WP1.E1 / THEORETICAL EVALUATION OF PROMISING SYSTEM: Solar System Concept with Water Filled Collector Loop for Hot Water Preparation

Authors: Stefan Abrecht, Paradigma
Harald Drück, Elke Streicher, Institut für Thermodynamik und Wärmetechnik (ITW), Universität Stuttgart, Germany
Reviewers: Dagmar Jähnig, Claudius Wilhelms

CONTENTS

FURTHER INFORMATION

/1/ Stefan Abrecht, Wilfried Grießhaber, Britta Großmann Heizungswasser im Kollektor-kreis, Gentner Verlag Stuttgart, SBZ 14/2004
/2/ Wilfried Grießhaber, Heizungswasser statt Frost-schutzgemisch, Gentner Verlag Stuttgart, SBZ 07/2004
/3/ Jens Peter Meyer, Innovative Systeme der Solarthermie, Bielefelder Verlag, Sonne Wind & Wärme 3/2005
/4/ markt intern `markt intern`-Innovationspreis 2005 markt intern – Nr. ISH 18/26

SUMMARY

Today most solar thermal systems in Germany are used for domestic hot water production in single-family or small multi-family houses. These systems are designed to cover approximately 60 % of the annual hot water demand by means of solar thermal energy under the average German climate conditions.
In general a typical solar domestic hot water system shows the following configuration: The collector on the roof heats up a heat transfer medium, which usually is a mixture of water and glycol (anti-freeze). The electronic control unit monitors the temperature difference between the collector and the lower part of the hot water store. When this temperature difference is appropriate, a pump is activated to circulate the heat transfer fluid through the collector loop. Through a heat exchanger, the solar heat is transferred to the water in the hot water store. For auxiliary heating, a second heat exchanger, which is connected to the oil or gas boiler, is located in the upper part of the hot water store. This system type is taken as the reference system in the present report, as it represents the state of technology of solar domestic hot water preparation in Germany. The evaluation of the promising system type introduced in the second part of this report is based on a comparison with this reference system.
The promising system type is a solar domestic hot water system that works without antifreeze-fluid. An innovative freezing protection algorithm with minimal energy consumption prevents the collector loop from freezing. This is performed by circulating warm water through the collector loop. This warm water is heated up while passing the heat exchanger in the store.
The existing hot water store does not have to be exchanged / replaced by a special solar store, since the heat transfer medium in the collector loop is water and not a special antifreeze-fluid. The solar loop is directly connected to the heating loop.
Technically, the main advantages compared to the reference system is that

- the existing hot water store does not have to be replaced,
- no antifreeze fluid is needed.

From a marketing point of view the system allows to exploit a new important market: single family homes where solar heating may be added, because no existing (presumably recently installed) component has to be replaced.

Reference system

Choice and use of the reference system

In this report, the system evaluation is based on a comparison with a reference system. The reference system matches the state of the art of system technology used for (solar) water heating in Germany.
All statements in the *evaluation* section below are relative to (or in comparison with) the properties of the reference system.

Description of the reference system

Application: Primary purpose: solar domestic hot water heating

Description: Most common systems for solar domestic hot water heating consist of a store with two integrated heat exchangers, one for the solar loop and one for the auxiliary heating loop, as can be seen from the hydraulic scheme below. In general, the heat transfer medium consists of a mixture of water and antifreeze fluid in order to avoid freezing of the collector during the winter season. Therefore the collector circuit has to be separated from the water in the store by means of a heat exchanger.

A boiler is not regarded as being part of the reference system and therefore it is not included in the cost indicated below. The costs of an appropriate gas or oil boiler will be approximately EURO 3000 (including VAT).

