SOLAR THERMAL SYSTEMS FOR DOMESTIC HOT WATER AND SPACE HEATING

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ABSTRACT. The market for solar thermal systems in Europe is growing. Solar domestic hot water systems or combined solar hot water and space heating systems are more and more common in building technologies.

In the recent past, new system designs emerged. Low flow, matched flow or enhanced stratification are the important headlines. The new system designs are presented and compared to more traditional designs regarding performance. An other important factor, mainly in Germany, are the official guidelines to solve the legionella problem. The influence on system design is discussed and some new concepts will be presented. Furthermore, combined systems as hot water and space heating become more important. The design of these systems and a brief discussion about new trends are presented.

1. INTRODUCTION

Travelling through European countries like Austria, Switzerland, Germany and many others, you will recognise more and more solar thermal collectors on buildings. This is an obvious sign, that the installed collector area is growing. The statistics of the mentioned countries shows impressive yearly growth rates of 10 to 20 %.

In Switzerland, similar to other countries the market is stimulated by nationwide subsidy programs for solar thermal systems (political market stimulation). An additional advantage of a uniform subsidy program all over Switzerland is to get detailed information from the applicant. This is done by a simple questionnaire which delivers helpful information.

Total number of DHW and combi-systems built 1997 in Switzerland: 2020 units. This number of systems is divided into 1100 DHW- and 920 combi-systems. Only very few with more than 100 m^2 were built. There is a lack of industry applications.

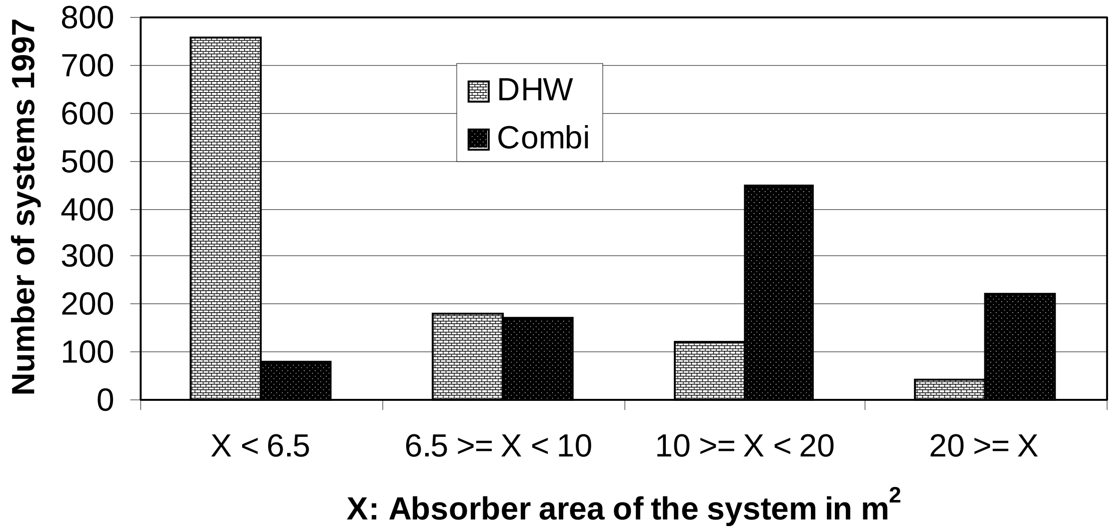


Figure 1: Classification of DHW and combi-systems according to their collector field size (Absorber area)

Figure 1 demonstrates the different distribution regarding collector field size. The typical DHW-system is about two to three times smaller than a combi-system. The ratio of DHW to combi-systems is about 54 to 46. The market situation in the adjacent countries is not very much different (Austria, Germany, Denmark, Sweden). Since the above mentioned system types represent the main application, the discussion will be focused on them.

All discussed systems include forced circulation of liquid heat transfer media in the collector loop since thermosyphon and integrated collector storage systems have almost no market share in middle Europe.

This confinement should not be misinterpreted; especially thermosyphon systems have their excellent application in southern climates as for instance Greece or many others.

