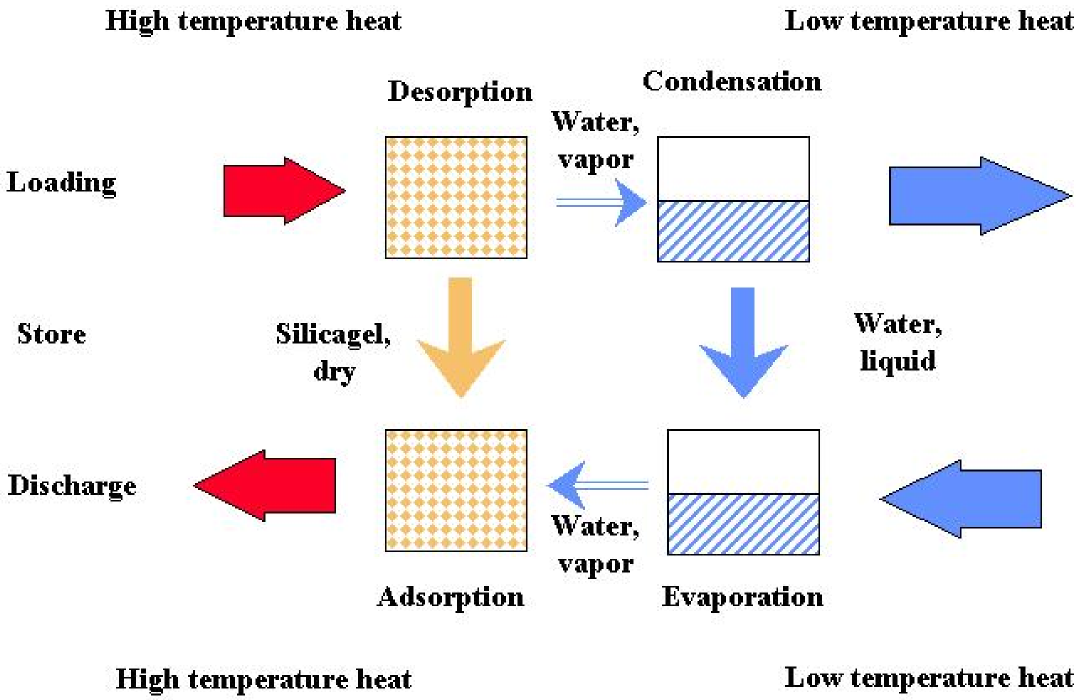
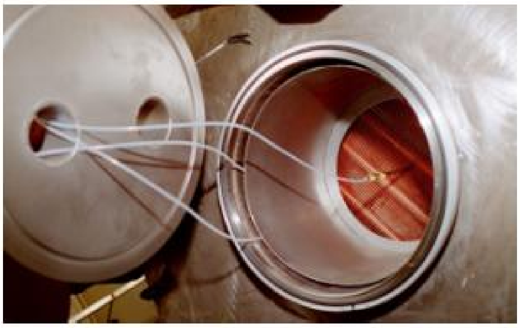


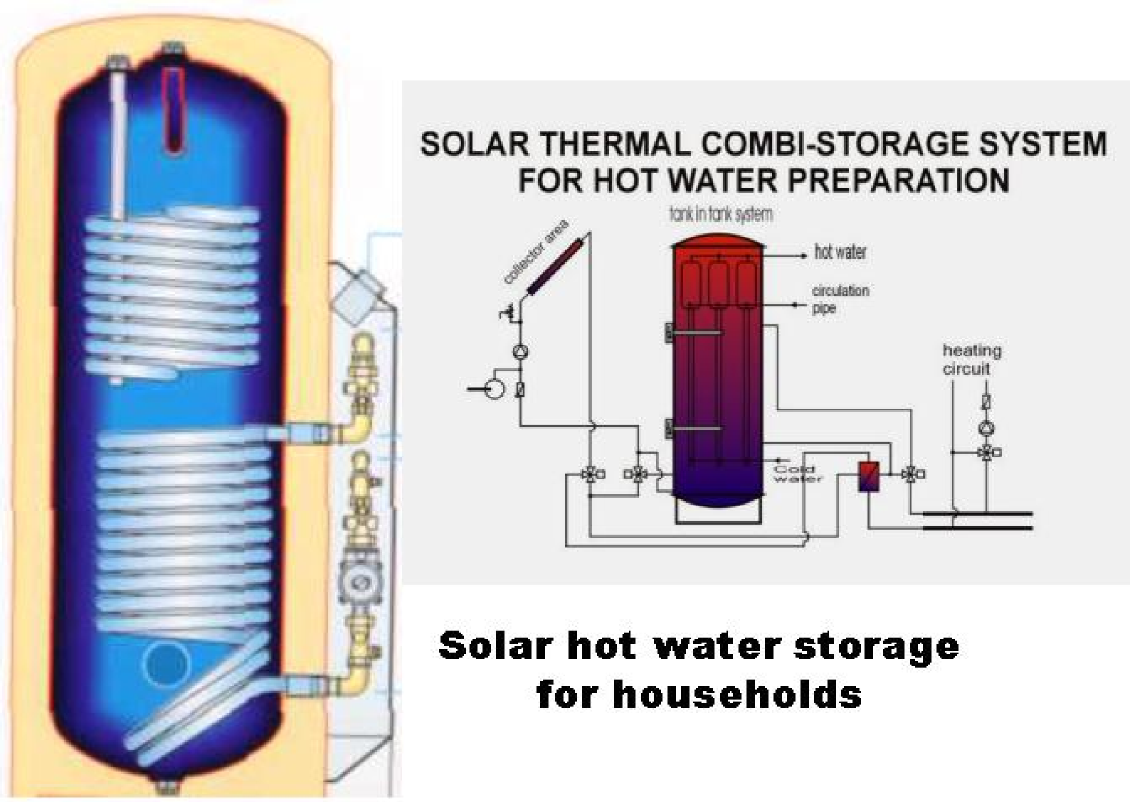
Fig. 3: Physical principles of sorption process



(AEE-INTEC, Gleisdorf/Austria)