Cost (retail sales price of the reference system without installation, including VAT): Euro 4000.
Dimensioning of the reference system:
Collector aperture area: 5 m²
Store volume: 300 l

The schematic set-up of the reference solar domestic hot water system is shown in Figure 1:

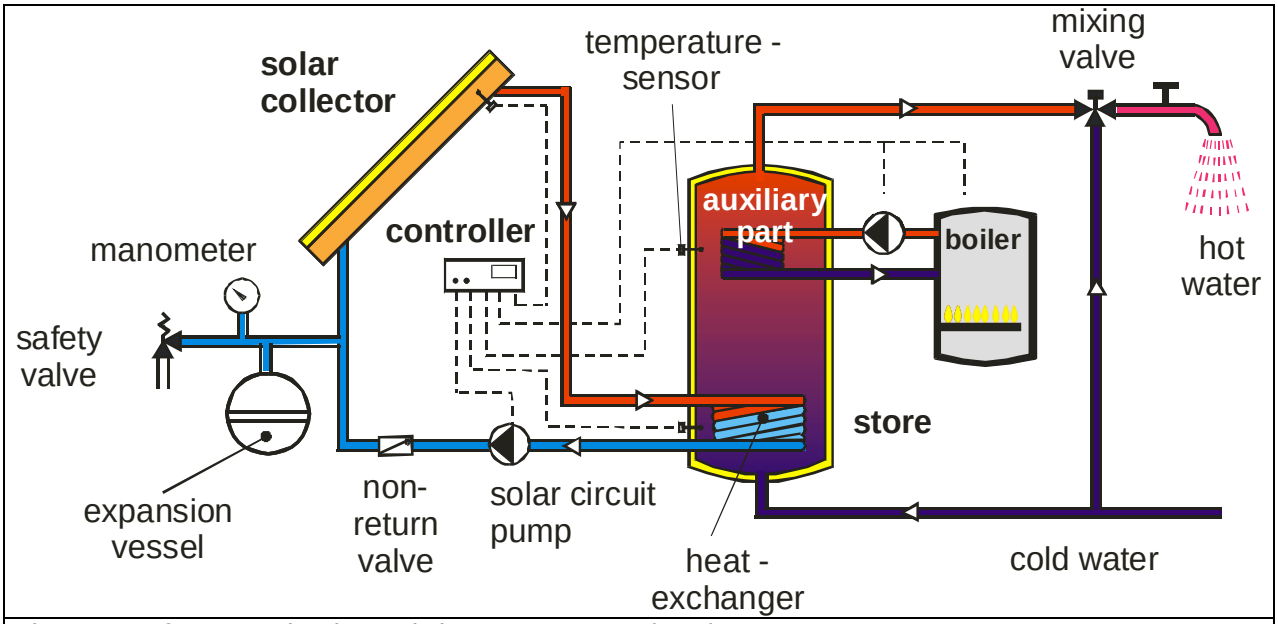


Figure 1: Reference solar domestic hot water system /ITW/

Market: The reference system represents the state of the technology in Germany in the year 2005.

Reference: The reference system is described in more detail in NEGST WP1.D1 / SUMMARY REPORT ON TODAY'S SYSTEM TECHNOLOGY, Appendix Germany

Evaluation

Description of the evaluated system – solar system concept with water filled collector loop and ETC for DHW heating particularly suitable for retrofitting

Application: Primary purpose: solar domestic hot water system

Description: The collector loop piping of a vacuum tube collector with CPC reflector is directly connected by trap elbows to the store of a conventional heating system. The existing hot water store does not have to be exchanged / replaced by a special solar store, since the heat transfer medium in the collector loop is water and not a special antifreeze-fluid. The collector is operated on the same or higher temperature levels as provided by the gas or oil boiler. An innovative freezing protection algorithm with minimal energy consumption prevents the collector loop from freezing. This is performed by circulating warm water from the store through the collector loop.

The schematic set-up of the innovative concept for domestic hot water preparation (DHW) in combination with a horizontal store is shown in Figure 2:

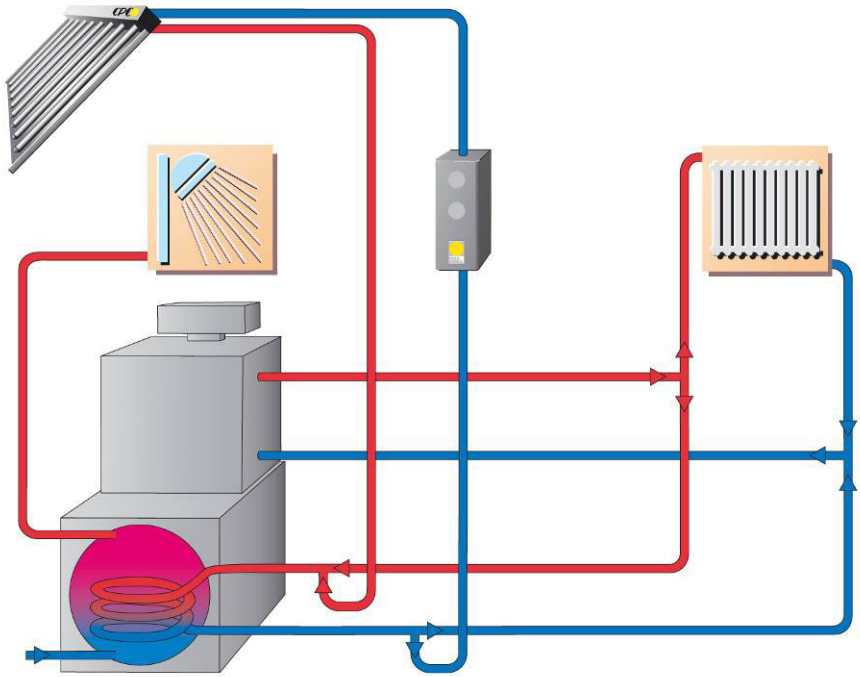


Figure 2: Innovative concept for DHW heating with horizontal store /Paradigma/

The schematic set-up of the innovative concept for domestic hot water preparation (DHW) in combination with a vertical store is shown in Figure 3:

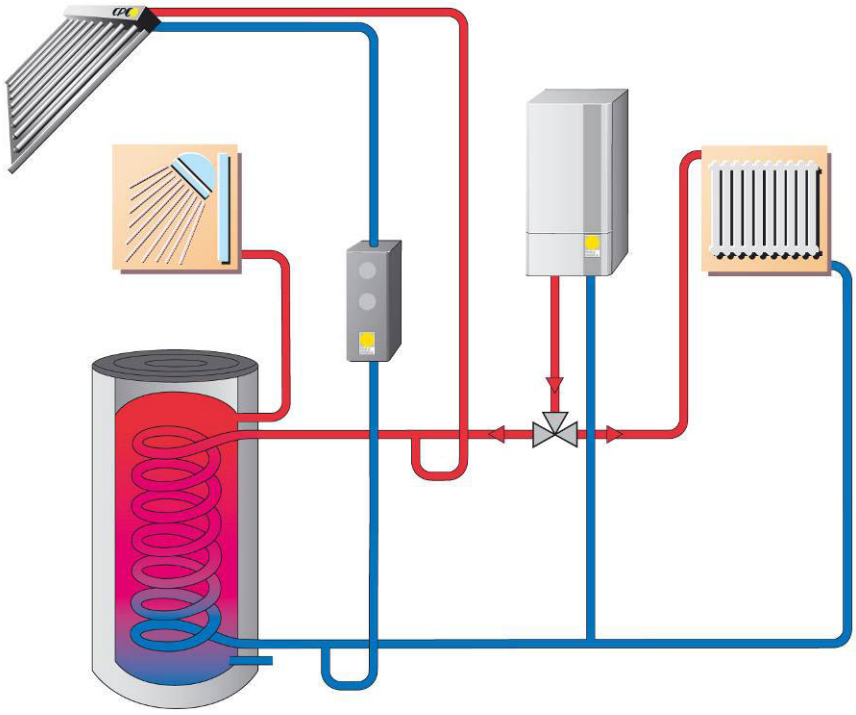
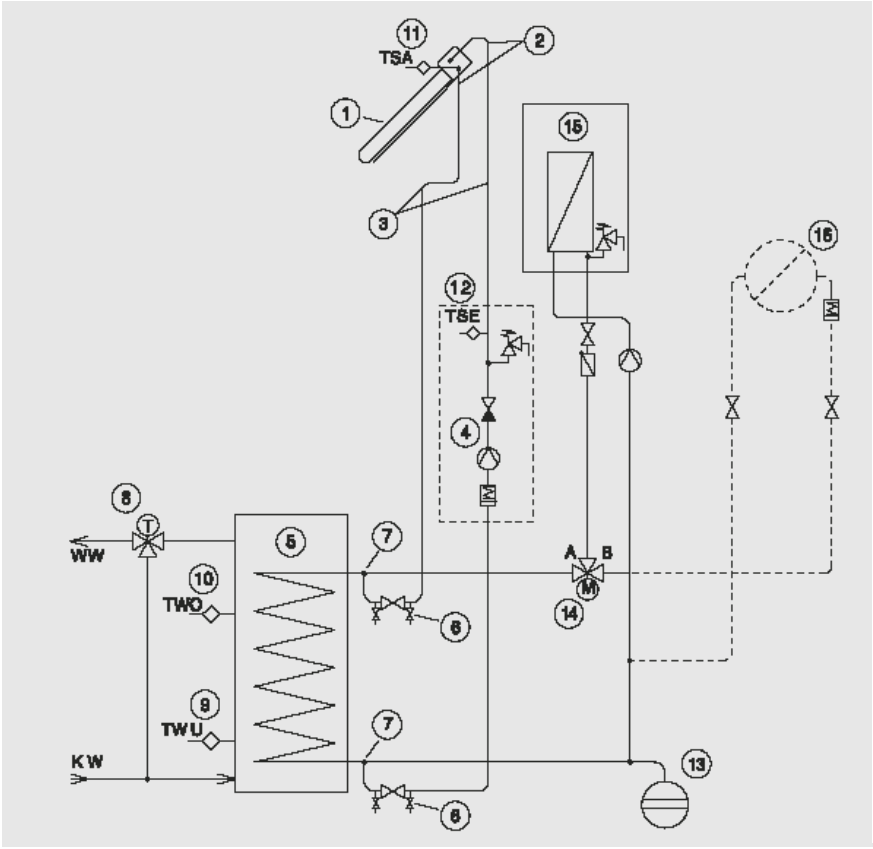


