WP1.D2 / Report about theoretical system evaluation

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CONTENTS

SUMMARY

Nine promising solar thermal system concepts for single family homes were evaluated qualitatively. The aspects included are:

- Cost and savings (installation; maintenance; performance and energy savings, including embodied energy; cost-performance ratio)
- Additional benefits (safety and health; range of application, extra service, extra comfort, extra function; environmental friendliness; aesthetics, building integration and space requirement; technical integration)
- Markets and marketing considerations (the potential to open up new and niche markets or expand existing markets)

In an extensive survey previously conducted in NEGST, existing trends and promising system concepts were identified. The results of the survey are reported in WP1.D1 (/Vog06-1/). Specific features, that are important for the evolution of solar thermal system technology were also identified. These specific features are:

- Standardization (to create possibilities for larger production quantities. For example: a design that allows slight variations but has standardised core components; a design that can be successful in several markets; a modular design, which allows for larger production numbers of core components; or a concept with a large market potential). The objective is to lower product production cost.
- Prefabrication (design which allows as much factory assembly as possible). The objective is to reduce installation cost and effort, and to reduce the risk of improper installation.
- Simplification and reduction (improve the system in such a way that it requires a small number of components. To do this, several functions may have to be combined in one component). The objective is to reduce the cost for production or installation.
- Adaptation of an existing system concept to a new market or country by adaptation of components, optimization of sizing, etc. for the system to suit another climate or to be compatible with different standards or regulations.
- Integration (make the system fit in with the building). There

may be several objectives: make the system more attractive or more versatile; reduce overall cost, etc. The two important features of building integration are:

– the collector is designed to replace a part of the roof
– the components that are placed indoors are combined in one compact unit, which is good-looking, silent and can be installed nearly anywhere in the house.

Even though integration could be considered to be part of the system concept, rather than a question of mere product design, the building integration is not included in the features listed in table 1 below. However, the trend towards thorough integration of the indoor installation is important. System 4 (compact SDHW and gas unit) and the systems 5 and 6 (REBUS-pellet, REBUS-gas) unite all indoor components in one (or several) units which are compatible with the standard 60 x 60 cm cabinet size for domestic appliances, such as dishwashers or refrigerators. Normally, with this type and degree of integration, the features *prefabrication* and *standardization* also apply.

specific feature / concept	standardization	prefabrication	simplification and reduction	adaptation
SDHW or combisystem with water filled collector loop (1, 2)			**X**	
drainback SDHW system (3)		x	**X**	x
compact SDHW and gas heating unit (4)	x	**X**		
combisystem with integrated pellets or gas auxiliary (5, 6)	x	**X**		
combisystem with non-pressurized store and polymer collector (7)	x	x	**X**	
integrated collector storage (8)	x	x	x	**X**
combisystem for Southern European climate (9)				**X**

Table 1: Overview of specific features of the evaluated system concepts.
X *indicates a feature strongly associated with the concept. Only one bold* **X** *was assigned to any concept.*
x *indicates a feature of minor importance or a feature inherent to the system concept.*

The system concepts evaluated demonstrate that there is a generation of new systems being studied, in development, in the process of market introduction or already successfully marketed, which is expected to have a significant effect on:

- the enhancement of solar thermal system technology and
- the positive development of solar thermal energy utilization.

In the following, the system concepts and their evaluation are described briefly.

1: Solar system concept with water filled collector loop for hot water preparation

In most Central and Northern European countries the typical solar domestic hot water system is a so-called pumped system. The evaluation of the new system concept was based on a comparison with this **reference system**. Its configuration is as follows: The collector supplies heat to a heat transfer medium, which is usually a mixture of water and glycol (anti-freeze). The heat is transferred to the water in the hot water store by means of a heat exchanger located in the lower part of the store. For auxiliary heating, a second heat exchanger, which is connected to the auxiliary heater (e.g. an oil or gas boiler), is located in the upper part of the hot water store. In Germany most solar thermal systems are of this type and designed to cover approximately 60 % of the annual hot water demand.

The **evaluated system concept** is a solar domestic hot water system that works without anti-freeze-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 water is heated by the heat exchanger in the store. The details of the innovative freezing protection algorithm are not disclosed.

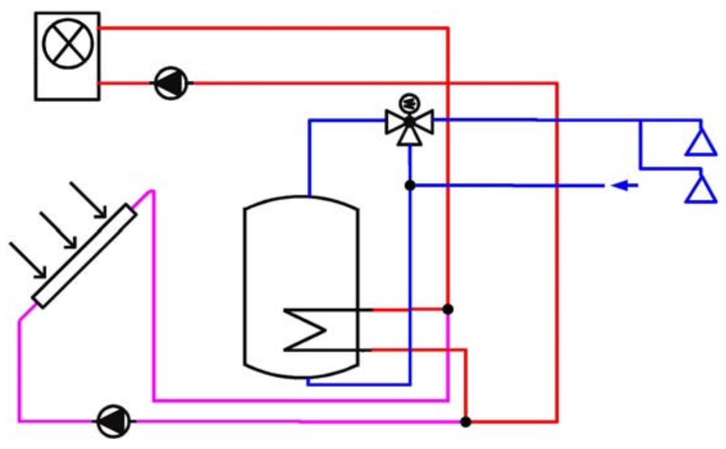

Fig. 1: Hydraulic scheme of the solar system concept with water filled collector loop for DHW-heating. This system concept has been developed by the German company Paradigma. It is introduced to the German market as AquaSystem.