Fig. 4: Sorption thermal storage under development

Fig. 5a: Water storage with thermal stratification



Solar hot water storage for households

Fig. 5b: Water tanks for solar hot water and combined space heating in housings

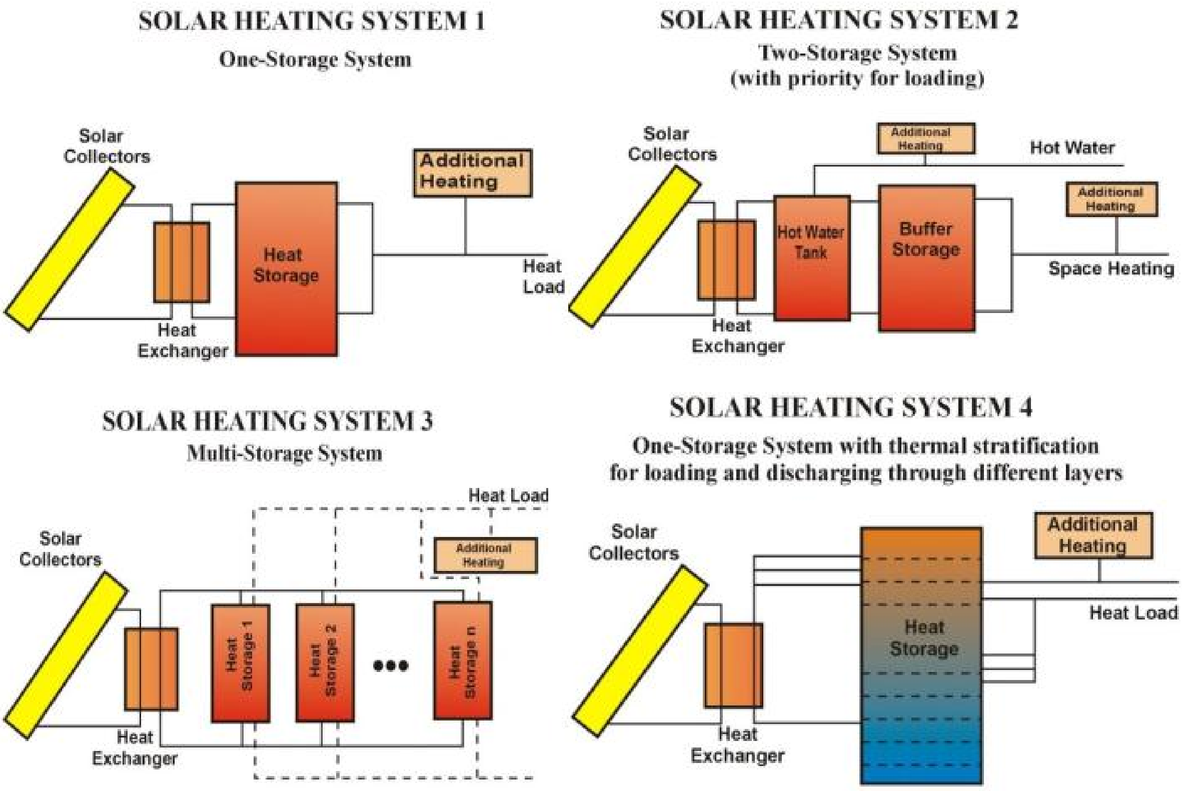


Fig. 6: Principle hydraulic schemata of solar heating systems

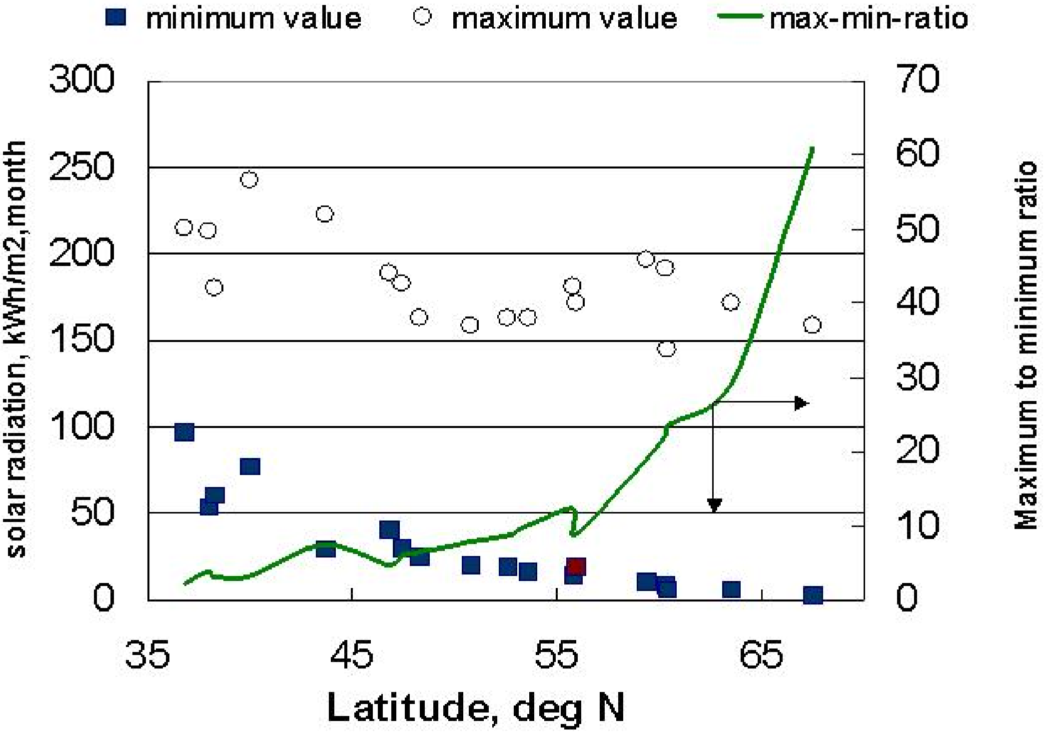
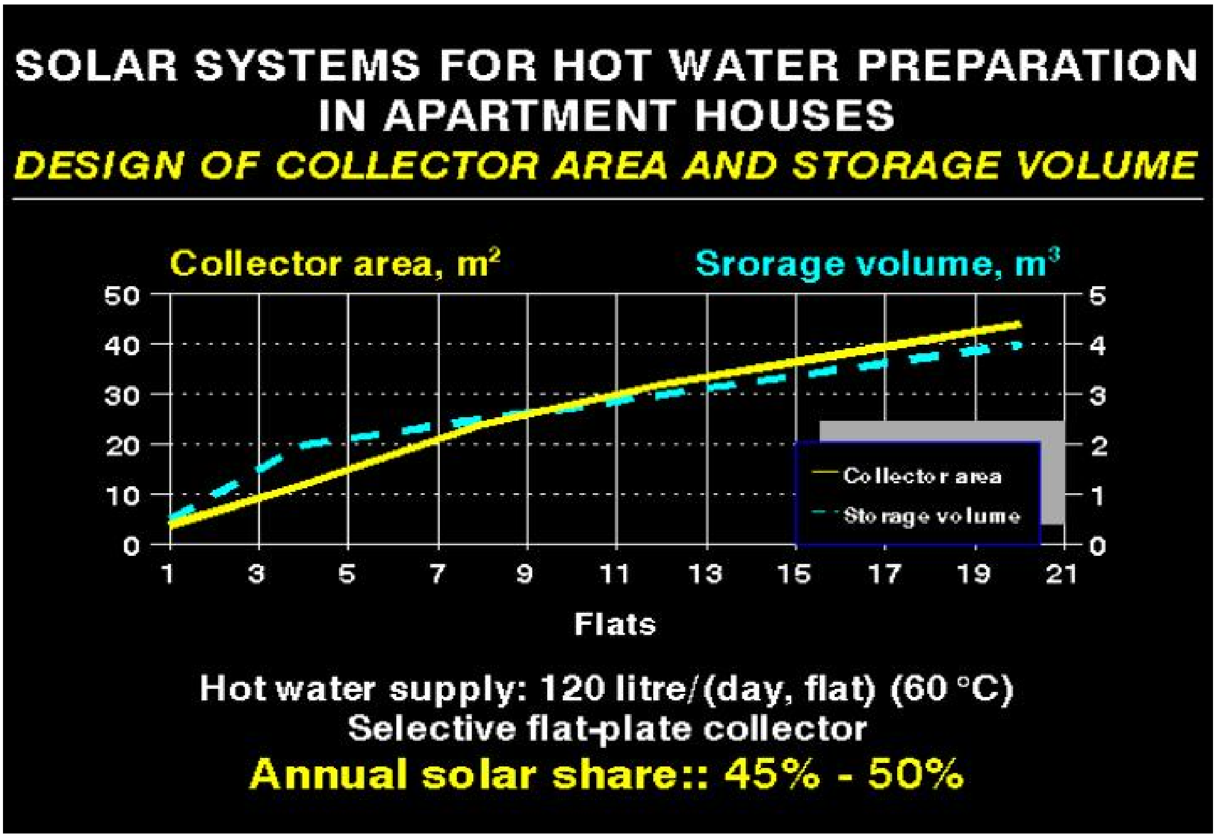