2. DOMESTIC HOT WATER SYSTEMS

Solar energy utilization for domestic hot water (DHW) is more and more common worldwide. The reasons are diverse and dependent on regional factors. In central Europe, the seasonally nearly independent need, favours this type of installation.

Since the yearly heating load can be drastically decreased by improved buildings (passive solar energy, high insulation technics etc.) the fraction of the heat used for domestic hot water becomes more and more a significant part of the annual heat load. In addition DHW pre-heating systems have already today the potential to achieve as low energy costs as conventional heat sources.

In the last three years, remarkable improvements have been accomplished for small DHW-systems used in single-family houses. On the one hand, thanks to more efficient components and innovative operating strategies, the performance of the systems increased clearly. On the other hand, the prices for the complete installed systems dropped by 20 to 30%. The reasons are a more appropriate dimensioning adapted to the needs, simpler installation and reduced material and production costs due to higher production volumes.

In parallel to this development, the system technology changed from custom built systems to factory built systems (so called “kits”). This means optimized systems regarding performance and costs are delivered by the same supplier, from the collector to the storage tank up to the last screw. An other important advantage of factory built systems is, that they can be tested as complete units in a test laboratory. In Switzerland a certification procedure including requirements on minimum performance and quality has been established. So far 12 systems have successfully passed the certification procedure. Such activities increase the confidence in DHW-systems.

The “kits” idea is not limited to DHW-systems for single-family houses. It is well conceivable, to apply a similar approach to preheating systems for multi family houses or for combi-systems.

2.1 OPTIMIZATION FROM A TRADITIONAL TO A LOWFLOW SYSTEM

As an example optimization of a traditional to an advanced lowflow system is demonstrated step by step:

Let's start from a traditional system with 4.5 m^2 absorber area and a storage tank with a content of 400 l. The area of the ripped tube heat exchanger is 1.8 m^2.

The height of the heat exchanger itself, placed in the lower part of the storage tank, is 50 cm. The feed and return tubing is made of copper (inner diameter 10 mm). The tubing is insulated with 19 mm of synthetic rubber foam. The system represents the state of the art in 1990 and works according to its design. This system has served as a reference at SPF since beginning of the system testing in 1992.

The optimization of the thermal performance is demonstrated in 5 intermediate steps. The aim is to show the influence on performance by each single step. Often the effect of one single parameter is overestimated. A high efficient system is in general the result of numerous single optimization steps.

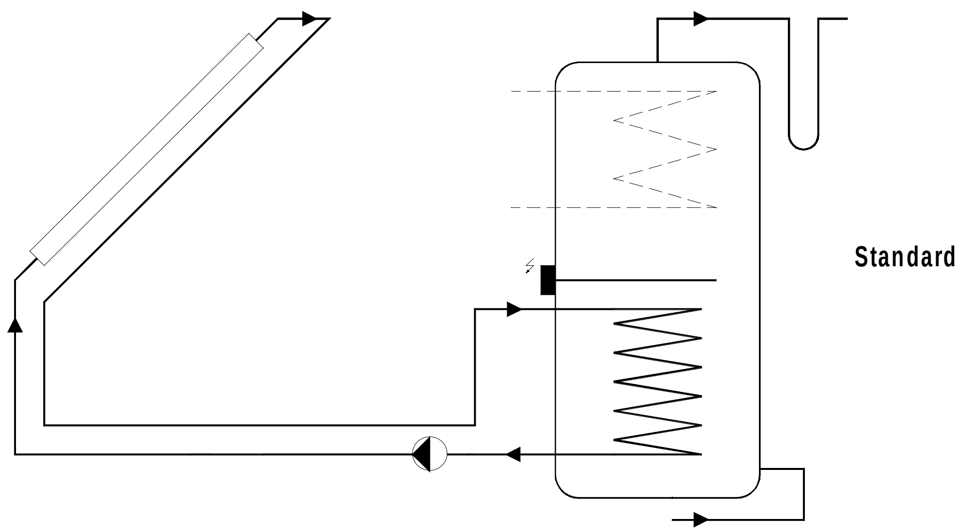


Figure 2: Traditional DHW-system

The optimization steps are (in brackets label in figure 4 and 5):

1. (HX) Optimization of the heat exchanger (smooth tube of approximately the same area)
2. (LF) lowflow strategy including a second heat exchanger in the upper part of the system
3. (Tubing) Use of an integrated tubing, length 13 m
4. (Collector) Collector with lowflow absorber design (meander), reduction of the absorber area from 4.5 to 4 m^2
5. (storage) Exchange of the enamel coated steel storage tank (volume 400 l) with a stainless steel storage tank, this results in a reduced lateral thermal conductivity and a slightly better insulation.