The existing hot water store does not have to be replaced by a special solar store, because the heat transfer medium in the collector loop is not a special antifreeze-fluid but water. The solar loop is connected in parallel with the auxiliary heater.

Because solar collectors with a low heat loss rate are employed (evacuated tube collector, ETC), the heat losses incurred to avoid freezing are marginal. Also, elevated collector temperatures are possible without inadmissibly reducing solar gain. This allows the solar collector loop to utilize the same heat exchanger as the auxiliary heater: Therefore the new system concept can do with only one heat exchanger. It does not require any special solar DHW store.

Technically, the main advantages compared to the reference system are:

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

The concept opens up an important new market: single family homes where solar heating may be added because no existing (presumably recently installed) component has to be replaced.

The system concept was developed and introduced by the German company Paradigma under the name AquaSystem. The concept, including its innovative freeze-protection algorithm, has been tested extensively. Field tests of a large number of systems were also carried out with positive results. Market introduction is successful and the product is about to be on sale in many European countries. More details of the system and its evaluation are documented in the evaluation report labelled WP1.E1 (/Abr06-1/).

2: Solar combisystem with water filled collector loop

In several Central European countries, among them Germany, there is a trend towards so-called solar combisystems in single family homes. Solar combisystems contribute to both, domestic hot water preparation and space heating. Normally, these combisystems save between 20 and 30 % of the total heating energy and are equipped with a combined buffer and DHW-store (combistore). This system type served as the **reference system** for comparison with the system evaluated. In the reference system, the combistore is connected to the system in such a way that it can be charged simultaneously by solar energy and by auxiliary energy (e.g. from a boiler). The space heating loop is directly connected to the combistore. The thermal energy from the combistore is transferred to the domestic hot water line via either an internal heat exchanger, an external heat exchanger or an immersed DHW tank.

The **evaluated system concept** is related to the system concept for solar domestic water heating described above. 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 water is heated by the heat exchanger in the store.

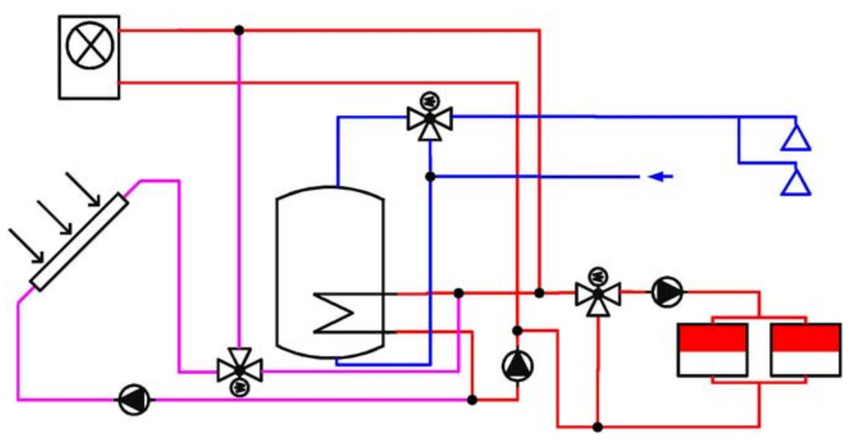

Fig. 2a: Solar combi-system concept with water filled collector loop. In this configuration, solar energy is charged into the supply line of the existing heating system.

The existing hot water store does not have to be replaced by a special solar store, since the heat transfer medium in the collector loop is not a special antifreeze-fluid but water. The solar loop is directly connected to the heating loop. Depending on the existing components, the system relies on the DHW-store (only) for heat storage or it uses an existing boiler with integrated DHW-preparation or storage. If the existing DHW-store or the boiler is sized sufficiently, no new store has to be installed. Different types of hydraulic concepts are used: For space heating the solar collector may supply heat to the return line or to the supply line. Both types are described in more detail in /Abr06-2/.

As in the SDHW system concept described above (1), solar collectors with a low heat loss rate (evacuated tube collector, ETC) are used.

Technically, the main advantages compared to the reference system are:

- ideally no major existing component has to be replaced,
- no antifreeze fluid is needed.

If the circumstances are favourable, no special solar store needs to be added. As in the case of the related solar domestic hot water system (1) above, this is an important marketing feature.