Fig. 7: The solar fluctuation



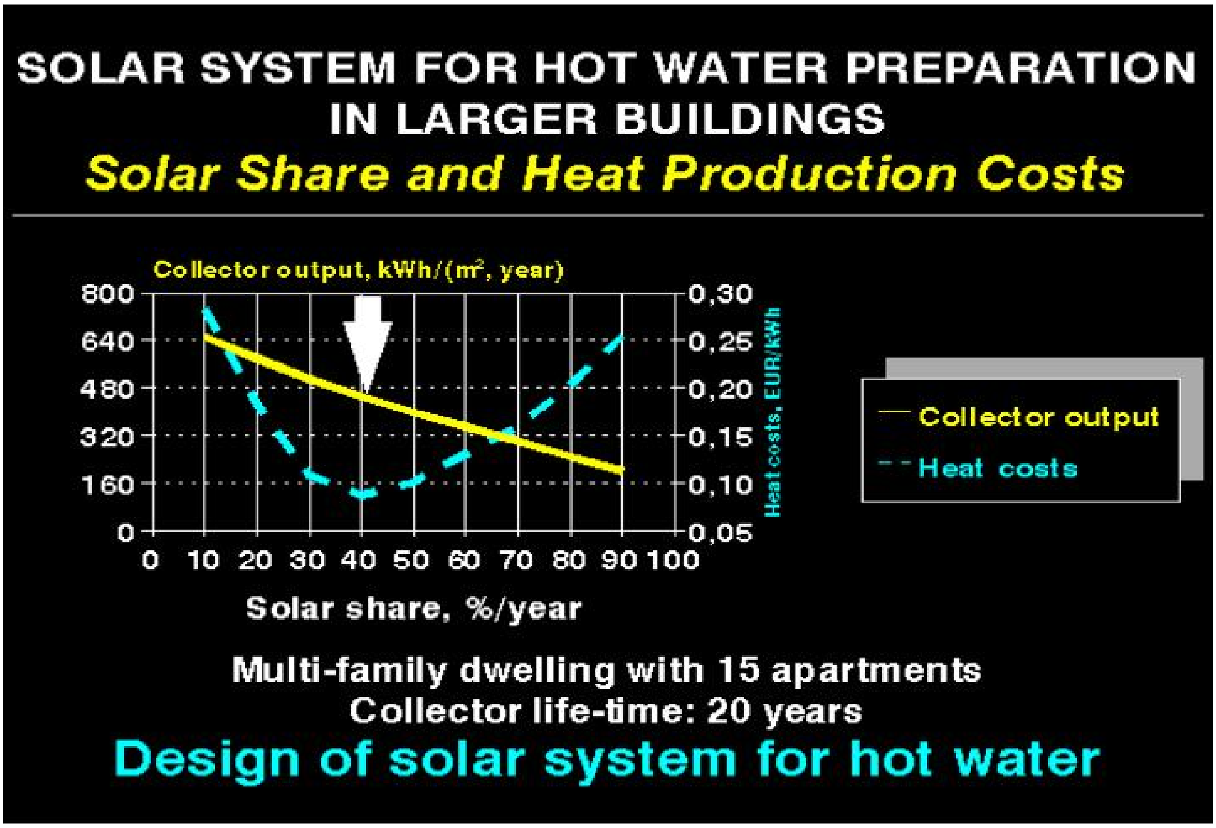
SOLAR SYSTEMS FOR HOT WATER PREPARATION IN APARTMENT HOUSES

DESIGN OF COLLECTOR AREA AND STORAGE VOLUME

Hot water supply: 120 litre/(day, flat) (60 °C)
Selective flat-plate collector

Annual solar share:: 45% - 50%

Fig. 8: Design of collector area and storage volume



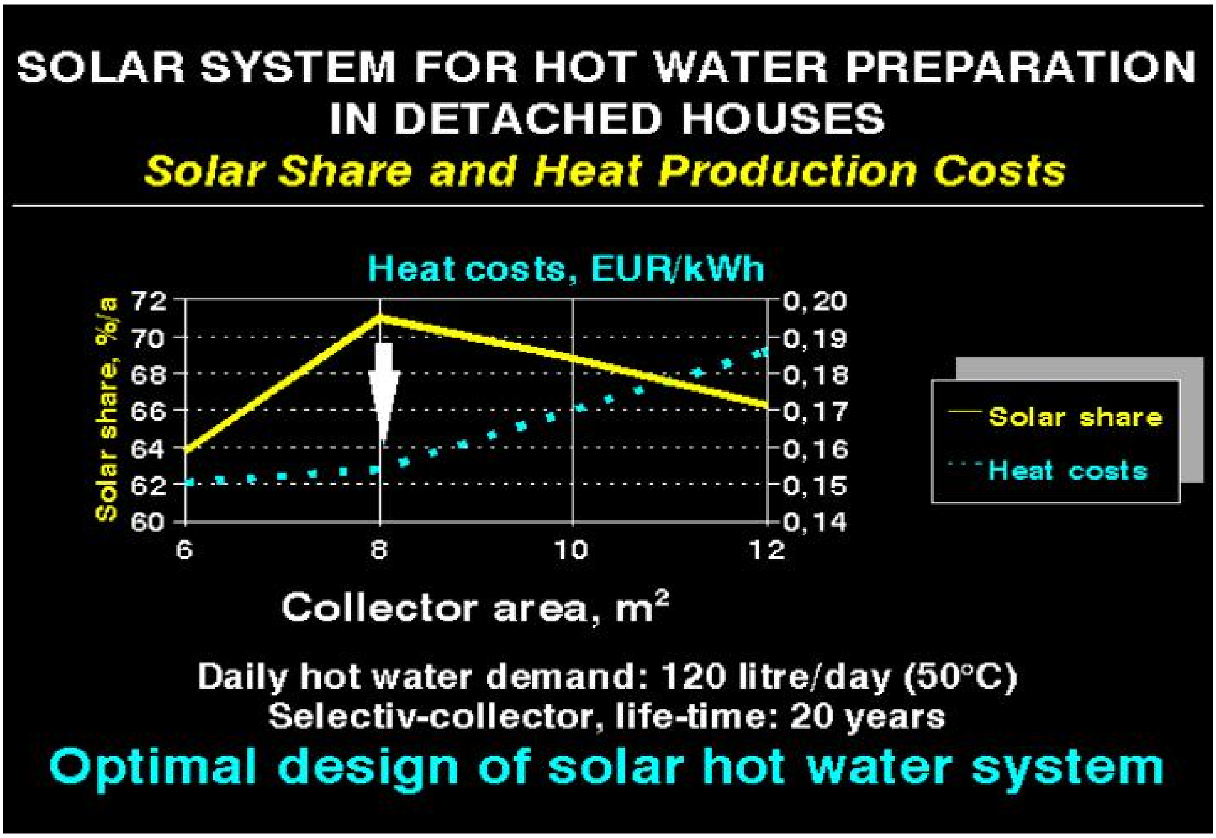
SOLAR SYSTEM FOR HOT WATER PREPARATION IN LARGER BUILDINGS

Solar Share and Heat Production Costs

Multi-family dwelling with 15 apartments
Collector life-time: 20 years

Design of solar system for hot water

Fig. 9: Optimal design of collector area and storage volume



SOLAR SYSTEM FOR HOT WATER PREPARATION IN DETACHED HOUSES

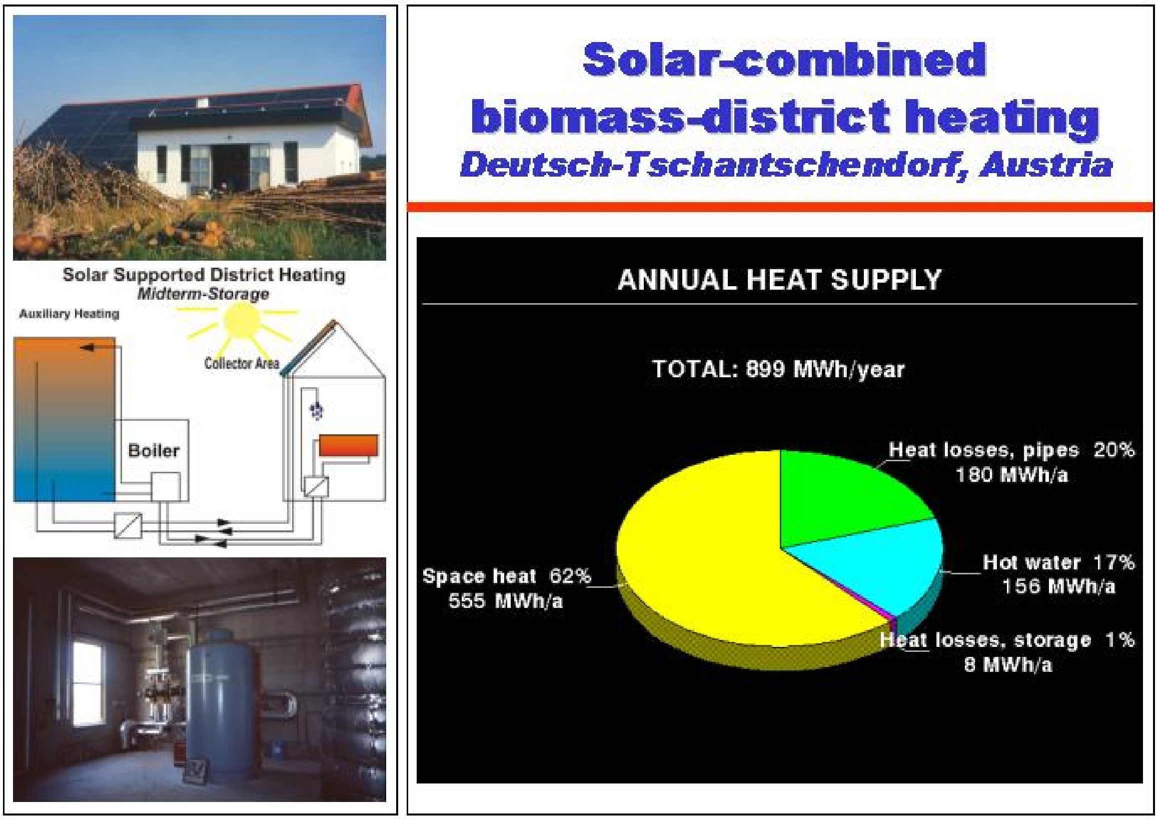
Solar Share and Heat Production Costs

Daily hot water demand: 120 litre/day (50°C)
Selectiv-collector, life-time: 20 years

Optimal design of solar hot water system

Fig. 10: Optimal design of collector area and storage volume

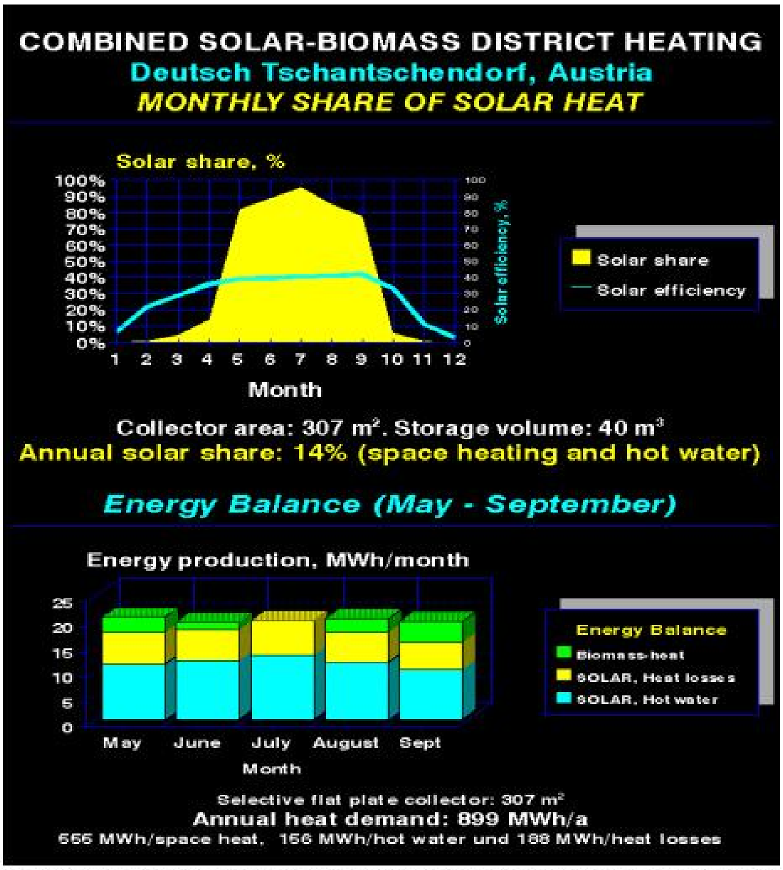
Fig. 11: Water tank for thermal store of solar heat
for small district heating (housing estate Gneiss-Moos/Salzburg)