Figure 3: Innovative concept for DHW heating with vertical store /Paradigma/

Figure 4 shows the detailed set-up of the Innovative concept for DHW heating discussed in this report.



1 Vacuum tube collector CPC Allstar
2 Connection set CPC Allstar
3 Solar piping SPEED
4 Solarstation STAqua
5 Hot water store
6 Plug
7 Connection T-piece
8 Hot water mixing valve
9 Sensor TWU (store bottom)
10 Hot water sensor TWO (top of store)
11 Sensor TSA (collector)
12 Sensor TSE
13 Expansion vessel
14 3-way valve
15 Heating boiler
16 Heating circuit

Figure 4: Solar thermal system evaluated /Paradigma/

The innovative system concept is sold as CPC AquaSystem for solar domestic hot water preparation (DHW) by the company Paradigma, Germany.

The package comprises the components mentioned below. Please note that the names are product specific.

Package components: (in brackets values for a smaller collector)

- Collector CPC 40 (32) Allstar – Aperture 4.0 m² (3.2 m²)
- Installation kit for sloped roof, flat roof or front mounting
- Corrugated hose connection set for collector
- Optional DHW-store Aqua 190 but existing stores with volume >= 160 l (>=120 l) can be used
- Pump unit STAqua
- Controller SystaSolar Aqua
- Mixing valve for DHW
- Hydraulic accessory equipment

The major components of the innovative concept for domestic hot water preparation (DHW) are shown in Figure 5:

Figure 5: components innovative concept for DHW heating /Paradigma/

Cost (retail sales price of the system without installation and VAT):

- Package with Collector CPC 32 Allstar including DHW store: Euro 2,804
- Package with Collector CPC 32 Allstar without DHW store: Euro 2,016
- Package with Collector CPC 40 Allstar including DHW store: Euro 3,166
- Package with Collector CPC 40 Allstar without DHW store: Euro 2,373

Advantages of the innovative concept for solar domestic hot water preparation:

- Existing domestic hot water (DHW) stores can be used because almost every heat store with a single heat exchanger can be retrofitted with this system, even horizontal stores
- Separate store volume on low temperature level is not necessary because the highly efficient CPC Collector feeds the DHW-store only with the same or even higher temperatures than the conventional boiler.
- Smaller specific store volume is possible (>40 litres/m² collector area) than in typical solar systems (60-80 litres/m² collector area) because the DHW store can be operated on higher temperatures by the collector without reducing the efficiency of the CPC collector significantly.
- Immediate charging of the upper volume of vertical DHW store with a vertically extended heat-exchanger because a significant thermal stratification is generated due to the control algorithm used for operation of the collector loop
- No additional expansion tank for the collector loop is necessary if the expansion tank of the existing heating system is large enough (usually >= 35 litres)
- No maintenance (exchange) of the heat transfer medium is necessary, because no glycol is used in the system since the collector loop is operated with pure water.
- Standard heating system circulation pumps are used
- Electric energy consumption for the circulation pump is reduced to 50% because an innovative control algorithm reduces the annual operation time of the collector loop from about 2000 h to 800 h. Furthermore this control algorithm maximizes the transported thermal energy in the collector loop related to the amount of fluid volume circulated.
- Automatic function control with daily check of the volume flow rate, counteracting of gravity circulation and acoustic alarm in case of failures cares for correct and secure operation of the system

Disadvantage

- The innovative concept can be operated only with highly efficient CPC vacuum tube collectors. Otherwise neither the control algorithm of the collector loop nor the freeze protection algorithm is applicable. Simulations using a good flat plate collector (5 m²) in with the innovative concept show that the energy savings compared to the CPC collector (4 m²) are less than half.
- Heat from the store is used for freeze protection. However, under average German climate conditions this disadvantage is negligible (ca. 30 kWh thermal energy plus ca. 2 kWh electrical energy for the pump).

Cost and savings

Material and manufacturing:

- In most applications no additional solar store or expansion vessel is needed, especially when the already installed components are not too old.
- Antifreeze heat transfer medium is not necessary.
- In comparison to the reference system about 20% less collector area and therefore less material is needed for the same energy savings, because of a higher collector efficiency resulting in a larger energy output per m² collector area if the CPC collector is used.

Installation:

- The existing store does not have to be replaced. There are not many changes required in the conventional part of the heating system. It is just necessary to insert two conduit tees, one in the flow line and one in the return line of the DHW store directly near to the store. The piping of the solar circuit is connected by trap elbows to these tees.
- The existing expansion tank of the heating system is also used to compensate the expansion of the solar circuit, which needs a significant expansion volume only in summer during stagnation time, when the heating is switched off and therefore does not need the expansion volume.
- No separate venting for the solar circuit has to be installed, because the air is led into the heating system where usually air bleeders are installed. Entrainment of air into the solar circuit is prevented by the trap elbow connection.
- The filling and venting of the system can easily be done by connecting the solar circuit to the tap water, which usually provides enough pressure. A special pressure pump is not necessary. So the process of taking the system into operation takes less time than for the reference system.

Maintenance:

- As the system has a function control with acoustic alarm any matter which affects the function of the system seriously is detected. Possible failures are determined by special algorithms i.e. a too low volume flow rate in the collector loop. When the acoustic alarm is activated, the installer has to be informed to check the system. If a failure is detected, the controller reacts in a way to prevent the solar system from being harmed and keeps the system in operation if possible
- Regularly maintenance should take place during the annual maintenance of the heating system, as the innovative concept is directly connected to the heating system. Most of the maintenance like the check of the system pressure, the pressure of the expansion tank and the anodes of the store have to be done also without having a solar thermal system installed. The only necessary solar specific maintenance is to check the volume flow rate in the collector loop and a visual inspection of the collector, e. g. if the vacuum tubes and the thermal insulation of the piping is undamaged. The cost of maintenance is lower than for usual solar thermal system because the heat transfer medium doesn't have to be checked and also not to be replaced. If water is missing in the system, the system can simply be filled up by using the pressure of tap water. For systems operated with antifreeze heat transfer medium an additional pump is required for filling up the system.

Combined cost:

With regard to the sum of the costs for material, manufacturing, installation and maintenance a substantial cost reduction can be expected of the innovative concept for DHW heating compared to the reference system.