The performance of the system concept depends not only on the store volume, which may be crucial, particularly if no additional store is installed, but also on the type of house and climate. Generally, houses with a low space heating demand require a relatively large storage volume to deploy a high solar performance whereas houses with a high space heating demand and a long heating season can do with a small storage volume.

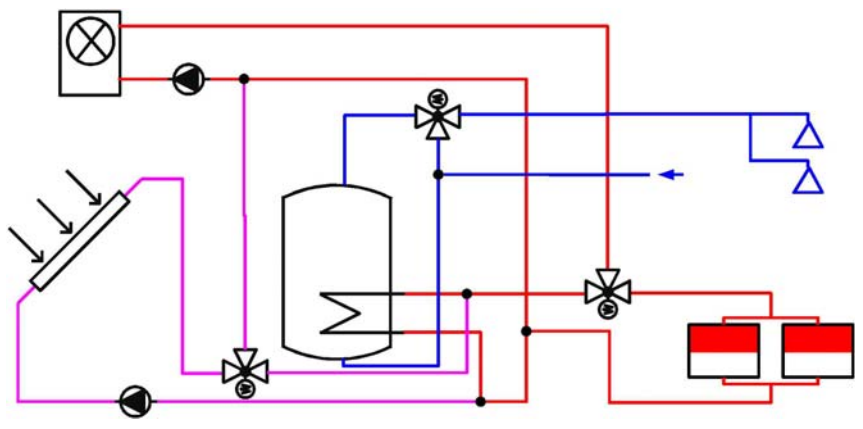

Fig. 2b: Solar combisystem concept with water filled collector loop. In this configuration, solar energy is charged into the return line of the existing heating system.

The system concept is also on sale as AquaSystem from Paradigma. Market introduction has started successfully. More details of the system and its evaluation are documented in the evaluation report labelled WP1.E2 (/Abr06-2/).

3: Drainback solar water heating system

A new drainback solar water heating system which does not require any special drainback vessel has been evaluated. The evaluation was based on comparison of the new system concept with two different **reference systems**:

- a state-of-the art drain-back solar water heater and
- a thermosiphon solar water heater, as used in Southern European countries.

At the beginning of collector loop operation the collector loop of a drainback system is filled by a pump, which during normal operation drives the fluid through the collector loop. When the pump stops, the collector is emptied through gravity and the collector fluid is stored in a tank, normally in a special drainback vessel.

In the case of the **evaluated system**, there is no special drainback vessel. The upper part of the heat exchanger which transfers the collected energy to the domestic hot water (DHW) store also takes over the function of the drainback vessel (see Fig. 3a). If installed correctly, drainback systems may be operated with water. In the case of the evaluated system, antifreeze is used for extra safety in case of inappropriate installation.

The main advantages **compared to a traditional drainback system** result from the fact that one special component (the drainback vessel) is not needed. Therefore the system concept is

- less expensive to produce,
- less complicated and less expensive to install.

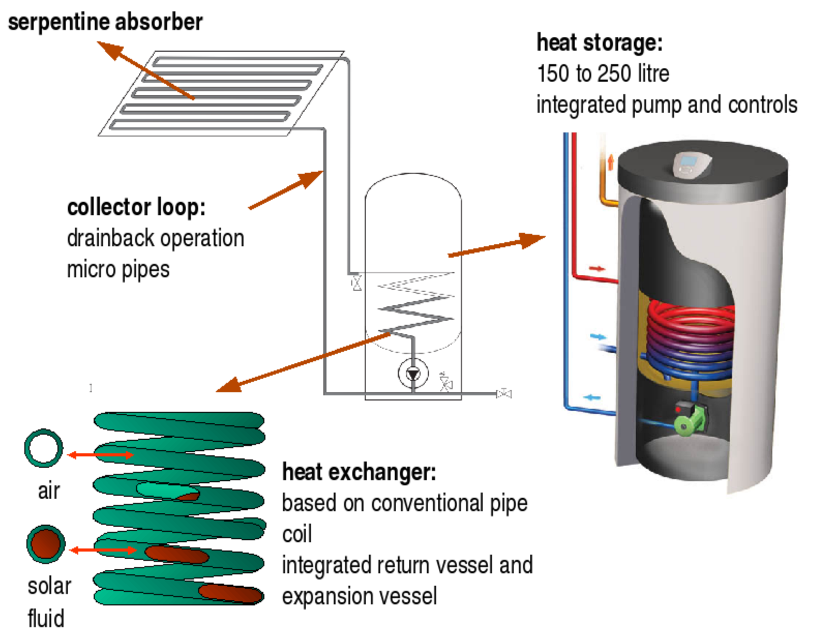

Fig. 3a: Illustration of the system concept with a solar heat exchanger acting as a drainback vessel.

The main advantages **compared to thermosiphon systems** are:

- The store is not located on the roof above the collector (improved aesthetics, security and stability).
- A higher solar fraction is expected.
- It has a high durability with little maintenance needs.