For the simulations TRNSYS/1/ has been applied. The system in the initial state as well as the final result of the optimization is based on measured results.

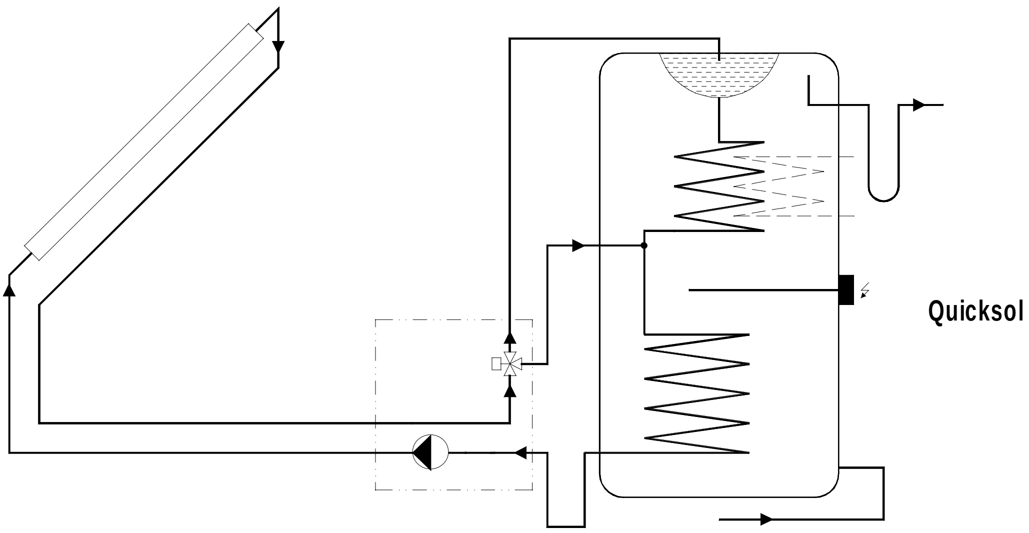


Figure 3: Optimised lowflow DHW-system

Boundary condition table:

- auxiliary heating by means of a gas fired furnace (15 kW)
- daily consumption: 10 kWh (215 l)
- tap temperature: 50°C
- tap profile: 8 withdrawals, distributed from 07:00 to 22:00
- System location: Rapperswil, Switzerland
- Orientation / tilt angle: south / 45°
- tube length: 13 m feed and return pipe
- ambient temperature of the storage tank: 18°C
- power consumption of pump: 50 W (50% is considered as heat input into the system)

- the judgement of energy savings by the thermal solar system is done by a comparison to a non solar standard system
- Yearly energy demand of the non solar system: Q_{KONV} = 4074 kWh

Overview of results:

System	Q_{SS} kWh/year	Fss -
Traditional system	2211	0.54
Optimised system	2431	0.60

Nomenclature:

	Definition / Symbol	Unit
Auxiliary heat demand	Q_Z	kWh
Electrical auxiliary energy (pump and control)	Q_H	kWh
Sum Auxiliary solar system	$Q_{NS} = Q_Z + Q_H$	kWh
Hot tap water	Q_{WW}	kWh
Heat losses non solar system	Q_{VV}	kWh
Energy demand of the non solar system	$Q_{KONV} = Q_{VV} + Q_{WW}$	kWh
Solar Savings	$Q_{SS} = Q_{KONV} - Q_{NS}$	kWh
Fractional solar savings	$Fss = Q_{SS} / Q_{KONV}$	-