Solar-combined biomass-district heating

Deutsch-Tschantschendorf, Austria

Fig. 12a: Solar-supported biomass district heating: Design principles



COMBINED SOLAR-BIOMASS DISTRICT HEATING

Deutsch Tschantschendorf, Austria

MONTHLY SHARE OF SOLAR HEAT

Collector area: 307 m². Storage volume: 40 m³

Annual solar share: 14% (space heating and hot water)

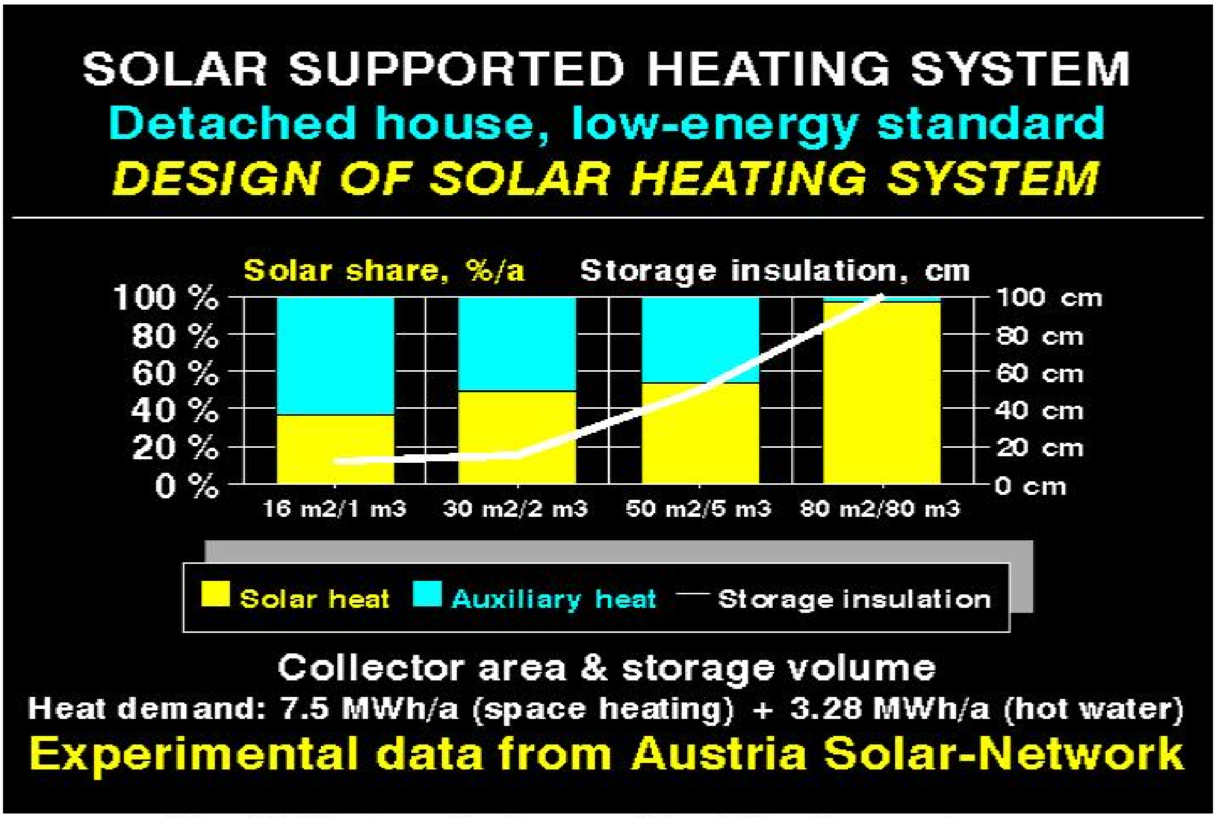
Energy Balance (May - September)

Selective flat plate collector: 307 m²

Annual heat demand: 899 MWh/a

555 MWh/space heat, 156 MWh/hot water und 188 MWh/heat losses

Fig. 12b: Solar-supported biomass district heating: Design principles



SOLAR SUPPORTED HEATING SYSTEM

Detached house, low-energy standard

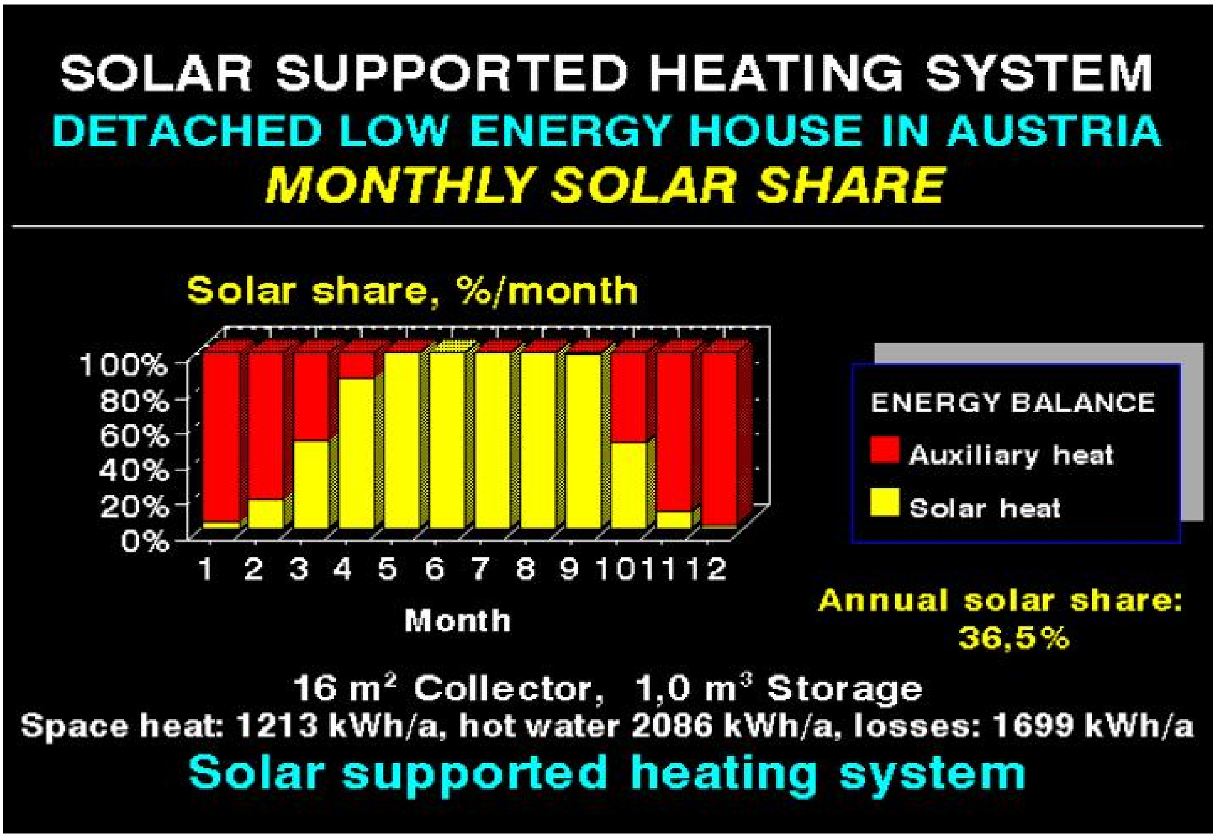
DESIGN OF SOLAR HEATING SYSTEM

Collector area & storage volume

Heat demand: 7.5 MWh/a (space heating) + 3.28 MWh/a (hot water)