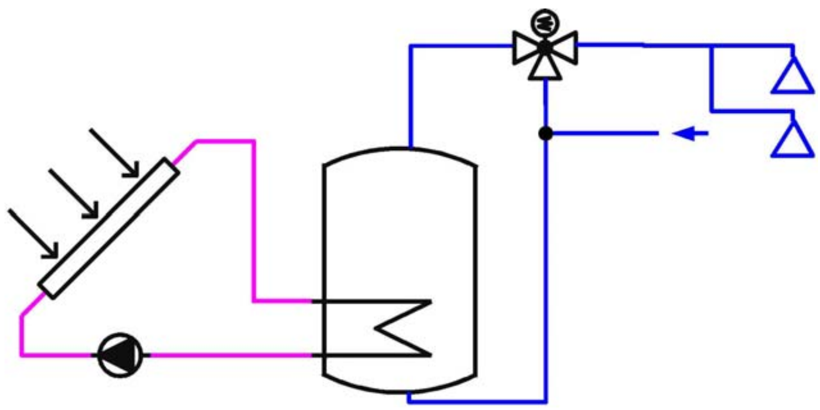

Fig. 3b: Hydraulic scheme of the evaluated system concept

The evaluated system concept was invented and is patented by the German company Wagner & Co Solartechnik. The product that corresponds to the evaluated system concept is branded Secusol and marketed primarily in Southern European countries. However, the concept may suit almost any other climate.

More details of the system and its evaluation are documented in the evaluation reports labelled WP1.E3a (/Wil06a/, comparison with drainback system) and WP1.E3b (/Wil06b/, comparison with thermosiphon system).

4: Compact heating unit for solar domestic hot water (SDHW) preparation

The evaluated system concept is a compact heating unit for solar domestic hot water (SDHW) preparation. In the evaluation it was compared to a **reference system** which represents the state of the art of technology for solar domestic hot water preparation in Germany. (See section 1 above, for a brief description of the reference system and /Ima06/ for more detailed information.)

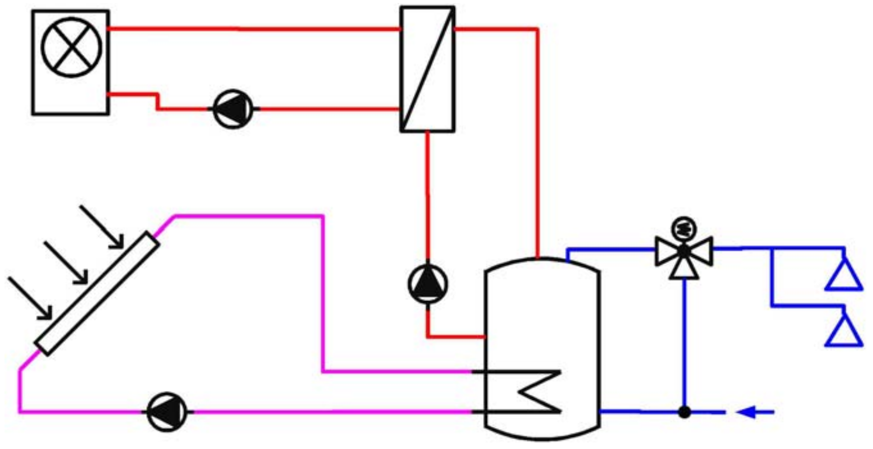

Fig. 4: Hydraulic scheme of the evaluated system concept. Note that all the components except for the solar collectors, the solar loop pipes and the solar loop expansion vessel (not shown here) are integrated in one single ("heating") unit.

The **compact heating unit** combines all functions that are needed to supply heat for space heating and domestic hot water in a single family house. It includes a condensing gas boiler and a small DHW store. The German company Vaillant has developed a system designed according to this concept. It is marketed as auroCOMPACT. In the case of this product, the auxiliary heater supplies hot water at a useful temperature level to the top of the store which results in a sharp temperature stratification. With the exception of the solar loop expansion vessel (and of course the solar collectors and pipes), the unit incorporates all components within one single casing. It is compatible with the standard 60x60 cm installation grid size for domestic appliances such as dishwashers, refrigerators, etc. Thus, the unit is designed to be installed nearly anywhere in the house, from the cellar to the attic. At present (beginning of 2006) similar compact heating units for solar domestic hot water preparation are offered in Germany by three different manufacturers.

The major **advantages** of the evaluated system concept are:

- Reduced product and installation cost: A better cost-performance ratio is claimed.
- Substantially reduced installation effort and reduced risk of installation errors.

The **disadvantages** with respect to the reference system are:

- A lower solar performance, thus a lower solar fraction.

And, if installed in an existing building:

- The existing auxiliary heater (boiler) has to be replaced.

More details of the system and its evaluation are documented in the evaluation report labelled WP1.E4 (/Ima06/).