Discussion: Influence of the optimization steps on the auxiliary energy needed and collected solar energy:

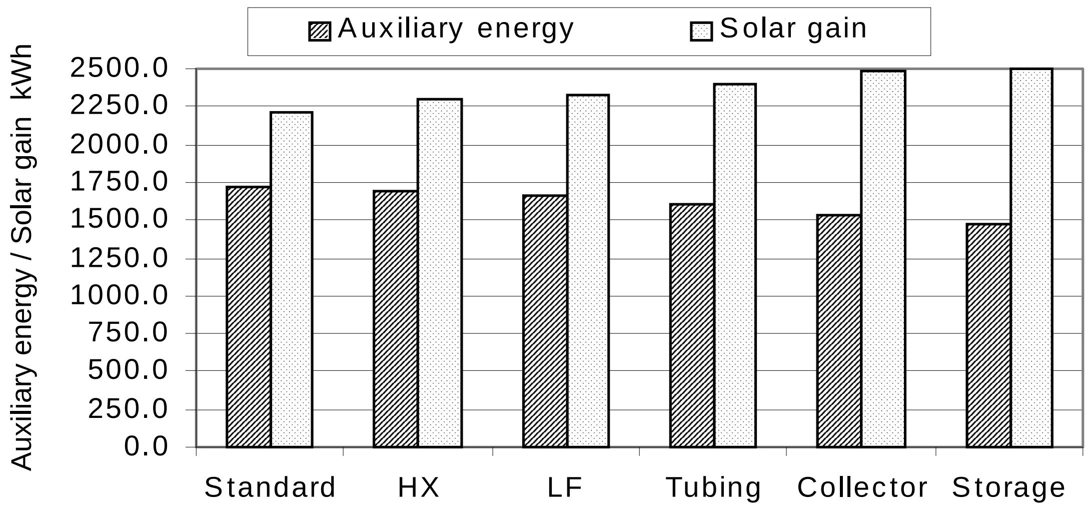


Figure 4: The influence of the individual steps on the yearly auxiliary demand as well as at the yearly solar gain to the storage are presented.

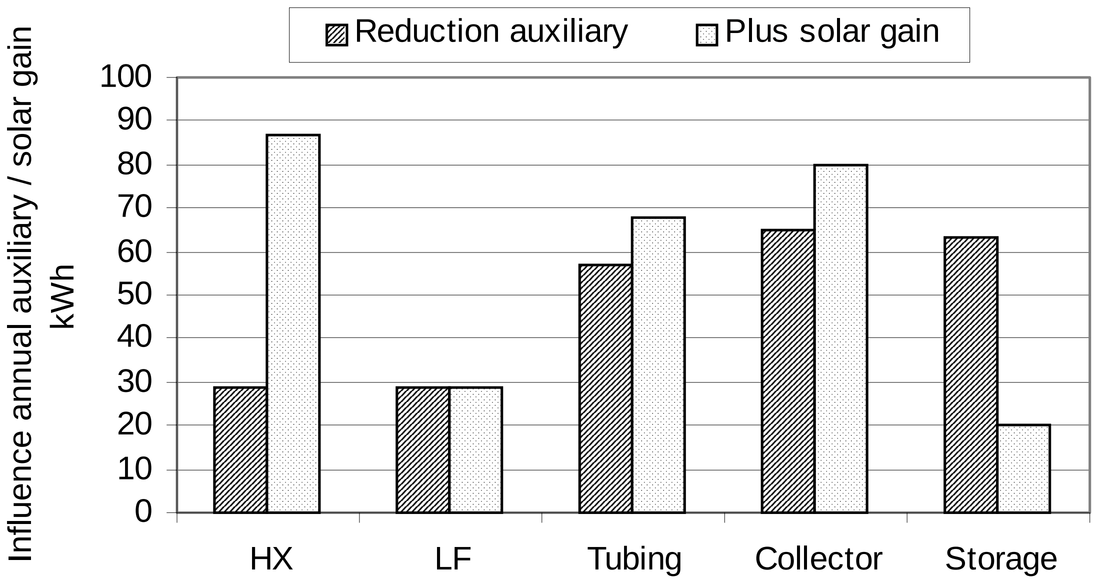


Figure 5: Decrease of the annual auxiliary demand and increase of the annual solar gain through the optimization steps.