Experimental data from Austria Solar-Network

Fig. 13: Design of solar combined heating systems



SOLAR SUPPORTED HEATING SYSTEM

DETACHED LOW ENERGY HOUSE IN AUSTRIA

MONTHLY SOLAR SHARE

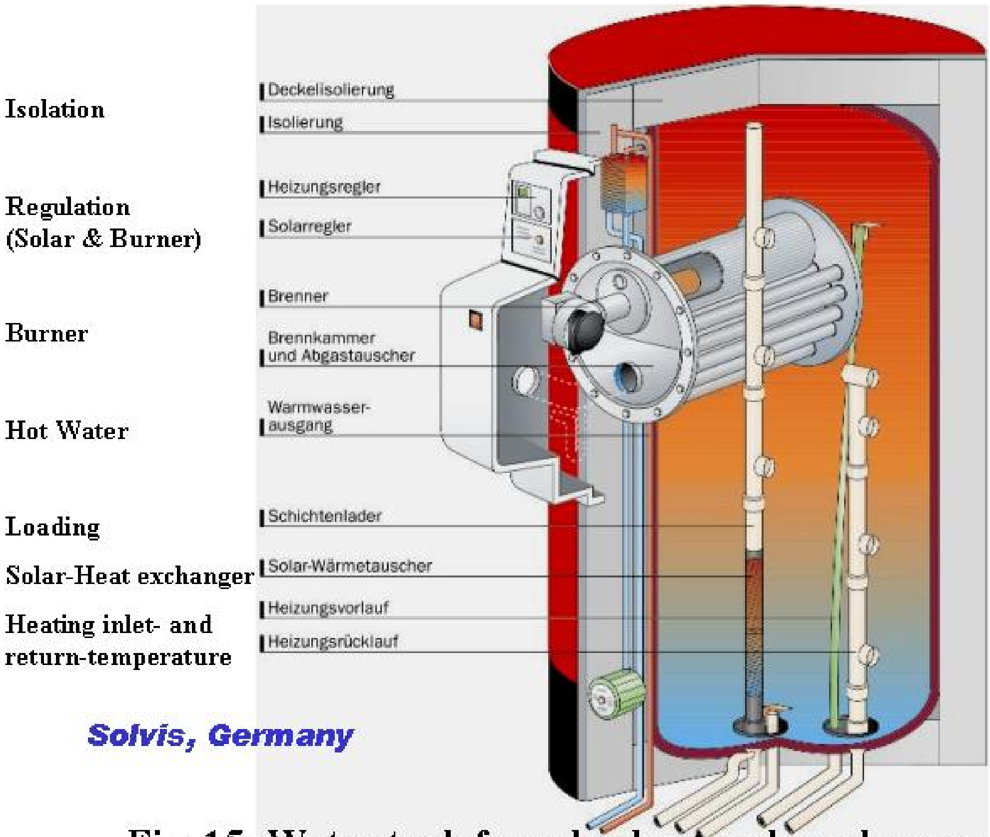
Annual solar share: 36,5%

16 m² Collector, 1,0 m³ Storage

Space heat: 1213 kWh/a, hot water 2086 kWh/a, losses: 1699 kWh/a

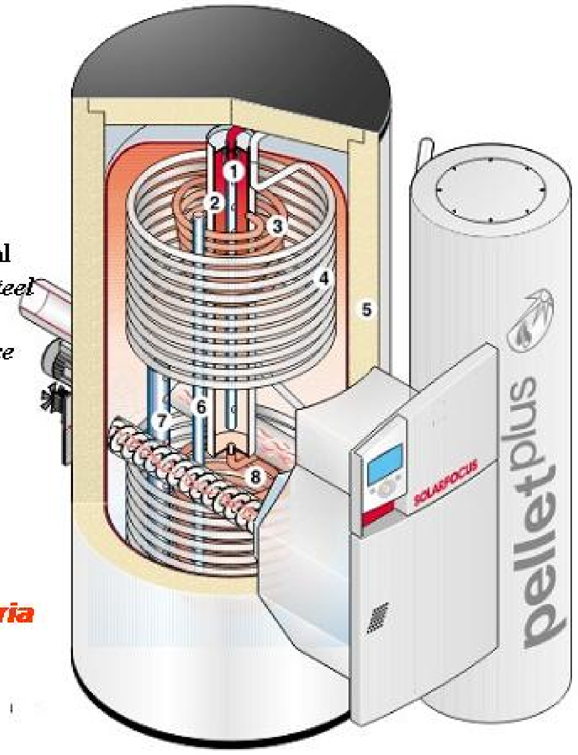
Solar supported heating system

Fig. 14: Energy-economic design of solar combined heating systems



Solvis, Germany

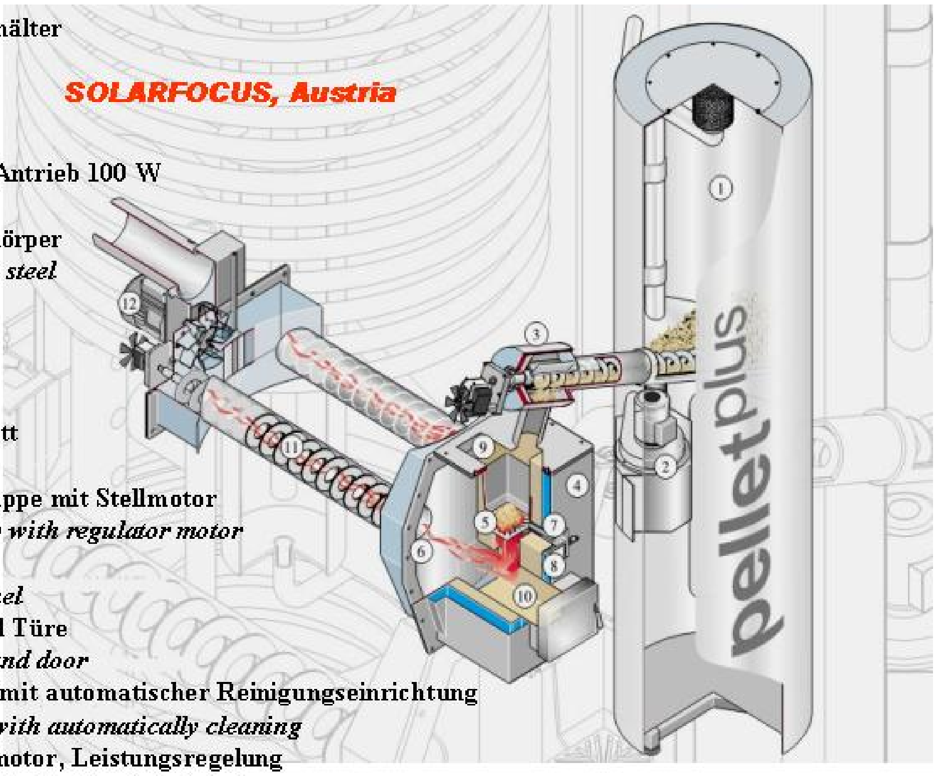
Fig. 15: Water tank for solar heat and gas-burner



1 Thermo-Schichtladelanze
Loading tube for thermal stratification
2 Schichtrohr-Wärmetauscher
Tube heat exchanger
3 Low-Flow Wärmetauscher
Low-Flow heat exchanger
4 Trinkwasser-Wärmetauscher, Edelstahl
Hot water heat exchanger, high-grade steel
5 Isolierung, 90 mm, mit Alublech
Heat insulation, 90 mm, with Alu-surface
6 Heizungs-Vorlauf
Heating inlet
7 Heizungs-Rücklauf
Heating outlet
8 Solar-High-Flow-Wärmetauscher
Solar-High-Flow-heat exchanger

SOLARFOCUS, Austria

Fig. 16a: Storage for combined solar-pellets boiler



SOLARFOCUS, Austria

1 Pellets-Vorratsbehälter
Pellets store
2 Saugturbine
Suction turbine
3 Förderschnecke, Antrieb 100 W
Srew conveyor
4 Edelstahl-Kesselkörper
Boiler, high-grade steel
5 Brennrost
Burner roast
6 Lambda-Sonde
Lambda Detektor
7 Glühstab, 260 Watt
Electrical heater
8 Sekundär-Luftklappe mit Stellmotor
Secundary-air flap with regulator motor
9 Primärluftkanal
Primary air-channel
10 Aschenraum und Türe
Ashes container and door
11 Wärmetauscher mit automatischer Reinigungseinrichtung
Heat exchanger with automatically cleaning
12 Saugzuggebläsemotor, Leistungsregelung
Fan motor regulated by Lambda detector