5: Compact and modular solar combisystem with integrated pellet boiler (REBUS-pellet)

An advanced solar combisystem concept has been developed in the frame of a Scandinavian project entitled *competitive solar heating systems for residential buildings (REBUS)*. The **reference system** that it was compared to for evaluation is a standard Swedish combisystem with external boiler and single buffer store containing three finned tube heat exchangers, one for the solar circuit and two for preparation of hot water.

The **evaluated solar combisystem** is characterised by the following features:

- Fully prefabricated "technical unit" comprising all active components in the system as well as controller and expansion vessels. It includes a compact pellet boiler and 80 l auxiliary buffer store.
- Modular construction in 60 x 60 cm units, the same size as standard cabinets for washing machines, cupboards etc.
- Flexible system size with solar preheat store that can either be one (or more) 60 x 60 cm cabinet(s) of 300 l volume if placed in the living area, or one store of any suitable size if placed in the cellar.
- High level of integration and prefabrication for minimised installation time and costs.
- All-in-one controller for all system control aspects.
- Optimised for high system efficiency and low emissions.
- The technical unit can be sold as a solar prepared boiler, and the collector and solar preheat store can be added later.
- A water mantled pellet stove can be used instead of the integrated boiler without changing the hydraulic layout or controller.

The system is designed for a new market niche in Scandinavia: pellet and solar heating in houses without a cellar. The system is meant to compete with ground coupled heat pumps, the predominant heating system sold in Sweden.

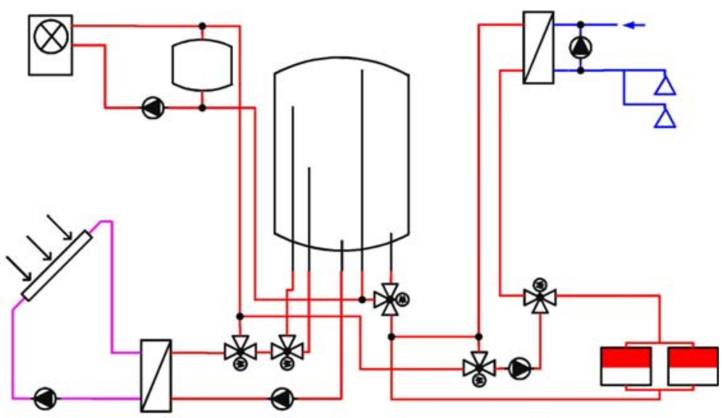

Fig. 5: Hydraulic scheme of the evaluated system concept. All the components except for the solar collector and the collector loop pipes are combined in one unit. More standard size buffer tank units or a large buffer tank may be added. There is a small ("standby") buffer tank adjacent to the boiler (top left in the scheme) for optimal boiler operation.

The evaluated system is not yet on the market. Although it has been tested in a laboratory and is currently undergoing field trials, it should be considered as still under development. There are plans to make it simpler, based on the results of the field and lab trials. Certain features have not been described in detail due to constraints from industry.

More details of the system and its evaluation are documented in the evaluation report labelled WP1.E5 (/Lor06/).

6: Compact and modular solar combisystem with integrated gas boiler (REBUS-gas)

There are two variants of the advanced solar combisystem concept developed in the frame of a Scandinavian project entitled *competitive solar heating systems for residential buildings (REBUS).* The variant with a pellet auxiliary heater is described above (see section 5). The other variant includes a natural gas fired auxiliary heater. In the case of the evaluation of REBUS-gas, the **reference system** used is a standard Danish combisystem with external boiler and a hot water tank containing two heat exchanger spirals, one for the solar collector loop and one for the boiler loop. An external heat exchanger can transfer solar heat from the solar collector loop to the space heating system. The reference system is described in more detail in /Thü06/.

The **evaluated solar combisystem** is characterised by practically the same features as the model with integrated (or external) pellet boiler described above. In this variant the fully prefabricated "technical unit" includes a natural gas boiler but does not have a small buffer store in the technical unit. The system is designed to compete with other natural gas fired heating systems and is suitable to be installed in houses without a cellar.

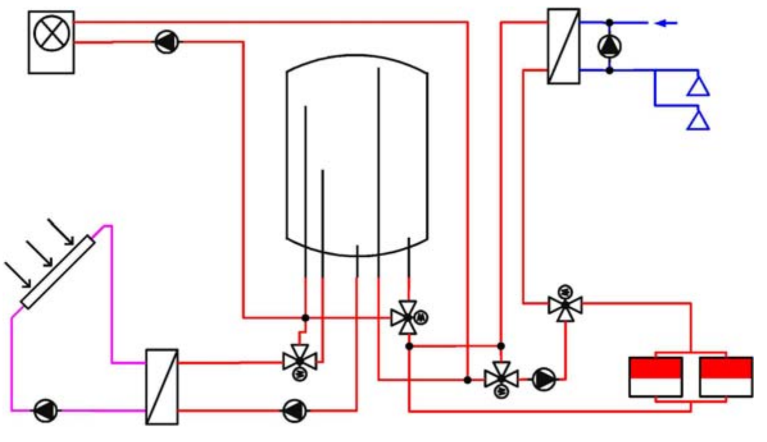

Fig. 6: Hydraulic scheme of the evaluated system concept. All the components except for the solar collector and the collector loop pipes are combined in one unit. More standard size buffer tank units or a large buffer tank may be added.