Figure 5 shows clearly which measure is effective to reduce auxiliary energy and how the relation between increase of the solar gain and the reduction of auxiliary energy takes place. The improved heat exchanger increases essentially the storage losses. The second heat exchanger in the upper part of the storage including the change to lowflow in the collector loop leads in equal size to enhanced solar gain and reduced auxiliary demand. The replacement of the tubing to an integrated design with reduced low flow like tube sizes shows a clear decrease of auxiliary energy. The same effect might be observed through the adaptation of the collector for low flow conditions even if the absorber area is reduced from 4.4 to 4.1 m^2. The last step is the replacement of the storage tank. The enamel plated 400 l steel tank is replaced by a stainless steel tank with 450 l. The advantage of the stainless steel tank is the reduced vertical conductivity which has an often underestimated influence on the stability of the stratification. An insignificantly better thermal insulation leads to a reduction of the thermal losses in the order of 10%

2.2 LARGE DHW-SYSTEMS

Large DHW-systems, with an absorber area of 100 m^2 or more, are still not very common. Especially systems with a small solar fraction (< 20%) represent one of the most cost effective applications for flat plate collectors. The reason for low acceptance is, at least in Switzerland, a number of difficult obstacles:

- Typical owners of large multi family houses are big insurance companies, retirement funds etc. with complex decision procedures.

- There is no financial benefit for the house owner, since typical rental conditions leave the energy costs, including heat, to the tenant.

Even new financial concepts e.g. „contracting“ doesn’t help to improve the situation significantly. It is difficult to predict, how the actually discussed idea „Guaranteed Results Solar“ (GRS/2/) may influence positive decisions, to built pre-heating systems.

The „State of the Art“ of preheating DHW-systems show a very simple design. As solar fraction is small, a preheat tank including an internal or external heat exchanger take up all energy delivered by the solar system. In a second tank following the preheat tank insufficient hot water temperature is heated up to the required tap temperature by an auxiliary source.

Many of the bigger hot water systems include circulation. Especially in older multi family houses the thermal losses through hot water circulation exceed the energy consumption through hot water tapping. By applying a matched flow design (high flow during pre-heating mode, low(er) flow to directly achieve hot water temperature), there is an interesting potential to cover, at least in summer time, a significant part of circulation losses. The control of the flow rate must be optimized in order to reduce the need of conventional auxiliary heat.

2.3 TRENDS FOR DHW-SYSTEMS INCLUDING COMPONENTS

The price of the completely, installed system has to be further reduced, to make it more competitive to conventional heat sources. It is obvious, what the next steps should be:

- Increase production volume by strategic alliances of specialized solar business enterprises (collector, storage etc.)
- Improve the degree of integration; that means more compact units which include storage tank, pump, controller etc. to reduce installation costs.

Also a number of new components should help to reduce costs and improve performance of DHW- systems:

- New pump designs with lower energy consumption, optimized for matched-flow or low-flow concepts.
- High flexible integral tubing including new materials leading to easier and faster installation.
- Advanced controller with self diagnostic functions to check the correct operation of the system.
- New collector designs such as high performance unglazed collectors for pre-heating systems or large roof modules for large systems.

3. COMBI-SYSTEMS

The fraction of combi-systems compared to pure DHW-systems differs from country to country. The situation in Switzerland and Austria for 1997 shows an almost equal number for both system types. In terms of installed collector area the combi-systems are clearly dominating the marked. Combi-systems have a number of advantages and disadvantages compared to pure DHW-systems:

Pros:
Typically sized combi-systems in single family houses (10 m^2 flat plate absorber area, 1200 l storage tank) offers in central Europe a 100 % solar fraction from April to September. During this time period, there is extra comfort through almost un-limited hot water at disposal or by heating the bathroom to an elevated temperature.