Fig. 16b: Pellets store and pellets burner

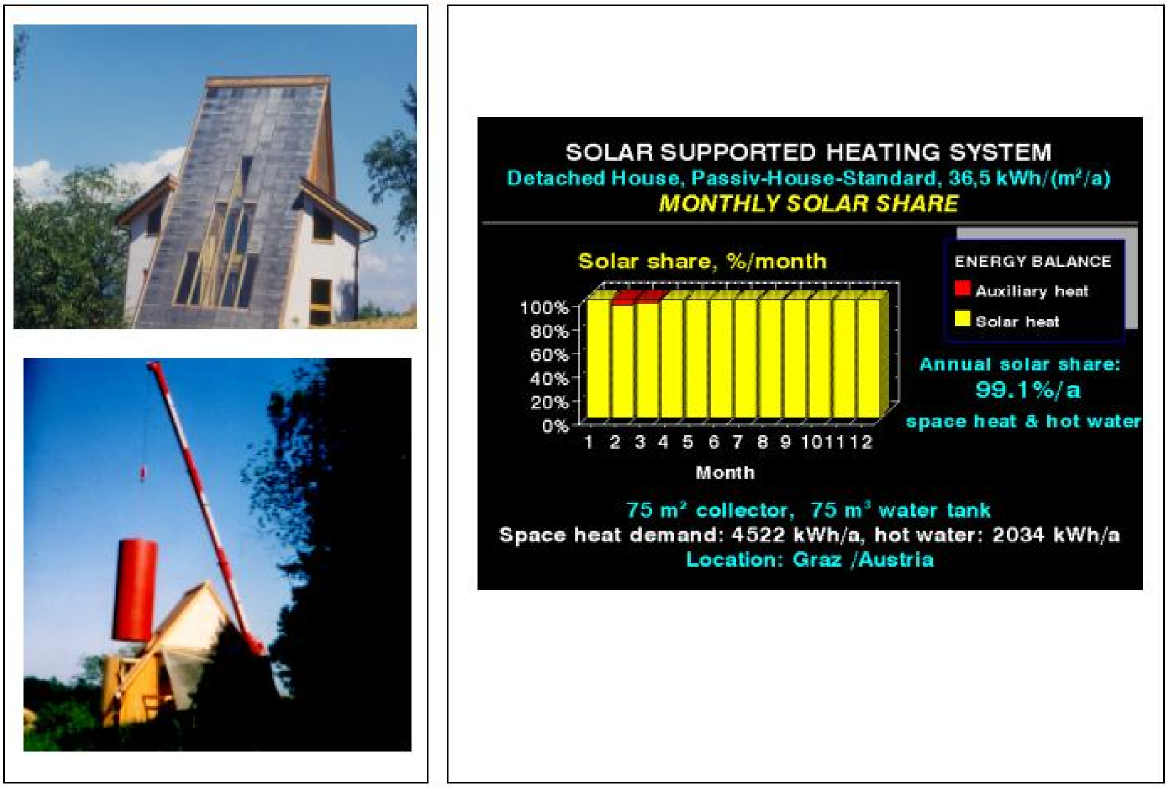


Fig. 17: Solar supported heating systems for single-family house

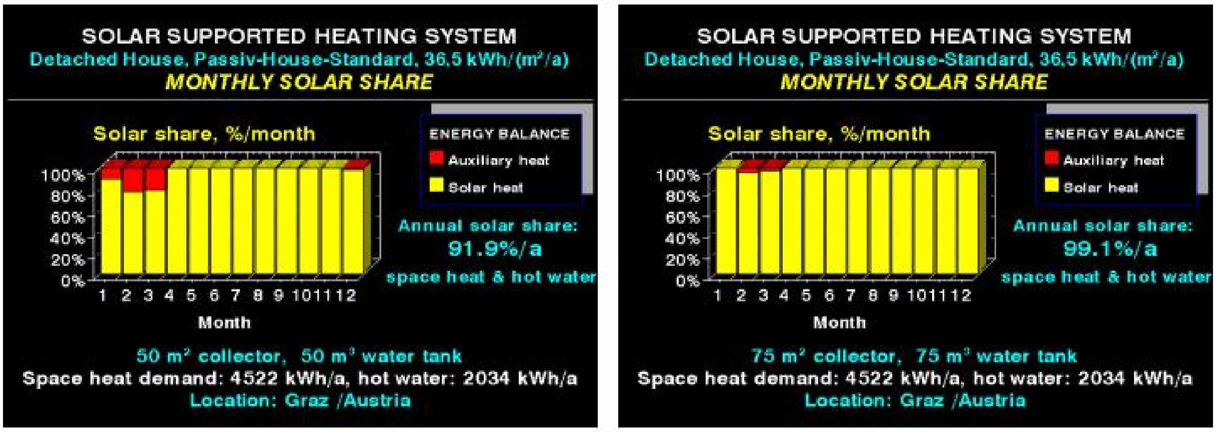


Fig. 18: Solar combined heating system with high annual solar share in detached housing

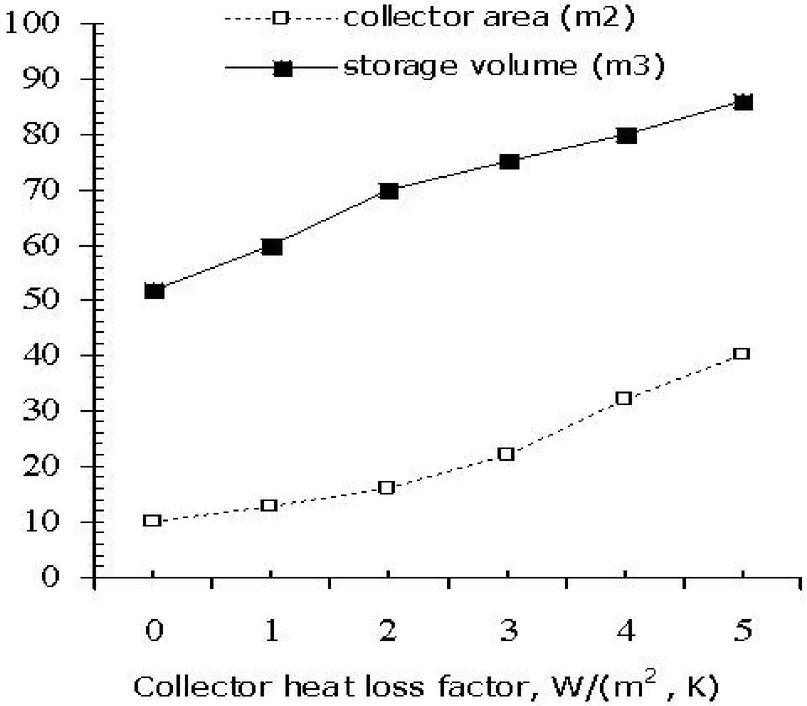


Fig. 19:: Thermal storage and collector requirement versus collector technology improvements to achieve a 100% solar fraction (central Europe)