REBUS-gas has been laboratory-tested. Field trials are in preparation. Further optimization based on the results from the laboratory and field tests is intended. More details of the system and its evaluation are documented in the evaluation report labelled WP1.E6 (/Thü06/). However, not all technical details could be described.

7: Combisystem with non-pressurized store and polymer collectors

The evaluated combisystem concept was compared to a **reference system**, which is the state of the art combisystem in Sweden (generic system #11 in /Wei03/). A more detailed description of the reference system can be found in /Lor06/.

The main features of the **evaluated system concept** are:

- The system uses inexpensive lightweight collectors with moderate efficiency. They are made of polymer materials, are inexpensive and designed for roof or facade integration. They are designed to replace a significant part of the building envelope.
- The collector loop is water filled and supplies heat to the store directly (without any heat exchanger) and makes use of the drain-back technology.
- With the exception of the domestic hot water, the hydraulic system is entirely non-pressurized. This includes a non-pressurized heat buffer store made of stainless steel instead of a pressurized store. The store acts as heat buffer, expansion vessel (of the space heating system) and drainback vessel (of the collector loop).

The three main features could be evaluated separately. Particularly the polymer collector is not a feature which is necessarily included in the concept. However, there are several technical reasons for combining these features, which are not discussed in detail here. The Norwegian company Solarnor has developed a system which combines the above features and in the following, the different features are not dealt with separately. Relative to the reference system, the main **advantages** of the evaluated system concept are:

- Reduction of cost, material demand and maintenance and simplified installation through reduction of components (no heat exchangers, no antifreeze, no expansion or drainback vessel) and lightweight store and collectors.

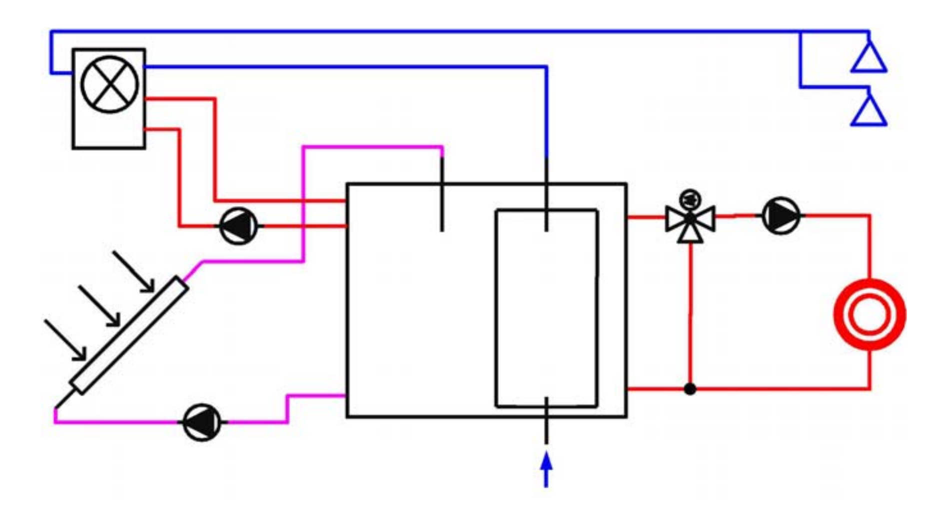

Fig. 7: Hydraulic scheme of the evaluated system concept. The collectors have to be installed above the tank.

The main **disadvantage** of the system concept might be related to the fact that in nearly all countries where central heating systems are common the state-of-the-art are closed and pressurized systems, whereas this system concept is open and non-pressurized.

- This concept requires a change of installation habits and a corrosion resistant auxiliary heater (boiler) as well as a corrosion resistant space heat distribution system (e.g. corrosion resistant floor heating) or additional heat exchangers.

This disadvantage may be a major impediment for short term market expansion. However, this system concept might lead the way towards thorough simplification and cost reduction of solar thermal combisystems.

The Solarnor system is on sale and well introduced in the Norwegian market. More details of the system and its evaluation are documented in the evaluation report labelled WP1.E6 (/Rek06/).

8: Integrated collector storage (ICS)

The solar water heater described in this section is an ICS (Integrated Collector Storage) system, because the collector and store are combined in one unit.

The system evaluated is planned to be marketed in Southern European countries, as a competitor to the thermosiphon systems commonly applied there. Therefore, to evaluate the ICS, it was compared to a small thermosiphon water heater as a **reference system**.