Cons:
The often generous sizing of combi-systems is leading to a huge overproduction of heat during summer time. Simply stopping the pump in the collector loop is causing problems e.g. degrading the heat transfer fluid (usually glycol water mixtures) espe-cially if high efficient collectors are used.
Compared to other applications of thermal collectors, the yearly performance is low. This is especially true for typical central European climate.

3.1 COMBI-SYSTEMS IN SINGLE FAMILY HOUSES

The number of parameters influencing the design of a combi-system is much higher than for a pure DHW-system. In a given climate, the characteristics of the building influence strongly the optimal design of a combi-system. Of course the specifications of the builder play also an important role. 8 quite different small combi-systems as tested in the laboratory (ITW /3/) showed for a given building (low energy house) and climate (Würzburg, Germany) astonishing small variations in performance. The solar fraction ranges only from 19.5 to 24 %, the specific yield per square meter aperture area (flat plate collectors) ranges from 252 to 339 kWh/m^2).

A solar fraction of 20 % means also, that 80 % is contributed by the auxiliary source. Therefore, an important concern of a system designer must be not to deteriorate the performance of the auxiliary source. Especially for boiler with condensation technique, this is a difficult job. For the system design, standard commercial simulation programs are available, to study the influence of relevant parameters e.g. storage tank volume or collector area. In many applications this simulation programs work well and results are acceptable /4/. As it comes to close interactions between the building-design and the combi-system more complex simulation (e.g. TRNSYS) is needed.

In many low energy buildings, using most appropriate solar engineering (pas-sive solar application, transparent insulation materials, ventilation systems etc.) the heating load becomes very low. In this type of state of the art buildings, combi-systems are in competition with passive means such as south oriented windows. It is therefore important, for this type of building, to study in detail the application of a combi-system with respect to solar gain in comparison to a pure hot water system.

3.2 STATE OF THE ARTE COMBI SYSTEMS

Most combi-systems need an auxiliary heat source. A very common, reasonable and ecological auxiliary source is a wood fired furnace. In this case the storage tank serves both sources and investment is used twice. An important factor for this combination is increased comfort for the user not to run the wood furnace in summertime. Especially in Austria, Sweden and Switzerland this combination plays an important role.

The auxiliary sources gas or oil supplied furnaces are also used in standard systems. As already mentioned above one has to take care not to deteriorate the efficiency of the furnace by implementing in the system.

System designs like “tank in tank” are often designed for solar fractions from 20 to 80 %. The storage tank volume is typically in the range from 800 l to 5 m^3. Solar fractions > 80 % for standard low energy buildings need large storage tanks of 20 m^3 or more. These designs are technically feasible but are leading to very low specific solar gains and high costs /5/.

3.3 COMBI-SYSTEMS IN MULTI FAMILY HOUSES

The obstacles to realise large combi-systems are comparable with the situation for DHW preheating systems. It is even more difficult since the systems are more expensive.

In principal there is very little difference between a combi-system for a single family and for a multi family house. Of course the sizing of the components should be designed by the specialized engineer according to the builders specifications.
For small buildings (3 or 4 apartments) there is a remarkable number of systems installed per year (1997 in CH: 50). If it comes to larger buildings with more than 8 apartments only few systems are realized (1997 in CH: 8). The scheme of one example is shown in figure 6. The building “Sevelen II" was built in 1996 and has been inhabited since spring 1997. It contains 8 apartments and represents the state of the art of low energy technology, including a mechanical ventilation with heat recovery system. The installation is equipped with a data acquisition system to be measured it in detail.