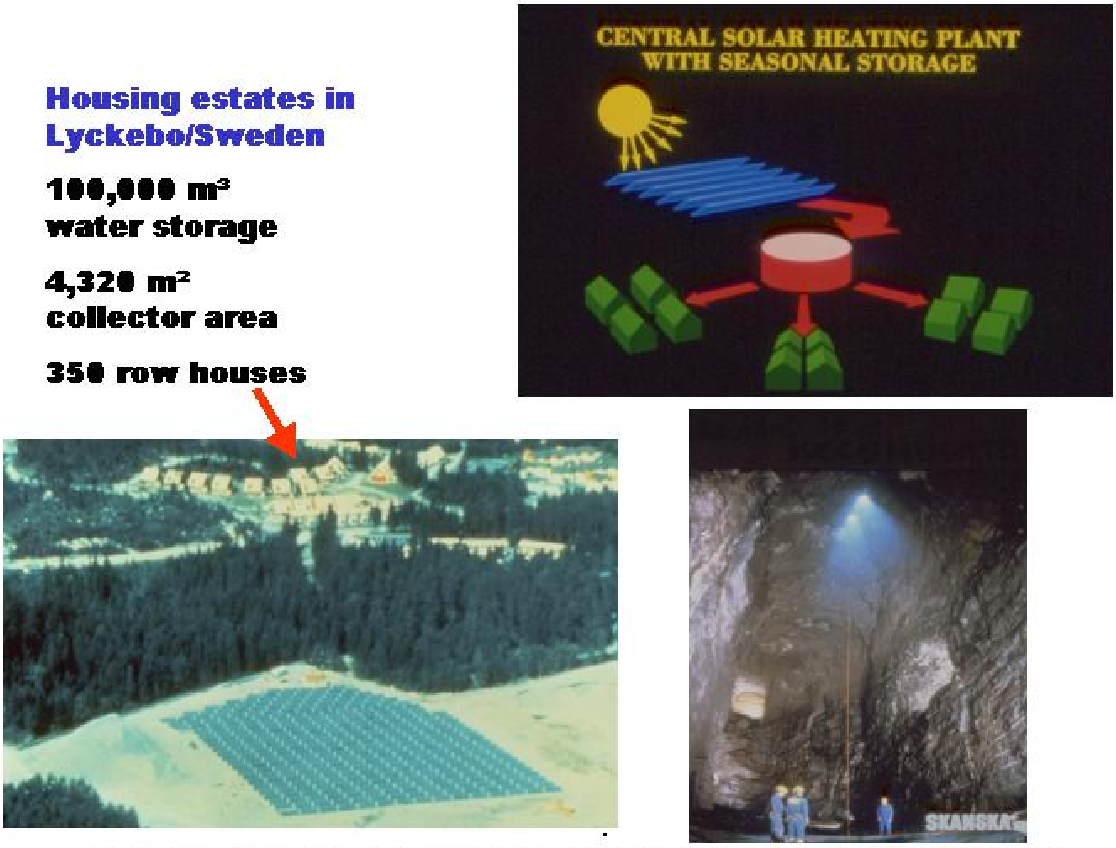


Fig. 20: Seasonal solar thermal storage for housing estate

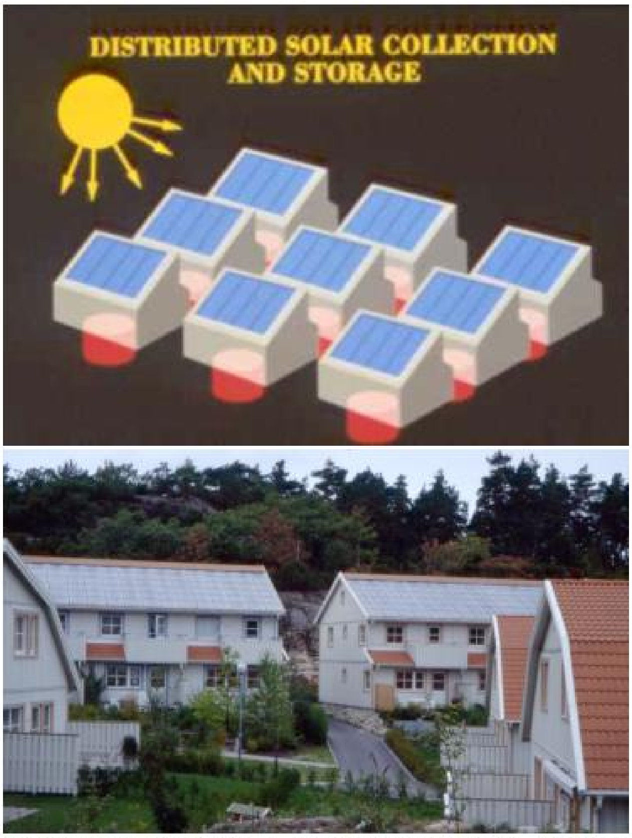
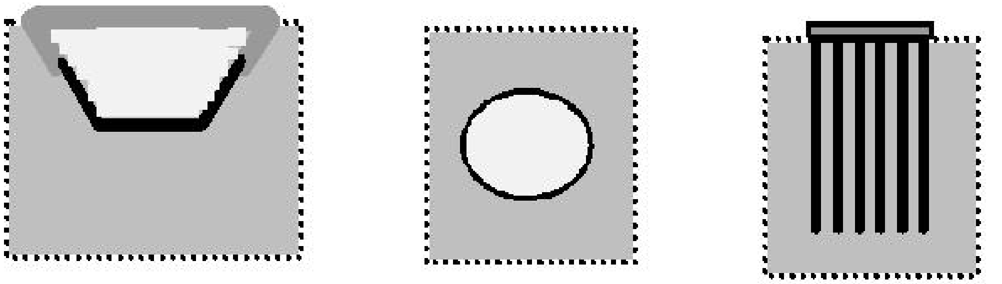


Fig. 21: Decentralised solar thermal storage


1. Partly insulated earth pit
2. Rock cavern
3. Vertical pipes in ground

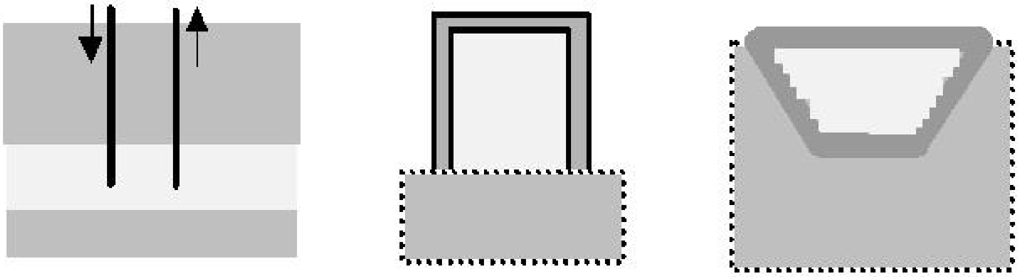

4. Aquifer
5. On-ground water tank
6. Insulated earth pit

Fig. 22: Seasonal storage options for large-scale applications

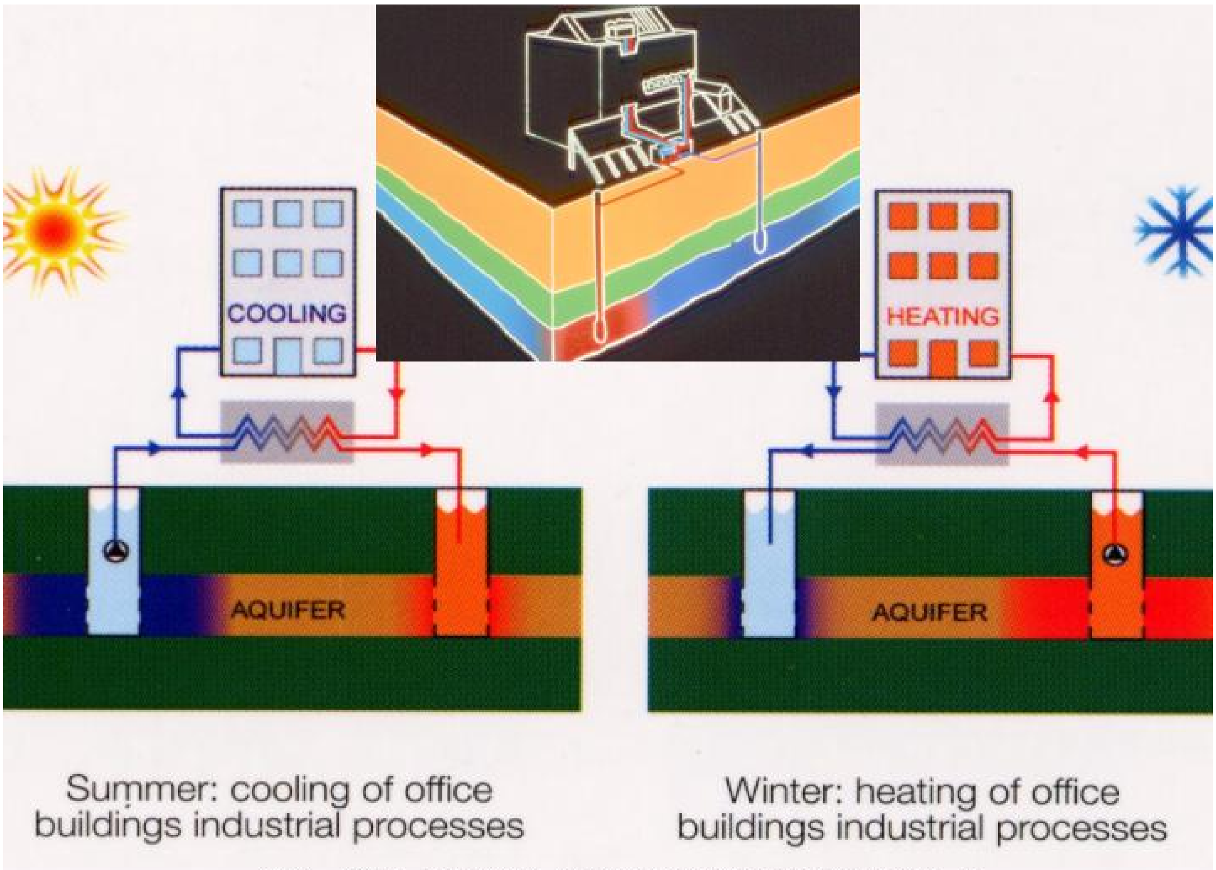


Fig. 23: Aquifer seasonal thermal storage

Friedrichshafen, Germany

Fig. 24: Ground seasonal (pit) storage for solar heat

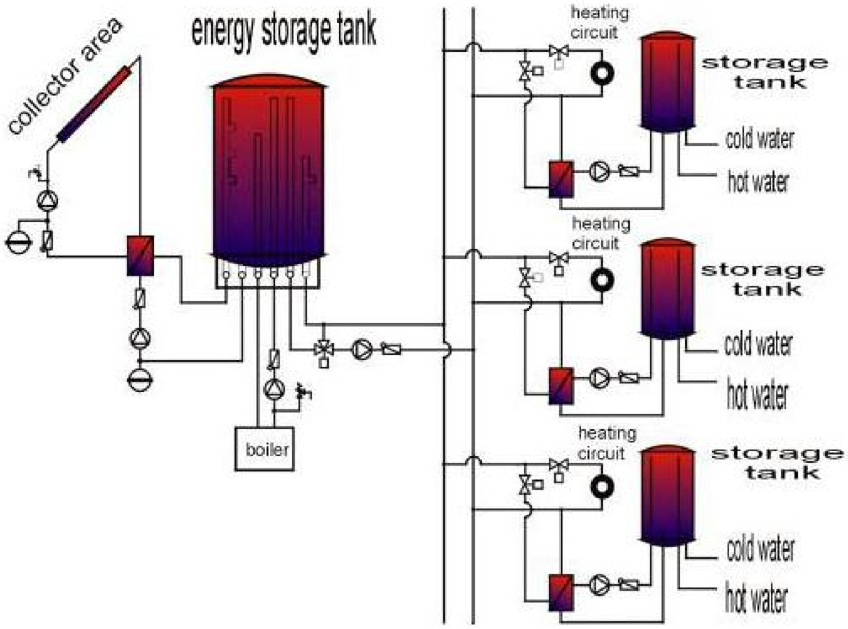


Fig. 25a: Solar thermal system with central storage in combination with decentralised hot water storages: 2-pipe net