The **evaluated system** is characterized by the following features:

- It consists of a few parts only, many of which are made of polymer material. The essential parts are: A cylindrical tank made of stainless steel under a transparent dome and a reflector behind the tank.
- Overheating, frost and scalding protection are given much attention by combining passive and active safety measures.
- It does not have any built-in auxiliary or emergency heater.
- It requires neither antifreeze fluid nor a corrosion protection anode.

Not all technical details could be revealed. Compared to the reference thermosiphon systems, the most important **advantage** of this ICS is:

- Lower cost, less installation effort and no maintenance. A significantly better cost-performance ratio is expected.
- Its versatility to cope with very different climatic conditions, due to special measures against overheating and for frost- and scalding protection, may be an important marketing feature.

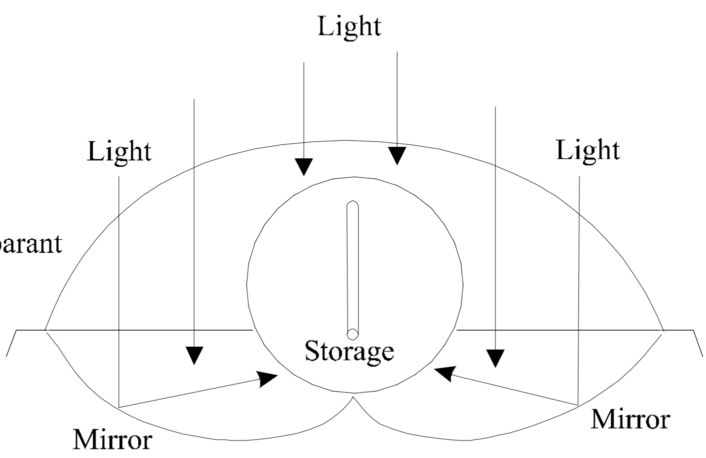

Fig. 8-1: Sketch of the evaluated ICS and its principle to collect solar radiation.

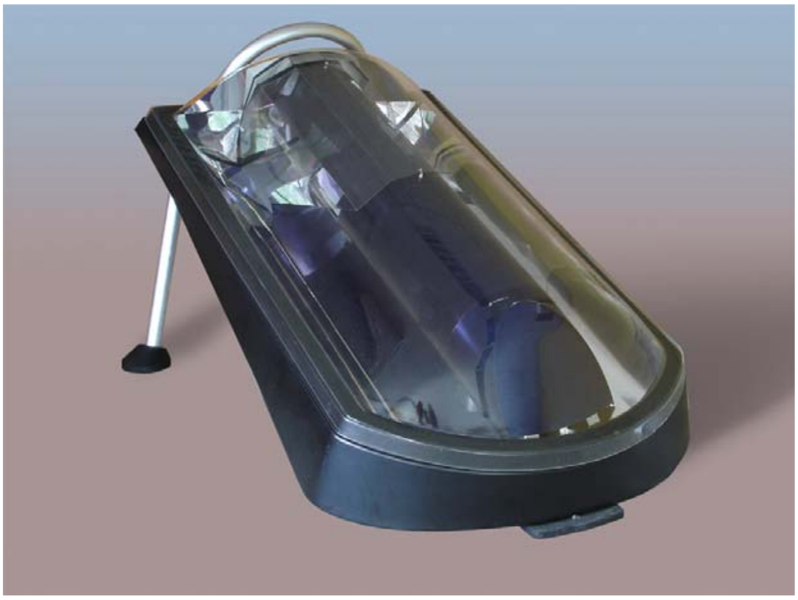

Fig. 8-2: Picture of the evaluated ICS (with flat roof support)

The system may be used as a solar-only system in very sunny climates. In less sunny locations it is intended to be used as a solar pre-heater to an instantaneous water heater or a hot water store.

- In many climates (e.g. Southern European countries) an additional auxiliary heater will be required for all-year availability of domestic hot water. For marketing, this might be a **disadvantage** compared to the reference system. Thermosiphon systems often have a built-in electric auxiliary (or “emergency”) heater. However, the use of the integrated auxiliary heater in a thermosiphon system considerably reduces solar gain, which makes it a two edged feature, if not a would-be advantage.

The ICS evaluated has been designed by the Dutch company Ecofys. Field trials have started. More details of the system and its evaluation are documented in the evaluation report labelled WP1.E8 (/Ree06/).

9: Solar system for combined domestic hot water, space and pool heating

The theoretical evaluation performed focused on systems that can provide hot water, space heating and swimming pool heating in single-family houses in southern climates.

The evaluation was made using as a **reference system** the most commonly used solar heating system for domestic water heating in Portugal: a thermosiphon system with a 4 m^2 collector area and a 300 l storage tank. Thus, compared to the reference system, the **evaluated system** offers substantial extra service: space heating and swimming pool heating.

The system evaluated comprises a combistore for solar hot water preparation and space heating. A six month period for space heating was considered. During the other six months the solar heating system may supply energy for pool heating.