Performance and energy savings, including embodied energy:

The performance is expected to be similar to the performance of the reference system but with about 20% less effective collector area. The embodied energy is significantly smaller as there is usually no need for a new store. This is due to the aspect that the amount of energy additionally required for the freeze protection is under average German conditions negligible and that the system is equipped with a high efficient tubular collector.

Cost performance ratio:

An improvement/reduction of the cost/performance ratio compared to the reference is expected.

Additional benefits

Safety and health:

As the annual tap water temperature at the outlet of the DHW store compared to the reference is higher, the growth of legionella will be reduced.

Range of application, extra service, extra comfort, extra function:

The range of application for the innovative concept for DHW heating is very wide. Additional standard systems are available for direct heating in combination with a DHW store (low solar fraction) and with combi stores (high solar fraction). Larger systems for district heating, solar cooling and process heat are under development and pilot plants are currently monitored.

Environmental friendliness:

The CPC vacuum tube collector is built up mostly of pure materials like glass, metal, and other homogenous materials. Only a very small amount of insulation material is used and materials are not glued together. The structural components can be separated easily and used again. This allows easy recycling of the used materials.

The use of water as heat transfer medium avoids environmental problems which could occur in the production, during starting-up, operation, maintenance of the systems and disposal of antifreeze agents. E.g. if glycol flows into a rainwater collecting system through a leaking pipe or collector, problems can occur by growing of algae and bacteria.

Aesthetics, building integration and space requirement:

The CPC collector has an aperture/gross area ratio of more than 90% which is comparable to flat plate collectors. As the energy output is about 20% higher the system needs less space than the reference on the roof. Since there is no need for a large special solar store; small boiler rooms are no obstacle for the installation of the innovative concept for DHW heating.

Technical integration:

The integration of the innovative concept for DHW heating is simple and is done almost in the same way as connecting a second boiler. The piping of the already existing heating system doesn't have to be changed. With regard to the temperature levels, the innovative concept is operated like a conventional boiler.

Markets and marketing considerations

Opening-up of new and niche markets:

Usually typical solar thermal systems for DHW are built in single or multi-family houses only if the heating system is renovated. However, most of the existing heating systems do not need to be renovated because they are still up-to-date and working. The consequence is that it is very unlikely that a customer decides on a solar thermal system when he has to exchange a store which is maybe only 5 years old. The innovative concept for DHW heating makes it possible to add a solar system without a renovation of the heating system. The heating system can be renewed at a later stage when this is really necessary. With this new generation of solar thermal systems a large share of the market can be served which will lead to additional market growth.

Expansion of existing market:

The above mentioned arguments are valid in the existing market as well as for newly built systems.

Special considerations and limitations

Pressurized solar thermal systems with water as heat transfer medium have been investigated by Paradigma since 2000. First AquaSystems have been tested in pilot plants since winter 2002/2003 followed by an extensive field test with about 100 systems in 2003/2004. In the same winter extensive measurements were performed at ITW Stuttgart. A complete system as described above was built up at an outdoor test stand and operated under realistic ambient conditions. In a later step, the same system was examined in a climatic chamber with temperatures down to -25°C. The functionality and security of the system was confirmed by ITW. The energetic evaluation was done by using the simulation programme Trnsys (ITW) and ColSim (Paradigma) and validated with the measurements of ITW. The TRNSYS and ColSim simulations showed good conformity. The determination of the energy payback time for the system was also performed by ITW and showed good results.

The sales of AquaSystems started in April 2004. At the end of the very strong German winter of 2004/2005 about 2000 systems were installed. Only minor problems occurred mostly due to failures of the installer. Since April 2005 also AquaSystems for additional direct space heating are available. At the end of 2005 more than 6000 AquaSystems are installed in Germany. Also in Italy these systems are sold and in France the sales have recently started. The installers are satisfied with the AquaSystems and the acceptance of the users is high. According to the manufacturer of the system many more solar thermal systems are sold for the operation with water in the collector loop than with a water/glycol-mixture as heat transfer medium. Even though both versions are offered in parallel and at the same price level.

The AquaSystem was awarded the “Innovationspreis 2005” of the installer newspaper “Markt intern”.