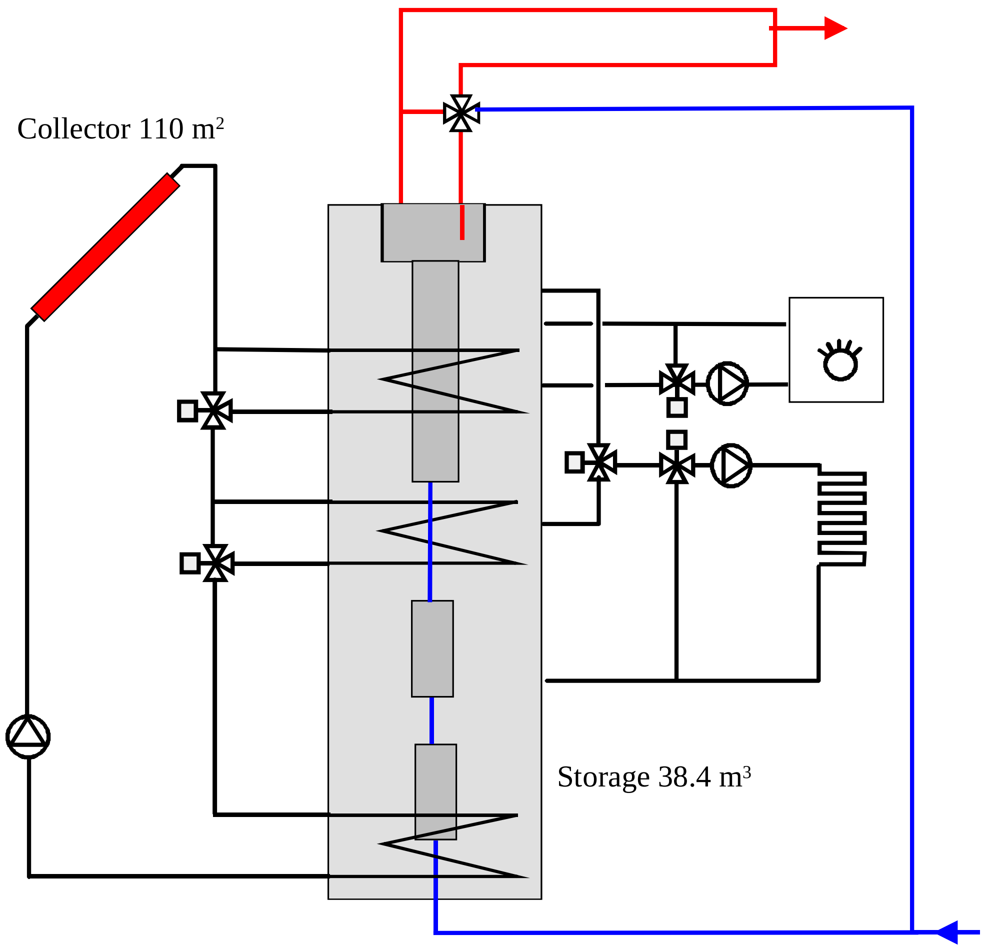


Figure 6: Scheme of the combi-system in the “Sevelen-house II”

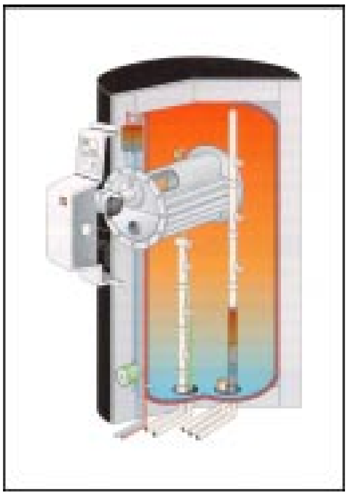
Some data and results of the measurement campaign in 1997:

Solar insolation in the collectors plane	1331	kWh/m^2
Solar insulation during collector loop pump ON	1154	kWh/m^2
Solar gain gross	46925	kWh
Auxiliary heat demand by oil furnace	30346	kWh
Heating load	38915	kWh
Hot water tapping	14154	kWh
Losses through hot water circulation and storage	6928	kWh
SF_i	61	%

3.4 TRENDS FOR COMBI-SYSTEMS INCLUDING COMPONENTS

There are a number of similarities between trends in pure DHW-systems and combi-systems. For instance price reduction is an important issue. One way is to create kit’s for common system sizes. Similar to pure DHW-systems a high degree of integration, that means more compact units which include storage tank, pump, controller etc. may reduce installation costs.