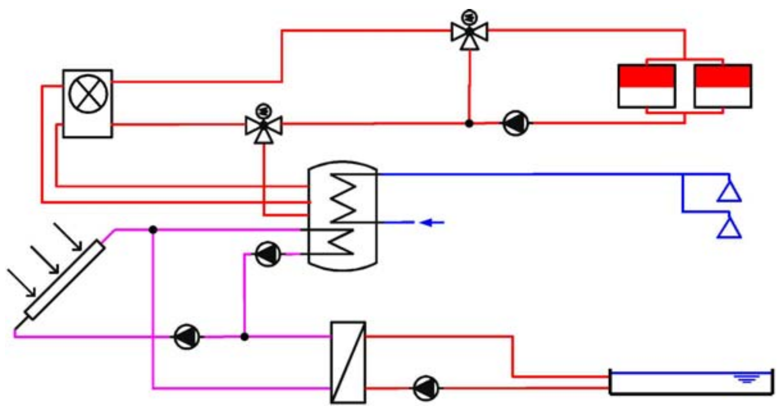

Fig. 9: Hydraulic scheme of the evaluated system concept. Apart from the pool heating, his combisytem concept is often used in Germany and several other countries. For practical reasons, the simulations, which the evaluation was based on, were carried out, using this particular combisytem design.

- The evaluation, based on simulations and cost estimates, showed that in southern European climates a solar combisystem, which is used for pool heating in the hot season, can be economically interesting. The cost-performance ratio of the evaluated system concept is similar to the cost-performance ratio of the reference system. This result is based on the assumption that pool heating is equally appreciated as water heating and space heating.

However, if the same system is not used for pool heating, the cost-performance ratio is clearly less interesting. The evaluated system concept is not related to any specific product. More information can be found in /Car06/ (evaluation report) and /Car05/ (simulation study and economic analysis).

Special considerations and limitations

System concepts were evaluated, rather than products. The boundary between concept and system (and product) is difficult to define. Furthermore, the quality of a system is greatly influenced by the way a concept is transformed into a product. Several of the concepts evaluated are represented by a specific product. Any judgement – positive or negative – on a product, its specific design or materials used is not within the scope of this report.

This report is based on the information made available by manufacturers, researchers and representatives of test institutions. This information is summarized in the evaluation reports referenced below. The verification of information or any verification by physical examination or testing of a product or concept was neither within the scope of the evaluations, nor in the scope of this report.

This report presents a selection of points raised and statements made by the authors of the separate evaluation reports (see section *references*). The selection was made by the author of this report, who has added a few more points. Thus, on the one hand, it reflects the opinion of the author (of this report), and on the other hand it selectively summarized the opinion of the authors or reviewers of the evaluation reports.

Remarks and conclusions

None of the nine evaluated system concepts, focuses specifically on the improvement of efficiency or performance. All concepts focus on cutting cost, or providing extra service. Although several specific features are common to more than one concept (see page 2, table 1), the degree of variation among the nine system concepts is remarkable. The concepts are different because of the variety of users, houses, applications, climates, markets and niches the they are developed for.

- They vary from fixed size and small SDWH-systems (8, ICS and 4, compact SDHW unit with gas auxiliary) via the variably sized (extendable/modular) concept of the REBUS-combi-systems (5 and 6) to a concept with non-pressurized hydraulics (7) which is (also) suitable for large size systems (due to its relatively inexpensive storage concept).
- They range from an integrated collector storage system without any auxiliary heater (8, ICS) via systems which, as an essential feature, comprise the existing auxiliary heater in the system concept (water filled systems 1 and 2) to systems with a fully integrated auxiliary heater (system 4, compact SDHW unit with gas auxiliary and combisystems 5 and 6, REBUS)
- Applications range from solar domestic hot water pre-heating (system 1, ICS) to water, space and pool heating (concept 9, combisystem for Southern European climate).

The systems demonstrate that solar thermal system technology evolves rapidly. Sometimes new developments use a fundamentally new approach (e.g. concepts with water filled collector loop (1 and 2) and the combisystem with non-pressurized store and polymer collector (7). In these cases the approaches lead to a significant cost reduction. However, it should be kept in mind that, if fundamental changes are made (by the manufacturers), they also have to be accepted by the market. The success of a new generation of solar systems depends on the ability of the solar thermal industry to convey new ideas and concepts to the end users. Furthermore, the success is likely to depend on the (solar-)specific competence of the installers and their ability to accept and adopt change. It might be no coincidence that the *AquaSystem* (concepts 1 and 2), which is at the same time revolutionary and successful, is distributed exclusively through specially trained installers.

Acknowledgements

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This report mostly summarizes and compiles information given in individual evaluation reports *(THEORETICAL EVALUATION OF PROMISING SYSTEM)*. The titles of the resource documents and their authors are listed in the section *references* below). The reviewers of the source documents are: Dagmar Jähnig, Ulrike Jordan, Klaus Vajen and Claudius Wilhelms. The authors and reviewers deserve special acknowledgement.

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