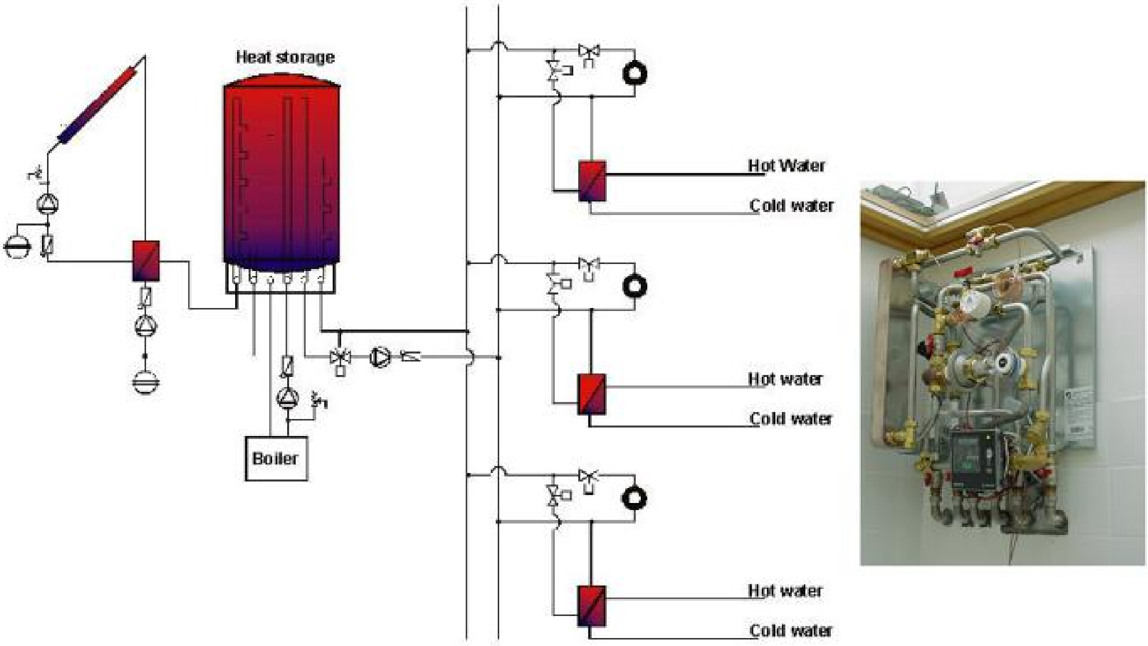


Fig. 25b: Solar thermal system with central storage in combination with decentralised heat exchangers: 2-pipe net

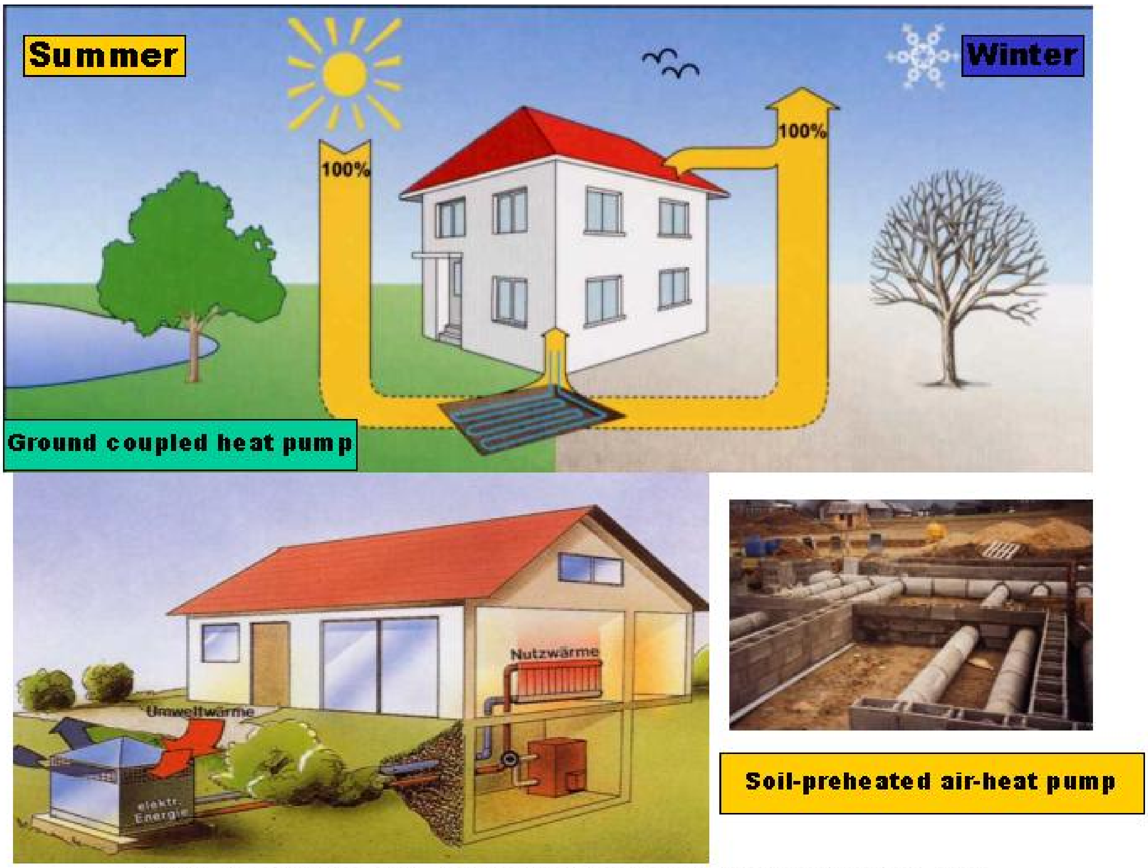


Fig. 26: Ground coupled heat pump technologies

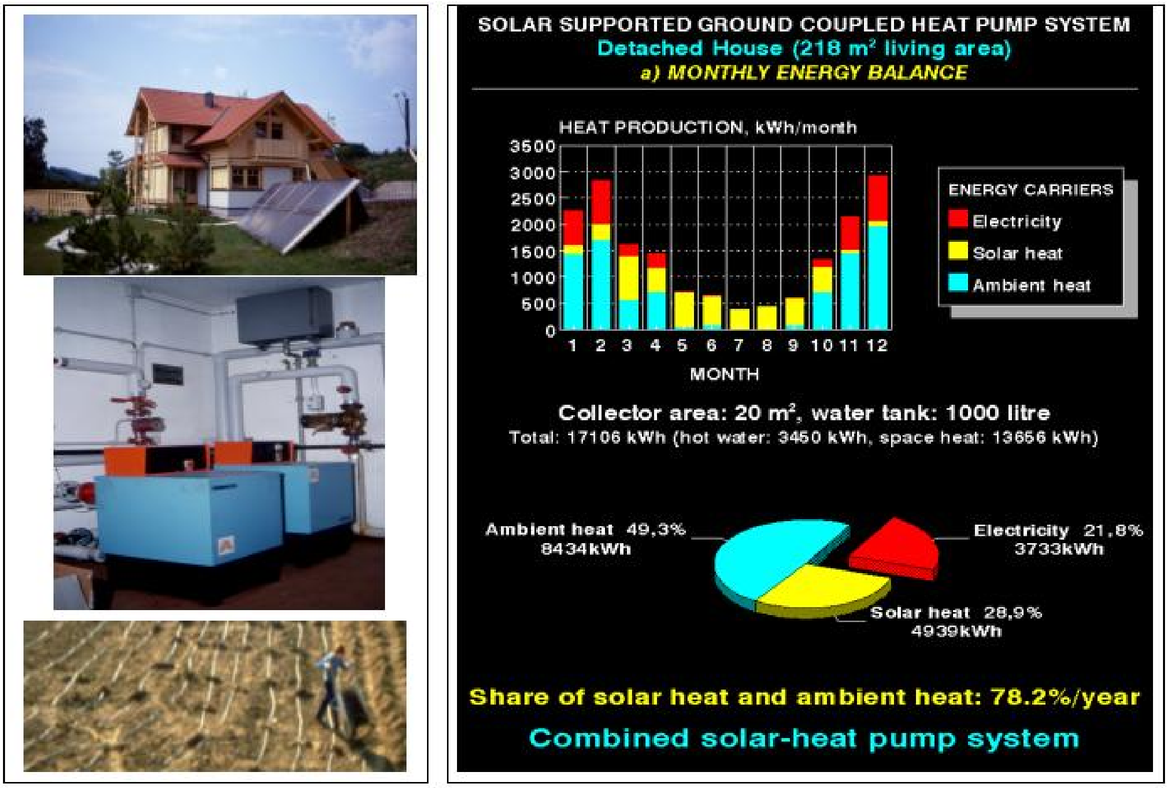


Fig. 27: Solar-supported ground coupled heat pump in single-family house