Integration of the auxiliary source e.g. the gas boiler inside the storage tank seems to be one way to lower system costs. Some products are already commercially on the marked.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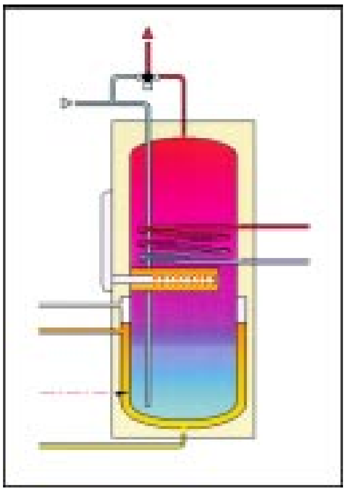
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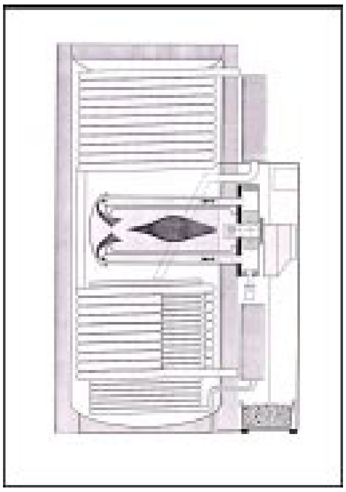
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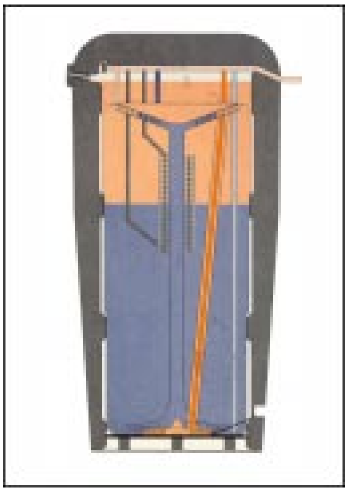
Figure 7: Integration of the gas-burner in the storage tank

The process to optimize the performance of combi-systems is underway. More and more matched flow concepts are introduced including devices for better stratification in the storage tank.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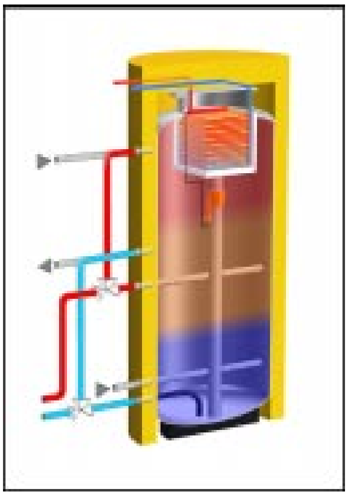
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Figure 8: Stratification enhancement by improved storage tank design

The new components which should help to reduce costs and improve performance are in general the same as for pure DHW- systems (see chapter 2.3)

4. CONCLUSIONS

In the recent past, a lot of scientific work has been done on DHW-systems. As an example of positive, prosperous international collaboration, the former IEA Task 14 (Solar Heating and Cooling Program), "Advanced solar domestic hot water systems" has to be mentioned /6/. The results of this work is seen by the numerous well designed factory built DHW-systems in different participating countries (e.g. Germany, Denmark, Canada, the Netherlands, Switzerland etc.). A similar input is needed for combi-systems. Thanks to the initiative of some individuals, also the IEA executive committee recognized the lack of know-how in this important issue. Especially for small combi-systems with typical solar fractions of 20 to 30 % a potential for further improvement is detectable.

Most of the current developments of advanced DHW-systems are trying to make the system more cost effective. One example is to improve the degree of integration to reduce installation costs or to cooperate with other manufacturers to increase production volume by strategic alliances.

Similar activities might be observed for combi-systems. Some new products are available with storage integrated gas-fired burners. Small combi-system kits also show up on the marked. The further optimization of these systems is important and will be an important issue for the new IEA Task 26.

Also a number of new components should help to reduce costs and improve performance of DHW- and combi-systems: e.g. pumps for lowflow operation, flexible tubing for fast installation or advanced controllers with included diagnostic functions.

Large preheating systems are still not very common. This is very unfortunate, since these systems are remarkable cost effective. To stimulate the market, strong political means are necessary to overcome the difficult obstacles.

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